Enclosed you will find your Technical Bulletin Binder. If properly utilized, it will become your pipe reference bible.

Briefly, the binder has been set up with the categories of "General, Pressure and Sewer." Each category will be disected into subcategories which will expound on specific areas of interest. Information on competitive products as well as A/C products have been included.

I strongly suggest that you review the information in your binder as it will serve not only as a pipe material refresher but as a continuing source of information.

Any comments or suggestions on the binder are welcome.

Norm Sutterer

General

INDEX OF TABS

PIPE SPECIFICATIONS

A/C PRESSURE PIPE

SUBJECT	SPECIFICATION	COMMENTS
Pipe	AWWA C-400	4" through 16"
Pipe Selection	AWWA C-401	4" through 16"
Transmission Pipe	AWWA C-402	18" through 42"
"FT" Pipe Selection	AWWA C-403	18" through 42"
Installation	AWWA C-603	
Pipe	ASTM C-296	4" through 36"
Transmission Pipe	ASTM C-668	6" through 42"

A/C SANITARY SEWER PIPE

Pipe	ASTM C-428	CL 1500 through CL 7000 Sizes 8" through 42"
Pipe	ASTM C-644	CL 1500, CL 2400, CL 3300 Sizes 4", 5", 6"

A/C MISCELLANEOUS

Definitions	ASTM C-460	
Methods of Testing Pipe	ASTM C-500	
Perforated Underdrain Pipe	ASTM C-508	4" through 12"
Pipe Linings	ASTM C-541	
Storm Drain Pipe	ASTM C-663	Sizes 4" through 42" CL II, III, 2500 D, IV, V
Conduit and Fittings	ASTM C-875	Sizes 3", 4", 5", 6" Class B & C
Gaskets	ASTM D-1869	For Pressure and Non-Pressure applications

CAST IRON PIPE

SUBJECT	SPECIFICATION	COMMENTS
Thickness Design	AWWA C-101 (ANSI A21.1)	3" through 48"
Pipe	AWWA C-106 (ANSI A21.6)	Centrifugally cast in metal molds 3" through 24"
Pipe	AWWA C-108 (ANSI A21.8)	Centrifugally cast in sand-lined molds 3" through 48"
Installation	AWWA C-600	3" through 48"

DUCTILE IRON PIPE

Thickness Design	AWWA C-150 (ANSI A21.50)	3" through 54"
Pipe	AWWA C-151	Centrifugally cast in metal molds or sand-lined molds 3" through 54"
Culvert Pipe	ASTM A-716	Centrifugally cast in metal or sand-lined molds 14" through 54"

CAST IRON AND DUCTILE IRON PIPE MISCELLANEOUS

Cement Linings	ASTM C-140 (ANSI A21.4)	
Polyethylene Encasement	AWWA C-150 (ANSI A21.5)	
Fittings	AWWA C-110 (ANSI A21.10)	2" through 48"

continued . . .

CAST IRON AND DUCTILE IRON PIPE MISCELLANEOUS

SUBJECT	SPECIFICATION	COMMENTS
Gaskets	AWWA C-111 (ANSI A21.11)	Push-on and Mechanical joints
Dininfecting	AWWA C-601	Applied to all water mains

CONCRETE PRESSURE PIPE

Pipe	AWWA C-300	Steel cylinder Not prestressed 20" through 96"
Pipe	AWWA C-301	Steel Cylinder Prestressed 16" through 72"
Pipe	AWWA C-302	Plain Reinforced 12" through 144" Low head 55 psi
Pipe	AWWA C-303	Steel Cylinder Prestressed
Pipe	ASTM C-361	12" through 108" Low head 55 psi
Pipe	ASTM C-14	Non-Reinforced 4" through 36"
Pipe	ASTM C-76	Reinforced 12" through 144"
Joints	ASTM C-443	Rubber Gaskets
Manhole	ASTM C-478	

PLASTIC PRESSURE PIPE

PVC Municipal Pipe	AWWA C-900	4" through 12"
PVC Schedule 40, 80 and 120	ASTM D-1785	1/8" through 12"
Polyethylene (PE) Pipe (SDR-PR)	ASTM D-2239	1/2" through 6"

continued .

PLASTIC PRESSURE PIPE

SUBJECT	SPECIFICATION	COMMENTS
PVC (SDR-PR)	ASTM D-2241	1/8" through 12"
Thermoplastic Gas Pressure Pipe	ASTM D-2513	1/2" through 12"
Polybutylene (PB) Pipe (SDR-PR)	ASTM D-2662	1/2" through 6"
Polybutylene (PB) tubing	ASTM D-2666	1/2" through 2"
Bell - End PVC Pipe	ASTM D-2672	1/8" through 8"
Polyethylene (PE) tubing	ASTM D-2737	1/2" through 2"

PLASTIC SEWER PIPE

ABS DWV Pipe and Fittings	ASTM D-2661	1 1/2" through 6"
Drain, Waste & Vent Pipe & Fittings	ASTM D-2665	PVC (DWV)
Acrylonitrile - Butadiene	ASTM C-2680	8" through 15"
Styrene (ABS) Composite Pipe		
PVC Sewer Pipe and Fittings	ASTM D-2729	2" through 6"
ABS Pipe and Fittings	ASTM D-2751	3" through 12"
Type PSP PVC Pipe & Fittings	ASTM D-3033	4" through 15"
Type PSM PVC Pipe & Fittings	ASTM D-3034	4" through 15" C-T

PLASTIC PIPE MISCELLANEOUS

Definitions	ASTM D-883	Relating to plastics
Material	ASTM D-1248	Polyethylene (PE)
Long-term Hydro-test	ASTM D-1598	Plastic pipe

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PLASTIC PIPE MISCELLANEIOUS

SUBJECT	SPECIFICATION	COMMENTS
Short-term Rupture test	ASTM D-1599	Plastic tubing & fittings
Material	ASTM D-1784 (ABS)	Rigid PVC & Chlorinated PVC
Material	ASTM D-1788	
Acetone Immersion Test	ASTM D-2152	PVC pipe
Stress under Internal Pressure	ASTM D-2153	Plastic Pipe
Solvent Cement	ASTM D-2235	(ABS)
Installation	ASTM D-2321	Flexible Thermoplastic Sewer Pipe
Parallel - Plate Loading Test	ASTM D-2412	Plastic Pipe
Impact Test	ASTM D-2444	Thermoplastic Pipe
PVC pipe fittings, socket type	ASTM D-2466	Schecule 40
PVC pipe fittings, socket type	ASTM D-2467	Schedule 80
Solvent Cement	ASTM D-2564	PVC Pipe
Installation	ASTM D-2774	Thermoplastic pressure pipe
Making solvent cemented joints	ASTM D-2855	PVC
Gaskets	ASTM D-3139	Plastic Pressure pipe
Gaskets	ASTM D-3212	Drain and sewer plastic pipe
Handling Solvent Cement	ASTM F-402	Thermoplastic pipe and fittings
Definitions	ASTM F-412	Plastic piping systems
Gaskets	ASTM F-477	Plastic pipe
Thermoplastic Well Casings	ASTM F-480	Pipe and couplings (SDR)
Smooth Wall Conduit and fittings	ASTM F-512	PVC

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continued . . . . . .

VITRIFIED CLAY SEWER PIPE

SUBJECT	SPECIFICATION	COMMENTS
Pipe	ASTM C-700	STD & Extra Strength 30" through 42" Perforated 4" through 24"
Installation	ASTM C-12	
Clay Drain Tile Pipe	ASTM C-498	Perforated 4" through 18"
Joints	ASTM C-425	Compression Joints

STEEL

Welded Steel	AWWA C2-1-66
Mill Grade Steel	AWWA C202-66
Coal Tar Protective	AWWA C203-
Coal Tar Lining & Coating	AWWA C203-
Mortar Linings & Coatings	AWWA C205-

J. Niedergang · BB ·

CertainTeed

Technical Bulletin

TO: ALL A/C TECHNICAL BULLETIN BINDER COPYHOLDERS

FROM: ROMAN KOROBIJ

SUBJECT: PHYSICAL PROPERTIES OF A/C PIPE

Attached is a short report on the physical properties of Asbestos-Cement pipe.

Though this information is very technical in nature, you may find it surprisingly useful.

By having this information handy in your A/C Technical Bulletin Binder, you will be able to present this information to a customer upon his request.

NOTE: This report should be placed after the red colored "General" tab of your A/C Technical Bulletin Binder.

PHYSICAL CHARACTERISTICS OF ASBESTOS CEMENT PIPE

Asbestos cement pipe is composed of an intimate mixture of either: (1) portland cement or portland blast furnace slag cement and asbestos fiber with or without silica; or (2) portland pozzolana cement and asbestos fiber. Either can be with or without the addition of curing agents. The pipe is formed under pressure and cured. The finished pipe is free from organic materials.

Indestructible Asbestos is as permanent as rock itself. It will not burn, will not rot, cannot corrode. In ready-to-use form, these fibers are finer than silk, stronger than iron, flexible enough to be spun into threads and woven into cloth.

The ancient Chinese, the early Greeks and the Egyptians used Asbestos centuries ago. The Greeks named it "Amianthus, " meaning "Incorruptible." We call it "Asbestos."

The ancient people prized Asbestos for its resistance to fire, heat, most acids and the weather -- and its durability. They used it for centuries without finding the adequate substitute for these unusual properties. They learned how to card the flexible fiber, and to weave cloth from it. In the nineteenth century a third outstanding quality of Asbestos was discovered. That is as a reinforcing material for portland cement.

Asbestos used in the asbestos cement pipe production is brought in from Canada and Africa. Continuous research and product development has produced a formulation wherein the proper amount of several types of fiber are used to assure maximum product strength. Most of the fiber used is Chrysotile which comes from the free world.

Asbestos is a broad term applied to numerous fibrous mineral silicates composed of silicon, oxygen, hydrogen, and metal cations such as sodium, magnesium, calcium, or iron. There are two major groups of asbestos, serpentine (chrysotile) and amphibole.

The chemical composition of different asbestos fibers varies widely and typical formulas are presented in Table I (U.S. EPA, 1976). It should be noted that the values obtained from actual chemical analysis of the various fibers also may differ slightly from the typical formulas. Although chrysotile is considered to be a distinct mineral, the five amphibole minerals are each varieties of other minerals. These minerals differ from each other both chemically and physically with the exception that they all contain silicon and all form fibers when crushed. Good quality asbestos will form fibers with higher ratios of length to width than poorer grades.

TABLE I

Typical Formulas for Asbestos Fibers

1.	Serpentines	chrysotile	$Mg_3Si_2O_5(OH)_4$
2.	Amphiboles	amosite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
		crocidolite	$Na/_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
		anthophyllite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$
		tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
		actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

The basic crystal form of the amphibole minerals is less complicated than for chrysotile. The basic structure consists of a double silica chain (Si_4O_{11}) that is paired back-to-back with a layer of hydrated cations between the chains.

Some typical physical properties of three different mineral forms are presented in Table 2.

TABLE 2

Typical physical properties of chrysotile (white asbestos), crocidolite (blue asbestos) and amosite

	Units	Chrysotile (white asbestos)	Crocidolite	Amosite (blue asbestos)
Approximate diameter of smallest fiber	micron	0.01	0.08	0.1
Specific gravity	--	2.55	3.37	3.45
Average Tensile Strength	$lb./inch^2$	3.5×10^5	5×10^5	1.75×10^5
Modulus of elasticity	$lb./inch^2$	23.5×10^6	27.0×10^6	23.5×10^6

Asbestos minerals, despite a relatively high fusion temperature, are completely decomposed at temperatures of 1,000°C. Both the dehydroxlation temperature and decomposition temperature increase with increased MgO content among the various amphibole species.

The solubility product constants for various chrysotile fibers range from 1.0×10^{-11} to 3×10^{-12}. Most materials have a negative surface charge in aqueous systems. However, since chrysotile has a positive (+) charge, it will attract, or be attracted to, most dispersed materials. The highly reactive surface of asbestos causes many surface reactions which are intermediate between simple absorption and a true chemical reaction. The absorption of various materials on the surface of chrysotile has a greater affinity for polar molecules (e.g. H_2O, NH_3) than for non-polar molecules.

Of all the asbestos minerals, chrysotile is the most susceptible to acid attack. It is almost completely destroyed within one hour in 1 N HCL at 95°D. Amphibole fibers are much more resistant to mineral acids.

The resistance of the asbestos fibers to attack by reagents other than acid is excellent up to temperatures of approximately 100°C with rapid deterioration observed at higher temperatures. Chrysotile is completely decomposed in concentrated KOH at 200°C. In general, organic acids have a tendency to react slowly with chrysotile.

Type 1 Portland Cement is used in manufacturing Asbestos Cement Pipe. This cement meets the appropriate ASTM specification. A complete analysis of each shipment of cement is made by the cement company. The pipe manufacturing company's laboratory also checks the cement for strength. All cement is subject to maximum controls to assure its uniformity and ability to meet the high strength requirements.

Silica is subjected to strict specifications as to percentage of pure silica (95% SiO_2) and also as to fineness. The silica receives further processing after it is received at the pipe manufacturing plant. First it is dried completely and then fed automatically into a ball mill where it is ground into flour-like fineness. The extremely minute particles that result provide the utmost surface area for maximum chemical and physical combination with the cement-thereby imparting highest strength and corrosion resistance.

Some of the physical properties of asbestos cement pipe are as follows:

Modulus of eleasticity	2.5 - 3.5 X 10^6 psi
Density	100 - 115 lb/ft^3
Thermal conductivity	K = 5.5 BTU/Hr/^{o}F/sq.ft/in.
Thermal coef. of expansion	4 - 5 X 10^{-6} in./in./^{o}F
Specific heat	0.27 BTU/lb/^{o}F at 212^{o}F
Moisture coef. of expansion	1.5 - 2.0 X 10^{-5}in./in./% moist. cont.
Hazen Williams'coef.	C = 140
Manning's coef.	n = 0.010
Axial tensile stress	500 - 3000 psi (depending on blend)
Axial compressive stress	8000 psi (full pipe cross section)
Shear stress	Laminar 1000 psi Across pipe axis 4000 psi
Permeability	0.3 - 0.5 grains/Hr/ft^2/in.Hg/in.thick
Poissons ratio	0.2
Dielectric constant	20 (dry) 100 (wet)
Water absorption	24 hr. immersion 15 - 20% (depending on blend)
Hardness	Rockwell M ID = 87 OD = 60
Temperatures	A/C material can withstand temperatures on the order of 570^{o}F without notable degredation unless mechanical fissurations are brought about by thermal tensions or by retreats due to irregular desiccations of the mass. Dry A/C pipes do not undergo any degredation until temperatures around -122^{o}F.

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CertainTeed

Technical Bulletin

TO: All District Managers
All Territory Managers
All Sales Engineers - Mr. Roman Korobij
All P&PG Personnel

FR: J. F. Baker/bam

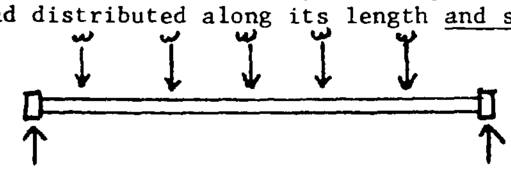
RE: <u>10' VS. 13' LENGTHS OF A/C PIPE</u>

DATE: 3/8/78

Periodically this question raises its ugly head in the marketplace and it appears to be reoccurring with greater frequency in the last few months.

Promotion of 10' lengths by one of our competitors should be put in proper perspective. A 10' length has no engineering merit over a 13' length in withstanding failure as a beam, and our competitor knows this (in my opinion). In my opinion, they are promoting 10' lengths out of desperation because they have 10' machines throughout the country basically built to produce thin wall small diameter products such as telephone duct, electrical duct, small diameter sewer pipe, etc. These markets have now been vitrually lost to plastic materials and they are trying desperately to sell the concept that the 10' length is superior to the 13' length for pressure pipe and 8" sewer pipe. By so doing, they also gain a proprietary position and are free to gouge the customer for any price they desire and at the same time can use their idle 10' machine capacity.

Let's examine the facts regarding a 10' vs. 13' length of pipe. Our competitor contends and promotes the idea that a piece of pipe acts as a simple beam witn a uniform load distributed along its length <u>and supported at the ends</u>:



There pitch is, therefore, that the bending moment is expressed by the formula:

$$M = \frac{Wl^2}{8}$$

Where M = the bending moment in feet lbs.
l = the length of the span in feet
w = the weight of the soil in lbs/ft.

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They therefore allege that the following comparison is valid:

10' length	13' length
$M_{10} = \frac{W\,(10)^2}{8}$	$M_{13} = \frac{W\,(13)^2}{8}$

Since w, the load per foot is the same in either case and 8 is a constant in either case, the bending moment of 13' vs. the 10' is equal to the square of the length. Therefore:

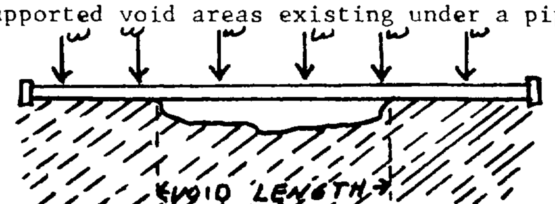
$$\frac{169}{100} = 69\% \text{ greater}$$

bending moment exerted, on the 13' length than on the 10' length.

This contention is true if the pipe is only supported by the couplings.

But, let's examine what really happens in a ditch to a partically supported piece of pipe.

Sometimes poor installation practice or subsequent excavation for other utility lines result in unsupported void areas existing under a pipe.



The unsupported void length is the critical length for developing bending moment on the pipe not the length of the pipe itself. If this void length is 6' long the (l) factor in the formula is 36 regardless of the length of the pipe. Only after the void length exceeds 10', the length proposed as the answer to the pipe buyers prayers, does the comparison outlined earlier begin to be true. In practicality, it is virtually impossible for the pipe to rest in the ditch with no support throughout its entire length - this just doesn't happen.

What does happen in field practice is that the void length can exceed the critical length that the pipe wall can withstand as a beam and a failure can occur.

The attached chart shows what void length is required inorder to develop a bending moment greater than the pipe can withstand. This chart is for class 150 pipe, buried 5', in a 120 lb/ft. soil.

What this chart says is that a 6" class 150 pipe has the beam strength to withstand the bending stress developed when a void under the pipe does not exceed 6.33 ft. in length. If that void length is exceeded the pipe will probably fail - This is true regardless of the length of the pipe.

Please study this bulletin and use it to destory the 10' length myth whenever it arises.

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P.S. An excellent study on this subject was done in 1972 by A. F. Felgendreger of CertainTeed. It is more detailed and technical and would be of particular value if an indepth technical answer is required. By separate cover, a copy of this report is being sent to each district office to be used if more technical detail is required. A copy is also being forwarded to each Sales Engineer.

J. F. Baker

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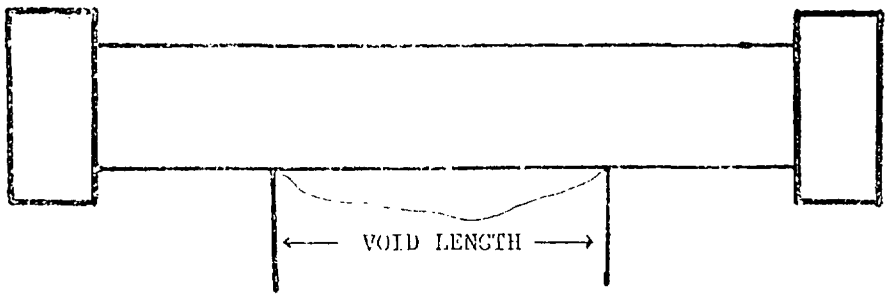
B E A M   S T R E N G T H

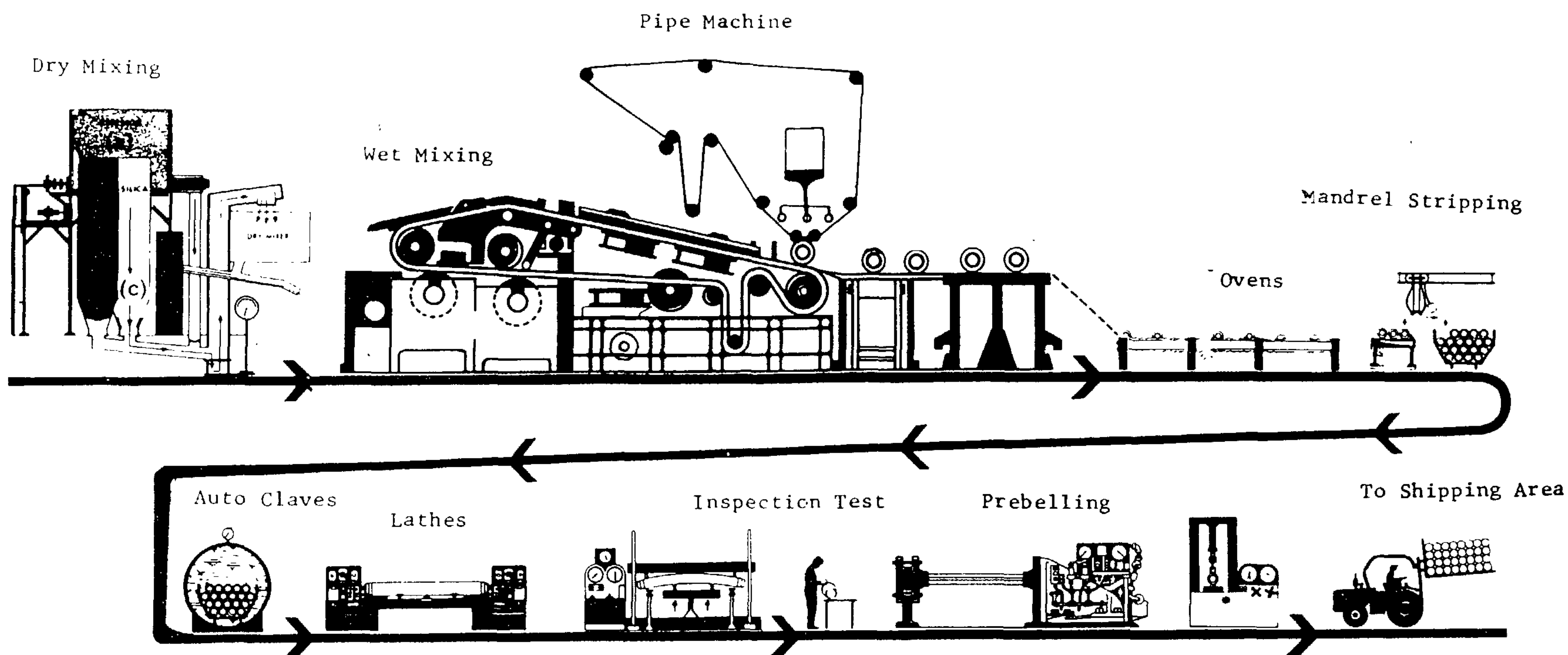


PIPE SIZE (INCHES)	EARTH LOAD 5' Dp. (#/ft.)	VOID LENGTH (FEET)
4"	1026	4.19
6"	1171	6.33
8"	1267	8.68
10"	1365	11.97
12"	1458	Exceeds Span

MANUFACTURING PROCESS OF A/C PIPE

Attached is a basic flow diagram demonstrating the manufacturing process of Asbestos Cement Pipe.

In the dry mixing stage, closely controlled amounts of asbestos fiber, cement and silica are blended. Water is then added to this mixture to form a slurry. This slurry is formed under pressure on a precision sized mandrel on the pipe machine to form the actual Asbestos Cement Pipes. The pipes, still formed on the mandrel, are sent through ovens for an initial cure. The mandrels are then removed leaving a smooth precise bore. The pipe is then sent to high pressure steam autoclaves where controlled temperature and moisture impact chemical stability and physical strength to the pipe. Fully automated lathes accurately machine pipe ends to meet national specifications. Various hydrostatic, flexure and compression tests are then performed to assure compliance with rigid requirements for burst, beam strength, and crush resistance. With the exception of Small Diameter Sewer (4" & 6") the pipe is then factory prebelled with one coupling and Fluid-Tite gasket. Pipe is then stored in a wide variety of sizes and classes available for immediate shipment.



MANUFACTURE OF —
ASBESTOS CEMENT PIPE

Resistance of asbestos-cement pipe to corrosive soil conditions

BY R. L. MARKS AND C. R. HUTCHCROFT

Reprinted from the July, 1968 issue of WATER AND WASTES ENGINEERING

Fig. 1. Electron microphotographs of calcium silicate hydrate compounds (binders). Top, normal cured. Bottom, autoclave cured

Resistance of asbestos-cement pipe to corrosive soil conditions

Asbestos-cement pipe is non-metallic in composition and, therefore, not subject to the same mechanics of corrosion as are evidenced by most ferrous metal products. A difference in corrosion resistance and chemical resistance characteristics also exists between autoclave-cured asbestos-cement pipe and normal-cured concrete pipe; asbestos-cement pipe produced in the United States is cured at high temperatures and pressures, reducing the incidence of free lime in the finished product by 10 to 30 times. High temperature steam curing makes asbestos-cement a more chemically stabilized cement product.

This paper discusses the properties of asbestos-cement pipe and its performance characteristics under actual conditions in service. For background information, and to place asbestos-cement pipe in perspective within the framework of the piping industry as a whole, a brief outline of general manufacturing methods, history, and usage is presented.

IT IS HELPFUL to look upon the asbestos-cement silica system as a composite material consisting of a matrix or binder reinforced with asbestos fiber. The asbestos fiber contributes to the high tensile and impact strength of the product. The portland cement-silica is the binder for this system, and the products formed on curing are largely responsible for the chemical resistance of the product.

The chemical reactions that take place during the setting of portland cement are very complex, and the final reaction products produced during autoclaving are substantially different from those produced by the normal curing process.

Because different chemical reactions take place in the autoclaving and the normal curing processes, different ingredients are used for each type of product. A typical normal cured asbestos-cement product contains approximately 20 percent asbestos fiber and 80 percent portland cement. A typical autoclave cured product contains 20 percent asbestos fiber, 40 to 50 percent portland cement, and 30 to 40 percent silica flour.

The binder in a normal cured formulation (about 28 days in water) consists of a poorly crystallized gel of hydrated calcium silicate (CSH-I gel) and up to 15 percent calcium hydroxide. The calcium hydroxide is released from the portland cement during the hydration process and is the principal cause of the poor chemical stability of normal cured asbestos-cement products.

The binder produced by the autoclaving process is microcrystalline hydrated calcium silicate (tobermorite). The chemical composition of this binder is not greatly different from the binder formed in the normal curing process, but the improved crystallinity of the autoclaved binder (tobermorite) over the amorphous normal cured binder results in a greater chemical resistance. The electron microphotographs of the two types of binder are shown in Fig. 1.

The most significant feature of the autoclaved product is the absence of any appreciable amount of free calcium hydroxide. Under autoclave conditions, the free lime produced by the hydration of the cement reacts with the silica flour to form additional tobermorite. Silica flour is not commonly used in the normal cured formulations because it does not react with the calcium hydroxide at ambient conditions.

Soil exposure

Soil exposure means potential corrosion by soils. Each year millions of dollars and much effort are consumed

BY R. L. MARKS AND C. R. HUTCHCROFT

Mr. Marks is staff manager, Johns-Manville Corp., New York, N. Y., and Mr. Hutchcroft is technical service manager, Certain-teed Products Corp., Ambler, Pa. This joint effort was reviewed by technical personnel of the Asbestos-Cement Pipe Co. and the Flintkote Co.

in preventing or retarding attack of underground piping systems by corrosive soils.

Typically, pipe is buried in the soil to transport liquids and to act as protection to other materials (such as electrical or telephone cable). The choice of piping materials and means of protecting those materials is dictated by the nature of the soil in which the pipe is to be installed. An obvious first choice is a material that offers economy of installation and operation, strength, and a wide range of resistance to soil environments without requiring costly and complicated protective measures.

Soils may be divided into two broad categories: natural soils are those that have been produced by purely natural means and are undisturbed other than for installation of pipe. Artificial or manmade soils are those produced, for example, by the disposal of various wastes, dredging operations, or other land fill, or by leveling or elevating operations.

Likewise, corrosive tendencies of soils may be divided into two broad categories: naturally corrosive soils have a basic natural composition that provides an environment inimical to piping materials. Such characteristics as sulfate content, bacterial activity, acid content, compaction, mineral content, etc., cause soils to be naturally corrosive. Induced corrosive potential is caused by man's actions in waste disposal, topography alteration, etc., which have either produced an environment corrosive to piping materials or have enhanced an already corrosive soil environment.

As knowledge of soil-induced corrosion has become more widespread, terms such as redox potential, cathodic protection, electrolysis, and galvanic action have become common. These terms are used in connection with the subject of corrosion of an electrical or electrochemical character. Corrosion of this type is produced by or produces a flow of electrical current. It relies upon such electrical effects as electrolysis, galvanic action, certain forms of bacterially-associated electrical activity, soil aeration, electrolyte activity, etc. This type of corrosion is important in pipes composed of electrically conductive materials, but it has no real bearing on non-metallic, nonconductive piping materials such as asbestos-cement.

Acid soils

Certain types of soil or soil conditions can, however, have an effect upon asbestos-cement pipe as well as on metallic piping. Soils that contain acids, for example, will tend, by chemical action, to attack asbestos-cement pipe as well as metallic pipe, but the attack on the former does not involve electrolytic corrosion.

Hardened portland cement silica, which forms the binder in autoclaved asbestos-cement pipe, is composed of many complex silicate structures, all of which are alkaline in nature. These al-

Asbestos-cement pipe—What it is

The first patents for asbestos-cement pipe were granted in 1913 in Italy, where equipment was installed and production started. By 1921, asbestos-cement pipe was well accepted in Europe. In 1929, Johns-Manville Corp. acquired rights to manufacture and sell asbestos-cement pipe, and the first length was made in the United States in September of that year.

In many applications, asbestos-cement pipe gradually superseded other pipe materials because of its good performance, economic installation, and other characteristics. Steady growth followed, both abroad and in the United States.

Continued product improvements such as high pressure steam curing (autoclaving) and tighter, more easily assembled joints, created increasing demands for increased production and additional plants. There was further expansion from water pressure pipe to sewer, building sewer, telephone and electrical ducts, gas vent pipe, industrial vent pipe, stacks, irrigation pipe, air duct, underdrain and storm drain pipe applications. In 1938, the Keasbey and Mattison Co., now Certain-teed Products Corp., entered the industry, followed by the Flintkote Corp. in 1963 and Cement Asbestos Products Co. in 1965, bringing further expansion. Today, hundreds of thousands of miles of asbestos-cement pipe are in service throughout the United States.

Composition

Asbestos-cement pipe is made by combining the basic raw materials—asbestos, portland cement, silica, and water—using modern manufacturing techniques. The asbestos is separated into fibers, which provide high tensile strength reinforcement to the pipe. The fibers are batch mixed with cement and silica flour in the dry state, water is then added, forming a slurry, which is agitated to assure uniformity. The slurry is deposited on a wide, endless belt where it is carried to the pipe-forming section of the machine as shown in the accompanying flow sheet. Here it is transferred under pressure to a steel mandrel as a continuous sheet wound up to form a high-density homogeneous pipe throughout its thickness and length.

The pipe is released from the mandrel, and after an air curing period, is placed in high presssure steam curing tanks (autoclaves) for final curing. After autoclaving, the pipe is trimmed and machined to required dimensions for jointing, then inspected, tested, and packaged for shipment. Asbestos-cement pipe couplings are manufactured by the same process as the pipe.

Autoclaving process

The durability of cement-based structures has been of great concern since the Roman days. The very nature of pipe applications demands a material that has a long operating life and requires a minimum of maintenance and repair. This requirement is, of course, in addition to the usual ones of high strength and dimensional stability. The adoption of high pressure steam curing (autoclaving)[1] by the American asbestos-cement pipe industry was the culmination of a search for a curing method that would give rapid strength development and improve the chemical stability of the products.

The autoclaving process refers to the curing of portland cement products in a saturated steam atmosphere at a temperature above the normal boiling point of water. The process is generally carried out in the temperature range of 325 to 385°F, with pressures of about 80 to 200 psi. A period of pre-curing, prior to autoclaving, in a moist atmosphere of ambient pressure is used to increase handling strength. The total time required for atmosphere and autoclave curing will range up to 48 hr.

In contrast to the above autoclaving method, the so-called "normal curing" process requires 20 to 30 days, with the product either in a moist atmosphere or under water. In addition to the rapid strength development, the autoclaved cured products have the following advantages:

Increased resistance to sulfate and other chemically aggressive environments.

An approximate 50 percent reduction in the volume change that takes place during the wetting and drying of the product.

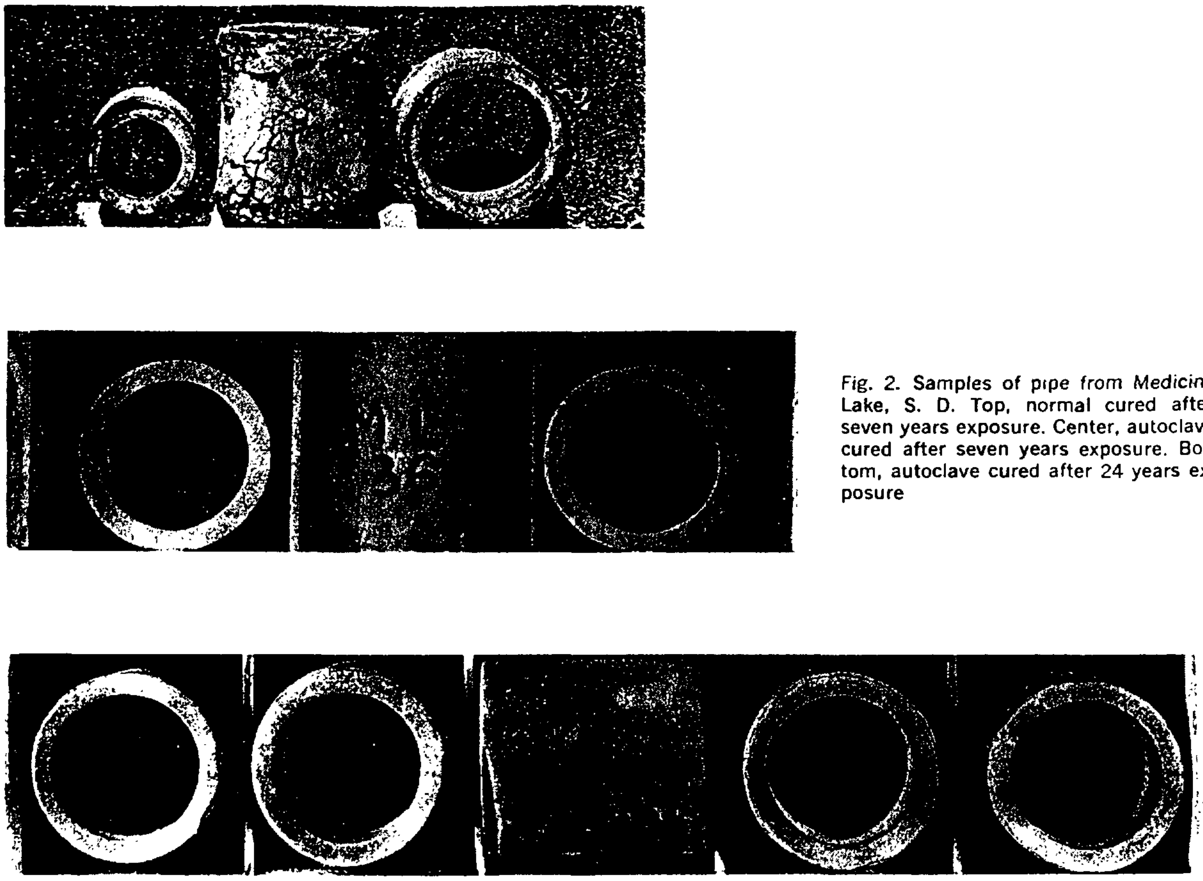


Fig. 2. Samples of pipe from Medicine Lake, S. D. Top, normal cured after seven years exposure. Center, autoclave cured after seven years exposure. Bottom, autoclave cured after 24 years exposure

kalis react with the acid in the soil, causing some of the silicate materials to be chemically altered. Mere presence of acid, however, is not the determining factor in such chemical corrosion; corrosion is dependent upon the amount and type of acid. Many soil acids are only weakly ionized, i.e., their effect upon pH is slight, and most soil acids are weak organic acids rather than stronger inorganic acids.

Except for sulfuric acid, strong acids are rarely found to occur naturally in soils because they are too reactive and water soluble. Mine drainage water is generally strongly acidic, with pH values often ranging down to 1.5 or 2.0, because of the presence of sulfuric acid. Such acid mine waters, when percolating through soil, produce low soil pH values in the range of 3.5 to 5.5. Decomposition of organic matter in swamps and salt marshes can also produce acidic conditions. It becomes apparent that neutralization of alkaline constituents in asbestos-cement materials by soil acids is theoretically possible. The amount of readily available soil acid, as denoted by the pH, is the determining factor in such chemical corrosion.

The conclusion could be reached from the above that any condition in which the pH is below the neutral point (7.0) could lead to chemical attack; this is not, in fact, the case. Considering that the amount of acid attack is the governing factor in the overall service life of an asbestos-cement pipe, one may then ask the relationship between performance life and acid concentration. Test sample burials reported by the National Bureau of Standards[2] for periods up to 12 years in soils of pH as low as 4.3 show only a negligible effect on asbestos-cement pipe in such environments. Actual in-service installations under similar acid conditions for 20 to 25 years substantiate these findings. The type of soil plays as large a part in chemical aggression as does its acid concentration.

The reaction of an acid with an alkaline material produces a salt of that acid. The nature of the salt produced has substantial effect upon the life of the alkaline material in its acidic environment. The corrosive effects of two strong acids, hydrochloric and sulfuric, present in equal concentrations can be compared as follows: Nearly all the salts produced by the reaction of hydrochloric acid with alkaline materials are very soluble in water. When such salts are formed upon contact of this acid with asbestos-cement pipe (calcium chloride), they are carried away from their site of formation.

While the same reaction (i.e., neutralization) will take place between sulfuric acid and asbestos-cement pipe, the salt produced, gypsum, is only sparingly soluble in water and so usually remains where it is formed. Its presence slows down the rate of attack, substantially prolonging the service life of the product. Most of the common organic acids found in soils also produce salts that are sparingly soluble and duplicate the effect noted above. The fact that most of these organic acids are weak acids produces further retardation of reaction and prolongation of life.

Low hardness waters

Waters of very low hardness (i.e., low levels of calcium and magnesium content) tend to extract calcium and magnesium from materials rich in these constituents. Asbestos-cement pipe is composed of complex calcium silicates and hence may be expected to release

TABLE 1—FREE LIME CONTENT AND SULFATE RESISTANCE OF NORMAL AND AUTOCLAVE CURED CEMENTS

Type of cure	Silica/cement	Cement type	Free lime (%)	Sulfate resistance: expansion (%)*
Autoclave, 125 psi,	0.6/1.0	I	0.4	0.03
16 hr		V	0.5	0.03
Normal, underwater	0.0/1.0	I	15.5	0.16
28 days		V	13.7	0.11

* U. S. Bureau of Reclamation sulfate resistance test; measures expansion after 28 cycles.

TABLE 2—$Ca(OH)_2$ CONTENT AND EXPANSION OF NORMAL AND AUTOCLAVE CURED CEMENTS

Product	Curing	$Ca(OH)_2$ (%)	Expansion in Na_2SO_4 sol'n. at given age (%) 28 days	3 months	8 months
Asbestos-cement	In water, 28 days	9.6	0.047	0.080	0.113
Asbestos-cement silica	High pressure steam	0.2	0.019	0.030	0.037

TABLE 3—EFFECT OF AUTOCLAVING ON SULFATE RESISTANCE

(Mix contained by weight): 1 part portland cement A, 1 part ground sand,* 6 parts 18 to 25 mesh sand

Curing	Storage solution	Length of storage (weeks)	Expansion (%)
7 days, water, 18°C	Na_2SO_4	8	0.49
	$MgSO_4$	8	0.49
Autoclaved, 7 hr, 183.5°C	Na_2SO_4	200	0
	$MgSO_4$	200	0

* Through 170 BS mesh

calcium to a soft or calcium-starved water. While such can be the case, the likelihood of calcium-starved water being present in a soil is slight because contact with the soil will increase the hardness. Furthermore, such water in a soil in contact with an asbestos-cement pipe would tend to be quiescent, i.e., not flowing. As such a quiescent soft water picks up calcium, its softness, and hence its aggressiveness, is reduced. Certain gravelly or sandy areas subjected to high rainfall or runoff may produce soft water leaching of calcium from calcium rich materials.

A soil's physical characteristics may also play a part in its corrosivity. Aeration of a soil affects the availability of oxygen and moisture and is dependent upon such physical characteristics as apparent specific gravity, particle size and distribution, and moisture content. Localized differences in these characteristics lead to differential aeration. This results in the formation of oxygen concentration cells, wherein low oxygen areas become anodic (sites of corrosion) compared to sites along the same conductive pipeline where oxygen is more accessible.

A manmade soil or foreign material in a natural soil can often be more corrosive than a purely natural soil. Direct addition of some waste materials produces acids upon decomposition and creates acidic soil conditions that can be detrimental to piping materials.

Sulfate environmental effects

Sulfate soils, natural or manmade, provide another corrosion potential, both to metals and to materials composed of portland cement. Extensive research has been carried out in the laboratory and in the field to determine the main causes for the attack of asbestos-cement products in a sulfate containing environment. In general, the sulfate environment will react readily with the free calcium hydroxide or slowly with the available calcium in the loosely bound, poorly crystallized CSHI binder gel, to form gypsum ($CaSO_4 \cdot 2H_2O$) and/or ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$), a complex salt of sulfate and cement clinker component $3CaO \cdot Al_2O_3$, accompanied by volume expansion in both cases.

This research has also included a search for ways of protecting the asbestos-cement product from this type of chemical attack. Two interesting field tests, a laboratory study, and other available data illustrate that autoclaved asbestos-cement pipe is more sulfate resistant than normal cured pipe.

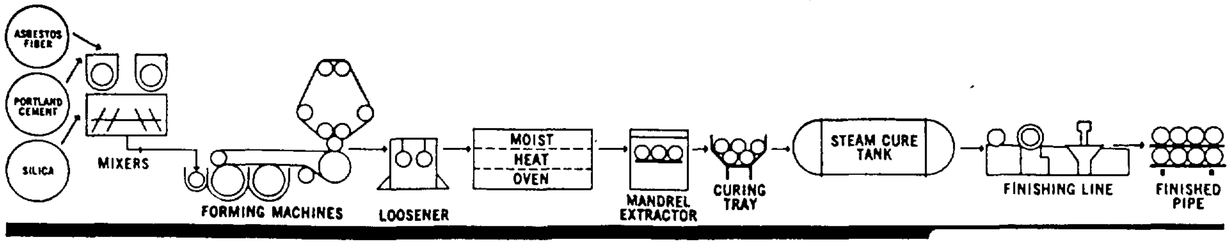
Medicine Lake studies.[3,4] Asbestos-cement pipe cured by both normal and autoclave techniques was exposed to the waters of Medicine Lake, S. D., for periods up to 24 years. This water is exceptionally aggressive to ordinary cement products because it is high in sulfates (5 to 8 percent) with two-thirds of the total salt as magnesium sulfate, one-quarter as sodium sulfate, and the remainder a mixture of several salts present in minor quantities.

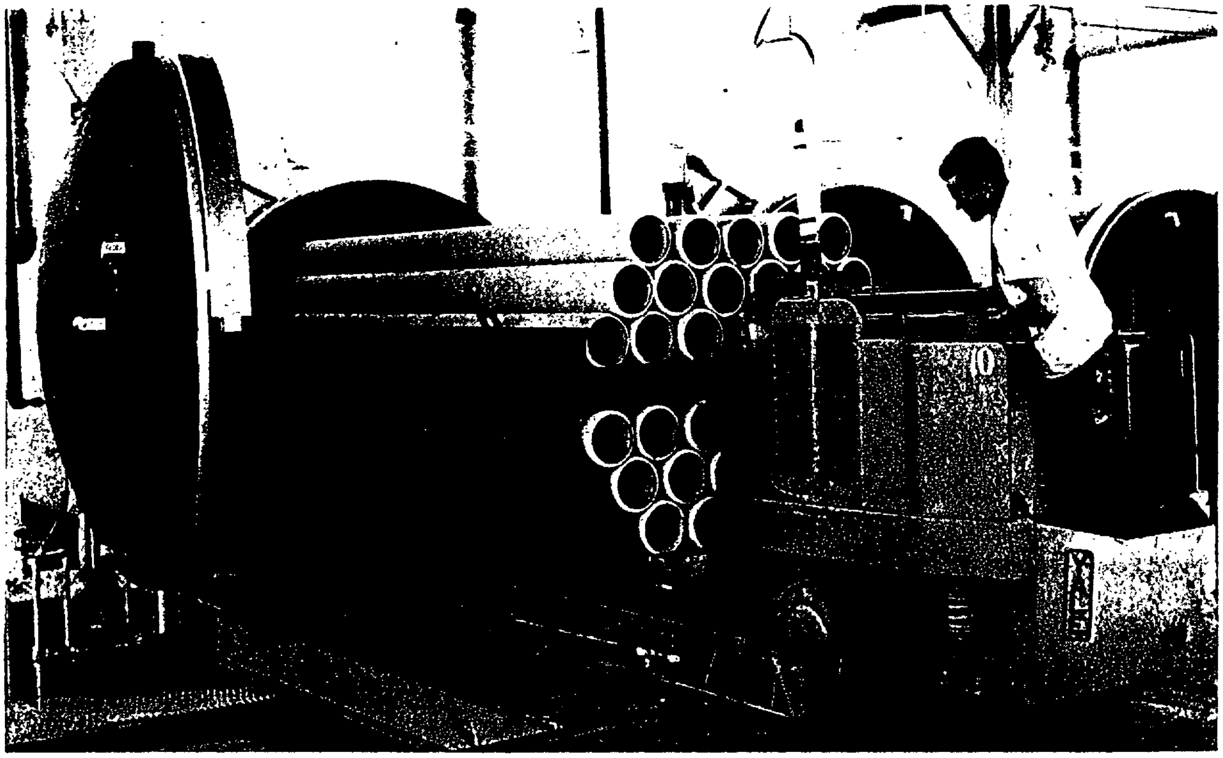
The sulfate expansion of normal cured pipe and autoclaved pipe exposed to this severe environment is shown in Fig. 2. At the end of seven years, the normal cured pipe was badly deteriorated, while after 24 years, the autoclaved pipe showed essentially no attack.

The badly deteriorated condition of the normal cured material in the later years made it possible to obtain meaningful compressive test results. However, an interesting aspect of the autoclaved sample was the increase in compressive strength from 8320 psi at one year to 14,590 psi after 24 years, an increase in compressive strength of more than 77 percent.

Manson[4] concludes in his report, "it should be emphasized that any concrete that gives a high strength after 10 years exposure to the sulfate waters of Medicine Lake can be classified as highly sulfate resistant. Any

Simplified flow diagram of asbestos-cement pipe manufacture





Asbestos-cement pipe being placed in an autoclave for curing

concrete that gives a good test after 20 years exposure to the sulfate waters of Medicine Lake can be classified as an extremely high sulfate resistant concrete."

Certainly the performance of the autoclaved asbestos-cement pipe samples warrants its classification as a product with extremely high sulfate resistance.

Ordway studies.[4] In 1934, a normal cured asbestos-cement pipeline was installed in Ordway, Colo., an area that has high sulfate content soil conditions (2 to 3.0 percent SO_3). Approximately six years after installation, the deterioration of pipe wall in spots caused leaks and ruptures in the line. Microscopic examination of the affected portion of the pipe showed bands of a fibrous crystallation material (ettringite, $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$), running perpendicular to the bands. This compound is formed by the reaction between free calcium hydroxide, portland cement, and the sulfate environments, and is usually accompanied by large volume expansion.

As these breaks occurred in sections, new lines of autoclaved asbestos-cement pipe replaced the old material. The entire replacement was completed within 13 years. Inspection in 1960 showed no visible evidence of sulfate attack nor failure of the autoclaved product.

Laboratory data. Yang and Blair[5] tested sulfate resistance of asbestos-cement pipe using normal and autoclave curing Type I (general purpose) and Type V (high sulfate resistance) cements in each process. Table 1 shows that Type I cement with autoclaving is as sulfate resistant as the Type V with autoclaving and that autoclaving in either case is superior to normal curing. In addition, the amount of free lime is reduced by autoclaving.

Literature data. Committee C-17[6] of ASTM confirmed by test that autoclaving reduced uncombined calcium hydroxide and reduced expansion of autoclaved vs. normal cured products when subjected to a sulfate medium as shown in Table 2.

Lea's paper[7] provides excellent data on the effect of high pressure steam curing on the sulfate resistance of mortars with ground silica sands, as shown in Table 3.

Sulfate resistance of asbestos-cement products is determined by the chemical stability of the cement binders. Autoclaved formulations with autoclave curing insure a more resistant pipe by:

Removing free lime, which is susceptible to sulfate attack.

Forming stable calcium silicate binder tobermorite of crystalline form.

Minimizing the volume changes and maintaining structural strength.

Forming stable binder material, which is also more chemically resistant than the binder of normal-cured asbestos-cement products.

The National Bureau of Standards field test[2] involving exposure to a wide range of soils at 15 test sites was conducted for periods up to 13 years. These soils ranged in pH from 2.6 to 9.4, resistivity measured from 84 to 17,800 ohm-cm, and the amount of air present covered a wide range. The summary of this study states: "even under the most adverse conditions to which the specimens were exposed, the bursting and crushing strengths of all of the samples after exposure were considerably higher than the requirements of the Federal Specification for Asbestos-Cement Pressure Pipe." □□

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KEY WORDS

Corrosion Control; Pipe.

CTD029335

Pressure

[illegible] Capacity

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In June of 1974, the attached bulletin concerning the CertainTeed Pressure Pipe Flow Calculator was sent to all field personnel. Due to cost and an adequate place to carry the calculator in this binder, we have chosen not to include the calculator itself.

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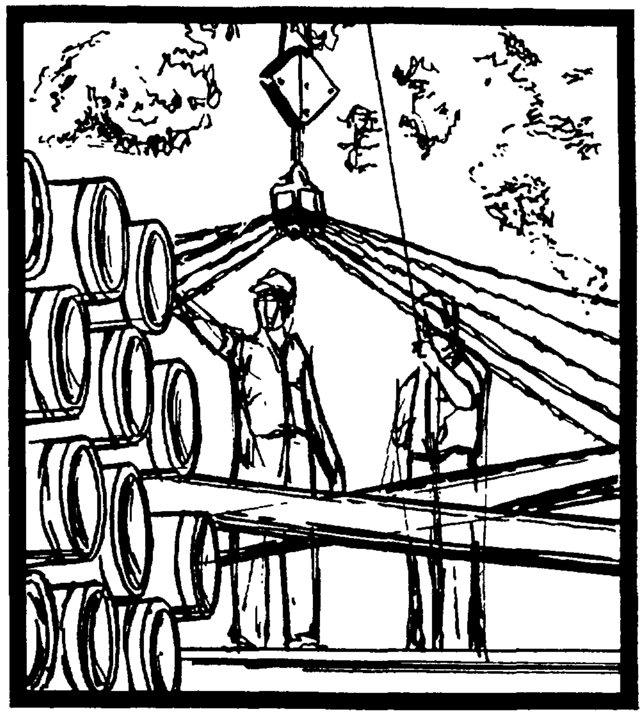

WATER SYSTEMS

pipes and piping

water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

PART 1/PIPING SYSTEM DESIGN

PART 2/MATERIALS

PART 3/INSTALLATION

PART 4/MAINTENANCE

CTD029338

GEORGE E. SYMONS, PH.D.

PUBLISHED BY DUN • DONNELLEY PUBLISHING CORPORATION,
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water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

CONTENTS

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FOREWORD

THIS MANUAL OF PRACTICE, the second in a projected series to be published by WATER AND WASTES ENGINEERING, has been prepared for a specific purpose; namely, to assemble, digest, collate, and organize basic information on pipes and piping systems used in water supply systems.

No manual of this size or type can include all of the myriad of details that apply to different types of pipe materials, their design, installation, and maintenance. This manual is not intended to be a detailed compendium. It was prepared to provide concise and basic information on the general subject. A glossary of terminology relating to pipes and piping will appear in Manual of Practice No. 3/Wastewater Systems Pipes and Piping.

It is hoped that this manual will be of interest and use to managers, superintendents, designers, engineers, and operators of municipal and investor-owned utilities and industrial water supply systems, and to teachers and students as well.

water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

WATER SYSTEMS

pipes and piping

PART 1/ PIPING SYSTEM DESIGN

THE ORIGIN OF THE CLOSED conduit, or pipe, is unknown, but in importance to mankind, its discovery ranks only behind those of fire, the wheel, and the lever. It is known that copper pipes were used in Egypt in 3800 B.C. The Chinese probably used hollow bamboo as pipes about the same time or even earlier. Tile pipe was used in palaces in the Middle East in 2500 B.C., and by King Solomon in 1500 B.C. Lead pipe was used for service connections to aqueducts by the Romans between 300 B.C. and 450 A.D.

Modern water pipe had its origin in the development of cast iron cannons in Europe in the mid-14th century. Early water pipes in England and America were bored logs. The first cast iron water distribution system in England was laid in 1774; and the first in America was in Philadelphia in 1802. All other water piping system materials now being used have been developed since 1900.

The importance of water pipe lines to the economy and to the water industry is evident from these facts:

- As a transportation system, water pipe lines carry a greater tonnage of product per day than any other single transportation system.
- Approximately two-thirds of the total value of water supply systems is in the transmission and distribution systems.
- Approximately 80 percent of the value of a distribution system is in piping and valves.
- In the five-year period 1961-65, approximately 48 percent of the total construction costs for water supply systems was for transmission and distribution (19 and 29 percent, respectively).

There are four types of piping systems in water utilities: transmission lines, distribution mains, services, and in-plant systems.

Pipe lines are fixed-installation facilities; they contain no moving parts (except in valves). Therefore, pipelines do not operate; neither are they operated, *per se*. Any discussion of transmission and distribution system operation actually refers to the water that flows in the pipes. Included in the subject of operation of these systems are these topics: booster stations, centralized control, extension of mains, fire flow tests, leakage surveys, metering (main line), nonrevenue water, pump control, records, sanitary checks, storage, and valves and hydrants. The latter topic on valves and hydrants is scheduled for coverage in Manual of Practice No. 4, and the other topics will be covered in another scheduled manual on distribution system operation.

Operation of services is, in reality, a matter principally of metering and customer service, to be covered in a manual on management. Operation of inplant piping systems will be covered in a manual on treatment plant operation.

BY GEORGE E. SYMONS, PH.D.

Dr. Symons is editor of WATER AND WASTES ENGINEERING. He is a Diplomate of the American Academy of Environmental Engineers; a Fellow of ASCE and APHA; Life Member and Fuller Awardee of AWWA; an Honorary Member of WPCF; and a Member of ACS, AIChE, AIDIS, and NSPE. Author of numerous articles on water supply and wastewater disposal, he was editor of 29 design criteria manuals for the Engineering Facilities Command, U. S. Navy, and author and editor of two manuals on operation and maintenance of water supply and wastewater disposal systems for EFC of the U. S. Navy.

Section 1—Transmission Lines

Transmission lines are pipes (or open conduits) that carry water from a source of supply to a treatment works or from a treatment works and/or main pumping station to a distribution system in a community.

The design of transmission lines must take into account these factors: location, type, carrying capacity (size), operating head and velocity, friction loss, material of construction, and installation conditions.

Location

Information required for the design of transmission lines includes a topographic map, soil map, and climatic data. If the line is to be a tunnel, a geologic survey is also necessary.

The route selected should provide economical construction and also have as many as possible of the following characteristics: gravity flow; shortest possible distance; few, if any, peaks and depressions; accessibility for construction and repairs, and freedom from landslides and flood waters.

When possible, it is often desirable to lay transmission lines along highways to avoid right-of-way costs. However, such locations should be used only if there is assurance that no future relocation will be required when the highway is widened, regraded, or moved.

Type of line

Choice of line type depends on several factors; for example:

Aqueducts or canals may be used under special circumstances but are not usually employed in this country.

Tunnels, either gravity or pressure, may be used if there is no alternative or where economy of construction dictates their use.

Pipe lines are generally preferable to other types, but they should be designed for gravity flow, if possible, to avoid pumping costs and to reduce line pressure.

Capacity

Transmission lines should be designed to meet future needs, domestic demands, fire flow demands, and flow velocity limitations.

Future requirements. Transmission lines should be sized to provide the capacity that will be desired at least 25 years hence. This capacity must be sufficient to provide domestic, industrial, and fire flow demands. In some cases, it may be desirable to lay two parallel lines, some distance apart, each line with a capacity equal to 75 percent of the capacity required 25 years later. The actual pipe size (diameter) should be such as to provide the desired capacity at the design working pressure.

Domestic demand. The per capita consumption to be provided varies with the size of the community. Statistical data for 1960 by Seidel and Cleasby[1] show that water production is related to population size (Table 1).

These data show that water consumption (production) varies with community size and that the ratio of mean con-

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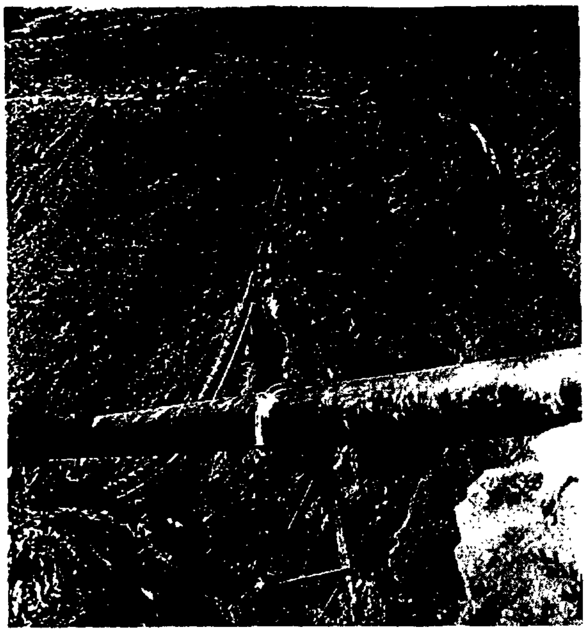

Steel transmission main in mountains of Utah.

sumption to maximum demand may range from 1 : 4 in small communities to 1:1.6 or 1:1.9 in large cities.

A compromise design criteria should provide transmission lines with 150 percent of mean consumption, or provide storage on the distribution system for peak loads. Without storage, the capacity must be able to meet peak hour demands.

TABLE 1—WATER UTILITY PRODUCTION BY POPULATION GROUPS

		Production (gpcd)		
Group	Population	Min.	Max.	Mean
1	1000	...	...	(85)
2	1,000–5,000	29	495	121
3	5,000–10,000	29	446	123
4	10,000–25,000	30	353	124
5	25,000–50,000	52	543	137
6	50,000–100,000	45	371	129
7	100,000–250,000	66	359	137
8	250,000–500,000	71	214	131
9	500,000	73	274	147
4–9 (1960)				128
4–9 (1955)				137
4–9 (1950)				138

Fire flow. Water system capacity must meet the criteria of the American Insurance Association (AIA), formerly NBFU. In general, it is necessary to provide sufficient flow capacity to meet both domestic demand plus a fire-flow capacity according to this equation.[2]

$$\text{gpm} = 1020\sqrt{P} \times (1 - 0.01\sqrt{P}) \qquad \text{Eq. 1}$$

where P = 1000 persons

The AIA generally requires that this fire-flow capacity be available for 10 hr in cities of 6000 or more and for 4 to 9 hr in communities of 1000 to 5000 population. Where it is uneconomical to provide this fire-flow capacity plus domestic demand, then storage on the distribution system must be provided to meet this fire-flow demand.

Burdick[3] developed a table of rates of flow required and storage necessary in communities of various sizes (see Table 2). These data are applicable to both transmission lines and distribution systems.

Flow velocity. Velocity of flow is a factor in capacity as are operating head and head loss. Velocities should normally be 5 fps or less because of high friction losses. If higher velocities are necessary, however, they should not exceed 15 fps in pipe or 12 fps in unlined tunnels.

Materials

The various materials available for water supply system pipe lines are set forth in Table 3, adapted from NAVDOCKS DM-5, (Facilities Engineering Command, U. S. Navy).[4]

Selection factors include corrosion resistance, strength against internal and external pressures, hydraulic characteristics installation and field conditions, and economic considerations. These factors will be covered in Part 2 of this manual.

Structural requirements. All pipe selected should meet the requirements as set forth in the standards and handbooks of the American Water Works Association. (See Table 4.)

Protective coatings that provide corrosion resistance must be used wherever soil or water conditions warrant. For information on protective coatings see Part 2 of this manual.

Installation

Criteria for and methods of installing transmission pipelines are given in Part 3 of this manual. Interconnections should be provided, wherever possible, with nearby potable supplies.

Section 2—Distribution System

Distribution systems are pipelines (mains) that carry water from transmission lines and distribute it throughout a community. Distribution systems include a network of mains plus distributing reservoirs, elevated storage tanks, booster stations, valves, hydrants, and service lines. (Note: this manual of practice deals only with mains and service lines; other elements will be covered in future manuals.)

Components

Arterial mains. Sometimes called trunk mains or feeders, arterial mains are pipe lines of fairly large size connected to transmission lines, and they feed the distribution network.

All major demand areas should be served by an arterial-loop system. Where possible, arterial mains should be laid in duplicate, but not in the same street. It is preferable to lay two moderately-sized arterial mains a few blocks apart than to lay a single large main. If laid in duplicate, arterial mains should be cross-connected at intervals of one mile or so, with the valving arrangements necessary to provide isolation of areas. Air relief valves and blowoffs need to be provided at high and low points respectively. Interconnections should be provided, either on transmission lines or arterial mains, to nearby potable supplies.

Distribution mains. All major demand areas should be supplied by distributors tied to the arterial loop to form a complete gridiron system, without dead ends. Areas of extra hazard should be tied into two arterial mains where possible. Tree arrangement systems are not recommended.

Minor distributors. These components make up the secondary system or grid; they supply fire hydrants and domestic and commercial consumers.

TABLE 2—RATES OF FLOW REQUIRED IN CITIES OF VARIOUS SIZES

Population	Flow at 140 gpcd (mgd)	150% of probable max. daily flow (mgd)	300% of probable hourly peak (mgd)	Max. rate for fire protection (mgd)	Storage for hourly peak (20% of max. day) (mil gal)
1,000	0.14	0.21	0.42	1.44	0.04
2,000	0.28	0.42	0.84	2.16	0.08
4,000	0.56	0.84	1.68	2.88	0.13
10,000	1.40	2.10	4.20	4.32	0.42
28,000	3.92	5.88	11.76	7.20	1.17
60,000	8.40	10.60	21.20	10.08	2.12
100,000	14.00	21.00	42.00	12.96	4.20
200,000	28.00	42.00	84.00	17.28	8.40

TABLE 3—TRANSMISSION AND DISTRIBUTION PIPELINE MATERIALS

Materials	Diam. (in.)	Normal max. working pressure (psi)	Advantages	Disadvantages
Asbestos-cement	4–36	200	Corrosion resistant; good flow characteristics; light weight; easy handling; low maintenance	Low flexural strength in small sizes; more subject to impact damage; difficult to locate underground
Cast iron (cement-lined)	4–48	350	Durable and strong; good corrosion resistance; easily tapped; flow characteristics good	Subject to electrolysis and attack from acid and alkali soils; heavy to handle
Cast iron (ductile) (cement-lined)	4–30	350	Durable, strong, high flexural strength; lighter weight than cast iron; greater carrying capacity for same external diameter; fracture resistant; easily tapped	Similar to cast iron
Concrete (reinforced)	12–168	50	Durable with low maintenance; good corrosion resistance; flow characteristics good; resists backfill and external loads	May deteriorate in alkali or soil, if cement type is improper, or in acid soil if not protected
Concrete (prestressed)	16–120	250	Durable, low maintenance; good corrosion resistance; good flow characteristics; resists backfill and external loads	Same as above
Steel	4–120	High	Light weight and easily installed; high tensile strength; low cost; good hydraulically when lined; adapted to locations where some movement may occur	Subject to electrolysis; external corrosion in acid or alkali soil; poor corrosion resistance unless properly lined, coated, and wrapped; low resistance to external pressure in larger sizes; air-vacuum valves imperative large sizes; subject to tuberculation when unlined

TABLE 4—AWWA STANDARDS FOR WATER PIPE

Pipe material	AWWA Standard no.
Asbestos-cement	C 400-65, H2-64
Cast iron	H 1-67, C 104-64, C 106-62, C 108-62, C 110-64, C 111-64, C112-65
Concrete	C 300-64, C 301-64, C 302-64,
Ductile iron	H 3-65, C 151-65
Steel	C 201-60T, C 202-64T, C 207-55, C 208-59

High service systems. Separate distribution systems that serve areas on high ground or where high pressure requirements exist are called high service systems.

Valve system. Shut-off valves should be provided to sectionalize the distribution system. The sections should be laid out so that most of the flow will be maintained if any one section is cut out of service. Valves for sectionalizing purposes should be spaced at 1200 ft intervals and at all branches from arterial mains.

Where line intersections exist in a grid, no more than one branch, preferably none, should be without a valve. (Note: valve and hydrant selection, installation, and operation will be covered in Manual of Practice No. 4.) Where cross connections are made between an industrial and domestic supply, the connection must be by a backflow preventer that has state health department approval.

System planning

Information required for distribution system planning and operation includes a topographic map of the area served, location of other utilities, maps of the system, and quantity and pressure requirements.

Maps. A topographic map (400 ft to the inch) should show the following information for the entire system:

The existing system
Present and planned streets
Areas outside the system (possible future expansion)
Ground level elevations and contours
Streams, grade changes, topographic features
Installed utility lines including sewers, storm drains, gas and steam lines, and underground electric and telephone cables
Population densities in different areas
Normal water consumption by areas
Pressure at strategic points

Sectional maps, usually 24 by 36 in., scaled 50 or 100 ft to the inch, should be drawn for the entire system and should show complete details including valve and hydrant locations. Maps scaled at 20 ft to the inch may be desirable for intersections or congested areas. Distribution system record books should be keyed to the sectional maps.

Layout. Distribtuion system layout may be designed to fit one of three configurations or a combination.

Loop. A complete loop, or belt, of arterial mains around the area, with branches projecting inward to serve the distributors (see Fig. 1).

Gridiron. All ends of distributor mains are connected to eliminate dead ends (see Fig. 2). This arrangement may become a loop system or it may be a single arterial main through the area, with the branches looped.

Tree. This arrangement consists of a single arterial main that decreases in size with length. Branches are taken off at right angles, with sub-branches from each branch.

Growth planning. System planning must include a long range program for distribution system growth. This program should include regular revisions of growth charts showing population data and average- and maximum-day pumpage plotted against years. Projection of these data should be made each year for 10 years hence. The projected data should include population growth and domestic water usage and also expected growth of commercial and industrial water usage. In large cities, such future projections and planning should be made for important growth areas within the community.

Sizing mains

The size of a main is a measure of its carrying capacity, and sizes must be selected to provide the flow (capacity) to meet domestic, commercial, and industrial demands plus the fire flow required under the maximum-day demand conditions and pressure required in the area to be served.

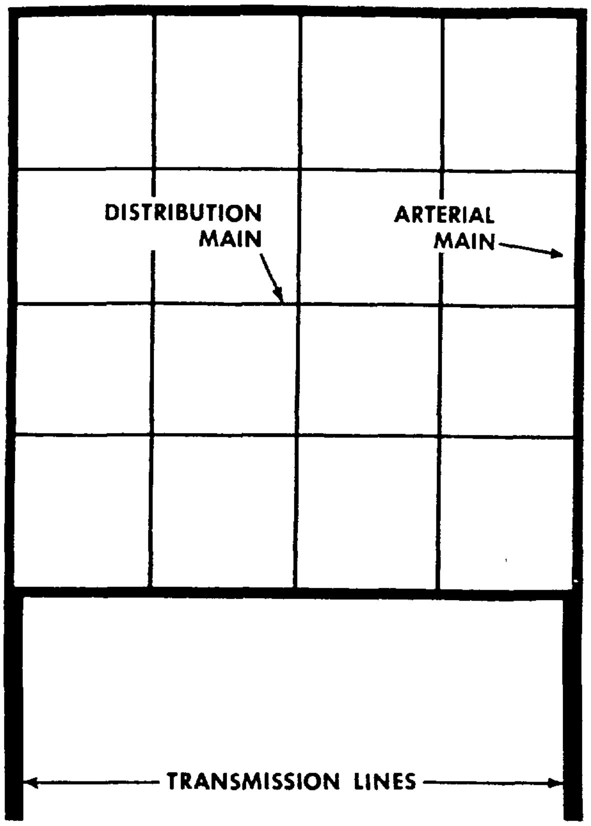

Fig. 1. Arterial loop system.

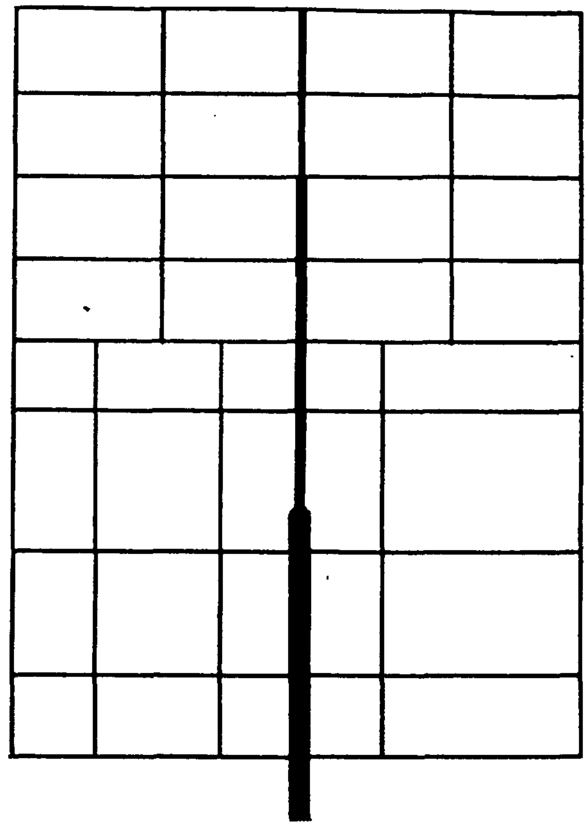

Fig. 2. Grid type of distribution system.

These capacity criteria should be for the needs anticipated 25 years hence.

Minimum pipe sizes. No main in a distribution system should be less than 6 in. in diameter, a limitation suggested by the American Insurance Association. For sound design, it is desirable to select the next size larger than that indicated by calculations of pipe size required.

The American Insurance Association further recommends that minimum pipe sizes should be governed in part by the type of area served, for example: High value districts should have minimum pipe sizes of 12 and 8 in.; residential areas should have minimum sizes of 8 and 6 in. The smaller sizes should be used only when they complete a good grid.

Quantity requirements. Domestic usage requirements for any service area should be based on the data in Table 1, adjusted for commercial and industrial factors and population growth factors.

Fire flow requirements should be based on Eq. 1, and the conditions set forth by the AIA.[2] AIA has set required fire flow (in gpm) for cities of 1000 to 200,000 population and the hours of duration that this flow must be maintained in these various city sizes.[2]

In residential districts, the fire flow is determined on the basis of structural conditions and congestion of buildings.[2]

TABLE 5—TYPE OF RESIDENTIAL AREA VS. FIRE FLOW REQUIRED

Area description	Flow required (gpm)
One-third of the lots have buildings of low height and small area	500
Buildings of larger area or greater height	1000
Closely built, or high value residences, apartments, etc.	1500–3000
Densely-built districts with 3-story or higher buildings	6000

In this respect, AIA sets the limitations shown in Table 5.

Pressure requirements. Minimum static pressure at all fire hydrants should be 30 psi; pressure should be higher in areas requiring high fire-flow capacity. Pressures at consumers' residences should be at least 20 psi, preferably 30 psi. For buildings up to ten stories, the pressure should be 50–65 psi.

Flow capacity. Pipe-carrying capacity depends on pipe size, pressure, flow velocity, and head loss resulting from friction. Friction factors include roughness of pipe and Reynolds Number, which depends on flow velocity and pipe diameter.

The required pipe size is calculated from required flow (in gpm), head loss for pipe length desired, and flow velocity. The Hazen-Williams formula (Eq. 2) is:

$$V = 1.318\ CR^{0.63}\ s^{0.54} \qquad \text{Eq. 2}$$

where

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V = flow velocity (fps)
C = Roughness coefficient
R = hydraulic radius of pipe (ft)
s = hydraulic gradient (ft per 1000 ft)

The applications of this formula has been simplified by the use of a special slide rule (Fig. 3).* Nomograms, for solving the Hazen-Williams formula, may be used in place of the slide rule.** A number of these published nomograms are listed in a reference work on nomograms.[5] Also useful are charts based on the Hazen-Williams formula for differ-

* This slide rule may be obtained, free, from The Cast Iron Pipe Research Assn., Chicago, Ill., or from the Grinnell Co., Providence, R. I., Interpace Pipe Div., Parsippany, N. J., American Concrete Pipe Assn., Chicago, Ill., and CertainTeed Products Corp., Ambler, Pa.

**Available from Johns-Manville, New York, N. Y.

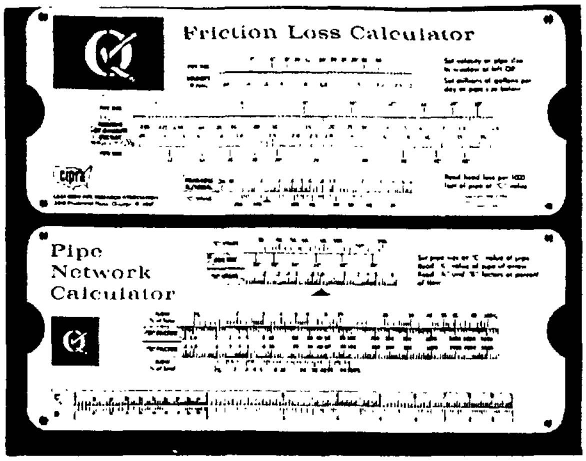
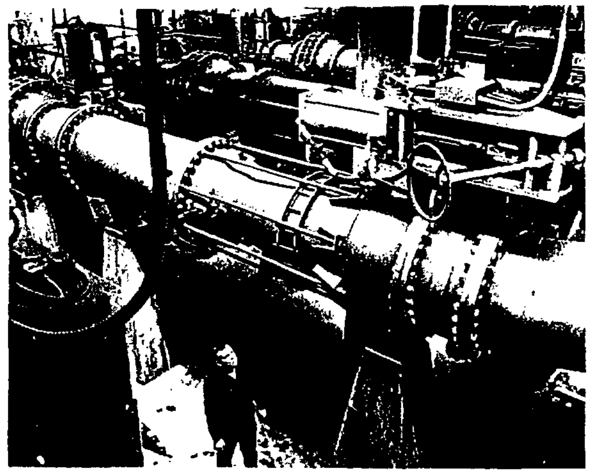


Fig. 3. Hazen-Williams slide rule.



Inplant piping system in pump station.

ent pipe sizes.[6] Useful tables of cast iron pipe based on the Hazen-Williams formula have been published for various pipe sizes and various C-values.[7] Table 6 lists C-values of new pipe of various materials and age.

In making flow calculations for pipe line design, it is good practice to use C-values shown in Table 7. For old lines, these values should be reduced.

TABLE 6—C-VALUES OF VARIOUS PIPE MATERIALS

Pipe material	C-value
Asbestos-cement	140+
Cast iron (new)	140+
Bitumastic enamel, centrifugally applied	140+
Cement-lined, centrifugal method, actual diameter	140+
Pit cast, tar dipped	140
Cast iron (20 years old)	100
Tar dipped (inactive water)	130
Bitumastic enamel (inactive water)	135
Cement lined	140
Tuberculated	100*
Concrete (quality pipe)	140+
Ductile iron (cement lined)**	140+
Plastic	140+
Steel	140+
Wood stave (smooth)	120

* Less with high degree of tuberculation
** Greater capacity because of larger internal diameter for normal outside diameters.

TABLE 7—PREFERRED C-VALUES FOR FLOW CALCULATIONS

Type of line	C-value
Transmission lines	140*
Arterial mains	130
Distribution mains	
Old	120
New	100

*In the absence of growths.

System analysis. Where the distribution is extensive, it is necessary to analyze the system and balance the flow among all areas in relation to demand. This computation involves determination of the take-off quantity from the arterial mains to the various branches and sub-branches and determination of the hydraulic grade line of the system. In short, this analysis requires a plot of the pressures and flows at points throughout the system.

There are five principal methods for system analysis: Electric network analyzer, Hardy-Cross method, equivalent-pipe method, graphical method, and uncontrolled trial and error. It is also possible to construct a hydraulic model, but this method is exacting and expensive.

The electric network analyzer is most useful, but the equipment is expensive, unless it can be used for continuous updating of the system. The Hardy-Cross method[8] involves many calculations, but the time-consuming operations can be reduced by the use of a computer.

The equivalent-pipe method technique[9] offers a simplified, yet effective approach to distribution system analysis.

Materials

The selection of materials for distribution mains should be based on the same criteria that are used for transmission lines; see above and Tables 4 and 6. In addition to meeting these criteria, distribution mains must also be easily tapped. Corrosion protection and maintenance of flow conditions are also important; see Part 2.

Installation. Criteria for installation procedures and methods of installation are covered in Part 3.

Section 3—Services

Services or service lines are pipes of small diameter that run from distributor mains or branch mains to customers' premises.

Materials

The selection of service line material is influenced by the following factors: size, durability, water characteristics, corrosion resistance, availability, ease of installation, maintenance, and economics. All of these factors should be taken into consideration before materials are selected.

Types of material. Lead was probably the earliest material used for service lines. (It was used in Rome about 300 B.C.) This metal is no longer popular for service lines because of its cost and its tendency to dissolve in soft waters at low pH.

Copper is now the most popular service line material. Approximately half the water utilities in the United States use copper exclusively, and most of the other half use more copper than other materials. Plastic pipe has gained in popularity for service line use; as its formulations improved, application experience grew. Several types of material are available for service line use, including a number of plastics. Plastic pipe selected for potable waters should meet approved specifications and should carry the seal of approval of the National Sanitation Foundation.

Sizing services

Modern practice must take into account the customer demands including peak-hour demands for lawn sprinkling, dish-washing, laundering, and other household uses.

Minimum service-line size should be 3/4 in., preferably 1 in. For large residences with many baths and large lawns, service lines should be 1-1/4 or 1-1/2 in. Multiple dwelling buildings require larger services. The City of Richmond, Va., relates service-line size to number of fixtures, or combinations of fixtures, together with flow in meters of different sizes, through the use of tables and charts.[10]

TABLE 8—INPLANT PIPING MATERIALS

Use	Asbestos-cement	Cast iron	Concrete	Copper	Galvanized iron	Glass	Plastic	Rubber	Steel	Wrought iron
Air lines		√		√	√	√	√	√	√	√
Chemical feeding	√	√		√	√	√	√	√	√	
Filter piping	√	√	√				√		√	√
Gas lines		√		√	√	√	√		√	√
Heating systems	√	√		√	√				√	√
High service	√	√	√						√	√
Low service	√	√	√						√	√
Plumbing	√	√			√		√		√	√
Pump discharge	√	√	√						√	√
Pump suction	√	√	√						√	√
Sampling lines	√	√		√	√	√	√	√	√	
Wash water system	√	√	√				√		√	√

Rule-of-thumb is not good practice for determining the size of service lines. It is necessary to consider not only the customer demands as estimated from an analysis of fixtures and other factors such as lawn sprinkling, but also the expected hydraulic losses. These losses can be relatively high, as indicated by the following data.

For a 3/4-in. copper service line 40-ft long and a 5/8-in. meter, the hydraulic friction loss at a flow of 10 gpm is approximately 13 psi. If 30 psi is available at the main, such a loss would leave only 17 psi of head at the house to overcome static head from basement to top floor and friction loss in the plumbing system. This pressure is insufficient for good service. A 1-in. line would have a friction loss of only 5.5 psi for the same installation.

Some indication of the range of hydraulic friction losses is shown in the following data on 1/2- and 3/4-in. service lines.

Flow rate (gpm)	Friction loss (psi) 20-ft line 1/2-in.	20-ft line 3/4-in.	100-ft line 1/2-in.	100-ft line 3/4-in.
1	0.28	0.19	1.4	0.4
10	15.6	10.73	78	22.7

These data show clearly why small service lines should not be used. Complete tables and curves for hydraulic friction losses have been published by the American Water Works Association.[7]

Location and ownership

In rapidly growing areas, taps may be made and corporation cocks installed on mains as they are laid, with the services spaced according to lot width. About half the water utilities in this country follow this practice, but there are sound reasons for not doing so. The principal objections to this practice are: the service line may be the wrong size or poorly spaced when the area is developed; there is a possibility that many connections will not be used; and such services are possible sources of leakage.

About half of all services are owned by the utility and half by the customer, but utilities install approximately two-thirds of all services (about 20 percent are charged to the customer). When services must be replaced before street resurfacing or installation of permanent pavement, the cost is borne by the utility about 70 percent of the time.

Installation

Criteria for installation procedures are covered in Part 3.

Section 4—Inplant Piping

Inplant piping systems include pipes and piping in pump stations, treatment plants and filter galleries.

Design

Factors important in the design of inplant piping systems include: use (application or service), material selection, size, pressure, flow capacity, and layout and arrangement. The selection of pipe size and material will depend on the required flow capacity and working pressure of the fluid to be handled.

Material selection

Table 8 lists various uses or systems and types of pipe generally suitable for use. Final selection of the material must include all factors listed above.

Layout and arrangement

Whatever the particular service of the system, piping should always be arranged to provide a minimum interruption of service as a result of any one piping break or outage. This rule is particularly applicable to low and high service lines and suction and discharge headers.

Layout of piping and valves should be systematic and should conform to the placement of pumps and other equipment, with a minimum of bends and fittings so that head loss is held to a minimum.

Piping arrangements should provide for easy access to pumps, valves, and other equipment during installation or maintenance procedures.

Suction piping, in particular, should be carefully designed to avoid air pockets. These lines should rise gradually to the pump. Eccentric reducers should be used to prevent the formation of air pockets.

Color coding

It is highly desirable to color code all pipe lines in every inplant piping system. A standard color-code system[11] has been developed by the U. S. A. Standards Institute (formerly the American Standards Association). Most water plant designers and managers prefer some variations of this standard system. Whatever the colors selected, they should be easily recognized. Include the following items in the lines to be color-coded:

- Air lines
- Chemical feed lines (color code each chemical)
- Chemical feeder waste lines
- Filter lines
- Gas lines
- Heating systems
- High service (finished water)
- Low service (raw water)
- Potable water systems
- Plumbing waste line (sewers)
- Sampling lines
- Washwater system

Color-coding systems may employ solid colors, or solid colors plus distinctive bands, and lettered labels at points where the information is desirable. Directional arrows on all lines are also desirable. The colors and shades should be easily visible and recognizable in the light available at all locations.

water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

WATER SYSTEMS

pipes and piping

PART 2/ PIPE MATERIALS

For use in transmission and distribution systems, pipe materials must have certain characteristics:

Ability to withstand internal pressure and external load
Ample tensile strength
Resistance to beam load failure
Maximum flow capacity for particular pipe size
Resistance to aggressive soils and waters
Long life, toughness, imperviousness, ease of tapping, and tight joints

The following sections discuss various types of pipe material including design and manufacture, pipe sizes, testing, protective coatings, joints, and shipping.

Section 1—Asbestos-Cement Pipe

The ingredients used to make asbestos-cement pipe are simple: asbestos fibers, silica sand, and cement. Although asbestos fibers make up the smallest percentage of the total volume of pipe material ingredients, their high tensile properties add significantly to the overall pipe strength.

Asbestos is a mineral fiber produced by extreme geological pressures during the formation of the earth's crust and is found in many countries. It is both strong and silky. Three types occur: chrysotile, amosite, and crocidolite. Most of the asbestos used in this country comes from Canada and South Africa.

Design

Asbestos-cement pipe was first made in Europe in 1913, and it was introduced into this country in 1929. As a water pipe, it is designed to meet the conditions of installation and service.

Factors of design. Pipe strength design is determined by consideration of these factors: internal pressure, external load, and safety.

The method for selecting the pipe-wall thickness is set forth in detail in AWWA Handbook H-2 entitled "Standard Practice for the Selection of Asbestos-Cement Water Pipe."[12] The following paragraphs describe the method.

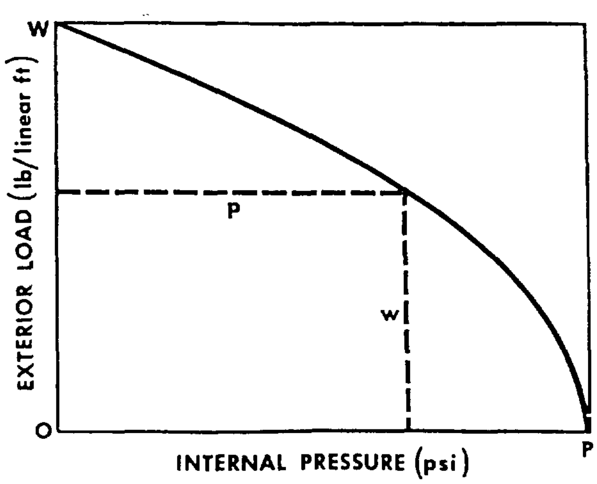


Fig. 4. Load-pressure curve for pipe.

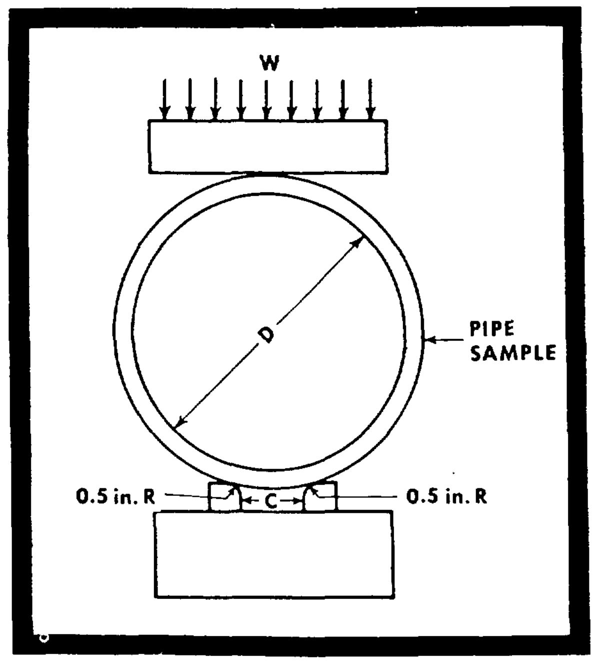


Fig. 5. Three-edge bearing test for A-C pipe. W represents load; R, approximately 0.5 in., the radius of the bearings; D, the nominal diameter of the pipe; and C, the clear space between wooden supports. C should be 0.5 in. for diameters of 12 in. and under, 1 in. for 14 to 24 in. inclusive, and 2 in. for 30 in. and over.

Combined loading. The relationship between the combined effect of internal hydrostatic pressure and external loads is represented by an empirical parabolic curve (Fig. 4) and the following equation:

$$w = W\sqrt{\frac{P - p}{P}} \qquad \text{Eq. 3}$$

where w = external load at which the pipe will fracture in combination with internal pressure p (lb per lin ft)*

W = crushing load of pipe in a three-edge bearing test, with no internal pressure (lb per lin ft)

p = internal pressure at which pipe will fracture in combination with external load w* (psi)

P = bursting pressure of pipe when no external load exists (psi)

* Three-edge bearing test, see accompanying description.

Three-edge bearing load. The usual method for determining the crushing strength (W) is the three-edge bearing test (Fig. 5). It is necessary to adjust the value obtained from

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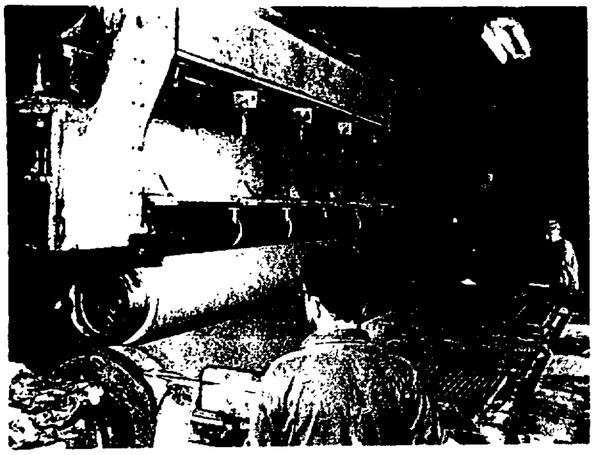

Manufacture of asbestos-cement pipe.

this test to field conditions because of the supporting strength of the installation conditions. Therefore, a load factor is applied to the three-edge bearing loads to correlate them to field loads. In this relationship, the value is expressed as the external load calculated by multiplying the three-edge bearing load by the bedding conditions load factor. Table 9 shows typical field installation conditions and the load factor for various pipe sizes.

TABLE 9—RELATION OF BEDDING CONDITIONS, PIPE SIZE, AND LOAD FACTORS FOR ASBESTOS-CEMENT PIPE

Bedding condition (class)	Description	Pipe size (in.)	Load factor
A	Gravel or sand base; backfill tamped	4–12	1.7
		14–20	1.8
		24–36	2.0
B	Same as A; but backfill not tamped	4–36	1.5
C	Pipe laid on earth mounds or pipe barrel on flat trench bottom with excavated coupling holes; backfill tamped	4–12	1.3
		14–20	1.4
		24–36	1.5
D	Same as C; but backfill not tamped	4–36	1.1

External loads. Two factors contribute to external loads on pipe: backfill and superimposed loads (either static or moving, or both).

Gravity earth loads are computed on the theory[13] that the load on a buried conduit is equal to the weight of a prism of earth (interior prism) directly over the pipe, plus or minus frictional shearing forces transferred to that prism from adjacent prisms of earth. The general equation for this theory is:

$$W = Cw B^2 \qquad \text{Eq. 4}$$

where W = vertical load on conduit due to earth load (lb per lin ft)
w = weight of earth (lb per cu ft)
B = trench width or pipe outside diameter depending on installation conditions (ft)
C = coefficient consisting of four factors:
(1) ratio of fill height to trench or conduit width
(2) shearing force between interior and adjacent earth prisms
(3) direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions
(4) rigidity of conduit support for embankment conditions

Superimposed loads are determined by this equation:

$$W_{SC} = C_S \frac{PF}{L} \qquad \text{Eq. 5}$$

where W_{SC} = load on the pipe (lb per lin ft)
P = concentrated load on pipe (lb)
F = impact factor due to dynamic load of moving vehicles (see Table 10)
C_S = load coefficient*
L = effective length of pipe (ft); use 3 ft for pipe lengths greater than 3 ft and actual length for lengths less than 3 ft

* Load coefficient is a function of $B_c/2H$ and $L/2H$; where B_c is pipe diameter (ft), H is distance from ground surface to top of pipe (ft), and L is effective pipe length (ft) (data for these values may be obtained from tables in AWWA Handbook H-2).[12]

TABLE 10—IMPACT FACTORS DUE TO MOVING VEHICLES (FOR ASBESTOS-CEMENT PIPE)

Type of traffic	Impact factor (F)
Highway	1.50
Railway	1.75
Airfield runways	1.00
Airfield taxi ways, aprons	1.50

Internal pressure. Possible hydrostatic pressure within the pipe results from a combination of operating pressure and surge pressures. Operating pressures are determined from the service provided. For normal service installations, a safety factor of 4.0 is applied to operating pressure in the combined internal-external loading calculation, which is more than adequate for most surge conditions. For exceptional surge conditions, water hammer allowance is calculated by special equations (see AWWA Handbook H-2).[12]

Safety factor. In developing the selection curves,[12] a safety factor of 4.0 was applied to internal pressures and a factor of 2.5 to external loads. Pipe selected from the curves[12] will have a safety factor of 2.5 for internal pressure when combined with a safety factor of 2.5 for an external loading of the normal earth load plus a 10,000-lb wheel and impact load.

Pipe classes. According to AWWA Standard C400-65,[14] asbestos-cement pipe intended for water service is manufactured in three classes: Class 100, Class 150, and Class 200; to be used respectively for operating pressures of 100, 150, and 200 psi. Detailed requirements for this type of pipe, set forth in the AWWA Standard,[14] will be discussed in the paragraphs under the topic "Manufacture."

Selection curves. From calculations of the combined loading factors for different laying conditions, pressures, external loads, etc., a set of selection curves for asbestos-cement pipe have been published in the AWWA Handbook H-2.[12] Two of these sets of curves are shown in Fig. 6.

Thickness and surfaces. The AWWA Standard C400-65[14] requires the wall thickness of the machined portion of any length of pipe to be within 0.08 in. of the manufacturer's standard, for pipes with a wall thickness of 1 in. or less, and within 0.10 in., for pipes with a wall thickness greater than 1 in.

The standards also require the inside of each pipe to be free from bulges, dents, and tears that could cause a variation of more than 0.2 in. from the diameter of adjacent areas. Couplings must be free of dents and gouges.

Flaking of the exterior surface and edge of machined ends may not extend back more than 0.50 in. from the end, or have a depth of more than 0.125 in., and may not extend more than 0.50 in. around the perimeter at any point.

Manufacture

The manufacture of asbestos-cement pipe begins with the opening of the natural "bundles" of fibers. The individual strands are spread apart to develop the ultimate strength of the fiber. The fibers, finer than human hair, are placed in a

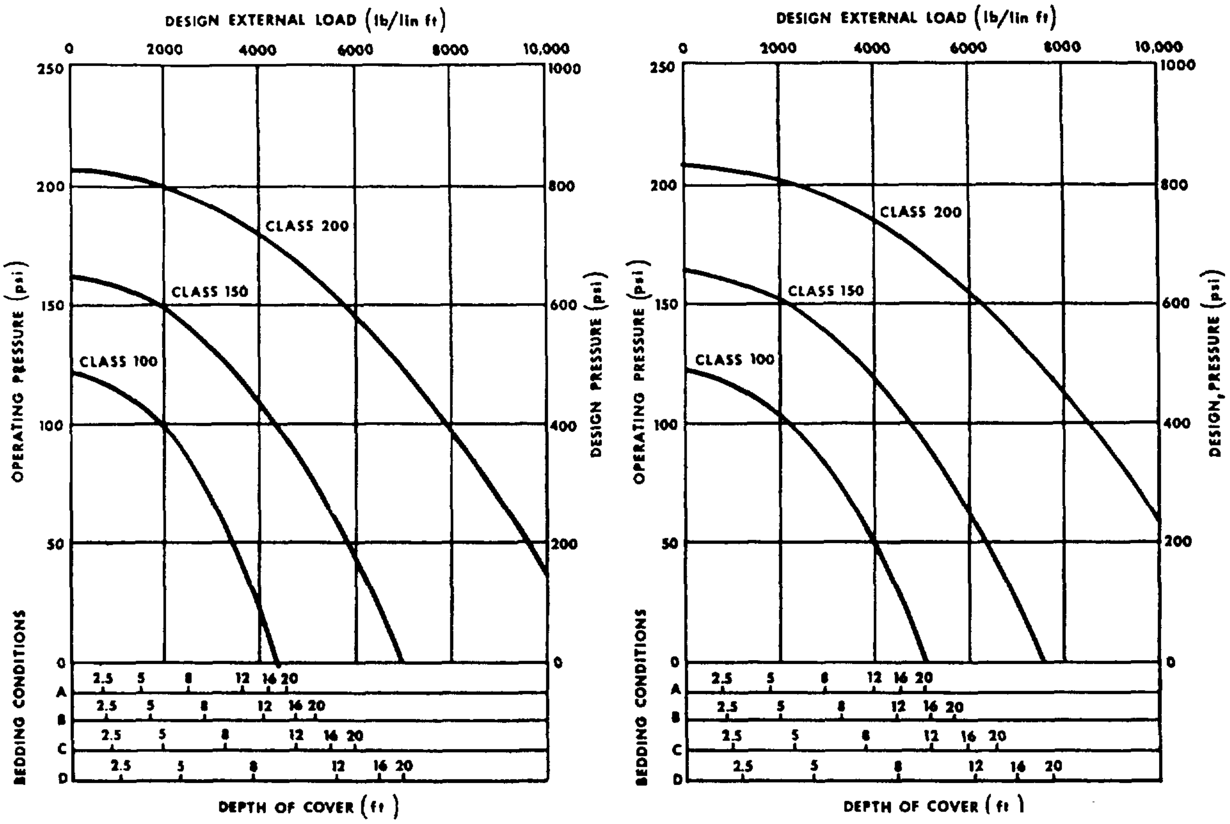

Fig. 6. Examples of A-C pipe selection curves.

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special machine for the bundle-opening operation and are cleaned electromagnetically to remove any iron compounds, which are frequently associated with asbestos deposits.

Materials. Besides the asbestos fiber, asbestos-cement is composed of portland cement, or portland blast furnace slag cement, or portland pozzolana cement, and silica. The amount of each used varies but is usually in the following ranges: asbestos, 15 to 20 percent; silica, 32 to 34 percent; and cement, 48 to 51 percent.

Process. After the asbestos is milled and cleaned, the various types of fibers are blended and stored in hopper bins. The portland cement and finely ground silica are also stored in bins. The ingredients are weighed automatically in the proportional amounts and discharged to a series of blenders, where they are physically and thoroughly mixed. To this mixture is added a metered amount of water, and a slurry is produced for transport to the pipe-making machines.

Pipe production. The following brief description of pipe manufacture is based on the material in Section V of "Sewers for Growing America."[15] The slurry is discharged into vats in which are located long revolving drums covered with a fine-mesh screen. The solid mixture deposits as a thin film on the screen, and water drains through as the drums rotate.

The rotating drum carries the film to a point where it makes contact with a moving felt. The thin continuous sheet is transferred to the felt, which moves the film to the next step. The drum length and felt width are slightly more than the finished pipe length.

The film and felt pass over a vacuum box, where excess water is removed, and then come in contact with a rotating, smoothly-polished, heavy-walled steel mandrel. As the felt and mandrel make contact, the thin film is continuously deposited on the mandrel until the desired pipe thickness is obtained. Hydraulic pressures on the felt compress the asbestos-cement mixture into a uniform, homogeneous solid with low water-content and high density.

Heat drying. When the desired wall thickness has been reached, the mandrel and pipe are taken out of the pipe-forming machine and placed in a heat chamber where the pipe wall sets. The mandrel is removed from inside the pipe, and the pipe is subjected to additional heat to increase the strength, rigidity, and stability for further inplant handling.

Curing. Asbestos-cement pipe is cured by subjecting it to high-pressure steam in an autoclave. The purpose of the curing process is to reduce the content of uncombined calcium hydroxide that results from the curing of the portland cement mixes. The calcium hydroxide content is reduced to less than 0.5 percent. The result is a more stable and chemically-resistant cementing compound produced by reaction of the calcium hydroxide with the pulverized silica. Steam curing lasts 10 to 12 hr, after which the pipe is removed from the autoclave and trimmed to the standard length of 13 ft. Each pipe end is then machined to accept the coupling unit. Couplings are produced in the same manner as pipe.

Testing

In accordance with AWWA Standard C400-65,[14] asbestos-cement pipe for use in water lines is subjected to tests to ensure its proper service. All pipe and couplings are tested in a normal air-dried condition.

Hydrostatic test. Every length of pipe is subjected to a hydrostatic test for a period of 5 sec. Test pressure are: 350 (Class 100); 525 (Class 150); and 700 psi (Class 200). All air is expelled from the pipe and the pressure increased at a uniform rate of not less than 100 psi per sec.

From each 300 standard lengths of each size and class, one length is tested at pressures of four times the operating pressure for that class.

Cement-mortar coating being added to steel pipe.

Flexure test. Each pipe length of 4-, 6-, or 8-in. diam. pipe is tested for flexure for 5 sec, with the load applied at a minimum rate of 500 lb per sec. The pipe is placed on bearing points 9 or 12 ft apart, depending on the pipe length. Pressure is applied at third points of the pipe length, one-half of the total pressure being applied at each point. The total load applied for each pipe class is shown in Table 11. Each pipe must support the loads noted in Table 11 with no evidence of cracks or other defects.

TABLE 11—FLEXURAL TEST LOADS FOR ASBESTOS-CEMENT PIPE

Pipe size (in.)	Total applied load (psi)		
	Class 100	Class 150	Class 200
4	1200	1460	1860
6	2800	3700	4900
8	5330	7600	10130

Crushing test. One length of pipe out of each 300 lengths of each size and class (or each lot of 100 if less than 300 in a lot) is subjected to a crushing test. A 12-in. specimen is cut from the unmachined section of the pipe and is placed on a two-edge bearing support (the distance between supports being determined by the pipe size),[14] and the load is applied along the full length of the specimen.

After 75 percent of the total load is applied, the loading is increased at a uniform rate of 2000 lb per min. An acceptable test allows failure only after the total load applied exceeds the values given in Table 12.

Rejection. When pipe test specimens fail to withstand 75 percent of the crushing load given in Table 12, the entire lot is discarded. When specimens fail between 75 and 100 percent of the crushing test values in Table 12, tests are made on two additional specimens. If these do not meet the requirements of Table 12, the entire lot of pipe is rejected.

TABLE 12—CRUSHING TEST LOADS FOR ASBESTOS-CEMENT PIPE

Pipe size (in.)	Load applied (lb/lin ft)		
	Class 100	Class 150	Class 200
4	4,100	5,400	8,700
6	4,000	5,400	9,000
8	4,000	5,500	9,300
10	4,400	7,000	11,000
12	5,200	7,600	11,800
14	5,200	8,600	13,500
16	5,800	9,200	15,400
18	6,500	10,100	17,400
20	7,100	10,900	19,400
24	8,100	12,700	22,600
30	9,700	15,900	28,400
36	11,200	19,600	33,800

Uncombined calcium hydroxide. Purchasers may specify a limit for uncombined calcium hydroxide. A standard test procedure utilizes phenolphthalein indicator, glycerol-ethanol solvent, and standard ammonium acetate solution,[14] and the results are reported as the percent of uncombined calcium hydroxide by weight.

Surface characteristics

By virtue of its method of manufacture, asbestos-cement pipe is smooth on the outside, and due to the polished mandrel used in its formation, it normally has a very smooth interior bore. Therefore no coatings of any kind are used.

Because of its chemical composition, the pipe is unaffected by corrosive water or soils. With its smooth bore, it has a high C value at installation, a value that remains high throughout use. The low content of uncombined calcium hydroxide ensures that the leaching effects of soft waters will be at a minimum.

Pipe sizes

Asbestos-cement water pipe is supplied in standard sizes in each class as follows: 4, 6, 8, 10, 12, 14, 16, 18, 20, 24, 30, and 36 in. The average inside diameter of a standard or random pipe length may not be less than the nominal diameter by more than 5 percent for sizes through 16 in., and 1.5 percent for sizes 18 in. and above.

Joints

Asbestos-cement pipe lengths are joined by special couplings, also made of asbestos-cement. These couplings, somewhat larger than the outside diameter of the pipe, are machined to fit over the machined ends of the pipe. Two flexible rubber O-rings are placed within the coupling proper and make a water tight seal. These joints also provide some degree of flexibility in laying the pipe without leakage. Figure 7 shows a coupling for asbestos-cement pipe.

Shipping

Asbestos-cement pipe and couplings are marked with the manufacturer's name and a "T" to indicate that the pipe has been hydrostatically tested. Rubber jointing rings are marked for identification with size, year, and class of pipe with which it is to be used.

The pipe is carefully handled, palletized, and loaded on trucks or railroad cars and tied down to prevent damage in transit. Installation and handling procedures are covered in Part 3.

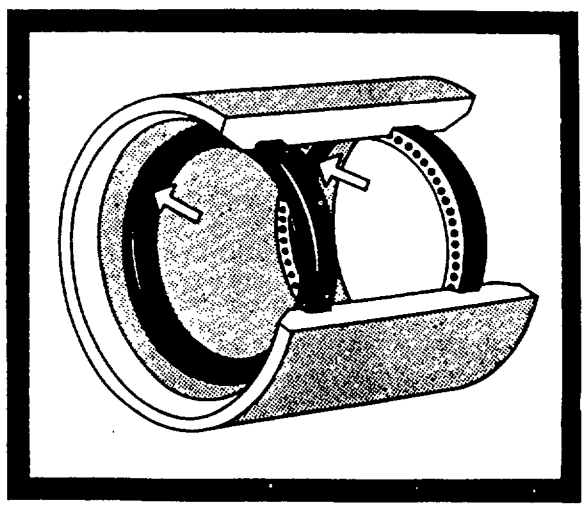

Fig. 7. Coupling for A-C pipe.

Section 2—Cast Iron Pipe

Design

There are two types of cast iron available for water piping systems: gray cast iron and ductile iron. Gray cast iron has a history of use that dates back more than 300 years. Ductile iron was developed in 1948, and its use has been increasing since 1960.

Gray cast iron. The characteristics of long life, toughness, imperviousness, and ease of tapping are provided in gray cast iron by the chemical composition of the metal, and carrying capacity is ensured by proper lining. (See discussion on manufacture.) The ability of pipe to withstand internal pressure and external load are matters of design of strength and thickness of the pipe.

Factors of design. Five factors determine pipe design: internal pressure, external load, safety, allowance for corrosion, and foundry tolerance.

The method for calculating pipe wall thickness and strength for different pipe sizes and installation and operating conditions is generally termed the "American Standard Method of Design." A brief description here will serve to acquaint the reader with the fundamental principles of the method, details of which are set forth in AWWA Handbook H-1, entitled "American Standard for Thickness Design of Cast Iron Pipe."[16]

This empirical method of cast iron pipe design, based on a series of intensive research studies, provides the means whereby required barrel thickness can be established for use in any reasonable combination of internal pressure and external loads. The empirical relationship for the combination of external load and internal pressure at which a pipe will fail is shown in Fig. 4.

The y-axis intercept of this curve represents the external breaking load (W), when no internal pressure exists. The x-axis intercept represents the bursting pressure (P), when there is no external load on the pipe. This load pressure curve is the basis of the system of barrel thickness computation, and the equation of this load-pressure parabola is expressed by this formula:

$$w = \frac{W}{\sqrt{P}} \sqrt{P - p} \qquad \text{Eq. 6}$$

where w = external load at which the pipe will fracture in combination with internal pressure p (lb per lin ft)
W = crushing load in three-edge bearing, with no internal pressure (lb per lin ft)
p = internal pressure at which pipe will fracture in combination with external load w (psi)
P = bursting pressure of pipe with no external load (psi)

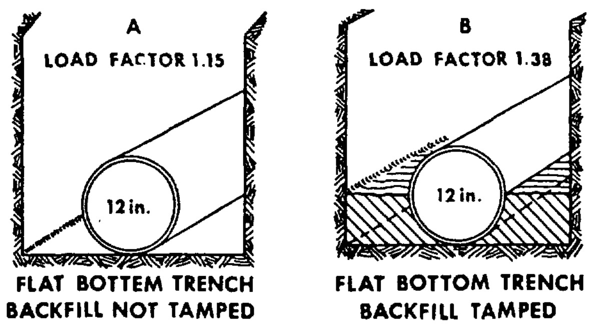

Fig. 9. Types of trench bottoms.

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The value of P is determined from Eq. 7.

$$P = \frac{2tS}{d} \qquad \text{Eq. 7}$$

where t = pipe thickness (in.)
S = bursting strength from full length bursting test (psi)
d = internal diameter of pipe (in.)

The value of W (lb per lin ft of pipe supported in three-edge bearing) is given by the following equation:

$$W = \frac{t^2R}{0.0795\,(d + t)} \qquad \text{Eq. 8}$$

where W = crushing load (lb per lin ft)
R = modulus of rupture of the metal (psi)
d = internal diameter (in.)
t = wall thickness (in.)

Modulus of rupture is determined from crushing tests in the three-edge bearing test (see Fig. 8), with the pressure applied at the top bearing uniformly along the full specimen length. R values of 40,000 or 45,000 are standard for gray cast iron. This test is a convenient means for computing field conditions.

External loads. The external load on a pipe consists of two factors: weight of backfill and weight of traffic plus impact. The load-carrying capacity of a pipe is influenced by the laying conditions (see Fig. 9). The best method of laying pipe is the one that provides the highest load factor. The most common methods used and their load factors for 12-in. pipe are:

A—Flat bottom trench, backfill not tamped (1.15)
B—Flat bottom trench, backfill tamped (1.38)

Where greater load capacity is desired, the pipe may be bedded in gravel or sand, with backfill tamped (load factor 1.85).

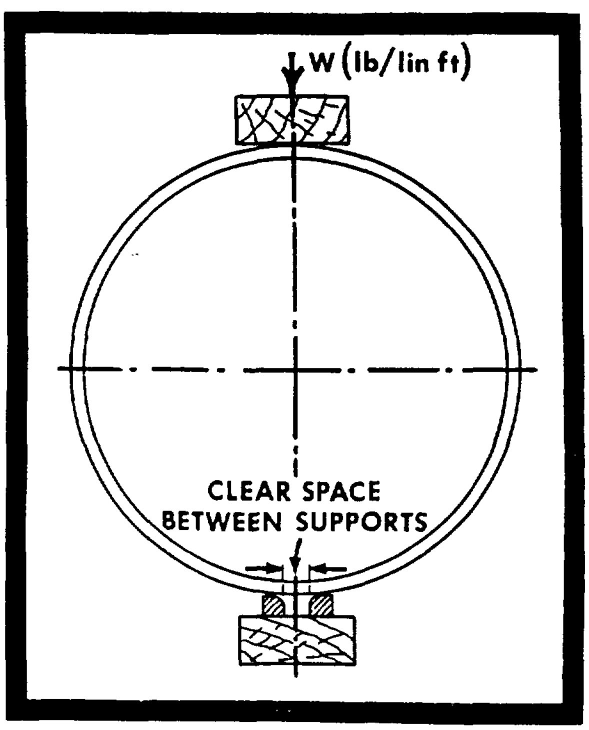
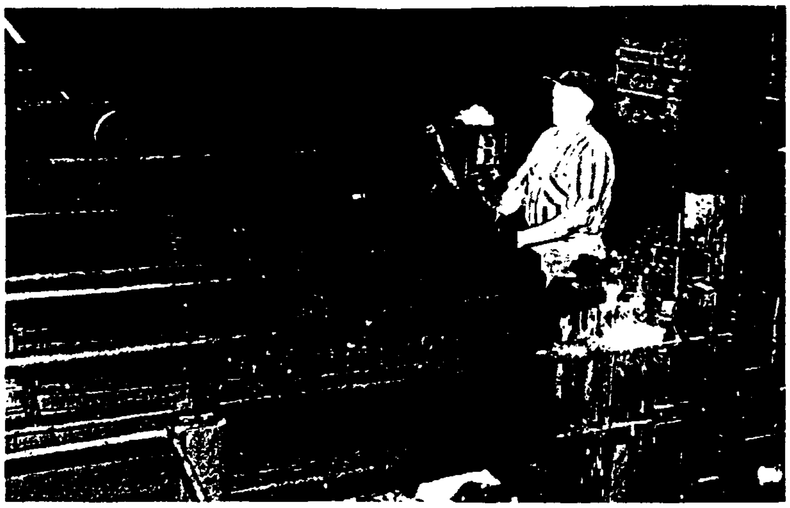


Fig. 8. Three-edge bearing test for cast iron pipe.



Hydrostatic testing of wrought iron pipe. All other types of pipe are hydrostatically tested in similar manner.

Continuous weld wrought iron pipe is formed from skelp.

Internal pressure. Internal pressure consists of two components: normal working pressure and water hammer. The former is readily ascertained, but water hammer, caused by rapidly closing valves or stopping centrifugal pumps, may vary widely. An allowance of 70 to 120 psi is made, depending on pipe size. (See Table 13.)

TABLE 13—ALLOWANCES FOR WATER HAMMER

Pipe size (in.)	Water hammer (psi)
4–10	120
12–14	110
16–18	100
20	90
24	85
30	80
36	75
42–48	70

Design calculation. To determine the required barrel thickness, the calculation is made for two conditions: Case 1—normal working pressure plus backfill and traffic loads; Case 2—normal working pressure plus water hammer and backfill load. The thickness selected is the greater of these two values obtained from the calculations.

There are eight steps in the calculation, as illustrated by the following example for the determination of the thickness of a 16-in. gray cast iron pipe for a normal working pressure of 150 psi, installed with laying condition B in a trench of width (d + 2) ft and under 5 ft of earth cover.

Step 1: Determine earth fill load for the laying condition, trench width, and depth of cover. (Diagrams and tables are given in AWWA Handbook H-1.)[16] Divide the earth fill load by load factor for laying condition and pipe size, multiply by a 2.5 factor of safety. This is w for Case 1.

$$w = \frac{1470 \text{ lb/ft}}{1.43} \times 215 = 2570 \text{ lb/ft}$$

Step 2: Calculate truck load for two passing 18,000-lb axles with inboard wheels 3 ft apart. (Refer to diagrams and tables in AWWA Handbook H-1.)[16] Adjust values according to laying condition and pipe size. Increase the truck load by 50 percent for impact. Add the truck load to the earth fill load, divide the sum by the load factor, and multiply by a 2.5 factor of safety. This is w for Case 2.

$$w = \frac{1.50\,(393) + 1470}{1.43} \times 2.5 = 3600 \text{ lb/ft}$$

Step 3: Add water hammer allowance (Table 13) to the normal working pressure and multiply the sum by a 2.5 factor of safety. This is p for Case 1.

$$p = (150 + 100)\,2.5 = 625 \text{ psi}$$

Step 4: Multiply the normal working pressure by a 2.5 factor of safety. This is p for Case 2.

$$p = 150 \times 2.5 = 375 \text{ psi}$$

Step 5: For Case 1, with w = 2570 lb per ft and p = 625 psi, use the appropriate nomograph in AWWA Handbook H-1,[16] select a net thickness for 16-in. pipe of 0.39 in.

Step 6: For Case 2, with w = 3,600 lb per ft and p = 375 psi, the required net thickness would be 0.38 in.

Step 7: To the greater of the two thickness values obtained in Steps 5 and 6, add a foundry tolerance (see table in AWWA Handbook H-1)[16] and a corrosion allowance of 0.08 in. to obtain the calculated thickness.

$$t = (0.39 + 0.08 \pm 0.08) = 0.55 \text{ in.}$$

Step 8: Refer to the table of Standard Thickness Classes in AWWA Handbook H-1,[16] and select the thickness nearest the calculated thickness of Step 7. For the 16-in. pipe of the problem, select Class 22.

Nomographs and charts are available from which it is possible to read directly the total thickness for conditions A and B and to make all the necessary calculations.

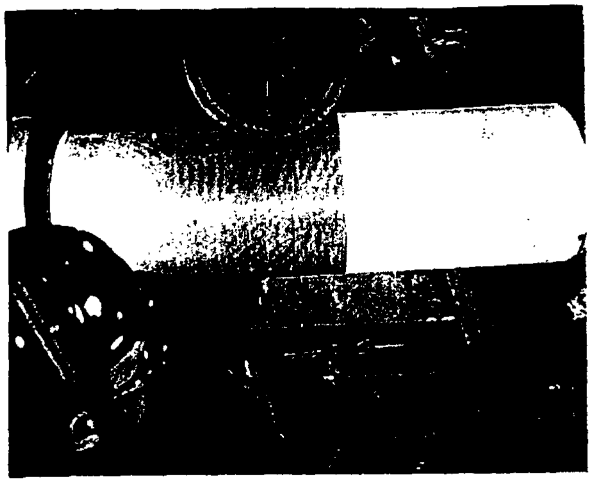
Pipe classes. Cast iron pipe is not made in every diameter or in incremental thickness of 0.01 in., but it is available in standard manufacturing thickness classes. These classes are separated in weight by incremental increases of 8 percent.

From these tables of standard classes, the pipe designer chooses the pipe class that gives the wall thickness nearest to that calculated as above. (See AWWA Handbook H-1.)[16]

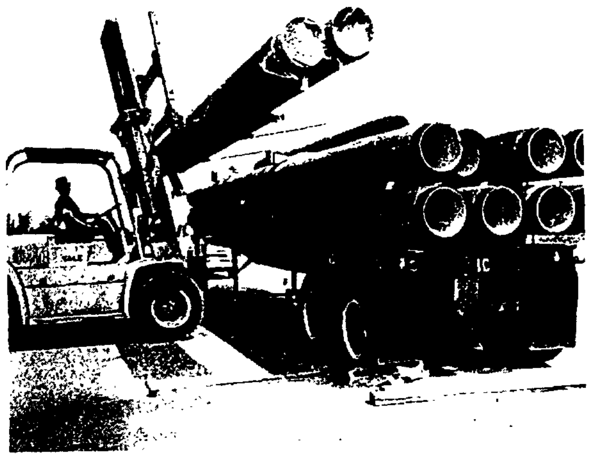
Ductile-iron pipe. This type of pipe is stronger, tougher, and more ductile than gray cast iron. Its characteristics are due to the configuration of the free carbon or graphite in the iron.

The method for thickness design of ductile iron pipe is presented in AWWA Handbook H3-65.[17] The method is based on flexible-pipe principles and the characteristics that distinguish flexible pipe from rigid pipe. Particular consideration is given to the reduction in bending stress from trench load by lateral soil reaction; the rerounding effect of internal pressure on the initial deflection resulting from trench load; and the fact that flexible pipe, in deflecting under earth load, transfers a significant part of the load to the side fill soil columns.

Thickness selection. The required wall thickness for ductile iron pipe is determined as the larger of the net values determined separately for external load (bending stress) and internal pressure (hoop stress). To this net thickness is added a corrosion allowance and a casting tolerance. The



Prestressing concrete pipe.



Steel pipe (lined and coated) being loaded.

final thickness for specifying and ordering is selected from a table of standard thickness classes.[17]

Steps in calculation. The directions for selecting the required pipe thickness are as follows:

Step 1: Design for trench load and the usual field conditions (A and B as for cast iron). Use tables in AWWA Handbook H3-65[17] to determine the trench load per linear foot and the earth load and truck super load that is applicable; then proceed with the calculation for the conditions involved.

Step 2: Design for internal pressure using this equation for hoop stress:

$$t = \frac{pD}{2s} \qquad \text{Eq. 9}$$

where t = net wall thickness (in.)
p = working pressure plus surge pressure (psi)
D = outside/diameter (in.)
s = design hoop stress (psi)

Step 3: Select the larger of the two values from Steps 1 and 2. To this figure add a corrosion allowance of 0.08 in. and a foundry tolerance. The foundry tolerance will vary from 0.05 in. (for 3- to 8-in. pipe) to 0.08 in. (for 48-in. pipe).

Step 4: Select the standard thickness class that equals the value obtained in Step 3. If the calculated value falls between two classes, select the larger class size. If the calculated thickness is less than the smallest standard class, select the smallest standard class.

Manufacture

The production of cast iron pipe begins with the melting of the metal in a furnace (cupola) and the addition of such other materials as contribute to final desired composition.

Gray cast iron pipe. Charges of iron, scrap, coke, and limestone are carefully weighed and proportioned to give the desired chemical composition to the iron. As the molten iron is withdrawn from the cupola to a ladle, small amounts of graphite and ferrosilicon are added to adjust the carbon and silicon content; this is termed inoculation. The amounts of carbon, silicon, manganese, etc., although small, materially affect the structure of the iron.

Chemical characteristics. Each of the chemicals added is controlled in amounts to produce the desired qualities in the castings. High *carbon* content produces soft iron; low carbon, hard iron. *Silicon* promotes graphitization, and high silicon content makes the iron softer. *Manganese* is added to minimize the detrimental effects of sulfur. Phosphorus makes molten iron easier to pour at low temperatures.

In gray cast iron, the major part of the carbon content occurs as free carbon or graphite in the form of flakes interspersed throughout the metal. An appreciable volume of graphite flakes makes gray cast iron more resistant to corrosion than the purer forms of iron because graphite does not corrode. When gray cast iron does corrode, the products of corrosion adhere tightly, protecting the metal underneath.

Graphite in cast iron also affects the machinability of the pipe, that is, it makes the pipe more easily tapped and threaded for insertion of a corporation cock.

Casting. The first cast iron pipe was molded in a horizontal position in short lengths of 3+ ft. Longer pipe lengths were produced by placing the mold at a slight angle, and the length was increased to 5, then to 9 ft, the standard for about 200 years. With the advent of pit casting in 1846, and the adoption of vertical molds, lengths were increased to 12, then 16 ft.

Centrifugal casting. There are two centrifugal casting processes. The first, sometimes called the de Lavaud process after its inventor, quickly produces pipe from the molten iron. The casting machine consists essentially of a cylindrical water-jacketed metal mold mounted on rollers so that it can be rotated at high speeds. The molten iron is fed into the mold from a small casting ladle containing the measured amount of molten metal required to make one length of pipe of the diameter and wall thickness desired.

The mold is rotated at original speed until it has cooled to approximately 1500°F. The pipe is then removed from the mold. The casting operation requires 1-1/2 to 8 min, depending on pipe length and diameter. From the casting machine, the pipe passes through an annealing oven and is then ready to be coated and lined.

Sand-lined mold. A second process for casting pipe centrifugally is the sand-lined mold process. Molds are prepared by either of two methods. In one, a metal cylindrical flask is placed on end, and a metal pattern corresponding to the outside diameter of the pipe is centered within the flask. Molding sand is rammed into the annular space between the pattern and flask, then the pattern is withdrawn. In the other method, no pattern is used, and the mold is prepared by centrifugally lining the flask with a thermosetting, resin-bonded sand mixture.

The mold is placed horizontally on a centrifugal casting machine, on which it is spun by rollers, and prior to casting, the mold ends are closed with cores, one forming a bell socket. Molten metal is added in exact amounts, while the flask is spun, until the pipe has solidified; whereupon the casting machine is stopped and the flask removed. Gray iron cast in rammed sand molds is allowed to cool in the mold before removal and does not require annealing. Pipe cast in resin-sand molds is removed after solidification and oven-cooled under controlled time-temperature conditions.

Ductile iron pipe. Ductile iron is defined as cast iron with graphite in spheroidal (nodular) form. It is produced by adding an inoculant, usually magnesium, to molten iron.

Chemical characteristics. Ductile iron is chemically akin

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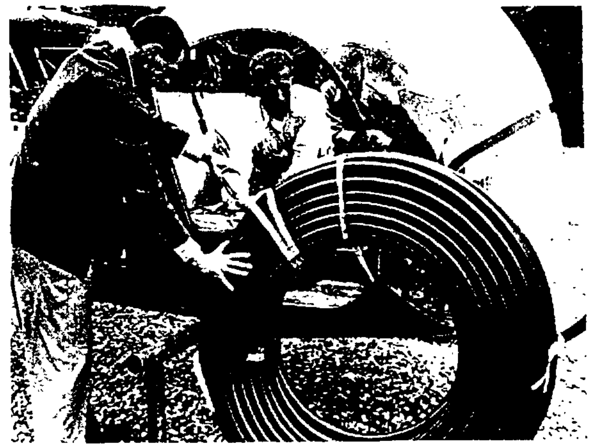
Handling cast iron pipe from railroad car to truck.



Helicopter transports plastic pipe for service lines.

to gray cast iron of low phosphorus and low sulfur content; the latter obtained by desulfurizing in the cupola.

Magnesium can be added, after the removal of sulfur, in a post-inoculation treatment with a silicon-base magnesium alloy. These process steps produce a change in the manner by which the graphite is formed during the solidification of the iron. In gray iron, the carbon is interlaced in flake form in the iron. In ductile iron the graphite appears as myriads of isolated spheroids (Fig. 10). The matrix becomes relatively continuous, and the strength, ductility, and impact resistance of the metal are increased.

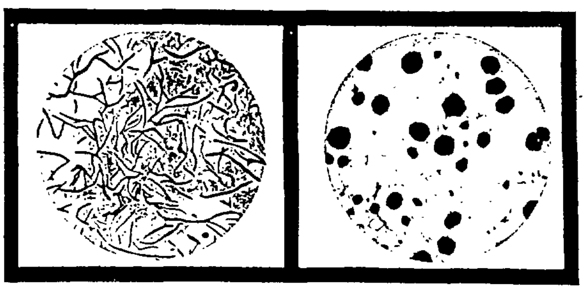


Fig. 10. Microstructure of gray iron and ductile iron at same magnification.

The mechanical properties of ductile iron are unlike those of gray iron. Ductile iron has a definite yield point, with a modulus of elasticity of 24 million psi.

As a result of an extensive period of testing by manufacturers, it was determined that measurement of tensile and impact properties of test specimens cut from a pipe could define the basic quality of the ductile iron in the pipe. The minimum requirements were set at: ultimate strength, 60,000 psi; yield strength, 42,000 psi; elongation, 10 percent.

Casting. Ductile-iron pipe is centrifugally cast in the same manner as gray cast iron, but the melting and inoculation phase of the process is more complex; the casting phase is the same. A product specification for ductile iron pipe has been established (AWWA C 151), as follows:[18]

Working pressure (psi)	350
Nominal laying length (ft)	18 and 20
Thickness tolerance (in.)	
3–8 in. pipe	0.05
10–12 in. pipe	0.06
14–42 in. pipe	0.07
48 in. pipe	0.08
Weight tolerance (%)	
4–12 in. diam.	Not less than 5
12 in. diam. and up	Not less than 4
Hydrostatic test (psi)	500
Acceptance test (see "Testing")	

Testing

In selecting a product for a specific use, it is necessary to know how well the product will meet the requirements of the application to be met. For this reason, pipe production is controlled by specific tests.

Gray cast iron pipe. Quality control tests in the modern pipe foundry include: frequent chemical analysis for each mix used in the cupola, chill tests for graphitizing tendency, Talbot strip tests, ring tests, bursting tests, and others.

Several physical tests are utilized to make certain that the pipe will meet the following characteristics when installed: imperviousness, internal pressure capacity, tensile strength, toughness, beam-load capacity, and external load capacity.

Hydrostatic test. Each length of pipe produced is subjected to a hydrostatic test at 500 psi, several times the normal working pressure. This test is made in a special machine that handles all sizes of pipe.

Bursting test. A pipe's ability to withstand internal pressure can best be measured by submitting it to high hydrostatic internal pressures. Periodic bursting tests in a special machine are run on full length specimens of pipe selected at random from any run of pipe production. Bursting pressures, for 6-in. pipe, for example, are in excess of 2700 psi.

Tensile strength. Termed the Talbot Strip Test, after the late Professor A. N. Talbot of the University of Illinois, the test for tensile strength consists of loading a 10-1/2-in. strip, cut from a pipe specimen, as a beam on supports 10 in. apart, with the load applied at the third points. These tests permit the manufacturer to certify the design value of the modulus of rupture of the iron.

Deflection and beam load capacity. A pipe must be able to withstand beam stresses in handling and service. This characteristic is determined by a full length beam test, made on random selections of pipe at periodic intervals.

Full length specimens are placed on supports 15 ft apart and subjected to load at the third points. Both the total load and deflection are recorded. Standard 6-in. pipe will usually deflect 2-1/2 in. and bear 21,000+ lb load before breaking.

Ring compression test. To determine the ability of pipe to withstand external stress resulting from backfill and traffic loads, a ring compression or three-edge bearing test is used.

A section of pipe, about 12 in. long, depending on pipe diameter, is cut from a pipe and tested as shown in Fig. 8. Load is applied at the top until the ring fails. In this test, a standard 6-in. pipe may be expected to carry a load of more than 19,000 lb per lin ft. The machine used determines both the deflection and the total load, which is applied at a steadily increasing rate. From this test, the modulus of rupture is calculated; 40,000 psi is a minimum.

Ductile cast iron. The acceptance tests applied to ductile cast iron pipe differ from those applied to gray iron.

Hydrostatic test. Each pipe is subjected to hydrostatic tests of not less than 500 psi for at least 10 sec, either before or after the standard outside coating and bituminous inside coating have been applied.

Tensile strength. The tensile test strip is cut longitudinally from the midsection of the pipe wall, and machined and tested according to ASTM designation E 8-61T. All tests are made at 70 ± 10°F. Minimum acceptable tensile strength is 60,000 psi.

Impact test. Two impact tests are made at different temperatures. The test is made in accordance with ASTM designation E-23-62, Notched Charpy Tests, except that the specimens are 0.500 in. wide and full thickness of the pipe wall. The impact values are adjusted to 0.4 in. At least one tensile and impact sample is taken during each casting period of 3 hr.

Room temperature test. The adjusted acceptance value for tests conducted at 70 ± 10°F is 7 ft-lb.

Low temperature test. These tests are made on at least one-third of the samples collected. The adjusted acceptance value for tests conducted at −40°F is 3 ft-lb.

Rejection. If a pipe specimen fails to meet any physical acceptance test requirement, all pipe cast in the same casting period is rejected, except as additional tests on other pipe sizes indicate acceptability.

Coating and lining

Although cast iron has a certain resistance to corrosion, there are some "aggressive" waters that cause the pipe to lose an appreciable part of its carrying capacity because of tuberculation. Tuberculation consists of the formation and growth of nodules of iron corrosion products within the pipe.

Tar coating. The first attempt to control tuberculation and corrosion was the coating of pipe inside and out with a bitumastic tar. Hot bitumastic tar is sprayed from application nozzles to the inside and outside of each length of pipe and allowed to cool before storage. Tar-coated pipe resists tuberculation to a greater extent than uncoated pipe, but holidays in the coating allow penetration by the water, and some tuberculation results.

Cement lining. The development in 1922 of a process for lining pipe with a thin coating of cement has made it possible to eliminate tuberculation and thus maintain the carrying capacity of the pipe. The process of coating and lining pipe is the same for both gray cast iron and ductile iron pipe.

The common method of cement lining is by the extrusion of cement mortar through a hollow shaft inserted into the pipe. The pipe to be lined is mounted horizontally on rollers. The hollow shaft is inserted to the far end of the pipe. The pipe is rotated rapidly while the mortar is extruded during the withdrawal of the shaft. High speed rotation compacts the mortar, removing excess water at the same time.

The cement mortar after compaction is about 1/8-in. thick. It adheres closely, and the pipe may be cut or tapped without damage to the lining. Immediately following the lining process, the pipes are stored in a moist atmosphere for curing, or a bituminous seal coat may be applied to prevent too rapid loss of moisture.

Pipe sizes

Cast iron pipe comes in standard classes as to wall thickness and in the following standard sizes:

Gray cast iron (in.):	2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20, 24, 30, 36, 42, 48
Ductile iron (in.):	4, 6, 8, 10, 12, 14, 16, 18, 20, 24, 30, 36, 42, 48, 54

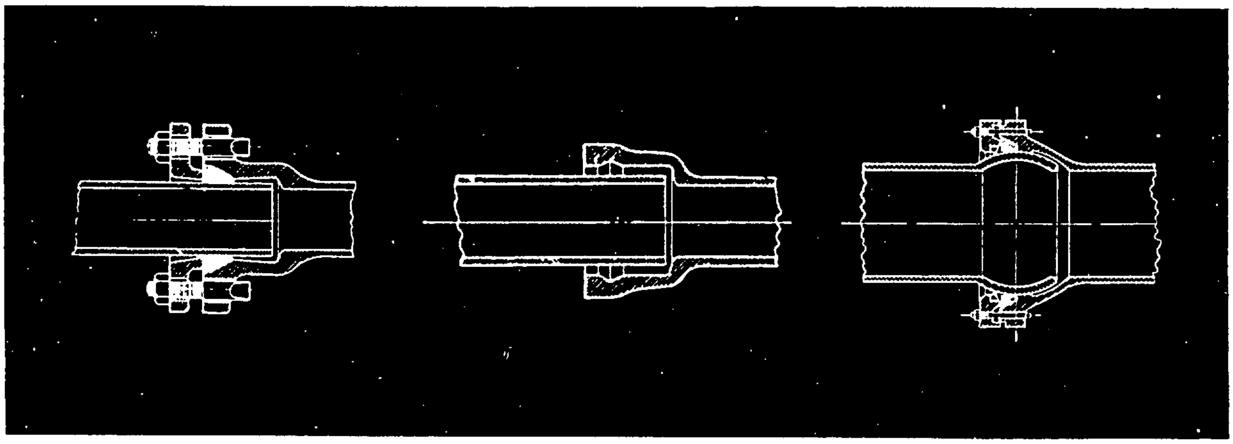


Fig. 11. Types of cast iron pipe joints. Left to right: mechanical, bell and spigot, submarine.

Joints

Pipe lengths may be joined together by several types of joints. Manufacturers can produce many types of joints. The following descriptions are given chronologically by development. Illustrations of the various types of joints are shown in Fig. 11. The earliest type of joint was a tapered end inserted into a flared end of the pipe, probably with a tar seal of some sort. This idea later came to be the bell and spigot, but the original flare and taper joint lasted until the mid-1600s.

Flange joints. The late 1600s saw the development of the flanged joint. The famous Versailles palace pipe line installed in 1664 utilized leather gaskets. Later gaskets were made of lead. This type of joint is still used for many aboveground plant installations. Gaskets are usually of rubber, or rubber with cloth insertion.

Bell and spigot. This joint was invented in 1785 and was used exclusively until the 1920s. It requires some means of sealing to make it watertight. Early installations used a variety of jointing materials, but calked lead soon became the preferred material; it is still in common use. Sulfur joint compounds were developed toward the end of the 19th century and had a wide usage for many years, but are not popular now. Portland cement as a jointing material has been used to a limited extent (particularly in the Pacific Coast and Southwest states) for more than 50 years.

Mechanical joint. This type of joint was developed for the gas industry in the 1920s; it became popular with water utilities some time later. It utilizes the basic principle of the stuffing box and combines the fluid tightness of a flanged joint with a flexibility greater than that of the bell and spigot joint.

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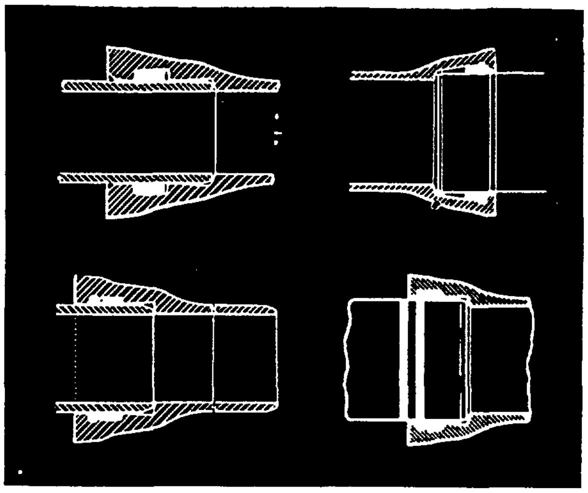


Fig. 12. Examples of slip joints for cast iron pipe joints.

Submarine joint. This joint is a type of ball and socket and is often so called. It can be deflected up to 15 degrees and is useful for installations across rivers. There is also a boltless type of flexible pipe joint employing the ball and socket principle.

Push-on joint. The most recently developed pipe joint is the most popular in water distribution systems today. The joint consists of a bell, with a specially designed recess to accept a rubber ring gasket, and a beveled-end spigot. The joint offers ease of installation, and when made up, the rubber ring gasket is compressed to produce water tightness and is locked in place against further displacement. It is available in several designs (Fig. 12). Besides ease of installation and water tightness, the joint permits about 3 percent deflection, a fact that makes it possible to install pipe on a curve.

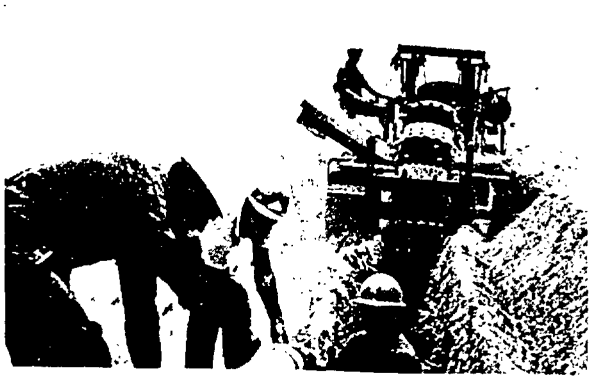
Shipping

After manufacture, cast iron pipe is stacked in the yard to await shipment. All pipe receives a final inspection before shipping to make certain that it is in good condition. When shipped, the pipes are carefully lowered to the floor of the truck or railroad car. Special crane-operated hooks are used to prevent damage as the pipe is picked up.

As loading proceeds, bell ends of pipe in alternate rows are stacked to face in opposite directions to guard against damage in transit. Packages of pipe separated by wooden blocking may be banded together by steel bands, for ease of handling and shipment.

Damage from rough handling in transit is always a possibility. Therefore, all pipe should be inspected when it is being unloaded. Rough treatment is usually evidenced by broken straps or wrecked wooden bracing that was placed at the foundry to minimize damage. Handling and unloading of pipe is discussed in Part 3 on "Installation."

Machine trenching operation.



Deep trenches in some soils require shoring and sheeting.

Section 3—Concrete Pipe

Probably the earliest use of concrete as a water pipeline material was for a 12,336-ft. 38-in. concrete tunnel transmission line installed on the Denver, Colo., supply in 1893. Concrete pipe as used today was first installed in 1910 and came into wider use after 1930.

The ingredients used in making concrete pipe are portland cement, sand and gravel aggregates, water, and reinforcing.

Design

There are three types of concrete water pipe, classified according to the method of reinforcement. These types are: steel cylinder, not prestressed; steel cylinder, prestressed; and non-cylinder, not prestressed. Table 14 sets forth the general design requirements and specifications for the three types of pipe. The material in this table was abstracted from AWWA Standard C 300-64,[19] AWWA Standard C 301-64,[20] and AWWA Standard C 302-64.[21]

Steel cylinder type—not prestressed. Minimum thickness of wall and lining, and limitations on reinforcing are shown in Table 15, adapted from AWWA C 300-64.[19] Minimum requirements for reinforcing are given in Table 14. Where the pipe is expected to be subjected to abnormal internal loads or water hammer, the reinforcing design must meet design requirements of the contract documents.

Steel cylinder type—prestressed. Core thickness including the steel cylinder, and coating thickness are established according to Table 16, excerpted from AWWA C 301-64.[20]

Design factors. Pipe may be designed for any normal combination of internal pressure and external load, but the minimum permissible combination is an internal design pressure of 40 psi and external earth load of at least 6 ft of earth cover, where the pipe bedding is ordinary.

Unshored trench with 24-in. concrete pipe.

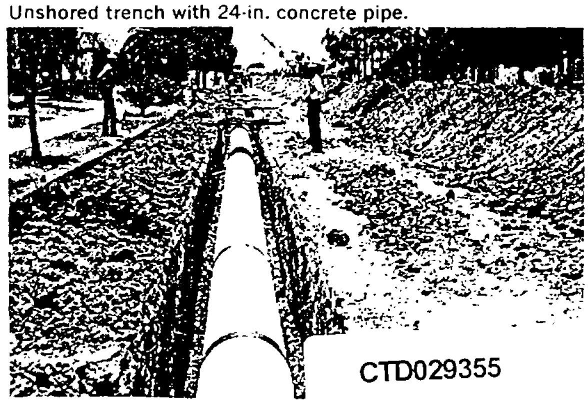


TABLE 14—GENERAL DESIGN REQUIREMENTS FOR CONCRETE PIPE

	Steel cylinder, not prestressed; AWWA C 300–64	Steel cylinder, prestressed; AWWA C 301–64	Noncylinder, not prestressed; AWWA C 302–64
Material specifications included	Cement, fine and coarse aggregate, water, steel (for cylinders, reinforcement, joints, rings, fittings, specials)	Same as C 300–64, except fine aggregate has requirements for both concrete, sand and mortar coating sand	Same as C 300–64
Pipe length (ft)	12, 14, 16	Min. 16	Min. 8 Max. 8-1/2 (12 to 15 in. diam.) 12 (16 to 21 in. diam.) 16 (24 in. diam. and up)
Mortar coating (in.)		5/8	
Allowable tolerance from true round (in.)			
36-in. diam.	1/4	1/4	1/4
42 to 48 in.	3/8	3/8	3/8
54 to 78 in.	1/2	1/2	1/2
84 in. up	3/4	3/4	3/8
Min. wall and lining thickness, reinforcing, spacing, cages, etc.	See Table 15		See Table 17
Core coating thickness specs.		See Table 16	
Steel cylinder	Welded steel, not less than 10 gage	Same as C 300–64	
Reinforcing	Cage and cylinder cross section limited to area producing max. stress of 12,500 psi under design operating conditions; area of cage must be a min. of 40% of combined area of cage and cylinder	Wire for circumferential reinforcement must meet ASTM Des. A 227 for hand drawn spring steel wire Min. 8 gage Gross wrapping stress less than 75% of wires ultimate min. tensile strength Min. space between wires, 3/16 in., max. 1-1/2 in.	Rods or bars—ASTM Des. A 15 structural grade Wire: ASTM Des. A 82 Wire fabric: ASTM Des. A 185
Joint rings (steel)	Self-centering	Same	Same
Rubber gaskets	Specified composition to meet specifications for tensile strength, elongation at rupture; specific gravity, and cold flow; must completely fill recess		

TABLE 15—DESIGN REQUIREMENTS FOR REINFORCED CONCRETE PIPE—NOT PRESTRESSED*

	Pipe wall			Reinforcing spacing	
Pipe ID (in.)	Min. thickness (in.)	Allowable variation below normal (in.)	Concrete lining min. thickness (in.)	Min. (in.)	Max. (in.)
20	3-1/4	1/8	1	1-1/4	4
24–30	3-1/2	1/8	1	1-1/4	4
36	4	1/8	1	1-1/4	4
42	4-1/2	3/16	1	1-3/4	5
48	5	3/16	1-1/4	1-3/4	5
54	5-1/2	1/4	1-1/4	1-3/4	5
60	6	1/4	1-1/4	1-3/4	5
66	6-1/2	1/4	1-1/2	2	6
72	7	1/4	1-1/2	2	6

* Pipe from 78 to 96 in. also has specified minimums not included in Table 1, and pipe larger than 96-in. must meet specifications of purchaser.

Pipe design must also consider transient conditions caused by short-duration overloads resulting from water hammer or external live loads (traffic). The final design may not exceed the design limits for either of these two conditions: (1) normal operating pressure plus water hammer plus backfill load, or (2) normal operating pressure plus backfill plus live traffic load plus impact.

Design procedures. Either of two procedures may be used for the calculation of the core thickness of the pipe and the wire area, tension, and spacing under which the wire is wound. The Appendix A procedure of AWWA C 300-64[19] is generally used east of the Rocky Mountains, and the Appendix B procedure is used west of the Rocky Mountains.

The first combination design procedure utilizes the cubic parabola method[20] to determine the combination of design pressure and earth load.

The design curve is expressed by this equation:

$$w = \frac{W_0}{\sqrt[3]{P_0}}\left[\sqrt[3]{P_0 - p}\right] \qquad \text{Eq. 10}$$

where w = maximum three-edge bearing load, equivalent to earth load in combination with design pressure p (psi)

W_0 = 0.9 multiplied by the three-edge bearing load that produces incipient core cracking with no internal pressure (lb per lin ft)*

P_0 = internal pressure require to overcome all compression in the core concrete, exclusive of external load (psi)

p = maximum design pressure in combination with the three-edge bearing load (w), it may not exceed 0.8 P_0 for lined cylinder pipe (psi)

*Three-edge bearing loads are based on manufacturers' test data.

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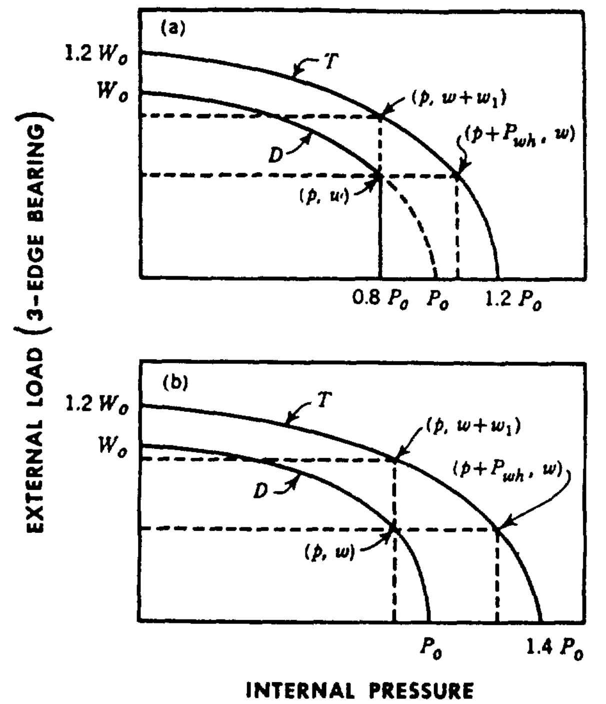

Fig. 13. Cubic parabola design curves for concrete pipe.[19] Graph (a) is for lined and Graph (b) embedded cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; w_1 is for the three-edge-bearing load equivalent to live load; and P_{wh} is for water hammer in excess of the normal operating or design pressure.

The design resulting from the calculation is varied to make the specific combination of internal pressure and earth load fall on or under the curves (a and b) published in AWWA C 301-64[20] (see Fig. 13). According to Appendix A of AWWA C 301-64, "the resulting design has a transient load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line for water hammer or live load until it intersects the transient-load curve." (See AWWA C 301-64[20] for details.)

Where water hammer exceeds 40 percent of design pressure, or live load (including impact) exceeds the AASHO H-20* loading, the greater value should be used.

*American Association of State Highway Officials.

The second combination design procedure utilizes the stress analysis method. In this method a different equation and a different set of curves are used. The calculation, however, results in a design with "a transient-load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line [in the published curves[20]] or live load until it intersects the transient-load curve." (See AWWA C 301-64[20] for details.)

If water hammer or earth load exceeds stated values, the design should reflect the conditions to be expected.

Noncylinder type—not prestressed. Minimum and nominal requirements for pipe wall thickness and reinforcing requirements are shown in Table 17, extracted from AWWA C 302-64.[21] When earth cover is nominal, the pipe is designed for internal pressure with a steel stress of 12,500 psi. According to AWWA C 302-64,[21] where external loading is the determining design factor, a combination analysis must be made to determine the steel area. For combined load designs, tensile stresses in the tension steel should not exceed 22,000 psi, and compressive stresses in the concrete should not exceed 45 percent of the specified 28-day strength.

Manufacture

The manufacture of concrete pipe begins with fabrication of the steel cylinder and/or steel reinforcement cage, a process that is done in accordance with the AWWA Standards.[19,20,21]

Table 18 is a brief presentation of the items included in the manufacturing process requirements as set forth in the AWWA Standards.[19,20,21]

Testing and rejection. There are specifications for limits on various characteristics of materials used in the manufacture of concrete pipe. Most of these characteristics are included in Table 18. For the most part, the specified testing procedures are those set up by pertinent ASTM designations.

Hydrostatic pressure tests and external loading tests on finished pipe are made only when specified by the purchaser. Hydrostatic tests of cylinders are made as stated below.[21]

Hydrostatic tests. This test may be made on individual randomly selected lengths or on two lengths joined together. Watertight bulkheads are used to close the pipe ends. The pipe is filled with water to the design pressure. (This type of pipe is allowed to stand two weeks.) The pressure is then increased gradually to 120 percent of design pressure and checked at the end of 20 min. Evidence of cracks, leakage, or leaking joints is cause for rejection. On noncylinder pipe, damp spots on the surface are not.

TABLE 16—DESIGN REQUIREMENTS FOR REINFORCED STEEL CYLINDER CONCRETE PIPE—PRESTRESSED[20]*

Pipe ID (in.)	Pipe with lined cylinder: Core thickness (in.)	Pipe with lined cylinder: Maximum design pressure (in.)	Pipe with embedded cylinder: Core thickness (in.)	Pipe with embedded cylinder: Maximum design pressure (psi)	Coating thickness: Mortar (min. thickness over the wire) (in.)	Coating thickness: Concrete (nominal thickness over the core) (in.)
16	1	250			5/8	1-1/2
18	1-1/8	250			5/8	1-1/2
20	1-1/4	250			5/8	1-1/2
24	1-1/2	200	2-1/4	275	5/8	1-1/2
30	1-7/8	200	2-1/4	240	5/8	1-1/2
36	2-1/4	200	2-1/4	210	5/8	1-1/2
42	2-5/8	175	2-5/8	190	5/8	1-1/2
48	3	150	3	175	5/8	1-1/2
54			4	200	5/8	1-1/2
60			4-1/2	200	5/8	1-1/2
66			5	200	5/8	1-1/2
72			5-1/4	200	5/8	1-1/2

* Pipe from 78 to 96 in. also has specified minimums not included in table, and pipe over 96-in. diameter with embedded cylinder must meet design specifications of the purchaser.

TABLE 17—DESIGN REQUIREMENTS FOR NONCYLINDER CONCRETE PIPE—NOT PRESTRESSED*

Pipe ID (in.)	6000 psi centrifugal concrete: Min. pipe wall thickness (in)	Min. no. of cages	4500 psi poured concrete: Nominal pipe wall thickness (in)	Min. no. of cages	Circumferential reinforcement spacing: Min. (in.)	Max. (in.)	Min. total steel area per lin ft (sq in.)
12	2	1			1-1/4	4	0.08
15	2	1			1-1/4	4	0.11
16	2-1/8	1			1-1/4	4	0.12
18	2-1/4	1			1-1/4	4	0.14
20	2-3/8	1			1-1/4	4	0.16
21	2-3/8	1			1-1/4	4	0.17
24	2-1/2	1	3	1	1-1/4	4	0.20
27	2-5/8	1	3-1/4	1	1-1/4	4	0.23
30	2-3/4	1	3-1/2	1	1-1/4	4	0.25
33	2-7/8	1	3-3/4	2	1-1/4	4	0.28
36	3	1	4	2	1-1/4	4	0.30
42	3-1/2	2	4-1/2	2	1-3/4	5	0.35
48	4	2	5	2	1-3/4	5	0.40
54	4-1/2	2	5-1/2	2	1-3/4	5	0.45
60	5	2	6	2	1-3/4	5	0.50
66	5-1/2	2	6-1/2	2	2-1/4	6	0.61
72	6	2	7	2	2-1/4	6	0.71

* For pipe larger than 96 in. in diameter, dimensions and details of design shall be subject to approval by the purchaser.

TABLE 18—MANUFACTURING PROCESS SPECIFICATIONS FOR CONCRETE PIPE

	Steel cylinder—not prestressed AWWA C 300-64	Steel cylinder—prestressed AWWA C 301-64	Noncylinder—not stressed AWWA C 302-64
Cylinder fabrication	Shape to size; lap weld	Shape to size; butt weld	
Reinforcement	Continuous or welded steel rod or wire, butt welded, (tested to stress specifications); helically wound	Continuous steel rod, applied around core, at designed predetermined spacing and tension, 7 days after pouring	Same as C 300-64
Hydrotest	Test to 20,000 to 25,000 psi stress		
Concrete			
Proportioning ingredients	Control to obtain homogeneous, dense, workable, durable concrete of specified strength		
Material measurement	Measure cement, aggregate, and water within 1% accuracy		
Mixing	Use approved mixing time consistent with mixer used		
Cylinder test	Follow ASTM Des. C-31		
Compressive strength			
Standard			
7 day (psi)	3000	3000	3000
28 day (psi)	4500	4500	4500
Centrifugal cast			
7 day (psi)		4000	4000
28 day (psi)		7000	6000
Forms	Use smooth welded, steel, nonleaking forms, cleaned and oiled between each pour		
Placement	Use approved methods only. Do not remove forms until concrete sets	Core may be centrifugally or vertically cast under specified procedures	
Pipe coating		Use mortar or concrete of approved mixture, and cure	
Interior seal coat	Add bituminous coating if purchaser so specifies		

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Hydrostatic tests on cylinder-type pipe are made on the cylinder, with joint rings welded to its ends, at a steel stress between 20,000 and 25,000 psi.

External load crushing tests. These tests are made in accordance with ASTM dsignation C 497 and are generally limited to the loading required to produce the first crack 1 ft long. The purchaser sets the conditions of loading and acceptance.

Coating on lining. If the purchaser so specifies, concrete pipe may be coated inside with a cutback asphalt, spray applied. This coating is normally required only for waters having a negative Langlier index.

Pipe sizes. The AWWA Standards list specifications up to 96 in. diameter, but concrete pipe can be made in any size and has been produced in diameters up to 180 in.

Joints. Jointing for concrete pipe employs a modified bell and spigot arrangement, in which a gasket is used to ensure a tight fit (see Table 14), and the space between pipe lengths is filled with mortar. Pointing is used for the interior joint recess, and the outer joint is filled by placing a cloth diaper around the adjoining pipe ends as a form to pour the mortar.

Shipping. Concrete pipe may be manufactured at the site or at a central plant. It may be shipped by rail or truck; in either case it should be protected against damage enroute.

Section 4—Plastic and Plastic-Lined Pipe

Plastic pipe as a commercial product was first introduced in Germany in 1930 and in this country in 1940. Polyvinyl chloride (PVC) was the first type produced. Later came cellulose acetate butyrate (CAB) and polyvinyledine chloride (Saran).

Volume production of plastic pipe began in 1948, when polyethylene (PE) was accepted for various water uses. Early development of pipe for water use was accompanied by studies to determine that the materials were nontoxic when used in water supplies. The outgrowth of these studies was a testing and approval program by the National Sanitation Foundation. All pipe offered for use in the water supply industry now carries an NSF seal of approval.

Early production of plastic pipe was in sizes under 2 in., and most of the plastic pipe sold was for service lines and household plumbing systems. As developments in the plastics industry progressed, larger pipe sizes became available, and plastic pipe is now being used for water distribution mains in many localities in this country, as well as for service and inplant piping systems.

With reference to acceptance, the Plastics Pipe Institute reports that more than 50,000 miles of plastic piping was installed in potable water systems in 1965, mostly outside buildings. It is also reported that since 1953 the Farmers Home Administration has approved plastic piping for rural water systems, and that from 1960 to 1965, FHA financed more than 10,000 miles of water distribution pipe, most of it plastics.

Design

There are two major types of plastic material: thermoplastic resins and thermosetting resins. Thermoplastic materials can be softened and reshaped repeatedly by the application of heat. Thermosetting materials set or harden permanently after a single heating. The former are generally lower in strength and have inferior resistance to deterioration by heat, but they are easier to fabricate. Thermosetting resins and the following thermoplastic resins are not used in water systems: acrylics (ethylmethacrylate, Lucite, Plexiglas), high impact styrene, and Lexan (aromatic polycarbonates).

Lowering cast iron pipe into trench with a clamp.

All plastic pipe used in water supply systems is manufactured in accordance with ASTM, Department of Commerce Commercial Standards, and USASI Standards. A number of manufacturers produce pipe of higher quality characteristics than specified by the commercial standards.

Table 19 contains an alphabetical listing of various plastic materials that are, have been, or may be used in water systems. Only three are in common use today, PVC, PE, and ABS, in that order; ABS is now used primarily for drainage, waste, and vent (DWV) fittings and pipe for interior application. ABS was popular a few years ago for water systems, but inasmuch as it has only half the available hoop stress, compared to PVC, when subjected to internal pressure, the latter product is considered to be a better material for water lines.

TABLE 19—PLASTIC PIPING MATERIALS

Name	Composition	Application	Standard No.	Comment
ABS	Polymers of acrylonitrile, butadiene, styrene	Inplant chemical lines; service lines	ASTM D2282-65 CS 254-63 USASI B72.3-67	Chemically resistant; lightweight; can be threaded, solvent welded, or slip coupled; low mechanical strength
CAB	Cellulose acetate butyrate	Salt water; water lines; inplant systems		Range from flexible to rigid; can be threaded, slip sleeved, or solvent welded; low heat resistance
Delrin	Linear acetal	Water lines		Good mechanical properties; stability; low heat resistance
Penton	Chlorinated polyether	Pipe lining		Good heat resistance; dimensional stability; chemical inertness
PE	Polyethylene	Distribution mains; service lines; inplant systems	ASTM D2239-65 CS 256-63 USASI B72.1-67	Resists impact at subzero temperatures; flexible, noncorrosive, soft
PVC	Polyvinyl chloride	Distribution mains; service lines; inplant systems.	ASTM D2241-65 CS 255-63 USASI B72.2-67	Some forms resist impact; can be cut, threaded, welded, drilled; noncombustible; rigid
PP	Polypropylene	Service lines; inplant systems		Greater high temperature resistance than PE; poor resistance to low temperature
Saran	Vinylidene chloride	Pipe lining		Chemically resistant; brittle at low temperature
Teflon	Fluorocarbons	Pipe lining; inplant systems		Self-supporting tubing

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For the purpose of this manual, this section will be limited to ABC, PE, PVC, and plastic lined pipe.

Characteristics. All plastic pipe has an exceptionally smooth interior surface and a C-value of at least 150, thus minimizing loss of head in lines. All these materials are chemically inert, corrosion resistant, and do not react in any way with the water that passes through the pipe.

Pressure rating. All plastic pipe manufactured under the standards listed in Table 19 is made in standard thermoplastic pipe dimensions and is pressure rated for water at 160 psi or above.

Plastic pipe is pressure-rated at a standard temperature of 73.4° F, and pressure resistance decreases with temperature until a critical point is reached above 150 to 160° F. Table 20 shows this temperature-pressure relationship. Temperature for pipe in buried applications is not critical because most water temperatures run below 73.4° F. The only critical time for temperature considerations is during installation periods.

The standard thermoplastic pipe dimension ratio (SDR) is the ratio of pipe diameter to wall thickness. In the case of ABS and PVC pipe, the outside pipe diameter is used; for PE, the inside pipe diameter is used.

Pressure rating (PR) is the estimated maximum operating internal water pressure (psi) at which the pipe can function without failure.

The relation between SDR, hydrostatic design stress, and pressure rating is given by either Eq. 11 or Eq. 12. These equations are commonly known as the ISO equations.

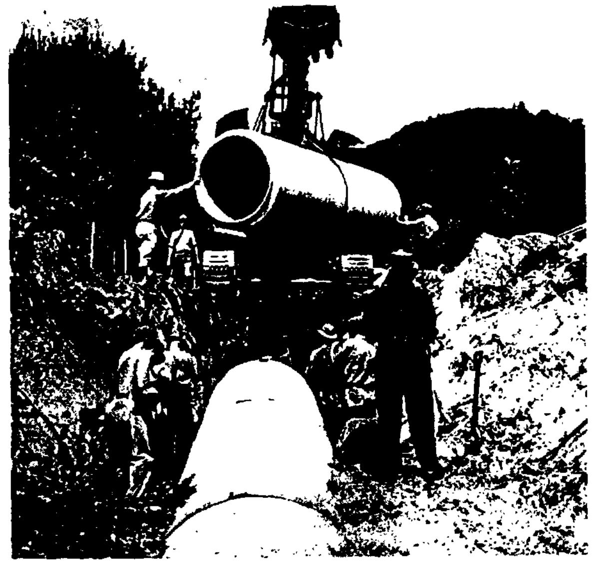
For ABS and PVC pipe:

$$\frac{2S}{P} = SDR - 1 \text{ or } \frac{2S}{P} = \frac{OD}{t} - 1 \qquad \text{Eq. 11}$$

For PE pipe:

$$\frac{2S}{P} = SDR + 1 \text{ or } \frac{2S}{P} = \frac{ID}{t} + 1 \qquad \text{Eq. 12}$$

where, for the two equations
S = hydrostatic design stress (psi)
P = pressure rating (psi)
OD = outside diameter (in.)
ID = inside diameter (in.)
t = minimum wall thickness (in.)
SDR = standard thermoplastic pipe dimension ratio, i.e., (OD/t for ABS and PVC; and ID/t for PE pipe).



Lowering concrete pipe into trench with steel cable.

Manufacture

All thermoplastic pipe is manufactured by an extrusion process; fittings by an injection mold process. In the extrusion process, pellets of plastic material are heated under pressure and forced through a shaping die, such that they conform to the dimensional requirements of the piping product. Subsequent to this shaping process, the product is slowly cooled and further shaped through sizing devices to make its dimensions fall within that required by standards.

Material. The standards under which plastic pipes (ABS, PE, and PVC) are manufactured specify that the plastics used to make pipe are categorized by two criteria: short-term tests and long-term tests.

TABLE 20—PLASTIC PIPE PRESSURE RATING VS. TEMPERATURE

Temp (° F)	Rating in terms of 73.4°F (%) ABS	PE	PVC
60	105	110	115
73.4	100	100	100
100	84	70	60
130	67		30

TABLE 21—MATERIAL REQUIREMENTS AND PIPE CLASSIFICATION FOR ABS, PE, AND PVC PIPE

Pipe des.	Material Type	Material Grade	Hydrostatic design stress (psi)*	Pressure rating (psi) SDR 7	SDR 9	SDR 11.5	SDR 13.5	SDR 15	SDR 17	SDR 21	SDR 26	SDR 32.5	SDR 41	SDR 64
ACRYLONITRILE-BUTADIENE-STYRENE (ABS)**														
ABS 1106	I	1	630				100		80					
ABS 1210	I	2	1000				160		125	100	80			
ABS 2112	II	1	1250				200		160	125	100			
POLYETHYLENE (PE)†														
PE 2305	II	3	500	125	100	80								
PE 2306	II	3	630		125	100		80						
PE 3206	III	2	630		125	100		80						
PE 3306	III	3	630		125	100		80						
POLYVINYL CHLORIDE (PVC)††														
PVC 1120	I	1	2000				315		250	200	160	125	100	63
PVC 1220	I	2	2000				315		250	200	160	125	100	63
PVC 2110	II	1	1000				160		125	100	80	63	50	
PVC 4116	IV	1	1600				250		200	160	125	100	80	50

* At 23°C (73.4°F).
** ASTM Des. D1788-60T.
† ASTM Des. D1248-60T.
†† ASTM Des. D1784-60T.

Most plastic pipe is manufactured from virgin material, but the standards* allow the use of rework material (only within the same production plant) as long as the pipe produced is of equal quality to that extruded from virgin material.

The raw materials used in the manufacture of thermoplastic pipe and fittings are products of petrochemical technology and basically consist of extremely long hydrocarbon molecules. By combining various ingredients, an unlimited range of materials and physical properties can be generated. The thermoplastic materials commonly used in water service and distribution lines are selected for this application. They are based on a favorable combination of physical and economic properties to ensure a system of long life at low initial and maintenance costs.

Table 21 gives the material requirements, pipe classifications, and pressure ratings for ABS, PE, and PVC plastic pipe.

Tolerances. Plastic pipe diameters and wall thicknesses are held to close tolerances throughout the range of sizes, types of material, and standard dimension ratios. The limitations of these acceptable tolerances are shown in Table 22. Within these minimum to maximum ranges are other ranges that relate to different standard dimension ratios for the different pipe materials.

A tolerance of ±1 in. is allowed in pipe lengths of ABS and PVC pipe.

TABLE 22—MANUFACTURING TOLERANCE RANGES FOR PLASTIC PIPE

	ABS		PE		PVC	
Measurement	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Out-of roundness (in.)	±0.008	±0.075				
Wall thickness	0.10	0.606	0.06	0.404	0.06	0.750
Tolerance (in.)	±0.020	±0.073	±0.020	±0.048	+0.02	+0.09
ID (in.)			0.622	6.065		
Tolerance (in.)			−0.035	+0.020		
OD (in.)					0.405	12.75
Tolerance (in.)					±0.008	+0.075

Pipe sizes

There are three different sizing systems commonly used on plastic pipe. The IPS (iron pipe size) was the initial dimensioning system adopted by the plastics pipe industry. It is still in use today.

Recognition of the strength properties of plastics brought about a new sizing system, termed the SDR-PR (standard dimension ratio-pressure rated) system. The system differs from the IPS system in that pipe of any size made to the SDR basis has the same pressure rating. That is, the user can purchase ABS or PVC, for instance, with a 160-psi pressure rating in all sizes ranging from ½ to 6 in. Using the IPS system, this is not possible because of the decrease in pressure rating with increasing size, i.e., there is not a constant relationship between OD and wall thickness.

The third pipe sizing system, commonly termed the SWP (solvent weld pipe) system, is associated with ABS material exclusively. This system has almost completely given way to the SDR system because it was extremely difficult to use SWP pipe and then adapt the more common IPS system. Although the SWP system is still in existence, it is now used generally for only submersible and jet pump installation rather than for service line or water distribution pipe.

It should also be pointed out that the SDR system is based on IPS ODs so that it is completely compatible with the IPS system. SWP pipe is not compatible with either SDR or IPS. Polyethylene pipe is based on the SDR system as well, but instead of the OD conforming to IPS system dimensions, it conforms to IPS dimensions. As a result, the outside diameter of polyethylene pipe "floats" and cannot be associated with any other sizing system. The reason for the ID control on polyethylene pipe was that joining of these materials was first accomplished through ID fittings rather than OD connection commonly found in ABS or PVC.

Plastic pipe for water supply system use is available in a wide range of sizes, as follows:

ABS: 1/2, 3/4, 1, 1-1/4, 1-1/2, 2, 2-1/2, 3, 3-1/2, 4, 5, 6, 8, 10, 12

PE: 1/2, 3/4, 1, 1-1/4, 1-1/2, 2, 2-1/2, 3, 4, 6,

PVC: 1/2, 3/4, 1, 1-1/4, 1-1/2, 2, 2-1/2, 3, 3-1/2, 4, 5, 6, 8, 10, 12, 16

There are smaller sizes available, but these are not used for house service lines. There are also some exceptions to the above listing in some of the SDR categories, particularly in ABS and PVC pipe.

ABS and PVC, being semi-rigid products, are normally supplied in 20- to 39-ft lengths. PE pipe, being flexible, is supplied in coils 100 to 500 ft in length. The straight lengths are shipped in bundles containing 100 ft, normally unprotected. Premium (ultra-high molecular weight PE) is supplied wrapped or in cartons for on-the-job dispensing of the desired amount for the service line being installed.

Testing

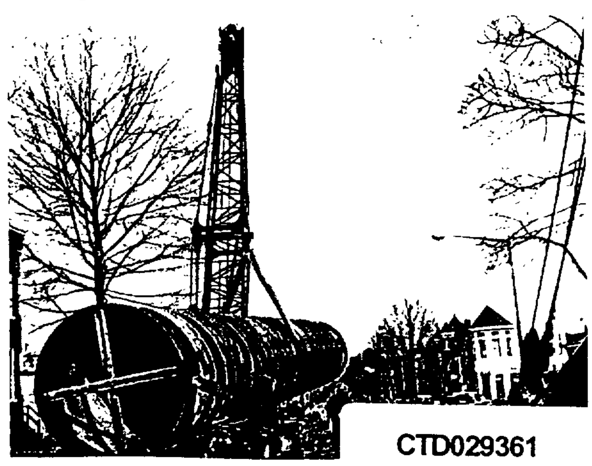
Plastic pipe is subjected to the following tests during manufacture:

Test	ABS	PE	PVC
Carbon black		√	
Ballooning	√	√	√
Bursting pressure	√	√	√
Density		√	
Eccentricity	√	√	√
Environmental cracking		√	
Extrusion quality	√		√
Failure	√	√	√
Flattening			√
ID measure		√	
OD measure	√		√
Seepage or weeping	√	√	√
Sustained pressure	√	√	√
Wall thickness	√	√	√

All tests are conducted under rigid controls at the standard test temperature of 23°C (73.4°F).

The test conditions set for pressure tests vary not only with the composition of the pipe, but also with the standard dimension ratio categories. The tabulation of data in Table 23 indicates the ranges of pressures used. The data also in-

Lowering 66-in. steel pipe into trench with a sling.



* See Table 19 for standard designation.

TABLE 23—DATA ON PRESSURE TEST RANGES FOR PLASTIC PIPE

Pipe des.	SDR 5 Sust. press.* (psi)	SDR 5 Burst. press.** (psi)	SDR 7 Sust. press. (psi)	SDR 7 Burst. press. (psi)	SDR 9 Sust. press. (psi)	SDR 9 Burst. press. (psi)	SDR 11 Sust. press. (psi)	SDR 11 Burst. press. (psi)	SDR 13.5 Sust. press. (psi)	SDR 13.5 Burst. press. (psi)	SDR 15 Sust. press. (psi)	SDR 15 Burst. press. (psi)	SDR 41 Sust. press. (psi)	SDR 41 Burst. press. (psi)	SDR 64 Sust. press. (psi)	SDR 64 Burst. press. (psi)
ACRYLONITRILE-BUTADIENE-STYRENE (ABS)																
ABS 1106	680	1650			340	830	270	660	220	530			70	160		
ABS 1210	1070	2620			540	1320	430	1050	340	830			110	240		
ABS 2112	1350	3300			680	1650	540	1320	430	1050			140	330		
POLYETHYLENE (PE)																
PE 2305			265	500	210	400	170	320								
PE 2306					265	500	210	400			165	320				
PE 3206					265	500	210	400			165	320				
PE 3306					265	500	210	400			165	320				
POLYVINYL CHLORIDE (PVC)																
PVC 1120	2100	3170			1050	1600	840	1250	670	1000			210	320	130	200
PVC 1220	2100	3170			1050	1600	840	1250	670	1000			210	320	130	200
PVC 2110	1150	2500			580	1250	460	1000	370	800			120	250	70	160
PVC 4116	1840	3170			920	1600	740	1250	580	1000			180	320	120	200

* Sustained pressure—1000 hr.
** Bursting pressure—60 to 90 sec.

dicate that as the SDR increases, that is, as the pipe diameter increases with respect to wall thickness, the maximum sustained pressure and bursting pressure levels decrease.

Joints

There are several types of jointing methods and systems used for plastic pipe, and these methods vary with the type of material.

ABS pipe. This type of pipe is available with fittings of all types, and connecting joints may be made by screw-threaded couplings, solvent weld, or with victaulic or Dresser-type joints. Inasmuch as this type of material is not used for water service systems as frequently as the other materials, the subject of joints is of less interest.

PE pipe. There are basically two methods of joining polyethylene: insert fittings and flaring. One of the reasons that PE pipe sizing is based on inside rather than outside diameters is that the joining of these materials was first done by means of inside fittings. As a result, joining had to be accomplished by mechanical means, such as insert fittings etc. The polyethylene material, because of its inherent low modulus, high flexibility, cold flow, or creep characteristics, could not be permanently joined through an outside clamping or mechanical joining device without an internal support. The initial joining system thus became associated with internal support and is commonly known as the insert fitting method.

Recent developments with polyethylene have made the material capable of being flared in a manner similar to copper and joined directly into conventional curb and corporation stops. Flaring is normally accomplished by specially designed flaring tools and the application of heat to the end of the pipe so that the material can be softened and flared easily. As a result, a new sizing system, the tubing-size system, has developed for polyethylene. In this system, the OD of polyethylene is exactly the same as ODs for Type K copper tube. The inside diameter thus floats and is dependent on pressure rating. This tubing is joined by flaring rather than by insert fittings.

A third system for joining PE pipe is also evolving. It is termed the compression joint method and can be accomplished on copper-tube-sized pipe as well as IPS-ID pipe. In this system, the use of internal metal stiffener sleeves is normally recommended. The pipe is joined by means of a compression fit between an O-ring around the circumference of the pipe. The O-ring is pressed against the pipe surface and resisted principally by the internal support sleeve. The use of polyethylene for water service applications has witnessed the use of all three joining methods, although the insert fitting methods is the most common and oldest system in use. Flaring requires a little more skill in installation than does the use of insert fittings. The compression joint system is probably the easiest to install.

PVC pipe. There are several means of joining PVC pipe sections. In the solvent-weld system, the pipe and fitting are chemically joined through the use of solvents that degrade the outer surface of the material. Basically this action plasticizes the plastic such that when pipe is mated to the fitting, the solvated plastics on the fitting and pipe side are mixed. The solvent evaporates leaving a monolithic joint.

In addition, belled-end PVC is available in two fashions, one a straight bell on one end of the pipe, which basically eliminates a coupling. It employs the solvent weld system. The other method is an O-ring joint employing a belled end in which an O-ring is fitted (Fig. 14). This system is devoid of solvent-weld-type of joining; sealing is accomplished

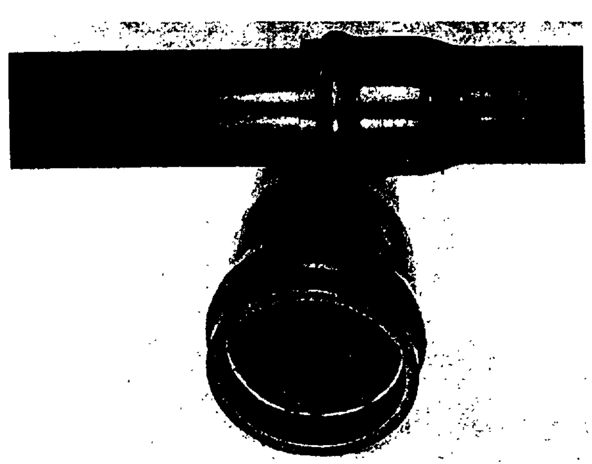


Fig. 14. PVC pipe joint for large size pipe.

CTD029362

Lowering plastic pipe into trench by hand.

completely by compression of the O-ring against the pipe. The O-ring system is associated with the larger PVC water distribution applications because of the relative ease of joining and the speed to which it can be accomplished compared to solvent welding.

For PVC, other joining methods can be employed, such as the victaulic method, flanged fitting, etc., but the methods listed above are the most common, most economical, and easiest to use.

Plastic-lined pipe

There are at least three plastic materials used to line cast iron and steel pipe. These lining materials are Penton (chlorinated polyether), polypropylene, and Saran (vinylidene chloride). All three are chemical- and corrosion-resistant.

Design. Plastic pipe liners are nearly hydraulically smooth. When it is necessary to estimate the pressure drop in any plastic-lined pipe line, the following equation is used:

$$P = \frac{0.0286}{D^3}\left(\frac{G}{D}\right)^{1.97} \qquad \text{Eq. 13}$$

where P = pressure loss in line (psi/100 ft)
G = flow (gpm)
D = inside pipe diameter (in.)

Manufacture and testing. Manufacture of plastic-lined steel pipe involves locking the stabilized plastic liner firmly inside the pipe so that the liner and tube expand and contract as one unit. The outside diameter of the plastic-lined steel pipe is made to stadard iron pipe sizes.

During the lining process, the lined pipe is spark-tested twice to ensure product quality. The pipe is designed for either 125 or 150 psi pressure classes.

Pipe sizes, lengths, and joints. Plastic-lined pipe is manufactured in these sizes; 1, 1-1/4, 1-1/2, 2, 2-1/2, 3, 4, 6, and 8-in. diameters, and in 10-ft lengths. Joints are made by flanged fittings screwed on to threaded pipe ends. The pipe may be cut in the field and threaded for use with couplings or flange connections. The pipe ends are protected against damage during shipment.

Section 5—Steel Pipe

Steel pipe in water systems dates back more than 100 years. Its early use for carrying water was in large, long, and exposed transmission lines in relatively dry areas where corrosion was not a problem. Other applications in other areas became more common as coal-tar coatings became available. Steel pipe is now used in many distribution and inplant systems, as well as in transmission lines.

Steel pipe has four characteristics that make it useful in water systems: strength, an ability to resist load but yield to it, an ability to bend without breaking, and resistance to shock.

A full treatise (AWWA M11)[22] on steel pipe, its characteristics, uses, standards, design, manufacture, and installation has been published by the American Water Works Association, which has also published a number of standards related to steel pipe.[23,24,26,27]

Design

As described by AWWA Standards,[23,24] there are two types of steel water pipe*: fabricated, electrically-welded steel pipe and mill-type steel pipe; both may be coated and lined. In determining the required wall thickness of either type, the designer must consider all factors that affect design. These factors are: internal pressure (static and surge), external load (trench load, earth fill, and uniform collapse pressure, either atmospheric or hydraulic), special physical loading (for saddle or ring supports), and practical requirements. All of these factors are discussed in detail in AWWA Manual M11.[22]

Once the internal pressure conditions are established, the wall thickness is calculated according to this equation

$$t = \frac{pd}{2s} \qquad \text{Eq. 14}$$

where t = wall thickness (in.)
p = pressure (psi)
d = outside diameter (in.)
s = allowable stress (psi)*

* Normally 50 percent of yield strength of steel selected.

Tables are available[22] for selecting wall thickness directly, based on Eq. 14.

The following discussion of pipe design is divided between the two types of steel pipe and is based on AWWA standards.[23,24]

Fabricated, electrically-welded pipe. AWWA Standard C201-66[23] gives a description of the pipe with respect to material, pipe dimensions, ends, and seams.

Steel plate. Plate used for fabrication must be Grade B, C, or D of ASTM Des. A 283 "for low and intermediate tensile strength for structural quality." When requested by the purchaser, specimen plates for testing must be submitted by the manufacturer.

When large diameter steel pipe is used, the wall thickness is often governed by internal pressure, but external load and deflection control may dictate the required wall thickness. If high water pressures exist, a steel plate of higher strength than the above grade should be used for the pipe.

Steel sheets and coils. Sheet or coil steel must be Grade A of ASTM Des. A 245 "for light-gage, structural-quality, flat, hot-rolled carbon steel." Test results certifying physical properties of the steel pipe must be furnished.

Plate thickness. In the determination of required steel

* These standards relate to the original methods used to produce steel pipe. Now, there is essentially no difference, and a committee has been established to merge the two standards into one.

pipe plate thickness, Eq. 14 is adapted to include the factor of joint efficiency as follows:

$$t = \frac{pR}{f_t e} \qquad \text{Eq. 15}$$

where t = pipe thickness (in.)
p = internal bursting pressure (psi)
R = pipe radius (in.)
f_t = allowable unit stress (psi)
e = joint efficiency

Welded pipe is considered to have a joint efficiency of 1.0, but for riveted pipe the value of e is taken as the smaller of the two calculated values: plate efficiency and rivet efficiency. With the modern welding techniques available, rivet pipe is rarely used anymore and may be considered obsolete.

The design of plate-steel pipe must also take into consideration combined direct and flexural stresses caused by external loads, temperature, jointing, and support arrangements, etc.

To prevent buckling as a result of critical external pressures, stiffening rings may be used. The critical pressure without stiffening rings is given by Equation 16. (Note: these critical pressures refer to uniform pressure exerted on a pipe aboveground or in a subaqueous installation.)

$$P = \frac{5\,E\,(t)^3}{3\,d} \qquad \text{Eq. 16}$$

where P = external pressure (lb per lin ft)
E = modulus of elasticity of metal (psi)
t = pipe wall thickness (in.)
d = pipe diameter (in.)

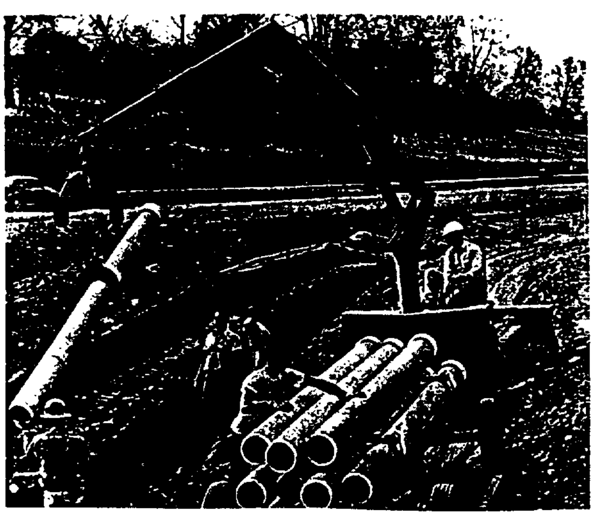
Tolerances. Manufacturing tolerances[23] are set for end, size, length, straightness, and bead.

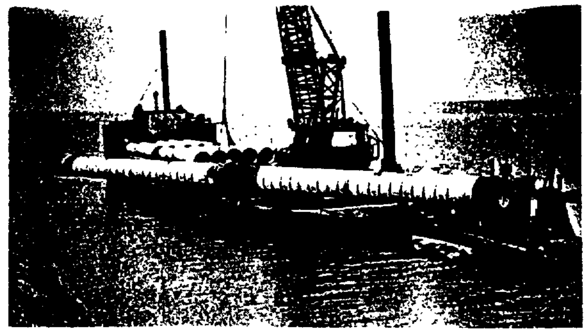
Ends. For a distance of 10 in. from the ends, both outside and inside diameters for different types of joints must be within these limits: not more than 1/16 in. smaller or more than 1/8 in. larger than the nominal circumference calculated either from the nominal outside diameter or the nominal inside diameter plus twice the nominal wall thickness. Slip joint bells and tapered sections for lap riveted field joints have these tolerances: inside diameter of bell—plain end diameter + 1/32 to 3/16 in.

Tapered sections diameter—inside section diameter + 1/16 to 1/8 in.

Size, length, straightness, and bead. Tolerances for these physical measurements of steel pipe are as shown in Table 24. In bell and spigot rubber gasket joint pipe, the tolerance difference between inside diameter of the bell and outside diameter of the spigot is 0.06 in. minimum and 0.2 in. maximum.

Lowering asbestos-cement pipe into trench with a clamp.





Underwater pipeline installation.

TABLE 24—MEASUREMENT TOLERANCES FOR ELECTRICALLY-WELDED STEEL PIPE

Measurement	Tolerance
Outside circumference (%)	
<20 in. diam.	1.0
>20 in. diam.	0.5
Straightness deviation (in.)	
10-ft length	1/8
Length (in.)	
Pipe sections	±2
Special straight sections	±1/8
Weld bead height*	
Outside, max. (in.)	+1/8
Inside, max. (in.)	+1/16

* Bead may not be below surface at any point.

Mill-type steel pipe. AWWA Standard C202-64T[24] sets forth specifications for chemical and mechanical properties for three mill types of pipe, as follows:

Type	Grade	Weld type
Furnace welded		Continuous furnace weld or furnace butt weld
Electrically welded	A, B, or X 42	Induction butt weld; spiral- or straight-seam resistance butt weld; spiral- or straight-seam fusion butt weld
Seamless	A, B, or X 42	

Chemical properties. Steel supplied for use in pipe should conform to a ladle analysis as shown in Table 25.

Mechanical properties. The minimum required tensile strength of the steel will vary depending on the grade used, as shown in Table 26.

TABLE 25—MAXIMUM ALLOWABLE CHEMICAL CONTENT OF STEEL

Steel type	Manganese (%)	Phosphorus (%)	Sulfur (%)
Furnace butt-welded	0.65	0.11	0.06
Grade A	1.25	0.04	0.05
Grade B	1.25	0.11	0.05
Grade X 42	1.25	0.10	0.05

TABLE 26—MINIMUM REQUIRED TENSILE STRENGTH FOR MILL-TYPE STEEL WATER PIPE

Steel type	Tensile strength (psi)	Yield point (psi)
Furnace butt-welded	45,000	25,000
Grade A	48,000	30,000
Grade B	60,000	35,000
Grade X 42	60,000	42,000

Yield strength is the point at which the steel specimen, under load, will return to its original length when the load is removed. Minimum elongation requirements for seamless and electrically-welded mill-type steel water pipe vary with wall thickness, grade of steel, and welding method. These variations are given in AWWA C202-64T.[24] For wall thicknesses of seamless and electrically welded pipe not tabulated in this standard,[24] the minimum allowable elongation is calculated according to one of these equations:

Grade A	$E = 56t + 17.5$	Eq. 17a
Grade B	$E = 48t + 15.0$	Eq. 17b
Grade X 42	$E = 40t + 12.5$	Eq. 17c

where E = minimum elongation in 2 in. (%)
t = tabulated wall thickness (in.)

Some manufacturers can supply intermediate diameters and wall thicknesses that are acceptable under these standards.

Ring deflection. Like other types of pipe material, buried steel water pipe is subjected to compression under external loads that may contribute to ring deflection.

Backfill load. Ring deflection is not significantly influenced by pipe wall thickness, but it is an important consideration with respect to the lining thickness. After the steel cylinder thickness has been calculated for factors of internal pressure (limited to allowable hoop stress), it is necessary to determine if this thickness, in conjunction with the specified backfilling procedure, will limit ring deflection, caused by external loads, to an acceptable amount. The support offered by soil backfill plays an important part in the proper functioning of a flexible pipe buried underground. Acceptable deflections that will not damage linings or coatings are based on the following safety factors.

Coating and lining	Allowable deflection (%)
Flexible lining and coating	5
Cement-mortar lined and flexible coating	4
Cement-mortar lined and coated	2

Tables of predicted percent deflection of the three lining and coating conditions (at 85 and 90 percent backfill compaction), along with formulas and diagrams for calculating ring deflection, have been published.[25]

Live load. As with other pipeline materials, buried steel pipe is subject to two types of superimposed loads: concentrated and distributed. Below 7- to 8-ft depths, the live-load effect is considered as negligible. For other depths, the equation for superimposed concentrated load is:

$$W = C_s \frac{P F}{L} \qquad \text{Eq. 18}$$

where W = superimposed load (lb per lin ft)
P = concentrated load (lb)
F = impact factor
C_s = load coefficient [a function of $D/2H$ and $L/2H$; H = depth of fill to conduit top (ft); D = outside pipe diameter (in.)]
L = effective length of conduit (ft) (use actual length under 3 ft, and 3 ft above 3 ft).

Impact factors will vary with vehicle speed, vibration, roadway roughness, and depth of backfill cover. Use these values:

Depth of cover (ft)	Impact factor (F)
0-1	1.3
1-2	1.2
2-3	1.1
>3	1.0

Tolerances. Manufacturing tolerances for mill-type steel water pipe are set forth in brief in Table 27, developed from AWWA C202-64T.[24]

TABLE 27—MEASUREMENT TOLERANCES FOR MILL-TYPE STEEL PIPE

Measurement	Max. tolerance
Outside diam.	
<1.9 in. (in.)	±0.016; −0.031
>1.9 in. (%)	±1.0
<10-3/4 in. (in.)*	−1/64
12-3/4 to 20 in. (in.)*	−1/32
22 in. and larger	−1/32; +3/32
Wall thickness	
18 in. or less diam. (% of specified)	−12.5; +15.0
20 in. and up diam. (% of specified)	−10.0; +15.0
Weight	
Per foot (% variation)	−3.5; +10.0
Carload lots (% of specified)	−1.75
Length (in.)**	1/8
Straightness	Reasonable

* For 4 in. from end.
** For specified 17-1/2-ft lengths, no length may be less than 9 ft.; for specified 35-ft lengths, no more than 10 percent may be shorter than 26-1/2 ft, and no lengths less than 14 ft; for specified lengths of 20 ft or more, no more than 10 percent may be less than 75 percent of specified length, and no length may be less than 40 percent of the specified length.

Ends. Tolerances for ends vary with the type of joint to be made, as follows: [24]

Joint	Specification
Plain end for mechanical coupling	Square cut, beveled, no burrs
Field butt welding	
Wall thickness of 1/4 in.	Bevel inside and out to 30 degrees, with max. plus tolerance of 5 degrees (no minus tolerance); width of root face 1/16 in., with tolerance of 1/32 in.
Wall thickness less than 1/4 in.	Not beveled
Bell and spigot, with rubber gasket	Difference between outside circumference of spigot and inside circumference of bell, min. 0.06 in.; max. 0.20 in.
Threaded ends	API Spec. S L (Section IX)
Other ends	By agreement

Manufacture

The method of fabricating pipe differs according to the type of pipe and the welding process used.

Fabricated electrically-welded pipe. This pipe may be produced by automatic welding machines or by manual welding operations, Operators of either process must be qualified under the ASME Boiler and Pressure Vessel Code. AWWA C201-66[23] states detailed specifications for plate edge preparation, lap breaking and forming, surface cleaning, fitting up, welding, weld corrections, section rounding, end sizing, end preparation, and automatic and manual welding operations.

Pipe ends and seams. Any one of eight types of pipe section ends may be specified. These include four variations for field welding (plain ends for slip or lap joint, plain ends with butt straps, beveled ends with butt straps, and plain or beveled end for field butt welding), plain ends fitted with flanges, bumped ends for field riveting, tapered ends for lap riveted field joints, and bell and spigot ends with rubber gasket. Longitudinal seams, spiral seams, and girth seams are butt welded.

Mill-type steel pipe. As indicated previously, this type of pipe may be furnace welded (continuous butt-welded or furnace butt-welded), electrically welded, or seamless.

Furnace-welded pipe. In this process, the pipe may be formed either by bell welding or continuous welding.

Bell-welded pipe. In this method of manufacture, pipe is produced in individual lengths from cut-length skelp (the plate or strip of steel from which pipe is made), with its longitudinal butt joint force-welded by mechanical pressure developed in drawing the furnace-heated skelp through a cone-shaped die (welding bell) that serves as a combination forming and welding die.

Continuous butt-weld pipe. In the production of small diameter pipe, coiled skelp is formed into continuous-weld pipe at speeds of nearly 8 mph, with the skelp size depending on the size of pipe to be formed. The first step consists of unrolling the skelp lengths and welding the ends together to form a continuous strip.

The skelp then passes through a furnace, where it is heated to about 2200° F, and then through forming rolls, where it is gradually formed and then butt welded to become pipe. From the welding step, the pipe enters a stretch reducing mill where it is stretched to final size (seven pipe sizes can be made from only two skelp widths).

The pipe is then marked and cut by a rotary-type hot saw while moving at high speed. After cutting, it moves across cooling tables to the straightening operation, then to cropping, end-finishing, testing, coating, and preparation for shipment.

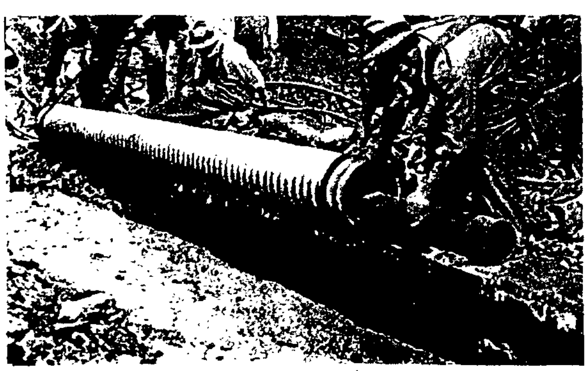
Electrically-welded pipe. There are two types of electrically welded pipe: longitudinal-weld (3-1/2 to 36 in.) and spiral weld (6 to 80 in.)

Longitudinal weld. This type of pipe is produced in a continuous straight line process. The steel skelp is drawn through a series of vertical and horizontal forming rolls that progressively form the strip of steel into a cylindrical shape. The cylinder then moves through a high-frequency resistance welder, where the edges are heated to a plastic state. Pressure rolls immediately force the edges together to form a strong continuous weld.

After the weld has been accomplished, the pipe cylinder is cooled and then passed through a series of rolls to provide the desired diameter and straightness. Predetermined pipe lengths are cut automatically by a flying cut-off saw. Testing, coating, etc., follows.

Spiral weld. In this process the steel skelp is drawn from the coil holder and fed to main drive rolls. As the steel enters the forming rolls, it is spirally wound into a cylinder and automatically welded by the submerged arc process. The pipe then proceeds to a cut-off mechanism and is cut to predetermined lengths. Testing follows.

Seamless pipe. This type of pipe is made by piercing a solid steel round bar or billet to produce a rough heavy-walled tube. In this process, the bar or billet is heated uniformly to the desired forging temperature. The length and diameter of the billet are predetermined to produce the required tube size and weight. Only high quality steel is used.



Installing pipe line in conduit under railroad.

After heating, the billet is pulled, by rolls, over a piercing point and mandrel bar, thus producing a rough tube. Following the piercing operation, different mills use different methods of rolling, heating, and sizing to produce the final seamless tube.

Pipe sizes. The following listing shows the most commonly available pipe sizes for the different types of steel pipe.

Type	Outside diameter (in.)
Fabricated, electrically-welded	4 to 144
Mill-type	
Furnace welded	0.405 to 36
Electrical-welded	
Longitudinal-weld	3 1/2 to 36
Spiral-weld	6 to 80
Seamless	2 to 4

Testing

Tests performed during manufacture are made in accordance with standards [23,24] to ensure an acceptable product.

Fabricated, electrically-welded steel pipe. As set forth in detail in AWWA C201-66, [23] the following tests are made in accordance with the specifications: weld test; free-bend test; root-bend test; nick-break test; and hydrostatic test. The specimens of pipe selected for these tests must meet minimum requirements.

Hydrostatic test. Hydrostatic test conditions differ for different sizes of pipe.

Above 30-in. diameter. The test pressure used for pipes larger than 30-in. diam. may not exceed that given by this formula:

$$P = \frac{2\,st}{D} \qquad \text{Eq. 19}$$

where P = test pressure (psi)
s = allowable fiber stress (psi) (85% of yield point of plate).
t = wall thickness required for working pressure (in.)
D = inside diam. (in.)

Below 30-in. diameter. Pipe under 30-in. diam. is tested to specified pressures ranging from 1200 psi in the smaller size to 600 psi in the larger size. The detailed specified pressures are tabulated in AWWA C201-66.[23]

Mill-type steel pipe. The detailed tests that may be required by the purchaser on this type are set forth in AWWA C202-647.[24] The listing* includes:

- Ladle analysis (followed by check analyses on drillings or cuttings from pipe)
- Tensile strength tests (transverse and longitudinal specimens)
- Flattening tests (on nonexpanded electrically-welded pipe; nonexpanded resistance-welded pipe; cold-expanded electrically-welded pipe; and butt-welded pipe 2-7/8 in. and larger)
- Bend tests for butt-welded pipe
- Fusion weld tests
- Hydrostatic tests

Hydrostatic test. Each length of pipe is subjected to a hydrostatic test in the mill. Test pressures for different size pipes are specified [24] and range from a minimum of 700 psi for 1/8-in. pipe to a maximum of 2500 psi, with each pipe size having a specified test pressure range depending on the wall thickness and pipe grade (A, B, X 42).

* Many special tests are mill extras and may increase the cost by $20 a ton. Normally, a purchaser will accept the same tests as for "C201 pipe" and avoid these extras.

Coating and lining

The American Water Works Association has issued two standards for coating and lining steel pipe, one for coal-tar enamel protective coatings[26] and one for cement-mortar protective lining and coating.[27]

Coal-tar enamel. The AWWA standard[26] covers corrosion protection for five conditions:

- Inside of all pipe
- Outside of all pipe less than 30-in. diam. for underground placement
- Outside of all pipe more than 30-in. diam. for underground placement**
- Outside of all pipe for aboveground placement
- Outside of all pipe for aboveground placement where corrosive conditions exist

Material. The AWWA standard[26] sets forth the specifications for the several materials used in connection with this protective coating. These materials include: primer, coal-tar enamel, white wash, synthetic red lead primer, synthetic white enamel, aluminum bronzing pigment, cold-applied coal-tar coating, and cold-applied coal-tar emulsion asbestos felt wrap, fibrous glass mat wrap, and sand shield.

Primer. Two types of primer are used: Type A (coal tar) and Type B (fast-drying).

Enamel. The coal-tar enamel used must be specially processed coal-tar pitch and must not contain any petroleum- or natural-base asphalts. It must meet rigid maximum and minimum specifications for physical characteristics set forth in the standard.[26] The following tests are conducted to determine if the characteristics meet the standards: high-temperature test, low-temperature test, deflection test (initial heating), deflection test (after 2-hr heating), peel, initial bond, bond after 72 hr, impact test (direct and indirect).

Aboveground coatings. When steel pipe is installed aboveground, it is given two primer coats of red lead pigment in a synthetic-resin vehicle. If exposed to or installed during hot weather, the second primer coat is synthetic white enamel.

Application of coal tar. Primers and enamels are applied in the shop, but some application is necessary in the field to protect joints and to repair damage to the coating during handling.

Shop application. When coatings are applied in the shop, the pipe surfaces are cleaned and, if necessary, warmed to 85 to 100°F; primer is added by hand brushing, air-gun spraying, or spraying and brushing. The prime-coated pipe must be protected from moisture, dust, etc.

After the primer has dried for the specified time, the coal tar, which has been heated to the proper temperature, is applied to the pipe. For coating the inside of the pipe, the enamel is applied by centrifugal casting. Either of two application methods may be used: trough method, or retracting weir, i.e., feed-line method. Details of those methods appear in AWWA C203-62.[26]

Coal tar is applied to exterior surfaces by pouring the heated material onto the pipe as it revolves, making certain that each spiral of applied coating overlaps the next, and that the coating is continuous, free from defects, and 3/32 ± 1/32 in. thick.

Electrical inspection with a flaw detector operating at 8000 to 10,000 v (and low amperage) is used to check for holidays in the coating.

Field application. Coated pipe must be handled from shop to installation with care to prevent damage to the coating. In the field, both interiors and exteriors of joints must be inspected for damage and repaired.

** This procedure is not generally followed today. Nearly all pipe is coated and wrapped in a manner similar to the standards for pipe 30 in. and less.

Application of aboveground coating. Exterior surfaces of pipe installed aboveground are cleaned and coated according to specifications in the AWWA standard.[26]

For ordinary service in a noncorrosive atmosphere, two coats of red lead primer (or one coat of synthetic red lead and one coat of synthetic white enamel) and one coat of aluminum bronze paint are applied.

For corrosive atmospheres, the steel surface receives one coat of heavy-bodied, cold-applied coal-tar coating, one coat of heavy-bodied coal-tar emulsion, and one coat of aluminum paint.

Additional exterior coating. Where additional exterior coating is desired on pipe to be placed underground, the coating process consists of a coat of primer, followed by a hot coat of coal-tar enamel onto which is bonded a single layer of asbestos felt wrap, followed by one coat of water-resistant white wash, or a single wrap of kraft paper. Coal-tar enamel and bonded double-asbestos felt wrap may be called for where extraordinarily severe soil conditions exist or for submarine lines and river crossings. Another type of wrap that may be used for these severe conditions is a coal-tar enamel, fibrous-glass mat, and bonded asbestos felt wrap. A sand shield (i.e., bedding and immediate backfill) may be used in severe soil conditions. A reinforced cement-mortar shield for additional protection may be required in some areas. This shield is covered in AWWA C205-62T.[27]

Mortar lining. Specifications for cement-mortar lining and coating are covered in AWWA-C205-62T.[27]

Pipe surfaces to which cement-mortar is to be applied must be clean, and the mortar used must be proportioned correctly by weight (3 parts sand to 1 part cement, with a maximum water-to-cement ratio of 0.5 to 1.0, by weight). Materials used should meet the specifications in Table 28.

TABLE 28—SPECIFICATIONS FOR MATERIALS FOR CEMENT-MORTAR LINING AND COATING OF STEEL WATER PIPE

Materia	Specification
Cement	Type II, ASTM C50
Sand	Inert, hard, strong, durable, and uncoated; free from dirt, with no more than 1% shale, 1% clay lumps, and 3% mica (maximum allowable deleterious substances, 5%)
Water	Clean, colorless; no objectionable amounts of organic matter, alkali, or salt
Sealing compound	ASTM Des. C309; may not impart taste or odor to water after drying
Paint	4-hr-drying, corrosion resistant, with good bonding characteristics

Straight sections are lined by rotating the pipe in a special machine with the mortar applied centrifugally to the inside of the pipe. Specials are lined by mechanical or pneumatic placement, or by hand trowelling, and finished to produce a smooth, dense surface.

Acceptable mortar lining thicknesses are given in Table 29. (Note: Linings and coatings covered by AWWA Standards C203 and C205 can be used interchangeably, that is, the pipe can be cement-mortar lined and coal-tar enamel coated or coated and lined with any other desirable combination.)

TABLE 29—THICKNESS SPECIFICATIONS FOR CEMENT-MORTAR LINING FOR STEEL WATER PIPE

Pipe size (in.)	Thickness (in.)	Tolerance (in.)
4–10	1/4	±1/32
11–23	5/16	±1/16
24–36	3/8	±1/16
>36	1/2	±1/16

Curing. Immediately after the mortar is applied, the pipe ends are closed to prevent drying of the lining, and within 1 hr thereafter, the pipe lining is subjected to curing by either water or steam.

Water curing. This treatment consists of keeping the lining moist and within temperature limits, by sprinkling heads or other methods, for a period of 7 days before shipment. If exterior coating is to be applied, the application is made after 24 hr of curing, and the pipe is then cured for 6 days more.

Steam curing. This treatment consists of introducing steam into the pipe and making certain that the temperature of the pipe is maintained between 130 and 150° F for a period of at least 42 hr.

Mortar coating. External protection of steel pipe is provided by a mortar coating. The cement-mortar (3-1/2 parts of sand to 1 part cement by weight, with controlled water content) is applied, over reinforcing, by mechanical placement or by the steam-pneumatic process. Application by the air-pneumatic (gunite) process is permissible, with the mortar composition limitation being 4 parts sand to 1 part cement, and controlled water content to prevent sag, run, or segregation of the mortar.

The material used for the coating should be the same as that given in Table 28.

Mortar thickness. Exterior coating thickness is usually specified to meet the limitations given in Table 30.

TABLE 30—THICKNESS SPECIFICATIONS FOR CEMENT-MORTAR COATING FOR STEEL WATER PIPE

Pipe size (in.)	Thickness (in.)	Tolerance (in.)
4-12	1/2	+1/8
13-19	5/8	+1/8
20 and up	3/4	+1/8

Reinforcement. Cement-mortar coatings must be reinforced. The reinforcing may be by spiral wire, wire fabric, or wire mesh (ribbon mesh), specified as follows:

Type	Gage	Max. spacing (in.)	ASTM Des.
Spiral wire	15	1 1/4	A-82
Wire fabric	13	2 × 4	A-185
Ribbon mesh	18	1 × 1	A-82
	17	1-1/2 × 1-1/2	A-82

Machine coating. When application is by mechanical or pneumatic placement, the coating may be applied in courses, but the application time interval between first and last course may be no more than 2 hr. The AWWA standard[29] places restrictions on such factors as support and interrupted placement, particularly with respect to spiral-wire and wire fabric or ribbon mesh reinforcement.

Curing. Cement-mortar coatings must be cured after the initial set. The water curing process (see linings, above) may be used (minimum curing period—7 days); or steam curing (as with linings) may be used (minimum period—42 hr).

Field joints. For inside joints, the cement mortar for field joints should be composed of 1 part cement to 2 parts sand, dry-mixed, and moistened just enough to make troweling and calking possible without crumbling. For outside joints, the mortar is composed of 1 part of cement and 3 parts sand, with sufficient water to provide a flowing consistency. Details of application for different size pipes are given in AWWA C205-62T.[27]

Section 6—Wood-stave Pipe

Wood-stave pipe is not used in water distribution systems but is used in large-diameter transmission lines, particularly for industrial or power plants located in rough terrain, where the pipeline is usually located above ground.

This type of pipe has certain advantages: light weight, fairly long life, high carrying capacity, corrosion resistance, and ease of construction in difficult locations.

Design

There are two types of wood-stave pipe, continuous stave and machine-banded. Both may be made in any desired diameter up to 20 ft and for pressures up to 150 psi.

Wood-stave pipe is designed to resist internal bursting pressure but not external flexural stress, although the latter may have some importance if the pipe is installed in a trench and backfilled.

In addition to internal pressure, the diameter and spacing of the bands are important design factors. The latter two are interdependent. Generally, the band diameter is determined first to develop the full crushing strength of the wood. Then the spacing is determined. Equations relating stress to pipe diameter, wood-stave thickness and strength, and band radius and strength, etc. are used to calculate the band diameter and spacing.

Manufacture

Continuous-stave pipe is usually manufactured in cradles at the site. Staves are laid together in such a way that joints between staves are staggered. Joints are planed radially and may have a copper or zinc plate between the stave ends to make them water tight. These joint "gaskets" are used because longitudinal swelling of the wood stave is small.

Wire bands are placed around the pipe and spaced as calculated, but never more than 12 in. apart. The bands are held firmly in metal shoes, which are connected by bolts that apply the required tension.

Continuous stave pipe is usually made in one continuous length. It can be curved without difficulty on a minimum radius of 50 times the pipe diameter.

Machine-banded pipe is usually factory made and shipped to the site. The staves are held together by tensioned spirally wound steel bands. Pipe lengths, usually limited to 20 ft for ease of handling, are joined by collars placed around the outside of the pipe, or by means of recessed or tenon joints. Recessed joints are suitable only for low pressure. Collars may be of wood stave, cast iron, or steel.

Connections to wood pipe are generally made by special iron castings fastened to a saddle held in place by iron bands.

Section 7—Wrought Iron Pipe

One of the earliest recorded uses of wrought iron pipe in water systems is that of some 12,500 ft of small diameter (1½ and 2-in.) laid in Alexandria, Va., in 1852. More than a third of this pipe was still in use a century later. Another early use was in San Francisco, where more than 250,000 ft of large diameter pipe (23- and 20-in.) was installed in the 1860s. About half was still in use 80 years later.

Probably the most historical installation of OD wrought iron pipe was in a portion of New York City's Croton Aqueduct, built under the Harlem River in 1860 and still in service. It was constructed of ½-in. wrought iron plates, fabricated to form a 90-in. pipeline.

Another historical installation of interest is the 21 mile, 11½-in. wrought iron pipeline installed in 1873 to bring water to famed Virginia City, Nev., site of the Comstock lode. Much of the line is an inverted syphon that carries water 2000 ft down one side of the Washoe Valley and up 1600 ft on the other side. Although the population has dwindled from more than 15,000 to less than 1000, the syphon is still in service.

Wrought iron pipe also finds wide use for inplant systems, for submarine lines, cooling lines, well casings, heating and plumbing systems, and electrical conduits.

Design

Wrought iron is a two-component material consisting of high-purity iron and iron-silicate (slag). The silicate (about 2½ percent of the total weight) is not chemically combined with the iron. Rather, it is physically distributed throughout the iron (Fig. 15) and gives the iron a distinctively fibrous structure, similar to that of green wood.

Characteristics. Wrought iron possesses qualities of toughness, ductility, malleability, mechanical strength, weldability, and corrosion resistance. These characteristics stem almost wholly from the even distribution of silicate fibers, of which there are approximately 250,000 in each cross-sectional square inch (see Fig. 15).

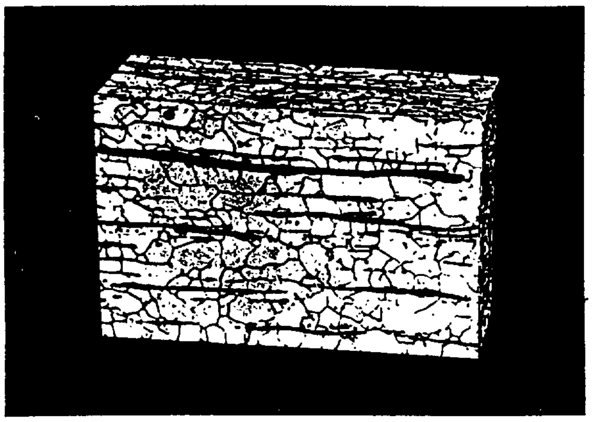


Fig. 15. Photomicrograph of wrought iron (100 X) shows glass-like siliceous fibers in metal.

These glass-like fibers form a defense against corrosion and force it to to disperse, thus preventing deep pitting and penetration of the pipe.

Wrought iron can be welded easily by any electric or oxy-weld method. It can readily be bent formed, hot or cold, by hand or machine, merely by following good bending practices. Because of the presence of the silicate fibers, the surface of wrought iron is rougher than that of other materials. This rougher surface provides a better anchorage for galvanizing or for nonmetallic coating.

Typical wrought iron contains the following substances in the amounts indicated: carbon, 0.03 percent maximum; manganese, 0.06 percent maximum; phosphorus, 0.120 to 0.140 percent; sulfur, 0.15 percent maximum; silicon, 0.10 to 0.20 percent; and iron silicate slag, 2.50 percent.

Physical and mechanical properties. All wrought iron pipe, including that made from plate, must meet recognized engineering standards. ASTM Des. A-419 covers the fabrication of large OD pipe, and wrought iron plate is manufactured in accordance with ASTM Des. A-42. Typical physical design properties under these ASTM Designations are given in Table 31.

Wrought iron pipe may also be specified in accordance with Federal Specification WWP-441, and welded tubing according to Military Specification MIL-T-17168 (NAVY).

Manufacture

Wrought iron is manufactured either by hand puddling or by the Byers-Aston process. The former method was used in both the United States and Britain until about 1930, when the latter process was introduced in this country. There are three basic steps in the manufacture of wrought iron: melting and refining of the metallic iron or base metal; production of a controlled iron silicate slag; and mechanical incorporation of the refined iron into the iron silicate slag by pouring melted iron (2900°F) into molten slag (2500°F).

The temperature of the molten slag is a few hundred degrees lower than that of the molten iron at the time the two are mixed. This causes the iron to solidify rapidly as it is poured into the liquid silicate slag. Rapid solidification of the refined iron causes dissolved gases to be liberated with such force that the metal shatters into small fragments. This results in the formation of a 3- to 4-ton "sponge ball." Rolling this ball into a bloom causes the iron silicate to elongate in the direction of rolling. Microscopic inspection (Fig. 15) shows the glass-like iron (nonrusting) fibers.

Pipe sizes. Wrought iron pipe from ¼ to 4 in. is produced on a special machine that utilizes a continuous weld system. Sizes from 4½- through 14-in. are lap-welded. These pipe sizes are threaded for couplings or flanges. Table 32 shows pipe sizes and physical data up to 14-in. diam. pipe.

Large OD pipe (above 14-in. diam.) is produced from plates of desired size and thickness by fusion welding. Table 33 lists physical data for pipes 14-in. in diameter and above.

Coating and lining. Wrought iron pipe may be specified with either of two types of protective coatings, metallic or nonmetallic. Hot dip galvanizing is a very popular coating process.

Nonmetallic coatings range from cement mortar to simple paints. Some wrought iron pipe manufactured for distribution system mains is cement-lined. The method of application of cement lining is the same as that used in cast iron pipe manufacture.

Handling and shipping. Wrought iron pipe should be handled with the same care given to other pipes, especially if the pipe is coated or lined. Shipping practice is similar to that for other pipe; i.e., truck or rail.

TABLE 31—TYPICAL PHYSICAL PROPERTIES OF WROUGHT IRON*

Property	Pipe A-72	Plate A-42
Tensile strength, min. (psi)	42,000	48,000
Yield strength, min. (psi)	25,000	27,000
Elongation in 8 in., min. (%)	12	14
Weight (lb/cu ft)	480	
Specific gravity	7.70	
Modulus of elasticity (psi)	29×10^6	
Shear strength (psi)	46,000	
Shear modulus (psi	11.8×10^6	
Tension modulus (psi)	29.5×10^6	
Poisson's ratio	0.30	
Hardness, Brinell	97 to 105	
Hardness, Rockwell	B55 to B60	
Impact, strength		
Standard Charpy, keyhole notch, double refined rounds (ft/lb)	24 to 28	
Standard Izod, Izod V-notch (double) refined rounds (ft/lb)	50 to 60	
Modified Charpy, Izod V-notch (double) refined rounds (ft/lb)	70 to 85	
Modified Charpy, Izod V-notch, plate (ft/lb)	40 to 44	
Melting point, approximate (°F)	2750	
Specific heat (BTU lb/°F)	0.11	
Thermal conductivity, K (BTU in./hr/sq ft/°F)		
At 64°F	417.89	
At 212°F	414.99	
Mean coefficient of thermal expansion, (68–200°F) (in./in./°F)	$7.4 \times 10\times^6$	
Electrical resistivity at 69.8°F (ohms cm/sq cm)	11.97	

*Properties at 68°F unless otherwise stated.

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TABLE 32—PHYSICAL DATA ON PIPE SIZES TO 12 IN.

	Standard weight pipe									Extra strong pipe								
				Weight/ft (lb)				Couplings					Weight/ft (lb)				Couplings	
Nom. size (in.)	Ext. diam. (in.)	Int. diam. (in.)	Wall thick-ness (in.)	Plain ends	Threads and couplings	Threads/in.	Mill test pres-sure (psi)	Nom. OD (in.)	Nom. length (in.)	Ext. diam. (in.)	Int. diam. (in.)	Wall thick-ness (in.)	Plain ends	Threads and couplings	Threads/in.	Mill test pres-sure (psi)	Nom. OD (in.)	Nom. length (in.)
CONTINUOUS-WELD																		
1/2	0.840	0.617	0.111	0.85	0.85	14	700	1.063	1-9/16	0.840	0.539	0.151	1.09	1.09	14	850	1.063	2-1/8
3/4	1.050	0.819	0.115	1.13	1.13	14	700	1.313	1-5/8	1.050	0.735	0.157	1.47	1.48	14	850	1.313	2-1/8
1	1.315	1.043	0.136	1.68	1.68	11-1/2	700	1.576	2	1.315	0.949	0.183	2.17	2.18	11-1/2	850	1.576	2-5/8
1-1/4	1.660	1.374	0.143	2.27	2.28	11-1/2	1000	1.900	2-1/16	1.660	1.269	0.195	3.00	3.03	11-1/2	1300	2.054	2-3/4
1-1/2	1.900	1.604	0.148	2.72	2.73	11-1/2	1000	2.200	2-1/16	1.900	1.491	0.204	3.63	3.66	11-1/2	1300	2.200	2-3/4
2	2.375	2.060	0.158	3.65	3.68	11-1/2	1000	2.750	2-1/8	2.375	1.929	0.223	5.02	5.08	11-1/2	1300	2.875	2-7/8
2-1/2	2.875	2.460	0.208	5.79	5.82	8	1000	3.250	3-1/8	2.875	2.311	0.282	7.66	7.78	8	1300	3.375	4-1/8
3	3.500	3.059	0.221	7.58	7.62	8	1000	4.000	3-1/4	3.500	2.887	0.306	10.25	10.35	8	1300	4.000	4-1/4
3-1/2	4.000	3.538	0.231	9.11	9.20	8	1200	4.625	3-3/8	4.000	3.350	0.325	12.51	12.67	8	1700	4.625	4-3/8
4	4.500	4.016	0.242	10.79	10.89	8	1200	5.000	3-1/2	4.500	3.811	0.344	14.98	15.22	8	1700	5.200	4-1/2
LAP-WELD																		
5	5.563	5.036	0.263	14.62	14.81	8	1200	6.296	3-3/4	5.563	4.797	0.383	20.78	21.15	8	1700	6.296	4-5/8
6	6.625	6.053	0.286	18.97	19.18	8	1200	7.390	4	6.625	5.743	0.441	28.57	28.98	8	1700	7.390	4-7/8
8*	8.625	8.059	0.283	24.70	25.00	8	1200	9.625	5-1/4	8.625	7.605	0.510	43.39	44.04	8	1700	9.625	5-1/4
8*	8.625	7.967	0.329	28.55	28.80	8	1200	9.625	5-1/4									
10*	10.750	10.181	0.284	31.20	32.00	8	1000	11.750	5-3/4	10.750	9.730	0.510	54.74	56.02	8	1600	11.750	5-3/4
10*	10.750	10.124	0.313	34.24	35.00	8	1000	11.750	5-3/4									
10*	10.750	10.005	0.372	40.48	41.13	8	1000	11.750	5-3/4									
12*	12.750	12.077	0.336	43.77	45.00	8	1000	14.000	6-1/8	12.750	11.730	0.510	65.42	66.81	8	1600	14.000	6-1/8
12*	12.750	11.985	0.383	49.56	50.70	8	1000	14.000	6-1/8									
14*	14.000	13.250	0.375	53.49	56.16	8	800	15.000	6-3/8	14.000	13.000	0.500	70.68	73.04	8	1100	15.000	6-3/8
										14.000	12.874	0.563	79.16	89.60	8	1200	15.000	6-3/8

*Weight per foot must be specified. Sizes 1/4 in. through 4 in. normally furnished in 21 ft. uniform lengths. Sizes 5 in. through 12 in. furnished in random lengths. Double random lengths are available. Regularly furnished threaded and coupled.

TABLE 33—PHYSICAL DATA ON WROUGHT IRON PIPE, 14-IN. DIAM. AND ABOVE*

	Plate thickess (in.)																	
	Weight/ft (lb)									Mill test pressure psi)								
Size OD (in.)	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4
14	27.12	35.99	44.79	53.49	62.12	70.68	79.16	87.54	104.06	375	550	650	800	950	1100	1200	1300	1600
15		38.61	48.06	57.43	66.72	75.92	85.05	94.08	111.92		500	625	750	875	1000	1100	1200	1500
16		41.23	51.34	61.36	71.30	81.15	90.94	100.64	119.77		450	600	700	800	950	1050	1150	1400
17		43.85	54.60	65.30	75.86	86.39	96.83	107.16	127.62		425	550	650	750	900	1000	1100	1300
18		46.47	57.89	69.19	80.46	91.63	102.73	113.73	135.48		400	500	600	700	825	900	1000	1200
20		51.69	64.43	77.03	89.63	102.10	114.19	126.79	151.18		375	450	550	650	750	850	950	1100
22		56.94	70.97	84.91	98.77	112.57	126.27	139.91	163.57		340	425	500	600	675	750	850	1000
24		62.16	77.53	92.76	107.96	123.04	138.06	152.99	182.59		315	400	450	550	625	700	800	950
26		67.39	84.06	100.61	117.12	133.51	149.83	166.29	198.29		290	350	425	500	575	650	725	850
28		72.64	90.61	108.47	126.27	143.99	161.60	179.17	214.00		270	325	400	475	550	600	675	800
30		77.89	97.16	116.32	135.42	154.46	173.39	192.26	229.72		250	300	376	450	500	550	625	750

* Weight per foot is calculated, variations being governed by tolerances required in rolling plates. Permissible variation in weights is 10% below or above normal weights given in table. The 14-in. size is lap-welded; all other larger sizes are produced by fusion welding. Large OD pipe is normally furnished with ends beveled for welding, but may be obtained with ends prepared for special couplings.

TABLE 34—DATA ON SERVICE LINE MATERIALS

Material	Type	Standard no.	Flexible	Rigid	Size range (in.)	Weight range[1] (lb/ft)	Working pressure (psi)	Comments
Asbestos-cement		AWWA C400-65 AWWA H3		√	3, 4, 6		Class 100, 150, 200	Noncorrosive; not available below 3-in.; slip coupling joints
Brass	Red seamless Regular Extra strong	ASTM B43-47		√	1/2 to 6 1/2 to 6	0.93–19.0		Long life under normal conditions; corrodes in acid soils; uses threaded coupling joints; requires gooseneck connection
Cast iron	Gray	AWWA C102		√	2, 3, 4, 6	12–30	Class 50, 100, 150, 200	Corrosion resistant when lined and coated; not available in small diameters; rigidity and short length require joints and gooseneck connection
Copper	Type K[2]	AWWA C800-55 ASTM B88-47	√		1/2 to 6	0.344–13.9		Direct connection to mains; corrosion resistant; dissolves in soft water with high CO_2 content
Galvanized iron				√	1/2 to 3			Not highly resistant to corrosion; requires threaded joints and gooseneck connection
Lead	AA (XS) AAA (XXS)	AWWA C800-50 CS 95-41	√		3/8 to 2	2.0–19.5	75 100	Direct connection mains; corrosion resistant except in soft waters with high CO_2; some tendency to creep or crack unless properly formulated
Plastics								
ABS	[3]	CS 254-63 ASTM D2282-65 USASI B72.3-67		√	1/2 to 6	0.05–2.8	40–160	All sizes not available in all types and all pressure ratings; all types will resist limited number of freeze-thaw cycles; will hold pressures up to 150–160°F. Check with manufacture for available sizes and pressure ratings
PE	[3]	CS 255-63 ASTM D7239-65 USASI B72.1-67	√	√	1/2 to 2	0.07–1.8	80–160	
PVC	[3]	CS 256-66 ASTM D2241-65 USASI B72.2-67		√	1/2 to 6	0.16–3.2	160–300	
Steel	Black or galvanized	ASTM A120-47		√	1/2 to 6	0.85–53.16	200	Available in three grades: strong, extra-strong, double extra-strong. Weight per foot range covers three grades; not resistant to corrosion unless cement-lined
	Cement-lined	Fed. Spec. WWP-406		√	1/2 to 6			
Wrought iron	Black or galvanized	ASTM A72-95 ASTM A90-39			1/2 to 6	0.85–53.16	200	Same comments apply as for steel

[1] Weight per foot varies with material, type, wall thickness, etc.
[2] Type L specified by Copper Development Association "Copper Tube Handbook."
[3] See Part 2, Section 4 of this manual.

Section 8—Service Lines

According to AWWA Manual M8,[7] "The most important factor affecting the useful life of service lines is the ability of the material used to resist internal and external corrosion." Internal corrosion, either pitting or tuberculation, adversely affects the carrying capacity of the pipe. External corrosion may result in leakage. Table 34 lists the most commonly used materials, the more important pertinent physical characteristics, and advantages and disadvantages. An AWWA Committee Report published as a part of AWWA C800-55[28] covers current standards for certain types of service line materials.

Hydraulic-flow characteristics are good on all newly installed pipe and remain so on lines of asbestos-cement, copper, lead, and plastics. More detailed information on the characteristics of asbestos-cement, cast iron, plastics, steel, and wrought iron is presented in previous sections of Part 2.

Flexible materials can be connected directly to the corporation cock in the main and to the stop-and-waste valve inside the foundation wall of the house. Nonflexible materials require a flexible "gooseneck" connection to the corporation cock and sometimes may need a flexible connection to the house plumbing system. Gooseneck connections may be lead, copper, or flexible plastic. Flexible materials are not damaged by freezing, but electrically-nonconductive materials, when frozen, cannot be thawed electrically.

Relative costs of these various materials are not compared in Table 34. Costs vary, not only with time, but also with location, point of manufacture, installation conditions, and other local factors. Inasmuch as the cost of installing service may exceed 10 percent of the total investment of a water utility, it is important to select service line materials that will provide the longest possible effective service. Selection should be made only after consideration of all data.

Section 9—Inplant Systems

As indicated in Table 8, almost every type of material used in water systems may be and is used for all types of inplant systems piping, including lines for air, chemical feed, filter influents, effluents, and wash lines, gas, heat, high and low service, plumbing, pump suction and discharge, and sampling.

Pipe materials used in inplant systems have the same design and are manufactured by the same process as materials used for distribution and service lines. With the exception of glass and rubber, these materials have been discussed in previous sections of Part 2.

Pyrex glass has been used for chlorine gas and solution lines, a notable example being the Chicago Central District Filtration Plant. These lines are rigid, and require support and special fittings. Copper is also used where flexible chlorine connections are required. Hard rubber and iron are used for conducting liquid chlorine under pressure.

Flexible rubber lines are also used to handle chlorine solutions and to transport other solutions, carbon slurries, etc.

Inplant piping systems, particularly of large size pipe used on high- and low-service lines, usually utilize flanged joints. Other types of joints may be used, depending on line size, material, and application.

WATER SYSTEMS

pipes and piping

PART 3/ INSTALLATION PRACTICES

Section 1—Transmission and Distribution

Several operations in the installation of transmission and distribution lines are the same regardless of the pipe material used. Therefore these operations will be discussed here without reference to specific materials, except as may be necessary. The American Water Works Association has issued standards for laying asbestos-cement pipe[29] and for laying cast iron pipe,[30] for rubber gaskets for cast iron pipe,[31] and for field welding of steel pipe joints.[32]

Pipe handling

All pipe receives a final inspection before shipment. Care is taken to make certain that every length leaving the manufacturing plant is in first-class condition. Damage from rough handling in transit will occur occasionally, so pipe should be inspected when it arrives or as it is being unloaded from the railroad car or truck. Rough treatment in transit is usually evident from broken tie straps or wrecked wooden blocking placed at the factory. Metal pipe can be checked for in-transit damage by "ringing" each length with a hammer. Failure to ring properly indicates damaged pipe, which should be reported to the manufacturer and rejected for use.

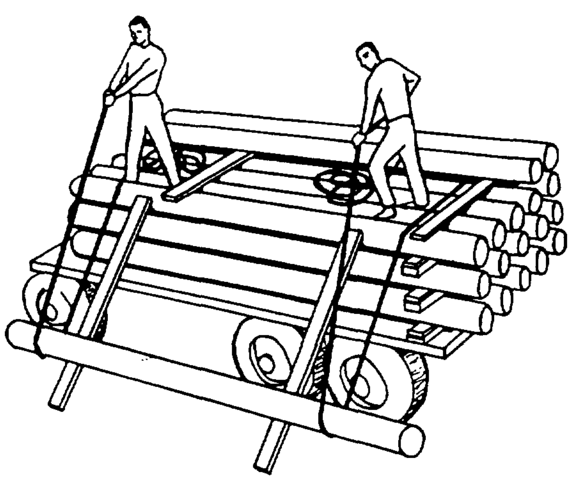

Fig. 16. Method of unloading pipe with snubbing ropes and skids.

Unloading. Handling includes unloading from the transporting vehicle (railroad car or truck). Small diameter pipe may be unloaded by derrick. Large diameter pipe should be unloaded with the aid of skids and snubbing ropes using a rolling hitch at each end (Fig. 16). Pipe unloaded on skids should never be rolled against other pipe.

When pipe is unloaded to storage, it should be stacked according to the manufacturer's directions, with the stack height controlled within the limits of safety and practicality, and with blocking as necessary. Belled-pipe is stacked with the bells at right angles in each layer. For smaller pipe diameters, the maximum number of layers is ten; for larger diameters, the maximum is less; the maximum practical stack height is 12 ft.

In the delivery of small diameter pipe to be laid by hand, the pipe lengths should be strung along the route. (Belled-pipe should have the bells facing in the direction the work is to proceed.)

The method of unloading pipe from trucks or cars may utilize a derrick and cable with hooks for engaging each pipe end. Hooks for handling lined pipe should be rubber covered. Both small and large-diameter pipe may be handled by sling, hooks, or by skids and snubbing ropes. Some types of pipe may be handled by fork-lift truck.

Stringing pipe. To avoid unnecessary handling, both pipe and fittings should be placed as near as possible to their final location in the line, with due respect to the safety of the traveling public. Pipe should be placed as close to the trench site as possible and on the side opposite that where the excavated dirt is to be piled. Asbestos-cement pipe is usually not strung along the trench line in advance of laying operations but is delivered from storage to trench site as needed.

When pipe is to be moved only a short distance, it should be rolled by hand or moved by hoist; it should never be pushed by bulldozer blade. Pipe with a special exterior coating should be handled by canvas belt sling or special cable around the middle of the pipe. Patented lifting tongs are also available for handling pipe by hoist and cable. Whenever rubber gaskets are to be used in pipe joints, they should be stored out of direct sunlight and protected from dirt until needed.

Detailed directions and precautions for handling, storing, and stringing pipe along the right-of-way may be obtained from the manufacturer or from the pipe manufacturing associations.

Trenching

Water mains are generally installed to a definite line and grade as established by the project engineer. This is particularly true where other subsurface utilities are located in the streets.

The trench itself may be dug by hand or by excavating machine. Earth trenching employs one technique, rock excavation, another. Solid rock must be blasted.

Trench depth. Generally the designing engineer specifies the trench depth or, more particularly, the depth of cover over the pipe after the trench is backfilled. The amount of cover specified usually depends on the frost line in northern states (minimum cover 5 ft) and on the surface load conditions in southern states (minimum cover 2½ to 4 ft). Sometimes the pipe is laid aboveground, as for example, the pipeline from Hollywood to Key West, Fla., long transmission mains in the west, and on bridges over water. Sometimes pipe is laid in subaqueous trenches across rivers, harbors, and lakes. Laying subaqueous lines requires special underwater excavating equipment, divers, and special laying techniques.

The trench should be as shallow as possible and still provide for frost protection and surface loading. Deep trenches are costly; they require shoring and bracing and are often wet, a situation that requires pumping. Standard pipe selection tables are based on pipe installed with a 5-ft cover, with the pipe laid on a flat-bottom trench, and with the backfill tamped to the centerline of the pipe.

Trench widths. The width of the trench should be sufficient to permit proper installation of the pipe, with room for the workmen to make up the joints and to tamp backfill under and around the pipe. Trench widths are governed by type of soil, pipe size, and excavating equipment. Most trench specifications allow the trench width to be 1 to 2 ft more than the outside pipe diameter.

For asbestos-cement pipe, the following widths are suggested.

Pipe diam. (in.)	Trench width Min. (in.)	Trench width Max. (in.)
4	18	28
6 or 8	20	32
10 or 12	24	36
14 or 16	30	42

For cast iron pipe, the suggested trench width for pipe 4 to 18 in. in diameter is the pipe diameter plus 15 in.; for pipe 20 to 60 in. in diameter, the suggested width is the pipe diameter plus 18 in.

Suggested trench widths for concrete pipe are as follows (where D is inside diameter of pipe).

Pipe diam. (in.)	Trench width Min. (in.)	Trench width Max. (in.)
16, 18, 20	D + 12	D + 22
24	D + 13	D + 23
30, 36	D + 14	D + 24
42	D + 15	D + 25
48	D + 16	D + 26

Wide trenches for small diameter pipe should be avoided, particularly in hard clay soils. The weight of backfill in a wide trench is out of proportion to the beam strength of small pipe. For example, if the specifications call for a trench width of 4 ft, and if the trench is actually 5 ft wide, the load on the pipe could increase by 56 percent. The excess load is not in direct relation to the change in the pipe diameter–trench width ratio.

Pipe laid in a curve. Where pipe is to be laid on a curve, it will utilize the available deflection characteristic of the joint. For such situations, the trench width will be somewhat wider than normal. The offset of pipe and radius of permissible curve for asbestos-cement pipe are given in Table 35, for cast iron pipe in Table 36,[33] and for concrete pipe in Table 37.

TABLE 35—OFFSET OF PIPE AND RADIUS OF PERMISSIBLE CURVE FOR ASBESTOS-CEMENT PIPE

Degree of deflection	Pipe length (ft) 3-1/4 Offset (in.)	3-1/4 Radius (ft)	6-1/2 Offset (in.)	6-1/2 Radius (ft)	13 Offset (in.)	13 Radius (ft)
1	.7	187	1.3	374	2.7	748
2	1.4	93	2.7	186	5.4	372
3	2.0	62	4.0	124	8.0	248
4	2.7	46	5.4	93	10.8	186
5	3.4	37	6.8	74	13.6	148

TABLE 36—MAXIMUM DEFLECTION FULL LENGTH CAST IRON PIPE[33]

Pipe diam (in.)	Deflec. angle (deg)	Max. deflec. (in.) for pipe lengths (ft) of 12	16	18	20	Approx. radius of curve (ft) produced by succession of joints for pipe lengths (ft) of 12	16	18	20
PUSH-ON TYPE JOINT									
2	5	12	17	19	21	140	185	205	230
2-1/4	5	12	17	19	21	140	185	205	230
3	5	12	17	19	21	140	185	205	230
4	5		17	19	21		185	205	230
6	5		17	19	21		185	205	230
8	5		17	19	21		185	205	230
10	5		17	19	21		185	205	230
12	5		17	19	21		185	205	230
14	3		10	11	12		300	340	380
16	3		10	11	12		300	340	380
18	3		10	11	12		300	340	380
20	3		10	11	12		300	340	380
24	3		10	11	12		300	340	380
30	2		6	7-1/2	8		450	510	570
36	2		6	7-1/2	8		450	510	570
42	2		6	7-1/2	8		450	510	570
48	2		6	7-1/2	8		450	510	570
MECHANICAL-JOINT PIPE									
	Bend in one joint angle (deg-min)								
3	8-18	21	28	31		85	110	125	
4	8-18	21	28	31		85	110	125	
6	7- 7	18	24	27		100	130	145	
8	5-21	13	18	20		130	170	195	
10	5-21	13	18	20		130	170	195	
12	5-21	13	18	20	22	130	170	195	220
14	3-35	9	12	13-1/2	15	190	250	285	320
16	3-35	9	12	13-1/2	15	190	250	285	320
18	3- 0	7-1/2	10	11	12	230	300	340	380
20	3- 0	7-1/2	10	11	12	230	300	340	380
24	2-23	6	8	9	10	300	400	450	500
30	2-23	6	8	9	10	300	400	450	500
36	2- 5	5	7	8	9	330	440	500	550
42	2- 0	5	6	7-1/2	8	340	450	510	570
48	2- 0	5	6	7-1/2	8	340	450	510	570

TABLE 37—DEFLECTION DATA ON CONCRETE PRESSURE PIPE[34]

	Pipe diameter (in.) 16	18	20	24	30	36	42	48
Offsets (in.)								
Pipe	0 to 5-1/4	0 to 4-1/2	0 to 4-1/4	0 to 3-1/2	0 to 2-3/4	0 to 2-1/4	0 to 2	0 to 3/4
Half-bevel			3-1/4 to 11-1/2	3-1/2 to 10-1/2	4-1/4 to 9-3/4	4-3/4 to 9-1/4	5 to 9	5-1/4 to 8-3/4
Bevel	7-3/4 to 18-1/4	9-1/4 to 18-1/2	10-1/2 to 18-3/4	10-1/2 to 17-1/2	11-1/4 to 16-3/4	11-3/4 to 16-1/2	12-1/4 to 16-1/4	12-1/2 to 16
Angles (deg)								
Pipe	0 to 1-1/2	0 to 1-1/4	0 to 1-1/4	0 to 1	0 to 3/4	0 to 3/4	0 to 1/2	0 to 1/2
Half-bevel			1 to 3-1/2	1 to 3	1-1/4 to 3	1-1/2 to 2-3/4	1-1/2 to 2-3/4	1-1/2 to 2-3/4
Bevel	2-1/4 to 5-1/2	2-3/4 to 5-1/2	3 to 5-1/2	3 to 5-1/4	3-1/4 to 5	3-1/2 to 5	3-3/4 to 4-3/4	3-3/4 to 4-3/4
Grade change (%)								
Pipe	0 to 2.7	0 to 2.4	0 to 2.2	0 to 1.8	0 to 1.5	0 to 1.2	0 to 1.1	0 to 0.9
Half-bevel			1.6 to 6.0	1.8 to 5.5	2.2 to 5.1	2.4 to 4.9	2.6 to 4.8	2.8 to 4.6
Bevel	4.0 to 9.6	4.8 to 9.6	5.4 to 9.8	5.5 to 9.1	5.8 to 8.8	6.1 to 8.5	6.3 to 8.5	6.5 to 8.3

• Deflection in any length of pipe can be obtained by opening the joint. The offsets in this table are based on a maximum joint opening of 1/2 in. on a 16-ft length. For 20-ft lengths, increase offsets by 25 percent. The long and short sides of elbows and bevel pipe are indicated by punch marks on the end of the spigot ring. Half and full bevel adapters have same deflection as beveled pipe.

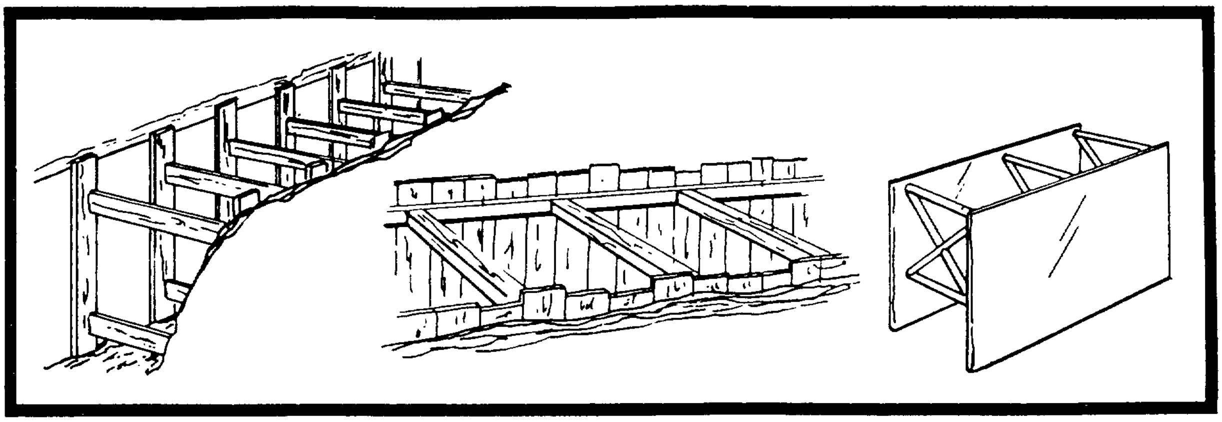

Fig. 17. Examples of trench sheeting. Left, open; center, closed; right, movable shield.

Excavation. Whether excavation is by hand or by machine, the excavated soil is piled on one side of the trench at a distance sufficiently away from the trench wall to prevent excavated material from rolling back into the trench, and also to allow room for walking along the trench. The pipe is strung out on the opposite side of the trench.

Rock excavation. The term "rock" applies to solid rock, ledge rock, and to loose boulders more than 8 in. in diameter occurring in large gravel formations. In any type of rock formation, the rock must be excavated to a level 6 in. below the grade line of the pipe bottom (see Bedding). Excavated rock should be hauled away and not used for backfill.

Bad soil. Where soil conditions are bad (e.g., coal mine debris, cinders, sulfide clays, mine tailings, factory waste, or garbage), the soil should be excavated to a depth 6 in. below the grade line for the bottom of the pipe (see Bedding). All excavated bad soil should be hauled away and not used for backfill.

Sheeting and bracing. Whether or not the sidewalls must be protected against cave-in depends on soil conditions and trench depth. This protection is accomplished by the use of sheeting and bracing (see Fig. 17), and serves not only to prevent delays in pipe laying, but also as a safety measure to protect both the workman and the public.

Many cities have established regulations for sheeting and bracing based on local soil conditions, as determined from experience.

Bedding. All types of pipe must be supported properly by the trench bottom. Pipe can be laid directly on the trench bottom if the bottom has been leveled properly. A leveling board should be used to ensure that there are no voids or high spots and that the grade is correct. Any high spots should be shaved off, and voids should be filled with well tamped soil.

For greater load-bearing ability by the pipe, the trench bottom may be hollowed out to conform to the contour of the pipe circumference. This method of bedding is used in special cases. Usually, the design engineer specifies the type of bedding, including tamped backfill (see Backfill).

Asbestos-cement pipe may be laid directly on the trench bottom or on earth pads (see Joint holes and Backfill).

Special bedding. For pipe laid in rock, bad soil, or soft or wet soil, special bedding must be provided.

In rock soil areas, the rock is excavated to a depth of 6 in. below the grade line for the bottom of the pipe. The trench bottom is then built up with a 6-in. bed of sand or good soil free of clods, placed, leveled, and tamped to grade. In bad soil areas, the material is excavated 6 in. below grade and replaced with sand or good soil.

Where soils are soft or wet, the ground may have inadequate bearing. In such areas, either crushed stone or gravel should be used to support the pipe throughout its entire length. In extreme situations, pile supports and stringers may be utilized.

Joint holes. Where pipe lengths are joined together, provision is made in the trench to allow proper jointing with the type of joint employed.

Asbestos-cement pipe joints. Where the pipe is directly on the trench bottom, a coupling hole is dug at the joint location; the hole is 3 in. deep and 6 in. longer than the coupling.

Instead of using coupling holes, the pipe may be laid on two earth pads, 12 in. wide, minimum 2 in. high, and full trench width. These pads are located 31 in. from each end of a 13-ft length, or one-fifth of the pipe length from each end for shorter pipe lengths. These pads should be made of tamped good backfill material, free of stones, lumps, or other hard material. Pipe should be firmly positioned on these pads and aligned for coupling. The space between pads is backfilled later (see Backfill).

Cast iron pipe joints. For cast iron pipe joints of the *bell and spigot* type, which are to be made up with lead calking, the trench is excavated somewhat wider and deeper at the joint location to allow room for the calker to work.

Cast iron pipe utilizing the *slip-on* type of joint requires no extra trench width but does require the trench bottom to be excavated below grade sufficient to receive the bell and to make certain that the remainder of the pipe length rests solidly on the trench bedding.

Mechanical joints require no extra trench width at the joint location and only a hole in the trench bottom sufficient to allow the bolts to be inserted and tightened.

Concrete pipe joints. Joint holes for this type of pipe must be large enough to allow for bells or couplings and for making up and mortaring the joint.

Plastic pipe joints. Bell and spigot type of plastic pipe, with O-ring gasket, requires no extra working width in the trench but does require a slightly deeper excavation at the joint locations to accept the bell.

Steel and wrought iron pipe. Pipe that is joined by welding requires no extra width or extra trench depth at the joints if the welding is done outside of the trench.

Joints

Types of available joints are discussed in some detail in Part 2, Section 2 under each type of material. The listing in Table 38 brings this information together for convenience.

Where a metal line must be maintained as an electrical conductor for cathodic protection, or where the pipe may need electrical thawing, some special provision must be made in jointed pipe installations. For example, in cast iron, lead-tipped rubber gaskets are used on mechanical joints, and conductor wedges are used at the side of the bell on push-on joints. On steel pipe, bonding cables and lugs are

TABLE 11—PIPE JOINTS AND THEIR APPLICATIONS

Pipe material	Type of joint	Application
Asbestos-cement	Coupling with rubber ring gasket	All locations
Cast iron	Push-on	General use
	Mechanical	Soft soils where settlement is anticipated, or where flexibility is required
	Bell and spigot	Only in stable soil where settlement is not excessive
	Flanged	Where valves or fittings are to be attached in vaults or above grade
	Flexible ball	River crossings
Concrete	Galvanized steel-ring, bell and spigot types or their variations, with rubber gaskets and cement fills	All locations
Plastics	Solvent weld	In small lines
	Couplings	In small lines
	Bell and spigot with rubber O-ring	In large sizes
Steel	Mechanical-type couplings	Pipes <24 in. ID especially with coal tar linings
	Welded joints	Pipes >24 in. ID with inside coatings
	Flanged joints	Where valves or fittings are to be attached
	Expansion joints (stuffing box type)	At points to relieve strain on welded joints
Wood	Woodstave collars	On machine-made pipe
Wrought iron	Welded	All locations

used at rubber-gasketed expansion joints. Welded joints do not require special provisions for electrical conductance.

Packing for bell and spigot joints on cast iron pipe may be calked lead or special rubber gaskets in push-on joints. Rubber gaskets (O-ring) are also used for asbestos-cement, concrete, some plastic pipe, and steel pipe expansion joints.

Laying pipe

A number of general directions for laying pipe apply to all types of pipe. The more important ones follow:

1. Before pipe is lowered into the trench, it should be inspected for damage and any unsatisfactory lengths rejected for use. The inside of each pipe length should be swabbed to remove loose dirt and other foreign matter.

2. If mud and surface water have been permitted to stand or flow through strung-out pipe, the inside should be swabbed with strong hypochlorite solution. All gaskets should be kept clean and dry.

3. Pipe should never be pushed off the bank or allowed to fall into the trench. Pipe up to 12-in. in diameter may be lowered by two ropes, one at each end; larger pipe must be handled by machinery.

4. Pipe that is joined by couplings may be laid in either direction, but belled-end pipe is normally laid with the bells facing in the direction in which the work progresses, except downhill, where the direction is reversed.

5. When pipelaying is not in progress, the open ends of installed pipe should be closed by appropriate means to prevent the entrance of dirt and trench water.

6. Pipe lengths should never be deflected in the joint to any greater degree than recommended by the manufacturer.

Jointing procedures. The particular method for making up pipe joints depends on the type of pipe material and type of joint.

Asbestos-cement pipe. This type of pipe is joined by a coupling with rubber ring gaskets that permit easy assembly and provide a tight seal (Fig. 7). The surfaces of the gasket are tapered to facilitate assembly of the joint. Standards for installing this type of joint appear in AWWA C603-647.[29]

To make up the joint, place rubber gaskets inside the coupling as directed by manufacturer's instructions; clean and lubricate pipe ends; place coupling on installed length; align pipe ends; insert last length into coupling, and push on free end until the joint is seated properly. Some pipe (prebelled) is furnished with a coupling already present on one end of each length.

"Pushing the pipe home" is accomplished by pressure from a crowbar against a block of wood across the free end of the pipe (Fig. 18). For large pipes, a mechanical puller device may be used. Details on the use of the puller may be obtained from the pipe manufacturer.

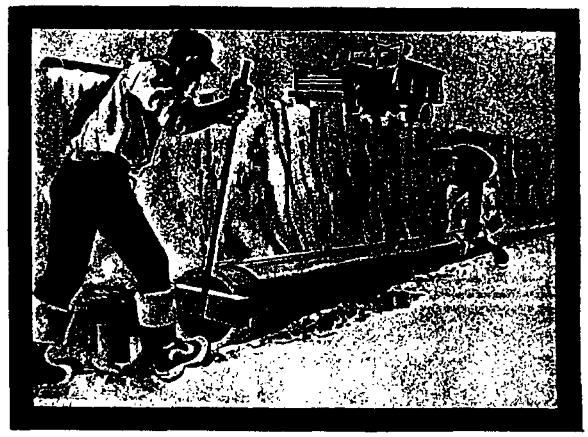

Fig. 18. Method of pushing pipe lengths together.

Cast iron pipe. The procedures for making up joints on cast iron pipelines vary with the type of joint used.

Bell and spigot joint. This joint generally uses a yarn and lead calking. As each length of pipe is placed in the trench, the spigot end of the pipe is centered in the bell and forced home. The pipe is forced home with a crowbar or mechanical jack. The procedure for making up the joint has five steps.[30]

Step 1: Bring the pipe length to correct line and grade and secure it in that position by soil tamped under the pipe, except at the bells.

Step 2: Place yarn (preferably braided) around the spigot end and push it into the bell as far as it will go. The yarn should overlap at its ends when around the pipe.

Step 3: Place a heat resistant runner around the spigot end and push it tightly against the bell face; add a pouring gate of clay at the top of the pipe.

Step 4: Pour melted lead into the pouring gate. On smaller diameter pipes, the entire pour should be from one ladle; if more than one ladle of lead is required, the interval between pourings should be as short as possible. On extremely large pipes, pouring may be done in halves. The depth of the lead joint should be at least 2¼ in. for pipes under 20-in. diam., 2½ in. for pipes 20 to 36 in.; and 3 in. for pipe diameters greater than 36 in.

Step 5: After the lead has solidified and cooled to the temperature of the pipe, compact (calk) it with either pneumatic or hand calking tools until the finished joint shows a hard and even hammered surface overall.

Cement joints may be used in place of lead, in a proportion of 1 quart of cement to ¼ pint of water. The cement is placed inside the bell and thoroughly compacted. When

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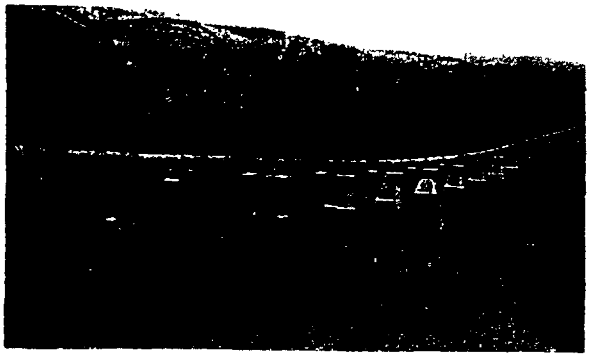

Steel pipeline installed on concrete piers above ground.

using this type of joint, six or eight pipe lengths are usually left uncovered behind the length being installed.

Mechanical joints. This type of joint consists of four parts: a flange cast as an integral part of the bell of the pipe, a rubber gasket [31] that fits a recess in the socket, a gland (follower ring) to compress the gasket, and nuts and bolts to tighten the joint. The installation steps are four in number.

Step 1: Clean the pipe ends, and paint with a soap solution.

Step 2: Place gland on spigot end with the face toward the bell; then place rubber gasket over the spigot end, with the thick edge facing the follower gland.

Step 3: Push the pipe forward to seat the spigot, and press the follower gland into place within the bell.

Step 4: Insert bolts in flange and follower gland; screw on nuts thumb tight; then tighten nuts at opposite positions using a torque wrench until all are tightened equally.

Push-on joints. This type of joint consists of a special bell cast integrally with the pipe and a special rubber gasket[31] designed to fit into a groove inside the bell. The spigot end of the pipe is beveled. The joint is put together in three steps.

Step 1: After the inside of the bell and the outside of the spigot are cleaned, the circular rubber is flexed and inserted into the gasket recess in the bell socket.

Step 2: A thin film of gasket lubricant (supplied by the manufacturer) is applied either to the inside of the gasket or to the beveled spigot end of the pipe, or to both.

Step 3: The spigot end is entered into the bell, using some care to keep it from coming into contact with any soil, and the joint is completed by forcing the plain (spigot) end to the bottom of the bell, using a forked tool, or jack-type tool. Complete detailed instructions are furnished by the pipe manufacturer.

Underwater joints. Where the installation is to be in shallow water and only small joint deflections are required, standard mechanical joint pipe is generally used. Where the water is deep and the contour of the river bed requires considerable joint deflection, a ball and socket type of joint is used. Deflections up to 15 degrees are possible.

The pipe is generally laid in a trench cut in the bottom of the stream bed. The pipe lengths may be joined on shore and the pipe pulled into the water, using buoyant barrels attached to keep the pipe off the bottom until the crossing is complete. Sometimes several lengths are assembled on land then floated to the desired location, lowered to the bottom, and joined by divers. Submarine pipelines are usually laid with joints that are provided with positive locking devices to prevent the pipe from being pulled apart. This type of pipe may also be assembled on a barge and lowered from the rear end of the barge to the bottom as the work progresses.

Concrete pipe. Concrete pipe may be of a bell and spigot or a steel joint type; both use rubber gaskets. Concrete pipe is frequently lowered into the trench by cable sling attached to the backhoe, or by cable attached to a mobile crane. There are four steps involved in making concrete pipe joints.

Step 1: After the ends of the pipe are thoroughly cleaned inside and out, the pipe length is lowered halfway into the trench, and both the spigot and bell ends are lubricated thoroughly with a vegetable soap. Where steel joints are used, they too are thoroughly cleaned with rags, a wire brush, emery cloth, or file as may be necessary, then lubricated thoroughly with a compound furnished by the manufacturer.

Step 2: When the pipe is lowered halfway into the ditch, the rubber gasket is immersed in the lubricating compound, then stretched around the spigot end, and pushed into the groove designed to receive it. Next the gasket is completely covered with lubricant.

Step 3: The pipe is then lowered to position, the spigot inserted into the bell and pushed home.

In the case of concrete pipe joints, the pipe is not pushed home until a feeler gage has indicated that the gasket is properly placed around the pipe. In large pipe, this "feeler gage" operation is done by a man inside the pipe; on pipe less than 20 in., the "feeler gage" operation is from outside the pipe.

The choice of method for "pushing the pipe home" depends on various factors: size of pipe, location, equipment available, etc.

The operation may be accomplished by manipulating the backhoe supporting the pipe by attached cable, or by crane with pulleys. In the latter case, there are three methods recommended for making the actual jointing. One consists of using a deadman three lengths back, with a cable connected through a 3-ton pull lift to a strong-back across the bell of the pipe. The second utilizes a winch anchored in a joint recess three lengths back, connected by cable to a strong-back across the bell. The third method utilizes a cable choker sling around the last pipe installed, attached by ratchet hoist to the laying sling of the pipe length being installed. Exerting the necessary tension in any of these methods will pull the pipe into final position.

Step 4: The joint is completed with a dry mix cement (1:2) inside wetted up for the outside. (Pipe lines smaller than 20-in. diam. do not require an inside mortaring as the exposed metal on these sizes has received an extra heavy zinc coating.) On large pipe sizes, the inside joint is packed with mortar and troweled smooth.

Outside joints on steel-type joints are covered with a cloth (or burlap) diaper held tightly in place by wire (or straps). Grout is poured to fill the joint on both sides of the pipe. A stiffer mix is troweled over the top of the pipe. Joints are left uncovered for several lengths back to allow for setting before backfill operations begin.

Plastic pipe. This type of pipe, being flexible or somewhat flexible, is usually joined outside the trench and lowered into the trench as the work progresses, except in the larger sizes where bell-and-spigot type joints are used.

Bell and spigot joints. This type of joint requires a three-step operation.

Step 1: Clean the bell and plain end and set the gasket ring in its depression in the bell, with the marked edge facing toward the end of the bell.

Step 2: Lubricate the plain end of the pipe.

Step 3: Push pipe end into the bell so the the reference mark on the pipe is in line with the face of the bell or is just within the bell.

Other joint types. In Part 2, Section 4, under the discussion of manufacture of plastic materials, the methods of jointing are discussed with reference to insert fittings, to flaring and compression joints for polyethylene pipe, and to solvent weld and coupling methods for PVC pipe.

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Steel and wrought iron pipe. This type of pipe is welded in the trench. Standards for equipment, welding procedures, operators joint design (butt or lap), design and procedure details, testing, etc., have been published by the American Water Works Association.[32]

Anchoring. In most pipe lines, particularly those with joints, all dead end fittings, along with bends, tees, and hydrants must be anchored to prevent movement caused by internal pressure. Various methods are used depending on the pipe material. This subject will be covered in Manual of Practice No. 4/Valves, Hydrants, and Fittings.

Fittings. Crosses, tees, ells, hydrants, and valves are installed as the pipeline is laid. Usually, they utilize joints such as have been discussed above. The subject of fittings will be covered in Manual of Practice No. 4.

Pipe under railroads. Whenever pipelines are installed under railroad tracks, it is essential that the installation be such that the pipe is protected against superimposed extra dead and impact loads. One of the most general methods used is to install a culvert pipe capable of withstanding the load and to pull the water main through this culvert by wire cable. The culvert should be at least 6 in. larger in diameter than the outside diameter of the pipe bells or couplings. Joints that provide some degree of flexibility are preferred. The space between the pipe and the culvert should not be filled. Some types of pipe may be designed to be jacked directly under the tracks. Pipe laid under highways does not require the culvert treatment.

Deflection. Many joints have an inherent ability to be deflected to some small degree, a characteristic that permits pipe to be laid on a long-radius curve. The permissible offset and deflection for different types of joints and different pipe materials are given in Tables 35, 36, and 37.

Testing

All pipelines, of whatever material, should be subjected to hydrostatic test, either by sections as completed or *in toto* after completion. Such testing is usually done after the trench has been partially backfilled.[28,30]

Asbestos-cement pipe. In asbestos-cement pipelines, leakage and pressure tests are usually made at the same time over a period of at least 1 hr. After the pipeline is completed, it is filled with water, allowed to stand 24 hr, and then subjected to hydrostatic test. The test pressure is usually 1.5 times the operating pressure, and the test is made on sections before the backfilling is completed. Allowable leakage is set by AWWA standard;[29] it ranges from 0.71 gph per 100 couplings on 4-in. pipe at 50 psi pressure to 13.5 gph per 100 couplings on 36-in. pipe at 225 psi pressure. The data in AWWA C603-64T[29] are based on a standard pressure of 150 psi and a leakage of 30 gpd per mile of pipe per inch of pipe diameter for 13-ft pipe lengths.

Cast iron pipe. The usual procedure for testing cast iron pipe is to fill each valve section of the pipeline slowly until all air is expelled, usually through corporation cocks. Then the pressure is brought up to the test level to determine if any leakage exists at joints. When joints do show evidence of leakage, they should be recalked, otherwise adjusted, or repaired as the joint-type may require.

Following observations for leaking joints, cracked pipe, etc., and when the necessary repairs have been made, a leakage test is made over a 2-hr period at the required pressure. In reference to cast iron pipe lines, leakage is defined[30] as the quantity of water that must be supplied into newly laid pipe (or any valved section) to maintain the specified leakage-test pressure in the pipeline after all air is expelled.

For cast iron pipe lines, the allowable leakage is limited by two formulas:

For mechanical and push-on joints:

$$L = \frac{ND\sqrt{P}}{3700} \qquad \text{Eq. 20A}$$

and for calked bell and spigot joints:

$$L = \frac{ND\sqrt{P}}{1850} \qquad \text{Eq. 20B}$$

where L = allowable leakage (gph)
N = number of joints in section tested
D = nominal pipe diameter (in.)
P = average test pressure (psi)

These formulas[29] are based on an allowable leakage in mechanical and push-on joints of 23.3 gpd per mile of pipe per inch diameter for 18-ft pipe lengths at a pressure of 150 psi, or a leakage of twice that amount for bell and spigot pipe of the same length under the same conditions.

Other pipe materials. Standard procedures for testing pipelines of materials other than asbestos-cement or cast iron have not yet been issued by the American Water Works Association, but it is good practice to test all pipelines for leakage regardless of pipeline material and to make certain that leakage is within acceptable limits.

Backfilling

Regardless of the type of pipe material, the proper handling of backfilling operations is important and deserves more than casual attention.

Common practice involves a two-step procedure: partial backfill before leakage tests and completed backfill after tests. The partial backfill procedure usually leaves joints exposed or covered only by a relatively shallow layer.

Whatever the pipe material or the method of backfill, the backfill material should be good soil which does not contain any rocks, bad soil, or frozen clods.

The following directions are abstracted from AWWA standards.[29,30]

Asbestos-cement pipe. Backfill material is deposited at both sides of the trench uniformly and for full trench width up to the horizontal centerline of the pipe. It is then tamped in layers 4-in. thick after compaction. The backfill material should contain sufficient moisture to permit thorough compaction under and on each side of the pipe to provide void-free support for the pipe.

Where visual inspection during leakage tests is not required, backfill is added to the depth indicated above and then a cushion of hand-placed material is added to cover the pipe to a depth of 12 in. for all pipe sizes. When visual inspection is required and joints are left exposed during leakage tests, hand-placed material is deposited to a depth of 12 in. over pipe 8-in. in diameter or less, and to a depth of 24 in. over larger pipe.

After leakage tests are completed, exposed couplings are covered with hand-placed material to a depth of 12 in. The remainder of the backfill material (no more than 25 percent stones, all less than 6-in. in diameter) is deposited in the trench by hand or by bulldozer.

If trenches are in a roadway right-of-way, the backfill is compacted to a 90 percent compaction density. Backfill in other trenches need not be tamped.

Cast-iron pipe lines. Selected backfill (i.e., sand, gravel, crushed rock, or limestone) is used only to a depth of 1 ft above the pipe, in situations requiring such material (see Bedding).

Backfilling under pipe, bells, valves, fittings, and appurtenances is done by hand from the trench bottom to the horizontal centerline of the pipe, with the fill being placed in 3-in. layers and compacted by tamping. Backfilling material is deposited in the trench to its full width on each side of the pipe.

Backfilling above the pipe centerline to a depth of 1 ft above the pipe is placed by hand or by approved mechanical methods to avoid either injury to or movement of the pipe. The type of backfill material must be suitable for local conditions.

From the point 1 ft above the pipe to the surface grade, the trench is backfilled either by hand or approved mechanical means, with backfill material suitable to the local conditions; usually this is excavated material, except in cases of rock or bad soil.

AWWA standards[30] specify details for backfilling under pavement, where settlement is important, backfilling in freezing weather, and type of selected backfill materials. Also covered are matters of removal, restoration, and maintenance of pavement surfaces, as well as cleanup after backfilling operations.

Concrete pipe. Only good soil or selected backfill material should be used. It is generally placed in 6- to 8-in. layers and tamped with curved tampers (Fig. 19) so that the fill is firmly compacted around the pipe to the springline. From this point to a depth of 12 in. above the pipe, the backfill material is shovel tamped. Above this point, the backfill material is placed in the trench by bulldozer or other mechanical equipment.

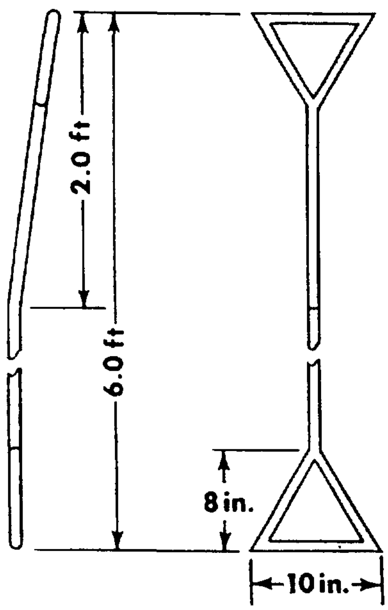

Fig. 19. Haunch hand tamping device for backfilling operations.

Other pipe materials. Similar backfilling and compaction operations are used for other types of pipe. In the case of plastic materials, the selection and placement of backfill material should be made with due consideration to the possible effect on the pipe.

Disinfection

Observations throughout the country have indicated that no single procedure for new main disinfection has been universally satisfactory. The procedure presented in brief here is based on the one set forth in AWWA Standard C601-54,[34] as it was adapted in BIF Industries Keep Sheet 12A.[35]

Contamination sources. Water pipe lying on the ground before installation is subject to contamination, and there is also a strong possibility of contamination while the line is being made up. Undesirable bacteria may be in the trench soil, and contaminated trench water may find its way into the open end of a pipe.

In pipelaying, the interior of pipes should be kept free from foreign matter and swabbed with an effective bactericide; open ends should be blocked to prevent trench water from entering pipe.

Joint packing materials (in order of preference) are: solid molded or tubular rubber rings, asbestos rope, treated paper rope, and braided cotton.

Preliminary flushing. Flushing a main prior to disinfection is desirable to remove foreign material from new or repaired mains. Flushing should be done after the pressure test at a minimum flushing velocity of 2.5 fps. Actual practice has shown that a velocity of approximately 3 fps is required for scouring.

The chart in BIF Industries Keep Sheet 12A[35] reveals the volume of water (in gallons per linear foot) required to fill various pipe sizes. From these values, the bleed rate to obtain a flushing velocity of 3 fps can be determined. For example, for a 24-in. main, each foot of length contains 23.5 gal. For a minimum velocity of 3 fps, the flow must be at least $23.5 \times 3 = 70.5$ gps or 42.30 gpm.

Disinfectant. The following disinfectants may be used on pipe: chlorine or chlorine water; calcium hypochlorite (HTH, Perchloron, Pittchlor, etc.); sodium hypochlorite solution; or chlorinated lime-water mixture.

Application point. Chlorine should be applied at one extremity of a pipe section and bled at the opposite extremity of a properly segregated section. Precautions must be taken to prevent dosed water from flowing into the potable water supply.

Chemicals are injected through corporation cock or capcock inserted in line for that purpose. All high points on section treated should be properly vented for air escape.

Chlorine dose. The chlorine requirement depends on the degree of contamination, type of packing used, and pH of water. These factors must be all considered in deciding on the dose. The rate of application should give a uniform dose of at least 25 mg per L at the end of section being treated. Higher chlorine dosages may be required.

Contact period. The average disinfecting period should be 24 hr and should produce no less than 10 mg per L at the end of the line after the retention period. If unfavorable or unsanitary conditions of installation, poor packing, or high pH exist, the period may need to be extended to 48 or 72 hr. If shorter retention periods must be used, the chlorine concentration must be increased to 50 or 100 mg per L. Experience dictates requirements.

The rate of final removal of chlorinated water is not important, but the line should be bled until the chlorine residual approaches that normally carried. The efficiency of disinfection should be checked by bacteriological tests wherever possible.

Calculations involved. Uniform application of the disinfecting solution involves the calculation of the capacity of the pipeline, using the pipe size and length of line to be sterilized. The amount of hypochlorite required is determined from the selected chlorine dosage, the available chlorine content of the hypochlorite solution, and the bleed rate. It is necessary to know the duration of the bleed-off period so that the chlorine dosage may be carried to the extremity of the line.

To accomplish constant bleed rate, an open nozzle discharge (calculated from formulas) may be used, or a Rate Setter, with flow reading in gpm, may be attached to a hydrant. The chart in Keep Sheet 12A is useful in making all of these calculations. An example on the chart shows steps for its use.

Equipment. Three factors govern the selection of equipment for main disinfection: the line pressure involved; the amount of chlorine compound to be fed; and the method of operating the feeding unit. These factors are considered in some detail in BIF Keep Sheet 12A.[35]

Repetition of procedure. If this procedure does not effect a thorough disinfection of the line, the operation should be repeated, or a residual chlorine content of 0.4 mg per L should be maintained in the main for a period of 20 to 30 days after it is put into operation.

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Tunneling mole for service line installation.

Section 2—Service Lines

Components of a customer's service line include a connection to the main (corporation cock), curb cock or turn-off valve, and the line itself.

The installation of service lines is usually done during the early construction period of the structure to be served. Generally, the service tap to the main is made at the same time, although some utilities have installed corporation cocks when the mains are laid (see discussion in Part 1, Section 3).

Determination of the size of the service (Part 1, Section 3) and selection of the materials (Part 2, Section 8) precede the installation operations. These operations consist of trenching, main tapping, laying the line, installing the valves, and backfilling.

Equipment

Every utility should have one or more trucks equipped with tools and materials for making service line installations. The truck should contain all necessary tools for trenching and installing the line and its appurtenances, as well as safety barricades and emergency items. In addition, it should contain service line pipe and appurtenances. The number of trucks needed depends on the size of the utility and the number of installations to be made in a normal work day. The size of the work crew will depend on the number of installations to be made and the extent of the work involved. This latter factor depends on whether or not the utility installs the line only to the property line or curb box and valve or to the premises.

The number of men needed for an installing crew depends on the extent of the work involved in each installation, but the minimum number should include a foreman, one skilled workmen for making the taps, plus unskilled laborers as needed. Some utilities maintain a separate truck and crew for installing services larger than 3 in.

Trenching

The depth at which service lines are laid is important. If too deep, the installation is too expensive; if too shallow, the line will be subject to freezing in cold climate areas.

The trench may be dug by hand or by small backhoe. When dug by hand, the width must be sufficient to accommodate the digger. Trenches dug by backhoe may be narrower, except at the location of the curb box and tap. At these points, the excavated area must be sufficiently large to permit workmen to carry out the task of making up the necessary connections.

The trench bottom should be relatively flat and on the grade necessary. Special bedding is not required unless the soil is corrosive in nature and the pipe is not corrosion resistant.

Where the service line connection must be made under a pavement, it is necessary to remove the pavement and replace it after the installation is completed.

Tunneling for installing service lines is possible with a pneumatic underground piercing tool. The missile-shaped device is 45 in. long and has a bit in the nose; it is powered by compressed air. It will pierce holes up to 5⅞ in. diam. for distances up to 100 ft. In operation, the device is moved through the soil by rapid hammer blows from an internal piston operating against the bit. The forward movement of the tool may be as much as 4 fpm in sandy soils, or as little as 1 in. per min in hard cemented soils. The use of this device requires only two holes to be dug, one at each end of the line, each hole large enough for a workman to operate the tool.

If the service line to be installed is of flexible material, the flexible service line itself may be used to carry air to the tool. As the tool moves forward, it pulls the service line with it, and when the hole is complete, the line is already in place. Shale and small stones do not alter the line of movement of the tool, but large rocks will deflect or stop it, requiring that an opening be dug at that point and the tool redirected on its course.

Tapping

Methods for making service line connections to mains vary depending on the service line size and material and the main size and material. Where the size and the wall thickness of the main are sufficient to provide adequate full threads for the corporation cock, service lines of ¾ in. are connected to the main by direct drilling, tapping, and insertion of the corporation cock into the main. If the main is under pressure, the tapping, drilling, and insertion operation is done with a special tapping device. This operation is known as a wet tap.

In multiple tappings for a single line, the taps should be spaced 10 in. apart and staggered around the pipe to avoid weakening it. Most utilities usually install single taps at a point 45 degrees above the horizontal center line of the pipe and on the side of the main nearest the premises to be served. Some utilities, however, install taps on top of or at the side of the pipe, and some at 22½ degrees above horizontal.

If the pipe wall is too thin for direct tapping or will not provide the required number of full threads, service clamps are used. In such cases, drilling is done through a corporation cock that has been screwed into the service clamp.

Tees, wyes, or special branch connections are used for connecting larger service lines, and larger drilling machines are used to drill through tapping sleeves and valves for making lateral or branch connections to mains in service.

This whole subject of valves, fittings, and their installation will be covered in detail in Manual of Practice No. 4 on valves, hydrants, and fittings.

Laying and backfilling

Installing the pipe involves not only the laying of the pipe line, but the installation and connection of the curb cock and valve box at the property line, and the connection of the line to the corporation cock and sometimes to the shutoff valve or meter at the premises. Where outside meters are set, the operation is frequently done as a part of the service line installation operation.

When the service line material is not flexible, a flexible gooseneck connection is made from the corporation cock to the curb shutoff valve, and, if necessary, from the line to the house shutoff valve or meter. The flexible gooseneck may be of lead, copper, or plastic.

The line itself should be laid on the trench bottom or snaked through the tunnel, as the case may be, with consideration given to prevention of kinds or bends. When the final connections are made, the installation should be tested under pressure.

Backfilling of trenches may be done by hand or by machine. In either case, large stones or boulders should not be placed directly on the line. Backfilling without tamping is usually done to some reasonable level above grade to allow for settlement. Backfill in areas to be paved should be tamped to at least 90 percent of the compaction value of surrounding areas, then allowed to stand with temporary pavement for at least 3 months before permanent pavement is replaced. Restrictions on and specifications for excavating, backfilling, and resurfacing paved areas are usually set forth explicitly by the utility or in contracts a utility may make with an independent contractor.

Section 3—Inplant Systems

Inplant piping systems are usually installed by the contractor during the construction of the facility, but additions to or revisions of installed lines may be done by utility personnel.

As indicated earlier, most large cast iron lines in plants utilize flange-type joints. Steel and wrought iron lines may be welded, or flange joints may be used where connections are made to equipment that is removable for maintenance and repair. Asbestos-cement pipelines utilize regular couplings or special fittings. Concrete pipelines are assembled in the same manner as in the field, except where connections are made to pumps, for example.

Small pipelines are usually joined by couplings or unions where the pipe has to be broken for removal or for removal of attached equipment. Plastic pipe is joined in the same manner as previously described. Rubber hose is connected through inside fittings, and glass through special joints.

Pipelines that are small or do not have sufficient rigidity to support themselves over the span of their length must be supported by hangers from above or below, by concrete blocks or pillars, or by metal pipe supports.

Pipelines installed in plant facilities should be painted and color-coded at the time of installation (see Part 1, Section 4).

water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

WATER SYSTEMS

pipes and piping

PART 4/ MAINTENANCE

Maintenance and repair procedures on pipelines are performed only when necessary to prolong the life of the line and to maintain its carrying capacity. In essence, this means to prevent or remedy deterioration effects on both the outside and inside of the pipe and to repair structural failure or leaks in the pipe system.

Deterioration effects result from the corrosive or erosive action of water inside and of soil moisture outside. The cause and nature of this corrosive action is a subject for a future Manual of Practice in this series and therefore will not be discussed here.

It is sufficient, for the purpose of this manual, to recognize that metals, concrete, and asbestos-cement all may be subjected to deleterious conditions, both inside and outside, and that, under some circumstances, these conditions may adversely affect the life and carrying capacity of the pipe. Pipelines constructed from any of these materials also may be subject to failure or leaks, under some circumstances, especially if the line has not been laid properly, or if joints are improperly made.

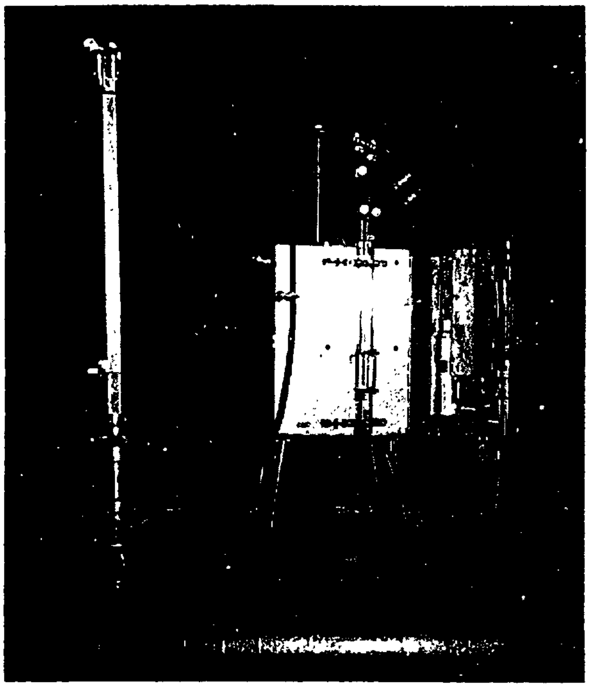
If a pipe should deteriorate or if the line should leak or fail, maintenance procedures are in order.

Various techniques to prevent corrosion and its adverse effects are used in modern pipe manufacture. These methods include coating and lining the pipe, curing, etc. These various methods have been discussed in some detail in the sections dealing with pipe manufacture in Part 2.

The performance of a transmission or distribution system depends on the ability of the pipe to resist unfavorable conditions and to operate at or near the capacity and efficiency that existed when the pipe was laid. This performance is checked in several ways: measurement of flow, fire flow tests, loss of head tests, pressure tests, simultaneous flow and pressure tests, and tests for leakage. These tests are carried out as a part of operation, and therefore, the details of the methods will be covered in a Manual of Practice on the distribution system. However, the results of some of these tests, particularly those related to leakage losses and loss of carrying capacity, are important to maintenance operations and will be covered here.

In general, the subject of maintenance as presented here is limited to a discussion of leakage, loss of carrying capacity, pipeline cleaning, lining mains in place, main break repair, cathodic protection, service line cleaning, and thawing of frozen pipelines. Maintenance of inplant piping systems is usually confined to external painting or the renewal of color-coding. Inplant line cleaning or repair, when necessary, generally can be done by the same methods as discussed in the following sections.

The cutting of pipe and the insertion or installation of valves, hydrants, or branches will be covered in Manual of Practice No. 4/Valves, Hydrants, and Fittings.



Pitometer unit for leak survey.

Section 1—Pipeline Leakage

Distribution mains and transmission lines are generally buried, and it is therefore not possible to carry out a comprehensive and systematic checking on any routine basis. One way to minimize incipient failures or deficiencies is to keep records of leakage and breakage observations; another way is to make pressure, flow, and pipe coefficient surveys on a more or less regular basis. A third approach is to have the employees in the field (installation and distribution crews, meter readers, and servicemen) note and report any unusual conditions related to pipe failure or leaks.

Whenever the amount of water pumped into a system is more than the quantity sold, as indicated by customers' meters, or by main line metering, then there is either leakage on the system or incorrect registration by the meters. Generally, nonrevenue or unaccounted-for water is a result of both factors. Meter repair and maintenance are not a part of piping system maintenance, but pipeline repair is.

Leak surveys

Leak surveys are essential to the location of wasted water. The importance of finding leaks is greater where main pressures are high because a system pressure of 100 psi results in more leakage than a pressure of 50 psi.

Pitometer surveys. The most effective method of locating leaks in a distribution system is a survey utilizing pitometer measurements to determine flows. These surveys are usually made at night, at times of minimum flow, with observations being made in sequential areas. Usually, most of the valves in the area are closed so that the water entering the area will come from one line only. A pitometer is inserted into this line, and the flow determined. If the flow is greater than should be expected for that area at that time of day, the area is divided into sub-areas, and pitometer flow measurements are made in each. In this manner, the location of the leak is narrowed to a small area.

Once the area of the leak is determined, the location of the actual leak is necessary before repairs can be made. Finding the leak itself may involve a number of different approaches, including the following: house to house inspection, observation of ground surface for wet spots, observation of sewer flows in the vicinity, sounding rods, study of the hydraulic grade line by pressure tests along the line, listening for sounds of running water by means of electronic sound amplification or sonoscope (aquaphone, geophone, or detectophone).

Leak repair

Having located the leak, the next step is to uncover the pipe and make the necessary repairs. Maintenance crews for this work need a truck and such tools, instruments, and communication and repair equipment as may be necessary to make the excavation and perform the repair operation. It is frequently necessary to utilize a dewatering pump to make it possible to work around the pipe.

Repair equipment and material used will depend on the type of leak. For example, joint leaks in calked bell and spigot joints can be recalked. Sometimes lead yarn is used. Sometimes new gaskets are driven into joints. In some cases, it may be necessary to shut off the line, remove the joint, and replace it. The type of pipe and joint will dictate the repair method.

If the pipe is cracked or has failed for any of the possible causes, it is usually necessary to shut off the line and remove the damaged section. A whole length may be removed and replaced, or the damaged section of a single pipe length may be cut out and replaced by an insert. Various types of tools and saws for cutting through the pipe are available. The design and operation of these cutting devices depend on the material to be cut.

Whether a whole pipe length or a short section is replaced, the operation should be performed with as much care as is used in installing new pipelines, and the equipment and materials used should be made for that specific purpose.

Splits or cracks in pipe or leaks through the pipe wall caused by corrosive pitting may also be repaired by cutting out the affected section, or they may be more simply repaired by the use of special repair sleeves. These sleeves come in various sizes and lengths and are simply placed around the pipe and tightened to produce an effective repair.

Leaks around valve stems are repaired by repacking the stem. Broken or damaged corporation cocks and service lines are replaced.

After the repair is made, the excavated hole is backfilled. Backfilling operations should receive the same attention as in installation of new pipelines. When paving has been cut, the process of repaving should be the same as used after installing new pipelines.

Before the repaired pipeline is placed back in service, it should be disinfected, using the same procedure as for disinfecting new lines. It is not usually necessary, however, to maintain any extra chlorine residual in the line after the disinfecting water has been bled off.

Value of leak repair. The effectiveness of such leak surveys and repairs is exemplified by this tabulation of results found in a large Midwestern city.

Location	Number of leaks	Leakage (gpd)
Service	146	1,728,000
Abandoned service	14	830,000
Main	32	2,502,000
Hydrant	22	248,000
Valve packing	6	67,000
Meter	43	154,000

It is not economically feasible to locate and repair all leaks. A rule of thumb regarding leak surveying of any area is that there is little likelihood of water waste when the night consumption rate of an area is less than 50 percent of its average daily use.

In the city cited above, nonrevenue water was reduced from 19.6 to 8.3 percent. That city also established the value of 3000 gpd per mile of main as the level below which it costs more to locate and repair the leak than to allow it to exist. Another value for this minimum has been stated as 250 gpd per inch diameter per mile of pipe. On this basis, the above minimum value of 3000 gpd would be for an average main size of 12 in.

Section 2—Loss of Carrying Capacity

Decreases in the carrying capacity of pipelines result from increased friction in the system, caused by roughness of the interior walls of the pipe, or from a decrease in the effective inside diameter of the pipe, or from both factors. Friction increases when the internal surface of the pipe becomes rough because of corrosion, pitting, tuberculation, deposits of sediment, or slime growths. In addition to causing rough or uneven surfaces, tuberculation, deposits, and slime growths reduce the internal diameter of the pipe. Tuberculation, that is, the growth of conelike barnacles, is limited to unlined metals of ferrous composition, but all other pipeline materials are subject to corrosion (or erosion), pitting, deposits, and slime growths.

Coefficient tests

The method used to determine loss of carrying capacity is generally called a flow coefficient test or C-value test. In this test, a section of the distribution system is isolated, and branch lines are shut off, so that no water can be withdrawn by consumers. A pitometer is inserted into each end of the isolated section, and pressure values at each end are recorded over a period of time, either under normal or induced-flow conditions. The difference between the pressure values at the two locations is a measure of the loss of head. From values for the slope of the pipeline, velocity of flow as indicated by the pitometer readings, and pipe diameter, the flow coefficient (C-value) is calculated. Any appreciable drop from the value for the pipe when new or from a previous observation indicates loss of carrying capacity and, therefore, a need to remedy the situation.

Remedies

Means for remedying loss of carrying capacity include operating procedures, or the use of special mechanical procedures for improving the internal surface of the pipe.

Operating procedures. Methods for improving carrying capacity by operating procedures are characterized as physical or chemical. The physical method involves line flushing to remove sediments and sometimes slimes. The chemical methods have one of two purposes: to prevent slimes or to prevent corrosive action.

Flushing. Flushing is accomplished simply by opening a fire hydrant at the end of a line or on a line and allowing the water to discharge freely until it runs clear. Greater flows through the line with fewer customer complaints can be achieved if the flushing is done late at night. Higher pumping pressures and/or the shutting-off of branch lines will increase the effectivness of the flushing operation. Unplanned main flushing may occur when hydrants are opened for fire-fighting purposes.

Chemical treatment. Chemicals may be added at the treatment plant to prevent loss of carrying capacity. The choice of chemical treatment depends on the desired effect.

Slime control. When loss of carrying capacity is caused by slime growths in pipelines, the use of chlorine or ammonia-chlorine treatment may be quite effective. The amounts of the chemicals added, point of application, and residual control are all matters of operation and relate to the particular situation and local conditions.

Control of aggressive water. Another operating treatment is the control of the aggressive characteristic of the water, either by pH control or by the maintenance of a positive calcium carbonate index. The addition of a hydroxide compound to react with carbon dioxide will increase the pH to a level that is not deleterious to pipe materials. Passage of highly carbonated water over limestone beds is also effective. The maintenance of a small excess of colloidal calcium carbonate will provide for a deposition of calcium carbonate on the interior surface of the pipe and protect against attack.

Glassy phosphates. The addition of sodium hexametaphosphate or sodium-zinc hexametaphosphates in small quantities is an effective means for combatting "red water," which is caused by attack on ferrous metal pipes. The amounts used (dosages of 2 to 4 mg per L), the point of application, control, etc., are all matters of operation.

Section 3—Cleaning and Lining

The process of removing corrosion deposits and slimes from the inside of pipelines by mechanical means is known simply as cleaning. The process of placing a protective coating on the inside of a pipeline that has been cleaned is termed lining, or lining-in-place.

Cleaning

Three basic techniques are used for in-place pipeline cleaning; these are drag, hydraulic, and mechanical. The choice of method depends on these factors: pipe diameter, water volume and pressure available, length of pipe to be cleaned, amount of encrustation or sediment, ease of access, distance between access points, provisions for disposal of wastewater from cleaning operations, and other local conditions.

Cleaning without lining is effective, but there can be no assurance that the pipe's carrying capacity will remain at its improved level for very long because cleaning does not remove the causes of pipeline deterioration. Cleaning alone is an expensive means of maintaining carrying capacity.

Drag cleaning. This method of cleaning is usually limited to pipe diameters of 4 to 24 in. The cleaning equipment is pulled through an out-of-service line by a power winch. Normal service may be maintained by a temporary bypass line.

Scraper tool for main cleaning.

Drag cleaning utilizes a spring-steel cleaning tool that is composed of a series of scrapers, followed by an assembly of tight-fitting squeegees. As the tool moves through the line, accumulated deposits are loosened by the scrapers, and then mechanically removed by the squeegees. The separate drag operations are repeated until the pipe wall is clean. Access openings are made in the pipeline at intervals of 300 to 500 ft, depending on pipe size, line configuration, and condition of pipe.

Hydraulic cleaning. This method of cleaning is most practical in long, comparatively straight runs of transmission or arterial mains. The method requires an adequate supply of water at a given pressure. The volume of water available and the required pressure depend on pipe size. The greater the volume of water available the lower the pressure required.

The tool used in the hydraulic cleaning process consists of spring scrapers so arranged that part of the water pushing the tool is released through it to flush the scrapings and debris ahead of it. The tool usually travels at a rate of 50 to 100 fpm. The travel speed is controlled by regulating the rate of discharge of wastewater at the end of the pipe run being cleaned.

The operation begins by cutting out a section of the pipe, inserting the tool, replacing the removed section, and making up the joints. At the discharge end of the run, a cut is made into the pipe and a special line attached to discharge the wastewater and debris above ground for ultimate disposal to sewers, storm drains, or acceptable runoff areas. If the tool cannot be discharged through the discharge line, it is stopped in the main and a cut is made in the pipe to remove it. Hydraulic cleaning is relatively rapid, effective, and economical.

Mechanical cleaning. In pipelines greater than 30 in. in diameter, hydraulic cleaning becomes less practical, and mechanical cleaning is used. Mechanical cleaning is accomplished by an electrically-driven and manually-operated machine with rotating scraping blades, which remove tuberculation, debris, and existing coatings by a honing action. These machines are driven by an operator who actually observes and controls the entire cleaning operation.

Lining

Lining of the pipe in place after the line is cleaned not only prevents recurrence of the internal surface deterioration, but also eliminates red water and stops leakage. There are three methods of applying cement-mortar linings to pipelines in place: centrifugal method, reinforced centrifugal method, and mandrel process. Prior to the lining process, the pipeline is cleaned by one of the methods outlined above.

Centrifugal process. After the pipe has been cleaned, access openings are cut every 500 to 700 ft (less in small pipes where bends occur). Bends cannot be negotiated in 4-, 6-, or 8-in. pipe sizes. After placement, the lining in these diameters may be troweled; in sizes above 10-in. diam., troweling is always done to provide a smoother finish and the extra carrying capacity that results.

The field equipment for centrifugal lining includes a variable speed winch for pulling the lining machine with its mortar hose and electric cable through the pipe; an electric generator to supply power to the winch and to the revolving head that dispenses the mortar; a specially-designed mortar mixer of the capacity needed to ensure ample mixing time; and a feeder to pump the mortar to the lining machine.

The lining material is usually a 1:2 portland cement mortar, and the volume of mortar applied to the wall is controlled by the travel speed of the machine. A lining thickness of 3/16 to 1/4 in. is common on cast iron pipelines, but it may be as little as 1/8 in. The thinner the lining, the smaller the reduction of the original cross-sectional area of the pipe. Fig. 20 is a diagram of the lining. Thin coatings may be sufficient in smaller pipelines. The thickness of lining for steel pipe lines depends on age, plate thickness, and condition of the metal.

In large mains that contain few service taps or lateral connections, all openings are plugged prior to lining and opened after lining by men working in the pipe. In lines under 16-in. diam., where men cannot work, very little mortar is thrown into lateral openings, and any obstruction at the corporation cock is removed by blowing out the service line before the mortar sets completely.

Small mains tapped for service lines are usually bypassed by a temporary aboveground line to maintain customer service.

The cost of centrifugal in-place lining depends on a number of factors, principally: pipe diameter, pipe length, condition of the line, plan and profile of the line, bends, location and type of valves, length of section that can be removed from service during the operation, bypass requirements, depth and type of soil cover, access, and traffic problems. The greater the length that can be lined at one

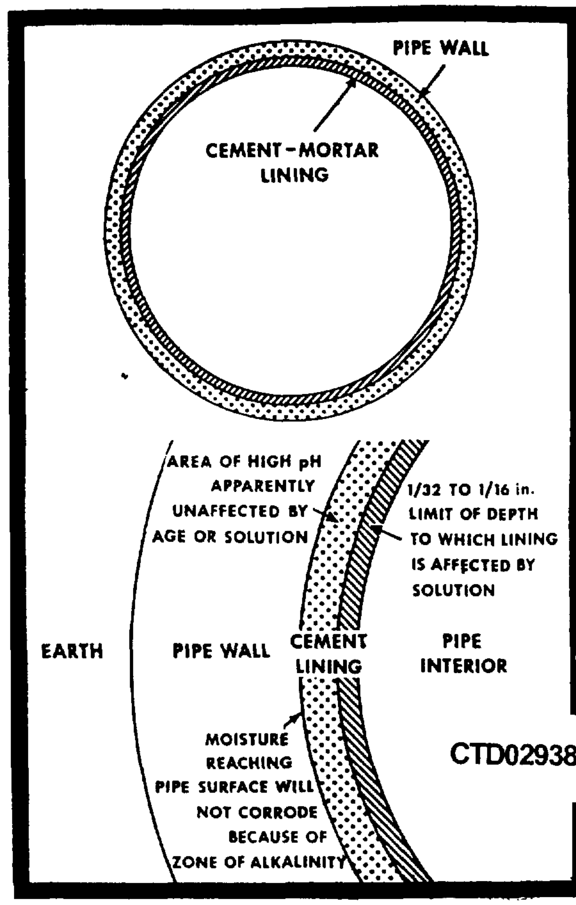


Fig. 20. Diagrams of cement-mortar linings; above, the inherent arch action, and below, the zone of alkalinity in the lining.

time, the greater the production rate and the lower the cost.

Centrifugal in-place lining is applicable to pipe sizes up to 144 in. One of its advantages is that the line can be placed in service 24 hr after the lining process. The effectiveness of this type of lining after cleaning is shown in Fig. 21. The process has also been used on newly-installed steel pipelines.

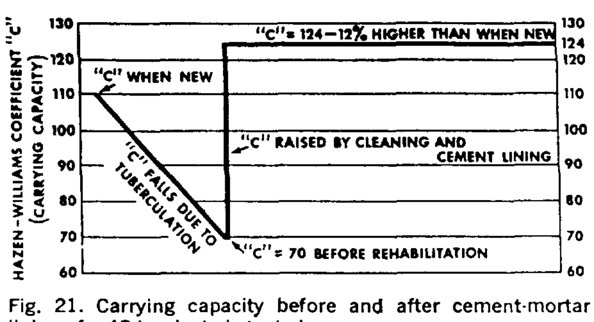
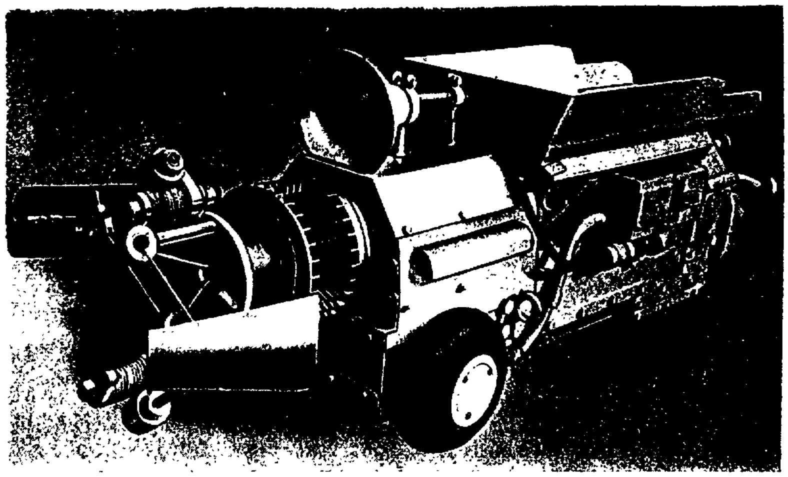


Fig. 21. Carrying capacity before and after cement-mortar lining of a 48-in. riveted steel pipe.

Reinforced lining. When pipelines of 24-in. or greater diameter are badly deteriorated, it may be desirable to reinforce the cement-mortar lining. This reinforcing process consists of three steps: first, a course of mortar one-half the final lining thickness is placed by centrifugal machine, without troweling. Next, spirally-wound reinforcing rod is placed. (The rod spacing depends on pipe size and strength requirements of the equivalent steel area. The size of the rod varies with the size of the pipe and the required reinforcing.) After the steel rod is placed, a second course of mortar is spun into place to the final desired thickness. The spiral rod has two advantages over prefabricated cage steel:



Machine for cement-mortar lining of mains in place.

it requires less steel, and it conforms to the inside contour of the line.

Mandrel process. The mandrel process, commonly called the Tate process after its Australian inventor, is applicable to lines from 4 to 16 in. in diameter containing relatively few service connections or laterals.

The process uses a pressurized extrusion technique, which can be described briefly as follows: after cleaning, a tight-fitting baffle is threaded onto a cable in the pipeline; a two-part sand, one-part cement mortar mix is loaded into the pipe against the baffle; and a conically-shaped mandrel is then secured to the cable. The mandrel is composed of centering springs, metering springs, a perforated skirt, and a troweling edge.

The assembly is pulled through the pipe, usually for distances of 350 to 450 ft. Back-pressure of the baffle forces the mortar over the cone of the mandrel and against the pipe wall. The perforated skirt squeezes out excess moisture, and the troweling edge produces a smooth, dense coating. Because of the pressure created during the lining process, existing side lines must be removed or plugged.

Section 4—Cathodic Protection

This type of protection against pipe deterioration is not economical or feasible to use for protecting a distribution system, but it may be useful on long transmission lines.

The economic considerations that enter into any justification of the use of cathodic protection of pipelines include the following: service life of line, importance of uninterrupted service, costs and hazards of leaks or failures, availability of repair crews, comparison of coating methods with cathodic protection, and probable cost of adding protection after construction. There are two cathodic protection systems: galvanic (or sacrificial) anode and applied potential.

In the galvanic system, use is made of the preferential solution potential of metals in the electromotive-force series. This system uses no external power but employs magnesium, zinc, or aluminum anodes. This type of system is particularly applicable where the current requirements are small, as in coated pipelines, or where no external source of electrical energy is available.

In the applied-potential system, an external source of power is necessary to impress the required potential onto the line. This system uses graphite, carbon, steel, iron, or aluminum anodes. The system also requires power convertor devices.

Pipelines to be protected by cathodic protection must be insulated from all other sections of the system, and they must provide continuous electrical connection from one section to another, as mentioned in Part 3 on installation.

The design of cathodic protection systems will be discussed in a manual on corrosion.

Section 5—Thawing and Cleaning Services

Where pipelines or services do not have sufficient cover to prevent freezing, it is often necessary to thaw the lines. This practice is generally confined to service lines, but may be applied to mains of relatively small diameter. There are two methods, electrical and steam thawing.

Electrical thawing is only applicable in metal lines capable of carrying an electrical current. Steam thawing is slow and most useful only on metal lines where insulating material in the pipe joints makes it impossible for the line to conduct electricity.

Thawing services

Electrical thawing is quick and relatively inexpensive. It requires a source of current (a d-c generator, such as a welding outfit, or a transformer connected to an a-c outlet) and two insulated wires connecting the current source and the pipe at points that define the frozen section. As current flows through the pipe, heat is generated, and the ice begins to melt at the wall. When the water starts to flow, the rest of the ice is melted by the flowing water. Services are usually thawed with 50 v or less; mains (600 ft maximum length) with 100 v.

The detailed procedures, which involve current and voltage control, time, precautions, personnel, etc., are matters of operation rather than maintenance and will be covered in a manual on distribution system management and operation.

Cleaning services

Under some conditions, service lines may become encrusted with calcium carbonate deposits or partially plugged by sediment.

Cleaning may be accomplished by dragging or pushing a scraper through the lines. These scrapers consist of cutting knives and brushes on a cable that is twisted as it progresses forward. Power twisting is most effective.

Carbonate encrustation may be removed by treatment with inhibited muriatic acid, which also will attack rust but not the pipeline itself. Two percent of aniline oil in a 5 percent solution of muriatic acid is effective. The line must be thoroughly flushed after cleaning.

Service line "shooting" with compressed air may be used to blow out sediment. An air compressor with reservoir tank is attached at the house, and the line is exposed at the corporation cock or shut off valve so that waste may be discharged freely to the air. Compressed air under 90 or 100 psi pressure is used to force the water out of the line. The air pressure is released into the line suddenly. When air exits from the open end of the line, the line is refilled with water and flushed, then the operation repeated until the flushing water flows clean.

Author's Note

In many places in this manual, it has been stated that certain subjects, related to the discussion at hand, were matters of operation that would be covered in subsequent manuals in this series. In a project of this type, limitations of page space available dictate the extent of coverage of any one manual. The reader may disagree with the organization of the material and the selection of material to be included in the several manuals. It is hoped, however, that as future manuals are published, the reasons for the content of each will be apparent, and a maximum overall usefulness of each will be attained.

ACKNOWLEDGMENT

For the preparation of this manual, the author has drawn heavily on both manuals and standards published by the American Water Works Association, as well as on source material and illustrations supplied by associations of pipe manufacturers and by individual pipe-producing companies.

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Palmer Brown, manager—pipe products, Visqueen Div., Ethyl Corp.
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LIST OF TABLES

Corrosion

CertainTeed

Technical Bulletin

TO: W. A. Krivsky
All P&PG Group Officers
All A/C Marketing Personnel
All District Sales Managers
All Territory Managers
All Field Service Managers
All Sales Engineers
All A/C Plant Managers
Technical Service People
Director of Communications

FR: J. F. Baker/ba JFB

RE: FUNDAMENTALS OF CORROSION

DATE: 6/12/78

Attached is a paper written by Roman Korobij on the basic fundamentals of corrosion of metallic pipe.

A complete understanding of the principal of corrosion is a necessity if we hope to compete with metal pipe in the marketplace.

Your attention is particularly directed to the explanation of Galvanic Corrosion detailed in paragraph IV. Please study this until it is clearly understood, then familarize yourself with the resistivity levels outlined in paragraph VI-5. Those resistivity levels are widely recognized in the industry and the iron people use them to analyze soil for customers to advise them when the polyethylene bag on iron pipe is required.

After you are conversant with this bulletin, make a call on the corrosion engineers for the gas company or power company providing service to your potential "Target City". He will be able to give you facts about the resistivity of the soil in your "Target City" and arm you with facts to refute the iron people's claim.

CTD029386

Cost Effectiveness

Case History

CertainTeed

The Product:
A/C Water Pipe
The Location:
San Antonio, Texas
The Issue:
Corrosion

San Antonio, tenth largest city in the United States, found that metallic water pipe corroded disastrously in soil characterized by low resistivity and that, by converting to A/C, its soaring maintenance costs could be cut in half.

The Situation

The corrosive effect of San Antonio's low soil resistivity on metallic water pipe was widely publicized during the 1960's. (See attached reprint from the April, 1961 issue of Southwest Water Works Journal). This report is an update on what has happened to the San Antonio water system over the past 10 years.

The Problem

Maintenance costs for metallic pipe had increased from $350,000 in 1951, to almost $900,000 in 1959. The projected cost for the year 1970 was estimated at an "increasing rate of increase" to be $4,000,000. This was in terms of 1959 dollars and without provision for the towering inflation of the 'seventies.

The City Water Board realized that additional municipal funding to cover such costs would be next to impossible to obtain.

It further recognized that the necessity of continuing to provide quality water to the city's rapidly rising population was absolute.

The Solution

City Water Board General Manager Robert P. Van Dyke explained how San Antonio tackled its problem just as 4,500 other cities have done: it converted the system to A/C pipe.

"When pipe fails, the real cost of replacement comes from the labor involved in digging it up, burying new pipe and covering it up," he says.

Today, 99% of all pipe being installed in both replacement and new development areas of San Antonio is A/C.

Director of Engineering Hugh R. Anderson says A/C now represents over one-half of all pipe in the system. He says the conversion rate to A/C will continue at the current rate.

The Benefit

Maintenance expense for the system today is well under $2,000,000 (half the figure projected in 1959). And this covers a 2400-mile system that is about 25% larger than it was only 10 years ago.

The Results

By 1973, the system had reached an equal balance between A/C and metallic pipe in miles. In that year, the number of all breaks per mile of metallic pipe was 0.34, compared with 0.09 breaks per mile of A/C. That same year, breaks due to corrosion alone on metallic pipe were 0.25 per mile.

From 1967 through 1976, the San Antonio water system experienced a total of 11,815 main breaks, 8,970 (75.9%) of which were in metallic pipe. Corrosion was the direct cause of 6,781 (75.5%) of the metallic pipe breaks. (The remaining 2,189 breaks occurring in metallic pipe were attributed to soil shift and accidental causes.) During the same period, there were 2,738 breaks in A/C pipe, or only 23% of the total number of breaks in the entire system and all attributed to accident or soil shift.

In this connection, Mr. Anderson said in a 1975 report to the Water Board: "The bonding action of highly plastic clay soil as the clay shrinks could probably be minimized by the use of an envelope of four to six inches of tamped sand around the

10-Year Incidence of Main Breaks:

Year	Total Breaks	Metallic Pipe Breaks	Metallic Breaks per Mile	Breaks Caused by Corrosion	Total A/C Breaks	A/C Breaks per Mile	Break Repair Expense	Miles in System
1976	1,185	888	0.37	640	288	0.12	$1,180,647	2,373.5
1975	1,439	957	0.40	562	477	0.20	1,050,222	2,347 3
1974	1,395	923	0.40	631	465	0.20	900,677	2,258.0
1973	999	741	0.34	548	202	0.09	765,826	2,167.7
1972	963	751	0.36	700	212	0.10	552,822	2,090.0
1971	1,104	898	0.44	870	206	0.10	612,189	2,034.4
1970	1,143	931	0.47	825	212	0.10	601,960	1,981.5
1969	1,163	909	0.46	683	254	0.13	520,214	1,957.9
1968	1,116	923	0.48	650	193	0.10	486,538	1,915.7
1967	1,308	1049	0.69	672	229	0.15	445.238	1,870.0

over ▸

pipe." This recommendation has since been adopted for all A/C pipe through the 12-inch diameter Since sand is a relatively low-cost commodity, it adds only minimally to installation expense.

Mr Anderson observes that, although the 1975 study of main breaks blamed "soil shifts" as the cause of a number of metallic pipe failures, "most of these breaks occurred on pipe sections that had already been significantly deteriorated and weakened by prior corrosion action."

"In the context of main breaks," he concludes, "the primary concern with metallic pipes is corrosion."

A/C pipe does not corrode. This is one major factor that has prompted so many municipalities to convert to value-engineered asbestos cement pipe Other factors include.

1. Low installed cost
2. Structural integrity
3. Self purging
4. Joint reliability
5. Versatility
6. Long service life

Case History

CertainTeed

The Product:
A/C Water Pipe
The Location:
Waterford Township, Michigan
The Issue:
Maintenance Costs

Waterford Township, a suburb of Detroit, found that because A/C water pipe is impervious both to extremely low ambient temperatures and to extremely "hot" (low resistivity) soil, repair costs literally are reduced to zero.

The Situation

Since the city of Detroit supplies water to 40% of the population of Michigan, it specifies the kinds of materials that may be used by many suburban water systems. Until the 1960's, the specification was predominantly for metallic pipe.

But because Waterford Township, located in the center of Oakland County, pumps its own water from 12 wells to serve 11,000 customers over a 36 sq. mi. area, it has never been under Detroit's aegis. It is the only suburban community free to make its own rules and draw up its own specifications for materials.

Rapid growth of sub-divisions in the late '50's and early '60's turned Waterford Township from open farmlands dotted with lakes and recreaction areas, into a community of homes. And with this growth came demands for a quality water system to serve the burgeoning community.

The Problem

Waterford Township has hot soil with high electrolytic concentrations. It also faces frequent "deep freezes" in wintertime.

The Water and Sewer Department of the township was well aware of the fragility of iron pipe under these conditions. Iron pipe, laid during the depression in an older section in the extreme southeastern corner of the township, was undergoing breaks at the rate of up to 40 a year with repair costs running up to $400 a break. The Department sought an alternative to metallic pipe, something which Alfred E. Beanblossom, assistant utility manager for the township, said would provide "more miles for the dollar" and stand up to the demanding climatic and soil conditions prevalent in the area.

The Solution

The township decided to go all the way with A/C pipe. Today, there are only ten miles of metallic pipe left in the entire system and, as it deteriorates, A/C is being used to replace it

The Result

Mr. Beanblossom put it best when he said: "I can't recall even one break in our A/C pipe due to natural causes since it was installed in the early '60's."

Any breaks occurring as a result of contractor error or accident stemming from operations of other utilities are billed back to the party at fault so the program indeed is one with almost zero maintenance expense.

Mr. Beanblossom said that during the very cold winter of 1977-1978, he personally examined a section of A/C pipe that had been completely encased in frost four feet below ground level.

"The water was flowing through that pipe as freely as it does on a summer day," he said.

The Waterford Township system was designed by computer, Mr. Beanblossom said. It employs A/C pipe in all available dimensions: Class 150 in the 6", 8", 10" and 12" diameters and Class 200 in the 16"

"Fifteen years ago, the city of Detroit tried to persuade us we shouldn't put in A/C pipe," he recalled. "Today, due to the success we're having with it, Detroit is relaxing its previous rules on A/C for the suburban systems it serves."

He cites Independence Township, just to the north of Waterford, as one example of a system that is converting to A/C as a result of Waterford Township's experience.

As a footnote, Mr. Beanblossom observed: "We use A/C everywhere in our sewer system which serves 9,955 customers—as well as in our water system, and we're getting good results from both."

Case History

CertainTeed

The Product:
A/C Water Pipe
The Location:
Hutchinson, Kansas
The Issue:
Installation Cost

This city, in the geographical center of the U.S., saved $149,000 (20%) by installing A/C water pipe and proved that, due to A/C's cost effectiveness, its very appearance in the specifications creates spirited competitive bidding on all materials specified.

The Situation

Until recently, metallic pipe, in one form or another, was the only material ever permitted in specifications written for the Hutchinson City Commission's water system. Except for certain circumstances, this also would have been the only specification permitted in a recent project for a municipal expansion area requiring 52,412 ft. of pipe as follows:

11,516 ft. of 12".
1,476 ft. of 10".
35,980 ft. of 6".

The above to be installed complete, including all related engineering work, fittings and valves.

As is the case in most municipalities, soaring inflation and the threat of further rate increases put mounting pressures upon the City Commission to keep down capital and maintenance costs and still provide satisfactory service to the community.

City Engineer Bernie Williams was faced with a financial dilemma of major proportions. After careful calculation, he estimated that this job would come in at about $739,000. Both he and the Commission recognized that the time had come to reexamine the city's standard specifications in a search for more cost-effective alternatives.

The Solution

The search led the city to consider *for the first time A/C Class 150 pipe.* The Commission listened to the case for "A/C as equal to Metallic" on the basis of both performance and cost. It heard estimates that the city could expect savings on first costs alone of from 10 to 15% by using A/C versus metallic in the city system. (Events proved even that estimate to be conservative.)

The Commission voted unanimously to allow A/C into the specifications, with one member expressing curiosity about why this had not been done long before.

The Benefits

Opening bids to A/C pipe had an immediate effect Ductile Iron pipe prices for the first time in many years became truly competitive.

In fact, some contractors attempted unsuccessfully to stockpile quantities of D.I. pipe at these drastically reduced prices for their own inventories.

Successful bidder was Eve, Inc., Hutchinson contractor, who quoted the job with CertainTeed A/C Class 150 pipe, installed complete, at $589,551.

"This bid represented a savings to the city of $149,500, or 20% below the original estimate," said Mr. Williams.

City officials said this further assured the community that water rates would not be increased for at least the next two years

The Hutchinson project was financed in the main through a federal grant from the HUD-administered Community Development Fund, with the balance supplied by the City Water Fund. Had financing come through a typical 5%, 20-year bond issue, the savings achieved through A/C would have totaled a quarter-million dollars at maturity.

The Results

After the installation was completed, the system tested out on the very *first try without a single leak or any* other problem. Mr. Williams was unable to estimate projected savings in maintenance costs through use of A/C pipe because: "We have no track record with A/C as yet on which to base such an estimate."

However, Mr. Williams said. "Prior to the specifications being changed to include A/C pipe, I was satisfied with its performance based on information received from other cities "

It would appear that after its textbook perfect acceptance test, Hutchinson will experience what other municipalities have already found: that A/C demonstrates the best track record of any pipe in the ground in every city where it replaces D.I.

An interesting sidelight was that the Hutchinson system was installed by a crew and foreman brand new to A/C pipe. Training was provided by CertainTeed personnel and some of the contractor's older hands, and the work proceeded without problem or incident.

Don Munsil, director of public works, said that by permitting A/C pipe to be bid, it resulted in a substantial saving in initial construction cost. "This left additional budgeted funds that could be allocated for other Water Department maintenance and operations or for future capital expenditures," he said. "Because of Hutchinson's water main extension policy, any saving in construction activity is a benefit for all our customers "

As a result of the success of the Hutchinson project, South Hutchinson has specified A/C pipe for a water main project that comes up for bid August 15. It comprises 11,000 ft. of 20" pipe, 11,000 ft. of 16", 6,000 ft of 14", 4,000 ft. of 12", and 1,400 ft. of 10" Here, too, ductile iron was originally to have been the only material allowed.

Case History

CertainTeed

The Product:
A/C Water Pipe
The Location:
Northern California to Los Angeles
The Issue:
Cost Effectiveness

This is one of the largest, privately-owned, profit-motivated water companies in the western U.S. It serves 300,000 customers in 37 communities through 3,682 miles of pipe. The company feels that the pipe it uses must be cost-effective if it is to contribute to profits while fulfilling its primary mission of providing an uninterrupted flow of high quality water.

Company officials feel that widespread use of A/C pipe is a major contributor to its profitability because, in the words of one spokesman, "It costs from 30 to 50 percent less than ductile iron, is less expensive to install, and is considerably more reasonable to maintain."

In the ten years since 1968, company revenues have doubled, its net profit has grown 60 percent, and it has increased its dividends to some 10,000 shareholders every single year.

The Situation

California Water Service Company has 500 employees. It operates throughout the state from the upper Sacramento River Valley in the north, through the San Francisco Peninsula, down to Los Angeles County in the south. It supplies water at retail through 21 separate systems.

Shortly after World War II, the company found its iron mains suddenly disintegrating at a disastrous rate. As many as 80 breaks a day were commonplace. In one district of 25,000 customers, a six-month moratorium had to be declared on new connections because of the mounting break rate.

The causes: corrosion due to low soil resistivity in a number of areas, including populous Stockton and East Los Angeles. Additionally, salt intrusion was "playing hob" with ferrous pipe in the "blue mud" flats of the San Francisco Peninsula. Repair costs were becoming prohibitive.

The Solution

The company, upon the advice of its Engineering Department, turned to A/C—all it could get its hands on, even though it was in short supply at the time. A/C became an absolute "must specification" for all areas with "hot" or salty soil characteristics.

From that critical time, A/C has been used to supplant ferrous pipe and is installed exclusively in all new and expansion areas in diameters up to 18"

The Benefits

Company Purchasing Agent William R. Lewis said the installed cost of A/C is considerably lower than for steel or ductile iron.

"In diameters of 6" to 8", A/C costs 50 percent less than ductile," he said. "In larger diameters, the cost of A/C is from 25 to 30 percent less."

Mr. Lewis also stated that when A/C is installed right, breaks from all causes are few and far between.

"We sand-bed most of our A/C," he said. "That gives excellent protection at a nominal cost, especially in adobe soil which has a tendency to dry and shift during late summer."

The Results

The California Water System Company now has 2,097 miles of A/C pipe in its system. Approximately 98 percent of it is Class 150. Here are the footages of A/C pipe in the system by diameters:

4"	879,000
6"	5,463,000
8"	3,276,000
10"	267,000
12"	964,000
14"	44,000
16"	97,000
18"	57,000
20"	17,000

Most of the A/C pipe being installed in the system is CertainTeed.

Since A/C has replaced iron in "hot" soil, salty soil, and even in earthquake-prone areas, maintenance and repair costs per foot have been substantially lower, according to Mr. Lewis.

An interesting sidelight is that the company does not require pressure tests after installation on pipe diameters up to 8" The reason is that the contractors used for these installations guarantee no leaks on these sizes for one year. On sizes over 8", the company does require pressure tests of 50 psi above the maximum operating pressures and never less than 150 psi.

"Our contractors are very pleased with the performance surety of A/C," Mr. Lewis said. "They have been for over 25 years."

Financing for sub-division installation work usually is done by the developer as is common with private utilities throughout California Developers can use one of the company-recommended contractors and advance the cost of piping and hydrants under a 20-year refundable contract. The alternative is to use the water company's specs and choose their own approved contractor under the same financial arrangement.

Mr. Lewis summed up A/C's positive impact on company earnings by stating

"A/C makes a definite contribution to our company's profits, not only because of its low initial cost, but because of its ease of installation, and much lower maintenance costs."

CTD029395

American Water Works Association

ANSI/AWWA C600-77

Revision of
C600-64

AMERICAN NATIONAL STANDARD

for

INSTALLATION OF GRAY AND DUCTILE CAST-IRON WATER MAINS AND APPURTENANCES

Approved by AWWA Board of Directors May 8, 1977.
Approved by American National Standards Institute Jun. 22, 1977.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

CTD029396

Committee Personnel

The AWWA Standards Committee on Installation of Cast-Iron Water Mains, which developed this standard, had the following personnel at the time of approval:

A. M. TINKEY, *Chairman*
W. HARRY SMITH, *Vice-Chairman*
ROBERT ZIMMERMAN, *Secretary*

Consumer Members

H. KENNETH ANDERSON, Water Bureau, Portland, OR	(AWWA)
E. M. BONADEO, Detroit Water and Sewage Department, Detroit, MI	(AWWA)
CHARLES A. FROMAN JR., Gary–Hobart Water Corp., Gary, IN	(AWWA)
ALBERT HELT, The Water Bureau, Metropolitan District, Hartford, CT	(NEWWA)
WILLIAM H. PRIESTER, Department of Water & Power, Los Angeles, CA	(AWWA)
JOHN E. READEY, Department of Water & Sewers, Chicago, IL	(AWWA)
MARK SADOLF, Utilities Department, Broward County, Ft. Lauderdale, FL	(AWWA)
WILLIAM R. THOMPSON,* Metropolitan District Commission, Boston, MA	(NEWWA)
A. M. TINKEY, St. Louis County Water Co., University City, MO	(AWWA)

General Interest Members

GORDON C. ANDERSON,* Insurance Services Office, New York, NY	(ISO)
WILLIAM A. BARKLEY, College of Engineering, Las Cruces, NM	(ASCE)
KENNETH J. CARL, Insurance Services Office, New York, NY	(ISO)
MARTIN P. DALY, Malcolm Pirnie, Inc., Paramus, NJ	(AWWA)
JOSEPH M. DENNIS, Department of Human Resources, Raleigh, NC	(CSSE)
EDWIN J. LASZEWSKI, City of Milwaukee, Milwaukee, WI	(APWA)
J. SAMUEL SLICER JR., Factory Mutual Research Corp., Norwood, MA	(FMR)
JOSEPH VELLANO, Latham, NY	(NUCA)
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Producer Members

T. C. JESTER, American–Darling Valve, Birmingham, AL	(MSS)
HAROLD KENNEDY JR., U.S. Pipe & Foundry Co., Birmingham, AL	(CIPRA)
EDWARD C. SEARS, American Cast Iron Pipe Co., Birmingham, AL	(CIPRA)
W. HARRY SMITH, Cast Iron Pipe Research Assn., Oak Brook, IL	(CIPRA)

* Alternate

Table of Contents

Foreword

This foreword is for information only and is not a part of AWWA C-600.

I. History of Standard

The first AWWA standard specifications, "Laying Cast Iron Pipe," (7D.1–1938) were adopted in Apr. 1938. They were intended as a guide in making extensions to existing distribution systems, and in preparing specifications for contracts for the construction of new systems or extensions. The standard was to be used as a guide for installing bell-and-spigot cast-iron pipe and did not cover the furnishing and delivery of material, any other type of pipe, or any other type of joint. The standard included a model addendum, which was to be used with project specifications, and was designed to be used as a part of the contract document. The standard was published in the Feb. 1938 edition of *Journal AWWA*.

The standard was revised in 1949, including a change of title to, "Standard Specifications for Installation of Cast-Iron Water Mains," (7D.1–T–1949 and C600–49T). The standard was expanded, adding numerous tables and installation guidelines. The model addendum was also expanded. The revised standard was published in the Dec. 1949 edition of *Journal AWWA*.

An additional section, Sec. 9b—Jointing of Mechanical-Joint Pipe—was added in May 1954. Section 9c—Joining of Push-on Joint Pipe—was added in 1964.

In 1975 the Standards Council formed the present C–600 Committee to revise C–600 to current practices and to add ductile iron as a pipe material.

In order to do this, the committee decided to completely change the character of the standard, removing the model addendum and making the standard more in compliance with the style of other AWWA standards.

II. Information Regarding the Use of This Standard

The AWWA standard, "Installation of Gray and Ductile Cast-Iron Water Mains and Appurtenances," can be used as a reference when making extensions to existing or constructing new distribution systems, using either ductile or gray cast-iron mains, with either mechanical- or push-on joints. It is not the intent for this standard to be used as a contract document but it may be used as a reference in the contract documents. It is based upon a consensus of the committee on the minimum practice consistent with sound, economical service under normal conditions, and its applicability under any circumstances must be reviewed by a responsible engineer. The standard is not intended to preclude the manufacture, marketing, purchase, or use of any product, process, or procedure.

III. Major Revisions

The standard has been rewritten completely and restructured to conform with the present style of AWWA standards. Ductile-iron pipe has been added to the standard, and normal installation practices have been updated completely. The addendum has been deleted.

Allowable leakage for both mechanical- and push-on joints has been reduced to one half of the value prescribed in the 1964 standard.

American Water Works Association

ANSI/AWWA C600–77

Revision of C600–64

AMERICAN NATIONAL STANDARD

for

Installation of Gray and Ductile Cast-Iron Water Mains and Appurtenances

Section 1—General

Sec. 1.1—Scope

This standard covers installation procedures for gray and ductile cast-iron pipe and appurtenances for water service.

1.1.1 *Conditions not covered.* Installations that require special attention, techniques, and materials are not covered. Each such installation requires special considerations based on many influencing factors and cannot be covered adequately in a single standard. This type of installation can best be accomplished by competent engineering design in consultation with representatives of the material manufacturing industry. Some of these typical installations are

1. Piping through rigid walls.
2. Subaqueous piping.
3. Piping on supports above or below ground.
4. Piping requiring insulation.
5. Plant- or pump-station piping.

Sec. 1.2—References

This standard references the following documents. They form a part of this standard to the extent specified herein. In any case of conflict, the requirements of this standard shall prevail.

AWWA C101, Thickness Design of Cast-Iron Pipe.

AWWA C104, Cement–Mortar Lining for Cast-Iron and Ductile-Iron Pipe and Fittings for Water.

AWWA C105, Polyethylene Encasement for Gray and Ductile Cast-Iron Piping for Water and Other Liquids.

AWWA C106, Cast-Iron Pipe Centrifugally Cast in Metal Molds, for Water or Other Liquids.

AWWA C108, Cast-Iron Pipe Centrifugally Cast in Sand-Lined Molds, for Water or Other Liquids.

AWWA C110, Gray-Iron and Ductile-Iron Fittings, 3 in. Through 48 in., for Water and Other Liquids.

AWWA C111, Rubber-Gasket Joints for Cast-Iron and Ductile-Iron Pressure Pipe and Fittings.

AWWA C115, Flanged Cast-Iron and Ductile-Iron Pipe With Threaded Flanges.

AWWA C150, Thickness Design of Ductile-Iron Pipe.

AWWA C151, Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds, for Water or Other Liquids.

AWWA C500, Gate Valves—3-in. Through 48-in.—for Water and Other Liquids.

AWWA C502, Dry-Barrel Fire Hydrants.

AWWA C503, Wet-Barrel Fire Hydrants.

AWWA C504, Rubber Seated Butterfly Valves.

AWWA C601, Disinfecting Water Mains.

AWWA No. 20104, Handbook of Occupational Safety and Health Standards for Water Utilities.

*AASHTO * T-99, Standard Method of Test for Moisture-Density Relationship for Soils.*

Sec. 1.3—Definitions

Under this standard, the following definitions shall apply:

1.3.1 *Gray cast iron.* Cast ferrous material in which a major part of the carbon content occurs as free carbon in the form of flakes interspersed through the metal.

1.3.2 *Ductile cast iron.* Cast ferrous material in which a major part of the carbon content occurs as free carbon in nodules or spheroidal form.

1.3.3 *Owner.* The municipality or other organization that will own and operate the completed piping system. The owner may designate agents, such as an engineer, purchaser, or inspector for specific responsibilities with regard to piping construction projects.

1.3.4 *Contractor.* The party responsible for water main construction.

1.3.5 *Mechanical joint.* The gasketed and bolted joint as detailed in AWWA C111.

1.3.6 *Push-on joint.* The single rubber-gasket joint as described in AWWA C111.

Section 2—Inspection, Receiving, Handling, and Storage

Sec. 2.1—Inspection

At the discretion of the owner, all materials furnished by the contractor are subject to inspection and approval at the manufacturer's plant.

2.1.1 *Post delivery.* All pipe and appurtenances are subject to inspection at the point of delivery by the owner. Material found to be defective due to manufacture or damage in shipment shall be rejected or recorded on the bill of lading and removed from the job site. The owner may perform tests as specified in the applicable AWWA standard to ensure conformance with the standard. In case of failure of the pipe or appurtenance to comply with such specifications, responsibility for replacement of the defective materials becomes that of the manufacturer.

* American Association of State Highway and Transportation Officials, 341 National Press Bldg., Washington, D.C. 20004.

2.1.2 *Workmanship.* All pipe and appurtenances shall be installed and joined in conformance with this standard and tested under pressure for defects and leaks in accordance with Sec. 4 of this standard.

Sec. 2.2—Handling and Storage

All pipe, fittings, valves, hydrants, and accessories shall be loaded and unloaded by lifting with hoists or skidding in order to avoid shock or damage. Under no circumstances shall such material be dropped. Pipe handled on skidways shall not be rolled or skidded against pipe on the ground.

2.2.1 *Padding.* Slings, hooks, or pipe tongs shall be padded and used in such a manner as to prevent damage to the exterior surface or internal lining of the pipe.

2.2.2 *Storage.* Materials, if stored, shall be kept safe from damage. The interior of all pipe, fittings, and other appurtenances shall be kept free from dirt or foreign matter at all times. Valves and hydrants shall be drained and stored in a manner that will protect them from damage by freezing.

2.2.2.1 Pipe shall not be stacked higher than the limits shown in Tables 1 and 2. The bottom tier shall be kept off the ground on timbers, rails, or concrete. Pipe in tiers shall be alternated: bell, plain end; bell, plain end. At least two rows of 4-in. × 4-in. timbers shall be placed between tiers and chocks affixed to each end in order to prevent movement.

2.2.2.2 Gaskets for mechanical- and push-on joints to be stored shall be placed in a cool location out of direct sunlight. Gaskets shall not come in contact with petroleum products. Gaskets shall be used on a first-in, first-out basis.

TABLE 1

Maximum Stacking Heights—Gray Cast-Iron Pipe

Pipe Size (in.)	Number of Tiers	
	18-ft length	20-ft length
3	18	18
4	16	16
6	13	13
8	11	11
10	9	8
12	8	7
14	7	7
16	6	6
18	6	5
20	5	4
24	4	3

TABLE 2

*Maximum Stacking Heights—Ductile Cast-Iron Pipe**

Pipe Size (in.)	Number of Tiers
3	18
4	16
6	13
8	11
10	10
12	9
14	8
16	7
18	6
20	6
24	5
30	4
36	4
42	3
48	3
54	3

* For 18- or 20-ft lengths.

2.2.2.3 Mechanical-joint bolts shall be handled and stored in such a manner that will ensure proper use with respect to types and sizes.

Section 3—Installation

Sec. 3.1—Alignment and Grade

The water mains shall be laid and maintained to lines and grades established by the plans and specifications with fittings, valves, and hydrants at the required locations unless otherwise approved by the owner. Valve-operating stems shall be oriented in a manner to allow proper operation. Hydrants shall be installed plumb.

3.1.1 *Prior investigation.* Prior to excavation, investigation shall be made to the extent necessary to determine the location of existing underground structures and conflicts. Care should be exercised by the contractor during excavation to avoid damage to existing structures.

3.1.2 *Unforeseen obstructions.* When obstructions that are not shown on the plans are encountered during the progress of work and interfere so that an alteration of the plans is required, the owner will alter the plans or order a deviation in line and grade or arrange for removal, relocation, or reconstruction of the obstructions.

3.1.3 *Clearance.* When crossing existing pipelines or other structures, alignment and grade shall be adjusted as necessary, with the approval of the owner, to provide clearance as required by federal, state, or local regulations or as deemed necessary by the owner to prevent future damage or contamination of either structure.

Sec. 3.2—Trench Construction

The trench shall be excavated to the required alignment, depth, and width and in conformance with all federal, state, and local regulations for the protection of the workmen.

3.2.1 *Trench preparation.* Trench preparation shall proceed in advance of pipe installation for only as far as stated in the specifications.

3.2.1.1 Discharge from any trench dewatering pumps shall be conducted to natural drainage channels, storm sewers, or an approved reservoir.

3.2.1.2 Excavated material shall be placed in a manner that will not obstruct the work nor endanger the workmen, obstruct sidewalks, driveways, or other structures and shall be done in compliance with federal, state, or local regulations.

3.2.2 *Pavement removal.* Removal of pavement and road surfaces shall be a part of the trench excavation and the amount removed shall depend upon the width of trench required for installation of the pipe and the dimensions of area required for the installation of valves, hydrants, specials, manholes, or other structures. The dimensions of pavement removed shall not exceed the dimensions of the opening required for installation of pipe, valves, hydrants, specials, manholes, and other structures by more than 6 in. in any direction unless otherwise required or approved by the owner. Methods, such as sawing, drilling, or chipping, shall be used to ensure the breakage of pavement along straight lines.

3.2.3 *Width.* The width of the trench at the top of the pipe shall be that of the single-pass capabilities of normally available excavating equipment and ample to permit the pipe to be laid and joined properly and allow the backfill to be placed as specified. Trench widths as shown in Table 3 may be used as a guide. Trenches shall be of such extra width, when required, to permit the placement of tim-

TABLE 3

*Suggested Trench Widths at the Top of the Pipe**

Nominal Pipe Size in.	Trench Width in.
4	28
6	30
8	32
10	34
12	36
14	38
16	40
18	42
20	44
24	48
30	54
36	60
42	66
48	72
54	78

* The trench should never be wider than the width used as design criteria.

ber supports, sheeting, bracing, and appurtenances.

3.2.4 *Bell holes.* Holes for the bells shall be provided at each joint but shall be no larger than necessary for joint assembly and assurance that the pipe barrel will lie flat on the trench bottom. Other than noted previously, the trench bottom shall be true and even in order to provide support for the full length of the pipe barrel, except that a slight depression may be provided to allow withdrawal of pipe slings or other lifting tackle.

3.2.5 *Rock conditions.* When excavation of rock is encountered, all rock shall be removed to provide a clearance of at least 6 in. below and on each side of all pipe, valves, and fittings for pipe sizes 24 in. or smaller, and 9 in. for pipe sizes 30 in. and larger. When excavation is completed, a bed of sand, crushed stone, or earth that is free from stones, large clods, or frozen earth, shall be placed on the bottom of the trench to the previously mentioned depths, leveled, and tamped.

3.2.5.1 These clearances and bedding procedures shall also be observed for pieces of concrete or masonry and other debris or subterranean structures, such as masonry walls, piers, or foundations that may be encountered during excavation.

3.2.5.2 This installation procedure shall be followed when gravel formations containing loose boulders greater than 8 in. in diameter are encountered.

3.2.5.3 In all cases, the specified clearances shall be maintained between the bottom of all pipe and appurtenances and any part, projection, or point of rock, boulder, or stones of sufficient size and placement which, in the opinion of the owner, could cause a fulcrum point.

3.2.6 *Previous excavations.* Should the trench pass over a sewer or other previous excavation, the trench bottom shall be sufficiently compacted to provide support equal to that of the native soil or conform to other regulatory requirements in a manner that will prevent damage to the existing installation.

3.2.7 *Blasting.* Blasting for excavation shall be permitted only after securing the approval of the owner who will establish the hours of blasting. The blasting procedure, including protection of persons and property, shall be in strict accordance with federal, state, and local regulations.

3.2.8 *Protection of property.* Trees, shrubs, fences, and all other property and surface structures shall be protected during construction unless their removal is shown in the plans and specifications or approved by the owner.

3.2.8.1 Any cutting of tree roots or branches shall be done only as approved by the owner.

3.2.8.2 Temporary support, adequate protection, and maintenance of all underground and surface structures, drains, sewers, and other obstructions encountered in the progress of the work shall be furnished by the contractor.

3.2.8.3 All properties that have been disturbed shall be restored as nearly as practical to their original condition.

3.2.9 *Unstable subgrade.* When the subgrade is found to be unstable or to include ashes, cinders, refuse, organic material, or other unsuitable material, such material shall be removed, to a minimum of at least 3 in., or to the depth ordered by the owner and replaced under the directions of the owner with clean, stable backfill material. When such materials are encountered, polyethylene encasement should be provided (see paragraph 3.4.5). The bedding shall be consolidated and leveled in order that the pipe may be installed in accordance with Sec. 3.2.4.

3.2.9.1 When the bottom of the trench or the subgrade is found to consist of material that is unstable to such a degree that, in the judgment of the owner it cannot be removed, a foundation for the pipe and/or appurtenance shall be constructed using piling, timber, concrete, or other materials at the direction of the owner.

3.2.10 *Safety.* Appropriate traffic control devices shall be provided in accordance with federal, state, or local regulations to regulate, warn, and guide traffic at the work site.

Sec. 3.3—Pipe Installation

Proper implements, tools, and facilities shall be provided and used for the safe and convenient performance of the work. All pipe, fittings, valves, and hydrants shall be lowered carefully into the trench by means of a derrick, ropes, or other suitable tools or equipment, in such a manner as to prevent damage to water-main materials and protective coatings and linings. Under no circumstances shall water-main materials be dropped or dumped into the trench. The trench should be dewatered prior to installation of the pipe.

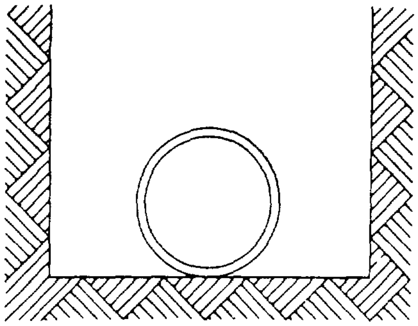
3.3.1 *Examination of material.* All pipe fittings, valves, hydrants, and other appurtenances shall be examined carefully for damage and other defects immediately before installation. Defective materials shall be marked and held for inspection by the owner, who may prescribe corrective repairs or reject the materials.

3.3.2 *Pipe ends.* All lumps, blisters, and excess coating shall be removed from the socket and plain ends of each pipe, and the outside of the plain end and the inside of the bell shall be wiped clean and dry and be free from dirt, sand, grit, or any foreign material before the pipe is laid.

3.3.3 *Pipe cleanliness.* Foreign material shall be prevented from entering the pipe while it is being placed in the trench. During laying operations, no debris, tools, clothing, or other materials shall be placed in the pipe.

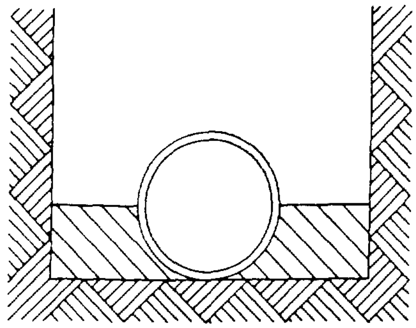
3.3.4 *Pipe placement.* As each length of pipe is placed in the trench, the joint shall be assembled and the pipe brought to correct line and grade. The pipe shall be secured in place with approved backfill material.

3.3.5 *Pipe plugs.* At times when pipe laying is not in progress, the open ends of pipe shall be closed by a watertight plug or other means approved by the owner. When practical, the plug shall remain in place until the trench is pumped completely dry. Care must be taken to prevent pipe flotation should the trench fill with water.



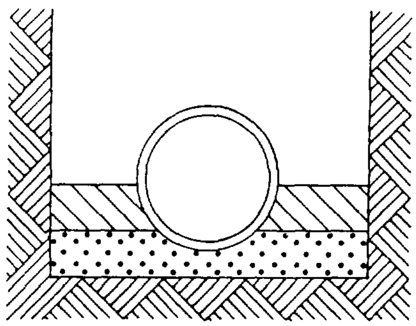
A

Flat bottom trench, untamped backfill.



B

Flat bottom trench, tamped backfill.



F

Pipe bedded in sand or gravel, tamped backfill.

Fig. 1. Laying Conditions for Gray Cast-Iron Pipe

3.3.6 *Gray-iron laying conditions.* The specified laying conditions for gray cast-iron pipe shall be completed in accordance with AWWA C101 and as illustrated in Fig. 1.

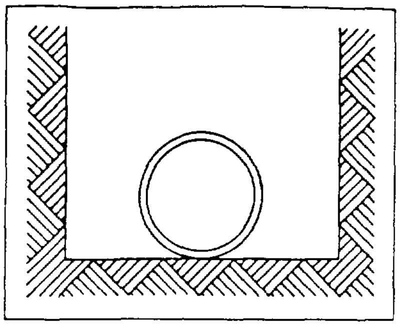
3.3.7 *Ductile-iron laying conditions.* The specified laying conditions for ductile-iron pipe shall be completed in accordance with AWWA C150 and as illustrated in Fig. 2 (page 8).

Sec. 3.4—Joint Assembly

3.4.1 *Push-on joints.* Push-on joints shall be assembled as described and illustrated in Fig. 3 (page 9).

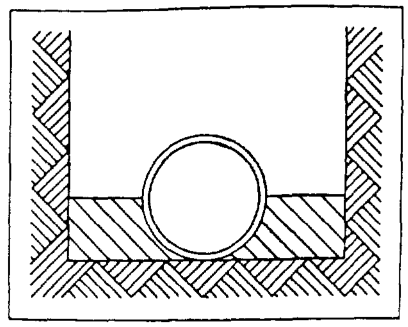
3.4.2 *Mechanical joints.* Mechanical joints shall be assembled as follows:

1. Wipe clean the socket and plain end. The plain end, socket, and gasket should be washed with a soap solution to improve gasket seating.



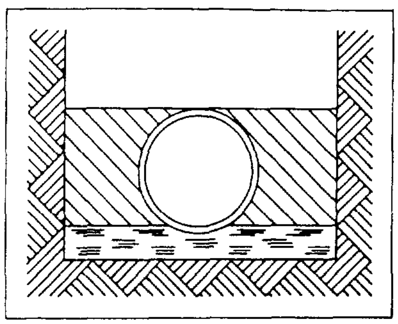
Type 1 *

Flat-bottom trench.† Loose backfill.



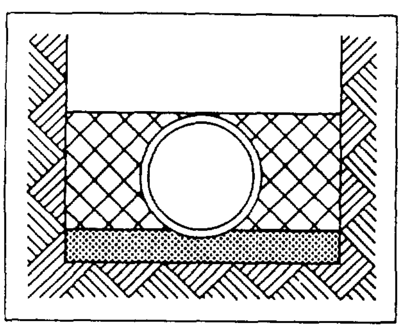
Type 2

Flat-bottom trench.† Backfill lightly consolidated to centerline of pipe.



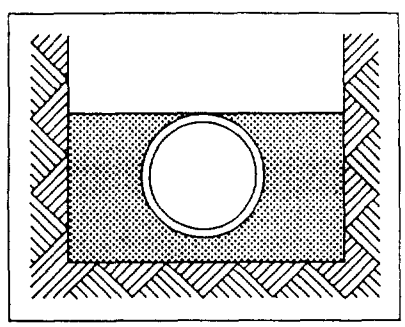
Type 3

Pipe bedded in 4-in. minimum loose soil.‡ Backfill lightly consolidated to top of pipe.



Type 4

Pipe bedded in sand, gravel, or crushed stone to depth of ⅛ pipe diameter, 4-in. minimum. Backfill compacted to top of pipe. (Approximately 80 per cent Standard Proctor, AASHTO T-99.)

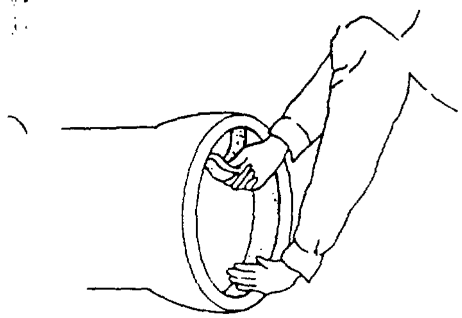


Type 5

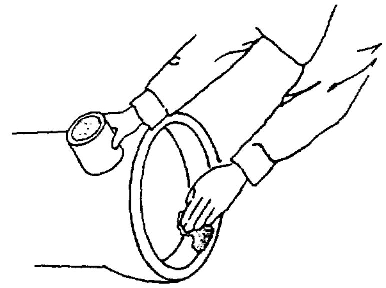
Pipe bedded in compacted granular material to centerline of pipe. Compacted granular or select‡ material to top of pipe. (Approximately 90 per cent Standard Proctor, AASHTO T-99.)

* For 30-in. and larger pipe, consideration should be given to the use of laying conditions other than Type 1.
† "Flat-bottom" is defined as undisturbed earth
‡ "Loose soil" or "select material" is defined as native soil excavated from the trench, free of rocks, foreign materials, and frozen earth.

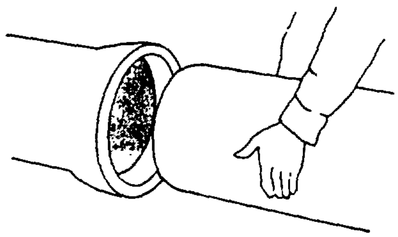
Fig. 2. Laying Conditions for Ductile Cast-Iron Pipe



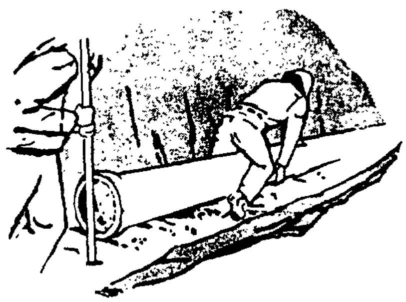
1. *Thoroughly clean the groove and bell socket and insert the gasket, making sure that it faces the proper direction and that it is correctly seated.*



2. *After cleaning dirt or foreign material from the plain end, apply lubricant in accordance with the pipe manufacturer's recommendations. The lubricant is supplied in sterile cans and every effort should be made to keep it sterile.*



3. *Be sure that the plain end is beveled; square or sharp edges may damage or dislodge the gasket and cause a leak. When pipe is cut in the field,* bevel *the plain end with a heavy file or grinder to remove all sharp edges. Push the plain end into the bell of the pipe. Keep the joint straight while pushing. Make deflection after the joint is assembled.*



4. *Small pipe can be pushed into the bell socket with a long bar. Large pipe require additional power, such as a jack, lever puller, or backhoe. The supplier may provide a jack or lever pullers on a rental basis. A timber header should be used between the pipe and jack or backhoe bucket to avoid damage to the pipe.*

Fig. 3. Push-on Joint Assembly

2. Place the gland on the plain end with the lip extension toward the plain end, followed by the gasket with the narrow edge of the gasket toward the plain end of the pipe.

3. Insert the pipe into the socket and press the gasket firmly and evenly into the gasket recess. Keep the joint straight during assembly. Make deflection after joint assembly but before tightening the bolts.

4. Push the gland toward the bell

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and center it around the pipe with the gland lip against the gasket.

5. Align bolt holes and insert bolts, with bolt heads behind the bell flange, and tighten opposite nuts to keep the gland square with the socket.

6. Tighten the nuts in accordance with Table 4.

3.4.3 *Pipe deflection.* When it is necessary to deflect pipe from a straight line in either the vertical or horizontal plane, or where long radius curves are permitted, the amount of deflection shall not exceed that shown in Tables 5 or 6.

TABLE 4

Mechanical Joint—Bolt Torques

Bolt Diameter *in.*	Torque *ft-lb*
$\frac{5}{8}$	45–60
$\frac{3}{4}$	75–90
1	85–100
$1\frac{1}{4}$	105–120

3.4.4 *Pipe cutting.* Cutting pipe for the insertion of valves, fittings, or closure pieces shall be done in a neat, workmanlike manner without creating damage to the pipe or cement-mortar lining.

3.4.4.1 Gray cast-iron pipe may be cut using a hydraulic squeeze cutter, abrasive pipe saw, rotary wheel cutter, guillotine pipe saw, or milling wheel saw.

3.4.4.2 Ductile cast iron may be cut using an abrasive pipe saw, rotary wheel cutter, guillotine pipe saw, milling wheel saw, or oxyacetylene torch.

3.4.4.3 Cut ends and rough edges shall be ground smooth, and for push-on joint connections, the cut end shall be beveled.

3.4.5 *Polyethylene encasement.* When polyethylene encasement is specified for gray and ductile cast-iron pipe, it shall be installed in accordance with Sec. 5–4 of AWWA C105.

TABLE 5

Maximum Deflection Full Length Pipe—Push-on Type Joint

Pipe Diameter *in.*	Deflection Angle *deg*	Maximum Deflection—*in.*		Approx. Radius of Curve Produced by Succession of Joints—*ft*	
		(18-ft length)	(20-ft length)	(18-ft length)	(20-ft length)
3	5	19	21	205	230
4	5	19	21	205	230
6	5	19	21	205	230
8	5	19	21	205	230
10	5	19	21	205	230
12	5	19	21	205	230
14	3	11	12	340	380
16	3	11	12	340	380
18	3	11	12	340	380
20	3	11	12	340	380
24	3	11	12	340	380
30	3	11	12	340	380
36	3	11	12	340	380
42	2	$7\frac{1}{2}$	8	510	570
48	2	$7\frac{1}{2}$	8	510	570
54	$1\frac{1}{2}$	$5\frac{1}{2}$	6	680	760

TABLE 6

Maximum Deflection Full Length Pipe—Mechanical Joint Pipe

Size of Pipe *in.*	Deflection Angle *deg-min*	Maximum Deflection—*in.*		Approx. Radius of Curve Produced by Succession of Joints—*ft*	
		(18-ft length)	(20-ft length)	(18-ft length)	(20-ft length)
3	8-18	31	35	125	140
4	8-18	31	35	125	140
6	7-7	27	30	145	160
8	5-21	20	22	195	220
10	5-21	20	22	195	220
12	5-21	20	22	195	220
14	3-35	13½	15	285	320
16	3-35	13½	15	285	320
18	3-0	11	12	340	380
20	3-0	11	12	340	380
24	2-23	9	10	450	500
30	2-23	9	10	450	500
36	2-5	8	9	500	550
42	2-0	7½	8	510	570
48	2-0	7½	8	510	570

Sec. 3.5—Backfilling

Backfill shall be accomplished in accordance with the specified laying condition as described in Sec. 3.3.

3.5.1 *Backfill material.* All backfill material shall be free from cinders, ashes, refuse, vegetable or organic material, boulders, rocks or stones, frozen soil, or other material that, in the opinion of the owner, is unsuitable.

3.5.1.1 From 1 ft above the top of the pipe to the subgrade of the pavement, material containing stones up to 8 in. in their greatest dimension may be used, unless otherwise specified.

3.5.1.2 When the type of backfill material is not indicated on the drawings or is not specified, the excavated material may be used, provided that such material consists of loam, clay, sand, gravel, or other materials that, in the opinion of the owner, are suitable for backfilling.

3.5.1.3 If excavated material is indicated on the drawings or specified for backfill, and there is a deficiency due to a rejection of part thereof, the required amount of sand, gravel, or other approved material shall be provided.

3.5.1.4 All sand used for backfill shall be clean, graded from fine to coarse, not lumpy or frozen, and free from slag, cinders, ashes, rubbish, or other material that, in the opinion of the owner, is objectionable or deleterious. It should not contain a total of more than 10 per cent by weight of loam and clay, and all material must be capable of being passed through a ¾-in. sieve. Not more than 5 per cent shall remain on a No. 4 sieve.

3.5.1.5 Gravel used for backfill shall consist of clean gravel having durable particles graded from fine to coarse in a reasonably uniform combination with no boulders or stones larger than 2 in. in size. It shall be free from slag, cinders, ashes, refuse, or other deleterious or objectionable materials. It shall not contain excessive amounts of loam and clay and shall not be lumpy or frozen. No more than 15 per cent shall pass a No. 200 sieve.

3.5.1.6 Screenings used for backfill shall consist of the products obtained from crushing sound limestone or dolomite ledge rock and shall be free from shale, dust, excessive amounts of clay, and other undesirable materials. All materials shall pass a ½-in. sieve, and no more than 25 per cent shall pass a No. 100 sieve.

3.5.2 *Compaction*. When special backfill compaction procedures are required, they shall be accomplished in accordance with project specifications or applicable federal, state, and local regulations.

3.5.3 *Partial backfilling during testing*. When specified by the owner, pressure and leakage testing may be accomplished before completion of backfilling and with pipe joints accessible for examination. In such cases, sufficient backfill material shall be placed over the pipe barrel between the joints to prevent movement.

Sec. 3.6—Valve-and-Fitting Installation

3.6.1 *Examination of material.* Prior to installation, valves shall be inspected for direction of opening, freedom of operation, tightness of pressure-containing bolting, cleanliness of valve ports and especially seating surfaces, handling damage, and cracks. Defective valves shall be corrected or held for inspection by the owner.

3.6.2 *Placement.* Valves, fittings, plugs, and caps shall be set and joined to the pipe in the manner specified in Sec. 3.3 for cleaning, laying, and joining pipe, except that 12-in. and larger valves should be provided with special support, such as treated timbers, crushed stone, concrete pads, or sufficiently tamped trench bottom so that the pipe will not be required to support the weight of the valve.

3.6.3 *Valve location*. Valves in water mains shall, where practical, be located on the street property lines extended in unpaved areas unless shown otherwise on the plans.

3.6.3.1 Mains shall be drained through drainage branches or blowoffs. Drainage branches, blowoffs, air vents, and appurtenances shall be provided with valves and shall be located and installed as shown on the plans. Drainage branches or blowoffs shall not be directly connected to any storm or sanitary sewer, submerged in any stream, or be installed in any other manner that will permit back siphonage into the distribution system.

3.6.4 *Valve protection*. A valve box or a vault shall be provided for every valve.

3.6.4.1 A valve box shall be provided for every valve that has no gearing or operating mechanism, or in which the gearing or operating mechanism is fully protected with a gear case. The valve box shall not transmit shock or stress to the valve and shall be centered over the operating nut of the valve, with the box cover flush with the surface of the finished area or such other level as may be directed by the owner.

3.6.4.2 A valve vault designed to prevent settling on the pipe shall be provided for every valve that has exposed gearing or operating mechanisms. The operating nut shall be readily accessible for operation through the opening in the valve vault which shall be set flush with the surface of the finished pavement or such other level as may be specified. Vaults shall be constructed to permit minor valve repairs and afford protection to the valve and pipe from impact where they pass through the vault walls.

3.6.4.3 In no case shall valves be used to bring misaligned pipe into alignment during installation. Pipe shall be supported in such a manner as to prevent stress on the valve.

3.6.5 *Plugs and caps.* All dead ends on new mains shall be closed with plugs or caps that are suitably restrained to prevent blowing off under test pressure. If a blowoff valve precedes the plug or cap, it too shall be restrained against blowing off. All dead ends shall be equipped with suitable blowoff facilities.

Sec. 3.7—Hydrant Installation

3.7.1 *Examination of material.* Prior to installation, inspect all hydrants for direction of opening, nozzle threading, operating-nut and cap-nut dimensions, tightness of pressure-containing bolting, cleanliness of inlet elbow, handling damage, and cracks. Defective hydrants shall be corrected or held for inspection by the owner.

3.7.2 *Placement.* All hydrants shall stand plumb and shall have their nozzles parallel with, or at right angles to, the curb, with the pumper nozzle facing the curb, except that hydrants having two-hose nozzles 90 deg apart shall be set with each nozzle facing the curb at an angle of 45 deg.

3.7.2.1 Hydrants shall be set to the established grade, with the centerline of the lowest nozzle at least 12 in. above the ground, or as directed by the owner.

3.7.2.2 Each hydrant shall be connected to the main with a 6-in. branch controlled by an independent 6-in. valve, unless otherwise specified by the owner.

3.7.2.3 When a dry-barrel hydrant is set in soil that is pervious, drainage shall be provided at the base of the hydrant by placing coarse gravel or crushed stone mixed with coarse sand, from the bottom of the trench to at least 6 in. above the waste opening in the hydrant and to a distance of 1 ft around the elbow. Where ground water rises above the drain port or when the hydrant is located within 8 ft of a sewer, the drain port shall be plugged and water pumped from the hydrant when freezing may occur.

3.7.2.4 When a dry-barrel hydrant with an open drain is set in clay or other impervious soil, a drainage pit 2 ft × 2 ft × 2 ft shall be excavated below each hydrant and filled with coarse gravel or crushed stone mixed with coarse sand, under and around the elbow of the hydrant and to a level of 6 in. above the drain port.

3.7.3 *Location.* Hydrants shall be located as shown on the plans or as directed by the owner.

3.7.4 *Protection.* In the case of hydrants that are intended to fail at the ground-line joint upon vehicle impact (traffic hydrants), specific care must be taken to provide adequate soil resistance to avoid transmitting shock moment to the lower barrel and inlet connection. In loose or poor load-bearing soil, this may be accomplished by pouring a concrete collar approximately 6 in. thick to a diameter of 2 ft at or near the ground line around the hydrant barrel.

Sec. 3.8—Thrust Restraint

3.8.1 *Hydrants.* The bowl of each hydrant shall be well braced against a sufficient area of unexcavated earth at the end of the trench with stone slabs or concrete backing, or it shall be tied

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to the pipe with suitable metal tie rods, clamps, or restrained joints as shown or directed by the owner.

3.8.1.1 Tie rods, clamps, or other components of dissimilar metal shall be protected against corrosion by hand application of a bituminous coating or by encasement of the entire assembly with 8-mil thick, loose polyethylene film in accordance with AWWA C105.

3.8.1.2 Thrust-restraint design pressure should be equal to the test pressure.

3.8.2 *Fittings.* All plugs, caps, tees, and bends, unless otherwise specified, shall be provided with reaction backing, or suitably restrained by attaching metal rods, clamps, or restrained joints as shown or specified by the owner.

3.8.3 *Restraint materials.* Vertical and horizontal reaction backing shall be made of concrete having a compressive strength of not less than 2000 psi after 28 days.

3.8.3.1 Backing shall be placed between solid ground and the fitting to be anchored; the area of bearing on the pipe and on the ground in each instance shall be that shown or directed by the owner. The backing shall, unless otherwise shown or directed, be so located as to contain the resultant thrust force and so that the pipe and fitting joints will be accessible for repair.

3.8.3.2 Restrained push-on joints, mechanical joints utilizing set-screw retainer glands or metal harness of tie rods, or clamps may be used instead of concrete backing if so indicated in the plans and specifications. Tie rods, clamps, or other components of dissimilar metal shall be protected against corrosion by hand application of a bituminous coating or by encasement of the entire assembly with 8-mil thick, loose polyethylene film in accordance with AWWA C105.

Section 4—Hydrostatic Testing

Sec. 4.1—Pressure Test

After the pipe has been laid, all newly laid pipe or any valved section thereof shall be subjected to a hydrostatic pressure of at least 1.5× the working pressure at the point of testing.

4.1.1 *Test pressure restrictions.* Test pressures shall

1. Not be less than 1.25× the working pressure at the highest point along the test section.
2. Not exceed pipe or thrust restraint design pressures.
3. Be of at least 2-hr duration.
4. Not vary by more than ±5 psi.
5. Not exceed twice the rated pressure of the valves or hydrants when

the pressure boundary of the test section includes closed gate valves or hydrants.

6. Not exceed the rated pressure of the valves if resilient-seated butterfly valves are used.

4.1.2 *Pressurization.* Each valved section of pipe shall be filled with water slowly and the specified test pressure, based on the elevation of the lowest point of the line or section under test and corrected to the elevation of the test gage, shall be applied by means of a pump connected to the pipe in a manner satisfactory to the owner.

4.1.3 *Air removal.* Before applying the specified test pressure, air shall be expelled completely from the pipe, valves, and hydrants. If permanent air vents are not located at all high points, the contractor shall install corporation cocks at such points so that the air can be expelled as the line is filled with water. After all the air has been expelled, the corporation cocks shall be closed and the test pressure applied. At the conclusion of the pressure test, the corporation cocks shall be removed and plugged, or left in place at the discretion of the owner.

4.1.4 *Examination.* All exposed pipe, fittings, valves, hydrants, and joints shall be examined carefully during the test. Any damage or defective pipe, fittings, valves, or hydrants that are discovered following the pressure test shall be repaired or replaced with sound material and the test shall be repeated until it is satisfactory to the owner.

Sec. 4.2—Leakage Test

A leakage test shall be conducted concurrently with the pressure test.

4.2.1 *Leakage defined.* Leakage shall be defined as the quantity of water that must be supplied into the newly laid pipe, or any valved section thereof, to maintain pressure within 5 psi of the specified test pressure after the air in the pipeline has been expelled and the pipe has been filled with water.

4.2.2 *Allowable leakage.* No pipe installation will be accepted if the leakage is greater than that determined by the following formula:

$$L = \frac{ND\sqrt{P}}{7400}$$

in which L is the allowable leakage, in gallons per hour; N is the number of joints in the length of pipeline tested; D is the nominal diameter of the pipe, in inches; and P is the average test pressure during the leakage test, in pounds per square inch gage.

4.2.2.1 Allowable leakage at various pressures is shown in Table 7 (page 16).

4.2.2.2 When testing against closed metal-seated valves, an additional leakage per closed valve of 0.0078 gal/hr/in. of nominal valve size shall be allowed.

4.2.2.3 When hydrants are in the test section, the test shall be made against the closed hydrant.

4.2.3 *Acceptance of installation.* Acceptance shall be determined on the basis of allowable leakage. If any test of pipe laid discloses leakage greater than that specified in Sec. 4.2.2, the contractor shall, at his own expense, locate and repair the defective material until the leakage is within the specified allowance.

4.2.3.1 · All visible leaks are to be repaired regardless of the *amount* of leakage.

TABLE 7

*Allowable Leakage per 1000 ft of Pipeline**—gph

Avg. Test Pressure *psi*	Nominal Pipe Diameter—*in.*																
	2	3	4	6	8	10	12	14	16	18	20	24	30	36	42	48	54
450	0.32	0.48	0.64	0.95	1.27	1.59	1.91	2.23	2.55	2.87	3.18	3.82	4.78	5.73	6.69	7.64	8.60
400	0.30	0.45	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00	3.60	4.50	5.41	6.31	7.21	8.11
350	0.28	0.42	0.56	0.84	1.12	1.40	1.69	1.97	2.25	2.53	2.81	3.37	4.21	5.06	5.90	6.74	7.58
300	0.26	0.39	0.52	0.78	1.04	1.30	1.56	1.82	2.08	2.34	2.60	3.12	3.90	4.68	5.46	6.24	7.02
275	0.25	0.37	0.50	0.75	1.00	1.24	1.49	1.74	1.99	2.24	2.49	2.99	3.73	4.48	5.23	5.98	6.72
250	0.24	0.36	0.47	0.71	0.95	1.19	1.42	1.66	1.90	2.14	2.37	2.85	3.56	4.27	4.99	5.70	6.41
225	0.23	0.34	0.45	0.68	0.90	1.13	1.35	1.58	1.80	2.03	2.25	2.70	3.38	4.05	4.73	5.41	6.03
200	0.21	0.32	0.43	0.64	0.85	1.06	1.28	1.48	1.70	1.91	2.12	2.55	3.19	3.82	4.46	5.09	5.73
175	0.20	0.30	0.40	0.59	0.80	0.99	1.19	1.39	1.59	1.79	1.98	2.38	2.98	3.58	4.17	4.77	5.36
150	0.19	0.28	0.37	0.55	0.74	0.92	1.10	1.29	1.47	1.66	1.84	2.21	2.76	3.31	3.86	4.41	4.97
125	0.17	0.25	0.34	0.50	0.67	0.84	1.01	1.18	1.34	1.51	1.68	2.01	2.52	3.02	3.53	4.03	4.53
100	0.15	0.23	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35	1.50	1.80	2.25	2.70	3.15	3.60	4.05

* For pipe with 18-ft nominal lengths. To obtain the recommended allowable leakage for pipe with 20-ft nominal lengths, multiply the leakage calculated from the table by 0.9. If the pipeline under test contains sections of various diameters, the allowable leakage will be the sum of the computed leakage for each size.

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Section 5—Disinfection

Upon completion of a newly installed main or when repairs to an existing pipe are made, the main shall be disinfected according to instructions listed in AWWA C601 of latest revision.

Section 6—Highway and Railroad Crossings

Sec. 6.1—Casing Pipe

When casing pipe is specified for highways or railroad crossings, the project shall be completed in accordance with applicable federal, state, and local regulations. In the case of railroad crossings, the project should comply further with regulations established by the railroad company. General practice permits boring for casing diameters through 36 in. with maximum length of about 175 ft; jacking for diameters 30 in. through 60 in. with lengths of about 200 ft; and tunneling for pipes 48 in. and larger for longer lengths.

Sec. 6.2—Carrier Pipe

The casing pipe should be 6–8 in. larger than the outside diameter of the gray or ductile cast-iron pipe bells. Carrier pipe may be pushed or pulled through the completed casing pipe. Chocks or skids should be placed on the carrier pipe to ensure approximate centering within the casing pipe and to prevent damage during installation. Care must be exercised in order to avoid metal-to-metal contact. In order to avoid the transfer of earth and live loads to the carrier pipe, the space between the carrier and casing pipes should not be filled completely.

Section 7—Service Taps

Sec. 7.1—Tapping

Corporation stops may be installed either before or after pipe installation. Generally, they are located at ten or two o'clock on the circumference of the pipe and may be screwed directly into the tapped and threaded main without any additional appurtenances. When more than one tap in a gray cast-iron pipe is necessary to deliver the required flow, they should be staggered around the circumference at least 12 in. apart (not in a straight line). Ductile-iron pipe in all classes may be directly tapped with standard corporation stops; however, torque requirement for the installation may be effectively reduced by the application of two layers of 3-mil TFE tape to the male threads of the corporation stop.

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American Water Works Association

AWWA C401-77

(Revision of
AWWA C401-64)

AWWA STANDARD PRACTICE

for

THE SELECTION OF ASBESTOS-CEMENT DISTRIBUTION PIPE, 4 IN. THROUGH 16 IN., FOR WATER AND OTHER LIQUIDS

First edition approved by AWWA Board of Directors Jan. 27, 1964.
This edition approved May 8, 1977.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

Committee Personnel

The Standards Committee on Asbestos–Cement Pressure Pipe, which reviewed and approved this standard, had the following personnel at the time of approval:

R. S. Bryant, *Chairman*
J. L. Warden, *Vice-Chairman*
T. R. Gillen, *Secretary*

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* Alternate

Table of Contents

Foreword

This foreword is for information only and is not a part of AWWA C401.

I. History of Standard

The information contained in this standard was first published as, "AWWA Handbook H2," with AWWA Board of Directors approval on Jan. 27, 1964. The designation was changed later to, "AWWA C401-64." Originally, it covered sizes 4–36 in. although the design was primarily based on service conditions generally related with smaller (4–16 in.) distribution sizes. In the smaller diameters the effect of water hammer generated by the opening and closing of fire hydrants can be of significant magnitude because of the high velocities generated by open hydrant flow conditions on small diameter lines in distribution systems. It is difficult to evaluate accurately the magnitude of surges, and if calculated, it would be impractical to attempt to control the surge by the use of surge tanks or other devices.

Rather than employ a rule-of-thumb surge allowance based upon an assumed velocity change, a large factor of safety is applied to the class pressure rating of the pipe to take into account the undetermined surges.

AWWA C403, "Standard Practice for the Selection of Asbestos-Cement Transmission and Feeder Main Pipe, 18 in. Through 42 in.," is a standard containing information similar to that contained herein but dealing with larger diameter pipes. In AWWA C403 the design is based on evaluation of all design conditions including surge pressures. Also, adequate factors of safety are applied to the combination of pressures to which the pipe line will be subjected.

The primary difference between AWWA C401 and AWWA C403 is one of differing methods for designing pipelines to account for surge pressures. In the small sizes where surges can be of great magnitude and are impractical to control, a large factor of safety is employed to compensate for the unknown. In the large sizes the design is based upon a more detailed evaluation of the magnitude of surge pressures, and a factor of safety based upon a more precise knowledge of actual operating conditions is employed.

II. Major Revisions

Major changes to the 1964 edition of this standard made in this revision are:

1. The title has been changed to indicate that the pipe is intended for use in distribution systems.
2. The size range has been changed to limit the maximum size covered by this standard to 16-in. diameter pipe.
3. Figure 2, Crushing Test Assembly, has been changed to show the C dimension to be approximately 1 in./ft of internal pipe diameter but in no case less than 1 in.

American Water Works Association

AWWA C401-77

(Revision of AWWA C401-64)

AWWA Standard Practice for

The Selection of Asbestos-Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids

Section 1—General

Sec. 1.1—Scope

This standard has been prepared so that design engineers can quickly determine the correct class of asbestos-cement pipe to use under various combinations of internal pressure and external loading. Curves are included to expedite the selection of the correct class of pipe. Detailed analyses of the various structural factors affecting pipe design and selection are treated under separate headings.

1.1.1 *Pressure classes.* Pipe pressure class designations of 100, 150, and 200 refer to the similarly numbered classes specified in AWWA C400, "Standard for Asbestos-Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids."

1.1.2 *Installation.* Detailed coverage of the installation of asbestos-cement pipe can be found in AWWA C603, "Standard for the Installation of Asbestos-Cement Pressure Pipe."

Sec. 1.2—References

This standard references the following documents. They form a part of this standard to the extent specified herein. In any case of conflict, the requirements of this standard shall prevail.

1. SCHLICK, W.J. Supporting Strengths for Cast-Iron Pipe for Water and Gas Service, *Iowa State Col. Eng. Sta. Bull.*, No. 146 (Jun. 1940).
2. ASCE. *Design and Construction of Sanitary and Storm Sewers*, Manual of Engineering Practice No. 37, Am. Soc. Civ. Engrs., New York (1967).
3. KERR, S.L. Practical Aspects of Water Hammer, *Jour. AWWA*, 40: 699 (Jun. 1948).
4. MARSTON, ANSON. The Theory of External Loads on Closed Conduits in the Light of Latest Experiments, *Iowa State Coll. Eng. Exp. Sta. Bull.*, No. 96 (1930).

Section 2–Pipe Design and Selection

Sec. 2.1—Strength and Design Factors

The strength of asbestos–cement water pipe must be sufficient to withstand the combined forces of internal hydrostatic pressure and external loads. Furthermore, the conditions under which the pipe is installed will have a direct relationship to its ability to resist these forces. Therefore, satisfactory pipe performance in field service requires that the bedding conditions, as well as the internal and external forces acting on the pipe, be taken into consideration when selecting a class of pipe for any given installation. Finally, sound engineering practice requires that adequate safety factors be applied to strength requirements to ensure performance under less than ideal conditions.

2.1.1 *Bedding conditions.* The bedding conditions described in Table 1 have been selected as representative of typical installation conditions encountered in the field. They are illustrated in Fig. A2 in the appendix.

TABLE 1

Typical Field Installation Conditions

Bedding Condition Class	Description
A	Gravel or sand base, backfill tamped
B	Same as A but backfill not tamped
C	Pipe laid on earth mounds or pipe barrel on flat trench bottom with excavated coupling holes, backfill tamped
D	Same as C but backfill not tamped

2.1.2 *Safety factors.* In the selection curves, a safety factor of 4.0 is applied to the operating pressure and a safety factor of 2.5 is applied to earth loads. Furthermore, pipe selected from the curves will have a safety factor of at least 2.5 for the operating pressure when combined with a safety factor of 2.5 for resisting an earth load consisting of the total equivalent earth load plus a 10 000-lb wheel load and impact load. Under impact loading conditions, the 2.5 safety factor for the operating pressure represents sound design practice, for it is unlikely that internal surge pressure would occur at the same instant as external impact.

Sec. 2.2—Combined-Loading Theory

Tests of asbestos–cement pipe under various combinations of internal pressure and external load applied in three-edge bearing (see Sec. 2.3) indicate that there is a relationship between the combined loads at the point of pipe fracture. This relationship can be represented by a parabolic curve as shown in Fig. 1. The equation for the load pressure parabolic curve shown in Fig. 1 may be expressed as:

$$w = W\sqrt{\frac{P - p}{P}} \qquad \text{Eq 1}$$

in which, P is the internal pressure, in pounds per square inch, that will burst the pipe when no external load exists; W is the external load, in pounds per lineal foot of pipe in the three-edge bearing test, that will crush the pipe when no internal pressure exists; p is the internal pressure, in pounds per square inch which, in combination with some external load w applied in three-

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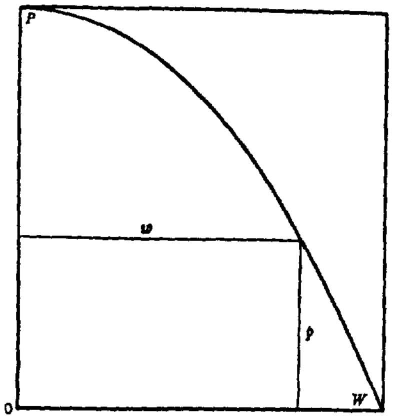

Fig. 1. Load Pressure Curve

P *represents the internal pressure;* W *the external load.*

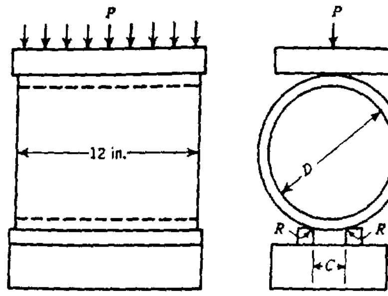

Fig. 2. Crushing Test Assembly

The diagram at the left shows a side view of the test assembly; that at the right, an end view. P *represents load;* R, *approximately 0.5 in.—the radius of the bearings;* D, *the nominal diameter of the pipe; and* C, *the clear space between supports.* C *should be approximately 1 in./ft of internal pipe diameter but in no case less than 1 in.*

edge bearing, will fracture the pipe; and w is the external load, in pounds per lineal foot of pipe applied in three-edge bearing which, in combination with some internal pressure p, will fracture the pipe.

Sec. 2.3—Three-Edge Bearing Load Factors

A convenient method of testing pipe for crushing strength W is the three-edge-bearing method of loading shown in Fig. 2. Because the field supporting strength of a conduit is influenced by the bedding conditions and the lateral pressure acting against the sides of the conduit, it is necessary to apply a load factor to the three-edge bearing loads in order to correlate them to the field loads. Since the external load equals the load factor times the three-edge bearing load, the load factor equals the external load divided by the three-edge bearing load. Table 2 shows load factors to be applied for each of the bedding conditions described in Table 1.

TABLE 2

Correlation of Bedding Conditions, Pipe Size, and Load Factors

Bedding Class	Pipe Size *in.*	Load Factor
A	4–12	1.7
	14–16	1.8
B	4–16	1.5
C	4–12	1.3
	14–16	1.4
D	4–16	1.1

Sec. 2.4—Hydrostatic Pressures

The hydrostatic pressures to be considered in pipeline design are static operating pressure and surge pressure. The static pressure will be fixed by the particular field service condition. Ordinary surge pressure conditions are allowed for in this standard by applying a safety factor of at least 4.0 to internal pressure in combined loading.

2.4.1 *Exceptional surge pressures.* When exceptional surge pressures are a necessary specific consideration in design, a conservative basis for surge allowance determination is the method proposed by S. Logan Kerr. His method considers the fundamental relations affecting water hammer, including velocity of flow in the pipeline, length of the pipeline, time of valve operation or interruption of flow, and the pressure wave velocity. Water hammer allowance is determined by the formulas of Eq 2 and 3.

$$h = 2.3p = \frac{aV}{g} \qquad \text{Eq 2}$$

in which,

h is the water hammer allowance, in feet; p is the water hammer allowance, in pounds per square inch; a is the velocity of the pressure wave, in feet per second; g is the acceleration due to gravity (32.2 fps/s); and V is the flow line velocity, in feet per second, cut off by the valve operation or other action in the critical time, or less.

$$a = \frac{4660}{\sqrt{1 + \frac{k}{E} \cdot \frac{d}{e}}} \qquad \text{Eq 3}$$

in which,

a is the pressure wave velocity in feet per second; k is the modulus of compression of water, in pounds per square inch (290 000–300 000 psi); E is the modulus of elasticity of asbestos–cement pipe, in pounds per square inch (3 400 000 psi); d is the internal diameter, in inches; and e is the wall thickness, in inches.

Sec. 2.5—External Loads

External-load determinations for underground conduit used in this standard are based on the data in Chapter 9 of the *Manual on Design and Construction of Sanitary and Storm Sewers* produced jointly by ASCE and WPCF. External loads on conduit are of two types: (1) those due to gravity earth loads and (2) those due to superimposed loads that may be static or moving.

2.5.1 *Gravity earth loads.* The magnitude of gravity earth loads may be computed by using the theory developed by Anson Marston which states, in general, that the load on a buried conduit is equal to the weight of a prism of earth (called the interior prism) directly over the conduit plus or minus the frictional shearing forces transferred to that prism by the adjacent prisms of earth. The magnitude and direction of these frictional forces are a function of the amount of relative settlement occurring between the interior and adjacent earth prisms. The general form of Marston's equation is

$$W = CwB^2 \qquad \text{Eq 4}$$

in which,

W is the vertical load, per lineal foot, acting on the conduit because of gravity earth loads; w is the weight of earth, in pounds per cubic foot; B is the trench or conduit width, depending on installation conditions; and C is the coefficient that includes the effect of:

1. The ratio of the height of the fill to the width of the trench or conduit,
2. the shearing forces between the interior and adjacent earth prisms,
3. the direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions, and
4. the rigidity of conduit support for embankment conditions.

2.5.1.1 Values for external loads may be determined by Marston's for-

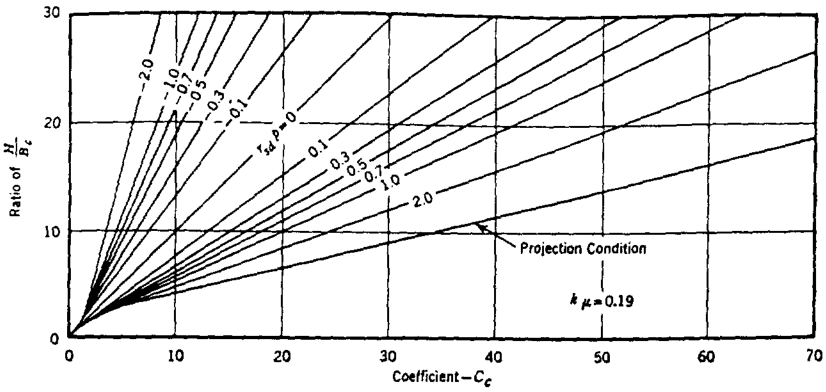

Fig. 3. Graph for Determining Load Coefficient Values

The graph shows a plot of load coefficient values C_c *against values obtained by dividing the height of the fill above the conduit by the outside width of the conduit* H/B_c.

mula as shown in Eq 5. Tables of external loads based on soil weight of 120 lb/cu ft are presented in Table A1 in the appendix.

$$W_c = C_c w (B_c)^2 \qquad \text{Eq 5}$$

in which,

W_c is the load on the conduit, in pounds per lineal foot; w is the unit weight of the soil, in pounds per cubic foot; B_c is the outside width of conduit, in feet; and C_c is the load coefficient.

In this formula load coefficient C_c is a function of H/B_c, p, r_{sd}, μ, and k. H is the height of the fill above the conduit, in feet. The projection ratio p is the ratio of the distance of the top of the conduit above the natural grade to the width of the conduit. r_{sd} is the settlement ratio, μ is the coefficient of internal friction of the backfill material, and k is the Rankins ratio of lateral pressure to vertical pressure.

2.5.1.2 Based on a Class C flat-bottomed, backfill-tamped trench, conservative values of $p = 1.0$, $r_{sd}p = 0.70$, and $k\mu = 0.192$ were used in the determination of external loads for the performance curves. C_c values may be determined from Fig. 3, which shows a plot of C_c against H/B_c ratios. For values of H/B_c greater than 1.3, when $r_{sd}p = 0.70$, the graph is linear and values may be determined by the empirical equation

$$C_c = 1.892\frac{H}{B_c} - 0.96 \qquad \text{Eq 6}$$

2.5.1.3 Occasionally, a trench condition exists in which the width of the trench is less than two or three times the widths of the conduit. In such cases, Marston's trench condition formula may be used for determinations of the gravity loads.

$$W_d = C_d w (B_d)^2 \qquad \text{Eq 7}$$

in which,

W_d is the vertical load, in pounds per lineal foot; B_d is the width of the trench; w is the weight of the backfill soil in pounds per cubic foot, and C_d is a load coefficient. (See Fig. 4 for values of C_d.)

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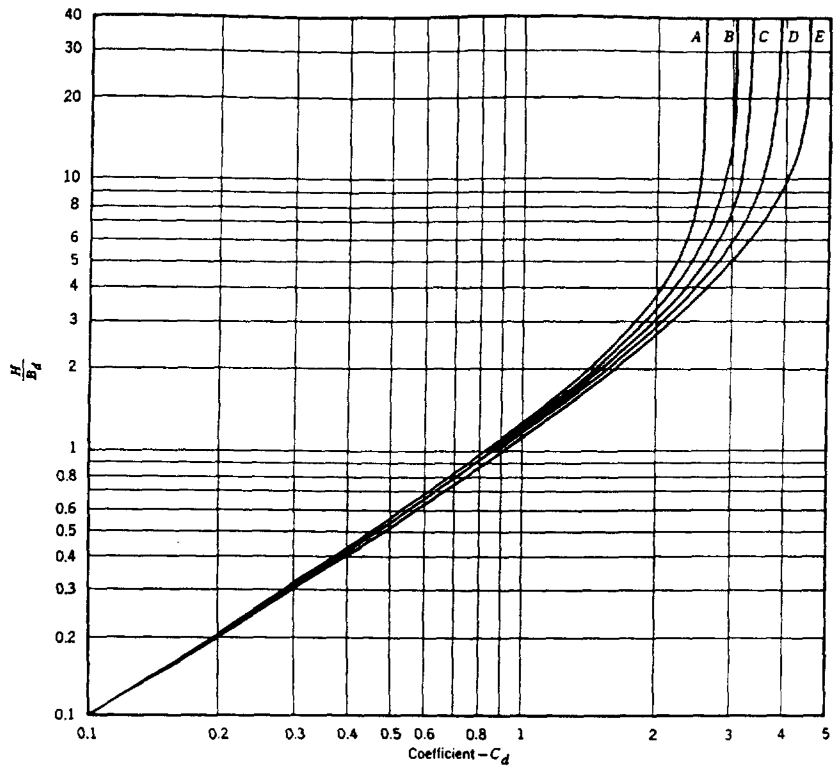

Fig. 4. Graph for Determining C_d Coefficients

Each of the above curves represent C_d *values for* $k\mu$ *and* $k\mu'$. A *represents 0.1924 for granular materials without cohesion;* B *is 0.165 maximum for sand and gravel;* C *is 0.150 maximum for saturated top soil;* D, *0.13 maximum for ordinary clay; and* E, *0.110 maximum for saturated clay. The symbol* μ', *is the coefficient of friction between the backfill material and the sides of the ditch.*

2.5.2 *Superimposed loads.* Where unusually heavy superimposed loads or impact loads are present, the solution of their magnitude may be computed for either a concentrated load (such as a truck load) or a distributed load condition. Normal truck and accompanying impact loads need not be considered when the depth of the cover is greater than 6 ft.

2.5.2.1 *Concentrated load.* The magnitude of a superimposed load produced by a concentrated load (see Fig. 5) is determined by use of the formula

$$W_{sc} = C_s \frac{PF}{L} \qquad \text{Eq 8}$$

in which,

W_{sc} is the load on the conduit, in pounds per lineal foot; P is the concentrated load, in pounds; F is the impact factor used to allow for the effects

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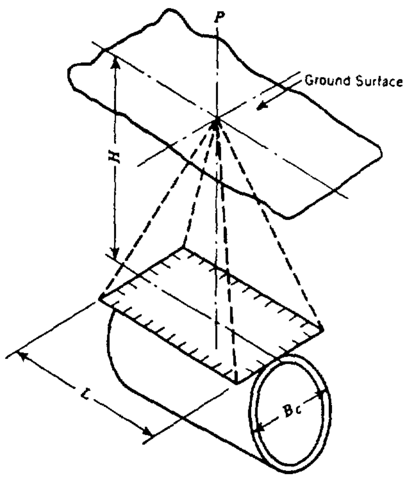

Fig. 5. Concentrated Superimposed Load

P represents the concentrated load; H, the height from the top of the conduit to the ground surface; B_c*, the width of the conduit; and L, the length of the conduit.*

of dynamic loads due to moving vehicles (see Table 3); C_s is a load coefficient, a function of $B_c/2H$ and $L/2H$ (see Tables 4 and 5); B_c is the width of the conduit, in feet (OD of the pipe); H is the height from the top of the conduit to the ground surface, in feet; and L is the effective length of the conduit, in feet. L is 3 ft for conduits greater than or equal to 3 ft in length, but is the actual length for conduits less than 3 ft in length.

2.5.2.2. *Distributed load.* In the case of a distributed superimposed load, the formula may be written in the form of

$$W_{sd} = C_s p F B_c \qquad \text{Eq 9}$$

in which,

W_{sd} is the load on the conduit, in pounds per lineal foot (see Fig. 6); p is the intensity of distributed load, in pounds per square foot; F is the

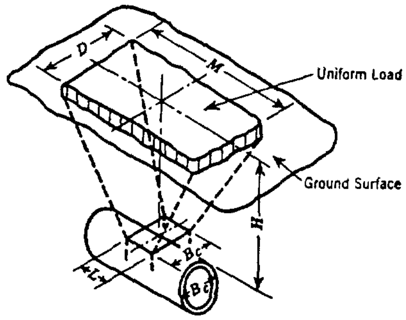

Fig. 6. Distributed Superimposed Load

D and M are the width and length, in feet, respectively, of the area over which the distributed load acts. The uniform load is lbs per sq ft acting on area D × M.

TABLE 3

Impact Factors Caused by Moving Vehicles

Type of Traffic	Impact Factor F
Highway	1.50
Railway	1.75
Airfield runways,	1.00
taxiways, aprons, or hardstands	1.50

impact factor (see Table 3); B_c is the width of conduit, in feet; C_s is a load coefficient, a function of $D/2H$ and $M/2H$ (see Table 4); H is the height from the top of the conduit to the ground surface, in feet; and D and M are the width and length, respectively of the area over which the distributed load acts, in feet.

Sec. 2.6—Selection Curves

Research tests and the application of statistical analysis have shown that asbestos-cement pipe strength may be graphically illustrated by combined-loading parabolic curves. The com-

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TABLE 4

Values of Load Coefficients for Concentrated and Distributed Superimposed Loads Centered Vertically Over Conduit

$D/2H$ or $B_c/2H$	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0 072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

TABLE 5

Values of Load Coefficients C_s for Concentrated Superimposed Loads Centered Vertically Over Conduit

Pipe Size *in.*	Depth of Cover—*ft*										
	2	2.5	3	4	5	6	8	10	12	16	20
4	0.105	0.076	0.055	0.033	0.022	0.016	0.009	0.006	0.004	0.002	0.0015
6	0.147	0.106	0.078	0.046	0.031	0.023	0.013	0.008	0.006	0.003	0.002
8	0.191	0.137	0.102	0.061	0.041	0.029	0.017	0.010	0.008	0.004	0.003
10	0.237	0.174	0.129	0.078	0.052	0.037	0.022	0.013	0.009	0.006	0.0035
12	0.279	0.202	0.153	0.092	0.062	0.044	0.025	0.016	0.011	0.007	0.004
14	0.317	0.232	0.175	0.106	0.071	0.050	0.030	0.018	0.013	0.008	0.005
16	0.354	0.259	0.197	0.121	0.081	0.057	0.034	0.021	0.015	0.009	0.0055

bined-loading theory developed by the late W.J. Schlick is used as the basis for selection curves for asbestos–cement water pipe.

2.6.1 *Curve development.* The selection curves included in this standard were developed using the load-pressure formula, with the external load intercept being the external load as tabulated in Table 2 of AWWA C400–77, "Standard for Asbestos–Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids," and the design point on the parabolic curve being that condition existing at a 5-ft depth of cover with the trench width assumed as pipe ID plus 2 ft, a bedding condition of Class C and a soil weight of 120 lb/cu ft. The external loads were based on the positive projecting conduit analysis because this analysis produced the governing load on the pipe at the conditions previously set forth. The design point for each class of pipe is based on a safety factor of 4 times the pipe pressure class and 2.5 times the three-edge bearing equivalent of the trench load. Once the parabolic curve has been established through the external load intercept and the control point, the equivalent depth of cover scale is correlated for the various bedding conditions utilizing either the trench load condition or the positive-projecting conduit-load condition, whichever is the governing load condition.

2.6.2 *Curve use.* The curves may be used conveniently by entering them through the depth of cover and bedding condition scales. The scales are correlated to the three-edge bearing equivalents of the design external loads with a safety factor of 2.5. When there is an external loading condition different from that due only to depth of cover, or when conditions warrant a change in the safety factor, the equivalent external load should be determined and the selection curve entered at the proper value on the design external load scale. The field supporting strength listed for pipe so selected has been proved conservative during many years of performance under various field conditions.

2.6.2. *Example.* The application of the curves to design is shown in the following problem:

Required: A 6-in. pipe to operate at a pressure of 120 psi at 8 ft depth of cover. Bedding condition Class C, soil weight 120 lb/cu ft.

Solution: Enter the selection curve for 6-in. pipe at bedding condition Class C, 8 ft cover. The intersection of the 8-ft cover line with the 120 psi operating pressure line falls between pipe Classes 100 and 150. Use 6 in., Class 150.

The intersection of the 8-ft cover line with the Class 150 curve is at 135 psi operating pressure, or 550 psi design pressure. Therefore, the pressure safety factor equals 550/120 = 4.6, with a safety factor of 2.5 for external load.

2.6.3 *Curves.* The selection curves for 4 in. through 16 in. asbestos–cement pipe are shown in Figs. 7 through 13 respectively.

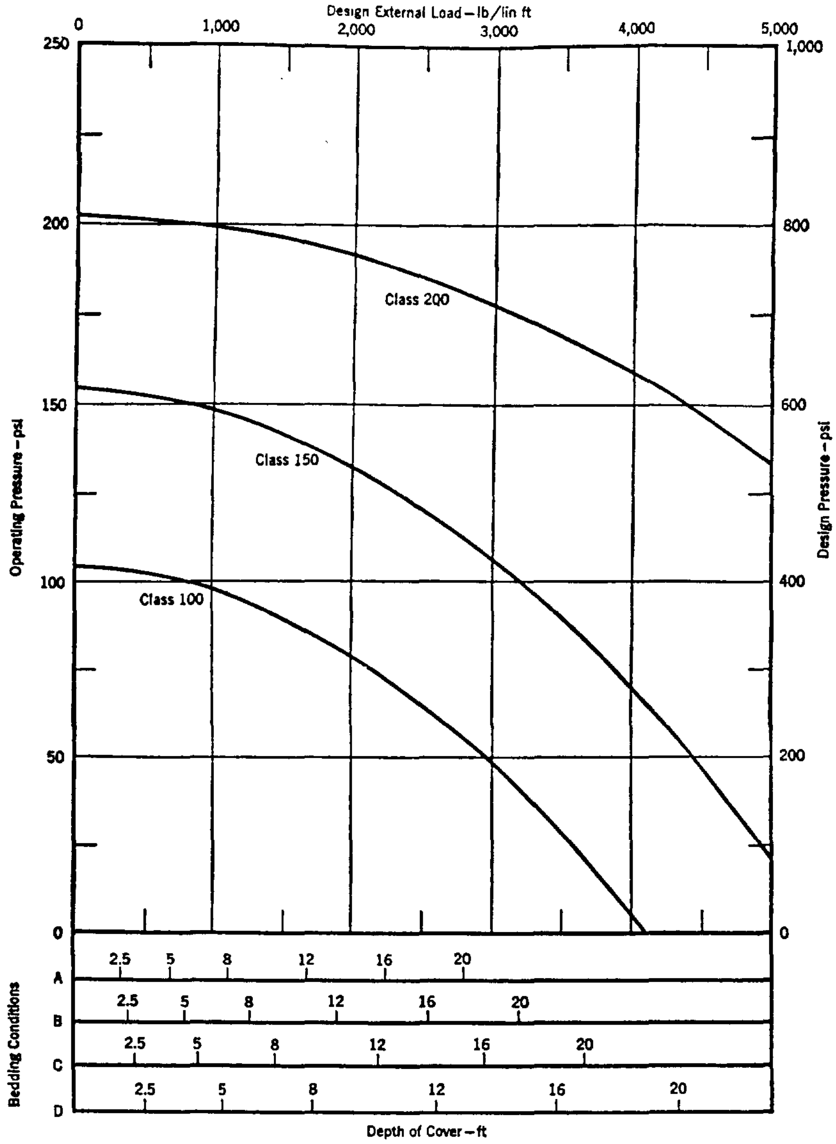

Fig. 7. Selection Curves for 4-in. Asbestos–Cement Pipe

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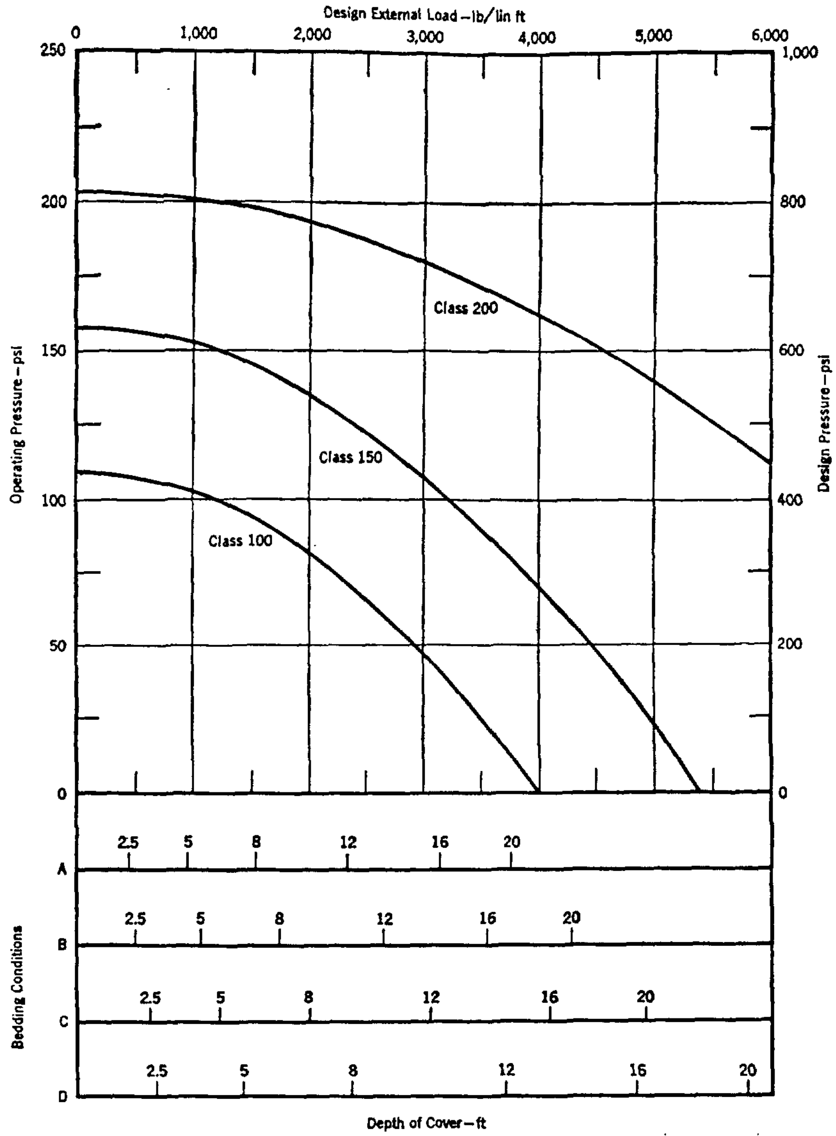

Fig. 8. Selection Curves for 6-in. Asbestos-Cement Pipe

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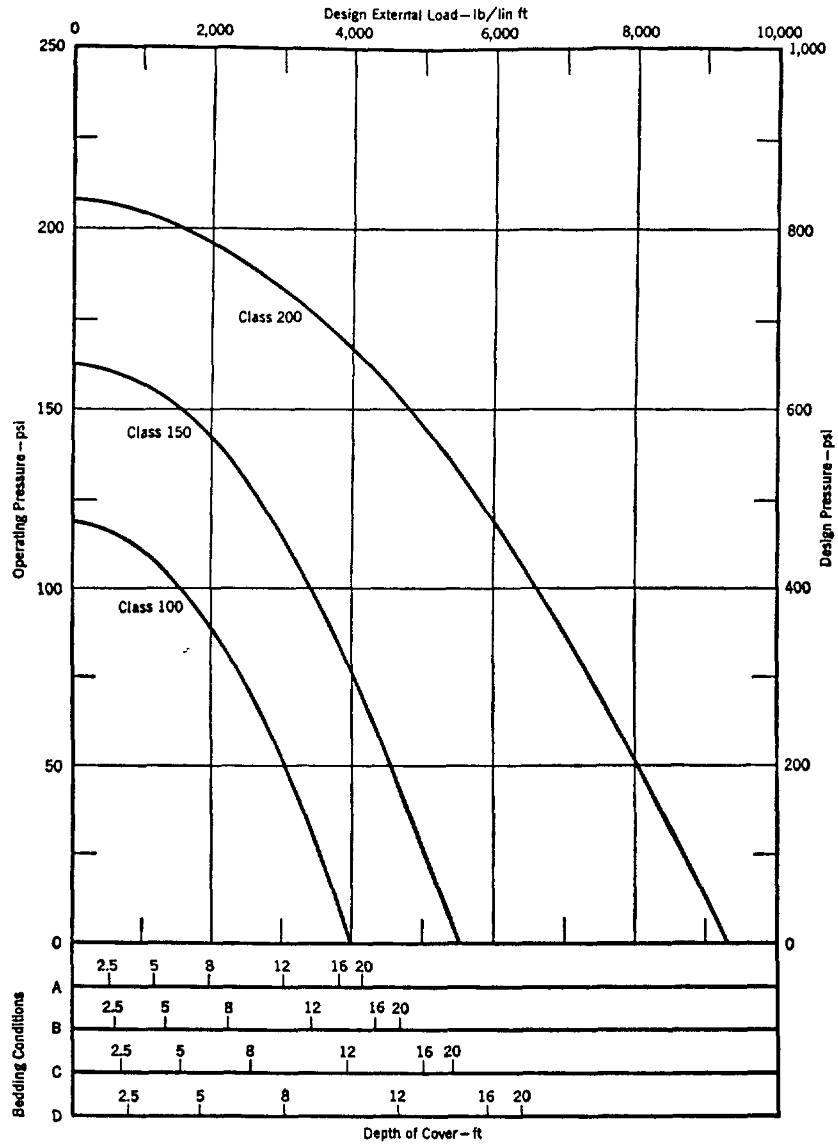

Fig. 9. Selection Curves for 8-in. Asbestos–Cement Pipe

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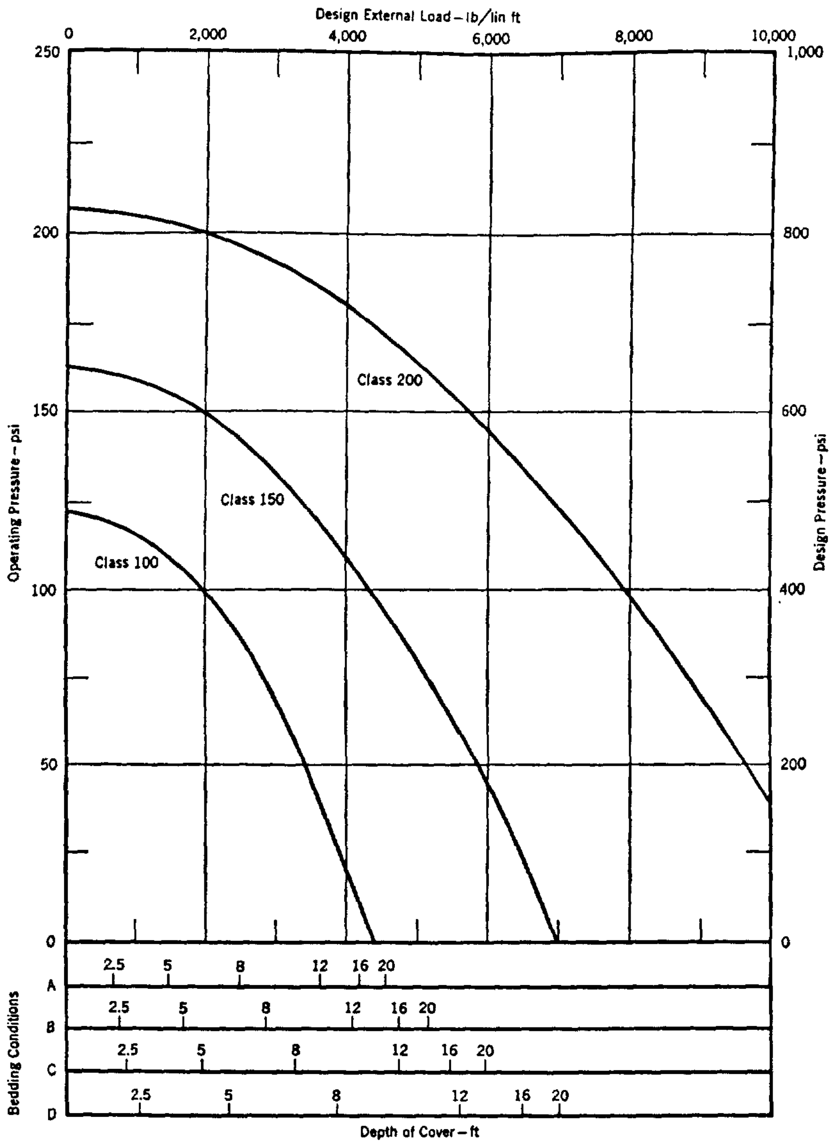

Fig. 10. **Selection Curves for 10-in. Asbestos–Cement Pipe**

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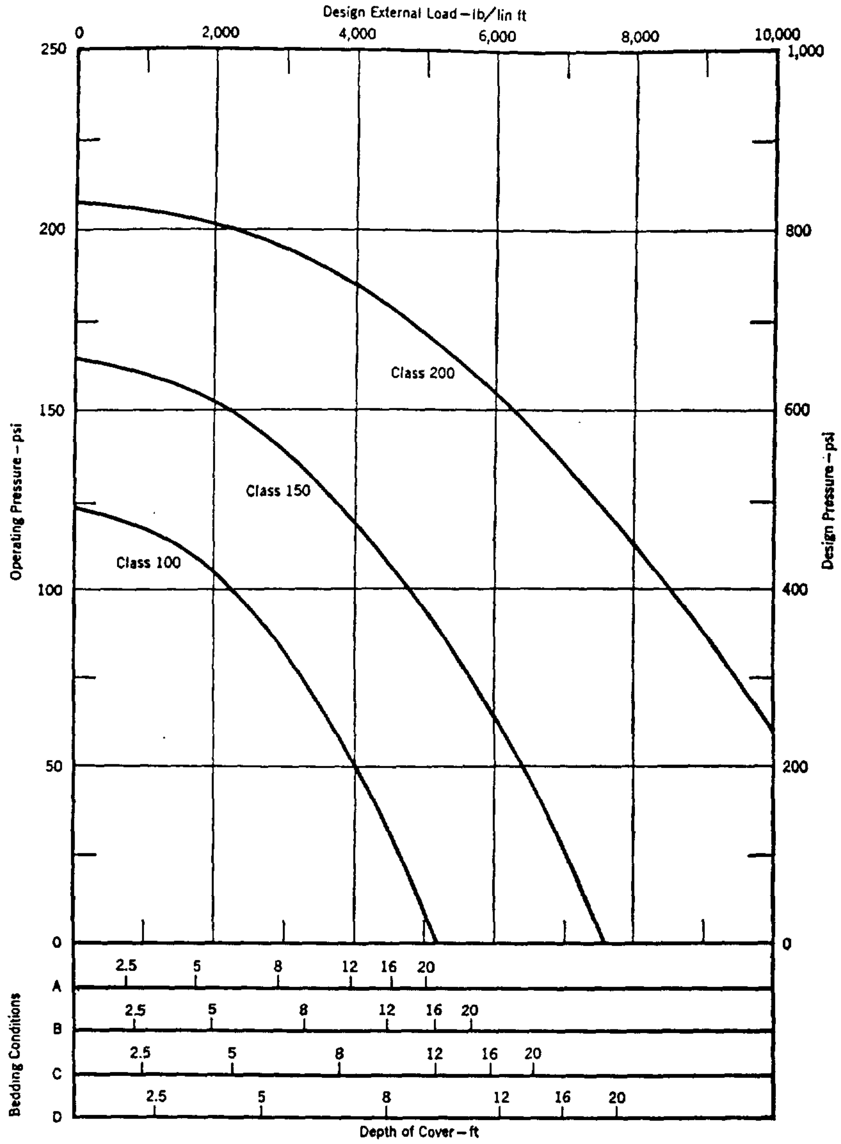

Fig. 11. Selection Curves for 12-in. Asbestos–Cement Pipe

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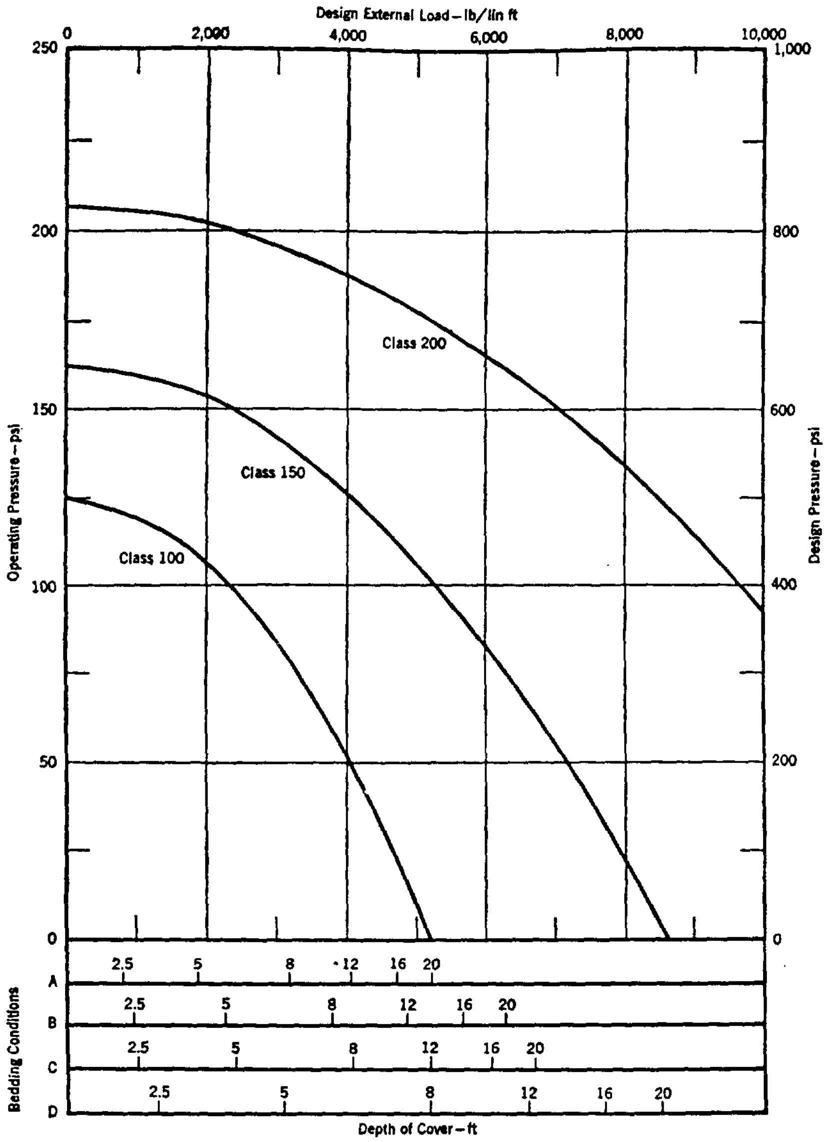

Fig. 12. Selection Curves for 14-in. Asbestos–Cement Pipe

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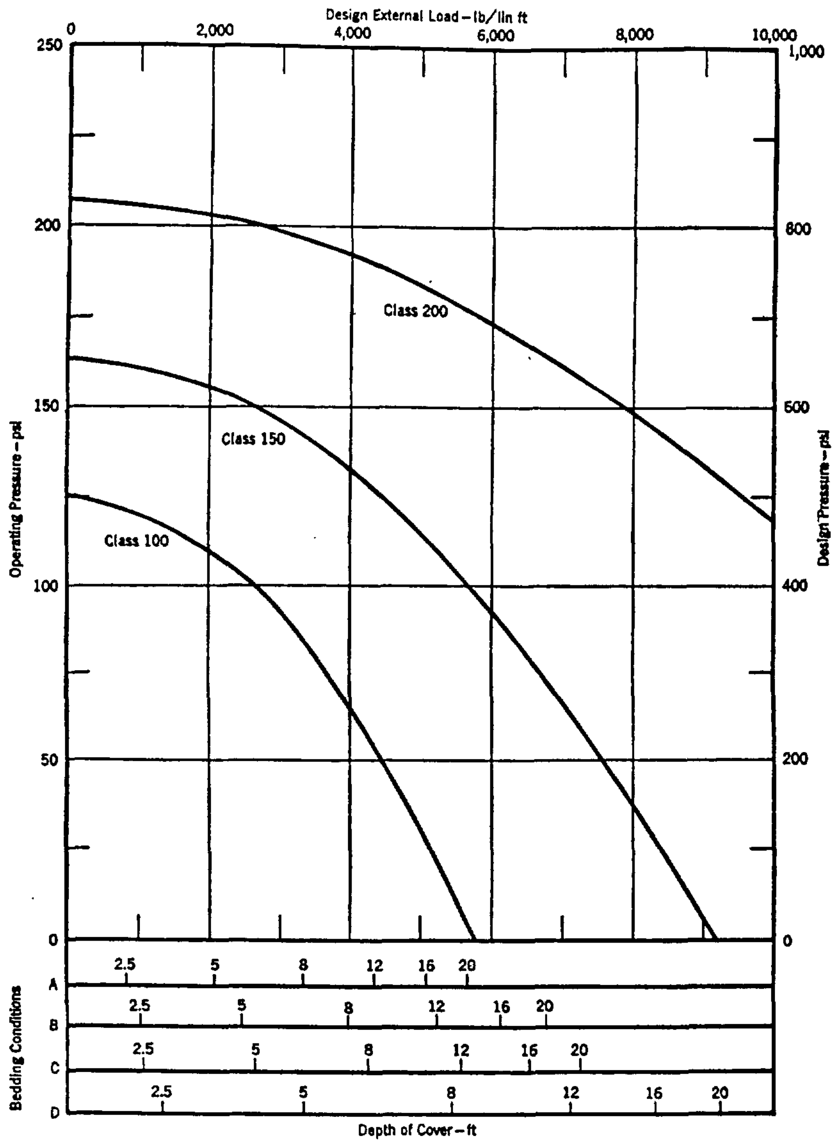

Fig. 13. Selection Curves for 16-in. Asbestos–Cement Pipe

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Appendix

This appendix is for information only and is not a part of AWWA C401.

A1. General

Data developed for the preparation of the selection curves are included in this appendix. Figures illustrating the various bedding conditions and the earth load conditions used in the preparation of the selection curves are included.

A2. Tables

In Table A2 of design internal pressure and design external load intercepts, the external loads are the crushing loads that the pipe must be able to support without failure as specified in AWWA C400. The tables of design earth load *w* for various field bedding conditions and depths of cover show the calculated loads for Class 150 pipe. For Class 100 pipe, similar calculated loads would be less than those shown in the tables, and for Class 200 pipe, the loads would be greater. The maximum variation would be less than 5 per cent.

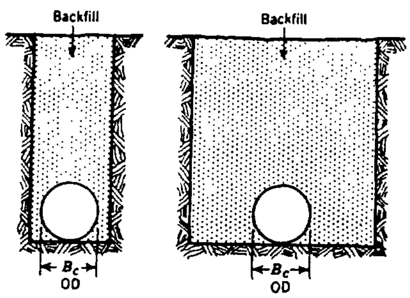

Fig. A1. Earth Load Conditions

The illustration on the left shows trench conduit conditions, that is, the trench width is less than two or three times B_c. The illustration on the right shows a positive projecting conduit condition; that is, the trench width is greater than two or three times B_c. The shaded area represents backfill.

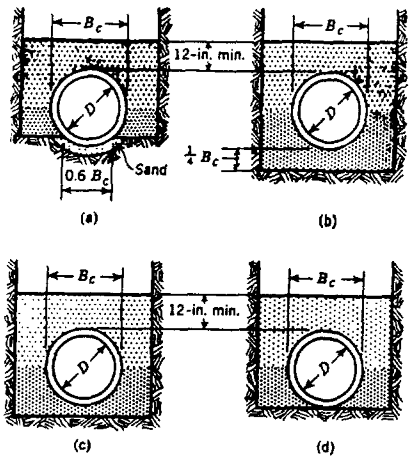

Fig. A2. Bedding Conditions Illustrated

Class A bedding conditions are shown in (a) and (b). Class C conditions are shown in (c) and (d). In all four diagrams, the lightly shaded area represents approved backfill, not frozen and free from lumps, large stones, boulders, or other unsuitable substances. The heavily shaded areas represent approved backfill, carefully compacted in 4-in. layers as specified by the engineer. In (a), a minimum of 2 in. of sand is placed in a shaped bottom under the pipe. In (b), the pipe is bedded in a gravel base. In (c), the pipe barrel rests on earth mounds and then the backfill between the earth mounds is compacted. In (d), the pipe barrel is resting on the flat bottom of the trench. Class B condition is the same as Class A, and Class D is the same as Class C except that the backfill is not tamped in B or D.

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TABLE A1

Determination of Design Earth Load w Applied in 3-Edge Bearing

Pipe Size in.	1 Ex-ternal Load lb	2 Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	3 w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)	1 Ex-ternal Load lb	2 Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	3 w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)	1 Ex-ternal Load lb	2 Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	3 w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)
Class A Bedding Condition									
	2.5 ft of Cover			5 ft of Cover			8 ft of Cover		
4	219	129	323	458	269	673	744	438	1,095
6	297	175	438	634	373	933	1,041	612	1,530
8	371	218	545	814	479	1,198	1,344	790	1,975
10	450	264	660	1,012	595	1,488	1,688	993	2,483
12	507	298	745	1,174	691	1,728	1,975	1,162	2,905
14	559	311	778	1,336	742	1,855	2,267	1,259	3,148
16	604	335	838	1,484	825	2,063	2,398	1,332	3,330
	12 ft of Cover			16 ft of Cover			20 ft of Cover		
4	1,127	663	1,658	1,510	888	2,220	1,893	1,113	2,783
6	1,584	932	2,330	2,124	1,249	3,123	2,550	1,500	3,750
8	2,051	1,206	3,015	2,602	1,531	3,828	2,816	1,656	4,140
10	2,451	1,441	3,603	2,835	1,668	4,170	3,076	1,809	4,523
12	2,678	1,575	3,938	3,078	1,811	4,528	3,402	2,001	5,003
14	2,886	1,603	4,008	3,367	1,870	4,675	3,727	2,070	5,175
16	3,130	1,738	4,345	3,663	2,035	5,088	4,063	2,257	5,643
Class B Bedding Condition									
	2.5 ft of Cover			5 ft of Cover			8 ft of Cover		
4	219	146	365	458	305	763	744	496	1,240
6	297	198	495	634	423	1,058	1,041	694	1,735
8	371	248	620	814	542	1,355	1,344	896	2,240
10	450	300	750	1,012	674	1,685	1,688	1,126	2,815
12	507	338	845	1,174	783	1,958	1,975	1,317	3,293
14	559	373	933	1,336	890	2,225	2,267	1,512	3,780
16	604	402	1,005	1,484	989	2,473	2,398	1,598	3,995
	12 ft of Cover			16 ft of Cover			20 ft of Cover		
4	1,127	751	1,878	1,510	1,007	2,518	1,827	1,218	3,045
6	1,584	1,056	2,640	1,224	1,416	3,540	2,550	1,700	4,250
8	2,051	1,367	3,418	2,602	1,735	4,338	2,816	1,877	4,693
10	2,451	1,634	4,085	2,835	1,890	4,725	3,076	2,050	5,125
12	2,678	1,785	4,463	3,078	2,052	5,130	3,402	2,268	5,670
14	2,886	1,924	4,810	3,367	2,244	5,610	3,727	2,485	6,213
16	3,130	2,086	5,215	3,663	2,442	6,105	4,063	2,708	6,770

TABLE A1—*Determination of Design Earth Load* w *Applied in 3-Edge Bearing (contd.)*

	1	2	3	1	2	3	1	2	3
Pipe Size in.	External Load lb	Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)	External Load lb	Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)	External Load lb	Equivalent Three-Edge Bearing Load (Col. 1 / Load Factor)	w Earth Load Applied in Three-Edge Bearing (Col. 2 × 2.5 Factor of Safety)
Class C Bedding Condition									
	2.5 ft of Cover			5 ft of Cover			8 ft of Cover		
4	219	168	420	458	352	880	744	573	1,433
6	297	228	570	634	488	1,220	1,041	801	2,003
8	371	286	715	814	626	1,565	1,344	1,034	2,585
10	450	346	865	1,012	778	1,945	1,688	1,299	3,248
12	507	390	975	1,174	903	2,258	1,975	1,519	3,798
14	559	400	1,000	1,336	954	2,385	2,267	1,619	4,048
16	604	431	1,078	1,484	1,060	2,650	2,398	1,712	4,280
	12 ft of Cover			16 ft of Cover			20 ft of Cover		
4	1,127	867	2,168	1,510	1,161	2,903	1,893	1,456	3,640
6	1,584	1,219	3,048	2,124	1,634	4,085	2,550	1,961	4,903
8	2,051	1,578	3,945	2,602	2,002	5,005	2,816	2,166	5,415
10	2,451	1,885	4,713	2,835	2,181	5,453	3,076	2,366	5,915
12	2,678	2,060	5,150	3,078	2,368	5,920	3,402	2,617	6,543
14	2,886	2,061	5,153	3,367	2,405	6,013	3,727	2,662	6,655
16	3,130	2,235	5,588	3,663	2,616	6,540	4,063	2,902	7,255
Class D Bedding Condition									
	2.5 ft of Cover			5 ft of Cover			8 ft of Cover		
4	219	199	498	458	416	1,040	744	677	1,693
6	297	270	675	634	577	1,443	1,041	946	2,365
8	371	338	845	814	740	1,850	1,344	1,221	3,053
10	450	409	1,023	1,012	920	2,300	1,688	1,535	3,838
12	507	461	1,153	1,174	1,068	2,670	1,975	1.795	4,488
14	559	509	1,273	1,336	1,214	3,035	2,267	2,061	5,153
16	604	549	1,373	1,484	1,349	3,373	2,398	2,180	5,450
	12 ft of Cover			16 ft of Cover			20 ft of Cover		
4	1,127	1,025	2,563	1,510	1,373	3,433	1,893	1,721	4,303
6	1,584	1,440	3,600	2,124	1,931	4,828	2,550	2,318	5,795
8	2,051	1,864	4,660	2,602	2,366	5,915	2,816	2,560	6,400
10	2,451	2,228	5,570	2,835	2,578	6,445	3,076	2,796	6,990
12	2,678	2,434	6,085	3,078	2,798	6,995	3,402	3,093	7,733
14	2,886	2,623	6 558	3,367	3,061	7,653	3,727	3,388	8,470
16	3,130	2,845	7,113	3,663	3,330	8,325	4,063	3,693	9,233

TABLE A2

Design Internal Pressure and Design Earth Load Intercepts for Use With Selection Curves

Pipe Size in.	Class 100		Class 150		Class 200	
	P psi	W lb/lin ft	P psi	W lb/lin ft	P psi	W lb/lin ft
4	417	4,100	616	5,400	809	8,700
6	441	4,000	632	5,400	815	9,000
8	472	4,000	653	5,500	824	9,300
10	490	4,400	650	7,000	826	11,000
12	490	5,200	658	7,600	830	11,800
14	500	5,200	650	8,600	826	13,500
16	500	5,800	654	9,200	825	15,400

2P–6M–5 78–43401

American Water Works Association

AWWA C400-77

(Revision of
AWWA C400-75)

AWWA STANDARD

for

ASBESTOS-CEMENT DISTRIBUTION PIPE, 4 IN. THROUGH 16 IN., FOR WATER AND OTHER LIQUIDS

First edition approved by AWWA Board of Directors May 15, 1953.
This edition approved Jan. 30, 1977.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

CTD029442

Committee Personnel

The Standards Committee on Asbestos-Cement Pressure Pipe that reviewed and approved this standard had the following personnel at the time of approval:

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J. L. Warden, *Vice-Chairman*
T. R. Gillen, *Secretary*

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CTD029443

Table of Contents

Foreword

This foreword is for information only and is not a part of AWWA C400

I—History of Standard

A new pipe material consisting of an intimate mixture of portland cement and asbestos fibers was introduced to the North American market in 1931 following several years of satisfactory usage in other countries, particularly Italy.

In the ensuing years this type of pipe gained popularity, and in 1949 AWWA established a committee on standard specifications for asbestos-cement pipe under the chairmanship of S.M. Clark of Greeley and Hanson, Chicago.

The committee developed a standard for asbestos-cement water pipe which was approved by the AWWA Board of Directors as a tentative standard, AWWA C400-53T, May 15, 1953. In 1958, the committee was reactivated as Committee 8340D on Asbestos-Cement Pipe under the chairmanship of Roy H. Ritter of Whitman, Requardt and Assocs., Baltimore to review several suggested changes and to recommend revisions to the standard. The committee produced a revised tentative standard adopted by AWWA as C400-64T Jan. 27, 1964, which was advanced to standard without revision Jul. 2, 1965.

In 1968 the committee was reactivated as the Standards Committee on Asbestos-Cement Pipe to review and revise all AWWA standards on asbestos-cement pipe. The committee produced a revised standard approved by the Board of Directors Jan. 31, 1972 designated as AWWA C400-72, "Asbestos-Cement Pressure Pipe for Water and Other Liquids."

In 1972 and 1973 the committee was reorganized and enlarged to include representation of national organizations having an interest in the scope of the committee and wishing to participate in the work. The reorganized committee reaffirmed C400-72 without revision so that it could be presented to the American National Standards Institute for designation as an American National Standard.

In 1975 the committee produced a revised standard approved by the AWWA Board of Directors Jan. 26, 1975 designated as AWWA C400-75, "Asbestos-Cement Pressure Pipe, 4 in. Through 24 in., for Water and Other Liquids." At that same time a new standard was produced by the committee and approved by the AWWA Board of Directors and designated as AWWA C402-75, "Asbestos-Cement Transmission Pipe, 18 in. Through 42 in., for Water and Other Liquids."

The possibility of confusion between the two standards—C400 and C402—was carefully reviewed by the committee. The result is this edition of C400-77 which reduces the sizes covered from 4 in. through 24 in. to 4 in. through 16 in. There is no overlap of sizes anymore.

II—Information Regarding Use of This Standard

II.A *General.* When ordering pipe covered by this standard, local installation and operating conditions should be considered to determine the class and type of pipe to specify. Also, certain other items must be specified to describe completely the pipe required.

According to the conditions of installation and operation in many water distribution systems, the pipe may be used at operating pressures equal to the class designations. The purchaser should determine for himself from AWWA C401, "Standard Practice for the Selection of Asbestos-Cement Distribution Pipe," the proper class of pipe to be used under the installation and operating conditions that will exist for the project on which the pipe is to be used.

The purchaser is referred to AWWA C603, "Installation of Asbestos-Cement Pressure Pipe," for guidance in laying of the pipe.

II B *Flexural load test.* The flexural load tests for pipe sizes 4, 6, and 8 in. (Sec. 2.2.1 and 5.2.3) are intended only for use as a quality control test, not as a simulated service test. Asbestos-cement pipe will not be subjected to flexural stresses if properly installed with satisfactory bedding methods.

For diameters 10 in. and larger, the wall thickness increases to a point at which the flexural strength is not a controlling factor, and hence, routine testing is not required.

II.C *Type of pipe.* The following criteria are presented for determining the type of pipe to be used under various soil and water conditions. Each condition should be considered separately even though each may exist in combination with others. These criteria are based on exposures within the temperature range of 40–80F (5–28C). For exposure of pipe to temperatures beyond these limits, consult the manufacturer.

TABLE F.1

Asbestos-Cement Pipe Type Recommended for Internal Water Aggressiveness

Internal Water Aggressiveness	Recommended Pipe Type*
Highly aggressive	†
Moderately aggressive	II
Nonaggressive	I and II

* Type I—no limit on uncombined calcium hydroxide. Type II—per cent or less uncombined calcium hydroxide

† The serviceability of pipe for such applications should be established by the purchaser in conjunction with the manufacturer.

The following criteria are referenced as:

1. Internal water (Table F.1).
2. External water (Table F.2).
3. Nonacid soluble sulfates—internal and external (Table F.3).
4. Acid soluble sulfates—internal and external.

II.C.1 *Internal water.* Aggressiveness of water transported through asbestos-cement pipe is related to the type designation of asbestos-cement pipe suitable for such use in Table F.1. Aggressiveness of water is defined as follows:

a. Highly aggressive:

$$\text{pH} + \log (AH) < 10.0$$

b. Moderately aggressive:

$$\text{pH} + \log (AH) = 10.0\text{–}11.9$$

c. Nonaggressive:

$$\text{pH} + \log (AH) \geq 12.0$$

where

pH = Index of acidity (or alkalinity) of the water—standard pH units

A = Total alkalinity—ppm (mg/l) as $CaCO_3$

H = Calcium hardness—ppm (mg/l) as $CaCO_3$

TABLE F.2

Aggressiveness of Nonsulfate Acidic Soils to Asbestos-Cement Pipe

Water Conditions Within the Soil Environment	Minimum pH of Acidic Soils When Using Asbestos-Cement Pipe	
	Type I	Type II
Essentially quiescent	5.0	4.0
Mildly fluctuating	5.5	5.0
Rapidly moving or grossly cyclic	6.3	5.5

TABLE F.3

Asbestos-Cement Pipe Type Designation Chemical Resistance to Nonacid ($pH = 7.0$) Soluble Sulfates in Water and Soils

Type Designation	Chemical Resistance to Nonacid Soluble Sulfates in Water and Soils
I*	Will be attacked to various degrees by all but the non-aggressive levels of sulfate concentrations in waters and soils.
II	Resistant to all levels of soluble sulfates.

*The guideline criteria for sulfate resistance of Type I pipe were taken from the *Concrete Manual*, 8th edition, Bureau of Reclamation, 1974. Sulfate resistance here applies to all soluble sulfates regardless of the cation.

It should be recognized that water that has a pH + log (AH) less than or equal to 10 is an extremely aggressive water and would be very corrosive to almost all materials found in a typical water system, including the plumbing in consumers' homes. Such waters should be treated to increase pH or hardness to protect the entire network of materials making up the system. If such water treatment is not undertaken, the manufacturer of each item used in the water system should be consulted for recommendations regarding the use of his product in an extremely corrosive environment.

NOTE: The expression pH + log (AH) is a modification of the Langelier Index. It has been prepared so that the aggressiveness of the water can be determined easily. A reasonable comparison of the two would be as indicated below.

II.C.2 *External water.* Aggressiveness of external water (water within the soil environment) is related to asbestos–cement pipe in Table F.2. The guidelines for the use of asbestos–cement pipe in nonsulfate acidic soils are based upon minimum pH factors alone. Asbestos–cement pipe may or may not perform satisfactorily in acidic soil environments that have pH values below those listed in Table F.2. To determine the suitability of asbestos–cement pipe in soils having lower pH values, each situation should be evaluated individually and take into consideration all aspects of soil environment that affect asbestos–cement pipe corrosiveness.

II.C.3 *Nonacid soluble sulfates—internal and external.* Aggressiveness of nonacid ($pH \geq 7.0$) soluble sulfates in water and soils is related to the type designation of asbestos–cement pipe suitable for such use in Table F.3.

	pH + log (AH)	Langelier Index
Highly aggressive water	<10.0	< -2.0
Moderately aggressive water	10.0–11.9	-2.0 to -0.1
Nonaggressive water	≥ 12.0	≥ 0

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Sulfate Aggressiveness Classification	Water	Soil
	Water Soluble Sulfates—*ppm* SO_4	Water Soluble Neutral Sulfates—*ppm* SO_4
Nonaggressive	150 and less	1000 and less
Mildly aggressive	150–1500	1000–2000
Moderately aggressive	1500–10 000	2000–20 000
Highly aggressive	10 000 and greater	20 000 and greater

Sulfate aggressiveness in water and soil can be classified as indicated above.

II.C.4 *Acid soluble sulfates—internal and external.* Aggressiveness of acid (pH < 7.0) soluble sulfate waters and soils to asbestos–cement pipe must be evaluated independently.

Acid sulfate soils and waters, whether the acid is inorganic or organic, must be evaluated independently of the criteria and guidelines set forth in Sec. II.C.2 and II.C.3 and must take into consideration soil permeability and other factors. Consult the manufacturer for guidance.

II.D *Supplementary specifications.* The following information summarizes the conditions and items that the purchaser should consider when preparing his supplementary specifications. The section in the standard where they can be found is also listed.

1. The standard used; that is, AWWA C400-77.
2. Affidavit of compliance, if required (Sec. 1.3).
3. Type of pipe to be furnished (Sec. 2.3 and Foreword II.C).
4. Class of pipe (Sec. 3.1).
5. Nominal inside diameter (Sec. 3.2).
6. Lineal feet to be furnished in standard and random lengths (Sec 3.3).
7. Number, size, type, class, lengths, and extent of machining of special short lengths (Sec. 3.3.3).
8. Whether inspection by the purchaser (Sec. 5.1) and special marking (Sec. 6.1.4) are required.

III—Major Revisions

Major changes to the 1975 standard that were made in this revision are

1. The title has been changed to indicate that the pipe is intended for use in distribution systems.
2. The size range has been changed to limit the maximum size covered by this standard to 16-in. diameter pipe.
3. A more detailed description of aggressive soil and water criteria has been added in Sec. II of the Foreword.
4. The lot definition of paragraph 1.2.3 has been revised to limit the quantity to a maximum of 300 sections instead of all sections manufactured in a shift.
5. Paragraph 5.2.5 *Machines for Testing* has been revised to allow couplings to be hydrostatically tested with a rubber bladder inside the coupling at 4× the pipe's class rating.

American Water Works Association

AWWA C400-77

(Revision of
AWWA C400-75)

AWWA Standard for

Asbestos-Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids

Section 1—General

Sec. 1.1—Scope

This standard covers three pressure classes of Type I and Type II asbestos-cement pipe, 4-16 in. in diameter, for water and other liquids intended to be laid underground in public and private rights-of-way.

1.1.1 *Use.* Asbestos-cement distribution pipe is to be used in pipe systems having relatively unpredictable flows and many appurtenances that do not permit reasonable hydraulic analyses, including that for surge pressure.

1.1.2 *Pressure classes.* The pressure class designations of class 100, class 150, and class 200 are the same as those used in AWWA C401 (formerly AWWA H2) "Standard Practice for the Selection of Asbestos-Cement Distribution Pipes."

Sec. 1.2—Definitions

Under this standard, the following definitions shall apply:

1.2.1 *Inspection.* Inspection of the pipe and the tests by the inspector.

1.2.2 *Inspector.* The authorized representative of the purchaser, entrusted with the duty of inspecting pipe produced and tests performed under this standard.

1.2.3 *Lot.* A lot as used herein is defined as all pipe of any one class, type, and size manufactured on any one machine in 24 hr but not to exceed 300 lengths.

1.2.4 *Manufacturer.* The person, firm, or corporation that manufactures the pipe.

1.2.5 *Operating pressure.* The maximum hydrostatic pressure to which the pipe will be subjected in normal operation after installation, exclusive of allowance for water hammer.

1.2.6 *Purchaser.* The person, firm, corporation, or government agency entering into a contract or agreement to purchase pipe according to the provisions of this standard.

Sec. 1.3—Affidavit of Compliance

Whether factory inspection has been required or not, the purchaser's supplemental specifications may require an affidavit of compliance from the manufacturer to the effect that the materials furnished under the purchaser's order comply with all applicable requirements of this standard.

Section 2—Materials

Sec. 2.1—Composition

Asbestos-cement pipe shall be composed of an intimate mixture of either: (1) portland cement or portland blast furnace slag cement and asbestos fiber with or without silica; or (2) portland pozzolana cement and asbestos fiber. Both (1) and (2) can be with or without the addition of curing agents. The pipe shall be formed under pressure and cured. The finished pipe shall be free from organic materials.

Sec. 2.2—Physical Requirements

2.2.1 *Flexural strength.* Each length of 4-, 6-, and 8-in. pipe tested in flexure by the procedure specified in this standard shall, except as otherwise provided, support the load indicated in Table 1.

2.2.2 *Bursting strength.* Each length of pipe and each coupling sleeve shall have sufficient strength to withstand the design internal pressure indicated for its class in Table 2 when subjected to the hydrostatic test procedure specified in this standard.

TABLE 1

Flexural Test Loads

Nominal Diameter in.	Class 100	Class 150	Class 200
	Total Applied Load—lb		
4	1,200	1,470	1,870
6	2,800	3,700	4,900
8	5,330	7,600	10,130

2.2.3 *Crushing strength.* Each length of pipe shall have sufficient strength to support the design external load indicated for its class in Table 2 when subjected to the crushing-test procedure specified in this standard.

Sec. 2.3—Chemical Requirements

Pipe shall be designated as either *Type I* or *Type II* according to its content of uncombined calcium hydroxide as determined by the test procedures in this standard for uncombined calcium hydroxide. The requirements for each type are

Type I—no limit on uncombined calcium hydroxide,

Type II—1 per cent or less uncombined calcium hydroxide.

TABLE 2

*Design Internal Pressure and Design External Load**

Pipe Size in.	Class 100		Class 150		Class 200	
	Internal Pressure psi	External Load lb/lin ft	Internal Pressure psi	External Load lb/lin ft	Internal Pressure psi	External Load lb/lin ft
4	417	4,100	616	5,400	809	8,700
6	441	4,000	632	5,400	815	9,000
8	472	4,000	653	5,500	824	9,300
10	490	4,400	650	7,000	826	11,000
12	490	5,200	658	7,600	830	11,800
14	500	5,200	650	8,600	826	13,500
16	500	5,800	654	9,200	825	15,400

* It is necessary to apply a load factor (see AWWA C401) to the three-edge bearing loads obtained in the crushing tests specified in Sec. 5.2.4 of this standard in order to correlate them to the field loads.

Section 3—Design

Sec. 3.1—Pipe Classes

Pipe supplied under this standard shall be made in one or more of the following classes: 100, 150, or 200.

Sec. 3.2—Pipe Diameters

Pipe shall be made with nominal inside diameters of 4, 6, 8, 10, 12, 14, and 16 in. The average inside diameter of a standard or random pipe length shall not be less than the nominal diameter by more than 5 per cent.

Sec. 3.3—Pipe Lengths

Pipe shall be produced in standard, random, and short lengths. At least 90 per cent of the total footage of pipe of any class, type, and size, excluding short lengths, shall be furnished in standard lengths. The remaining 10 per cent may be in random lengths.

3.3.1 *Standard lengths.* Standard lengths shall be 10 or 13 ft ±1 in. for pipe 4 in. and 6 in. in diameter, and 13 ft ±1 in. for pipe 8 in. in diameter or larger.

3.3.2 *Random lengths.* Random lengths shall be cut from standard lengths and shall not be less than 7 ft.

3.3.3 *Short lengths.* Short lengths for making connections to valves, fittings, or structures and for making closures shall be furnished as specified by the purchaser.

3.3.4 *Coupling areas.* Coupling areas for all lengths of pipe shall be properly machined at ends or over their entire length to serve their intended purpose, as specified by the purchaser.

Sec. 3.4—Couplings

A coupling shall consist of an asbestos-cement sleeve of the same type and class as the pipe and two rubber rings or a device that has equal or better jointing characteristics, strength, and serviceability as that of an asbestos-cement coupling. The manufacturer shall submit specifications and drawings of alternate couplings to the purchaser for approval prior to manufacturing.

3.4.1 *Amount furnished.* One coupling of the same size and class as the pipe shall be furnished with each standard and random length of pipe.

3.4.2 *Rubber rings.* Rubber rings shall conform to the requirements of the latest edition of ASTM D1869, "Rubber Rings for Asbestos-Cement Pipe."

Sec. 3.5—Joints

Joints shall be capable of withstanding, without leakage, a hydrostatic pressure test as defined in Sec. 5.2.2.1.

Sec. 3.6—Wall Thickness

The wall thickness of the machined portion of any length of pipe shall not be less than the manufacturer's standard by the tolerance listed in Table 3.

TABLE 3

Wall Thickness Tolerance

Pipe Size—*in.*	Wall Thickness Tolerance—*in*
4–12	−0.06
14–16	−0.12

Section 4—Workmanship and Finish

Sec. 4.1—Imperfections

4.1.1 *Interior surfaces.* The inside surface of each length of pipe shall be free from bulges, dents, and tears that could result in a variation in diameter of more than 0.20 in. from the diameter of adjacent unaffected portions of the surface.

4.1.2 *Coupling areas.* The coupling areas of the barrel of each length of pipe shall be free from dents and gouges that could cause leakage from the joint.

4.1.3 *Exterior surfaces.* Flaking on the exterior surface and edge of machined ends shall not extend back by more than 0.500 in. from the end, have a depth of more than 0.125 in., or extend around the perimeter for more than 0.500 in. at any one location.

4.1.4 *Straightness.* Each length of pipe shall not vary in straightness by more than 0.05 in./ft of length when the variation is measured as follows:

Measure the maximum ordinate from the exterior surface of the pipe by placing a straightedge or line that exceeds the pipe length against the exterior surface and measure the maximum distance from the exterior pipe surface to the straightedge or line.

Section 5—Inspection, Testing, and Rejection

Sec. 5.1—Inspection

5.1.1 *General.* Inspection by the purchaser shall not relieve the manufacturer of the responsibility to furnish material conforming in all respects to the requirements of this standard.

5.1.2 *Notification.* If inspection is specified by the purchaser under paragraph 5.1.4, the manufacturer shall notify the purchaser in advance of the date, time, and place of testing of the pipe so that the purchaser may be represented at the test.

5.1.3 *Access.* The inspector shall have free access to those parts of the manufacturer's plant that are involved in work performed under this standard. The manufacturer shall afford him, without charge, all reasonable facilities for determining whether the pipe meets the requirements of this standard.

5.1.4 *Testing.* If inspection is specified by the purchaser, he may, at his option, witness any or all test phases. The pipe to be tested will have passed the routine inspection and testing of this specification. The number of tests to be conducted for flexural strength (4, 6, and 8 in.), hydrostatic proof ($3\frac{1}{2}\times$ class), and, when required, crushing strength, shall be limited to 1 per each 300 standard lengths of each size, type, and class of pipe on the order. If uncombined calcium hydroxide tests are required, the number of tests will be one for each size, type, and class of pipe on the order. The purchaser or his authorized inspector may select the pipe to be tested. Retesting and rejection stipulations as shown in Sec. 5.3 shall apply.

Sec. 5.2—Physical Test Requirements

5.2.1 *Test specimens.* All pipe and couplings tested under this standard shall be in a normal air-dried condition when tested.

5.2.2 *Hydrostatic tests.*

5.2.2.1 Each standard, random, or short length of pipe and each coupling sleeve shall be tested under an internal hydrostatic pressure as shown for the proof test in Table 4. All air shall be expelled and the water pressure shall be increased to the test pressure at a uniform rate of not less than 100 psi/s. The test pressure shall be maintained for at least 5 s. Any pipe length or coupling sleeve showing leakage, sweating, or other defects shall be rejected.

5.2.2.2 From each lot that has passed the hydrostatic proof test, one standard length shall be hydrostatically tested to the lot test in Table 4 for that class in the manner specified in paragraph 5.2.2.1. Each length of the pipe so tested shall be retested in the manner and at the pressure specified in paragraph 5.2.2.1.

5.2.3 *Flexure tests.* Each standard length of pipe and each random length

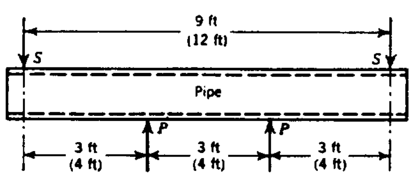

Fig. 1. Flexure Test Assembly

The numbers not in parentheses represent the distances between bearings S *and load points* P *for lengths of pipe shorter than 12.5 ft. The numbers in parentheses indicate the spacing that may be used on lengths of pipe longer than 12.5 ft. One half of the total load is applied at each point* P.

TABLE 4

Hydrostatic Tests

Class	Proof Test* psi	Lot Test† psi
100	350	400
150	525	600
200	700	800

* Every length per paragraph 5.2.2.1.
† One per lot per paragraph 5.2.2.2.

of more than 9.5 ft, having a nominal diameter of 4, 6, or 8 in., shall be tested in flexure for at least 5 s. The supports shall be 9 ft apart, except that, at the manufacturer's option, lengths greater than 12.5 ft may be tested on supports 12 ft apart at 75 per cent of the load specified in Table 1. The total load shall be divided equally and applied at the third points of the clear span as shown in Fig. 1. Each pipe so tested shall support, without evidence of cracks or other defects, the applicable total load shown in Table 1. The load shall be applied at a minimum rate of 250 lb/s, and the total load shall be maintained for at least 5 s.

5.2.4 *Crushing tests.* On lots containing more than 100 lengths of each size and class, one length from each 300 lengths or fraction thereof, shall be tested for crushing strength. If inspection by the purchaser has been specified, the length of pipe to be tested may be selected by the inspector. From each selected length, one unmachined section of pipe 1 ft long shall be cut. This section shall be tested by the crushing test method shown in Fig. 2. After 75 per cent of the specified load has been reached, the loading shall be applied at a uniform rate of approximately 2000 lb/min. The test section shall not fail

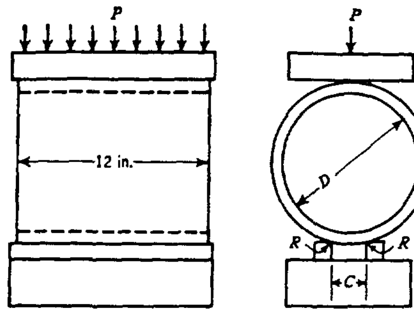

Fig. 2. Crushing Test Assembly

The diagram at the left shows a side view of the test assembly; that at the right, an end view. P *represents load;* R, *approximately 0.5 in.—the radius of the bearings;* D, *the nominal diameter of the pipe; and* C, *the clear space between supports.* C *should be approximately 1 in./ft of internal pipe diameter but in no case less than 1 in.*

until the total load applied meets or exceeds the applicable value shown in Table 2.

5.2.4.1 For this test, the two lower bearings shall consist of two straight strips with vertical sides, each strip having its interior top edge rounded to a radius of approximately 0.5 in. The strips shall be of hardwood or metal; if metal, a piece of leather belting $\frac{3}{16}$ in. in thickness shall be laid over each of them. The strips shall be fastened securely to a rigid block with the interior vertical faces parallel and at a distance apart of approximately 1 in./ft of internal pipe diameter but in no case less than 1 in. The upper bearing shall be a rigid wooden block straight and true from end to end. The upper and lower bearings shall extend the full length of the test section.

5.2.5 *Machines for testing.*

5.2.5.1 The machine used for the hydrostatic test shall have gaskets that seal the ends of the pipe, coupling, or pipe and coupling with factory assembled joint, but exert no end pressure. Couplings may be hydrostatically tested with a rubber bladder inside the couplings, and if so tested, each coupling shall have sufficient strength to withstand a test pressure of 4 times the class of the coupling.

5.2.5.2 The machines used for the flexure and crushing test shall be substantial and rigid throughout so that the distribution of the load will not be appreciably affected by the deformation or yielding of any part of the machine.

Sec. 5.3—Retests (Physical) and Rejection

5.3.1 *Crushing strength.* The failure of any specimen tested for crushing strength to support 75 per cent of the crushing load required in Table 2 shall be cause for rejection of that portion of the lot of that size, type, and class manufactured during the same shift as the test specimen. If any specimen tested for crushing strength supports more than 75 per cent but less than 100 per cent of the crushing load, two additional pipe sections of the same size, type, and class manufactured during the same shift shall be subjected to the same crushing test. The additional lengths may be selected by the inspector if inspection by the purchaser has been specified. The failure of one of these additional specimens to meet the full crushing strength requirement shall be cause for rejection of that portion of the lot of that size, type, and class manufactured during the same shift as the test specimen.

5.3.2 *Hydrostatic tests.* If any pipe subjected to the hydrostatic tests specified in Sec. 5.2.2.2 fails to withstand the specified pressure, two additional lengths of the same size and class manufactured during the same shift shall be subjected to the same hydrostatic test. The failure of one of these additional lengths to withstand the specified pressure shall be cause for rejection of that portion of the lot of that size, type, and class manufactured during the same shift as the test lengths.

Sec. 5.4—Test for Uncombined Calcium Hydroxide

The manufacturer shall perform this test as often as necessary to ensure compliance with the requirements for uncombined calcium hydroxide in Type II pipe.

5.4.1 *Reagents.*

Phenolphthalein indicator. Dissolve 1.0 g of phenolphthalein in 100.0 ml of absolute ethanol.*

Glycerol–ethanol solvent. Prepare a solution consisting of glycerol and anhydrous, or absolute ethanol,* 1:2 by volume. To each liter of this solution, add 2.0 ml phenolphthalein indicator. Adjust the solvent to slightly basic with either dilute NaOH in absolute ethanol * or standard ammonium acetate, depending on the original pH.

Strontium nitrate [$Sr(NO_3)_2$].

Standard ammonium acetate solution. Dissolve 16.0 g of dry crystalline ammonium acetate in 1 l of anhydrous or absolute ethanol.*

Standardize the ammonium acetate solution by titrating against pure CaO that has been freshly prepared by calcining pure calcium carbonate or calcium oxalate to constant weight in a platinum crucible at 1650–1830F (900–1000C).

When the calcined CaO has cooled in a desiccator, perform the following operations in rapid succession. Grind the CaO in an agate mortar. Then weigh out 0.05–0.06 g into a clean, dry 250-ml Erlenmeyer flask and add 60 ml of the glycerol–ethanol solvent and 2.0 g of anhydrous strontium nitrate to the flask. Place a TFE-encapsulated magnetic stirring bar into the flask and attach a reflux condenser. Adjust the heating rate and stirring speed to obtain a vigorous boiling and complete agitation. Titrate the hot solution with ammonium acetate solution every 5 min. The end point is reached when no further color appears in the solution after 10 min. of boiling. Titration is to be carried out only on a hot solution. A good titration procedure is evidenced by a change in the color of the solution to pink upon cooling.

5.4.2 *Procedure.*

Step 1. Brush representative pieces of the pipe free of dust and drill with a clean, sharp 0.25-in. carbide-tipped drill inward from the outer surface at a rate of penetration of approximately 1 in./min until the drill point emerges from the inside wall. Catch the drillings on a clean sheet of glazed paper, using a soft brush to collect all drillings. Screen through a 20-mesh screen immediately, and place in a weighing bottle.

Step 2. Place the bottle, with top removed, into a drying oven at 220F (105C) for 2 hr and then cool to room temperature in a desiccator.

Step 3. Weigh out 1 g ± 0.010 g of the dried sample to the nearest 0.001 g and place in a clean, dry 250-ml Erlenmeyer flask to which a TFE-encapsulated stirring bar, 60 ml of the glycerol–ethanol solvent, and 2.0 g $Sr(NO_3)_2$ have been added. Attach the flask to a water-cooled condensor (with a standard 24/40 glass joint) and

* Specially denatured alcohol No. 30, 3a, or 2b of the US Bureau of Internal Revenue, or alcohol consisting of 95 per cent specially denatured alcohol No. 3a plus 5 per cent isopropanol may be substituted.

place on a hot plate with a magnetic stirrer. Boil the solution gently for 30 min, stirring slowly. Then remove the flask and filter the mixture, under vacuum, through a Buchner funnel. Bring the filtrate to a boil and titrate to a colorless end point with the standardized ammonium acetate reagent. Determine the end point by comparison with a similar mixture containing no phenolphthalein indicator.

5.4.3 *Calculations.*

$$E = \frac{W\text{CaO} \times 1.32}{V_a}$$

where

E = the weight in grams of $Ca(OH)_2$ per milliliter of standardized ammonium acetate solution.

WCaO = the weight in grams of CaO in the standardized ammonium acetate solution.

V_a = the volume in milliliters of standardized ammonium acetate used in titration of the solution.

Percentage uncombined $Ca(OH)_2$

$$= \frac{EV}{W} \times 100$$

where

V = the volume of standardized ammonium acetate solution required by the sample, in milliliters.

W = the weight of the sample in grams.

Sec. 5.5—Test Records

The results of all tests shall be recorded and retained for one year, and shall be available to the purchaser at the place of manufacture.

Section 6–Marking and Delivery

Sec. 6.1—Marking

6.1.1 *Standard and random lengths.* Each standard or random length of pipe shall be clearly marked on the outside surface with the trade name, nominal inside diameter, class, type, hydrostatic test pressure, and date and shift of manufacture.

6.1.2 *Short lengths.* Each short length of pipe shall be clearly marked on the outside surface with the nominal inside diameter, class, type, and the letter *T* to indicate that it has been hydrostatically tested.

6.1.3 *Couplings.* All component parts of each coupling shall be clearly marked for use with the pipe for which they are intended. Each coupling sleeve shall also be marked with the letter *T* to indicate that it has been hydrostatically tested.

6.1.4 *Special markings.* If factory inspection is made by the purchaser or his authorized inspector, each pipe and each coupling sleeve shall receive an additional special marking of no more than three letters, as specified by the purchaser.

Sec. 6.2—Preparation for Shipment

All pipe and couplings, unless otherwise specified, shall be prepared for standard commercial shipment.

1P—15M—7/77—43400

ANSI/AWWA C101—67 (R1977)

[redacted]

Reaffirmed without revision 1977

AMERICAN NATIONAL STANDARD

for

THICKNESS DESIGN OF CAST-IRON PIPE

With Tables of Pipe Thicknesses

In Four Parts

Sec. 1-1—Thickness Tables for Standard Conditions

Sec. 1-2—General Procedure for Thickness Determination

Sec. 1-3—Design Theory—Determination of Net Thickness, Earth Load, and Truck Superload

Sec. 1-4—Thickness Determination for Pipe on Piers or Piling Aboveground or Underground

SPONSORS

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American Society for Testing and Materials

American Water Works Association

New England Water Works Association

Approved by The American National Standard Institute, Nov. 10, 1967

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Reaffirmed without revision Jun. 9, 1977

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American National Standard

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Committee Personnel

Subcommittee 1—Pipe, which reviewed and recommended reaffirmation of this standard without revision, had the following personnel at that time:

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WALTER AMORY, *Vice-Chairman*

User Members	*Producer Members*
ROBERT S. BRYANT	ALFRED F. CASE
FRANK E. DOLSON	W. D. GOODE
LEE J. DOSEDLO	THOMAS D. HOLMES
GEORGE F. KEENAN	HAROLD M. KENNEDY JR.
LEONARD ORLANDO JR.	W. HARRY SMITH
	SIDNEY P. TEAGUE

Standards Committee A21—Cast Iron Pipe and Fittings, which reviewed and reaffirmed this standard without revision, had the following personnel at that time.

LLOYD W. WELLER, *Chairman*
EDWARD C. SEARS, *Vice-Chairman*
PAUL A. SCHULTE, *Secretary*

Organization Represented	*Name of Representative*
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American Society of Civil Engineers	KENNETH W. HENDERSON
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Canadian Standards Association	W. F. SEMENCHUK *

* Liaison representative without vote.

Table of Contents

Sec. 1-3—Design Theory—Determination of Net Thickness, Earth Load, and Truck Superload

Sec. 1-4—Thickness Determination for Pipe on Piers or Piling Aboveground or Underground

Foreword

This foreword is provided for information only and is not a part of ANSI/AWWA C101.

History of Standard

On Sep. 10, 1902, NEWWA adopted a "Standard Specification for Cast-Iron Pipe and Special Castings," covering bell-and-spigot pit-cast pipe and fittings of ten thickness classes. The thickness classes were based on allowable internal pressures varying by increments of 50 ft of head.

On May 12, 1908, AWWA adopted a "Standard Specification for Cast-Iron Pipe and Special Castings," covering bell-and-spigot pit-cast pipe and fittings of eight classes, A through H, with allowable working pressures varying by increments of 100 ft of head from 100 to 800 ft. Dimensions and weights were given for pipe and fittings.

In 1926, ASA Sectional Committee (now ANSI Standards Committee) A21 on Cast-Iron Pipe and Fittings was organized under the sponsorship of AGA, ASTM, AWWA, and NEWWA. The present scope of Committee A21 is:

> Standardization of specifications for cast-iron and ductile-iron pressure pipe for gas, water, and other liquids, and fittings for use with such pipe. These specifications to include design, dimensions, materials, coatings, linings, joints, accessories, and methods of inspection and test.

Sectional Committee A21 sponsored many tests of pipe and fittings; these included subjection of pipe to combined earth load and internal pressures (which form the basis of pipe-thickness design), corrosion tests, measurement of hydraulic friction loss in fittings, and tests of bursting strengths of pipe and fittings. After exhaustive study of the test results and other research, the committee in 1939 issued A21.1, "American Standard Practice Manual for the Computation of Strength and Thickness of Cast-Iron Pipe." The manual included nomograms and thickness tables for pit-cast pipe with 11/31 * iron strength. As stated in the preface to that manual, however, the design method was applicable to pipe of any iron strength.

Discussions and interpretations [1,2] of the method of design of cast-iron pipe were published in 1939 and presented to AWWA and AGA. As a result of these publications and because of the general acceptance of A21.1, a substantial volume of cast-iron pipe was designed by the new method and furnished to manufacturers' standards between 1939 and 1953. A standard (A21.2) for pit-cast pipe with 11/31 iron strength also was issued in 1939. Work on standards for centrifugally cast pipe with 18/40 iron strength was started after the design was completed in 1939, but, owing to the intervention of World War II and other causes, they were not formally issued until 1953.

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* The first figure designates the bursting tensile strength in units of 1,000 psi and the second figure designates the ring modulus of rupture in units of 1,000 psi.

In 1957, a revision of A21.1 was issued. In that revision, designated ASA A21.1–1957 (AWWA H1–57) the major change was the addition of a method for computing earth loads on pipe laid under embankments and of nomograms and thickness tables for centrifugally cast pipe with 18/40 iron strength.

In 1958, Sectional Committee A21 was reorganized. Subcommittees were established to study each group of standards in accordance with the review and revision policy of ASA (now ANSI). The scope of Subcommittee 1—Pipe is:

> To include the periodic review of all current A21 standards for pipe, the preparation of revisions or new standards when needed, as well as other matters pertaining to pipe standards.

As a result of the work of Subcommittee No. 1 on this assignment, revisions of the cast-iron pipe standards A21.6 (AWWA C106), A21.7, A21.8 (AWWA C108), and A21.9 were issued in 1962 and again in 1970. Revision of A21.1–1957 (AWWA H1–57) was delayed in order for the subcommittee to carry out a new assignment from the sectional committee to develop a design standard and pipe standards for ductile-iron pipe. Subsequently, the subcommittee completed its study and a revision of A21.1 was issued in 1967.

In 1971 and again in 1976, Subcommittee No. 1 reviewed the 1967 edition and submitted a recommendation to Committee A21 that the standard be reaffirmed without change. Therefore, this reaffirmed edition is unchanged from the 1967 edition, except for the updating of this foreword. For convenience, the major features listed in the foreword of the 1967 edition are repeated here.

Major Features of 1967 Revision

Although ANSI A21.1–1967 (AWWA H1–67) contained no changes in the basic design method, a number of revisions were incorporated to simplify the design procedure and to reflect changes in technology. Major features of the 1967 revision are discussed.

1. *Format.* This revision is divided into four major sections: Sec. 1–1 gives thickness tables for standard conditions; Sec. 1–2 gives the general procedure for thickness determination; Sec. 1–3 gives design theory and provides methods for determining pipe thicknesses, earth loads, and truck superloads for both standard and special conditions; and Sec. 1–4 gives the design procedure for a special installation condition, pipe on piers aboveground or underground.

2. *Iron strength.* Thickness tables, nomograms, and other data for pit-cast pipe (11/31 iron strength) were deleted, as this type of pipe is seldom furnished today.

Centrifugally cast pipe covered under ANSI Standards A21.6 (AWWA C106), A21.7, A21.8 (AWWA C108), and A21.9 are specified to have an iron strength of not less than 18/40. Advances in production technology have enabled the manufacturers to furnish pipe with greater strength, and pipe with 21/45 iron strength has been available for many years. Thus, for the convenience of users, tables and figures in the standard cover pipe with iron strengths of both 18/40 and 21/45.

3. *Laying conditions.* Laying conditions C, D, and E (also called "field conditions" in the 1957 revision) were deleted. Conditions C and D were for pipe laid on blocks, a method sometimes used in the 1920s and 1930s. This method has been recognized as undesirable and is seldom used today. Condition E was for pipe laid with special bedding but without tamping the backfill. It was felt that this combination would rarely be used today; when special bedding is used, the backfill is almost always tamped, giving laying condition F, which was retained in this revision.

4. *Earth loads.* Formulas and procedures were added (Sec. 1-3) for determining earth loads for standard and special conditions. Earth loads shown in Table 1-8 are the same as those given in the 1957 revision, except that loads for 20 and 24 ft of cover were added.

5. *Allowance for truck superloads.* Formulas and procedures were added (Sec. 1-3) for determining truck superloads for standard and special conditions. These procedures may be used to compute truck superloads for unpaved roads, flexible pavement, or rigid pavement; one truck or two passing trucks; and any wheel load and impact factor, including AASHO truck loadings. Truck superloads for standard conditions are shown in Table 1-8 and are the same as given in the 1957 revision, except that loads for 20 and 24 ft of cover were added.

6. *Allowance for surge pressure.* The allowances for surge pressure (water hammer), shown in Table 1-10, are unchanged from those given in the 1957 revision.

7. *Allowance for corrosion.* A standard allowance for soil corrosion of 0.08 in., based on judgment and experience of early engineers, was used in the 1939 manual and continued in the 1957 revision. The allowance of 0.08 in. was also retained in this edition. It is very conservative for many soils, and has proved to be adequate in most. In areas suspected or known to be highly corrosive, however, the designer should take special precautions. Where unusually corrosive soil conditions are anticipated, a soil survey is recommended.

8. *Pipe on piers.* A new section (Sec. 1-4) was added to provide procedures for computing thicknesses of pipe installed on piers or piling, a condition sometimes encountered in laying pipe in unstable soil, across streams or swamps, either aboveground or underground, and in installing pipe on bridges and other aboveground structures.

Standard Thicknesses of Pit-Cast Pipe

As stated in the foregoing, thickness tables for pit-cast pipe were deleted in the 1967 edition. During the review of this standard in 1971, it was determined that some standards and codes refer to the table of standard thickness classes for pit-cast pipe shown as Table 10 in the 1957 edition of A21.1. For reference, the contents of that table are reproduced on the next page:

*Standard Thickness Classes for Pit-Cast Pipe**

Pipe Size *in.*	Pipe-Wall Thickness (*in.*) for Standard Thickness Class No.:													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3	0.37	0.40	0.43	0.46	0.50	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99
4	0.40	0.43	0.46	0.50	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07
6	0.43	0.46	0.50	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16
8	0.46	0.50	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25
10	0.50	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35
12	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46
14	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46
16	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46	1.58
18	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46	1.58	1.71
20	0.66	0.71	0.77	0.83	0.90	0.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79
24	0.74	0.80	0.86	0.93	1.00	1.08	1.17	1.26	1.36	1.47	1.59	1.72	1.86	2.01
30	0.87	0.94	1.02	1.10	1.19	1.29	1.39	1.50	1.62	1.75	1.89	2.04	2.20	2.38
36	0.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79	1.93	2.08	2.25	2.43	2.62
42	1.07	1.16	1.25	1.35	1.46	1.58	1.71	1.85	2.00	2.16	2.33	2.52	2.72	2.94
48	1.18	1.27	1.37	1.48	1.60	1.73	1.87	2.02	2.18	2.35	2.54	2.74	2.96	3.20
54	1.30	1.40	1.51	1.63	1.76	1.90	2.05	2.21	2.39	2.58	2.79	3.01	3.25	3.51
60	1.39	1.50	1.62	1.75	1.89	2.04	2.20	2.38	2.57	2.78	3.00	3.24	3.50	3.78

* Each class is made 8 per cent heavier than the preceding class, starting with the thinnest, i.e., minimum thickness, as the base class.

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ANSI/AWWA C101-77

Reaffirmed without revision 1977

American National Standard for

Thickness Design of Cast-Iron Pipe

Sec. 1-1—Thickness Tables for Standard Conditions

Sec. 1-1.1—General

Tables 1-1, 1-2, and 1-3, as applicable, permit the direct determination of the required thickness of cast-iron pipe limited to the following conditions:

a. Vertical-sided trench of width at top of pipe not greater than the nominal pipe diameter plus 2 ft

b. Unit weight of soil 120 lb/cu ft

c. $K\mu = 0.1924$, $K\mu' = 0.130$ (see Sec. 1-3.2 for definition)

d. Truck superload based on two passing trucks with adjacent wheels 3 ft apart, 9,000 lb wheel load, unpaved road or flexible pavement, 1.50 impact factor

e. Surge allowances as shown in Table 1-10

f. Iron strengths of 18/40 and 21/45 *

g. The three most common laying conditions:

A—Pipe laid on flat-bottom trench, backfill not tamped

B—Pipe laid on flat-bottom trench, backfill tamped

F—Pipe bedded in gravel or sand, backfill tamped

h. Allowances for casting tolerance as shown in Table 1-6

i. A corrosion allowance of 0.08 in.

Sec. 1-1.2—Trench Load and Internal Pressure

The required thickness of cast-iron pressure pipe is determined from a consideration of trench load and internal pressure in combination. Trench load is considered to consist of the earth load on the pipe plus any superload resulting from traffic over the trench. Internal pressure is considered to consist of the design working pressure plus an additional allowance for surge pressure. Two different combinations of trench load and internal pressure are considered in the design:

Case 1. Trench load (earth load but no truck superload) in combination with internal pressure (working pressure plus surge pressure) and with 2.5 factor of safety applied to both trench load and internal pressure

Case 2. Trench load (earth load plus truck superload) in combination with internal pressure (working pressure but no surge pressure) and with

* The first figure designates the bursting tensile strength (S) in units of 1,000 psi and the second figure designates the ring modulus of rupture (R) in units of 1,000 psi.

a 2.5 factor of safety applied to both trench load and internal pressure.

Sec. 1-1.3—Traffic Superload and Surge Pressure

In designing water pipe it is customary to assume that neither traffic superload nor surge pressure will occur in important magnitude simultaneously. Thus, calculations for the required thickness of water pipe are made for both conditions independently, and the greater of the two thicknesses thus determined is chosen as the net thickness.

In designing gas pipe the procedure is the same, except that surge pressure is not a factor and only Case 2 is considered.

Sec. 1-1.4—Corrosion Allowance and Casting Tolerance

To the net thickness determined as explained above, a corrosion allowance and a casting tolerance are added to obtain the calculated thickness shown in Tables 1-1, 1-2, and 1-3. The standard thickness class and/or the nominal thickness for this class shown in Tables 1-1, 1-2, and 1-3 are used for specifying and ordering pipe.

For other than standard conditions the formulas, tables, and diagrams in Sec. 1-2 may be used. The design theory on which Tables 1-1, 1-2, and 1-3 are based is presented in Sec. 1-3. Procedures for determining the net thickness of pipe on piers or piling above- or belowground are presented in Sec. 1-4.

TABLE 1-1

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi*						
			50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
		Three-Inch Water Pipe							
A	2½	Calculated Thickness	.21*	.21*	.22*	.22*	.22*	.22*	.23*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	3½	Calculated Thickness	.21*	.21*	.22*	.22*	.22*	.22*	.23*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	5	Calculated Thickness	.21*	.21*	.22*	.22*	.23	.23	.24
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	8	Calculated Thickness	.22*	.23*	.23*	.24	.24	.24	.25
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	12	Calculated Thickness	.24*	.25*	.25*	.26	.26	.27	.28
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	16	Calculated Thickness	.27	.27	.28	.28	.28	.29	.29
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
B	2½	Calculated Thickness	.21*	.21*	.22*	.22*	.22*	.22*	.23*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	3½	Calculated Thickness	.21*	.21*	.22*	.22*	.22*	.22*	.23*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	5	Calculated Thickness	.21*	.21*	.22*	.22*	.23	.23	.24
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	8	Calculated Thickness	.22*	.22*	.23*	.23*	.24	.24	.24
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	12	Calculated Thickness	.24*	.24*	.25	.25	.26	.26	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	16	Calculated Thickness	.26	.26	.27	.27	.28	.28	29
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
F	2½	Calculated Thickness	.21*	.21*	.21*	.21*	.22*	.22*	.23
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	3½	Calculated Thickness	.21*	.21*	.21*	.21*	.22*	.22*	.23
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	5	Calculated Thickness	.21*	.21*	.21*	.22*	.22*	.22*	.23
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	8	Calculated Thickness	.21	.21	.22	.22	.23	.23	.24
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	12	Calculated Thickness	.23	.23	.23	.24	.24	.24	.25
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32
	16	Calculated Thickness	.24	.24	.25	.25	.26	.26	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.32	.32	.32	.32	.32	.32	.32

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
		Four-Inch Water Pipe							
A	2½	Calculated Thickness	.23*	.23*	.24*	.24*	.24*	.25*	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	3½	Calculated Thickness	.23*	.23*	.23*	.24	.24	.25	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	.23*	.24*	.24*	.25	.26	.27	.28
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	.25*	.26	.27	.28	.28	.29	.30
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.29	.29	.30	.30	.31	.31	.32
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.31	.31	.32	.32	.33	.33	.34
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
B	2½	Calculated Thickness	.23*	.23*	.23*	.23*	.24*	.25	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	3½	Calculated Thickness	.23*	.23*	.23*	.24	.25	.26	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	.23	.24	.24	.25	.26	.27	.28
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	.25	.26	.27	.27	.28	.29	.29
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.28	.28	.29	.30	.30	.31	.32
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.30	.31	.31	.32	.32	.33	.33
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
F	2½	Calculated Thickness	.23*	.23*	.23*	.24*	.24	.25	.26
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	3½	Calculated Thickness	.23*	.23*	.23	.24	.24	.25	.26
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	.23	.23	.23	.24	.24	.25	.26
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	.24	.24	.25	.25	.25	.26	.27
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.25	.26	.27	.28	.28	.29	.30
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.28	.28	.29	.29	.30	.30	.31
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.35	.35	.35	.35	.35	.35	.35

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

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TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi*						
			50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Six-Inch Water Pipe									
A	2½	Calculated Thickness	*.29**	*.29**	*.30**	*.31**	*.32**	*.33**	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.28**	*.28**	*.29**	*.30**	*.31**	*.32**	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.29**	*.29**	*.30**	*.31**	*.33*	*.34*	*.35*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*.32*	*.33*	*.34*	*.35*	*.36*	*.37*	*.38*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.36*	*.37*	*.38*	*.38*	*.39*	*.40*	*.41*
		Use {Thickness Class	22	22	22	22	22	23	23
		Use {Thickness	.38	.38	.38	.38	.38	.41	.41
	16	Calculated Thickness	*.39*	*.40*	*.41*	*.42*	*.42*	*.43*	*.44*
		Use {Thickness Class	22	23	23	23	23	24	24
		Use {Thickness	.38	.41	.41	.41	.41	.44	.44
B	2½	Calculated Thickness	*.28**	*.28**	*.29**	*.30**	*.31**	*.32**	*.33**
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.27**	*.28**	*.28**	*.29**	*.30**	*.32*	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.28**	*.29*	*.30*	*.31*	*.32*	*.33*	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*.31*	*.32*	*.33*	*.34*	*.35*	*.36*	*.37*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.35*	*.35*	*.36*	*.37*	*.38*	*.39*	*.40*
		Use {Thickness Class	22	22	22	22	22	22	23
		Use {Thickness	.38	.38	.38	.38	.38	.38	.41
	16	Calculated Thickness	*.38*	*.38*	*.39*	*.40*	*.41*	*.42*	*.43*
		Use {Thickness Class	22	22	22	23	23	23	24
		Use {Thickness	.38	.38	.38	.41	.41	.41	.44
F	2½	Calculated Thickness	*.26**	*.27**	*.28*	*.29*	*.30*	*.32*	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.27*	*.27*	*.28*	*.29*	*.30*	*.32*	*.34*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.28*	*.28*	*.29*	*.29*	*.30*	*.32*	*.35*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*.29*	*.30*	*.31*	*.32*	*.33*	*.34*	*.35*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.32*	*.33*	*.34*	*.35*	*.36*	*.37*	*.38*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	.38	.38	.38	.38	.38	.38	.38
	16	Calculated Thickness	*.35*	*.35*	*.36*	*.37*	*.38*	*.39*	*.40*
		Use {Thickness Class	22	22	22	22	22	22	23
		Use {Thickness	.38	.38	.38	.38	.38	.38	41

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi*						
			50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Eight-Inch Water Pipe									
A	2½	Calculated Thickness	.34*	.35*	.36*	.37*	.38*	.39*	.40*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	3½	Calculated Thickness	.33*	.34*	.34*	.35*	.36*	.39	.41
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.34*	.35*	.36*	.37*	.39	.41	.43
		Use Thickness Class	22	22	22	22	22	22	23
		Use Thickness	.41	.41	.41	.41	.41	.41	.44
	8	Calculated Thickness	.38	.39	.40	.41	.43	.44	.46
		Use Thickness Class	22	22	22	22	23	23	24
		Use Thickness	.41	.41	.41	.41	.44	.44	.48
	12	Calculated Thickness	.43	.44	.45	.46	.47	.49	.50
		Use Thickness Class	23	23	23	24	24	24	25
		Use Thickness	.44	.44	.44	.48	.48	.48	.52
	16	Calculated Thickness	.46	.47	.48	.49	.51	.52	.53
		Use Thickness Class	24	24	24	24	25	25	25
		Use Thickness	.48	.48	.48	.48	.52	.52	.52
B	2½	Calculated Thickness	.32*	.33*	.34*	.35*	.36*	.38*	.39*
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	41	.41
	3½	Calculated Thickness	.32*	.33*	.33*	.34*	.36*	.38	.40
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.33*	.34*	.35	.36	.38	.40	.42
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	8	Calculated Thickness	.36	.37	.38	.40	.41	.43	.45
		Use Thickness Class	22	22	22	22	22	23	23
		Use Thickness	.41	.41	.41	.41	.41	.44	.44
	12	Calculated Thickness	.41	.42	.43	.44	.46	.47	.48
		Use Thickness Class	22	22	23	23	24	24	24
		Use Thickness	.41	.41	.44	.44	.48	.48	.48
	16	Calculated Thickness	.44	.45	.46	.47	.48	.50	.51
		Use Thickness Class	23	23	24	24	24	25	25
		Use Thickness	.44	.44	.48	.48	.48	.52	.52
F	2½	Calculated Thickness	.30*	.31*	.32*	.33*	.35	.37	.39
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	3½	Calculated Thickness	.29*	.30*	.31	.33	.35	.37	.39
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.30*	.31*	.32	.34	.36	.38	.40
		Use Thickness Class	22	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41	.41
	8	Calculated Thickness	.34	.35	.36	.37	.39	.41	.43
		Use Thickness Class	22	22	22	22	22	22	23
		Use Thickness	.41	.41	.41	.41	.41	.41	.44
	12	Calculated Thickness	.38	.39	.40	.41	.43	.44	.46
		Use Thickness Class	22	22	22	22	23	23	24
		Use Thickness	.41	.41	.41	.41	.44	.44	.48
	16	Calculated Thickness	.40	.41	.42	.43	.45	.46	.48
		Use Thickness Class	22	22	22	23	23	24	24
		Use Thickness	.41	.41	.41	.44	.44	.48	.48

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi*						
			50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Ten-Inch Water Pipe									
A	2½	Calculated Thickness	.40*	.41*	.42*	.43*	.45*	.46*	.48*
		Use: Thickness Class	22	22	22	22	22	23	23
		Use: Thickness	.44	.44	.44	.44	.44	.48	.48
	3½	Calculated Thickness	.39*	.40*	.41*	.42*	.44*	.46	.49
		Use: Thickness Class	22	22	22	22	22	23	23
		Use: Thickness	.44	.44	.44	.44	.44	.48	.48
	5	Calculated Thickness	.40*	.41*	.42*	.44	.46	.48	.51
		Use: Thickness Class	22	22	22	22	23	23	24
		Use: Thickness	.44	.44	.44	.44	.48	.48	.52
	8	Calculated Thickness	.44	.46	.47	.49	.51	.53	.55
		Use: Thickness Class	22	23	23	23	24	24	25
		Use: Thickness	.44	.48	.48	.48	.52	.52	.56
	12	Calculated Thickness	.51	.52	.53	.55	.56	.58	.60
		Use: Thickness Class	24	24	24	25	25	26	26
		Use: Thickness	.52	.52	.52	.56	.56	.60	.60
	16	Calculated Thickness	.53	.54	.56	.57	.59	.60	.62
		Use: Thickness Class	24	25	25	25	26	26	26
		Use: Thickness	.52	.56	.56	.56	.60	.60	.60
B	2½	Calculated Thickness	.38*	.39*	.40*	.41*	.43*	.45*	.47*
		Use: Thickness Class	22	22	22	22	22	22	23
		Use: Thickness	.44	.44	.44	.44	.44	.44	48
	3½	Calculated Thickness	.37*	.38*	.39*	.40*	.42*	.44	.48
		Use: Thickness Class	22	22	22	22	22	22	23
		Use: Thickness	.44	.44	.44	.44	.44	.44	.48
	5	Calculated Thickness	.38*	.39*	.40*	.42	.45	.47	.50
		Use: Thickness Class	22	22	22	22	22	23	24
		Use: Thickness	.44	.44	.44	.44	.44	.48	.52
	8	Calculated Thickness	.41*	.44	.45	.47	.49	.51	.53
		Use: Thickness Class	22	22	22	23	23	24	24
		Use: Thickness	.44	.44	.44	.48	.48	.52	.52
	12	Calculated Thickness	.48	.49	.51	.52	.54	.56	.58
		Use: Thickness Class	23	23	24	24	25	25	26
		Use: Thickness	.48	.48	.52	.52	.56	.56	.60
	16	Calculated Thickness	.50	.52	.53	.54	.56	.58	.60
		Use: Thickness Class	24	24	24	25	25	26	26
		Use: Thickness	.52	.52	.52	.56	.56	.60	.60
F	2½	Calculated Thickness	.35*	.36*	.37*	.38*	.41	.44	.47
		Use: Thickness Class	22	22	22	22	22	22	23
		Use: Thickness	.44	.44	.44	.44	.44	.44	.48
	3½	Calculated Thickness	.34*	.35*	.36*	.38	.41	.44	.47
		Use: Thickness Class	22	22	22	22	22	22	23
		Use: Thickness	.44	.44	.44	.44	.44	.44	.48
	5	Calculated Thickness	.35*	.36*	.38	.40	.42	.46	.48
		Use: Thickness Class	22	22	22	22	22	23	23
		Use: Thickness	.44	.44	.44	.44	.44	.48	.48
	8	Calculated Thickness	.39	.41	.42	.44	.46	.48	.51
		Use: Thickness Class	22	22	22	22	23	23	24
		Use: Thickness	.44	.44	.44	.44	.48	.48	.52
	12	Calculated Thickness	.44	.45	.46	.48	.50	.52	.54
		Use: Thickness Class	22	22	23	23	24	24	25
		Use: Thickness	.44	.44	.48	.48	.52	.52	.56
	16	Calculated Thickness	.46	.47	.49	.51	.52	.54	.56
		Use: Thickness Class	23	23	23	24	24	25	25
		Use: Thickness	.48	.48	.48	.52	.52	.56	.56

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Twelve-Inch Water Pipe									
A	2½	Calculated Thickness	.45*	.46*	.47*	.49*	.51*	.53*	.55*
		Use: Thickness Class	22	22	22	22	23	23	24
		Use: Thickness	.48	.48	.48	.48	.52	.52	.56
	3½	Calculated Thickness	.43*	.45*	.46*	.48*	.50*	.51	.55
		Use: Thickness Class	22	22	22	22	23	23	24
		Use: Thickness	.48	.48	.48	.48	.52	.52	.56
	5	Calculated Thickness	.45*	.46*	.47*	.49	.52	.54	.57
		Use: Thickness Class	22	22	22	22	23	24	24
		Use: Thickness	.48	.48	.48	.48	.52	.56	.56
	8	Calculated Thickness	.50	.52	.53	.55	.57	.60	.62
		Use: Thickness Class	23	23	23	24	24	25	25
		Use: Thickness	.52	.52	.52	.56	.56	.60	.60
	12	Calculated Thickness	.56	.57	.59	.60	.62	.64	.67
		Use: Thickness Class	24	24	25	25	25	26	26
		Use: Thickness	.56	.56	.60	.60	.60	.65	.65
	16	Calculated Thickness	.59	.60	.61	.63	.65	.67	.69
		Use: Thickness Class	25	25	25	26	26	26	27
		Use: Thickness	.60	.60	.60	.65	.65	.65	.70
B	2½	Calculated Thickness	.42*	.44*	.45*	.46*	.48*	.50*	.53*
		Use: Thickness Class	22	22	22	22	22	23	23
		Use: Thickness	.48	.48	.48	.48	.48	.52	.52
	3½	Calculated Thickness	.41*	.42*	.44*	.45*	.47*	.51	.55
		Use: Thickness Class	22	22	22	22	22	23	24
		Use: Thickness	.48	.48	.48	.48	.48	.52	.56
	5	Calculated Thickness	.42*	.43*	.45*	.47	.50	.53	.56
		Use: Thickness Class	22	22	22	22	23	23	24
		Use: Thickness	.48	.48	.48	.48	.52	.52	.56
	8	Calculated Thickness	.48	.49	.51	.53	.55	.57	.60
		Use: Thickness Class	22	22	23	23	24	24	25
		Use: Thickness	.48	.48	.52	.52	.56	.56	.60
	12	Calculated Thickness	.53	.54	.56	.57	.59	.61	.64
		Use: Thickness Class	23	24	24	24	25	25	26
		Use: Thickness	.52	.56	.56	.56	.60	.60	.65
	16	Calculated Thickness	.55	.57	.58	.60	.62	.64	.66
		Use: Thickness Class	24	24	25	25	25	26	26
		Use: Thickness	.56	.56	.60	.60	.60	65	.65
F	2½	Calculated Thickness	.39*	.40*	.41*	.43*	.45*	.49	.53
		Use: Thickness Class	22	22	22	22	22	22	23
		Use: Thickness	.48	.48	.48	.48	.48	.48	.52
	3½	Calculated Thickness	.38*	.39*	.40*	.42*	.45	.50	.53
		Use: Thickness Class	22	22	22	22	22	23	23
		Use: Thickness	.48	.48	.48	.48	.48	.52	.52
	5	Calculated Thickness	.39*	.40*	.41*	.43*	.46	.50	.54
		Use: Thickness Class	22	22	22	22	22	23	24
		Use: Thickness	.48	.48	.48	.48	.48	.52	.56
	8	Calculated Thickness	.44	.45	.47	.49	.52	.55	.58
		Use: Thickness Class	22	22	22	22	23	24	25
		Use: Thickness	.48	.48	.48	.48	.52	.56	.60
	12	Calculated Thickness	.48	.40	.51	.53	.55	.58	.61
		Use: Thickness Class	22	22	23	23	24	25	25
		Use: Thickness	.48	.48	.52	.52	.56	.60	.60
	16	Calculated Thickness	.50	.52	.53	.55	.57	.59	.62
		Use: Thickness Class	23	23	23	24	24	25	25
		Use: Thickness	.52	.52	.52	.56	.56	.60	.60

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Fourteen-Inch Water Pipe									
A	2½	Calculated Thickness	.51*	.52*	.54*	.55*	.58*	.60*	.62*
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	.51	.51	.55	.55	.59	.59	.64
	3½	Calculated Thickness	.50*	.51*	.53*	.54*	.57*	.60	.64
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	.51	.51	.55	.55	.59	.59	.64
	5	Calculated Thickness	.51*	.53*	.54*	.56*	.59	.62	.66
		Use Thickness Class	22	23	23	23	24	25	25
		Use Thickness	.51	.55	.55	.55	.59	.64	.64
	8	Calculated Thickness	.58	.60	.62	.64	.66	.69	.72
		Use Thickness Class	24	24	25	25	25	26	27
		Use Thickness	.59	.59	.64	.64	.64	.69	.75
	12	Calculated Thickness	.63	.65	.67	.69	.71	.74	.76
		Use Thickness Class	25	25	26	26	26	27	27
		Use Thickness	.64	.64	.69	.69	.69	.75	.75
	16	Calculated Thickness	.67	.68	.70	.72	.74	.76	.79
		Use Thickness Class	26	26	26	27	27	27	28
		Use Thickness	.69	.69	.69	.75	.75	.75	.81
B	2½	Calculated Thickness	.47*	.49*	.51*	.52*	.54*	.57*	.62
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	.48	.48	.51	.51	.55	.59	.64
	3½	Calculated Thickness	.46*	.47*	.49*	.51*	.54	.57	.63
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	.48	.48	.51	.51	.55	.59	.64
	5	Calculated Thickness	.48*	.49*	.52	.54	.57	.61	.65
		Use Thickness Class	21	22	22	23	24	24	25
		Use Thickness	.48	.51	.51	.55	.59	.59	.64
	8	Calculated Thickness	.54	.56	.58	.61	.63	.66	.69
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	.55	.55	.59	.59	.64	.64	.69
	12	Calculated Thickness	.59	.61	.63	.65	.68	.70	.73
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	.59	.59	.64	.64	.69	.69	.75
	16	Calculated Thickness	.62	.64	.66	.68	.70	.73	.75
		Use Thickness Class	25	25	25	26	26	27	27
		Use Thickness	.64	.64	.64	.69	.69	.75	.75
F	2½	Calculated Thickness	.44*	.45*	.47*	.49*	.52	.57	.61
		Use Thickness Class	21	21	21	21	22	24	24
		Use Thickness	.48	.48	.48	.48	.51	.59	.59
	3½	Calculated Thickness	.44*	.45*	.47	.50	.53	.57	.62
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.48	.48	.48	.51	.55	.59	.64
	5	Calculated Thickness	.45	.47	.49	.52	.55	.59	.64
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.48	.48	.48	.51	.55	.59	.64
	8	Calculated Thickness	.50	.52	.54	.57	.60	.64	.66
		Use Thickness Class	22	22	23	24	24	25	25
		Use Thickness	.51	.51	.55	.59	.59	.64	.64
	12	Calculated Thickness	.54	.56	.58	.61	.63	.66	.69
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	.55	.55	.59	.59	.64	.64	.69
	16	Calculated Thickness	.57	.58	.60	.63	.65	.68	.71
		Use Thickness Class	24	24	24	25	25	26	26
		Use Thickness	.59	.59	.59	.64	.64	.69	.69

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Sixteen-Inch Water Pipe									
A	2½	Calculated Thickness	*.54**	*.56**	*.58**	*.60**	*.62**	*.65**	*.68**
		Use Thickness Class	22	23	23	23	24	24	25
		Use Thickness	.54	.58	.58	.58	.63	63	.68
	3½	Calculated Thickness	*.54**	*.55**	*.57**	*.59**	*.61*	*.65*	*.70*
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	.54	.54	.58	.58	.63	.63	.68
	5	Calculated Thickness	*.56**	*.57**	*.59**	*.61**	*.64*	*.68*	*.72*
		Use Thickness Class	23	23	23	24	24	25	26
		Use Thickness	.58	.58	.58	.63	.63	.68	.73
	8	Calculated Thickness	*.62*	*.64*	*.66*	*.69*	*.72*	*.75*	*.78*
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	.63	.63	.68	.68	.73	.73	.79
	12	Calculated Thickness	*.68*	*.70*	*.72*	*.74*	*.77*	*.80*	*.83*
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	.68	.68	.73	.73	.79	.79	.85
	16	Calculated Thickness	*.72*	*.74*	*.76*	*.78*	*.81*	*.83*	*.86*
		Use Thickness Class	26	26	27	27	27	28	28
		Use Thickness	.73	.73	.79	.79	.79	.85	.85
B	2½	Calculated Thickness	*.50**	*.52**	*.54**	*.56**	*.59**	*.62**	*.65**
		Use Thickness Class	21	22	22	23	23	24	25
		Use Thickness	.50	.54	.54	.58	.58	63	.68
	3½	Calculated Thickness	*.50**	*.52**	*.53**	*.56**	*.59*	*.63*	*.68*
		Use Thickness Class	21	22	22	23	23	24	25
		Use Thickness	.50	.54	.54	.58	.58	.63	.68
	5	Calculated Thickness	*.52**	*.53**	*.55**	*.58*	*.62*	*.66*	*.70*
		Use Thickness Class	22	22	22	23	24	25	25
		Use Thickness	.54	.54	.54	.58	.63	.68	.68
	8	Calculated Thickness	*.58*	*.60*	*.62*	*.65*	*.68*	*.71*	*.75*
		Use Thickness Class	23	23	24	24	25	26	26
		Use Thickness	.58	.58	.63	.63	.68	.73	.73
	12	Calculated Thickness	*.63*	*.65*	*.68*	*.70*	*.73*	*.76*	*.79*
		Use Thickness Class	24	24	25	25	26	27	27
		Use Thickness	.63	.63	.68	.68	.73	.79	.79
	16	Calculated Thickness	*.67*	*.69*	*.71*	*.73*	*.76*	*.79*	*.82*
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	.68	.68	.73	.73	.79	.79	.85
F	2½	Calculated Thickness	*.47**	*.48**	*.50**	*.52**	*.56*	*.61*	*.67*
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.50	.50	.50	.54	.58	.63	.68
	3½	Calculated Thickness	*.46**	*.47**	*.50*	*.53*	*.57*	*.62*	*.67*
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.50	.50	.50	.54	.58	.63	.68
	5	Calculated Thickness	*.48**	*.50*	*.52*	*.56*	*.59*	*.64*	*.68*
		Use Thickness Class	21	21	22	23	23	24	25
		Use Thickness	.50	.50	.54	.58	.58	.63	.68
	8	Calculated Thickness	*.53*	*.55*	*.58*	*.61*	*.64*	*.68*	*.72*
		Use Thickness Class	22	22	23	24	24	25	26
		Use Thickness	.54	.54	.58	.63	.63	.68	.73
	12	Calculated Thickness	*.57*	*.59*	*.62*	*.65*	*.68*	*.71*	*.75*
		Use Thickness Class	23	23	24	24	25	26	26
		Use Thickness	.58	.58	.63	.63	.68	.73	.73
	16	Calculated Thickness	*61*	*.63*	*.65*	*.68*	*.71*	*.74*	*.77*
		Use Thickness Class	24	24	24	25	26	26	27
		Use Thickness	.63	.63	.63	.68	.73	.73	.79

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi*						
			50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Eighteen-Inch Water Pipe									
A	2½	Calculated Thickness	*.58**	*.60**	*.62**	*.65**	*.67**	*.70**	*.74**
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	.58	.58	.63	.63	.68	.68	.73
	3½	Calculated Thickness	*.56**	*.56**	*.62**	*.64**	*.67**	*.70*	*.76*
		Use Thickness Class	22	22	23	23	24	24	26
		Use Thickness	.58	.58	.63	.63	.68	.68	.79
	5	Calculated Thickness	*.60**	*.62**	*.64**	*.67*	*.70*	*.75*	*.79*
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	.58	.63	.63	.68	.68	.73	.79
	8	Calculated Thickness	*.67*	*.69*	*.72*	*.74*	*.77*	*.81*	*.85*
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	.68	.68	.73	.73	.79	.79	.85
	12	Calculated Thickness	*.73*	*.75*	*.78*	*.80*	*.83*	*.86*	*90*
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	.73	.73	.79	.79	.85	.85	.92
	16	Calculated Thickness	*.77*	*.80*	*.82*	*.85*	*.88*	*.91*	*.95*
		Use Thickness Class	26	26	27	27	27	28	28
		Use Thickness	.79	.79	.85	.85	.85	92	.92
B	2½	Calculated Thickness	*.54**	*.56**	*.58**	*.60**	*.63**	*.67*	*.73*
		Use Thickness Class	21	22	22	22	23	24	25
		Use Thickness	.54	.58	.58	.58	.63	.68	.73
	3½	Calculated Thickness	*.53**	*.55**	*.57**	*.60*	*.64*	*.69*	*.75*
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	.54	.54	.58	.58	.63	.68	.73
	5	Calculated Thickness	*.55**	*.58**	*.60*	*.63*	*.67*	*.72*	*.77*
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	.54	.58	.58	.63	.68	.73	.79
	8	Calculated Thickness	*.62*	*.64*	*.67*	*.70*	*.74*	*.77*	*.82*
		Use Thickness Class	23	23	24	24	25	26	27
		Use Thickness	.63	.63	.68	.68	.73	.79	.85
	12	Calculated Thickness	*.68*	*.70*	*.73*	*.75*	*.78*	*.82*	*.86*
		Use Thickness Class	24	24	25	25	26	27	27
		Use Thickness	.68	.68	.73	.73	.79	.85	.85
	16	Calculated Thickness	*.72*	*.74*	*.76*	*.79*	*.82*	*.85*	*.89*
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	.73	.73	.79	.79	.85	.85	.92
F	2½	Calculated Thickness	*.50**	*.51**	*.53**	*.56**	*.61*	*.67*	*.73*
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.54	.54	.54	.58	.63	.68	.73
	3½	Calculated Thickness	*.49**	*.51*	*.53*	*.57*	*.62*	*.67*	*.73*
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	.54	.54	.54	.58	.63	.68	.73
	5	Calculated Thickness	*.51**	*.53*	*.57*	*.60*	*.65*	*.70*	*.75*
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	.54	.54	.58	.58	.63	.68	.73
	8	Calculated Thickness	*.57*	*.59*	*.62*	*.65*	*.69*	*.74*	*.78*
		Use Thickness Class	22	22	23	23	24	25	26
		Use Thickness	.58	.58	.63	.63	.68	.73	.79
	12	Calculated Thickness	*.61*	*.64*	*.67*	*.70*	*.73*	*.77*	*.81*
		Use Thickness Class	23	23	24	24	25	26	26
		Use Thickness	.63	.63	.68	.68	.73	.79	.79
	16	Calculated Thickness	*.65*	*.67*	*.69*	*.72*	*.76*	*.80*	*.84*
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	.63	.68	.68	.73	.79	.79	.85

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condi-tion	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Twenty-Inch Water Pipe									
A	2½	Calculated Thickness	.62*	.65*	.67*	.70*	.73*	.76*	.80*
		Use: Thickness Class	22	23	23	24	24	25	25
		Use: Thickness	.62	.67	.67	.72	.72	.78	.78
	3½	Calculated Thickness	.62*	.64*	.66*	.69*	.72*	.76*	.80
		Use: Thickness Class	22	22	23	23	24	25	26
		Use: Thickness	.62	.62	.67	.67	.72	.78	.84
	5	Calculated Thickness	.65*	.67*	.69*	.72*	.75*	.80	.85
		Use: Thickness Class	23	23	23	24	25	25	26
		Use: Thickness	.67	.67	.67	.72	.78	.78	.84
	8	Calculated Thickness	.71	.73	.76	.79	.83	.87	.91
		Use: Thickness Class	24	24	25	25	26	26	27
		Use: Thickness	.72	.72	.78	.78	.84	.84	.91
	12	Calculated Thickness	.78	.80	.83	.86	.89	.93	.97
		Use: Thickness Class	25	25	26	26	27	27	28
		Use: Thickness	.78	.78	.84	.84	.91	.91	.98
	16	Calculated Thickness	.83	.86	.88	.91	.94	.97	1.01
		Use: Thickness Class	26	26	27	27	27	28	28
		Use: Thickness	.84	.84	.91	.91	.91	.98	.98
B	2½	Calculated Thickness	.57*	.59*	.62*	.65*	.68*	.72	.78
		Use: Thickness Class	21	21	22	23	23	24	25
		Use: Thickness	.57	.57	.62	.67	.67	.72	.78
	3½	Calculated Thickness	.57*	.58*	.62*	.64*	.68	.74	.80
		Use: Thickness Class	21	21	22	22	23	24	25
		Use: Thickness	.57	.57	.62	.62	.67	.72	.78
	5	Calculated Thickness	.59*	.61*	.64*	.67	.72	.77	.82
		Use: Thickness Class	21	22	22	23	24	25	26
		Use: Thickness	.57	.62	.62	.67	.72	.78	.84
	8	Calculated Thickness	.65	.68	.71	.74	.78	.82	87
		Use: Thickness Class	23	23	24	24	25	26	26
		Use: Thickness	.67	.67	.72	.72	.78	.84	.84
	12	Calculated Thickness	.71	.74	.77	.80	.84	.87	.92
		Use: Thickness Class	24	24	25	25	26	26	27
		Use: Thickness	.72	.72	.78	.78	.84	.84	.91
	16	Calculated Thickness	.76	.78	.81	.84	.87	.91	.95
		Use: Thickness Class	25	25	26	26	26	27	28
		Use: Thickness	.78	.78	.84	.84	.84	.91	.98
F	2½	Calculated Thickness	.51*	.53*	.57*	.60*	.64	.70	.77
		Use: Thickness Class	21	21	21	22	22	24	25
		Use: Thickness	.57	.57	.57	.62	.62	.72	.78
	3½	Calculated Thickness	.52	.54	.57	.61	.66	.72	.78
		Use: Thickness Class	21	21	21	22	23	24	25
		Use: Thickness	.57	.57	.57	.62	.67	.72	.78
	5	Calculated Thickness	.53	.56	.60	.64	.69	.74	.80
		Use: Thickness Class	21	21	22	22	23	24	25
		Use: Thickness	.57	57	.62	.62	.67	.72	.78
	8	Calculated Thickness	.60	.62	.65	.69	.73	.78	.83
		Use: Thickness Class	22	22	23	23	24	25	26
		Use: Thickness	.62	.62	.67	.67	.72	.78	.84
	12	Calculated Thickness	.65	.68	.71	.74	.78	.82	.87
		Use: Thickness Class	23	23	24	24	25	26	26
		Use: Thickness	67	67	.72	.72	.78	.84	.84
	16	Calculated Thickness	.69	.71	.74	.77	.81	.85	90
		Use: Thickness Class	23	24	24	25	26	26	27
		Use: Thickness	.67	.72	.72	.78	.84	.84	.91

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Twenty-four-Inch Water Pipe									
A	2½	Calculated Thickness	*.69**	*.72**	*.75**	*.78**	*.82**	*.86**	*.91**
		Use Thickness Class	22	23	23	24	25	25	26
		Use Thickness	.68	.73	.73	.79	.85	.85	.92
	3½	Calculated Thickness	*.69**	*.71**	*.74**	*.78**	*.81**	*.86*	*.93*
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	.68	.73	.73	.79	.79	.85	.92
	5	Calculated Thickness	*.72**	*.75**	*.78**	*.81**	*.85**	*.91*	*.96*
		Use Thickness Class	23	23	24	24	25	26	27
		Use Thickness	.73	.73	.79	.79	.85	.92	.99
	8	Calculated Thickness	*.80*	*.82*	*.86*	*.90*	*.94*	*.99*	*1.04*
		Use Thickness Class	24	25	25	26	26	27	28
		Use Thickness	.79	.85	.85	.92	.92	.99	1.07
	12	Calculated Thickness	*.88*	*.91*	*.94*	*.98*	*1.02*	*1.06*	*1.10*
		Use Thickness Class	25	26	26	27	27	28	28
		Use Thickness	.85	.92	.92	.99	.99	1.07	1.07
	16	Calculated Thickness	*.94*	*.97*	*1.00*	*1.03*	*1.07*	*1.11*	*1.15*
		Use Thickness Class	26	27	27	28	28	28	29
		Use Thickness	.92	.99	.99	1.07	1.07	1.07	1.16
B	2½	Calculated Thickness	*.63**	*.65**	*.68**	*.72**	*.76**	*.82*	*.90*
		Use Thickness Class	21	21	22	23	24	25	26
		Use Thickness	.63	.63	.68	.73	.79	.85	.92
	3½	Calculated Thickness	*.62**	*.65**	*.68**	*.71**	*.77*	*.84*	*.91*
		Use Thickness Class	21	21	22	23	24	25	26
		Use Thickness	.63	.63	.68	.73	.79	.85	.92
	5	Calculated Thickness	*.65**	*.67**	*.71**	*.76*	*.81*	*.88*	*.94*
		Use Thickness Class	21	22	23	24	24	25	26
		Use Thickness	.63	.68	.73	.79	.79	.85	.92
	8	Calculated Thickness	*.72*	*.75*	*.79*	*.83*	*.88*	*.94*	*.99*
		Use Thickness Class	23	23	24	25	25	26	27
		Use Thickness	.73	.73	.79	.85	.85	.92	.99
	12	Calculated Thickness	*.79*	*.82*	*.86*	*.90*	*.94*	*.99*	*1.04*
		Use Thickness Class	24	25	25	26	26	27	28
		Use Thickness	.79	.85	.85	.92	.92	.99	1.07
	16	Calculated Thickness	*.85*	*.88*	*.91*	*.95*	*.99*	*1.03*	*1.08*
		Use Thickness Class	25	25	26	26	27	28	28
		Use Thickness	.85	.85	.92	.92	.99	1.07	1.07
F	2½	Calculated Thickness	*.56**	*.58**	*.63**	*.67**	*.73*	*.81*	*.89*
		Use Thickness Class	21	21	21	22	23	24	26
		Use Thickness	.63	.63	.63	.68	.73	.79	.92
	3½	Calculated Thickness	*.56**	*.59*	*.63*	*.69*	*.75*	*.82*	*.90*
		Use Thickness Class	21	21	21	22	23	25	26
		Use Thickness	.63	.63	.63	.68	.73	.85	.92
	5	Calculated Thickness	*.59*	*.63*	*.67*	*.72*	*.78*	*.84*	*.92*
		Use Thickness Class	21	21	22	23	24	25	26
		Use Thickness	.63	.63	.68	.73	.79	.85	.92
	8	Calculated Thickness	*.66*	*.69*	*.73*	*.77*	*.83*	*.89*	*.95*
		Use Thickness Class	22	22	23	24	25	26	26
		Use Thickness	.68	.68	.73	.79	.85	.92	.92
	12	Calculated Thickness	*.72*	*.75*	*.79*	*.83*	*.88*	*.93*	*.99*
		Use Thickness Class	23	23	24	25	25	26	27
		Use Thickness	.73	.73	.79	.85	.85	.92	.99
	16	Calculated Thickness	*.77*	*.80*	*.83*	*.87*	*.91*	*.96*	*1.02*
		Use Thickness Class	24	24	25	25	26	27	27
		Use Thickness	.79	.79	.85	.85	.92	.99	.99

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Thirty-Inch Water Pipe									
A	2½	Calculated Thickness	*.83**	*.86**	*.90**	*.94**	*.98**	*1.04**	*1.10*
		Use Thickness Class	23	23	24	24	25	26	26
		Use Thickness	.85	.85	.92	.92	.99	1.07	1.07
	3½	Calculated Thickness	*.82**	*.85**	*.89**	*.93**	*.98**	*1.04*	*1.12*
		Use Thickness Class	23	23	24	24	25	26	27
		Use Thickness	.85	.85	.92	.92	.99	1.07	1.16
	5	Calculated Thickness	*.86**	*.90**	*.93**	*.97**	*1.03*	*1.10*	*1.18*
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	.85	.92	.92	.99	1.07	1.07	1.16
	8	Calculated Thickness	*.94**	*.98*	*1.02*	*1.07*	*1.12*	*1.19*	*1.25*
		Use Thickness Class	24	25	25	26	27	27	28
		Use Thickness	.92	.99	.99	1.07	1.16	1.16	1.25
	12	Calculated Thickness	*1.05*	*1.08*	*1.12*	*1.17*	*1.22*	*1.28*	*1.33*
		Use Thickness Class	26	26	27	27	28	28	29
		Use Thickness	1.07	1.07	1.16	1.16	1.25	1.25	1.35
	16	Calculated Thickness	*1.13*	*1.17*	*1.20*	*1.25*	*1.29*	*1.35*	*1.40*
		Use Thickness Class	27	27	27	28	28	29	29
		Use Thickness	1.16	1.16	1.16	1.25	1.25	1.35	1.35
B	2½	Calculated Thickness	*.74**	*.77**	*.81**	*.85**	*.90**	*.99*	*1.09*
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	.73	.79	.79	.85	.92	.99	1.07
	3½	Calculated Thickness	*.73**	*.76**	*.80**	*.85**	*.92*	*1.01*	*1.10*
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	.73	.79	.79	.85	.92	.99	1.07
	5	Calculated Thickness	*.77**	*.80**	*.84**	*.90*	*.97*	*1.05*	*1.13*
		Use Thickness Class	22	22	23	24	25	26	27
		Use Thickness	.79	.79	.85	.92	.99	1.07	1.16
	8	Calculated Thickness	*.84*	*.88*	*.93*	*.98*	*1.05*	*1.11*	*1.18*
		Use Thickness Class	23	23	24	25	26	26	27
		Use Thickness	.85	.85	.92	.99	1.07	1.07	1.16
	12	Calculated Thickness	*.93*	*.97*	*1.01*	*1.06*	*1.12*	*1.18*	*1.25*
		Use Thickness Class	24	25	25	26	27	27	28
		Use Thickness	.92	.99	.99	1.07	1.16	1.16	1.25
	16	Calculated Thickness	*1.00*	*1.04*	*1.08*	*1.13*	*1.18*	*1.24*	*1.30*
		Use Thickness Class	25	26	26	27	27	28	29
		Use Thickness	.99	1.07	1.07	1.16	1.16	1.25	1.35
F	2½	Calculated Thickness	*.66**	*.70**	*.74**	*.79**	*.88*	*.98*	*1.08*
		Use Thickness Class	21	21	21	22	23	25	26
		Use Thickness	.73	.73	.73	.79	.85	.99	1.07
	3½	Calculated Thickness	*.66**	*.70**	*.74**	*.80*	*.90*	*1.00*	*1.10*
		Use Thickness Class	21	21	21	22	24	25	26
		Use Thickness	.73	.73	.73	.79	.92	.99	1.07
	5	Calculated Thickness	*.70**	*.73**	*.79*	*.86*	*.93*	*1.01*	*1.11*
		Use Thickness Class	21	21	22	23	24	25	26
		Use Thickness	.73	.73	.79	.85	.92	.99	1.07
	8	Calculated Thickness	*.77*	*.81*	*.86*	*.93*	*1.00*	*1.07*	*1.15*
		Use Thickness Class	22	22	23	24	25	26	27
		Use Thickness	.79	.79	.85	.92	.99	1.07	1.16
	12	Calculated Thickness	*.85*	*.89*	*.94*	*.99*	*1.05*	*1.12*	*1.20*
		Use Thickness Class	23	24	24	25	26	27	27
		Use Thickness	.85	.92	.92	.99	1.07	1.16	1.16
	16	Calculated Thickness	*.91*	*.95*	*.99*	*1.04*	*1.10*	*1.16*	*1.23*
		Use Thickness Class	24	24	25	26	26	27	28
		Use Thickness	.92	.92	.99	1.07	1.07	1.16	1.25

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Thirty-six-Inch Water Pipe									
A	2½	Calculated Thickness	*.94**	*.98**	*1.02**	*1.07**	*1.13**	*1.19**	*1.27*
		Use Thickness Class	23	24	24	25	25	26	27
		Use Thickness	.94	1.02	1.02	1.10	1.10	1.19	1.29
	3½	Calculated Thickness	*.93**	*.97**	*1.02**	*1.07**	*1.12**	*1.19*	*1.31*
		Use Thickness Class	23	23	24	25	25	26	27
		Use Thickness	.94	.94	1.02	1.10	1.10	1.19	1.29
	5	Calculated Thickness	*.98**	*1.02**	*1.07**	*1.12**	*1.17**	*1.26*	*1.35*
		Use Thickness Class	24	24	25	25	26	27	28
		Use Thickness	1.02	1.02	1.10	1.10	1.19	1.29	1.39
	8	Calculated Thickness	*1.07**	*1.11**	*1.16*	*1.22*	*1.28*	*1.36*	*1.44*
		Use Thickness Class	25	25	26	26	27	28	28
		Use Thickness	1.10	1.10	1.19	1.19	1.29	1.39	1.39
	12	Calculated Thickness	*1.19*	*1.24*	*1.28*	*1.34*	*1.40*	*1.47*	*1.54*
		Use Thickness Class	26	27	27	28	28	29	29
		Use Thickness	1.19	1.29	1.29	1.39	1.39	1.50	1.50
	1	Calculated Thickness	*1.29*	*1.33*	*1.38*	*1.43*	*1.49*	*1.55*	*1.62*
		Use Thickness Class	27	27	28	28	29	29	30
		Use Thickness	1.29	1.29	1.39	1.39	1.50	1.50	1.62
B	2½	Calculated Thickness	*.82**	*.86**	*.91**	*.97**	*1.03**	*1.14*	*1.26*
		Use Thickness Class	21	22	23	23	24	25	27
		Use Thickness	.81	.87	.94	.94	1.02	1.10	1.29
	3½	Calculated Thickness	*.81**	*.85**	*.90**	*.96**	*1.04*	*1.15*	*1.28*
		Use Thickness Class	21	22	22	23	24	26	27
		Use Thickness	.81	.87	.87	.94	1.02	1.19	1.29
	5	Calculated Thickness	*.86**	*.90**	*.94**	*1.01*	*1.10*	*1.20*	*1.30*
		Use Thickness Class	22	22	23	24	25	26	27
		Use Thickness	.87	.87	.94	1.02	1.10	1.19	1.29
	8	Calculated Thickness	*.94*	*.99*	*1.05*	*1.11*	*1.18*	*1.27*	*1.36*
		Use Thickness Class	23	24	24	25	26	27	28
		Use Thickness	.94	1.02	1.02	1.10	1.19	1.29	1.39
	12	Calculated Thickness	*1.05*	*1.09*	*1.14*	*1.20*	*1.27*	*1.34*	*1.43*
		Use Thickness Class	24	25	25	26	27	28	28
		Use Thickness	1.02	1.10	1.10	1.19	1.29	1.39	1.39
	16	Calculated Thickness	*1.12*	*1.17*	*1.22*	*1.27*	*1.34*	*1.40*	*1.48*
		Use Thickness Class	25	26	26	27	28	28	29
		Use Thickness	1.10	1.19	1.19	1.29	1.39	1.39	1.50
F	2½	Calculated Thickness	*.73**	*.79**	*.84**	*.89*	*1.01*	*1.13*	*1.25*
		Use Thickness Class	21	21	22	22	24	25	27
		Use Thickness	81	.81	.87	.87	1.02	1.10	1.29
	3½	Calculated Thickness	*.73**	*.78**	*.83**	*.92*	*1.03*	*1.14*	*1.26*
		Use Thickness Class	21	21	21	23	24	25	27
		Use Thickness	.81	.81	.81	.94	1.02	1.10	1.29
	5	Calculated Thickness	*.78**	*.82**	*.89*	*.97*	*1.07*	*1.17*	*1.28*
		Use Thickness Class	21	21	22	23	25	26	27
		Use Thickness	.81	.81	.87	.94	1.10	1.19	1.29
	8	Calculated Thickness	*.86*	*.91*	*.97*	*1.04*	*1.13*	*1.22*	*1.33*
		Use Thickness Class	22	23	23	24	25	26	27
		Use Thickness	.87	.94	.94	1.02	1.10	1.19	1.29
	12	Calculated Thickness	*.95*	*1.00*	*1.06*	*1.12*	*1.20*	*1.28*	*1.37*
		Use Thickness Class	23	24	25	25	26	27	28
		Use Thickness	.94	1.02	1.10	1.10	1.19	1.29	1.39
	16	Calculated Thickness	*1.02*	*1.07*	*1.12*	*1.18*	*1.25*	*1.33*	*1.42*
		Use Thickness Class	24	25	25	26	27	27	28
		Use Thickness	1.02	1.10	1.10	1.19	1.29	1.29	1.39

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Forty-two-Inch Water Pipe									
A	2½	Calculated Thickness	*1.04**	*1.08**	*1.14**	*1.20**	*1.27**	*1.34**	*1.43*
		Use Thickness Class	23	23	24	25	26	26	27
		Use Thickness	1.05	1.05	1.13	1.22	1.32	1.32	1.43
	3½	Calculated Thickness	*1.04**	*1.08**	*1.14**	*1.20**	*1.27**	*1.33*	*1.46*
		Use Thickness Class	23	23	24	25	26	26	27
		Use Thickness	1.05	1.05	1.13	1.22	1.32	1.32	1.43
	5	Calculated Thickness	*1.09**	*1.14**	*1.19**	*1.25**	*1.32**	*1.43*	*1.52*
		Use Thickness Class	24	24	25	25	26	27	28
		Use Thickness	1.13	1.13	1.22	1.22	1.32	1.43	1.54
	8	Calculated Thickness	*1.19**	*1.24**	*1.30*	*1.37*	*1.45*	*1.53*	*1.63*
		Use Thickness Class	25	25	26	26	27	28	29
		Use Thickness	1.22	1.22	1.32	1.32	1.43	1.54	1.66
	12	Calculated Thickness	*1.33*	*1.38*	*1.44*	*1.50*	*1.58*	*1.65*	*1.74*
		Use Thickness Class	26	27	27	28	28	29	30
		Use Thickness	1.32	1.43	1.43	1.54	1.54	1.66	1.79
	16	Calculated Thickness	*1.46*	*1.51*	*1.56*	*1.62*	*1.68*	*1.75*	*1.83*
		Use Thickness Class	27	28	28	29	29	30	30
		Use Thickness	1.43	1.54	1.54	1.66	1.66	1.79	1.79
B	2½	Calculated Thickness	*.89**	*.94**	*1.00**	*1.07**	*1.14*	*1.28*	*1.42*
		Use Thickness Class	21	22	22	23	24	26	27
		Use Thickness	.90	.97	.97	1.05	1.13	1.32	1.43
	3½	Calculated Thickness	*.89**	*.94**	*1.00**	*1.07**	*1.17*	*1.30*	*1.43*
		Use Thickness Class	21	22	22	23	24	26	27
		Use Thickness	.90	.97	.97	1.05	1.13	1.32	1.43
	5	Calculated Thickness	*.94**	*.98**	*1.04**	*1.13*	*1.23*	*1.34*	*1.47*
		Use Thickness Class	22	22	23	24	25	26	27
		Use Thickness	.97	.97	1.05	1.13	1.22	1.32	1.43
	8	Calculated Thickness	*1.04*	*1.09*	*1.16*	*1.23*	*1.32*	*1.42*	*1.53*
		Use Thickness Class	23	24	24	25	26	27	28
		Use Thickness	1.05	1.13	1.13	1.22	1.32	1.43	1.54
	12	Calculated Thickness	*1.15*	*1.21*	*1.27*	*1.33*	*1.42*	*1.51*	*1.60*
		Use Thickness Class	24	25	26	26	27	28	29
		Use Thickness	1.13	1.22	1.32	1.32	1.43	1.54	1.66
	16	Calculated Thickness	*1.25*	*1.30*	*1.36*	*1.43*	*1.50*	*1.58*	*1.67*
		Use Thickness Class	25	26	26	27	28	28	29
		Use Thickness	1.22	1.32	1.32	1.43	1.54	1.54	1.66
F	2½	Calculated Thickness	*.80**	*.86**	*.92**	*1.00*	*1.15*	*1.28*	*1.42*
		Use Thickness Class	21	21	21	22	24	26	27
		Use Thickness	.90	.90	.90	.97	1.13	1.32	1.43
	3½	Calculated Thickness	*.80**	*.86**	*.92**	*1.04*	*1.17*	*1.29*	*1.43*
		Use Thickness Class	21	21	21	23	24	26	27
		Use Thickness	.90	.90	.90	1.05	1.13	1.32	1.43
	5	Calculated Thickness	*.85**	*.90**	*.98*	*1.08*	*1.19*	*1.32*	*1.45*
		Use Thickness Class	21	21	22	23	25	26	27
		Use Thickness	.90	.90	.97	1.05	1.22	1.32	1.43
	8	Calculated Thickness	*.94*	*1.00*	*1.08*	*1.16*	*1.26*	*1.36*	*1.49*
		Use Thickness Class	22	22	23	24	25	26	28
		Use Thickness	.97	.97	1.05	1.13	1.22	1.32	1.54
	12	Calculated Thickness	*1.05*	*1.10*	*1.17*	*1.25*	*1.34*	*1.43*	*1.54*
		Use Thickness Class	23	24	24	25	26	27	28
		Use Thickness	1.05	1.13	1.13	1.22	1.32	1.43	1.54
	16	Calculated Thickness	*1.13*	*1.18*	*1.24*	*1.32*	*1.40*	*1.49*	*1.59*
		Use Thickness Class	24	25	25	26	27	28	28
		Use Thickness	1.13	1.22	1.22	1.32	1.43	1.54	1.54

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-1 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thicknesses—*in.*						
Forty-eight-Inch Water Pipe									
A	2½	Calculated Thickness	*1.14**	*1.19**	*1.25**	*1.32**	*1.40**	*1.49**	*1.61*
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	1.14	1.23	1.23	1.33	1.44	1.44	1.56
	3½	Calculated Thickness	*1.14**	*1.20**	*1.26**	*1.33**	*1.40**	*1.50*	*1.66*
		Use Thickness Class	23	24	24	25	26	27	28
		Use Thickness	1.14	1.23	1.23	1.33	1.44	1.56	1.68
	5	Calculated Thickness	*1.22**	*1.27**	*1.32**	*1.39**	*1.47*	*1.58*	*1.71*
		Use Thickness Class	24	24	25	26	26	27	28
		Use Thickness	1.23	1.23	1.33	1.44	1.44	1.56	1.68
	8	Calculated Thickness	*1.33**	*1.38**	*1.44*	*1.53*	*1.61*	*1.71*	*1.83*
		Use Thickness Class	25	25	26	27	27	28	29
		Use Thickness	1.33	1.33	1.44	1.56	1.56	1.68	1.81
	12	Calculated Thickness	*1.49*	*1.55*	*1.61*	*1.69*	*1.77*	*1.85*	*1.96*
		Use Thickness Class	26	27	27	28	29	29	30
		Use Thickness	1.44	1.56	1.56	1.68	1.81	1.81	1.95
	16	Calculated Thickness	*1.63*	*1.68*	*1.74*	*1.81*	*1.89*	*1.98*	*2.08*
		Use Thickness Class	28	28	28	29	30	30	
		Use Thickness	1.68	1.68	1.68	1.81	1.95	1.95	
B	2½	Calculated Thickness	*.97**	*1.03**	*1.09**	*1.17**	*1.28*	*1.43*	*1.59*
		Use Thickness Class	21	22	22	23	25	26	27
		Use Thickness	.98	1.06	1.06	1.14	1.33	1.44	1.56
	3½	Calculated Thickness	*.98**	*1.03**	*1.10**	*1.17*	*1.31*	*1.45*	*1.61*
		Use Thickness Class	21	22	23	23	25	26	27
		Use Thickness	.98	1.06	1.14	1.14	1.33	1.44	1.56
	5	Calculated Thickness	*1.03**	*1.09**	*1.15**	*1.25*	*1.37*	*1.50*	*1.65*
		Use Thickness Class	22	22	23	24	25	27	28
		Use Thickness	1.06	1.06	1.14	1.23	1.33	1.56	1.68
	8	Calculated Thickness	*1.13*	*1.20*	*1.28*	*1.37*	*1.47*	*1.58*	*1.72*
		Use Thickness Class	23	24	25	25	26	27	28
		Use Thickness	1.14	1.23	1.33	1.33	1.44	1.56	1.68
	12	Calculated Thickness	*1.28*	*1.34*	*1.41*	*1.49*	*1.58*	*1.69*	*1.80*
		Use Thickness Class	25	25	26	26	27	28	29
		Use Thickness	1.33	1.33	1.44	1.44	1.56	1.68	1.81
	16	Calculated Thickness	*1.38*	*1.43*	*1.50*	*1.58*	*1.67*	*1.77*	*1.87*
		Use Thickness Class	25	26	27	27	28	29	29
		Use Thickness	1.33	1.44	1.56	1.56	1.68	1.81	1.81
F	2½	Calculated Thickness	*.88**	*.93**	*1.00**	*1.12*	*1.27*	*1.43*	*1.59*
		Use Thickness Class	21	21	21	23	24	26	27
		Use Thickness	.98	.98	.98	1.14	1.23	1.44	1.56
	3½	Calculated Thickness	*.88**	*.94**	*1.01**	*1.14*	*1.29*	*1.44*	*1.60*
		Use Thickness Class	21	21	21	23	25	26	27
		Use Thickness	.98	.98	.98	1.14	1.33	1.44	1.56
	5	Calculated Thickness	*.93**	*.99**	*1.08*	*1.20*	*1.33*	*1.48*	*1.63*
		Use Thickness Class	21	21	22	24	25	26	28
		Use Thickness	.98	.98	1.06	1.23	1.33	1.44	1.68
	8	Calculated Thickness	*1.03*	*1.10*	*1.19*	*1.28*	*1.40*	*1.52*	*1.67*
		Use Thickness Class	22	23	24	25	26	27	28
		Use Thickness	1.06	1.14	1.23	1.33	1.44	1.56	1.68
	12	Calculated Thickness	*1.15*	*1.22*	*1.29*	*1.39*	*1.48*	*1.60*	*1.73*
		Use Thickness Class	23	24	25	26	26	27	28
		Use Thickness	1.14	1.23	1.33	1.44	1.44	1.56	1.68
	16	Calculated Thickness	*1.25*	*1.31*	*1.38*	*1.46*	*1.56*	*1.67*	*1.78*
		Use Thickness Class	24	25	25	26	27	28	29
		Use Thickness	1.23	1.33	1.33	1.44	1.56	1.68	1.81

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Three-Inch Water Pipe									
A	2½	Calculated Thickness	0.20*	0.20*	0.20*	0.20*	0.21*	0.21*	0.21
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	3½	Calculated Thickness	0.20*	0.20*	0.20*	0.21*	0.21*	0.22*	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	5	Calculated Thickness	0.21	0.21	0.21	0.22	0.22	0.23	0.23
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	8	Calculated Thickness	0.22	0.23	0.23	0.23	0.24	0.24	0.25
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	12	Calculated Thickness	0.24	0.25	0.25	0.25	0.26	0.26	0.26
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	16	Calculated Thickness	0.26	0.26	0.27	0.27	0.27	0.28	0.28
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
B	2½	Calculated Thickness	0.19*	0.20*	0.20*	0.20*	0.21	0.22	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	3½	Calculated Thickness	0.19*	0.20*	0.20	0.21	0.21	0.22	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	5	Calculated Thickness	0.21	0.21	0.21	0.21	0.22	0.22	0.23
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	8	Calculated Thickness	0.22	0.22	0.22	0.23	0.23	0.24	0.24
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	12	Calculated Thickness	0.24	0.24	0.24	0.25	0.25	0.25	0.26
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	16	Calculated Thickness	0.25	0.26	0.26	0.26	0.27	0.27	0.27
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
F	2½	Calculated Thickness	0.19*	0.19*	0.19	0.20	0.20	0.21	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	3½	Calculated Thickness	0.19*	0.19	0.19	0.20	0.20	0.21	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	5	Calculated Thickness	0.19	0.20	0.20	0.21	0.21	0.22	0.22
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	8	Calculated Thickness	0.21	0.21	0.21	0.22	0.22	0.23	0.23
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	12	Calculated Thickness	0.22	0.22	0.23	0.23	0.24	0.24	0.25
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	16	Calculated Thickness	0.24	0.24	0.24	0.25	0.25	0.25	0.26
		Use: Thickness Class	22	22	22	22	22	22	22
		Use: Thickness	0.32	0.32	0.32	0.32	0.32	0.32	0.32

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Four-Inch Water Pipe									
A	2½	Calculated Thickness	0.22*	0.23*	0.23*	0.24*	0.24*	0.25*	0.25*
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.22*	0.22*	0.23*	0.23*	0.24	0.25	0.26
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.23*	0.23*	0.24*	0.24*	0.25	0.26	0.26
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.25	0.26	0.26	0.27	0.27	0.28	0.28
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.28	0.28	0.29	0.29	0.29	0.30	0.31
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	16	Calculated Thickness	0.30	0.30	0.31	0.31	0.32	0.32	0.33
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
B	2½	Calculated Thickness	0.22*	0.22*	0.23*	0.23*	0.24*	0.24*	0.24
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.22*	0.22*	0.22*	0.23*	0.24	0.24	0.25
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.22	0.23	0.23	0.24	0.25	0.25	0.26
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.25	0.25	0.25	0.26	0.27	0.28	0.28
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.27	0.27	0.28	0.28	0.29	0.29	0.30
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	16	Calculated Thickness	0.29	0.29	0.30	0.30	0.31	0.31	0.32
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
F	2½	Calculated Thickness	0.21*	0.21*	0.21*	0.22*	0.23	0.24	0.25
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.20*	0.21	0.21	0.22	0.23	0.24	0.25
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.21	0.22	0.22	0.23	0.24	0.25	0.25
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.23	0.24	0.24	0.25	0.25	0.26	0.27
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.25	0.26	0.26	0.27	0.27	0.28	0.28
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	16	Calculates Thickness	0.27	0.27	0.28	0.28	0.29	0.29	0.30
		Use {Thickness Class	22	22	22	22	22	22	22
		Use {Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Six-Inch Water Pipe									
A	2½	Calculated Thickness	0.28*	0.28*	0.29*	0.30*	0.30*	0.31*	0.32*
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.27*	0.27*	0.28*	0.29*	0.29*	0.30*	0.32
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.28*	0.28*	0.29	0.30	0.31	0.32	0.33
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.31	0.31	0.32	0.33	0.34	0.35	0.36
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.34	0.35	0.36	0.36	0.37	0.38	0.39
		Use Thickness Class	21	21	21	21	22	22	22
		Use Thickness	0.35	0.35	0.35	0.35	0.38	0.38	0.38
	16	Calculated Thickness	0.38	0.38	0.39	0.39	0.40	0.41	0.42
		Use Thickness Class	22	22	22	22	23	23	23
		Use Thickness	0.38	0.38	0.38	0.38	0.41	0.41	0.41
B	2½	Calculated Thickness	0.27*	0.27*	0.28*	0.29*	0.29*	0.30*	0.31*
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.26*	0.27*	0.27*	0.28*	0.29*	0.30	0.31
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.27*	0.27*	0.28*	0.29	0.30	0.31	0.32
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.30	0.30	0.31	0.32	0.33	0.34	0.35
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.33	0.34	0.34	0.35	0.36	0.37	0.38
		Use Thickness Class	21	21	21	21	21	22	22
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38
	16	Calculated Thickness	0.36	0.37	0.37	0.38	0.39	0.39	0.40
		Use Thickness Class	21	22	22	22	22	22	23
		Use Thickness	0.35	0.38	0.38	0.38	0.38	0.38	0.41
F	2½	Calculated Thickness	0.25*	0.26*	0.26*	0.27*	0.28*	0.29*	0.30
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.24*	0.25*	0.25	0.26	0.28	0.29	0.31
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.25	0.26	0.27	0.28	0.29	0.30	0.31
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	8	Calculated Thickness	0.28	0.28	0.29	0.30	0.31	0.32	0.33
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	12	Calculated Thickness	0.31	0.31	0.32	0.33	0.34	0.34	0.35
		Use Thickness Class	21	21	21	21	21	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	16	Calculated Thickness	0.33	0.34	0.34	0.35	0.36	0.37	0.38
		Use Thickness Class	21	21	21	21	21	22	22
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Eight-Inch Water Pipe									
A	2½	Calculated Thickness	0.33*	0.33*	0.34*	0.35*	0.36*	0.37*	0.38*
		Use Thickness Class	20	20	20	20	20	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38
	3½	Calculated Thickness	0.32*	0.32*	0.33*	0.34*	0.35*	0.36*	0.38
		Use Thickness Class	20	20	20	20	20	20	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.38
	5	Calculated Thickness	0.32*	0.33*	0.34*	0.35	0.36	0.38	0.39
		Use Thickness Class	20	20	20	20	20	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38
	8	Calculated Thickness	0.36	0.37	0.38	0.39	0.40	0.41	0.43
		Use Thickness Class	20	21	21	21	22	22	23
		Use Thickness	0.35	0.38	0.38	0.38	0.41	0.41	0.44
	12	Calculated Thickness	0.41	0.42	0.43	0.44	0.45	0.46	0.47
		Use Thickness Class	22	22	23	23	23	24	24
		Use Thickness	0.41	0.41	0.44	0.44	0.44	0.48	0.48
	16	Calculated Thickness	0.44	0.45	0.46	0.47	0.47	0.48	0.50
		Use Thickness Class	23	23	24	24	24	24	25
		Use Thickness	0.44	0.44	0.48	0.48	0.48	0.48	0.52
B	2½	Calculated Thickness	0.31*	0.32*	0.33*	0.34*	0.35*	0.36*	0.37*
		Use Thickness Class	20	20	20	20	20	20	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.38
	3½	Calculated Thickness	0.30*	0.31*	0.32*	0.33*	0.34*	0.35	0.37
		Use Thickness Class	20	20	20	20	20	20	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.38
	5	Calculated Thickness	0.31*	0.32*	0.33	0.34	0.35	0.37	0.38
		Use Thickness Class	20	20	20	20	20	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38
	8	Calculated Thickness	0.35	0.35	0.36	0.37	0.39	0.40	0.41
		Use Thickness Class	20	20	20	21	21	22	22
		Use Thickness	0.35	0.35	0.35	0.38	0.38	0.41	0.41
	12	Calculated Thickness	0.39	0.40	0.41	0.42	0.43	0.44	0.45
		Use Thickness Class	21	22	22	22	23	23	23
		Use Thickness	0.38	0.41	0.41	0.41	0.44	0.44	0.44
	16	Calculated Thickness	0.42	0.43	0.44	0.44	0.45	0.46	0.48
		Use Thickness Class	22	23	23	23	23	24	24
		Use Thickness	0.41	0.44	0.44	0.44	0.44	0.48	0.48
F	2½	Calculated Thickness	0.29*	0.30*	0.30*	0.31*	0.32*	0.34	0.36
		Use Thickness Class	20	20	20	20	20	20	20
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	3½	Calculated Thickness	0.28*	0.29*	0.30*	0.31*	0.33	0.35	0.36
		Use Thickness Class	20	20	20	20	20	20	20
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	5	Calculated Thickness	0.29*	0.30	0.31	0.32	0.34	0.36	0.37
		Use Thickness Class	20	20	20	20	20	20	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.35	0.38
	8	Calculated Thickness	0.32	0.33	0.34	0.35	0.36	0.38	0.39
		Use Thickness Class	20	20	20	20	20	21	21
		Use Thickness	0.35	0.35	0.35	0.35	0.35	0.38	0.38
	12	Calculated Thickness	0.36	0.37	0.38	0.39	0.40	0.41	0.42
		Use Thickness Class	20	21	21	21	22	22	22
		Use Thickness	0.35	0.38	0.38	0.38	0.41	0.41	0.41
	16	Calculated Thickness	0.38	0.39	0.40	0.41	0.42	0.43	0.44
		Use Thickness Class	21	21	22	22	22	23	23
		Use Thickness	0.38	0.38	0.41	0.41	0.41	0.44	0.44

*Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Ten-Inch Water Pipe									
A	2½	Calculated Thickness	0.38*	0.39*	0.40*	0.41*	0.42*	0.44*	0.45*
		Use Thickness Class	20	20	21	21	21	22	22
		Use Thickness	0.38	0.38	0.41	0.41	0.41	0.44	0.44
	3½	Calculated Thickness	0.37*	0.38*	0.39*	0.40*	0.41*	0.43*	0.44
		Use Thickness Class	20	20	20	21	21	22	22
		Use Thickness	0.38	0.38	0.38	0.41	0.41	0.44	0.44
	5	Calculated Thickness	0.38*	0.39*	0.40*	0.41	0.43	0.44	0.46
		Use Thickness Class	20	20	21	21	22	22	23
		Use Thickness	0.38	0.38	0.41	0.41	0.44	0.44	0.48
	8	Calculated Thickness	0.42	0.44	0.45	0.46	0.47	0.49	0.51
		Use Thickness Class	21	22	22	23	23	23	24
		Use Thickness	0.41	0.44	0.44	0.48	0.48	0.48	0.52
	12	Calculated Thickness	0.48	0.49	0.50	0.51	0.53	0.54	0.56
		Use Thickness Class	23	23	24	24	24	25	25
		Use Thickness	0.48	0.48	0.52	0.52	0.52	0.56	0.56
	16	Calculated Thickness	0.51	0.52	0.53	0.54	0.55	0.56	0.58
		Use Thickness Class	24	24	24	25	25	25	26
		Use Thickness	0.52	0.52	0.52	0.56	0.56	0.56	0.60
B	2½	Calculated Thickness	0.36*	0.37*	0.38*	0.39*	0.41*	0.42*	0.44*
		Use Thickness Class	20	20	20	20	21	21	22
		Use Thickness	0.38	0.38	0.38	0.38	0.41	0.41	0.44
	3½	Calculated Thickness	0.35*	0.36*	0.37*	0.39*	0.40*	0.41	0.44
		Use Thickness Class	20	20	20	20	21	21	22
		Use Thickness	0.38	0.38	0.38	0.38	0.41	0.41	0.44
	5	Calculated Thickness	0.36*	0.37*	0.38*	0.40	0.41	0.43	0.46
		Use Thickness Class	20	20	20	21	21	22	23
		Use Thickness	0.38	0.38	0.38	0.41	0.41	0.44	0.48
	8	Calculated Thickness	0.40	0.42	0.43	0.44	0.46	0.47	0.49
		Use Thickness Class	21	21	22	22	23	23	23
		Use Thickness	0.41	0.41	0.44	0.44	0.48	0.48	0.48
	12	Calculated Thickness	0.46	0.47	0.48	0.49	0.50	0.52	0.53
		Use Thickness Class	23	23	23	23	24	24	24
		Use Thickness	0.48	0.48	0.48	0.48	0.52	0.52	0.52
	16	Calculated Thickness	0.48	0.49	0.50	0.51	0.52	0.54	0.55
		Use Thickness Class	23	23	24	24	24	25	25
		Use Thickness	0.48	0.48	0.52	0.52	0.52	0.56	0.56
F	2½	Calculated Thickness	0.33*	0.34*	0.35*	0.37*	0.38*	0.40	0.43
		Use Thickness Class	20	20	20	20	20	21	22
		Use Thickness	0.38	0.38	0.38	0.38	0.38	0.41	0.44
	3½	Calculated Thickness	0.33*	0.33*	0.35*	0.36*	0.38	0.40	0.43
		Use Thickness Class	20	20	20	20	20	21	22
		Use Thickness	0.38	0.38	0.38	0.38	0.38	0.41	0.44
	5	Calculated Thickness	0.33*	0.34	0.36	0.38	0.40	0.42	0.44
		Use Thickness Class	20	20	20	20	21	21	22
		Use Thickness	0.38	0.38	0.38	0.38	0.41	0.41	0.44
	8	Calculated Thickness	0.37	0.38	0.40	0.41	0.43	0.45	0.47
		Use Thickness Class	20	20	21	21	22	22	23
		Use Thickness	0.38	0.38	0.41	0.41	0.44	0.44	0.48
	12	Calculated Thickness	0.42	0.43	0.44	0.45	0.47	0.48	0.50
		Use Thickness Class	21	22	22	22	23	23	24
		Use Thickness	0.41	0.44	0.44	0.44	0.48	0.48	0.52
	16	Calculated Thickness	0.44	0.45	0.46	0.47	0.48	0.50	0.52
		Use Thickness Class	22	22	23	23	23	24	24
		Use Thickness	0.44	0.44	0.48	0.48	0.48	0.52	0.52

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Twelve-Inch Water Pipe									
A	2½	Calculated Thickness	0.43*	0.44*	0.45*	0.47*	0.48*	0.49*	0.51*
		Use Thickness Class	21	21	21	22	22	22	23
		Use Thickness	0.44	0.44	0.44	0.48	0.48	0.48	0.52
	3½	Calculated Thickness	0.42*	0.43*	0.44*	0.45*	0.47*	0.48*	0.50*
		Use Thickness Class	20	21	21	21	22	22	23
		Use Thickness	0.41	0.44	0.44	0.44	0.48	0.48	0.52
	5	Calculated Thickness	0.43*	0.44*	0.45*	0.46*	0.48	0.50	0.52
		Use Thickness Class	21	21	21	22	22	23	23
		Use Thickness	0.44	0.44	0.44	0.48	0.48	0.52	0.52
	8	Calculated Thickness	0.48	0.49	0.50	0.52	0.54	0.55	0.57
		Use Thickness Class	22	22	23	23	24	24	24
		Use Thickness	0.48	0.48	0.52	0.52	0.56	0.56	0.56
	12	Calculated Thickness	0.53	0.54	0.56	0.57	0.58	0.60	0.62
		Use Thickness Class	23	24	24	24	25	25	25
		Use Thickness	0.52	0.56	0.56	0.56	0.60	0.60	0.60
	16	Calculated Thickness	0.56	0.57	0.58	0.60	0.61	0.63	0.64
		Use Thickness Class	24	24	25	25	25	26	26
		Use Thickness	0.56	0.56	0.60	0.60	0.60	0.65	0.65
B	2½	Calculated Thickness	0.41*	0.42*	0.43*	0.44*	0.46*	0.47*	0.49*
		Use Thickness Class	20	20	21	21	22	22	22
		Use Thickness	0.41	0.41	0.44	0.44	0.48	0.48	0.48
	3½	Calculated Thickness	0.39*	0.40*	0.42*	0.43*	0.45*	0.46*	0.49
		Use Thickness Class	20	20	20	21	21	22	22
		Use Thickness	0.41	0.41	0.41	0.44	0.44	0.48	0.48
	5	Calculated Thickness	0.40*	0.41*	0.42*	0.44*	0.46	0.48	0.51
		Use Thickness Class	20	20	20	21	22	22	23
		Use Thickness	0.41	0.41	0.41	0.44	0.48	0.48	0.52
	8	Calculated Thickness	0.45	0.46	0.48	0.49	0.51	0.53	0.55
		Use Thickness Class	21	22	22	22	23	23	24
		Use Thickness	0.44	0.48	0.48	0.48	0.52	0.52	0.56
	12	Calculated Thickness	0.50	0.51	0.52	0.54	0.56	0.57	0.59
		Use Thickness Class	23	23	23	24	24	24	25
		Use Thickness	0.52	0.52	0.52	0.56	0.56	0.56	0.60
	16	Calculated Thickness	0.52	0.54	0.55	0.56	0.58	0.60	0.61
		Use Thickness Class	23	24	24	24	25	25	25
		Use Thickness	0.52	0.56	0.56	0.56	0.60	0.60	0.60
F	2½	Calculated Thickness	0.37*	0.38*	0.39*	0.41*	0.42*	0.44*	0.48
		Use Thickness Class	20	20	20	20	20	21	22
		Use Thickness	0.41	0.41	0.41	0.41	0.41	0.44	0.48
	3½	Calculated Thickness	0.36*	0.37*	0.38*	0.40*	0.42	0.45	0.48
		Use Thickness Class	20	20	20	20	20	21	22
		Use Thickness	0.41	0.41	0.41	0.41	0.41	0.44	0.48
	5	Calculated Thickness	0.37*	0.38*	0.39*	0.42	0.44	0.47	0.49
		Use Thickness Class	20	20	20	20	21	22	22
		Use Thickness	0.41	0.41	0.41	0.41	0.44	0.48	0.48
	8	Calculated Thickness	0.41	0.43	0.44	0.46	0.48	0.50	0.53
		Use Thickness Class	20	21	21	22	22	23	23
		Use Thickness	0.41	0.44	0.44	0.48	0.48	0.52	0.52
	12	Calculated Thickness	0.45	0.47	0.48	0.50	0.52	0.54	0.56
		Use Thickness Class	21	22	22	23	23	24	24
		Use Thickness	0.44	0.48	0.48	0.52	0.52	0.56	0.56
	16	Calculated Thickness	0.48	0.49	0.50	0.52	0.54	0.55	0.57
		Use Thickness Class	22	22	23	23	24	24	24
		Use Thickness	0.48	0.48	0.52	0.52	0.56	0.56	0.56

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Fourteen-Inch Water Pipe									
A	2½	Calculated Thickness	0.48*	0.50*	0.51*	0.53*	0.54*	0.56*	0.56*
		Use Thickness Class	21	22	22	23	23	23	24
		Use Thickness	0.48	0.51	0.51	0.55	0.55	0.55	0.59
	3½	Calculated Thickness	0.47*	0.49*	0.50*	0.52*	0.53*	0.55*	0.58
		Use Thickness Class	21	21	22	22	23	23	24
		Use Thickness	0.48	0.48	0.51	0.51	0.55	0.55	0.59
	5	Calculated Thickness	0.49*	0.51*	0.52*	0.53*	0.55*	0.58	0.60
		Use Thickness Class	21	22	22	23	23	24	24
		Use Thickness	0.48	0.51	0.51	0.55	0.55	0.59	0.59
	8	Calculated Thickness	0.55	0.56	0.58	0.60	0.62	0.64	0.66
		Use Thickness Class	23	23	24	24	25	25	25
		Use Thickness	0.55	0.55	0.59	0.59	0.64	0.64	0.64
	12	Calculated Thickness	0.60	0.61	0.63	0.65	0.67	0.68	0.71
		Use Thickness Class	24	24	25	25	26	26	26
		Use Thickness	0.59	0.59	0.64	0.64	0.69	0.69	0.69
	16	Calculated Thickness	0.63	0.65	0.66	0.68	0.69	0.71	0.73
		Use Thickness Class	25	25	25	26	26	26	27
		Use Thickness	0.64	0.64	0.64	0.69	0.69	0.69	0.75
B	2½	Calculated Thickness	0.45*	0.47*	0.48*	0.50*	0.51*	0.53*	0.56*
		Use Thickness Class	21	21	21	22	22	23	23
		Use Thickness	0.48	0.48	0.48	0.51	0.51	0.55	0.55
	3½	Calculated Thickness	0.44*	0.46*	0.47*	0.49*	0.51*	0.53	0.57
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.48	0.48	0.48	0.48	0.51	0.55	0.59
	5	Calculated Thickness	0.46*	0.47*	0.49*	0.50	0.53	0.56	0.59
		Use Thickness Class	21	21	21	22	23	23	24
		Use Thickness	0.48	0.48	0.48	0.51	0.55	0.55	0.59
	8	Calculated Thickness	0.52	0.53	0.55	0.57	0.59	0.61	0.64
		Use Thickness Class	22	23	23	24	24	24	25
		Use Thickness	0.51	0.55	0.55	0.59	0.59	0.59	0.64
	12	Calculated Thickness	0.56	0.57	0.59	0.61	0.63	0.65	0.67
		Use Thickness Class	23	24	24	24	25	25	26
		Use Thickness	0.55	0.59	0.59	0.59	0.64	0.64	0.69
	16	Calculated Thickness	0.59	0.60	0.62	0.64	0.65	0.67	0.70
		Use Thickness Class	24	24	25	25	25	26	26
		Use Thickness	0.59	0.59	0.64	0.64	0.64	0.69	0.69
F	2½	Calculated Thickness	0.42*	0.43*	0.44*	0.46*	0.48*	0.51	0.55
		Use Thickness Class	21	21	21	21	21	22	23
		Use Thickness	0.48	0.48	0.48	0.48	0.48	0.51	0.55
	3½	Calculated Thickness	0.41*	0.42*	0.44*	0.45*	0.48	0.52	0.56
		Use Thickness Class	21	21	21	21	21	22	23
		Use Thickness	0.48	0.48	0.48	0.48	0.48	0.51	0.55
	5	Calculated Thickness	0.42*	0.43*	0.45	0.48	0.51	0.54	0.57
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.48	0.48	0.48	0.48	0.51	0.55	0.59
	8	Calculated Thickness	0.47	0.49	0.51	0.53	0.55	0.58	0.61
		Use Thickness Class	21	21	22	23	23	24	24
		Use Thickness	0.48	0.48	0.51	0.55	0.55	0.59	0.59
	12	Calculated Thickness	0.51	0.53	0.54	0.56	0.59	0.61	0.63
		Use Thickness Class	22	23	23	23	24	24	25
		Use Thickness	0.51	0.55	0.55	0.55	0.59	0.59	0.64
	16	Calculated Thickness	0.54	0.55	0.57	0.59	0.61	0.63	0.65
		Use Thickness Class	23	23	24	24	24	25	25
		Use Thickness	0.55	0.55	0.59	0.59	0.59	0.64	0.64

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	50	100	150	200	250	300	350
			Internal Pressure—*psi*						
			Barrel Thickness—*in.*						
Sixteen-Inch Water Pipe									
A	2½	Calculated Thickness	0.52*	0.53*	0.55*	0.57*	0.59*	0.61*	0.63*
		Use Thickness Class	22	22	22	23	23	24	24
		Use Thickness	0.54	0.54	0.54	0.58	0.58	0.63	0.63
	3½	Calculated Thickness	0.51*	0.53*	0.54*	0.56*	0.58*	0.60*	0.63*
		Use Thickness Class	21	22	22	23	23	23	24
		Use Thickness	0.50	0.54	0.54	0.58	0.58	0.58	0.63
	5	Calculated Thickness	0.53*	0.55*	0.56*	0.58*	0.60*	0.63	0.66
		Use Thickness Class	22	22	23	23	23	24	25
		Use Thickness	0.54	0.54	0.58	0.58	0.58	0.63	0.68
	8	Calculated Thickness	0.59	0.61	0.62	0.64	0.67	0.69	0.72
		Use Thickness Class	23	24	24	24	25	25	26
		Use Thickness	0.58	0.63	0.63	0.63	0.68	0.68	0.73
	12	Calculated Thickness	0.64	0.66	0.68	0.70	0.72	0.74	0.77
		Use Thickness Class	24	25	25	25	26	26	27
		Use Thickness	0.63	0.68	0.68	0.68	0.73	0.73	0.79
	16	Calculated Thickness	0.68	0.70	0.71	0.73	0.75	0.77	0.80
		Use Thickness Class	25	25	26	26	26	27	27
		Use Thickness	0.68	0.68	0.73	0.73	0.73	0.79	0.79
B	2½	Calculated Thickness	0.48*	0.50*	0.51*	0.53*	0.55*	0.58*	0.60*
		Use Thickness Class	21	21	21	22	22	23	23
		Use Thickness	0.50	0.50	0.50	0.54	0.54	0.58	0.58
	3½	Calculated Thickness	0.48*	0.49*	0.51*	0.53*	0.55*	0.57	0.61
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.50	0.50	0.50	0.54	0.54	0.58	0.63
	5	Calculated Thickness	0.49*	0.51*	0.53*	0.54	0.57	0.60	0.64
		Use Thickness Class	21	21	22	22	23	23	24
		Use Thickness	0.50	0.50	0.54	0.54	0.58	0.58	0.63
	8	Calculated Thickness	0.55	0.57	0.59	0.61	0.63	0.66	0.69
		Use Thickness Class	22	23	23	24	24	25	25
		Use Thickness	0.54	0.58	0.58	0.63	0.63	0.68	0.68
	12	Calculated Thickness	0.60	0.62	0.63	0.65	0.68	0.70	0.73
		Use Thickness Class	23	24	24	24	25	25	26
		Use Thickness	0.58	0.63	0.63	0.63	0.68	0.68	0.73
	16	Calculated Thickness	0.63	0.65	0.67	0.69	0.71	0.73	0.76
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	0.63	0.63	0.68	0.68	0.73	0.73	0.79
F	2½	Calculated Thickness	0.44*	0.46*	0.47*	0.49*	0.52*	0.55	0.60
		Use Thickness Class	21	21	21	21	22	22	23
		Use Thickness	0.50	0.50	0.50	0.50	0.54	0.54	0.58
	3½	Calculated Thickness	0.44*	0.45*	0.47*	0.49*	0.52	0.56	0.60
		Use Thickness Class	21	21	21	21	22	23	23
		Use Thickness	0.50	0.50	0.50	0.50	0.54	0.58	0.58
	5	Calculated Thickness	0.45*	0.47*	0.49	0.52	0.55	0.58	0.62
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.50	0.50	0.50	0.54	0.54	0.58	0.63
	8	Calculated Thickness	0.50	0.52	0.54	0.57	0.59	0.62	0.66
		Use Thickness Class	21	22	22	23	23	24	25
		Use Thickness	0.51	0.54	0.54	0.58	0.58	0.63	0.68
	12	Calculated Thickness	0.55	0.56	0.58	0.61	0.63	0.66	0.69
		Use Thickness Class	22	23	23	24	24	25	25
		Use Thickness	0.54	0.58	0.58	0.63	0.63	0.68	0.68
	16	Calculated Thickness	0.58	0.59	0.61	0.63	0.66	0.68	0.71
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.58	0.58	0.63	0.63	0.68	0.68	0.73

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Eighteen-Inch Water Pipe									
A	2½	Calculated Thickness	0.56*	0.57*	0.59*	0.61*	0.63*	0.66*	0.68*
		Use Thickness Class	22	22	22	23	23	24	24
		Use Thickness	0.58	0.58	0.58	0.63	0.63	0.68	0.68
	3½	Calculated Thickness	0.55*	0.57*	0.58*	0.60*	0.63*	0.65*	0.68
		Use Thickness Class	21	22	22	22	23	23	24
		Use Thickness	0.54	0.58	0.58	0.58	0.63	0.63	0.68
	5	Calculated Thickness	0.57*	0.59*	0.61*	0.63*	0.65	0.68	0.72
		Use Thickness Class	22	22	23	23	23	24	25
		Use Thickness	0.58	0.58	0.63	0.63	0.63	0.68	0.73
	8	Calculated Thickness	0.63*	0.65	0.67	0.69	0.72	0.75	0.78
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.63	0.63	0.68	0.68	0.73	0.73	0.79
	12	Calculated Thickness	0.69	0.71	0.73	0.75	0.78	0.80	0.83
		Use Thickness Class	24	25	25	25	26	26	27
		Use Thickness	0.68	0.73	0.73	0.73	0.79	0.79	0.85
	16	Calculated Thickness	0.73	0.75	0.77	0.79	0.82	0.84	0.87
		Use Thickness Class	25	25	26	26	27	27	27
		Use Thickness	0.73	0.73	0.79	0.79	0.85	0.85	0.85
B	2½	Calculated Thickness	0.51*	0.53*	0.55*	0.57*	0.59*	0.62*	0.65
		Use Thickness Class	21	21	21	22	22	23	23
		Use Thickness	0.54	0.54	0.54	0.58	0.58	0.63	0.63
	3½	Calculated Thickness	0.51*	0.53*	0.54*	0.56*	0.59*	0.62	0.67
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.54	0.54	0.54	0.58	0.58	0.63	0.68
	5	Calculated Thickness	0.53*	0.54*	0.56*	0.59	0.62	0.66	0.70
		Use Thickness Class	21	21	22	22	23	24	24
		Use Thickness	0.54	0.54	0.58	0.58	0.63	0.68	0.68
	8	Calculated Thickness	0.58	0.60	0.62	0.65	0.68	0.71	0.74
		Use Thickness Class	22	22	23	23	24	25	25
		Use Thickness	0.58	0.58	0.63	0.63	0.68	0.73	0.73
	12	Calculated Thickness	0.64	0.66	0.68	0.70	0.73	0.76	0.79
		Use Thickness Class	23	24	24	24	25	26	26
		Use Thickness	0.63	0.68	0.68	0.68	0.73	0.79	0.79
	16	Calculated Thickness	0.68	0.70	0.72	0.74	0.76	0.79	0.82
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	0.68	0.68	0.73	0.73	0.79	0.79	0.85
F	2½	Calculated Thickness	0.47*	0.49*	0.50*	0.53*	0.55*	0.60	0.65
		Use Thickness Class	21	21	21	21	21	22	23
		Use Thickness	0.54	0.54	0.54	0.54	0.54	0.58	0.63
	3½	Calculated Thickness	0.46*	0.48*	0.50*	0.52*	0.56	0.61	0.66
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.54	0.54	0.54	0.54	0.58	0.63	0.68
	5	Calculated Thickness	0.48*	0.50*	0.52	0.56	0.59	0.63	0.68
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.54	0.54	0.54	0.58	0.58	0.63	0.68
	8	Calculated Thickness	0.54	0.56	0.58	0.61	0.64	0.67	0.71
		Use Thickness Class	21	22	22	23	23	24	25
		Use Thickness	0.54	0.58	0.58	0.63	0.63	0.68	0.73
	12	Calculated Thickness	0.58	0.60	0.63	0.65	0.68	0.71	0.74
		Use Thickness Class	22	22	23	23	24	25	25
		Use Thickness	0.58	0.58	0.63	0.63	0.68	0.73	0.73
	16	Calculated Thickness	0.61	0.63	0.66	0.68	0.71	0.74	0.77
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.63	0.63	0.68	0.68	0.73	0.73	0.79

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Twenty-Inch Water Pipe									
A	2½	Calculated Thickness	0.59*	0.61*	0.63*	0.65*	0.68*	0.71*	0.74*
		Use Thickness Class	21	22	22	23	23	24	24
		Use Thickness	0.57	0.62	0.62	0.67	0.67	0.72	0.72
	3½	Calculated Thickness	0.59*	0.61*	0.63*	0.65*	0.68*	0.70*	0.73*
		Use Thickness Class	21	22	22	23	23	24	24
		Use Thickness	0.57	0.62	0.62	0.67	0.67	0.72	0.72
	5	Calculated Thickness	0.62*	0.64*	0.65*	0.67*	0.70*	0.73	0.77
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	0.62	0.62	0.67	0.67	0.72	0.72	0.78
	8	Calculated Thickness	0.67*	0.69	0.71	0.74	0.77	0.80	0.83
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.67	0.67	0.72	0.72	0.78	0.78	0.84
	12	Calculated Thickness	0.74	0.76	0.78	0.80	0.83	0.86	0.89
		Use Thickness Class	24	25	25	25	26	26	27
		Use Thickness	0.72	0.78	0.78	0.78	0.84	0.84	0.91
	16	Calculated Thickness	0.78	0.80	0.83	0.85	0.87	0.90	0.93
		Use Thickness Class	25	25	26	26	26	27	27
		Use Thickness	0.78	0.78	0.84	0.84	0.84	0.91	0.91
B	2½	Calculated Thickness	0.55*	0.56*	0.58*	0.61*	0.63*	0.66*	0.70*
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.57	0.57	0.57	0.62	0.67	0.67	0.72
	3½	Calculated Thickness	0.54*	0.56*	0.58*	0.60*	0.63*	0.66*	0.71*
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.57	0.57	0.57	0.62	0.62	0.67	0.72
	5	Calculated Thickness	0.57*	0.58*	0.60*	0.63*	0.66	0.70	0.74
		Use Thickness Class	21	21	22	22	23	24	24
		Use Thickness	0.57	0.57	0.62	0.62	0.67	0.72	0.72
	8	Calculated Thickness	0.62	0.64	0.66	0.69	0.72	0.76	0.79
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	0.62	0.62	0.67	0.67	0.72	0.78	0.78
	12	Calculated Thickness	0.68	0.70	0.72	0.75	0.77	0.81	0.84
		Use Thickness Class	23	24	24	25	25	26	26
		Use Thickness	0.67	0.72	0.72	0.78	0.78	0.84	0.84
	16	Calculated Thickness	0.72	0.74	0.76	0.78	0.81	0.84	0.87
		Use Thickness Class	24	24	25	25	25	26	26
		Use Thickness	0.72	0.72	0.78	0.78	0.84	0.84	0.84
F	2½	Calculated Thickness	0.50*	0.52*	0.54*	0.56*	0.59*	0.64	0.69
		Use Thickness Class	21	21	21	21	21	22	23
		Use Thickness	0.57	0.57	0.57	0.57	0.57	0.62	0.67
	3½	Calculated Thickness	0.49*	0.51*	0.53*	0.56*	0.60	0.65	0.70
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.57	0.57	0.57	0.57	0.62	0.67	0.72
	5	Calculated Thickness	0.51*	0.53	0.55	0.59	0.63	0.67	0.72
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.57	0.57	0.57	0.57	0.62	0.67	0.72
	8	Calculated Thickness	0.56	0.59	0.61	0.64	0.68	0.72	0.76
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	0.57	0.57	0.62	0.62	0.67	0.72	0.78
	12	Calculated Thickness	0.61	0.64	0.66	0.69	0.72	0.75	0.79
		Use Thickness Class	22	22	23	23	24	25	25
		Use Thickness	0.62	0.62	0.67	0.67	0.72	0.78	0.78
	16	Calculated Thickness	0.65	0.67	0.70	0.72	0.75	0.78	0.82
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.67	0.67	0.72	0.72	0.78	0.78	0.84

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Twenty-four-Inch Water Pipe									
A	2½	Calculated Thickness	0.66*	0.68*	0.71*	0.73*	0.76*	0.80*	0.84*
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	0.68	0.68	0.73	0.73	0.79	0.79	0.85
	3½	Calculated Thickness	0.66*	0.68*	0.70*	0.73*	0.76*	0.79*	0.83*
		Use Thickness Class	22	22	22	23	24	24	25
		Use Thickness	0.68	0.68	0.68	0.73	0.79	0.79	0.85
	5	Calculated Thickness	0.69*	0.71*	0.74*	0.76*	0.79*	0.83	0.88
		Use Thickness Class	22	23	23	24	24	25	25
		Use Thickness	0.68	0.73	0.73	0.79	0.79	0.85	0.85
	8	Calculated Thickness	0.75*	0.77	0.80	0.83	0.87	0.91	0.95
		Use Thickness Class	23	24	24	25	25	26	26
		Use Thickness	0.73	0.79	0.79	0.85	0.85	0.92	0.92
	12	Calculated Thickness	0.83	0.85	0.88	0.91	0.94	0.98	1.01
		Use Thickness Class	25	25	25	26	26	27	27
		Use Thickness	0.85	0.85	0.85	0.92	0.92	0.99	0.99
	16	Calculated Thickness	0.89	0.91	0.94	0.96	0.99	1.03	1.06
		Use Thickness Class	26	26	26	27	27	28	28
		Use Thickness	0.92	0.92	0.92	0.99	0.99	1.07	1.07
B	2½	Calculated Thickness	0.60*	0.62*	0.65*	0.67*	0.71*	0.74*	0.80
		Use Thickness Class	21	21	21	22	23	23	24
		Use Thickness	0.63	0.63	0.68	0.68	0.73	0.73	0.79
	3½	Calculated Thickness	0.59*	0.62*	0.64*	0.67*	0.70*	0.75	0.81
		Use Thickness Class	21	21	21	22	22	23	24
		Use Thickness	0.63	0.63	0.63	0.68	0.68	0.73	0.79
	5	Calculated Thickness	0.62*	0.65*	0.67*	0.70	0.74	0.79	0.85
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	0.63	0.63	0.68	0.68	0.73	0.79	0.85
	8	Calculated Thickness	0.68	0.71	0.74	0.77	0.81	0.85	0.90
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.68	0.73	0.73	0.79	0.79	0.85	0.92
	12	Calculated Thickness	0.75	0.78	0.80	0.83	0.87	0.91	0.95
		Use Thickness Class	23	24	24	25	25	26	26
		Use Thickness	0.73	0.79	0.79	0.85	0.85	0.92	0.92
	16	Calculated Thickness	0.80	0.82	0.85	0.88	0.91	0.95	0.99
		Use Thickness Class	24	25	25	25	26	26	27
		Use Thickness	0.79	0.85	0.85	0.85	0.92	0.92	0.99
F	2½	Calculated Thickness	0.54*	0.57*	0.59*	0.62*	0.66*	0.72	0.79
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.63	0.62	0.63	0.63	0.68	0.73	0.79
	3½	Calculated Thickness	0.54*	0.56*	0.59*	0.62*	0.67	0.73	0.80
		Use Thickness Class	21	21	21	21	22	23	24
		Use Thickness	0.63	0.63	0.63	0.63	0.68	0.72	0.79
	5	Calculated Thickness	0.57*	0.59*	0.62	0.66	0.71	0.76	0.82
		Use Thickness Class	21	21	21	22	23	24	25
		Use Thickness	0.63	0.63	0.63	0.68	0.73	0.79	0.85
	8	Calculated Thickness	0.62	0.65	0.68	0.72	0.76	0.81	0.86
		Use Thickness Class	21	21	22	23	24	24	25
		Use Thickness	0.63	0.63	0.68	0.73	0.79	0.79	0.85
	12	Calculated Thickness	0.68	0.71	0.74	0.77	0.81	0.85	0.90
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.68	0.73	0.73	0.79	0.79	0.85	0.92
	16	Calculated Thickness	0.72	0.75	0.78	0.81	0.85	0.89	0.93
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.73	0.73	0.79	0.79	0.85	0.92	0.92

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Thirty-Inch Water Pipe									
A	2½	Calculated Thickness	0.79*	0.81*	0.84*	0.88*	0.92*	0.96*	1.01*
		Use Thickness Class	22	22	23	23	24	25	25
		Use Thickness	0.79	0.79	0.85	0.85	0.92	0.99	0.99
	3½	Calculated Thickness	0.78*	0.81*	0.84*	0.87*	0.91*	0.95*	1.00
		Use Thickness Class	22	22	23	23	24	24	25
		Use Thickness	0.79	0.79	0.85	0.85	0.92	0.92	0.99
	5	Calculated Thickness	0.82*	0.85*	0.88*	0.91*	0.94	1.00	1.06
		Use Thickness Class	23	23	23	24	24	25	26
		Use Thickness	0.85	0.85	0.85	0.92	0.92	0.99	1.0[illegible]
	8	Calculated Thickness	0.89*	0.92	0.95	0.99	1.04	1.09	1.14
		Use Thickness Class	24	24	24	25	26	26	27
		Use Thickness	0.92	0.92	0.92	0.99	1.07	1.07	1.16
	12	Calculated Thickness	0.99	1.02	1.05	1.09	1.13	1.17	1.22
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	0.99	0.99	1.07	1.07	1.16	1.16	1.25
	16	Calculated Thickness	1.06	1.09	1.12	1.16	1.20	1.24	1.29
		Use Thickness Class	26	26	27	27	27	28	25
		Use Thickness	1.07	1.07	1.16	1.16	1.16	1.25	1.29
B	2½	Calculated Thickness	0.70*	0.73*	0.76*	0.80*	0.84*	0.89*	0.88
		Use Thickness Class	20	21	22	22	23	24	25
		Use Thickness	0.68	0.73	0.79	0.79	0.85	0.92	0.99
	3½	Calculated Thickness	0.69*	0.72*	0.75*	0.79*	0.83*	0.90	0.98
		Use Thickness Class	20	21	21	22	23	24	25
		Use Thickness	0.68	0.73	0.73	0.79	0.85	0.92	0.99
	5	Calculated Thickness	0.73*	0.76*	0.79*	0.83*	0.88	0.95	1.02
		Use Thickness Class	21	22	22	23	23	24	25
		Use Thickness	0.73	0.79	0.79	0.85	0.85	0.92	0.99
	8	Calculated Thickness	0.79	0.83	0.86	0.91	0.96	1.01	1.07
		Use Thickness Class	22	23	23	24	25	25	26
		Use Thickness	0.79	0.85	0.85	0.92	0.99	0.99	1.07
	12	Calculated Thickness	0.88	0.91	0.95	0.99	1.03	1.08	1.14
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	0.85	0.92	0.92	0.99	1.07	1.07	1.16
	16	Calculated Thickness	0.94	0.97	1.01	1.05	1.09	1.13	1.18
		Use Thickness Class	24	25	25	26	26	27	27
		Use Thickness	0.92	0.99	0.99	1.07	1.07	1.16	1.16
F	2½	Calculated Thickness	0.64*	0.67*	0.70*	0.74*	0.79*	0.87	0.96
		Use Thickness class	20	20	20	21	22	23	25
		Use Thickness	0.68	0.68	0.68	0.73	0.79	0.85	0.99
	3½	Calculated Thickness	0.63*	0.66*	0.69*	0.73*	0.81	0.88	0.97
		Use Thickness Class	20	20	20	21	22	23	25
		Use Thickness	0.68	0.68	0.68	0.73	0.79	0.85	0.99
	5	Calculated Thickness	0.66*	0.69*	0.73	0.78	0.85	0.92	0.99
		Use Thickness Class	20	20	21	22	23	24	25
		Use Thickness	0.68	0.68	0.73	0.79	0.85	0.92	0.99
	8	Calculated Thickness	0.72	0.76	0.80	0.85	0.90	0.96	1.03
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	0.73	0.79	0.79	0.85	0.92	0.99	1.07
	12	Calculated Thickness	0.80	0.84	0.87	0.91	0.96	1.02	1.08
		Use Thickness Class	22	23	23	24	25	25	26
		Use Thickness	0.79	0.85	0.85	0.92	0.99	0.99	1.07
	16	Calculated Thickness	0.85	0.89	0.92	0.96	1.01	1.06	1.12
		Use Thickness Class	23	24	24	25	25	26	27
		Use Thickness	0.85	0.92	0.92	0.99	0.99	1.07	1.91

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Thirty-six-Inch Water Pipe									
A	2½	Calculated Thickness	0.89*	0.92*	0.96*	1.00*	1.05*	1.10*	1.16*
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.87	0.94	0.94	1.02	1.02	1.10	1.19
	3½	Calculated Thickness	0.88*	0.92*	0.95*	1.00*	1.04*	1.10*	1.15
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.87	0.94	0.94	1.02	1.02	1.10	1.19
	5	Calculated Thickness	0.93*	0.96*	1.00*	1.04*	1.09*	1.14	1.22
		Use Thickness Class	23	23	24	24	25	25	26
		Use Thickness	0.94	0.94	1.02	1.02	1.10	1.10	1.19
	8	Calculated Thickness	1.01*	1.04*	1.08	1.13	1.18	1.24	1.31
		Use Thickness Class	24	24	25	25	26	27	27
		Use Thickness	1.02	1.02	1.10	1.10	1.19	1.29	1.29
	12	Calculated Thickness	1.13	1.16	1.20	1.25	1.30	1.35	1.41
		Use Thickness Class	25	26	26	27	27	28	28
		Use Thickness	1.10	1.19	1.19	1.29	1.29	1.39	1.39
	16	Calculated Thickness	1.22	1.25	1.29	1.33	1.38	1.43	1.48
		Use Thickness Class	26	27	27	27	28	28	29
		Use Thickness	1.19	1.29	1.29	1.29	1.39	1.39	1.50
B	2½	Calculated Thickness	0.78*	0.81*	0.85*	0.90*	0.95*	1.01*	1.12
		Use Thickness Class	21	21	22	22	23	24	25
		Use Thickness	0.81	0.81	0.87	0.87	0.94	1.02	1.10
	3½	Calculated Thickness	0.77*	0.81*	0.85*	0.89*	0.95*	1.03	1.12
		Use Thickness Class	20	21	22	22	23	24	25
		Use Thickness	0.75	0.81	0.87	0.87	0.94	1.02	1.10
	5	Calculated Thickness	0.81*	0.85*	0.89*	0.93*	1.00	1.08	1.16
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	.81	.87	.87	.94	1.02	1.10	1.19
	8	Calculated Thickness	0.88	0.92	0.97	1.02	1.08	1.15	1.22
		Use Thickness Class	22	23	23	24	25	26	26
		Use Thickness	0.87	0.94	0.94	1.02	1.10	1.19	1.19
	12	Calculated Thickness	0.99	1.02	1.07	1.12	1.17	1.23	1.30
		Use Thickness Class	24	24	25	25	26	26	27
		Use Thickness	1.02	1.02	1.10	1.10	1.19	1.19	1.29
	16	Calculated Thickness	1.06	1.10	1.14	1.19	1.24	1.29	1.35
		Use Thickness Class	25	25	25	26	27	27	28
		Use Thickness	1.10	1.10	1.10	1.19	1.29	1.29	1.39
F	2½	Calculated Thickness	0.71*	0.74*	0.78*	0.83*	0.90	1.00	1.10
		Use Thickness Class	20	20	21	21	22	24	25
		Use Thickness	0.75	0.75	0.81	0.81	0.87	1.02	1.10
	3½	Calculated Thickness	0.70*	0.74*	0.78*	0.83	0.92	1.01	1.11
		Use Thickness Class	20	20	21	21	23	24	25
		Use Thickness	0.75	0.75	0.81	0.81	0.94	1.02	1.10
	5	Calculated Thickness	0.74*	0.77*	0.82	0.88	0.96	1.05	1.14
		Use Thickness Class	20	20	21	22	23	24	25
		Use Thickness	0.75	0.75	0.81	0.87	0.94	1.02	1.10
	8	Calculated Thickness	0.81	0.85	0.90	0.96	1.02	1.10	1.18
		Use Thickens Class	21	22	22	23	24	25	26
		Use Thickness	0.81	0.87	0.87	0.94	1.02	1.10	1.19
	12	Calculated Thickness	0.90	0.94	0.98	1.04	1.09	1.16	1.23
		Use Thickness Class	22	23	24	24	25	26	26
		Use Thickness	0.87	0.94	1.02	1.02	1.10	1.19	1.19
	16	Calculated Thickness	0.96	1.00	1.04	1.09	1.15	1.21	1.28
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	0.94	1.02	1.02	1.10	1.19	1.19	1.29

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
		Forty-two-Inch Water Pipe							
A	2½	Calculated Thickness	0.99*	1.02*	1.07*	1.12*	1.17*	1.24*	1.31*
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.97	1.05	1.05	1.13	1.13	1.22	1.32
	3½	Calculated Thickness	0.99*	1.02*	1.07*	1.12*	1.17*	1.24*	1.30
		Use Thickness Class	22	23	23	24	24	25	26
		Use Thickness	0.97	1.05	1.05	1.13	1.13	1.22	1.32
	5	Calculated Thickness	1.04*	1.08*	1.12*	1.17*	1.22*	1.28*	1.37
		Use Thickness Class	23	23	24	24	25	26	26
		Use Thickness	1.05	1.05	1.13	1.13	1.22	1.32	1.32
	8	Calculated Thickness	1.13*	1.17*	1.21	1.27	1.33	1.40	1.48
		Use Thickness Class	24	24	25	26	26	27	27
		Use Thickness	1.13	1.13	1.22	1.32	1.32	1.43	1.43
	12	Calculated Thickness	1.26	1.30	1.35	1.40	1.46	1.52	1.59
		Use Thickness Class	25	26	26	27	27	28	28
		Use Thickness	1.22	1.32	1.32	1.43	1.43	1.54	1.54
	16	Calculated Thickness	1.37	1.41	1.46	1.51	1.56	1.62	1.68
		Use Thickness Class	26	27	27	28	28	29	29
		Use Thickness	1.32	1.43	1.43	1.54	1.54	1.66	1.66
B	2½	Calculated Thickness	0.85*	0.89*	0.94*	0.99*	1.05*	1.13	1.25
		Use Thickness Class	20	21	22	22	23	24	25
		Use Thickness	0.83	0.90	0.97	0.97	1.05	1.13	1.22
	3½	Calculated Thickness	0.85*	0.89*	0.94*	0.99*	1.05	1.15	1.27
		Use Thickness Class	20	21	22	22	23	24	26
		Use Thickness	0.83	0.90	0.97	0.97	1.05	1.13	1.32
	5	Calculated Thickness	0.89*	0.93*	0.98*	1.03*	1.11	1.21	1.31
		Use Thickness Class	21	21	22	23	24	25	26
		Use Thickness	0.90	0.90	0.97	1.05	1.13	1.22	1.32
	8	Calculated Thickness	0.97	1.02	1.07	1.13	1.21	1.29	1.37
		Use Thickness Class	22	23	23	24	25	26	26
		Use Thickness	0.97	1.05	1.05	1.13	1.22	1.32	1.32
	12	Calculated Thickness	1.09	1.13	1.18	1.24	1.30	1.38	1.45
		Use Thickness Class	24	24	25	25	26	27	27
		Use Thickness	1.13	1.13	1.22	1.22	1.32	1.43	1.43
	16	Calculated Thickness	1.18	1.22	1.27	1.32	1.38	1.45	1.52
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	1.22	1.22	1.32	1.32	1.43	1.43	1.54
F	2½	Calculated Thickness	0.77*	0.81*	0.86*	0.92*	1.00	1.12	1.24
		Use Thickness Class	20	20	20	21	22	24	25
		Use Thickness	0.83	0.83	0.83	0.90	0.97	1.13	1.22
	3½	Calculated Thickness	0.77*	0.81*	0.86*	0.92*	1.02	1.14	1.25
		Use Thickness Class	20	20	20	21	23	24	25
		Use Thickness	0.83	0.83	0.83	0.90	1.05	1.13	1.22
	5	Calculated Thickness	0.81*	0.85*	0.90	0.98	1.07	1.17	1.28
		Use Thickness Class	20	20	21	22	23	24	26
		Use Thickness	0.83	0.83	0.90	0.97	1.05	1.13	1.32
	8	Calculated Thickness	0.89	0.94	0.99	1.06	1.14	1.23	1.33
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	0.90	0.97	0.97	1.05	1.13	1.22	1.32
	12	Calculated Thickness	0.99	1.03	1.09	1.15	1.22	1.30	1.39
		Use Thickness Class	22	23	24	24	25	26	27
		Use Thickness	0.97	1.05	1.13	1.13	1.22	1.32	1.43
	16	Calculated Thickness	1.07	1.11	1.16	1.21	1.28	1.36	1.44
		Use Thickness Class	23	24	24	25	26	26	27
		Use Thickness	1.05	1.13	1.13	1.22	1.32	1.32	1.43

* Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor. When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec. 1-2.1.

TABLE 1-2 (*Continued*)

Schedule of Barrel Thickness for Water Pipe of 21/45 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 50	100	150	200	250	300	350
			Barrel Thickness—*in.*						
Forty-eight-Inch Water Pipe									
A	2½	Calculated Thickness	1.08*	1.12*	1.17*	1.23*	1.29*	1.37*	1.45*
		Use Thickness Class	22	23	23	24	25	25	26
		Use Thickness	1.06	1.14	1.14	1.23	1.33	1.33	1.44
	3½	Calculated Thickness	1.09*	1.13*	1.18*	1.24*	1.30*	1.37*	1.46
		Use Thickness Class	22	23	23	24	25	25	26
		Use Thickness	1.06	1.14	1.14	1.23	1.33	1.33	1.44
	5	Calculated Thickness	1.15*	1.19*	1.24*	1.30*	1.36*	1.43	1.53
		Use Thickness Class	23	24	24	25	25	26	27
		Use Thickness	1.14	1.23	1.23	1.33	1.33	1.44	1.56
	8	Calculated Thickness	1.25*	1.29*	1.34	1.41	1.48	1.56	1.65
		Use Thickness Class	24	25	25	26	26	27	28
		Use Thickness	1.23	1.33	1.33	1.44	1.44	1.56	1.68
	12	Calculated Thickness	1.41	1.45	1.51	1.57	1.63	1.70	1.77
		Use Thickness Class	26	26	27	27	28	28	29
		Use Thickness	1.44	1.44	1.56	1.56	1.68	1.68	1.81
	16	Calculated Thickness	1.53	1.58	1.63	1.68	1.75	1.81	1.89
		Use Thickness Class	27	27	28	28	29	29	30
		Use Thickness	1.56	1.56	1.68	1.68	1.81	1.81	1.95
B	2½	Calculated Thickness	0.92*	0.97*	1.02*	1.08*	1.16*	1.26	1.40
		Use Thickness Class	20	21	22	22	23	24	26
		Use Thickness	0.91	0.98	1.06	1.06	1.14	1.23	1.44
	3½	Calculated Thickness	0.93*	0.97*	1.03*	1.09*	1.17	1.29	1.42
		Use Thickness Class	20	21	22	22	23	25	26
		Use Thickness	0.91	0.98	1.06	1.06	1.14	1.33	1.44
	5	Calculated Thickness	0.98*	1.02*	1.08*	1.14	1.23	1.34	1.46
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	0.98	1.06	1.06	1.14	1.23	1.33	1.44
	8	Calculated Thickness	1.06	1.12	1.18	1.25	1.34	1.43	1.53
		Use Thickness Class	22	23	23	24	25	26	27
		Use Thickness	1.06	1.14	1.14	1.23	1.33	1.44	1.56
	12	Calculated Thickness	1.20	1.25	1.31	1.37	1.45	1.53	1.62
		Use Thickness Class	24	24	25	25	26	27	28
		Use Thickness	1.23	1.23	1.33	1.33	1.44	1.56	1.68
	16	Calculated Thickness	1.30	1.35	1.41	1.47	1.54	1.61	1.70
		Use Thickness Class	25	25	26	26	27	27	28
		Use Thickness	1.33	1.33	1.44	1.44	1.56	1.56	1.68
F	2½	Calculated Thickness	0.83*	0.88*	0.94*	1.01*	1.12	1.25	1.39
		Use Thickness Class	20	20	20	21	23	24	26
		Use Thickness	0.91	0.91	0.91	0.98	1.14	1.23	1.44
	3½	Calculated Thickness	0.84*	0.89*	0.94*	1.02	1.14	1.27	1.40
		Use Thickness Class	20	20	20	22	23	24	26
		Use Thickness	0.91	0.91	0.91	1.06	1.14	1.23	1.44
	5	Calculated Thickness	0.88*	0.93*	0.99	1.08	1.19	1.30	1.43
		Use Thickness Class	20	20	21	22	24	25	26
		Use Thickness	0.91	0.91	0.98	1.06	1.23	1.33	1.44
	8	Calculated Thickness	0.97	1.03	1.09	1.17	1.27	1.37	1.48
		Use Thickness Class	21	22	22	23	24	25	26
		Use Thickness	0.98	1.06	1.06	1.14	1.23	1.33	1.44
	12	Calculated Thickness	1.09	1.14	1.20	1.27	1.35	1.45	1.55
		Use Thickness Class	22	23	24	24	25	26	27
		Use Thickness	1.06	1.14	1.23	1.23	1.33	1.44	1.56
	16	Calculated Thickness	1.17	1.23	1.28	1.35	1.43	1.51	1.60
		Use Thickness Class	23	24	25	25	26	27	27
		Use Thickness	1.14	1.23	1.33	1.33	1.44	1.56	1.56

* *Asterisk following total calculated thickness indicates that truck superload (Case 2) is the controlling factor.* When total calculated thickness is not followed by asterisk, surge pressure (Case 1) is the controlling factor. See Sec 1-2.1.

TABLE 1-3

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
		Four-Inch Gas Pipe						
A	2½	Calculated Thickness	.23	.23	.23	.24	.24	.24
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	35
	3½	Calculated Thickness	.22	.23	.23	.23	.23	.23
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	.23	.23	.24	.24	.24	.25
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	.25	.25	.25	.26	.26	.27
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.27	.28	.28	.2[illegible]	.29	.29
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.30	.30	.30	.31	.31	.32
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
B	2½	Calculated Thickness	.23	.23	.23	.23	.23	.24
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	3½	Calculated Thickness	.22	.23	.23	.23	.24	.24
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	.23	.23	.23	.23	.24	.24
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	24	.24	.24	.25	.25	.26
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.28	.29	.29	.29	.30	.30
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.29	.29	.29	.30	.30	.31
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
F	2½	Calculated Thickness	.22	.22	.22	.22	.23	.23
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	3½	Calculated Thickness	.22	.22	.22	.22	.23	.23
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	5	Calculated Thickness	22	.22	.22	.22	.23	.23
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	8	Calculated Thickness	.23	.23	.23	.24	.24	.24
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	35	.35	.35	.35	.35	.35
	12	Calculated Thickness	.24	.24	.25	.25	.26	.27
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35
	16	Calculated Thickness	.26	.26	.27	.28	.28	.29
		Use {Thickness Class	22	22	22	22	22	22
		Use {Thickness	.35	.35	.35	.35	.35	.35

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Six-Inch Gas Pipe								
A	2½	Calculated Thickness	*.28*	*.29*	*.29*	*.30*	*.30*	*.32*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.27*	*.28*	*.28*	*.29*	*.30*	*.31*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.28*	*.29*	*.29*	*.30*	*.31*	*.32*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*.31*	*.31*	*.32*	*.33*	*.33*	*.34*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.34*	*.35*	*.35*	*.36*	*.37*	*.38*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	16	Calculated Thickness	*.38*	*.38*	*.39*	*.39*	*.40*	*.41*
		Use { Thickness Class	22	22	22	22	23	23
		Use { Thickness	.38	.38	.38	.38	.41	.41
B	2½	Calculated Thickness	*.27*	*.28*	*.28*	*.29*	*.30*	*.31*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.27*	*.27*	*.28*	*.28*	*.29*	*.30*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.28*	*.28*	*.28*	*.29*	*.30*	*.31*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*.29*	*30*	*.31*	*.31*	*.32*	*.33*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.33*	*.34*	*.34*	*.35*	*.35*	*.36*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	16	Calculated Thickness	*.36*	*.36*	*.37*	*.38*	*.38*	*.39*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
F	2½	Calculated Thickness	*.26*	*.26*	*.27*	*.27*	*.28*	*.29*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	3½	Calculated Thickness	*.26*	*.26*	*.26*	*.27*	*.28*	*.29*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	5	Calculated Thickness	*.26*	*.27*	*.27*	*.28*	*.28*	*.29*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	8	Calculated Thickness	*28*	*28*	*.29*	*.29*	*.30*	*.31*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	12	Calculated Thickness	*.30*	*.31*	*.31*	*.32*	*.33*	*.34*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38
	16	Calculated Thickness	*33*	*.33*	*.34*	*.35*	*.35*	*.36*
		Use { Thickness Class	22	22	22	22	22	22
		Use { Thickness	.38	.38	.38	.38	.38	.38

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover ft	Thickness Specifications	Internal Pressure—psi 10	50	100	150	200	250
			Barrel Thicknesses—in.					
Eight-Inch Gas Pipe								
A	2½	Calculated Thickness	.33	.34	.35	.36	.37	.38
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	3½	Calculated Thickness	.32	.33	.34	.34	.35	.36
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.33	.34	.35	.36	.37	.38
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	8	Calculated Thickness	.36	.37	.37	.38	.39	.40
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	12	Calculated Thickness	.41	.42	.42	.43	.44	.45
		Use Thickness Class	22	22	22	23	23	23
		Use Thickness	.41	.41	.41	.44	.44	.44
	16	Calculated Thickness	.44	.45	.45	.46	.47	.48
		Use Thickness Class	23	23	23	24	24	24
		Use Thickness	.44	.44	.44	.48	.48	.48
B	2½	Calculated Thickness	.32	.32	.33	.34	.35	.36
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	3½	Calculated Thickness	.31	.32	.33	.33	.34	.36
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.32	.33	.34	.34	.35	.37
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	8	Calculated Thickness	.35	.35	.36	.37	.38	.39
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	12	Calculated Thickness	.39	.39	.40	.41	.42	.43
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.41	.41	.41	.41	.41	.44
	16	Calculated Thickness	.42	.42	.43	.44	.45	.46
		Use Thickness Class	22	22	23	23	23	24
		Use Thickness	.41	.41	.44	.44	.44	.48
F	2½	Calculated Thickness	.29	.30	.31	.32	.33	.34
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	3½	Calculated Thickness	.29	.29	.30	.30	.31	.33
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	5	Calculated Thickness	.29	.30	.31	.32	.33	.34
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	8	Calculated Thickness	.32	.33	.33	.34	.35	.36
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41
	12	Calculated Thickness	.35	.36	.37	.37	.38	.39
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	41	.41
	16	Calculated Thickness	.38	.38	.39	.40	.41	.42
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.41	.41	.41	.41	.41	.41

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Ten-Inch Gas Pipe								
A	2½	Calculated Thickness	.39	.40	.41	.42	.43	.45
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	3½	Calculated Thickness	.38	.39	.40	.41	.42	.44
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	5	Calculated Thickness	.39	.40	.41	.42	.43	.44
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	8	Calculated Thickness	.43	.43	.44	.46	.47	.48
		Use Thickness Class	22	22	22	23	23	23
		Use Thickness	.44	.44	.44	.48	.48	.48
	12	Calculated Thickness	.48	.49	.49	.50	.51	.52
		Use Thickness Class	23	23	23	24	24	24
		Use Thickness	.48	.48	.48	.52	.52	.52
	16	Calculated Thickness	.50	.51	.52	.53	.54	.56
		Use Thickness Class	24	24	24	24	25	25
		Use Thickness	.52	.52	.52	.52	.56	.56
B	2½	Calculated Thickness	.37	.38	.39	.40	.41	.43
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	3½	Calculated Thickness	.36	.37	.38	.39	.40	.42
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	5	Calculated Thickness	.37	.38	.39	.40	.41	.43
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	8	Calculated Thickness	.40	.41	.42	.43	.44	.46
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.44	.44	.44	.44	.44	.48
	12	Calculated Thickness	.45	.46	.47	.48	.49	.50
		Use Thickness Class	22	23	23	23	23	24
		Use Thickness	.44	.48	.48	.48	.48	.52
	16	Calculated Thickness	.47	.48	.49	.50	.51	.53
		Use Thickness Class	23	23	23	24	24	24
		Use Thickness	.48	.48	.48	.52	.52	.52
F	2½	Calculated Thickness	.34	.35	.36	.37	.38	.40
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	3½	Calculated Thickness	.33	.34	.35	.36	.37	.39
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	5	Calculated Thickness	.34	.35	.36	.37	.38	.40
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	8	Calculated Thickness	.36	.37	.38	.39	.41	.42
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.44	.44	.44	.44	.44	.44
	12	Calculated Thickness	.41	.42	.43	.44	.45	.46
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.44	.44	.44	.44	.44	.48
	16	Calculated Thickness	.43	.44	.45	.46	.47	.48
		Use Thickness Class	22	22	22	23	23	23
		Use Thickness	.44	.44	.44	.48	.48	.48

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover ft	Thickness Specifications	Internal Pressure—psi: 10	50	100	150	200	250
			Barrel Thicknesses—in.					
Twelve-Inch Gas Pipe								
A	2½	Calculated Thickness	.44	.45	.46	.47	.49	.51
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.48	.48	.48	.48	.48	.52
	3½	Calculated Thickness	.43	.43	.45	.46	.48	.50
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.48	.48	.48	.48	.48	.52
	5	Calculated Thickness	.44	.45	.46	.47	.48	.50
		Use Thickness Class	22	22	22	22	22	23
		Use Thickness	.48	.48	.48	.48	.48	.52
	8	Calculated Thickness	.48	.49	.50	.52	.53	.55
		Use Thickness Class	22	22	23	23	23	24
		Use Thickness	.48	.48	.52	.52	.52	.56
	12	Calculated Thickness	.53	.54	.55	.57	.58	.59
		Use Thickness Class	23	24	24	24	25	25
		Use Thickness	.52	.56	.56	.56	.60	.60
	16	Calculated Thickness	.56	.56	.58	.59	.60	.62
		Use Thickness Class	24	24	25	25	25	25
		Use Thickness	.56	.56	.60	.60	.60	.60
B	2½	Calculated Thickness	.41	.42	.44	.45	.46	.48
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	3½	Calculated Thickness	.40	.41	.42	.44	.45	.47
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	5	Calculated Thickness	.41	.42	.43	.45	.46	.48
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	8	Calculated Thickness	.45	.46	.47	.49	.50	.52
		Use Thickness Class	22	22	22	22	23	23
		Use Thickness	.48	.48	.48	.48	.52	.52
	12	Calculated Thickness	.50	.51	.52	.53	.55	.56
		Use Thickness Class	23	23	23	23	24	24
		Use Thickness	.52	.52	.52	.52	.56	.56
	16	Calculated Thickness	.52	.53	.54	.56	.57	.59
		Use Thickness Class	23	23	24	24	24	25
		Use Thickness	.52	.52	.56	.56	.56	.60
F	2½	Calculated Thickness	.38	.39	.40	.41	.43	.45
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	3½	Calculated Thickness	.37	.38	.39	.40	.42	.44
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	5	Calculated Thickness	.38	.39	.40	.41	.43	.45
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	8	Calculated Thickness	.41	.42	.43	.45	.46	.48
		Use Thickness Class	22	22	22	22	22	22
		Use Thickness	.48	.48	.48	.48	.48	.48
	12	Calculated Thickness	.45	.46	.47	.48	.50	.52
		Use Thickness Class	22	22	22	22	23	23
		Use Thickness	.48	.48	.48	.48	.52	.52
	16	Calculated Thickness	.47	.48	.49	.50	.52	.53
		Use Thickness Class	22	22	22	23	23	23
		Use Thickness	.48	.48	.48	.52	.52	.52

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Sixteen-Inch Gas Pipe								
A	2½	Calculated Thickness	*.53*	*.54*	*.56*	*.58*	*.60*	
		Use Thickness Class	22	22	23	23	23	
		Use Thickness	.54	.54	.58	.58	.58	
	3½	Calculated Thickness	*.52*	*.54*	*.55*	*.57*	*.59*	
		Use Thickness Class	22	22	22	23	23	
		Use Thickness	.54	.54	.54	.58	.58	
	5	Calculated Thickness	*.54*	*.55*	*.57*	*.59*	*.61*	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.54	.54	.58	.58	.63	
	8	Calculated Thickness	*.60*	*.61*	*.63*	*.65*	*.67*	
		Use Thickness Class	23	24	24	24	25	
		Use Thickness	.58	.63	.63	.63	.68	
	12	Calculated Thickness	*.65*	*.66*	*.67*	*.69*	*.71*	
		Use Thickness Class	24	25	25	25	26	
		Use Thickness	.63	.68	.68	.68	.73	
	16	Calculated Thickness	*.68*	*.69*	*.71*	*.73*	*.75*	
		Use Thickness Class	25	25	26	26	26	
		Use Thickness	.68	.68	.73	.73	.73	
B	2½	Calculated Thickness	*.49*	*.50*	*.52*	*.54*	*56*	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	.50	.50	.54	.54	.58	
	3½	Calculated Thickness	*.49*	*.50*	*.52*	*.53*	*.56*	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	.50	.50	.54	.54	.58	
	5	Calculated Thickness	*.51*	*.51*	*.53*	*.55*	*.57*	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	.50	.50	.54	.54	.58	
	8	Calculated Thickness	*.55*	*.56*	*.58*	*.60*	*.62*	
		Use Thickness Class	22	23	23	23	24	
		Use Thickness	.54	.58	.58	.58	.63	
	12	Calculated Thickness	*.60*	*.61*	*.62*	*.64*	*.66*	
		Use Thickness Class	23	24	24	24	25	
		Use Thickness	.58	.63	.63	.63	.68	
	16	Calculated Thickness	*.63*	*.64*	*.66*	*.67*	*.69*	
		Use Thickness Class	24	24	25	25	25	
		Use Thickness	.63	.63	.68	.68	.68	
F	2½	Calculated Thickness	*.46*	*.47*	*.48*	*.50*	*.52*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.50	.50	.50	.50	.54	
	3½	Calculated Thickness	*.45*	*.46*	*.47*	*.49*	*.52*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.50	.50	.50	.50	.54	
	5	Calculated Thickness	*.47*	*.48*	*.49*	*.51*	*53*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.50	.50	.50	.50	.54	
	8	Calculated Thickness	*.51*	*.52*	*.53*	*.55*	*.57*	
		Use Thickness Class	21	22	22	22	23	
		Use Thickness	.50	.54	.54	.54	.58	
	12	Calculated Thickness	*.54*	*.55*	*.57*	*.59*	*.61*	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.54	.54	.58	.58	.63	
	16	Calculated Thickness	*.57*	*.58*	*.59*	*.61*	*.63*	
		Use Thickness Class	23	23	23	24	24	
		Use Thickness	.58	.58	.58	.63	.63	

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Twenty-Inch Gas Pipe								
A	2½	Calculated Thickness	.61	.62	.65	.67	.70	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.62	.62	.67	.67	.72	
	3½	Calculated Thickness	.61	.62	.64	.66	.69	
		Use Thickness Class	22	22	22	23	23	
		Use Thickness	.62	.62	.62	.67	.67	
	5	Calculated Thickness	.63	.65	.67	.69	.72	
		Use Thickness Class	22	23	23	23	24	
		Use Thickness	.62	.67	.67	.67	.72	
	8	Calculated Thickness	.69	.70	.72	.75	.77	
		Use Thickness Class	23	24	24	25	25	
		Use Thickness	.67	.72	.72	.78	.78	
	12	Calculated Thickness	.74	.76	.78	.80	.83	
		Use Thickness Class	24	25	25	25	26	
		Use Thickness	.72	.78	.78	.78	.84	
	16	Calculated Thickness	.79	.80	.82	.84	.87	
		Use Thickness Class	25	25	26	26	26	
		Use Thickness	.78	.78	.84	.84	.84	
B	2½	Calculated Thickness	.56	.57	.59	.62	.65	
		Use Thickness Class	21	21	21	22	23	
		Use Thickness	.57	.57	.57	.62	.67	
	3½	Calculated Thickness	.55	.57	.59	.62	.64	
		Use Thickness Class	21	21	21	22	22	
		Use Thickness	.57	.57	.57	.62	.62	
	5	Calculated Thickness	.58	.59	.61	.64	.67	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	.57	.57	.62	.62	.67	
	8	Calculated Thickness	.63	.64	.66	.69	.71	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.62	.62	.67	.67	.72	
	12	Calculated Thickness	.68	.69	.71	.73	.76	
		Use Thickness Class	23	23	24	24	25	
		Use Thickness	.67	.67	.72	.72	.78	
	16	Calculated Thickness	.71	.73	.75	.77	.80	
		Use Thickness Class	24	24	25	25	25	
		Use Thickness	.72	.72	.78	.78	.78	
F	2½	Calculated Thickness	.50	.51	.53	.57	.60	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.57	.57	.57	.57	.62	
	3½	Calculated Thickness	.50	.51	.53	.57	.60	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.57	.57	.57	.57	.62	
	5	Calculated Thickness	.52	.54	.56	.58	.62	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.57	.57	.57	.57	.62	
	8	Calculated Thickness	.56	.58	.60	.62	.65	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	.57	.57	.62	.62	.67	
	12	Calculated Thickness	.61	.62	.64	.67	.70	
		Use Thickness Class	22	22	22	23	24	
		Use Thickness	.62	62	.62	.67	.72	
	16	Calculated Thickness	.64	.66	.68	.70	.72	
		Use Thickness Class	22	23	23	24	24	
		Use Thickness	.62	.67	.67	.72	.72	

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Twenty-four-Inch Gas Pipe								
A	2½	Calculated Thickness	*.67*	*.69*	*.72*	*.75*	*.78*	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.68	.68	.73	.73	.79	
	3½	Calculated Thickness	*.67*	*.69*	*.71*	*.74*	*.78*	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.68	.68	.73	.73	.79	
	5	Calculated Thickness	*.71*	*.72*	*.75*	*.78*	*.81*	
		Use Thickness Class	23	23	23	24	24	
		Use Thickness	.73	.73	.73	.79	.79	
	8	Calculated Thickness	*.77*	*.79*	*.81*	*.84*	*.87*	
		Use Thickness Class	24	24	24	25	25	
		Use Thickness	.79	.79	.79	.85	.85	
	12	Calculated Thickness	*.84*	*.86*	*.88*	*.91*	*.94*	
		Use Thickness Class	25	25	25	26	26	
		Use Thickness	.85	.85	.85	.92	.92	
	16	Calculated Thickness	*.90*	*.91*	*.94*	*.97*	*1.00*	
		Use Thickness Class	26	26	26	27	27	
		Use Thickness	.92	.92	.92	.99	.99	
B	2½	Calculated Thickness	*.61*	*.63*	*.65*	*.68*	*.72*	
		Use Thickness Class	21	21	21	22	23	
		Use Thickness	.63	.63	.63	.68	73	
	3½	Calculated Thickness	*.59*	*.62*	*.65*	*.68*	*.71*	
		Use Thickness Class	21	21	21	22	23	
		Use Thickness	.63	.63	.63	.68	.73	
	5	Calculated Thickness	*.63*	*.65*	*.67*	*.71*	*.75*	
		Use Thickness Class	21	21	22	23	23	
		Use Thickness	.63	.63	.68	.73	.73	
	8	Calculated Thickness	*.69*	*.71*	*.73*	*.76*	*.79*	
		Use Thickness Class	22	23	23	24	24	
		Use Thickness	.68	.73	.73	.79	.79	
	12	Calculated Thickness	*.75*	*.77*	*.79*	*.82*	*.85*	
		Use Thickness Class	23	24	24	25	25	
		Use Thickness	.73	.79	.79	.85	.85	
	16	Calculated Thickness	*.80*	*.81*	*.84*	*.87*	*.90*	
		Use Thickness Class	24	24	25	25	26	
		Use Thickness	.79	.79	.85	.85	.92	
F	2½	Calculated Thickness	*.55*	*.56*	*.58*	*.63*	*.67*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.63	.63	.63	.63	.68	
	3½	Calculated Thickness	*.54*	*.56*	*.58*	*.62*	*.66*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	.63	63	.63	.63	68	
	5	Calculated Thickness	*.57*	*.58*	*.62*	*.65*	*.68*	
		Use Thickness Class	21	21	21	21	22	
		Use Thickness	63	.63	.63	.63	.68	
	8	Calculated Thickness	*.62*	*.64*	*.67*	*.70*	*.73*	
		Use Thickness Class	21	21	22	22	23	
		Use Thickness	63	.63	68	68	.73	
	12	Calculated Thickness	*67*	*.69*	*.72*	*.75*	*.78*	
		Use Thickness Class	22	22	23	23	24	
		Use Thickness	.68	.69	.73	.73	.79	
	16	Calculated Thickness	*71*	*.73*	*.76*	*.79*	*.82*	
		Use Thickness Class	23	23	24	24	25	
		Use Thickness	.73	.73	.79	.79	.85	

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
		Thirty-Inch Gas Pipe						
A	2½	Calculated Thickness	*.80*	*.83*	*.86*	*.90*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.79	.85	.85	.92		
	3½	Calculated Thickness	*.79*	*.82*	*.85*	*.89*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.79	.85	.85	.92		
	5	Calculated Thickness	*.84*	*.86*	*.90*	*.93*		
		Use Thickness Class	23	23	24	24		
		Use Thickness	.85	.85	.92	.92		
	8	Calculated Thickness	*.92*	*.94*	*.97*	*1.01*		
		Use Thickness Class	24	24	25	25		
		Use Thickness	.92	.92	.99	.99		
	12	Calculated Thickness	*1.01*	*1.03*	*1.06*	*1.09*		
		Use Thickness Class	25	26	26	26		
		Use Thickness	.99	1.07	1.07	1.07		
	16	Calculated Thickness	*1.07*	*1.09*	*1.12*	*1.15*		
		Use Thickness Class	26	26	27	27		
		Use Thickness	1.07	1.07	1.16	1.16		
B	2½	Calculated Thickness	*.69*	*.74*	*.77*	*.81*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.73	.73	.79	.79		
	3½	Calculated Thickness	*.69*	*.73*	*.76*	*.80*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.73	.73	.79	.79		
	5	Calculated Thickness	*.75*	*.77*	*.80*	*.85*		
		Use Thickness Class	21	22	22	23		
		Use Thickness	.73	.79	.79	.85		
	8	Calculated Thickness	*.81*	*.83*	*.86*	*.90*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.79	.85	.85	.92		
	12	Calculated Thickness	*.88*	*.90*	*.93*	*.97*		
		Use Thickness Class	23	24	24	25		
		Use Thickness	.85	.92	.92	.99		
	16	Calculated Thickness	*.94*	*.96*	*.99*	*1.03*		
		Use Thickness Class	24	25	25	26		
		Use Thickness	.92	.99	.99	1.07		
F	2½	Calculated Thickness	*.63*	*.66*	*.70*	*.74*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.73	.73	.73	.73		
	3½	Calculated Thickness	*.63*	*.66*	*.70*	*.74*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.73	.73	.73	.73		
	5	Calculated Thickness	*.68*	*.70*	*.73*	*.77*		
		Use Thickness Class	21	21	21	22		
		Use Thickness	.73	.73	.73	.79		
	8	Calculated Thickness	*.73*	*.75*	*.79*	*.83*		
		Use Thickness Class	21	21	22	23		
		Use Thickness	.73	.73	.79	.85		
	12	Calculated Thickness	*.79*	*.81*	*.85*	*.88*		
		Use Thickness Class	22	22	23	23		
		Use Thickness	.79	.79	.85	.85		
	16	Calculated Thickness	*.84*	*.86*	*.90*	*.93*		
		Use Thickness Class	23	23	24	24		
		Use Thickness	.85	.85	.92	.92		

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Thirty-six-Inch Gas Pipe								
A	2½	Calculated Thickness	*.91*	*.94*	*.98*	*1.02*		
		Use Thickness Class	23	23	24	24		
		Use Thickness	.94	.94	1.02	1.02		
	3½	Calculated Thickness	*.90*	*.93*	*.97*	*1.02*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.87	.94	.94	1.02		
	5	Calculated Thickness	*.95*	*.98*	*1.02*	*1.07*		
		Use Thickness Class	23	24	24	25		
		Use Thickness	.94	1.02	1.02	1.10		
	8	Calculated Thickness	*1.04*	*1.07*	*1.11*	*1.15*		
		Use Thickness Class	24	25	25	26		
		Use Thickness	1.02	1.10	1.10	1.19		
	12	Calculated Thickness	*1.15*	*1.17*	*1.21*	*1.25*		
		Use Thickness Class	26	26	26	27		
		Use Thickness	1.19	1.19	1.19	1.29		
	16	Calculated Thickness	*1.23*	*1.26*	*1.29*	*1.33*		
		Use Thickness Class	26	27	27	27		
		Use Thickness	1.19	1.29	1.29	1.29		
B	2½	Calculated Thickness	*.79*	*.82*	*.86*	*.91*		
		Use Thickness Class	21	21	22	23		
		Use Thickness	.81	.81	.87	.94		
	3½	Calculated Thickness	*.79*	*.81*	*.85*	*.90*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.81	.81	.87	.87		
	5	Calculated Thickness	*.83*	*.86*	*.90*	*.94*		
		Use Thickness Class	21	22	22	23		
		Use Thickness	.81	.87	.87	.94		
	8	Calculated Thickness	*.90*	*.93*	*.96*	*1.01*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.87	.94	.94	1.02		
	12	Calculated Thickness	*.99*	*1.01*	*1.05*	*1.10*		
		Use Thickness Class	24	24	24	25		
		Use Thickness	1.02	1.02	1.02	1.10		
	16	Calculated Thickness	*1.06*	*1.08*	*1.13*	*1.17*		
		Use Thickness Class	25	25	25	26		
		Use Thickness	1.10	1.10	1.10	1.19		
F	2½	Calculated Thickness	*.71*	*.73*	*.79*	*.84*		
		Use Thickness Class	21	21	21	22		
		Use Thickness	.81	.81	.81	.87		
	3½	Calculated Thickness	*.71*	*.73*	*.78*	*.83*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.81	.81	.81	.81		
	5	Calculated Thickness	*75*	*.78*	*.82*	*.87*		
		Use Thickness Class	21	21	21	22		
		Use Thickness	.81	.81	.81	.87		
	8	Calculated Thickness	*.81*	*.84*	*.88*	*.93*		
		Use Thickness Class	21	22	22	23		
		Use Thickness	.81	.87	.87	.94		
	12	Calculated Thickness	*.89*	*.91*	*.95*	*1.00*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.87	.94	94	1.02		
	16	Calculated Thickness	*.95*	*97*	*1.01*	*1.06*		
		Use Thickness Class	23	23	24	25		
		Use Thickness	.94	.94	1.02	1.10		

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
		Forty-two-Inch Gas Pipe						
A	2½	Calculated Thickness	*1.01*	*1.04*	*1.08*	*1.14*		
		Use Thickness Class	23	23	23	24		
		Use Thickness	1.05	1.05	1.05	1.13		
	3½	Calculated Thickness	*1.01*	*1.04*	*1.08*	*1.14*		
		Use Thickness Class	23	23	23	24		
		Use Thickness	1.05	1.05	1.05	1.13		
	5	Calculated Thickness	*1.07*	*1.09*	*1.14*	*1.19*		
		Use Thickness Class	23	24	24	25		
		Use Thickness	1.05	1.13	1.13	1.22		
	8	Calculated Thickness	*1.16*	*1.19*	*1.24*	*1.29*		
		Use Thickness Class	24	25	25	26		
		Use Thickness	1.13	1.22	1.22	1.32		
	12	Calculated Thickness	*1.29*	*1.32*	*1.36*	*1.41*		
		Use Thickness Class	26	26	26	27		
		Use Thickness	1.32	1.32	1.32	1.43		
	16	Calculated Thickness	*1.39*	*1.42*	*1.46*	*1.51*		
		Use Thickness Class	27	27	27	28		
		Use Thickness	1.43	1.43	1.43	1.54		
B	2½	Calculated Thickness	*.86*	*.89*	*.94*	*1.00*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.90	.90	.97	.97		
	3½	Calculated Thickness	*.86*	*.89*	*.94*	*1.00*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.90	.90	.97	.97		
	5	Calculated Thickness	*.91*	*.94*	*.98*	*1.04*		
		Use Thickness Class	21	22	22	23		
		Use Thickness	.90	.97	.97	1.05		
	8	Calculated Thickness	*.99*	*1.02*	*1.07*	*1.12*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.97	1.05	1.05	1.13		
	12	Calculated Thickness	*1.10*	*1.13*	*1.17*	*1.22*		
		Use Thickness Class	24	24	24	25		
		Use Thickness	1.13	1.13	1.13	1.22		
	16	Calculated Thickness	*1.18*	*1.21*	*1.25*	*1.30*		
		Use Thickness Class	25	25	25	26		
		Use Thickness	1.22	1.22	1.22	1.32		
F	2½	Calculated Thickness	*.77*	*.80*	*.86*	*.92*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.90	.90	.90	.90		
	3½	Calculated Thickness	*.77*	*.80*	*.86*	*.92*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.90	.90	.90	.90		
	5	Calculated Thickness	*.82*	*.85*	*.90*	*.96*		
		Use Thickness Class	21	21	21	22		
		Use Thickness	.90	.90	.90	.97		
	8	Calculated Thickness	*.89*	*.92*	*.97*	*1.03*		
		Use Thickness Class	21	21	22	23		
		Use Thickness	.90	.90	.97	1.05		
	12	Calculated Thickness	*.98*	*1.01*	*1.06*	*1.11*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	.97	1.05	1.05	1.13		
	16	Calculated Thickness	*1.06*	*1.08*	*1.13*	*1.18*		
		Use Thickness Class	23	23	24	25		
		Use Thickness	1.05	1.05	1.13	1.22		

TABLE 1-3 (*Continued*)

Schedule of Barrel Thickness for Gas Pipe of 18/40 Iron Strength

Laying Condition	Depth of Cover *ft*	Thickness Specifications	Internal Pressure—*psi* 10	50	100	150	200	250
			Barrel Thicknesses—*in.*					
Forty-eight-Inch Gas Pipe								
A	2½	Calculated Thickness	*1.10*	*1.14*	*1.19*	*1.25*		
		Use Thickness Class	23	23	24	24		
		Use Thickness	1.14	1.14	1.23	1.23		
	3½	Calculated Thickness	*1.11*	*1.14*	*1.20*	*1.26*		
		Use Thickness Class	23	23	24	24		
		Use Thickness	1.14	1.14	1.23	1.23		
	5	Calculated Thickness	*1.18*	*1.22*	*1.27*	*1.32*		
		Use Thickness Class	23	24	24	25		
		Use Thickness	1.14	1.23	1.23	1.33		
	8	Calculated Thickness	*1.29*	*1.33*	*1.38*	*1.43*		
		Use Thickness Class	25	25	25	26		
		Use Thickness	1.33	1.33	1.33	1.44		
	12	Calculated Thickness	*1.43*	*1.47*	*1.52*	*1.57*		
		Use Thickness Class	26	26	27	27		
		Use Thickness	1.44	1.44	1.56	1.56		
	16	Calculated Thickness	*1.55*	*1.58*	*1.63*	*1.69*		
		Use Thickness Class	27	27	28	28		
		Use Thickness	1.56	1.56	1.68	1.68		
B	2½	Calculated Thickness	*.93*	*.97*	*1.03*	*1.09*		
		Use Thickness Class	21	21	22	22		
		Use Thickness	.98	.98	1.06	1.06		
	3½	Calculated Thickness	*.94*	*.98*	*1.03*	*1.10*		
		Use Thickness Class	21	21	22	23		
		Use Thickness	.98	.98	1.06	1.14		
	5	Calculated Thickness	*.99*	*1.03*	*1.09*	*1.15*		
		Use Thickness Class	21	22	22	23		
		Use Thickness	.98	1.06	1.06	1.14		
		Calculated Thickness	*1.09*	*1.12*	*1.17*	*1.24*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	1.06	1.14	1.14	1.23		
	12	Calculated Thickness	*1.21*	*1.25*	*1.30*	*1.35*		
		Use Thickness Class	24	24	25	25		
		Use Thickness	1.23	1.23	1.33	1.33		
	16	Calculated Thickness	*1.30*	*1.34*	*1.38*	*1.44*		
		Use Thickness Class	25	25	25	26		
		Use Thickness	1.33	1.33	1.33	1.44		
F	2½	Calculated Thickness	*.84*	*.88*	*.93*	*1.00*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.98	.98	.98	.98		
	3½	Calculated Thickness	*.84*	*.88*	*.94*	*1.01*		
		Use Thickness Class	21	21	21	21		
		Use Thickness	.98	.98	.98	.98		
	5	Calculated Thickness	*.90*	*.93*	*.99*	*1.06*		
		Use Thickness Class	21	21	21	22		
		Use Thickness	.98	.98	.98	1.06		
	8	Calculated Thickness	*.97*	*1.01*	*1.07*	*1.13*		
		Use Thickness Class	21	21	22	23		
		Use Thickness	.98	.98	1.06	1.14		
	12	Calculated Thickness	*1.08*	*1.12*	*1.16*	*1.23*		
		Use Thickness Class	22	23	23	24		
		Use Thickness	1.06	1.14	1.14	1.23		
	16	Calculated Thickness	*1.15*	*1.20*	*1.25*	*1.31*		
		Use Thickness Class	23	24	24	25		
		Use Thickness	1.14	1.23	1.23	1.33		

Sec. 1-2—General Procedure for Thickness Determination

Sec. 1-2.1—Scope

This section gives the general method for determining the thicknesses of cast-iron pressure pipe. Thickness nomograms (Fig. 1-1 through 1-5) are included for two commonly used iron strengths (18/40 and 21/45); thicknesses for other iron strengths may be computed by the method presented in Sec. 1-3.1.

The required thickness of cast-iron pipe is determined by considering trench load and internal pressure in combination, and calculations of net thickness are made for two cases, namely:

Case 1. Trench load (earth load but no truck superload) in combination with internal pressure (working pressure plus surge pressure) and with a 2.5 factor of safety applied to both trench load and internal pressure

Case 2. Trench load (earth load plus truck superload) in combination with internal pressure (working pressure but no surge pressure) and with a 2.5 factor of safety applied to both trench load and internal pressure.

The larger thickness thus determined is chosen as the net thickness (only Case 2 is used for gas pipe). To the net thickness is added a corrosion allowance to obtain the minimum manufacturing thickness and a casting tolerance to obtain the total calculated thickness. Finally, the thickness for specifying and ordering is selected from a table of standard class thicknesses.

An example of this method is shown in Sec. 1-2.3.

Sec. 1-2.2—Procedure for Thickness Determination

This section gives the procedure for determining total calculated thicknesses and standard class thicknesses for pipe. This procedure was used in calculating the values shown in Sec. 1-1, Tables 1-1, 1-2 and 1-3.

1-2.2.1—Determination of Net Thickness

The net thickness for the more usual conditions may be readily determined using Tables 1-4 and 1-5 and the nomograms in Fig. 1-1 through 1-5. The bases for these tables and nomograms are described in Sec. 1-3. The three most commonly used methods of laying pipe, called "laying conditions," are defined below:

Laying Condition	Description
A	Pipe laid on flat-bottom trench, backfill not tamped
B	Pipe laid on flat-bottom trench, backfill tamped
F	Pipe bedded in gravel or sand, backfill tamped

After the pipe size, working pressure, iron strength, laying condition, and depth of cover have been established, the procedure for determining net thickness is as follows:

a. From Table 1-4, select for both Case 1 and Case 2 the value of w, which is the ring test load equivalent of trench load including a 2.5 safety factor (see Sec. 1-3.1 for definition of ring test load equivalent).

b. From Table 1-5, select for both Case 1 and Case 2 the value of p, which is the internal pressure including a 2.5 safety factor.

c. Thickness nomograms are provided in Fig. 1-1 through 1-5 for iron strengths of 18/40 * and 21/45.* Se-

* The first figure designates the bursting tensile strength in 1,000 psi and the second figure designates the ring modulus of rupture in 1,000 psi.

lect the nomogram for the desired iron strength and range of loads and pressures. Locate the values of w and p for Case 1 on the vertical scales. Connect these values with a straightedge and read the required thickness for Case 1.

d. Repeat this procedure using the above values of w and p for Case 2 and read the required thickness for Case 2.

e. The larger thickness, as determined for Cases 1 and 2, is the net thickness for water pipe. (For gas pipe, only Case 2 is applicable.)

1-2.2.2—*Addition of Allowances to Net Thickness*

a. A corrosion allowance of 0.08 in. is added to the net thickness. The resulting thickness is the minimum manufacturing thickness. Where severe corrosion is anticipated, an analysis of the condition should be made.

b. A casting tolerance from Table 1-6 is added to the minimum manufacturing thickness and the resulting thickness is the total calculated thickness.

1-2.2.3—*Selection of Standard Thickness*

Refer to Table 1-7 and select the standard class thickness nearest to the total calculated thickness. When the calculated thickness is halfway between two standard thicknesses, the larger of these is selected. When the calculated thickness is less than the smallest standard thickness, the smallest standard thickness is selected.

Sec. 1-2.3—Example for Determining Thickness of 18-in. Water Pipe

Determine the thickness for 18-in. cast-iron pipe laid on flat-bottom trench with tamped backfill (laying condition B), under 5 ft of cover for a working pressure of 200 psi. Iron strength is 18/40.

1-2.3.1—*Step 1—Determination of Net Thickness*

a. From Table 1-4, the ring test load equivalents of trench load, including a safety factor of 2.5, are

For Case 1, w = 2,786 lb/lin ft
For Case 2, w = 3,876 lb/lin ft

b. From Table 1-5, the internal pressures, including a safety factor of 2.5, are

For Case 1, p = 750 psi
For Case 2, p = 500 psi

c. Using Fig. 1-1, locate $w = 2{,}786$ and $p = 750$ on the vertical scales. Connect these values with a straightedge and read the thickness for Case 1, which is 0.47 in.

d. Using Fig. 1-1, locate $w = 3{,}876$ and $p = 500$ and read the thickness for Case 2, which is 0.46 in.

e. The larger of these two thicknesses is the net thickness. The controlling one in this example is 0.47 in. (Case 1).

1-2.3.2—*Step 2—Addition of Allowances to Net Thickness*

The total calculated thickness, as shown in Table 1-1, is determined as follows:

Net thickness	0.47 in.
Corrosion allowance	0.08 in.
Minimum manufacturing thickness	0.55 in.
Casting tolerance (Table 1-6)	0.08 in.
Total calculated thickness	0.63 in.

1-2.3.3—*Step 3—Selection of Standard Thickness*

From Table 1-7, the total calculated thickness of 0.63 in. is exactly the same as Class 23. Therefore, Class 23 is the standard thickness class for the pipe in this example.

In ordering or specifying, the foregoing pipe is identified as 18-in. size, thickness Class 23, conforming to ANSI Standard A21.6 or A21.8 as applicable.

TABLE 1-4

Ring Test Load Equivalents (w) of Trench Loads—lb/lin ft*

Laying Condition	Pipe Size in.	Depth of Cover—ft 2½	3½	5	8	12	16	20	24
		Case 1—Ring Test Load Equivalent of Earth Load (Use With Surge Pressure)							
	3	396	565	817	1,324	2,000	2,674	3,343	4,026
	4	491	704	1,024	1,663	2,515	3,367	4,222	5,074
	6	672	974	1,428	2,337	3,548	4,756	5,487	5,754
	8	826	1,211	1,791	2,948	4,491	5,635	6,120	6,446
	10	974	1,448	2,157	3,576	5,376	6,198	6,770	7,163
	12	1,111	1,674	2,520	4,239	5,839	6,774	7,433	7,902
	14	1,235	1,887	2,865	4,822	6,304	7,356	8,115	8,659
	16	1,341	2,085	3,196	5,176	6,776	7,954	8,804	9,433
	18	1,446	2,265	3,513	5,506	7,250	8,548	9,509	10,224
A	20	1,552	2,433	3,815	5,839	7,728	9,150	10,224	11,033
	24	1,770	2,730	4,372	6,509	8,693	10,378	11,678	12,680
	30	2,093	3,167	5,087	7,520	10,161	12,256	13,915	15,237
	36	2,437	3,626	5,713	8,537	11,643	14,167	16,220	17,882
	42	2,761	4,083	6,341	9,556	13,078	16,104	18,554	20,560
	48	3,102	4,550	6,991	10,580	14,646	18,061	20,928	23,354
	54	3,437	5,022	7,650	11,609	16,161	20,039	23,346	26,161
	60	3,778	5,493	8,313	12,643	17,815	22,028	25,776	28,998
	3	355	508	734	1,189	1,797	2,402	3,004	3,617
	4	438	628	913	1,483	2,242	3,002	3,764	4,523
	6	585	848	1,244	2,036	3,091	4,144	4,780	5,014
	8	709	1,039	1,537	2,530	3,855	4,836	5,252	5,531
	10	824	1,224	1,823	3,024	4,546	5,241	5,724	6,057
	12	926	1,395	2,100	3,533	4,866	5,645	6,194	6,586
	14	1,007	1,539	2,337	3,933	5,142	6,000	6,618	7,062
	16	1,079	1,677	2,570	4,163	5,449	6,397	7,080	7,586
	18	1,147	1,797	2,786	4,367	5,750	6,779	7,541	8,109
B	20	1,214	1,903	2,985	4,568	6,046	7,158	7,998	8,631
	24	1,339	2,066	3,307	4,924	6,577	7,852	8,836	9,593
	30	1,524	2,305	3,703	5,473	7,396	8,921	10,128	11,090
	36	1,709	2,543	4,006	5,986	8,165	9,935	11,373	12,540
	42	1,879	2,778	4,315	6,503	8,899	10,959	12,626	14,015
	48	2,074	3,042	4,674	7,074	9,792	12,076	13,993	15,615
	54	2,259	3,300	5,027	7,629	10,620	13,169	15,342	17,191
	60	2,455	3,569	5,401	8,215	11,575	14,312	16,747	18,841
	3	261	374	540	875	1,322	1,767	2,210	2,661
	4	323	463	673	1,093	1,653	2,213	2,774	3,334
	6	434	629	923	1,510	2,292	3,073	3,545	3,718
	8	528	774	1,144	1,883	2,869	3,600	3,910	4,118
	10	612	910	1,355	2,247	3,378	3,895	4,254	4,502
	12	691	1,041	1,566	2,635	3,630	4,211	4,620	4,912
	14	755	1,154	1,753	2,949	3,856	4,500	4,964	5,297
	16	812	1,262	1,934	3,133	4,101	4,815	5,329	5,709
	18	861	1,350	2,093	3,281	4,320	5,093	5,666	6,092
F	20	915	1,435	2,250	3,444	4,558	5,396	6,029	6,506
	24	1,018	1,570	2,514	3,742	4,999	5,968	6,715	7,291
	30	1,157	1,751	2,812	4,157	5,618	6,776	7,693	8,424
	36	1,310	1,949	3,070	4,588	6,257	7,613	8,716	9,610
	42	1,443	2,134	3,315	4,996	6,837	8,418	9,699	10,766
	48	1,586	2,326	3,573	5,408	7,485	9,231	10,697	11,937
	54	1,726	2,522	3,842	5,830	8,116	10,063	11,724	13,138
	60	1,881	2,735	4,139	6,295	8,869	10,967	12,832	14,436

* A safety factor of 2.5 is included. These ring test load equivalents are based on the earth loads in Table 1-8.

TABLE 1-4 (*Continued*)

Ring Test Load Equivalents (w) *of Trench Loads*—lb/lin ft*

Laying Condition	Pipe Size *in.*	Depth of Cover—*ft*							
		2½	3½	5	8	12	16	20	24
Case 2—Ring Test Load Equivalent of Earth Load Plus Truck Superload (Use Without Surge Pressure)†									
A	3	748	741	935	1,411	2,059	2,704	3,363	4,041
	4	1,137	1,057	1,200	1,780	2,602	3,426	4,261	5,104
	6	1,904	1,678	1,839	2,541	3,696	4,843	5,543	5,798
	8	2,528	2,267	2,437	3,270	4,696	5,752	6,198	6,506
	10	3,087	2,798	2,978	3,987	5,611	6,346	6,867	7,239
	12	3,635	3,317	3,517	4,767	6,104	6,950	7,548	7,991
	14	3,880	3,641	4,039	5,409	6,598	7,561	8,250	8,763
	16	4,183	3,996	4,478	5,880	7,128	8,220	8,980	9,567
	18	4,489	4,361	4,887	6,298	7,661	8,841	9,702	10,374
	20	4,865	4,772	5,400	6,730	8,198	9,502	10,456	11,213
	24	5,383	5,250	6,043	7,513	9,250	10,761	11,930	12,876
	30	6,278	6,115	7,083	8,746	10,865	12,726	14,226	15,476
	36	7,180	7,054	8,083	9,911	12,465	14,724	16,587	18,167
	42	7,878	7,887	9,035	11,115	14,076	16,778	19,000	20,939
	48	8,596	8,728	10,035	12,350	15,761	18,824	21,432	23,743
	54	9,165	9,483	10,967	13,563	17,452	20,861	23,902	26,572
	60	9,789	10,237	11,904	14,783	19,193	22,909	26,393	29,437
B	3	672	666	840	1,268	1,850	2,430	3,021	3,631
	4	1,014	942	1,070	1,587	2,320	3,054	3,798	4,550
	6	1,659	1,462	1,602	2,214	3,220	4,220	4,830	5,051
	8	2,170	1,946	2,091	2,806	4,030	4,937	5,319	5,584
	10	2,610	2,366	2,518	3,371	4,744	5,366	5,807	6,121
	12	3,029	2,765	2,931	3,973	5,087	5,792	6,290	6,659
	14	3,165	2,970	3,294	4,411	5,381	6,166	6,729	7,147
	16	3,364	3,213	3,601	4,729	5,733	6,610	7,222	7,694
	18	3,560	3,459	3,876	4,995	6,076	7,012	7,695	8,228
	20	3,806	3,733	4,225	5,265	6,413	7,434	8,180	8,772
	24	4,072	3,972	4,572	5,684	6,998	8,141	9,026	9,742
	30	4,570	4,451	5,155	6,366	7,908	9,263	10,354	11,264
	36	5,035	4,947	5,668	6,950	8,741	10,325	11,631	12,739
	42	5,361	5,367	6,148	7,564	9,578	11,417	12,929	14,248
	48	5,747	5,836	6,709	8,257	10,538	12,586	14,330	15,875
	54	6,023	6,232	7,207	8,913	11,469	13,709	15,707	17,461
	60	6,360	6,651	7,734	9,604	12,470	14,884	17,148	19,126
F	3	494	490	618	932	1,361	1,787	2,223	2,671
	4	747	694	789	1,170	1,710	2,251	2,800	3,354
	6	1,230	1,084	1,188	1,642	2,388	3,129	3,581	3,746
	8	1,615	1,449	1,557	2,089	3,000	3,675	3,960	4,157
	10	1,940	1,758	1,872	2,505	3,526	3,988	4,316	4,549
	12	2,260	2,062	2,187	2,964	3,795	4,320	4,692	4,968
	14	2,374	2,227	2,471	3,309	4,036	4,625	5,046	5,360
	16	2,532	2,418	2,711	3,559	4,315	4,975	5,436	5,791
	18	2,675	2,598	2,912	3,752	4,565	5,268	5,781	6,181
	20	2,869	2,814	3,185	3,969	4,835	5,604	6,167	6,613
	24	3,095	3,019	3,475	4,320	5,319	6,188	6,860	7,404
	30	3,471	3,381	3,916	4,835	6,007	7,036	7,865	8,556
	36	3,859	3,791	4,343	5,326	6,698	7,912	8,914	9,763
	42	4,118	4,123	4,723	5,810	7,358	8,771	9,932	10,945
	48	4,393	4,461	5,129	6,312	8,055	9,621	10,954	12,136
	54	4,603	4,762	5,508	6,811	8,764	10,476	12,003	13,344
	60	4,874	5,097	5,927	7,360	9,556	11,405	13,140	14,655

*A safety factor of 2.5 is included. These ring test load equivalents are based on the earth loads and truck superloads in Table 1-8.

† Truck superload is based on two passing trucks with adjacent wheels 3 ft apart, having a 9,000-lb wheel load on unpaved road or flexible pavement and an impact factor of 1.50 (see Sec. 1-3.3).

TABLE 1-5

Internal Pressures (p)*

Pipe Size *in.*	Rated Working Pressure—*psi*							
	10	50	100	150	200	250	300	350
	Case 1—Internal Pressure With Surge Pressure Allowances†							
3	—	425	550	675	800	925	1,050	1,175
4	—	425	550	675	800	925	1,050	1,175
6	—	425	550	675	800	925	1,050	1,175
8	—	425	550	675	800	925	1,050	1,175
10	—	425	550	675	800	925	1,050	1,175
12	—	400	525	650	775	900	1,025	1,150
14	—	400	525	650	775	900	1,025	1,150
16	—	375	500	625	750	875	1,000	1,125
18	—	375	500	625	750	875	1,000	1,125
20	—	350	475	600	725	850	975	1,100
24	—	338	463	588	713	838	963	1,088
30	—	325	450	575	700	825	950	1,075
36	—	313	438	563	688	813	938	1,063
42	—	300	425	550	675	800	925	1,050
48	—	300	425	550	675	800	925	1,050
54	—	300	425	550	675	800	925	1,050
60	—	300	425	550	675	800	925	1,050
	Case 2—Internal Pressure Without Surge Pressure Allowances							
3–60 all	25	125	250	375	500	625	750	875

* Safety factor of 2.5 included.
† For surge pressure allowances, see Table 1-10.

TABLE 1-6

Allowances For Casting Tolerance

Pipe Size *in.*	Casting Tolerance *in.*	Pipe Size *in.*	Casting Tolerance *in.*
3–8	0.05	14–24	0.08
10–12	0.06	30–48	0.10

TABLE 1-7—*Standard Thickness Classes of Cast-Iron Pipe*

(See note on facing page)

Pipe Size in.	Thickness for Standard Thickness Class Number—in.										
	20	21	22	23	24	25	26	27	28	29	30
3			**0.32***	0.35	0.38	0.41	0.44	0.48	0.52	0.56	0.60
4			**0.35***	0.38	0.41	0.44	0.48	0.52	0.56	0.60	0.65
6		0.35*	**0.38**	0.41	0.44	0.48	0.52	0.56	0.60	0.65	0.70
8	0.35*	0.38	**0.41**	0.44	0.48	0.52	0.56	0.60	0.65	0.70	0.76
10	0.38*	0.41	**0.44**	0.48	0.52	0.56	0.60	0.65	0.70	0.76	0.82
12	0.41*	0.44	**0.48**	0.52	0.56	0.60	0.65	0.70	0.76	0.82	0.89
14	0.43	**0.48***	0.51	0.55	0.59	0.64	0.69	0.75	0.81	0.87	0.94
16	0.46	**0.50***	0.54	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99
18	0.50	**0.54***	0.58	0.63	0.68	0.73	0.79	0.85	0.92	0.99	1.07
20	0.53	**0.57***	0.62	0.67	0.72	0.78	0.84	0.91	0.98	1.06	1.14
24	0.58	**0.63***	0.68	0.73	0.79	0.85	0.92	0.99	1.07	1.16	1.25
30	0.68*	**0.73**	0.79	0.85	0.92	0.99	1.07	1.16	1.25	1.35	1.46
36	0.75*	**0.81**	0.87	0.94	1.02	1.10	1.19	1.29	1.39	1.50	1.62
42	0.83*	**0.90**	0.97	1.05	1.13	1.22	1.32	1.43	1.54	1.66	1.79
48	0.91*	**0.98**	1.06	1.14	1.23	1.33	1.44	1.56	1.68	1.81	1.95

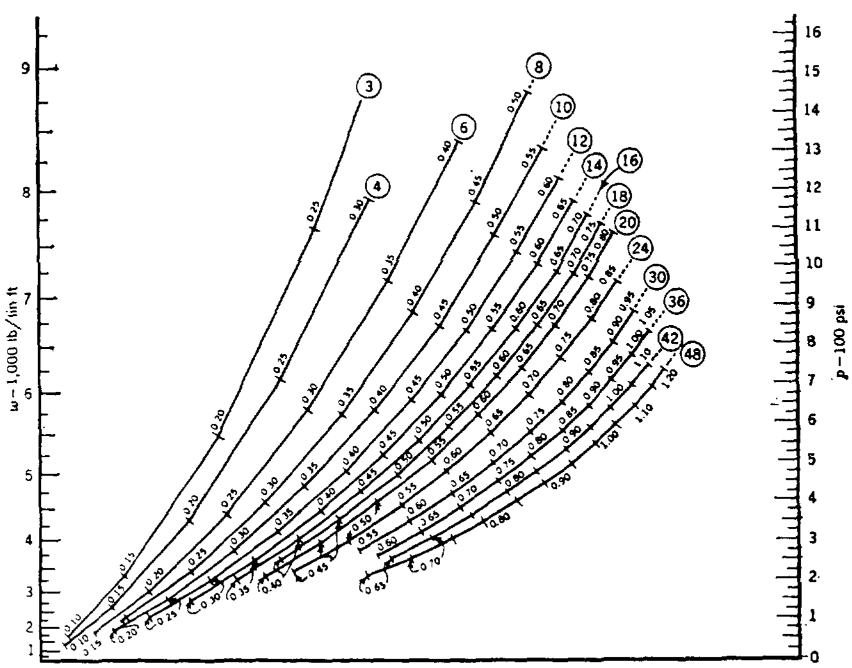

Fig. 1-1. Thickness Nomogram for Pipe of 18/40 Iron Strength, Low-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S *equals 18,000,* R *equals 40,000. The encircled values at the end of each curve are for pipe size, in inches.*

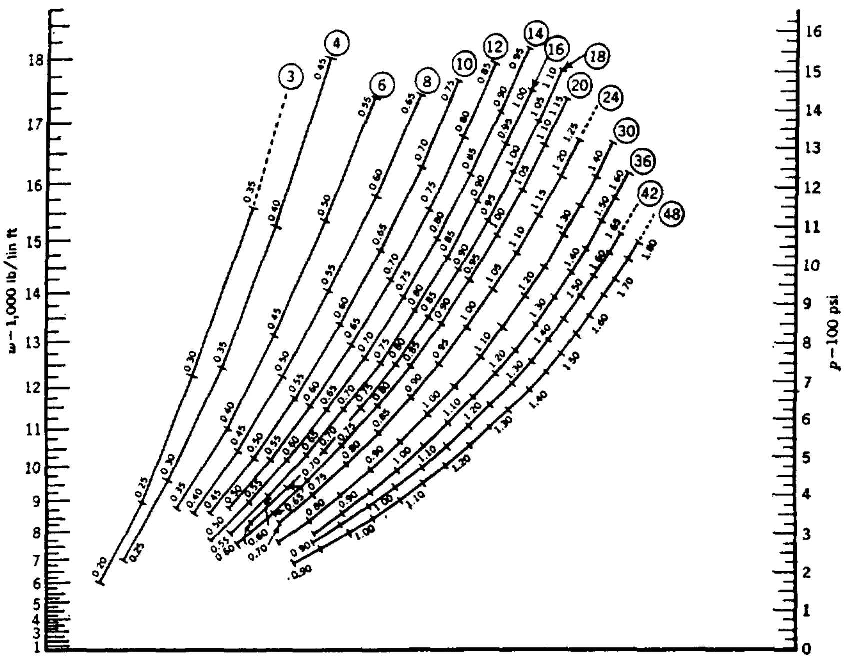

Fig. 1-2. Thickness Nomogram for Pipe of 18/40 Iron Strength, High-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S *equals 18,000,* R *equals 40,000. The encircled values at the end of each curve are for pipe size, in inches.*

Explanatory Note to Table 1-7

Irrespective of calculated thickness, standard thicknesses are not made less than certain minimums, which are the smallest thickness classes shown in the table. They have been chosen by judgment based on experience with the shocks received by pipe in handling and transporting. ANSI Standards A21.6, A21.7, A21.8, and A21.9 are based on iron strength of 18/40. The recommended minimum nominal thicknesses for such pipe are shown in boldface type. Pipe of 21/45 iron strength for water service may have thicknesses less than those pipe of 18/40 iron strength. Pipe of such reduced thickness should be used only after consideration of possible adverse conditions of installation and environment. The recommended minimum nominal thicknesses for such pipe are shown with an asterisk. Pipe with 21/45 iron strength in Thickness Class 20 are sometimes used in sizes 14–24 in., when the calculated thicknesses permit and where provisions are made for special handling.

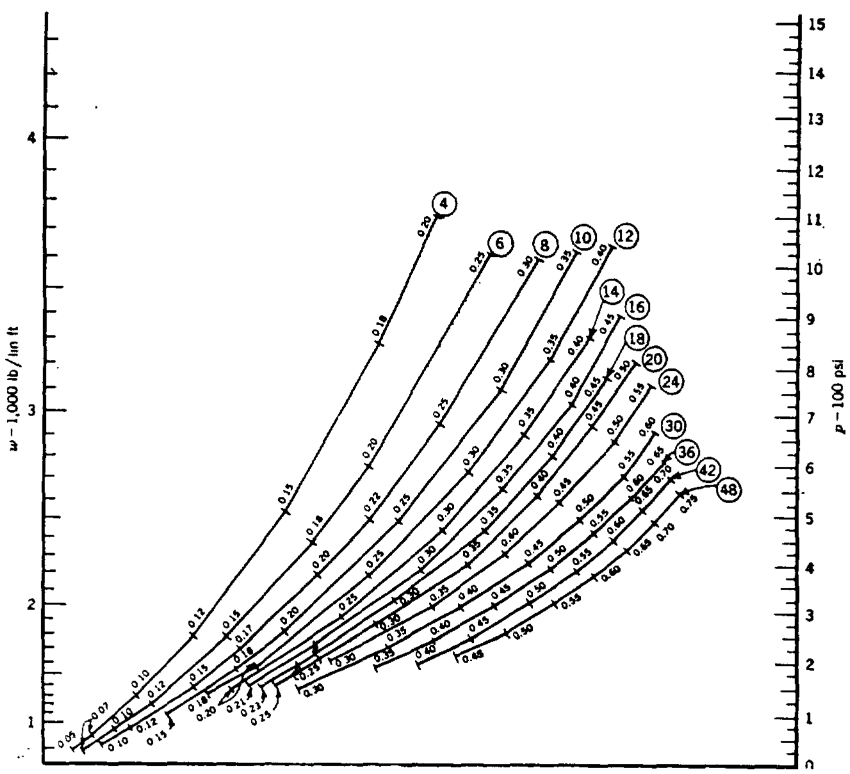

Fig. 1-3. Thickness Nomogram for Pipe of 21/45 Iron Strength, Low-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S equals 21,000. R equals 45,000. The encircled values at the end of each curve are for pipe size, in inches.

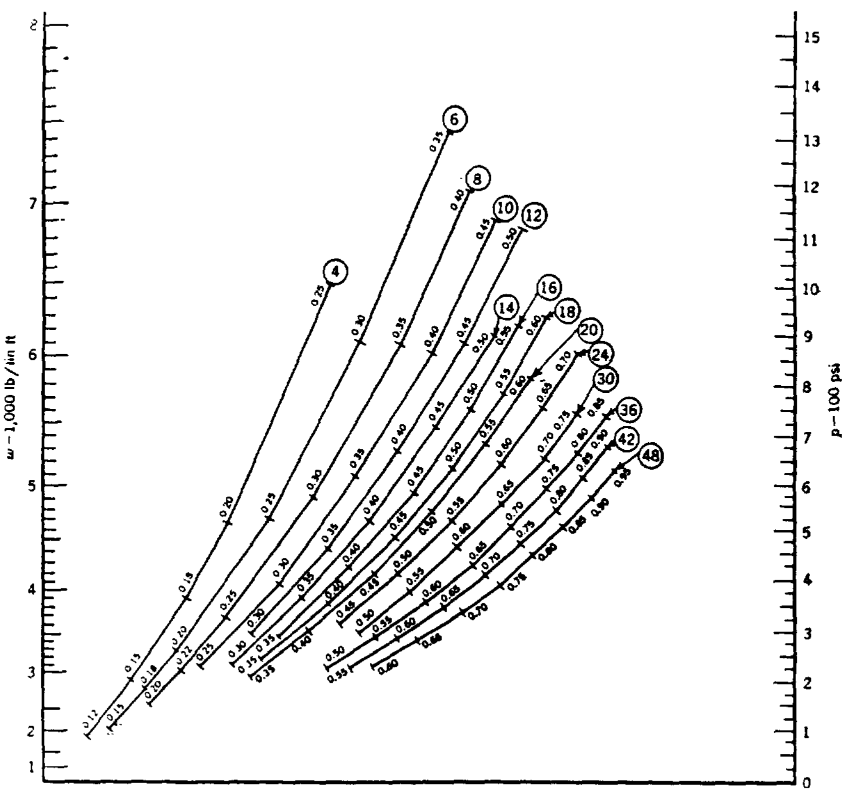

Fig. 1-4. Thickness Nomogram for Pipe of 21/45 Iron Strength, Medium-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S equals 21,000, R equals 45,000. The encircled values at the end of each curve are for pipe size, in inches.

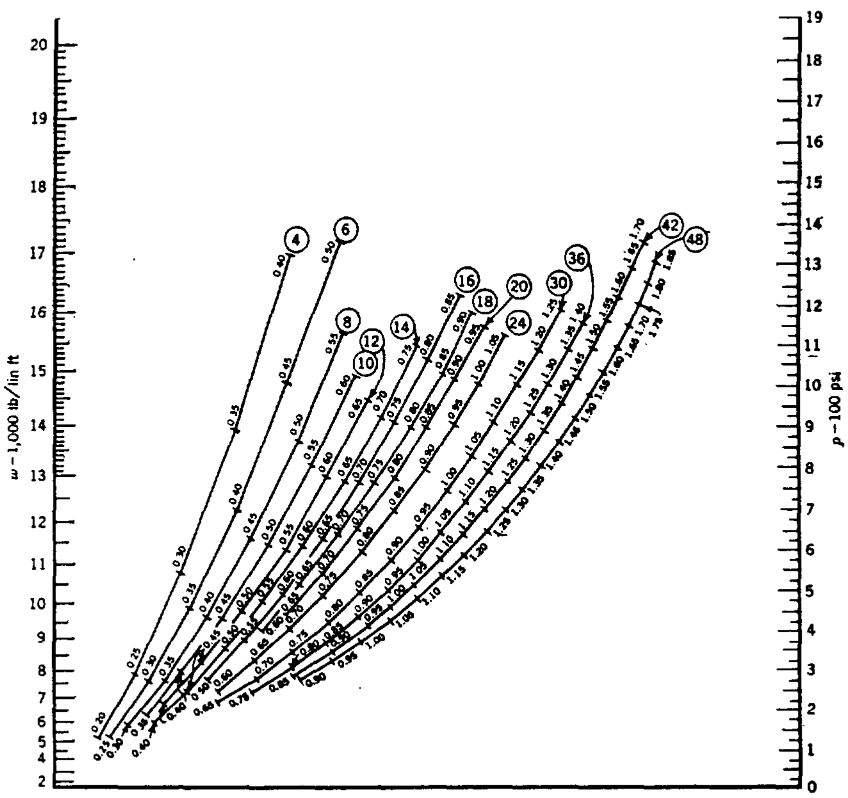

Fig. 1-5. Thickness Nomogram for Pipe of 21/45 Iron Strength, High-Range Load

Thicknesses are net, and computations are made using nominal pipe diameter for inside diameter. S *equals 21,000,* R *equals 45,000. The encircled values at the end of each curve are for pipe size, in inches.*

Sec. 1-3—Design Theory—Determination of Net Thickness, Earth Load, and Truck Superload

Sec. 1-3.1—Determination of Net Thickness

Tests made for ANSI Committee A21* showed that, when a pipe has both an external load applied in three-edge bearing (such as the laboratory ring test) and an internal pressure, the relation between external load and internal pressure at the point of breaking can be represented, with sufficient accuracy, by a parabola drawn as in Fig. 1-6.

The mathematical relationships expressed by the formula for the load-pressure curve are the basis for the whole system of pipe thickness calculations used in this standard.

The equation of the load-pressure parabola is

$$w = W\sqrt{\frac{P - p}{P}} \qquad (1)$$

in which:

W = ring test crushing load with no internal pressure (lb/lin ft)

P = bursting pressure with no external load (psi)

p and w are any combination of internal pressure and external load that will just cause fracture.

The values of W and P are calculated as follows:

$$W = \frac{Rt^2}{0.0795(d + t)} \qquad (2)$$

$$P = \frac{2St}{d} \qquad (3)$$

in which:

R = ring modulus of rupture (psi)

S = bursting tensile strength (psi)

t = net thickness (in.)

d = nominal pipe size (in.).

The symbols S and R denote the strength of the iron in the pipe and are based on periodic full-length bursting tests and ring tests as specified in ANSI Standards A21.6 (AWWA C106), A21.7, A21.8 (AWWA C108), and A21.9.

The design values of w to be used in solving Eq 1, either by nomogram or by trial calculation, are determined as follows:

For Case 1,

$$w = \frac{2.5W_e}{L_f} \qquad (4)$$

For Case 2,

$$w = \frac{2.5(W_e + W_t)}{L_f} \qquad (5)$$

in which:

w = ring test load equivalent of trench load (lb/lin ft), including a 2.5 safety factor

W_e = earth load (lb/ft) (Table 1-8 and Sec. 1-3.2)

W_t = truck superload (lb/ft) (Table 1-8 and Sec. 1-3.3)

L_f = load factor dependent on laying condition (Table 1-9)

2.5 = safety factor.

The load factor L_f converts the trench load (earth load only or earth

* See Ref. 3, "Foreword," p. x.

load plus truck superload) to an equivalent load in the laboratory ring test. Table 1–4 gives values of w computed from Eq 4 and 5 for standard depths of cover using the earth loads and truck superloads in Table 1–8 and the load factors in Table 1–9.

The design values of p to be used in solving Eq 1, either by nomogram or by trial calculation, are determined as follows:

For Case 1,

$$p = 2.5\,(p_w + p_s) \qquad (6)$$

For Case 2,

$$p = 2.5\,p_w \qquad (7)$$

in which:

p = internal pressure (psi), including a 2.5 safety factor
p_w = working pressure (psi)
p_s = allowance for surge pressure (psi) (Table 1–10)
2.5 = safety factor.

Table 1–5 gives values of p computed by Eq 6 and 7 for standard working pressures using the allowances for surge pressure in Table 1–10.

As described in Sec. 1–2.2, calculations for net thickness for water pipe are made for two conditions of combined loading: Case 1, which includes surge pressure but not truck superload; and Case 2, which includes truck superload but not surge pressure. The larger of the two thicknesses is used for design. Truck superload and surge pressure are transient and occasional loads, and it is considered extremely unlikely that they will occur simultaneously.

When Eq 2 and 3 are substituted in Eq 1, the result is a high-order equation which cannot be solved directly for the net thickness t by conventional mathematical procedure. It is necessary to resort to graphical solution or to successive approximation. The more convenient method for routine work is to use a nomogram as shown in Fig. 1–1 through 1–5. Such nomograms are prepared by the following steps:

a. Using the appropriate iron strength values of S and R, calculate W and P for a series of thicknesses for each pipe size by means of Eq 2 and 3.

b. For each thickness select two values of p and compute the corresponding values of w using Eq 1.

c. Set up parallel scales for w and p, using linear increments for the p scale and increments proportional to the square of the load for the w scale.

d. Using a straightedge to connect the corresponding values of w and p, locate and mark the intersection of the two lines determined by the two sets of values for each thickness.

e. Repeat for the full series of thicknesses to lay out the curve for each pipe size.

If it is desired to determine net thickness for iron strengths or loads and pressures not covered in the nomograms in Fig. 1–1 through 1–5, a trial calculation method may be used to solve Eq 1, as follows:

a. Based on the values of w and p corresponding to the design conditions, assume a trial value of t.

b. Using the known iron strength values S and R and the trial value of t, calculate W and P from Eq 2 and 3.

c. Using these values of W and P and the design value of p, solve Eq 1 for w.

d. Compare this calculated value of w to the design value of w and assume a smaller or larger value of t, as required, for the second trial calculation.

e. Continue until a change in assumed thickness of less than 0.01 in. results in a calculated w equal to or greater than the design w.

A graphical method may also be used for determining thicknesses for conditions not covered in the nomograms in Fig. 1-1 through 1-5. The parabolic graphical method is described in Sec. 1-12.3 of ANSI A21.1-1957 (AWWA H1-57).

Sec. 1-3.2—Earth Loads (W_e)

For computation of earth loads on cast-iron pipe the type of installation is identified as shown in Fig. 1-7. Ditch condition (Fig. 1-7a, b, c) denotes pipe laid in a relatively narrow trench and backfilled to the original ground surface. The trench width at the top of the pipe determines the load and the ditch may be widened above the top of the pipe for installation convenience (Fig. 1-7 b, c) without increasing the load on the pipe. Embankment condition includes two types of installation: positive projection condition (Fig. 1-7d) which denotes pipe laid on top of a subgrade and covered with fill, and negative projection condition (Fig. 1-7e) which denotes pipe laid in a trench in the subgrade and covered with fill, which extends substantially above the subgrade. Methods for calculating earth loads for these three installation conditions are given below:

1-3.2.1—*Ditch Condition*

The ditch condition is the most common method of installing cast-iron pipe and is the basis of the earth loads shown in Table 1-8. The load is obtained by selecting the lesser of the two loads computed by Eq 8 and 9.

$$W_e = C_d w B_d^2 \quad \text{(ditch condition)} \qquad (8)$$

$$W_e = C_c w B_c^2 \quad \text{(positive projection condition)} \qquad (9)$$

in which:

W_e = earth load, lb per linear ft
C_d = calculation coefficient, ditch condition
C_c = calculation coefficient, positive projection condition
w = soil density (120 lb/cu ft assumed in standard calculations)
B_d = width of trench at top of pipe (ft) (for standard calculations use nominal pipe diameter plus 2 ft)
B_c = outside diameter of pipe, ft.

This procedure was established by work done at Iowa State College,* which proved that for certain combinations of pipe size, trench width, and depth of cover, the load given by Eq 9 for positive projection condition should be used when it is the lesser of the two loads even though the pipe is laid in a trench.

The calculation coefficient C_d is obtained from Fig. 1-8 or from the following equation:

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'} \qquad (10)$$

in which:

K = ratio of active horizontal pressure at any point in the fill to the vertical pressure which causes the active horizontal pressure
μ' = coefficient of sliding friction between fill materials and sides of trench
$K\mu'$ = 0.130 for standard calculations

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* SPANGLER, M. G. *Soil Engineering.* International Textbook Co., Scranton, Pa. (2nd ed., 1960). p. 416.

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e = the base of natural logarithms (2.71828)
H = depth of cover to top of pipe (ft).

The calculation coefficient, C_c, is obtained from Fig. 1-9 or from the following equation:

$$C_c = \frac{e^{2K\mu \frac{H}{B_c}} - 1}{2K\mu} \qquad (11)$$

or

$$C_c = \frac{e^{2K\mu \frac{H_e}{B_c}} - 1}{2K\mu} + \left(\frac{H}{B_c} - \frac{H_e}{B_c}\right) e^{2K\mu \frac{H_e}{B_c}} \qquad (12)$$

in which:

μ = coefficient of internal friction in fill materials
$K\mu$ = 0.1924 for standard calculations
H_e = Height of equal settlement (ft) (vertical height from the top of conduit to the level at and above which the fill materials directly over the conduit settle equally with the adjacent fill materials).

Equation 11 is used when the height of fill, H, is equal to or less than the height of equal settlement, H_e. Equation 12 is used when the height of fill, H, is greater than the height of equal settlement, H_e.

The height of equal settlement, H_e, is obtained from the following equation:

$$e^{2K\mu \frac{H_e}{B_c}} - 2K\mu \frac{H_e}{B_c} = 2K\mu(r_{sd}p) + 1 \qquad (13)$$

in which:

r_{sd} = settlement ratio*
p = projection ratio*

For standard calculations the value of the product $r_{sd}p$ is taken to be 0.75. For this value, the height of equal settlement calculated by Eq 13 is, $H_e = 1.75\ B_c$ and Eq 12 reduces to:

$$C_c = 1.961 \frac{H}{B_c} - 0.934 \qquad (12a)$$

In most cases Eq 12a is used to calculate C_c becuase the depth of cover usually exceeds 1.75 times the pipe outside diameter.

Table 1-8 and Fig. 1-10 show earth loads computed by the above procedures for cast-iron pipe laid in trenches with widths, B_d, equal to the nominal pipe diameter plus 2 ft. Figure 1-11 shows a chart of earth loads computed by the above procedures for pipe installed in trenches where B_d is equal to the nominal pipe diameter plus 1 ft.

Figures 1-12 and 1-13 show charts computed by the above procedures for pipe laid in trenches with sides sloped 1:1 and 2:1, respectively.

For standard calculations, $K\mu = 0.1924$ is used for C_c and $K\mu' = 0.130$ is used for C_d in order to obtain conservative earth loads. Other values of $K\mu$ and $K\mu'$, which may be used in calculating earth loads for special soil conditions, are shown below with the corresponding soil type:

Soil Type	Value of $K\mu$ or $K\mu'$
Granular materials without cohesion	0.1924
Sand and gravel, maximum	0.165

* For a definition of these terms see: SPANGLER, M. G. *Soil Engineering*. International Textbook Co., Scranton, Pa. (2nd ed., 1960). p. 403.

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Saturated top soil, maximum	0.150
Clay, ordinary maximum	0.130
Saturated clay, maximum	0.110

1-3.2.2—*Positive-Projection Embankment*

The positive-projection condition may be encountered with pipe laid on top of a subgrade and covered with fill for highway or dam construction. The earth load is calculated from Eq 9 using Eq 12a for calculation of C_c when standard values of $r_{sd}p$ and $K\mu$ are used. For such standard values the load may also be read directly from Fig. 1-12 which was constructed from loads computed by Eq 9. The loads in Fig. 1-12 are based on soil weighing 110 lb/cu ft and may be adjusted to soil of 120 lb/cu ft by multiplying the graph load by 120/110. For calculation of pipe thicknesses, special load factors are used for positive projection embankment condition as shown in Table 1-9.

1-3.2.3—*Negative-Projection Embankment Condition*

The negative-projection embankment condition may be encountered in highway or dam construction when the pipe is laid in a relatively narrow trench cut in the subgrade, a more desirable method than installation directly on top of the subgrade. Loads for negative projection are calculated as follows.

$$W_e = C_n w B_d^2 \qquad (14)$$

in which:

C_n = calculation coefficient (negative projection condition).
Other terms are as defined for Eq 8 and 9.

The calculation coefficient, C_n, is read from Fig. 1-14 after the values of p' and H/B_d have been determined as follows:

$p' = h/B_d$
h = depth of cover in trench from top of pipe to subgrade (ft)
H = total height of fill from top of pipe to top of embankment (ft)
B_d = width of subgrade trench at top of pipe (ft)

Equation 14 is considered to give the maximum load that could occur on pipe laid in trenches under embankment conditions such as the case of embankment or additional fill added at some time, generally years, after the pipe was laid as a ditch conduit and backfill placed. In many embankment cases, Eq 14 may give loads which are too conservative.

In cases where pipe is laid in a subgrade trench with the embankment completed shortly thereafter, the load may be closer to that given by Eq 8 for ditch condition, and the embankment fill above the subgrade trench may be considered as equivalent to an increase of the trench width above the top of the pipe without significant effect on the earth load.

For other cases the load may lie somewhere between those given by Eq 8 and Eq 14. The correct load depends largely on relative soil compaction in the subgrade trench and overlying embankment and selection of the proper load for pipe design will be governed by engineering judgment based on the specific factors in each installation.

1-3.2.4—*Sample Calculation of Earth Load*

Determine earth load on 12-in. cast-iron pipe with 5 ft of cover. Pipe laid in a flat-bottom trench $(d + 2)$ ft wide.

Step 1. Calculate earth load for ditch condition using Eq 8.

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'} \quad (10)$$

$K\mu' = 0.130$
$H = 5$ ft

$$B_d = \frac{12}{12} + 2 = 3 \text{ ft}$$

$$C_d = \frac{1 - e^{-2(0.130)\left(\frac{5}{3}\right)}}{2(0.130)} = \frac{0.3516}{0.260} = 1.35$$

$$W_e = C_d w B_d^2 \quad (8)$$
$$= 1.35(120)(3)^2$$
$$= 1{,}460 \text{ lb/ft}$$

Step 2. Calculate earth load for projection condition using Eq 9.

$$H_e = 1.75\, B_c = 1.75\left(\frac{13.20}{12}\right)$$
$$= 1.75(1.10) = 1.92 \text{ ft}$$

H is greater than H_e, therefore use Eq 12 or 12a to calculate C_c. Using Eq 12a:

$$C_c = 1.961\,\frac{H}{B_c} - 0.934 \quad (12a)$$
$$= 1.961\left(\frac{5}{1.10}\right) - 0.934$$
$$= 7.98$$
$$W_e = C_c w B_c^2 \quad (9)$$
$$= 7.98\,(120)(1.10)^2$$
$$= 1{,}159 \text{ lb/ft}$$

Step 3. Select lesser load from Step 1 or 2. The load for projection condition is the lesser. Therefore, the earth load, W_e, is 1,159 lb/ft. This load is shown in Table 1-8.

Sec. 1-3.3—Truck Superloads (W_t)

The procedures in this section may be used to compute truck superloads for unpaved roads, flexible pavement or rigid pavement; one truck or two passing trucks; and any wheel load and impact factor. For unpaved road or flexible pavement Eq 15 is used. For rigid pavement Eq 16 is used.

$$W_t = CRPF \quad (15)$$

$$W_t = KB_cPF \quad (16)$$

in which:

W_t = Truck superload (lb/lin ft)
C = Surface load factor for unpaved road or flexible pavement (for one truck, see Table 1-11; for two trucks, see Table 1-12).
R = Reduction factor which takes account of the fact that the part of the pipe directly below the wheels receives the truck superload in its full intensity but is aided in carrying the load by adjacent parts of the pipe that receive little or no load from the truck. (See Table 1-13.)
P = Wheel load (lb)
F = Impact factor
K = Surface load factor for rigid pavement (see Table 1-14).
B_c = Outside diameter of pipe (ft) (see Table 1-15).

Equations 15 and 16 may be used in computing AASHO truck loading which is described in "Standard Specifications for Highway Bridges," American Assn. of State Highway Officials, 1961. The wheel loads and impact factors to be used in the equations are given in Art. 1.2.5 and

1.2.12 of the AASHO specification, as follows:

AASHO Truck	Gross Weight	Wheel Load, P
H-10	10 tons	8,000 lb
H-15	15 tons	12,000 lb
H-20	20 tons	16,000 lb

Depth of Cover	Impact Factor, F
0 ft to 1 ft, 0 in.	1.30
1 ft, 1 in., to 2 ft, 0 in.	1.20
2 ft, 1 in., to 2 ft, 11 in.	1.10
3 ft, 0 in., or more	1.00

The truck superload allowances given in Tables 1–4 and 1–8 are intended for standard conditions. They are based on two passing trucks with adjacent wheels 3 ft apart, 9,000-lb wheel load, unpaved road or flexible pavement, 1.50 impact factor. These loads in most cases equal or exceed the static load from a single AASHO H-20 truck with 16,000 lb on each rear wheel. These truck superloads are based on having the design depth of cover over the pipe. Consideration should be given to the loads that may be transmitted to the pipe if either truck superloads or heavy construction equipment is permitted to pass over the pipe at less than the design depth of cover.

TABLE 1-8

Earth Loads (W_e) *and Truck Superloads* (W_t)—lb/lin ft*

Pipe Size in.	Depth of Cover—ft															
	2½		3½		5		8		12		16		20		24	
	W_e	W_t	W_e	W_t	W_e	W_t	W_e	W_t	W_e	W_t	W_e	W_t	W_e	W_t	W_e	W_t
3	182	162	260	81	376	54	609	40	920	27	1,230	14	1,538	9	1,852	7
4	226	297	324	162	471	81	765	54	1,157	40	1,549	27	1,942	18	2,334	14
6	309	567	448	324	657	189	1,075	94	1,632	68	2,188	40	2,524	26	2,647	20
8	380	783	557	486	824	297	1,356	148	2,066	94	2,592	54	2,815	36	2,965	28
10	448	972	666	621	992	378	1,645	189	2,473	108	2,851	68	3,114	45	3,295	35
12	511	1,161	770	756	1,159	459	1,950	243	2,686	122	3,116	81	3,419	53	3,635	41
14	568	1,217	868	807	1,318	540	2,218	270	2,900	135	3,384	94	3,733	62	3,983	48
16	617	1,307	959	879	1,470	590	2,381	324	3,117	162	3,659	122	4,050	81	4,339	62
18	665	1,400	1,042	964	1,616	632	2,533	364	3,335	189	3,932	135	4,374	89	4,703	69
20	714	1,524	1,119	1,076	1,755	729	2,686	410	3,555	216	4,209	162	4,703	107	5,075	83
24	814	1,662	1,256	1,159	2,011	769	2,994	462	3,999	256	4,774	176	5,372	116	5,833	90
30	963	1,925	1,457	1,356	2,340	918	3,459	564	4,674	324	5,638	216	6,401	143	7,009	110
36	1,121	2,182	1,668	1,577	2,628	1,090	3,927	632	5,356	378	6,517	256	7,461	169	8,226	131
42	1,270	2,354	1,878	1,750	2,917	1,239	4,396	717	6,016	459	7,408	310	8,535	205	9,474	158
48	1,427	2,527	2,093	1,922	3,216	1,400	4,867	814	6,737	513	8,308	351	9,627	232	10,743	179
54	1,581	2,635	2,310	2,052	3,519	1,526	5,340	899	7,434	594	9,218	378	10,739	256	12,034	189
60	1,738	2,765	2,527	2,182	3,824	1,652	5,816	984	8,195	634	10,133	405	11,857	284	13,339	202

* Earth loads are based on the following conditions: trench width (B_d) equal to nominal pipe diameter plus 2 ft; unit weight of soil, 120 lb/cu ft; $K\mu$ equal to 0.1924 and $K\mu'$ equal to 0.130. Truck superloads are based on two passing trucks with adjacent wheels 3 ft apart, having a 9,000-lb wheel load on unpaved road or flexible pavement and a 1.50 impact factor.

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TABLE 1-9

Load Factors for Cast-Iron Pipe in Ditch and Embankment Conditions

Pipe Size in.	$\frac{H^*}{B_c}$	Laying Condition		
		A	B	F
		Load Factor (L_f)		
Ditch and Negative Projection Conditions†				
3		1.15	1.28	1.74
4		1.15	1.29	1.75
6		1.15	1.32	1.78
8		1.15	1.34	1.80
10		1.15	1.36	1.83
12		1.15	1.38	1.85
14		1.15	1.41	1.88
16		1.15	1.43	1.90
18		1.15	1.45	1.93
20		1.15	1.47	1.95
24		1.15	1.52	2.00
30		1.15	1.58	2.08
36		1.15	1.64	2.14
42		1.15	1.69	2.20
48		1.15	1.72	2.25
Ditch and Negative Projection Conditions† (*Continued*)				
54		1.15	1.75	2.29
60		1.15	1.77	2.31
Positive-Projection Condition†				
	0.5	1.50	2.16	
	1.0	1.36	1.84	
	1.5	1.29	1.74	
	2.0	1.26	1.68	
	3.0	1.26	1.64	
	5.0	1.26	1.60	
	10.0	1.26	1.58	

* H is depth of cover to top of pipe, in feet; B_c is outside diameter of pipe, in feet (see Table 1-15).
† See Fig. 1-7 and See Sec. 1-3.2.

TABLE 1-10

Allowances for Surge Pressure

Pipe Size in.	Surge Pressure psi	Pipe Size in.	Surge Pressure psi
3-10	120	24	85
12-14	110	30	80
16-18	100	36	75
20	90	42-60	70

TABLE 1-11

*Surface Load Factors (C) for One Truck on Unpaved Road or Flexible Pavement**

Pipe Size in.	Depth of Cover—ft												
	2	2½	3	3½	4	5	6	8	10	12	16	20	24
	Surface Load Factor												
3	0.028	0.020	0.014	0.011	0.009	0.006	0.004	0.002	0.0015	0.001	0.0006	0.0004	0.0002
4	0.034	0.024	0.017	0.013	0.011	0.007	0.005	0.003	0.002	0.0015	0.0008	0.0005	0.0003
6	0.048	0.034	0.025	0.020	0.015	0.010	0.007	0.004	0.003	0.002	0.001	0.0007	0.0004
8	0.062	0.044	0.033	0.026	0.020	0.013	0.009	0.006	0.0035	0.0025	0.0013	0.0008	0.0005
10	0.074	0.054	0.040	0.031	0.025	0.016	0.012	0.007	0.004	0.003	0.0016	0.001	0.0006
12	0.087	0.063	0.048	0.036	0.030	0.019	0.014	0.008	0.005	0.0035	0.002	0.0012	0.0007
14	0.099	0.072	0.055	0.042	0.034	0.022	0.016	0.010	0.006	0.004	0.0025	0.0015	0.0008
16	0.110	0.082	0.061	0.047	0.038	0.025	0.018	0.011	0.007	0.005	0.003	0.0017	0.001
18	0.122	0.090	0.068	0.052	0.042	0.028	0.020	0.012	0.008	0.0055	0.0035	0.002	0.0012
20	0.132	0.098	0.075	0.058	0.046	0.031	0.022	0.013	0.009	0.006	0.004	0.0025	0.0015
24	0.150	0.113	0.087	0.068	0.054	0.037	0.026	0.015	0.010	0.007	0.0045	0.003	0.0017
30	0.171	0.132	0.102	0.081	0.065	0.045	0.031	0.019	0.012	0.009	0.005	0.0035	0.002
36	0.188	0.148	0.117	0.093	0.076	0.052	0.037	0.022	0.015	0.010	0.006	0.004	0.0025
42	0.200	0.160	0.129	0.103	0.085	0.059	0.043	0.025	0.017	0.012	0.007	0.0045	0.003
48	0.210	0.170	0.139	0.113	0.093	0.066	0.048	0.029	0.019	0.013	0.008	0.005	0.0033
54	0.216	0.178	0.147	0.120	0.101	0.072	0.053	0.032	0.021	0.015	0.0085	0.0055	0.0036
60	0.222	0.184	0.153	0.126	0.107	0.077	0.057	0.035	0.023	0.016	0.009	0.006	0.004

* These factors are for a single concentrated wheel load centered over an effective pipe length of 3 ft. They were computed by the methods explained in Article 24.20 and Chap. 16 of M. G. Spangler's *Soil Engineering* (2nd ed., 1960; International Textbook Co., Scranton, Pa.).

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TABLE 1-12

*Surface Load Factors (C) for Two Passing Trucks on Unpaved Road or Flexible Pavement**

Pipe Size in.	Depth of Cover—ft												
	2	2½	3	3½	4	5	6	8	10	12	16	20	24
	Surface Load Factor												
3	0.019	0.012	0.008	0.006	0.005	0.004	0.0035	0.003	0.0025	0.002	0.001	0.0007	0.0005
4	0.032	0.022	0.016	0.012	0.009	0.006	0.005	0.004	0.0035	0.003	0.002	0.0013	0.0010
6	0.058	0.042	0.032	0.024	0.020	0.014	0.010	0.007	0.006	0.005	0.003	0.0019	0.0015
8	0.076	0.058	0.044	0.036	0.030	0.022	0.017	0.011	0.009	0.007	0.004	0.0027	0.0021
10	0.092	0.072	0.056	0.046	0.039	0.028	0.021	0.014	0.011	0.008	0.005	0.0033	0.0026
12	0.108	0.086	0.070	0.056	0.047	0.034	0.027	0.018	0.012	0.009	0.006	0.0039	0.0030
14	0.122	0.098	0.078	0.065	0.055	0.040	0.031	0.020	0.014	0.010	0.007	0.0046	0.0036
16	0.136	0.110	0.090	0.074	0.062	0.046	0.036	0.024	0.016	0.012	0.009	0.0060	0.0046
18	0.149	0.122	0.101	0.084	0.070	0.052	0.041	0.027	0.019	0.014	0.010	0.0066	0.0051
20	0.162	0.136	0.115	0.096	0.080	0.060	0.048	0.032	0.022	0.016	0.012	0.0079	0.0061
24	0.185	0.152	0.126	0.106	0.091	0.067	0.053	0.036	0.026	0.019	0.013	0.0086	0.0067
30	0.212	0.176	0.146	0.124	0.107	0.080	0.064	0.044	0.032	0.024	0.016	0.0106	0.0081
36	0.235	0.202	0.169	0.146	0.127	0.095	0.075	0.052	0.038	0.028	0.019	0.0125	0.0097
42	0.251	0.218	0.188	0.162	0.140	0.108	0.087	0.059	0.044	0.034	0.023	0.0152	0.0117
48	0.264	0.234	0.205	0.178	0.157	0.122	0.097	0.067	0.050	0.038	0.026	0.0172	0.0132
54	0.274	0.244	0.216	0.190	0.170	0.133	0.108	0.074	0.057	0.044	0.028	0.0190	0.0140
60	0.281	0.256	0.228	0.202	0.181	0.144	0.117	0.081	0.061	0.047	0.030	0.0210	0.0150

* The factors are for two trucks with 6-ft rear wheel spacing passing with inside rear wheels 3 ft apart. Effective pipe length is 3 ft, coinciding with the distance between the adjacent inside wheels. The factors were computed by the methods explained in Sec. 24.20 and Chap. 16 of M. G. Spangler's *Soil Engineering* (2nd ed., 1960; International Textbook Co., Scranton, Pa.)

TABLE 1-13

Reduction Factors (R)

Pipe Size *in.*	Depth of Cover—*ft*				Pipe Size *in.*	Depth of Cover—*ft*			
	2½–3½	4–7	8–10	>10		2½–3½	4–7	8–10	>10
	Reduction Factor					Reduction Factor			
3–12	1.00	1.00	1.00	1.00	20	0.83	0.90	0.95	1.00
14	0.92	1.00	1.00	1.00	24–30	0.81	0.85	0.95	1.00
16	0.88	0.95	1.00	1.00	36–60	0.80	0.85	0.90	1.00
18	0.85	0.90	1.00	1.00					

TABLE 1-14

Surface Load Factors (K) *For One Truck and Two Passing Trucks on Rigid Pavement**

Depth of Cover *ft*	One Truck				Two Passing Trucks			
	Pavement Thickness—*in.*				Pavement Thickness—*in.*			
	4	6	8	10	4	6	8	10
	Surface Load Factor							
2	0.0244	0.0149	0.0101	0.0076	0.0410	0.0263	0.0186	0.0142
2½	0.0213	0.0139	0.0097	0.0072	0.0364	0.0246	0.0177	0.0136
3	0.0186	0.0126	0.0090	0.0070	0.0333	0.0228	0.0167	0.0129
3½	0.0164	0.0114	0.0085	0.0066	0.0290	0.0206	0.0156	0.0122
4	0.0144	0.0102	0.0079	0.0061	0.0262	0.0187	0.0146	0.0117
5	0.0114	0.0084	0.0066	0.0054	0.0210	0.0156	0.0123	0.0102
6	0.0093	0.0071	0.0057	0.0047	0.0170	0.0133	0.0107	0.0088
8	0.0065	0.0052	0.0043	0.0036	0.0114	0.0097	0.0081	0.0069
10	0.0046	0.0039	0.0033	0.0029	0.0080	0.0070	0.0062	0.0055
12	0.0034	0.0030	0.0026	0.0023	0.0059	0.0054	0.0049	0.0045
16	0.0022	0.0019	0.0017	0.0016	0.0034	0.0032	0.0030	0.0028
20	0.0013	0.0011	0.0010	0.0009	0.0024	0.0023	0.0022	0.0021
24	0.0008	0.0007	0.0006	0.0005	0.0015	0.0014	0.0013	0.0012

* These factors were computed by the methods explained in "Vertical Pressure on Culverts under Wheel Loads on Concrete-Pavement Slabs", Bull. ST65, Portland Cement Assn., Chicago, Ill. In Bulletin ST65, K if expressed as c/L^2. These factors are based on a modulus of subgrade reaction of 100 lb/cu in. and a modulus os elasticity of 4,000,000 psi for the pavement concrete. The factors for two passing trucks are based on the inside rear wheels passing 3 ft apart.

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TABLE 1-15

Outside Diameters of Cast-Iron Pipe

Pipe Size *in.*	Outside Diameter *in.*	Outside Diameter (B_c) *ft*	Pipe Size *in.*	Outside Diameter *in.*	Outside Diameter (B_c) *ft*
3	3.96	0.330	20	21.60	1.800
4	4.80	0.400	24	25.80	2.150
6	6.90	0.575	30	32.00	2.667
8	9.05	0.754	36	38.30	3.192
10	11.10	0.925	42	44.50	3.708
12	13.20	1.100	48	50.80	4.233
14	15.30	1.275	54	57.10	4.758
16	17.40	1.450	60	63.40	5.283
18	19.50	1.625			

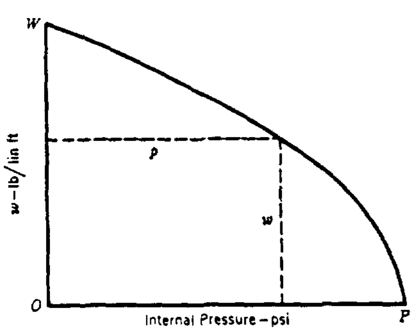

Fig. 1-6. Load-Pressure Curve

The parabola represents the relation between external load and internal pressure at the point of breaking.

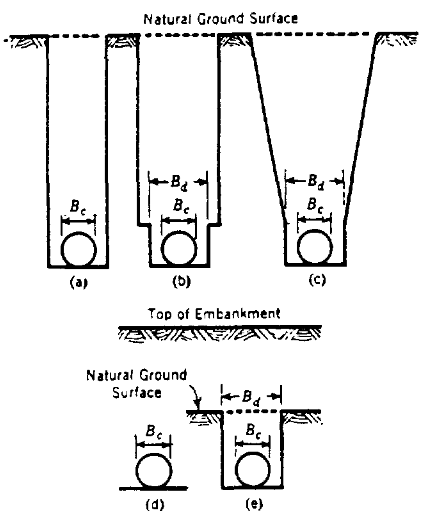

Fig. 1-7. Installation Conditions for Earth Load Calculations

Fig. 1-7(a)-(c) are for ditch conditions; Fig. 1-7(d) and (e) are for positive and negative projection embankment conditions, respectively.

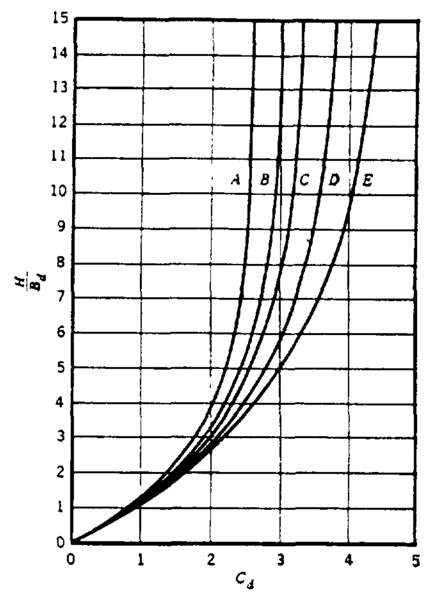

Fig. 1-8. Calculation Coefficients (C_d) for Ditch Condition

Curve A is for C_d for $K\mu$ and $K\mu'$ of 0.1924, the minimum for granular materials without cohesion; Curve B, C_d for $K\mu$ and $K\mu'$ of 0.165, the maximum for sand and gravel; Curve C, C_d for $K\mu$ and $K\mu'$ of 0.150, the maximum for saturated topsoil; Curve D, C_d for $K\mu$ and $K\mu'$ of 0.130, the ordinary maximum for clay; and Curve E, C_d for $K\mu$ and $K\mu'$ of 0.110, the maximum for saturated clay.

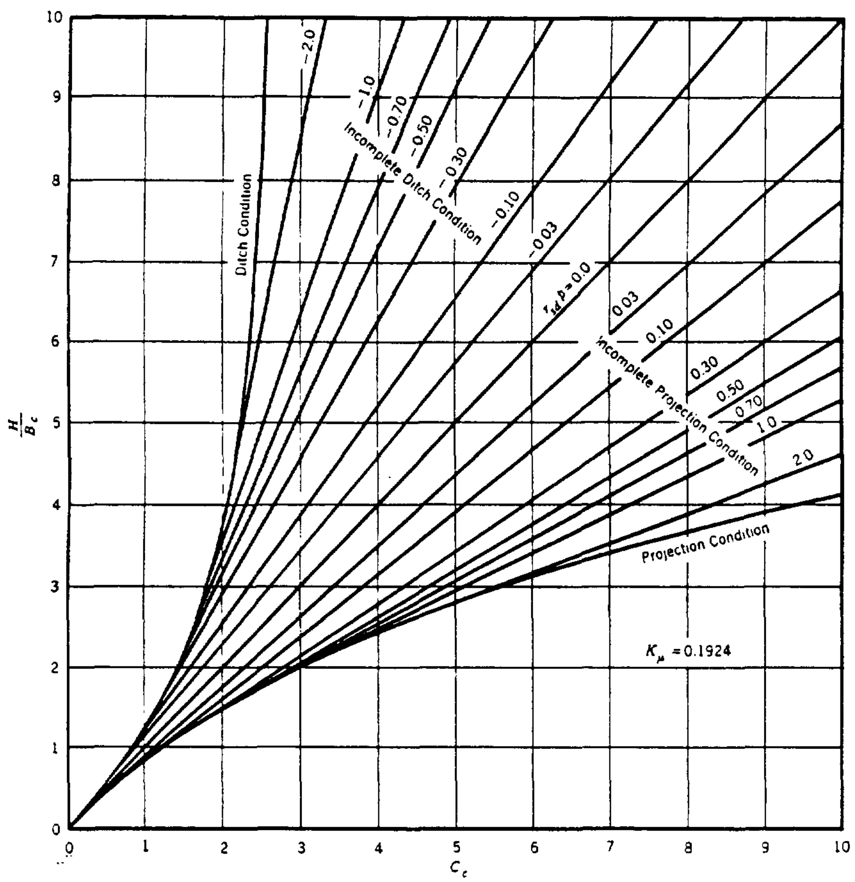

Fig. 1-9. Calculation Coefficients (C_c) for Positive-Projection Condition

The values of C_c may also be determined by Eq 11 or Eq 12, given in the text.

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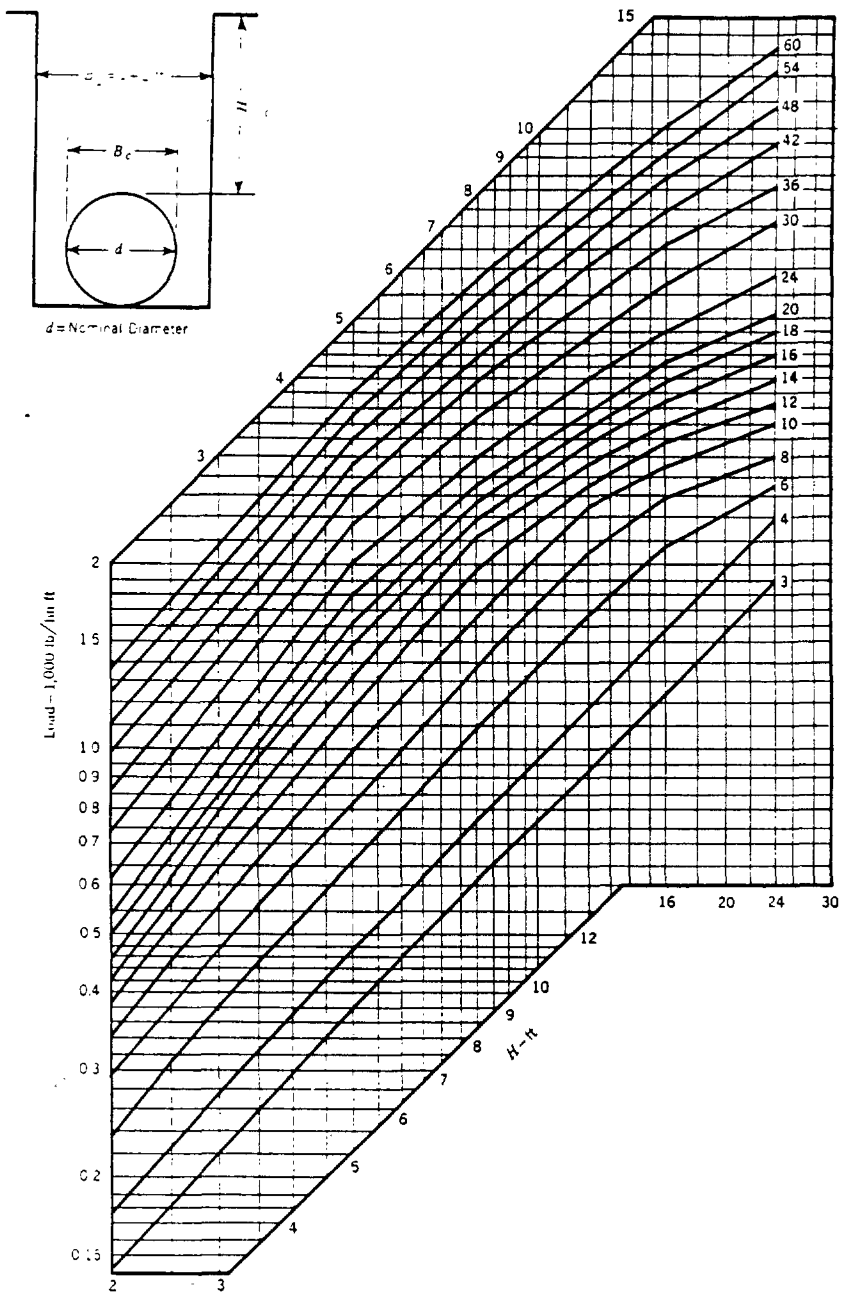

Fig. 1-10. Earth Loads on Pipe for Trench Width of (d + 2) ft

Values associated with each curve are for pipe size, in inches. It is assumed that the unit weight of fill is 120 lb/cu ft, that $K\mu$ equals 0.1924 and $K\mu'$ equals 0.130, and that $r_{sd}p$ is 0.75 for all sizes. B_c is pipe OD. For 3- and 8-60-in. pipe, OD is as shown in Table 1-15. OD of 4- and 6-in. pipe is 5.00 and 7.10 in., respectively.

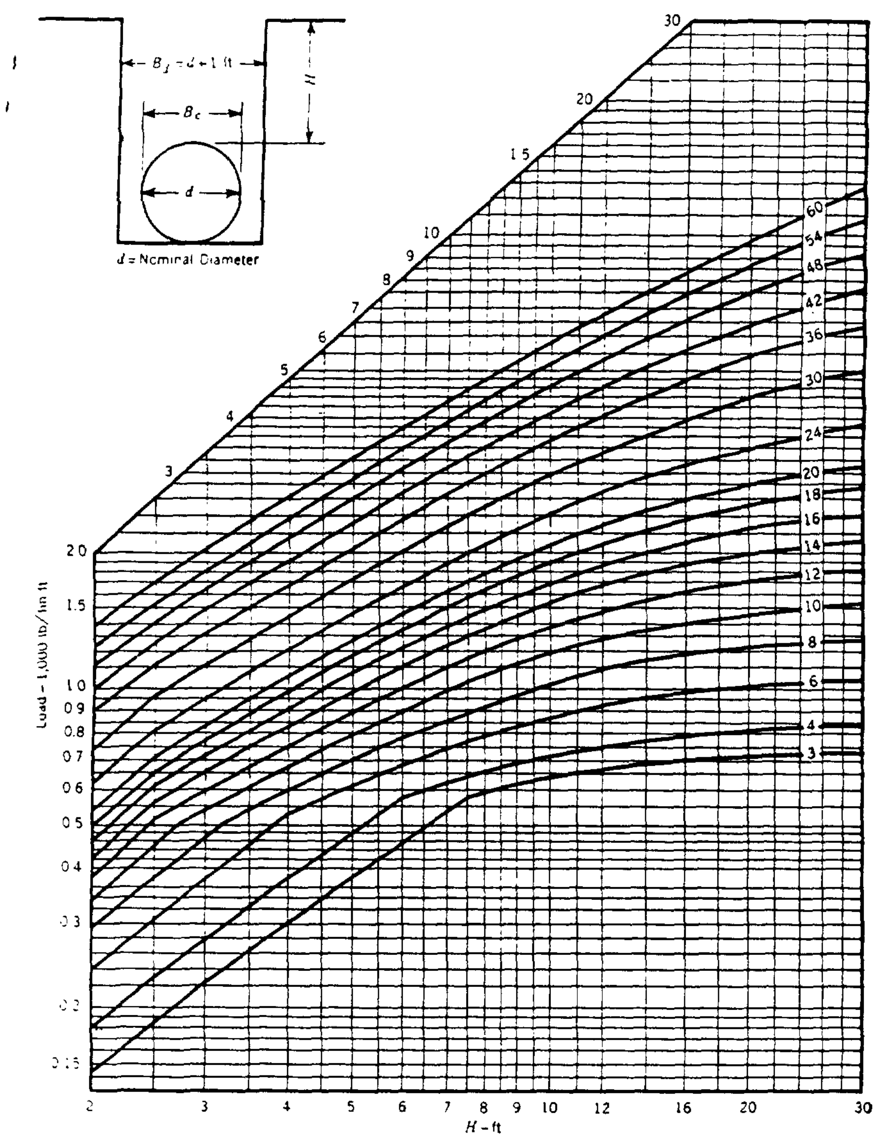

Fig. 1-11. Earth Loads on Pipe for Trench Width of $(d + 1)$ ft

Values associated with each curve are for pipe size, in inches. It is assumed that the unit weight of fill is 120 lb/cu ft, that $K\mu$ equals 0.1924 and $K\mu'$ equals 0.130. For wide ditches, $r_{sd}p$ is 0.75. B_c is pipe OD. For 3- and 8–60-in. pipe, OD is as shown in Table 1-15. OD of 4- and 6-in. pipe is 5.00 and 7.10 in., respectively.

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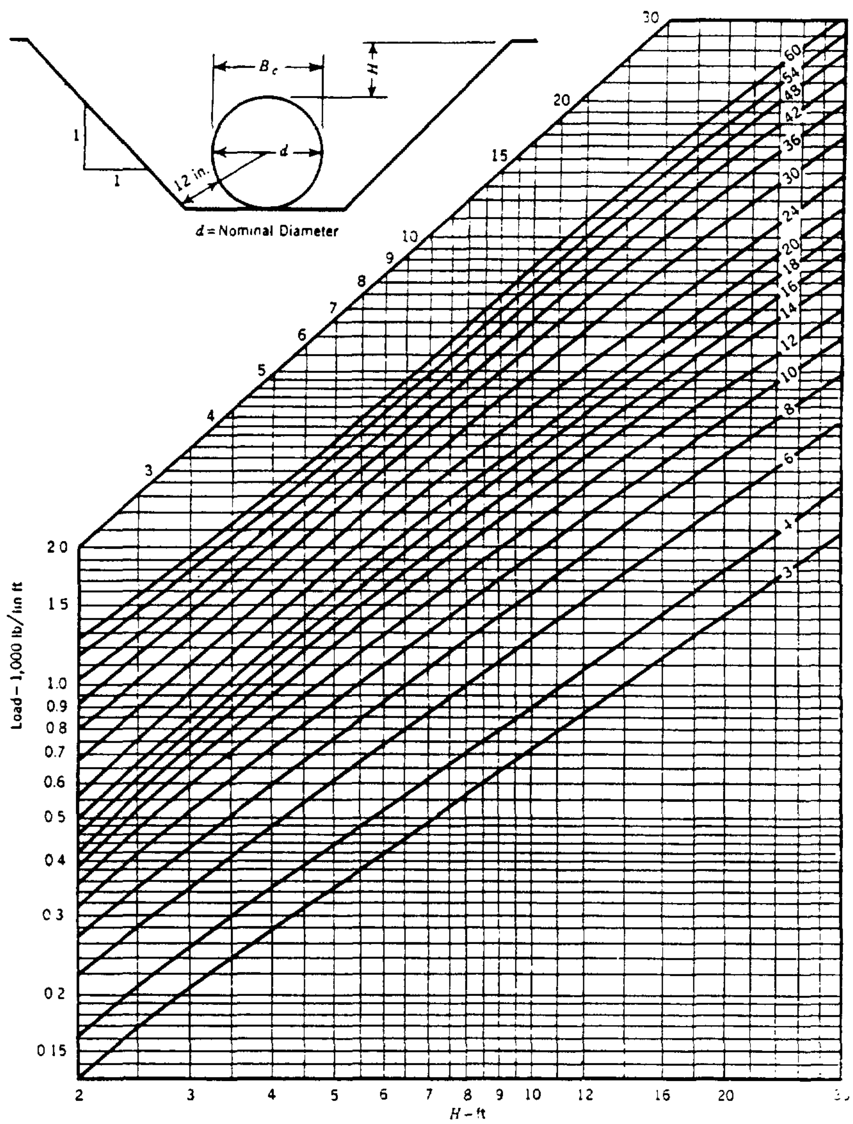

Fig. 1-12. Earth Loads on Pipe in Trench With 1:1 Side Slopes

Values associated with each curve are for pipe size, in inches. It is assumed that the unit weight of fill is 110 lb/cu ft; this load may be adjusted to soil of 120 lb/cu ft by multiplying the graph load by 120/110. For wide ditches, $r_{sd}p$ is 0.75. $K\mu$ equals 0.1924, $K\mu'$ equals 0.130. B_c is pipe OD. For 3- and 8–60-in. pipe, OD is as shown in Table 1-15. OD of 4- and 6-in. pipe is 5.00 and 7.10 in., respectively.

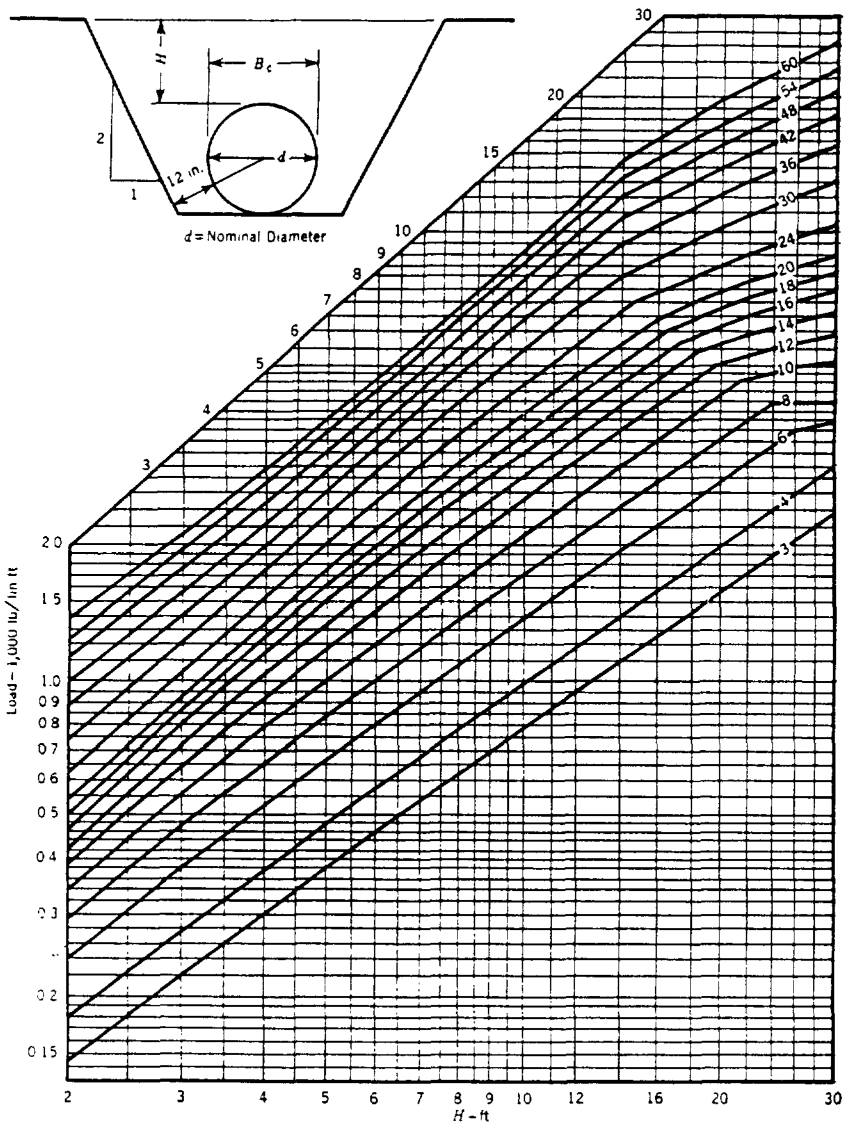

Fig. 1-13. Earth Loads on Pipe in Trench With 2:1 Side Slopes

Values associated with each curve are for pipe size, in inches. It is assumed that the unit weight of fill is 120 lb/cu ft. For wide ditches, $r_{sd}p$ equals 0.75. $K\mu$ equals 0.1924, $K\mu'$ equals 0.130. B_c is pipe OD. For 3- and 8–60-in. pipe, OD is as shown in Table 1-15. OD of 4- and 6-in. pipe is 5.00 and 7.10 in., respectively.

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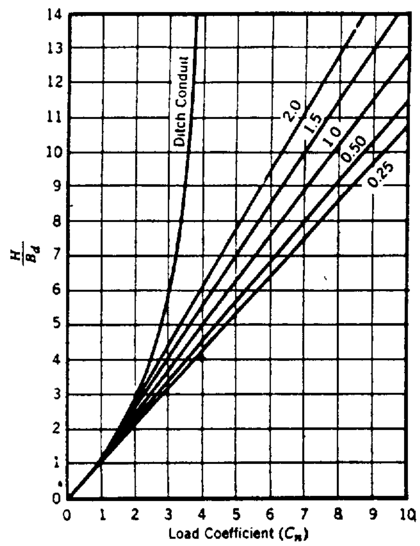

Fig. 1-14. Calculation Coefficients (C_n) for Negative-Projection Conditions

The values associated with the five curves to the right are for p′. $K\mu'$ *equals 0.130.* $r_{sd}p$ *equals 0.0.*

Sec. 1-4—Thickness Determination for Pipe on Piers or Piling Aboveground or Underground

Sec. 1-4.1—Scope

This section gives the procedures for determining the net thickness of cast-iron pipe supported at intervals rather than continuously. These procedures are applicable to pipe installed on piling bents and piers, with or without earth cover, as well as to pipe installed on bridges and other structures with hangers and other types of spaced supports.

Sec. 1-4.2—Pipe Installed Aboveground Without Earth Cover

a. Determine the ring test load equivalent of external load, including 2.5 safety factor, as follows:

$$w = \frac{2.5(W_p + W_w)}{L_f} \qquad (17)$$

in which:

w = ring test load equivalent (lb/ft)
W_p = weight of pipe (lb/ft) (see Table 1-16)
W_w = weight of contained water (lb/ft) (see Table 1-16)
L_f = load factor (see Table 1-17)

b. Select the internal pressure for Case 1 from Table 1-5 which includes surge pressure and 2.5 safety factor.

c. Enter the above values of ring test load equivalent and internal pressure in the appropriate nomogram and read the net thickness. To obtain total calculated thickness, corrosion allowance and casting tolerance are added to this net thickness as described in Sec. 1-2.2.

Sec. 1-4.3—Pipe Installed Underground With Earth Cover

Thicknesses are computed for two cases as described in Sec. 1-2.2 and the larger of the two thicknesses is used for design.

Case 1:

a. Determine the ring test load equivalent from the following formula:

$$w = \frac{2.5W_e}{L_f} \qquad (18)$$

in which:

w = ring test load equivalent (lb/ft)
W_e = earth load (see Table 1-8)
L_f = load factor (see Table 1-17)

b. Select the internal pressure to. Case 1 from Table 1-5 which includes surge pressure and 2.5 safety factor.

c. Enter the above values of ring test load equivalent and internal pressure in the appropriate nomogram and read the net thickness.

Case 2:

a. Determine the ring test load equivalent from the following formula:

$$w = \frac{2.5\,(W_e + W_t)}{L_f} \qquad (19)$$

in which W_t is the truck superload in pounds per foot (see Table 1-8) and other factors are as defined for Eq 18.

b. Select the internal pressure for Case 2 from Table 1-5 which includes a safety factor of 2.5.

c. Enter the values of ring test load equivalent and internal pressure in the appropriate nomogram and read the net thickness.

The net thickness is selected from Case 1 or Case 2, whichever gives the greater computed thickness. To obtain total calculated thickness, corrosion allowance and casting tolerance are added to this net thickness as described in Sec. 1–2.2.

Sec. 1–4.4—Design Examples

a. Calculate the thickness of 24-in. cast-iron pipe, 18/40 iron strength, installed aboveground on piers spaced 18 ft apart on centers with 60-deg saddle support. Working pressure is 150 psi.

Load factor (Table 1–17),

$$L_f = 0.29 \times 1.55$$
$$= 0.45$$

Ring test load equivalent,

$$w = \frac{2.5(177 + 196)}{0.45}$$
$$= 2{,}071 \text{ lb/ft}$$

Internal pressure (Table 1–5),

$$p = 588 \text{ psi}$$

Using the above values of w and p in the nomogram, Fig. 1–1, the net thickness is determined to be 0.49 in. Adding 0.08 in. corrosion allowance and 0.08 in. casting tolerance, the total calculated thickness is determined to be 0.65 in.

b. Calculate the thickness of 16-in. cast-iron pipe, 18/40 iron strength, installed underground on piers spaced 18 ft apart on centers with 120-deg saddle support, with 5-ft cover. Working pressure is 150 psi.

Case 1:

Load factor (Table 1–17),

$$L_f = 0.24 \times 2.13$$
$$= 0.51$$

Ring test load equivalent,

$$w = \frac{2.5 \times 1470}{0.51}$$
$$= 7{,}206 \text{ lb/ft}$$

Internal pressure (Table 1–5),

$$p = 625 \text{ psi}$$

Using the above values of w and p in the nomogram, Fig. 1–1, the net thickness is determined to be 0.57 in.

Case 2:

Ring test load equivalent,

$$w = \frac{2.5(1{,}470 + 590)}{0.51}$$
$$= 10{,}980 \text{ lb/ft}$$

Internal pressure (Table 1–5),

$$p = 375 \text{ psi}$$

Using the above values of w and p in the nomogram, Fig. 1–2, the net thickness is determined to be 0.65 in.

Case 2 gives the larger computed thickness, 0.65 in., which is selected as the net thickness. Adding 0.08 in. corrosion allowance and 0.08 in. casting tolerance, the total calculated thickness is determined to be 0.81 in.

Sec. 1–4.5—Calculation of Beam Stress and Deflection

For small-diameter pipe, generally 3 in. through 8 in., a check of the beam stress may be required. If the calculated beam stress exceeds 14,000 psi, the thickness is increased or the span between supports is decreased to limit the beam stress to 14,000 psi. In some types of installations, such as gravity flow sewers, beam deflection may be a significant factor in the design. Beam stress and deflection are calculated from the following two formulas:

$$f = \frac{15.28WDL^2}{D^4 - d^4} \qquad (20)$$

$$y = \frac{30fL^2}{DE} \qquad (21)$$

in which:

f = beam stress (14,000 psi maximum)

W = external load, lb per ft (for aboveground pipe $W = W_p + W_w$; for underground pipe, $W = W_e + W_t$)

L = distance on centers between supports (ft)

D = outside diameter of pipe (in.)

d = inside diameter (D-$2t$) (in.)

t = net thickness (in.)

y = deflection at mid-span (in.)

E = modulus of elasticity, 15,000,000 psi.

TABLE 1-16

Weights of Pipe and Contained Water for Design of Aboveground Pipe

Pipe Size in.	Weight—lb/ft		Pipe Size in.	Weight—lb/ft	
	Pipe (W_P)*	Water (W_w)†		Pipe (W_P)*	Water (W_w)†
3	12	3	18	114	110
4	16	6	20	135	136
6	26	12	24	177	196
8	37	22	30	257	307
10	49	34	36	339	442
12	63	49	42	439	601
14	78	67	48	545	785
16	94	88			

* Based on Class 22 pipe. Although the computed thickness may differ from that given for Class 22, the effect of the difference in pipe weight usually will not have a significant effect on the computed thickness and recalculation usually will not be necessary.

† Based on nominal pipe size.

TABLE 1-17

Load Factors for Pipe on Spaced Supports Aboveground and Underground

Pipe Size in.	Distance on Centers Between Supports—ft							
	6	8	9	10	12	16	18	20
	Load Factor for Flat Support							
3	0.19	0.14	0.13	0.11	0.10	0.07	0.06	0.06
4	0.22	0.17	0.15	0.13	0.11	0.08	0.07	0.07
6	0.31	0.23	0.21	0.19	0.16	0.12	0.10	0.09
8	0.40	0.30	0.27	0.24	0.20	0.15	0.13	0.12
10	0.50	0.38	0.33	0.30	0.25	0.19	0.17	0.15
12	0.60	0.45	0.40	0.36	0.30	0.23	0.20	0.18
14	0.67	0.50	0.45	0.40	0.33	0.25	0.22	0 20
16	0.73	0.55	0.49	0.44	0.36	0.27	0.24	0.22
18	0.78	0.59	0.52	0.47	0.39	0.29	0.26	0.23
20	0.81	0.61	0.54	0.49	0.40	0.30	0.27	0.24
24	0.87	0.65	0.58	0.52	0.43	0.33	0.29	0.26
30	0.93	0.70	0.62	0.56	0.46	0.35	0.31	0.28
36	0.96	0.72	0.64	0.58	0.48	0.36	0.32	0 29
42	0.98	0.73	0.65	0.59	0.49	0.37	0.33	0.29
48	0.99	0.74	0.66	0.60	0.50	0.37	0.33	0.30

Explanatory Note. 1. Load factor for saddle support is obtained by multiplying the load factor for flat support by the following modifiers:

Saddle Angle *deg.*	Modifier
30	1.25
45	1.40
60	1.55
90	1.87
120	2.13
180	2.35

2. Load factors for other distances between supports or for other saddle angles may be obtained by interpolation between tabulated values.

3. The load factor for flat support is equal to the load factor for laying condition C, A21.1–1957, multiplied by the ratio of 6-ft, the block spacing of laying condition C, to the distance between supports. The modifier for saddle support is obtained from Table 2 of Stresses in Pressure Pipelines and Protective Casing Pipes [M. G. Spangler, *J. Struct. Div. ASCE*, Vol. 82, No. ST5 (Sep. 1956)], by dividing K_b for 180 deg load and 0 deg support by K_b for 180 deg load and a support angle equal to the saddle angle.

4. The recommended minimum axial bearing length of supports, for underground pipe is 6 in. for 3–8-in. pipe, 12 in. for 10–24-in. pipe, and 18 in. for 30–48-in. pipe.

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ANSI A21.50–1976
(AWWA C150–76)

Revision of
A21.50–1971
(AWWA C150–71)

AMERICAN NATIONAL STANDARD

for the

THICKNESS DESIGN OF DUCTILE-IRON PIPE

SECRETARIATS

AMERICAN GAS ASSOCIATION
AMERICAN WATER WORKS ASSOCIATION
NEW ENGLAND WATER WORKS ASSOCIATION

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American National Standard

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WALTER AMORY, *Vice-Chairman*

User Members	*Producer Members*
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LEONARD ORLANDO JR.	HAROLD KENNEDY JR.
JOHN E. PERRY	W. HARRY SMITH
	SIDNEY P. TEAGUE

Standards Committee A21, Cast-Iron Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

LLOYD W. WELLER, *Chairman*
EDWARD C. SEARS, *Vice-Chairman*
JAMES B. RAMSEY, *Secretary*

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Table of Contents

Foreword

This foreword is for information only and is not a part of ANSI A21.50 (AWWA C150).

American National Standards Committee A21, Cast-Iron Pipe and Fittings, was organized in 1926 under the sponsorship of the American Gas Association, the American Society for Testing and Materials, the American Water Works Association, and the New England Water Works Association. Since 1972, the co-secretariats have been A.G.A., AWWA, and NEWWA, with AWWA serving as the administrative secretariat. The present scope of Committee A21 activity is

> Standardization of specifications for cast-iron and ductile-iron pressure pipe for gas, water and other liquids, and fittings for use with such pipe. These specifications to include design, dimensions, materials, coatings, linings, joints, accessories and methods of inspection and test.

The work of Committee A21 is conducted by subcommittees. The directive to Subcommittee 1—Pipe is that

> The scope of the subcommittee activity shall include the periodic review of all current A21 standards for pipe, the preparation of revisions and new standards when needed, as well as other matters pertaining to pipe standards.

The first edition of A21.50, the standard for thickness design of ductile-iron pipe, was issued in 1965 and a revision was issued in 1971. Subcommittee 1 reviewed the 1971 edition and submitted a proposed revision to American National Standards Committee A21 in 1975.

Major Revisions

The basic design procedures are unchanged from the 1965 and 1971 editions. Certain design parameters have been changed to the following.

1. Trench load, which includes earth load and truck load, is expressed as vertical pressure in pounds per square inch. Earth loads for all pipe sizes are based on the prism load concept. Truck load is based on a single AASHTO* H-20 truck with 16 000-lb wheel load and 1.5 impact factor. Truck load is included at all depths of cover. In addition to tabulated truck loads, equations are included for complete calculation of truck loads.
2. The design ring bending stress is 48 000 psi, which provides safety factors under trench loading of at least 1.5 based on ring yield strength, and at least 2.0 based on ultimate strength of the material.
3. The design pipe deflection is 3 per cent of the outside diameter. Tests have shown that 3 per cent deflection is permissible without causing any damage to cement linings of ductile-iron pipe.
4. The standard laying conditions have been expanded to include five types. Types 1, 2, and 5 replace A, B, and S, respectively, in A21.50–1971. Types 3 and 4 have been added to provide a wider selection of laying conditions.
5. The design for internal pressure is based on a 2.0 safety factor. The design pressure is obtained by adding 100-psi surge allowance to the working pressure and multiplying the sum by the 2.0 safety factor. (If anticipated surge pressures are greater than 100

* American Association of State Highway and Transportation Officials.

psi, the maximum anticipated pressure must be used.) The resulting design pressure is then applied to the minimum yield strength in tension of 42 000 psi.

6. The standard thickness classes have been renumbered. Class 1 becomes Class 51, Class 2 becomes Class 52, and so on. Class 50 has been added for 6–54-in. pipe and Class 51 has been expanded to include 3–12-in. pipe.

7. The tables have been modified to reflect the preceding changes. Also, a table has been added to show rated working pressure and maximum depth of cover for all the standard laying conditions and standard thickness classes.

ANSI A21.50–1976
(AWWA C150–76)

Revision of
A21.50–1971
(AWWA C150–71)

American National Standard
for the
Thickness Design of Ductile-Iron Pipe

Sec. 50–1—Scope

This standard covers the thickness design of ductile-iron pipe complying with the requirements of ANSI A21.51 (AWWA, C151), "Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds for Water or Other Liquids."

Section 50–2 outlines the design procedure and Sec. 50–3 gives a design example.

Section 50–4 explains the bases of design.

As opposed to using procedures in Sec. 50–2 or 50–4, the designer may reference Tables 12–14 directly.

Table 12 lists thicknesses for standard laying conditions and depths of cover up to 32 ft.

Table 13 lists thicknesses for 150–350 psi water working pressure.

The greater thickness from Table 12 or 13 for given trench load or internal pressure should be used.

Table 14 lists working pressures and maximum depths of cover for standard laying conditions and thickness classes.

Sec. 50–2—Procedure for Calculating Thickness

The thickness of ductile-iron pipe is determined by considering trench load and internal pressure separately.

50–2.1 *Step 1—Design for trench load.*

a. Determine trench load P_v. Table 1 gives trench load, including earth load, P_e, plus truck load P_t, for 2.5–32 ft cover.

b. Determine the standard laying condition from the descriptions in Table 2 and select the appropriate table for diameter–thickness ratios from Tables 7–11. Each table lists diameter–thickness ratios calculated for both bending stress and deflection over a range of trench loads.

c. For bending stress design, enter the column headed "Bending Stress Design" in the appropriate table of Tables 7–11 and locate the tabulated trench load, P_v, nearest to the calculated P_v from paragraph 50–2.1.a. (If the calculated P_v is halfway between two tabulated values, use the larger P_v value.)

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Select the corresponding $\frac{D}{t}$ value for this P_v.

Divide the pipe's outside diameter D (Table 5) by the $\frac{D}{t}$ value to obtain the net thickness t.

d. For deflection design, enter the column headed "Deflection Design" in the appropriate table of Tables 7–11 and locate the tabulated trench load, P_v, nearest to the calculated P_v from paragraph 50–2.1.a. (If the calculated P_v is less than the minimum P_v listed in the table, design for trench load is not controlled by deflection and this determination need not be completed.) If the calculated P_v is halfway between two tabulated values, use the larger P_v value.

Select the corresponding $\frac{D}{t_1}$ value for this P_v.

Divide the pipe's outside diameter D (Table 5) by the $\frac{D}{t_1}$ value to obtain minimum manufacturing thickness t_1. Deduct 0.08-in. service allowance to obtain net thickness t.

e. Compare the net thicknesses from steps c and d and select the larger of the two. This will be the net thickness required for trench load.

50–2.2 *Step 2—Design for internal pressure.* Calculate the net thickness required for internal pressure using the equation for hoop stress:

$$t = \frac{P_iD}{2S}$$

in which t is net thickness in inches; P_i is the design internal pressure, which is equal to the safety factor of 2.0 times the sum of working pressure (P_w) in pounds per square inch, plus 100 psi surge allowance (P_s) for water pipe. That is, $P_i = 2.0\ (P_w + P_s)$. If anticipated surge pressures are greater than 100 psi, then the maximum anticipated pressure must be used. D is outside diameter of pipe in inches, and S is minimum yield strength in tension (42 000 psi).

50–2.3 *Step 3—Selection of net thickness and addition of allowances.*

a. Select the net thickness t from step 1 or 2, whichever thickness is larger.

b. Add the service allowance of 0.08 in. to the net thickness t. The resulting thickness is the minimum manufacturing thickness t_1.

c. Add the casting tolerance from Table 3 to the minimum manufacturing thickness t_1. The resulting thickness is the total calculated thickness.

50–2.4 *Step 4—Selection of standard thickness and class.* Use the total calculated thickness from Sec. 50–2.3.c to select a standard class thickness from Table 5. Select the standard thickness nearest to the calculated thickness. When the calculated thickness is halfway between two standard thicknesses, select the larger of the two.

In specifying and ordering pipe, use the class number listed in Table 5 for this standard thickness.

Sec. 50–3—Design Example for Calculating Thickness

PROBLEM: Calculate the thickness for 30-in. ductile-iron pipe laid on a flat-bottom trench with backfill lightly consolidated to centerline of pipe, laying condition Type 2, under 10 ft of cover for a working pressure of 200 psi.

50–3.1 *Step 1—Design for trench load.*

a. Earth load (Table 1) P_e = 8.3 psi
Truck load (Table 1) P_t = 0.7 psi
Trench load, $P_v = P_e + P_t$ = 9.0 psi

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b. Select Table 8 for diameter–thickness ratios for laying condition Type 2.

c. Entering P_v of 9.0 psi in Table 8, the bending stress design requires $\frac{D}{t}$ of 128. From Table 5, diameter D of 30-in. pipe is 32.00 in.

Net thickness t for bending stress $= \frac{D}{\frac{D}{t}} = \frac{32.00}{128} = 0.25$ in.

d. Also, from Table 8, the deflection design requires $\frac{D}{t_1}$ of 108.

Minimum thickness t_1 for deflection design $= \frac{D}{\frac{D}{t_1}} = \frac{32.00}{108} = 0.30$ in.

Deduct service allowance	−0.08 in.
Net thickness t for deflection control	0.22 in

e. The larger net thickness is 0.25 in., obtained by the design for bending stress.

50–3.2 *Step 2—Design for internal pressure.*

$P_i = 2.0$ (Working pressure + 100 psi surge allowance)

(If anticipated surge pressures are greater than 100 psi, then the actual anticipated pressures must be used.)

$$P_i = 2.0\,(200 + 100) = 600 \text{ psi}$$

$$t = \frac{P_i D}{2S} = \frac{600 \times 32.00}{2 \times 42\,000} = 0.23 \text{ in.}$$

Net thickness t for internal pressure is 0.23 in.

50–3.3 *Step 3—Selection of net thickness and addition of allowances.* The larger of the thicknesses is given by the design for trench load, Step 1, and 0.25 in. is selected.

Net thickness	= 0.25 in.
Service allowance	= 0.08 in.
Minimum thickness	= 0.33 in.
Casting tolerance	= 0.07 in.
Total calculated thickness	= 0.40 in.

50–3.4 *Step 4—Selection of standard thickness and class.* The total calculated thickness of 0.40 in. is nearest to 0.39, Class 50, in Table 5. Therefore, Class 50 is selected for specifying and ordering.

Sec. 50–4—Design Method

50–4.1 The thickness of ductile-iron pipe is determined by considering trench load and internal pressure separately.

Calculations are made for the thicknesses required to resist the bending stress and the deflection caused by trench load. The larger of the two is selected as the thickness required to resist trench load. Calculations are then made for the thickness required to resist the hoop stress of internal pressure.

The larger of these is selected as the net design thickness. To this net thickness is added a service allowance to obtain the minimum manufacturing thickness and a casting tolerance to obtain the total calculated thickness.

The standard thickness and the thickness class for specifying and ordering are selected from a table of standard class thicknesses.

The reverse of the preceding procedure is used to determine the rated working pressure and maximum depth of cover for pipe of a given thickness class.

50–4.2 *Trench load,* P_v. Trench load is expressed as vertical pressure in pounds per square inch, and is equal to the sum of earth load P_e and truck load P_t.

50–4.3 *Earth load,* P_e. Earth load is computed by Eq 4 for the weight of the unit prism of soil with a height equal to the distance from the top of the pipe to the ground surface. The unit weight of backfill soil is taken to be 120 lb/cu ft. If the designer anticipates additional loads because of frost, the design load should be increased accordingly.

50–4.4 *Truck load*, P_t. The truck loads shown in Table 1 were computed by Eq 5 using the surface load factors in Table 6 and the reduction factors R from Table 4 for a single AASHTO H-20 truck on unpaved road or flexible pavement, 16 000-lb wheel load, and 1.5 impact factor. The surface load factors in Table 6 were calculated by Eq 6 for a single concentrated wheel load centered over an effective pipe length of 3 ft.

50–4.5 *Design for trench load.* Tables 7–11, the tables of diameter-thickness ratios used to design for trench load, were computed by Eq 2 and 3. Equation 2 is based on the bending stress at the bottom of the pipe. The design bending stress f is 48 000 psi, which provides at least a 1.5 safety factor based on minimum ring yield strength and a 2.0 safety factor based on ultimate strength. Equation 3 is based on the deflection of the pipe ring section. The design deflection Δx is 3 per cent of the outside diameter of the pipe, which is well below the deflection that might damage cement linings. Design values of the trench parameters E', K_b, and K_x are given in Table 2.

Tables similar to Tables 7–11 may be compiled for laying conditions other than those shown in this standard by calculating the trench loads P_v for a series of diameter–thickness ratios, $\frac{D}{t}$ and $\frac{D}{t_1}$, using Eq 2 and 3 with values of E', K_b, and K_x appropriate to the bedding and backfill conditions.

Design Equations

$$t = \frac{P_i D}{2S} \tag{1}$$

$$P_v = \frac{f}{3\left(\frac{D}{t}\right)\left(\frac{D}{t} - 1\right)\left[K_b - \dfrac{K_x}{\dfrac{8E}{E'\left(\frac{D}{t} - 1\right)^3} + 0.732}\right]} \tag{2}$$

$$P_v = \frac{\frac{\Delta x}{D}}{12K_x}\left[\frac{8E}{\left(\frac{D}{t_1} - 1\right)^3} + 0.732E'\right] \tag{3}$$

$$P_e = \frac{wH}{144} = \frac{120H}{144} = \frac{H}{1.2} \tag{4}$$

$$P_t = \frac{C \cdot R \cdot P \cdot F}{12D} \tag{5}$$

$$C = \frac{1}{3} - \frac{2}{3\pi}\arcsin\left[H\sqrt{\frac{A^2 + H^2 + 1.5^2}{(A^2 + H^2)(H^2 + 1.5^2)}}\right] + \frac{AH}{\pi\sqrt{A^2 + H^2 + 1.5^2}}\left[\frac{1}{A^2 + H^2} + \frac{1}{H^2 + 1.5^2}\right] \tag{6}$$

Explanation of Symbols for Equations

A = Outside radius of pipe in feet = $\frac{D}{24}$
C = Surface load factor (Table 6)
D = Outside diameter in inches (Table 5)
E = Modulus of elasticity (24×10^6 psi)
E' = Modulus of soil reaction in pounds per square inch (Table 2)
F = Impact factor—1.5
f = Design bending stress—48 000 psi
H = Depth of cover in feet
K_b = Bending moment coefficient (Table 2)
K_x = Deflection coefficient (Table 2)
P = Wheel load—16 000 lb
P_e = Earth load in pounds per square inch
P_i = Design internal pressure in pounds per square inch = 2.0 (working pressure + 100 psi surge allowance)
P_t = Truck load in pounds per square inch
P_v = Trench load in pounds per square inch = $P_e + P_t$
R = Reduction factor which takes account of the fact that the part of the pipe directly below the wheels is aided in carrying the truck load by adjacent parts of the pipe that receive little or no load from the wheels (Table 4)
S = Minimum yield strength in tension—42 000 psi
t = Net thickness in inches
t_1 = Minimum thickness in inches (t + 0.08)
w = Soil weight—120 pounds per cubic foot
Δx = Design deflection in inches $\left(\frac{\Delta x}{D} = 0.03\right)$

NOTE: In Eq 6, angles are in radians.

TABLE 50.1

Earth Loads P_e, *Truck Loads* P_t, *and Trench Loads* P_v—psi

Depth of Cover ft	P_e	3-in. Pipe		4-in. Pipe		6-in. Pipe		8-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	$P.$	P_v
2.5	2.1	9.9	12.0	9.9	12.0	9.9	12.0	9.8	11.9
3	2.5	7.4	9.9	7.4	9.9	7.3	9.8	7.3	9.8
4	3.3	4.4	7.7	4.5	7.8	4.4	7.7	4.4	7.7
5	4.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2
6	5.0	2.1	7.1	2.1	7.1	2.1	7.1	2.1	7.1
7	5.8	1.6	7.4	1.6	7.4	1.6	7.4	1.6	7.4
8	6.7	1.2	7.9	1.2	7.9	1.2	7.9	1.2	7.9
9	7.5	1.0	8.5	1.0	8.5	1.0	8.5	1.0	8.5
10	8.3	0.8	9.1	0.8	9.1	0.8	9.1	0.8	9.1
12	10.0	0.6	10.6	0.6	10.6	0.6	10.6	0.6	10.6
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.2	20.2	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

Depth of Cover ft	P_e	10-in. Pipe		12-in. Pipe		14-in. Pipe		16-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P	P_v
2.5	2.1	9.7	11.8	9.6	11.7	8.7	10.8	8.2	10.3
3	2.5	7.2	9.7	7.2	9.7	6.6	9.1	6.2	8.7
4	3.3	4.4	7.7	4.4	7.7	4.4	7.7	4.1	7.4
5	4.2	2.9	7.1	2.9	7.1	2.9	7.1	2.8	7.0
6	5.0	2.1	7.1	2.1	7.1	2.1	7.1	2.0	7.0
7	5.8	1.6	7.4	1.6	7.4	1.6	7.4	1.5	7.3
8	6.7	1.2	7.9	1.2	7.9	1.2	7.9	1.2	7.9
9	7.5	1.0	8.5	1.0	8.5	1.0	8.5	1.0	8.5
10	8.3	0.8	9.1	0.8	9.1	0.8	9.1	0.8	9.1
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

TABLE 50.1—(*cont.*)

Depth of Cover *ft*	P_e	18-in. Pipe		20-in. Pipe		24-in. Pipe		30-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	7.8	9.9	7.5	9.6	7.1	9.2	6.7	8.8
3	2.5	5.9	8.4	5.7	8.2	5.4	7.9	5.2	7.7
4	3.3	3.9	7.2	3.9	7.2	3.6	6.9	3.5	6.8
5	4.2	2.6	6.8	2.6	6.8	2.4	6.6	2.4	6.6
6	5.0	1.9	6.9	1.9	6.9	1.7	6.7	1.7	6.7
7	5.8	1.4	7.2	1.4	7.2	1.3	7.1	1.3	7.1
8	6.7	1.2	7.9	1.1	7.8	1.1	7.8	1.1	7.8
9	7.5	1.0	8.5	0.9	8.4	0.9	8.4	0.9	8.4
10	8.3	0.8	9.1	0.7	9.0	0.7	9.0	0.7	9.0
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

Depth of Cover *ft*	P_e	36-in. Pipe		42-in. Pipe		48-in. Pipe		54-in. Pipe	
		P_t	P_v	P_t	P_v	P_t	P_v	P_t	P_v
2.5	2.1	6.2	8.3	5.8	7.9	5.4	7.5	5.0	7.1
3	2.5	4.9	7.4	4.6	7.1	4.4	6.9	4.1	6.6
4	3.3	3.4	6.7	3.3	6.6	3.1	6.4	3.0	6.3
5	4.2	2.3	6.5	2.3	6.5	2.2	6.4	2.1	6.3
6	5.0	1.7	6.7	1.7	6.7	1.6	6.6	1.6	6.6
7	5.8	1.3	7.1	1.3	7.1	1.2	7.0	1.2	7.0
8	6.7	1.1	7.8	1.0	7.7	1.0	7.7	1.0	7.7
9	7.5	0.8	8.3	0.8	8.3	0.8	8.3	0.8	8.3
10	8.3	0.7	9.0	0.7	9.0	0.7	9.0	0.7	9.0
12	10.0	0.5	10.5	0.5	10.5	0.5	10.5	0.5	10.5
14	11.7	0.4	12.1	0.4	12.1	0.4	12.1	0.4	12.1
16	13.3	0.3	13.6	0.3	13.6	0.3	13.6	0.3	13.6
20	16.7	0.2	16.9	0.2	16.9	0.2	16.9	0.2	16.9
24	20.0	0.1	20.1	0.1	20.1	0.1	20.1	0.1	20.1
28	23.3	0.1	23.4	0.1	23.4	0.1	23.4	0.1	23.4
32	26.7	0.1	26.8	0.1	26.8	0.1	26.8	0.1	26.8

TABLE 50.2

Design Values for Standard Laying Conditions

Laying Condition*	Description	E'	Bedding Angle deg	K_b	K_x
Type 1†	Flat-bottom trench.‡ Loose backfill.	150	30	0.235	0.108
Type 2	Flat-bottom trench. Backfill lightly consolidated to centerline of pipe.	300	45	0.210	0.105
Type 3	Pipe bedded in 4-in.-minimum loose soil.§ Backfill lightly consolidated to top of pipe.	400	60	0.189	0.103
Type 4	Pipe bedded in sand, gravel, or crushed stone to depth of ⅛ pipe diameter, 4-in. minimum. Backfill compacted to top of pipe. (Approx. 80 per cent Standard Proctor, AASHTO T-99)**	500	90	0.157	0.096
Type 5	Pipe bedded to its centerline in compacted granular material, 4-in. minimum under pipe. Compacted granular or select§ material to top of pipe. (Approx. 90 per cent Standard Proctor, AASHTO T-99)**	700	150	0.128	0.085

* See Fig. 1.
† For pipe 30 in. and larger, consideration should be given to the use of laying conditions other than Type 1.
‡ Flat-bottom is defined as "undisturbed earth."
§ Loose soil or select material is defined as "native soil excavated from the trench, free of rocks, foreign material, and frozen earth."
** AASHTO T-99, "Moisture Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer 12-in. (305-mm) Drop."

TABLE 50.3

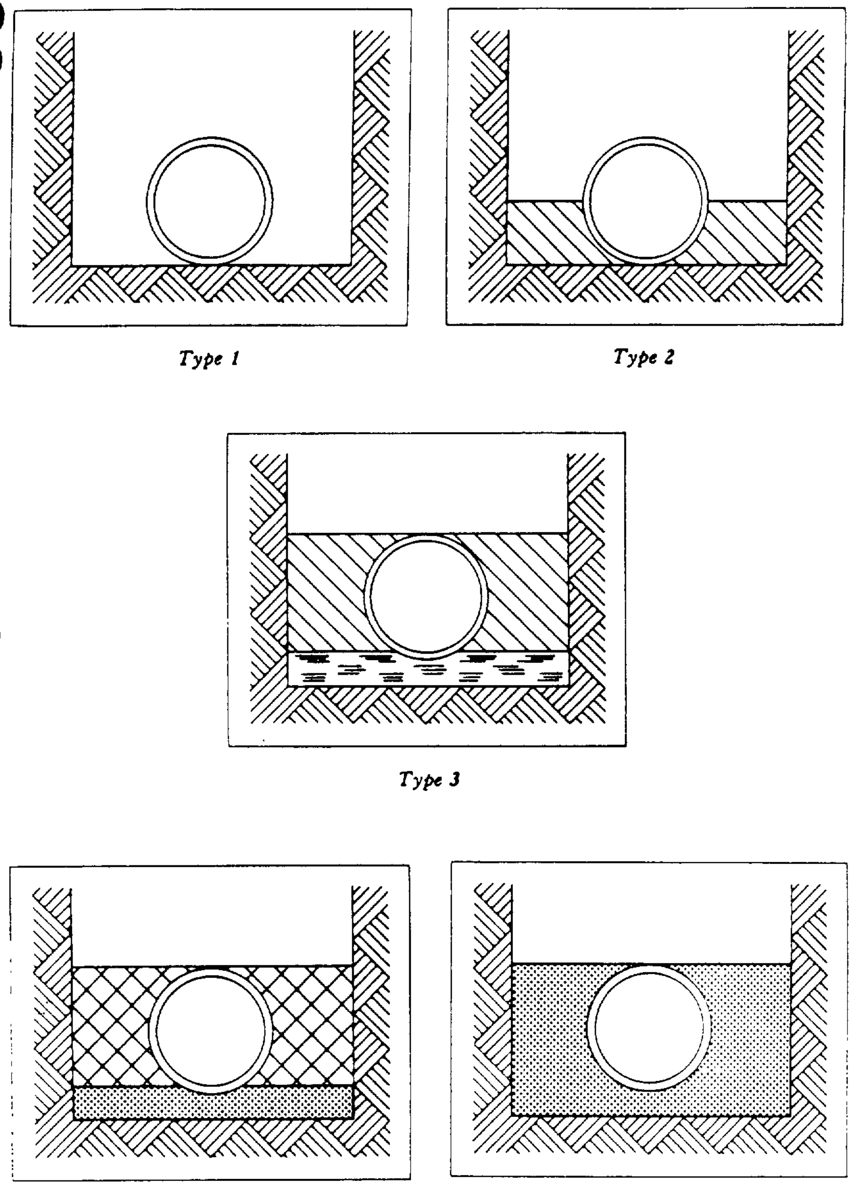
Allowances for Casting Tolerance

Size in.	Casting Tolerance in.
3–8	0.05
10–12	0.06
14–42	0.07
48	0.08
54	0.09

TABLE 50.4

Reduction Factors R for Truck Load Calculations

Size in.	Depth of Cover—ft			
	<4	4–7	8–10	>10
	Reduction Factor			
3–12	1.00	1.00	1.00	1.00
14	0.92	1.00	1.00	1.00
16	0.88	0.95	1.00	1.00
18	0.85	0.90	1.00	1.00
20	0.83	0.90	0.95	1.00
24–30	0.81	0.85	0.95	1.00
36–54	0.80	0.85	0.90	1.00



Type 1 *Type 2* *Type 3* *Type 4* *Type 5*

Figure 1. Standard Pipe Laying Conditions

See Table 2

TABLE 50.5

Standard Thickness Classes of Ductile-Iron Pipe

Size in.	Outside Diameter—in.	Thickness Class 50	51	52	53	54	55	56
		Thickness—in.						
3	3.96	—	0.25	0.28	0.31	0.34	0.37	0.40
4	4.80	—	0.26	0.29	0.32	0.35	0.38	0.41
6	6.90	0.25	0.28	0.31	0.34	0.37	0.40	0.43
8	9.05	0.27	0.30	0.33	0.36	0.39	0.42	0.45
10	11.10	0.29	0.32	0.35	0.38	0.41	0.44	0.47
12	13.20	0.31	0.34	0.37	0.40	0.43	0.46	0.49
14	15.30	0.33	0.36	0.39	0.42	0.45	0.48	0.51
16	17.40	0.34	0.37	0.40	0.43	0.46	0.49	0.52
18	19.50	0.35	0.38	0.41	0.44	0.47	0.50	0.53
20	21.60	0.36	0.39	0.42	0.45	0.48	0.51	0.54
24	25.80	0.38	0.41	0.44	0.47	0.50	0.53	0.56
30	32.00	0.39	0.43	0.47	0.51	0.55	0.59	0.63
36	38.30	0.43	0.48	0.53	0.58	0.63	0.68	0.73
42	44.50	0.47	0.53	0.59	0.65	0.71	0.77	0.83
48	50.80	0.51	0.58	0.65	0.72	0.79	0.86	0.93
54	57.10	0.57	0.65	0.73	0.81	0.89	0.97	1.05

TABLE 50.6

Surface Load Factors for Single Truck on Unpaved Road

Depth of Cover *ft*	Pipe Size—*in.* 3	4	6	8	10	12	14	16
	Surface Load Factor—*C*							
2.5	0.0196	0.0238	0.0340	0.0443	0.0538	0.0634	0.0726	0.0814
3	0.0146	0.0177	0.0253	0.0330	0.0402	0.0475	0.0546	0.0614
4	0.0088	0.0107	0.0153	0.0201	0.0245	0.0290	0.0335	0.0379
5	0.0059	0.0071	0.0102	0.0134	0.0163	0.0194	0.0224	0.0254
6	0.0042	0.0050	0.0072	0.0095	0.0116	0.0138	0.0159	0.0181
7	0.0031	0.0038	0.0054	0.0071	0.0087	0.0103	0.0119	0.0135
8	0.0024	0.0029	0.0042	0.0055	0.0067	0.0079	0.0092	0.0104
9	0.0019	0.0023	0.0033	0.0043	0.0053	0.0063	0.0073	0.0083
10	0.0015	0.0019	0.0027	0.0035	0.0043	0.0051	0.0060	0.0068
12	0.0011	0.0013	0.0019	0.0025	0.0030	0.0036	0.0042	0.0047
14	0.0008	0.0010	0.0014	0.0018	0.0022	0.0027	0.0031	0.0035
16	0.0006	0.0007	0.0011	0.0014	0.0017	0.0020	0.0024	0.0027
20	0.0004	0.0005	0.0007	0.0009	0.0011	0.0013	0.0015	0.0017
24	0.0003	0.0003	0.0005	0.0006	0.0008	0.0009	0.0011	0.0012
28	0.0002	0.0002	0.0003	0.0005	0.0006	0.0007	0.0008	0.0009
32	0.0002	0.0002	0.0003	0.0003	0.0004	0.0005	0.0006	0.0007

Depth of Cover *ft*	Pipe Size—*in.* 18	20	24	30	36	42	48	54
	Surface Load Factor—*C*							
2.5	0.0899	0.0980	0.1130	0.1321	0.1479	0.1604	0.1705	0.1784
3	0.0681	0.0746	0.0867	0.1028	0.1169	0.1286	0.1384	0.1466
4	0.0422	0.0464	0.0545	0.0657	0.0761	0.0853	0.0936	0.1008
5	0.0283	0.0312	0.0369	0.0449	0.0525	0.0595	0.0661	0.0720
6	0.0202	0.0223	0.0264	0.0323	0.0381	0.0435	0.0486	0.0534
7	0.0151	0.0167	0.0198	0.0243	0.0288	0.0329	0.0370	0.0409
8	0.0117	0.0129	0.0154	0.0189	0.0224	0.0258	0.0290	0.0322
9	0.0093	0.0103	0.0122	0.0151	0.0179	0.0206	0.0233	0.0259
10	0.0076	0.0084	0.0100	0.0123	0.0147	0.0169	0.0191	0.0213
12	0.0053	0.0059	0.0070	0.0086	0.0103	0.0119	0.0135	0.0151
14	0.0039	0.0043	0.0052	0.0064	0.0076	0.0088	0.0100	0.0112
16	0.0030	0.0033	0.0040	0.0049	0.0059	0.0068	0.0077	0.0087
20	0.0019	0.0021	0.0025	0.0032	0.0038	0.0044	0.0050	0.0056
24	0.0013	0.0015	0.0018	0.0022	0.0026	0.0030	0.0035	0.0039
28	0.0010	0.0011	0.0013	0.0016	0.0019	0.0022	0.0026	0.0029
32	0.0008	0.0008	0.0010	0.0012	0.0015	0.0017	0.0020	0.0022

TABLE 50.7

*Diameter-Thickness Ratios for Laying Condition Type I**

Trench Load (P_s)—psi		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
4.40	3.46	170
4.43	3.48	169
4.46	3.50	168
4.50	3.51	167
4.54	3.53	166
4.57	3.55	165
4.61	3.57	164
4.64	3.59	163
4.68	3.61	162
4.72	3.63	161
4.76	3.65	160
4.80	3.67	159
4.84	3.69	158
4.88	3.71	157
4.92	3.74	156
4.96	3.76	155
5.00	3.78	154
5.04	3.81	153
5.08	3.83	152
5.13	3.86	151
5.17	3.89	150
5.21	3.91	149
5.26	3.94	148
5.30	3.97	147
5.35	4.00	146
5.40	4.03	145
5.45	4.06	144
5.49	4.09	143
5.54	4.13	142
5.59	4.16	141
5.65	4.20	140
5.70	4.23	139
5.75	4.27	138
5.80	4.31	137
5.86	4.35	136
5.91	4.39	135
5.97	4.43	134
6.03	4.47	133
6.09	4.52	132
6.15	4.56	131
6.21	4.61	130
6.27	4.66	129
6.33	4.71	128
6.40	4.76	127
6.46	4.82	126
6.53	4.87	125
6.60	4.93	124
6.67	4.99	123
6.74	5.05	122
6.82	5.11	121
6.89	5.18	120
6.97	5.25	119
7.05	5.32	118
7.13	5.39	117
7.21	5.46	116
7.29	5.54	115
7.38	5.62	114
7.47	5.71	113
7.56	5.79	112
7.65	5.88	111
7.75	5.97	110
7.85	6.07	109
7.95	6.17	108
8.05	6.27	107
8.16	6.38	106
8.27	6.49	105
8.38	6.61	104
8.49	6.73	103
8.61	6.86	102
8.74	6.99	101
8.86	7.12	100
8.99	7.26	99
9.13	7.41	98
9.27	7.57	97
9.41	7.73	96
9.56	7.89	95
9.71	8.07	94
9.87	8.25	93
10.03	8.44	92
10.20	8.64	91
10.37	8.85	90
10.55	9.06	89
10.74	9.29	88
10.93	9.53	87
11.13	9.78	86

TABLE 50.7—(*cont.*)

Trench Load (P_v)—*psi* Bending Stress Design	Trench Load (P_v)—*psi* Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$
11.34	10.04	85
11.55	10.31	84
11.78	10.60	83
12.01	10.90	82
12.25	11.22	81
12.50	11.56	80
12.76	11.91	79
13.03	12.28	78
13.31	12.67	77
13.60	13.08	76
13.91	13.51	75
14.23	13.97	74
14.56	14.45	73
14.91	14.96	72
15.27	15.50	71
15.65	16.07	70
16.05	16.68	69
16.46	17.32	68
16.89	18.00	67
17.35	18.73	66
17.83	19.50	65
18.33	20.32	64
18.85	21.19	63
19.40	22.12	62
19.98	23.12	61
20.59	24.18	60
21.23	25.32	59

Trench Load (P_v)—*psi* Bending Stress Design	Trench Load (P_v)—*psi* Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$
21.91	26.54	58
22.63	27.85	57
23.38	29.26	56
24.18	30.77	55
25.02	32.39	54
25.92	34.15	53
26.86	36.05	52
27.87	38.10	51
28.94	40.32	50
30.07	42.73	49
31.28	45.35	48
32.57	48.20	47
33.95	51.31	46
35.42	54.72	45
37.00	58.44	44
38.69	62.53	43
40.50	67.03	42
42.46	71.99	41
44.56	77.47	40
46.84	83.54	39
49.30	90.28	38
51.96	97.80	37
54.86	106.20	36
58.02	115.62	35
61.46	126.21	34
65.23	138.18	33
69.36	151.73	32
73.92	167.15	31

* $E' = 150$; $K_b = 0.235$; $K_x = 0.108$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

TABLE 50.8

*Diameter-Thickness Ratios for Laying Condition Type 2**

Trench Load (P_t)—psi		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
6.29	6.18	170
6.34	6.19	169
6.39	6.21	168
6.44	6.23	167
6.50	6.25	166
6.55	6.26	165
6.60	6.28	164
6.66	6.30	163
6.71	6.32	162
6.77	6.34	161
6.82	6.37	160
6.88	6.39	159
6.94	6.41	158
6.99	6.43	157
7.05	6.46	156
7.11	6.48	155
7.17	6.50	154
7.23	6.53	153
7.29	6.56	152
7.35	6.58	151
7.42	6.61	150
7.48	6.64	149
7.54	6.67	148
7.61	6.70	147
7.67	6.73	146
7.74	6.76	145
7.80	6.79	144
7.87	6.83	143
7.94	6.86	142
8.01	6.89	141
8.08	6.93	140
8.15	6.97	139
8.22	7.01	138
8.29	7.05	137
8.37	7.09	136
8.44	7.13	135
8.52	7.17	134
8.59	7.22	133
8.67	7.26	132
8.75	7.31	131
8.83	7.36	130
8.91	7.41	129

Trench Load (P_t)—psi		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
8.99	7.46	128
9.07	7.51	127
9.16	7.57	126
9.25	7.63	125
9.33	7.69	124
9.42	7.75	123
9.51	7.81	122
9.60	7.87	121
9.70	7.94	120
9.79	8.01	119
9.89	8.08	118
9.99	8.16	117
10.09	8.23	116
10.19	8.31	115
10.29	8.40	114
10.40	8.48	113
10.51	8.57	112
10.62	8.66	111
10.73	8.76	110
10.84	8.86	109
10.96	8.96	108
11.08	9.07	107
11.21	9.18	106
11.33	9.29	105
11.46	9.41	104
11.59	9.54	103
11.73	9.67	102
11.87	9.80	101
12.01	9.94	100
12.16	10.09	99
12.31	10.24	98
12.46	10.40	97
12.62	10.56	96
12.79	10.73	95
12.96	10.91	94
13.13	11.10	93
13.31	11.29	92
13.49	11.50	91
13.68	11.71	90
13.88	11.94	89
14.08	12.17	88
14.30	12.42	87
14.51	12.67	86

TABLE 50.8—(*cont.*)

Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
14.74	12.94	85
14.97	13.22	84
15.21	13.52	83
15.46	13.83	82
15.72	14.16	81
15.99	14.50	80
16.28	14.86	79
16.57	15.24	78
16.87	15.64	77
17.19	16.06	76
17.52	16.51	75
17.86	16.98	74
18.22	17.48	73
18.59	18.00	72
18.98	18.56	71
19.39	19.14	70
19.82	19.77	69
20.27	20.43	68
20.73	21.13	67
21.23	21.87	66
21.74	22.67	65
22.28	23.51	64
22.85	24.41	63
23.45	25.37	62
24.07	26.39	61
24.74	27.49	60
25.43	28.66	59
26.17	29.91	58
26.95	31.26	57
27.77	32.71	56
28.64	34.26	55
29.56	35.93	54
30.53	37.74	53
31.57	39.69	52
32.67	41.80	51
33.84	44.09	50
35.08	46.56	49
36.41	49.26	48
37.83	52.19	47
39.34	55.40	46
40.96	58.89	45
42.70	62.73	44
44.57	66.93	43
46.57	71.56	42
48.73	76.66	41
51.06	82.29	40
53.57	88.54	39
56.30	95.48	38
59.25	103.21	37
62.46	111.85	36
65.96	121.54	35
69.79	132.44	34
73.98	144.74	33
78.57	158.68	32
83.64	174.54	31

* $E' = 300$; $K_b = 0.210$; $K_x = 0.105$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

TABLE 50.9

*Diameter-Thickness Ratios for Laying Condition Type 3**

Trench Load (P_t)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D_t}{t}$ or $\frac{D}{t_1}$
3.25	7.26	310
3.29	7.27	308
3.33	7.27	306
3.37	7.27	304
3.41	7.28	302
3.45	7.28	300
3.49	7.28	298
3.54	7.29	296
3.58	7.29	294
3.63	7.30	292
3.67	7.30	290
3.72	7.30	288
3.76	7.31	286
3.81	7.31	284
3.86	7.32	282
3.91	7.32	280
3.96	7.33	278
4.01	7.33	276
4.06	7.34	274
4.11	7.34	272
4.17	7.35	270
4.22	7.35	268
4.28	7.36	266
4.33	7.36	264
4.39	7.37	262
4.45	7.38	260
4.51	7.38	258
4.57	7.39	256
4.63	7.39	254
4.69	7.40	252
4.76	7.41	250
4.82	7.42	248
4.89	7.42	246
4.96	7.43	244
5.03	7.44	242
5.10	7.45	240
5.17	7.46	238
5.24	7.47	236
5.31	7.48	234
5.39	7.48	232
5.47	7.49	230
5.54	7.51	228

Trench Load (P_t)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D_t}{t}$ or $\frac{D}{t_1}$
5.62	7.52	226
5.70	7.53	224
5.79	7.54	222
5.87	7.55	220
5.96	7.56	218
6.04	7.58	216
6.13	7.59	214
6.22	7.60	212
6.32	7.62	210
6.41	7.63	208
6.51	7.65	206
6.60	7.66	204
6.70	7.68	202
6.80	7.70	200
6.91	7.72	198
7.01	7.74	196
7.12	7.76	194
7.22	7.78	192
7.33	7.80	190
7.45	7.82	188
7.56	7.84	186
7.68	7.87	184
7.80	7.89	182
7.92	7.92	180
8.04	7.95	178
8.16	7.98	176
8.29	8.01	174
8.42	8.04	172
8.55	8.07	170
8.62	8.09	169
8.69	8.11	168
8.75	8.13	167
8.82	8.14	166
8.89	8.16	165
8.96	8.18	164
9.03	8.20	163
9.10	8.22	162
9.17	8.24	161
9.25	8.27	160
9.32	8.29	159
9.39	8.31	158
9.47	8.33	157
9.54	8.36	156

TABLE 50.9—(*cont.*)

Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
9.62	8.38	155
9.69	8.41	154
9.77	8.43	153
9.85	8.46	152
9.92	8.49	151
10.00	8.52	150
10.08	8.54	149
10.16	8.57	148
10.24	8.60	147
10.33	8 64	146
10.41	8.67	145
10.49	8.70	144
10.58	8.73	143
10.66	8.77	142
10.75	8.81	141
10.83	8.84	140
10.92	8.88	139
11.01	8.92	138
11.10	8.96	137
11.19	9.00	136
11.28	9.04	135
11.37	9.09	134
11 46	9.13	133
11.56	9.18	132
11.65	9.23	131
11.75	9.28	130
11.84	9.33	129
11.94	9.38	128
12.04	9.44	127
12.14	9.49	126
12.25	9.55	125
12.35	9.61	124
12.45	9.67	123
12.56	9.74	122
12.67	9.80	121
12.78	9.87	120
12.89	9.94	119
13.00	10.02	118
13.11	10.09	117
13.23	10.17	116
13.34	10.25	115
13.46	10.34	114
13.58	10.42	113
13.71	10.51	112
13.83	10.61	111
13.96	10.71	110
14.09	10.81	109
14.22	10.91	108
14.36	11.02	107
14.50	11.13	106
14.64	11.25	105
14.78	11.37	104
14.93	11.50	103
15.08	11.63	102
15.23	11.77	101
15.39	11.91	100
15.55	12.06	99
15.71	12.21	98
15.88	12.37	97
16.06	12.54	96
16.23	12.72	95
16.42	12.90	94
16.61	13.09	93
16.80	13.29	92
17.00	13.50	91
17.21	13.72	90
17.42	13.95	89
17.64	14.18	88
17.86	14.43	87
18.10	14.70	86
18.34	14.97	85
18.59	15.26	84
18.85	15.56	83
19.12	15.88	82
19.40	16.21	81
19.68	16.56	80
19.99	16.93	79
20.30	17.31	78
20.62	17.72	77
20.96	18.15	76
21.31	18.61	75
21.68	19.09	74
22.07	19.59	73
22.47	20.13	72
22.88	20.69	71

TABLE 50.9—(*cont.*)

Trench Load (P_e)—*psi*			Trench Load (P_e)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
23.32	21.29	70	38.97	46.72	50
23.78	21.93	69	40.33	49.25	49
24.26	22.60	68	41.78	51.99	48
24.76	23.32	67	43.33	54.98	47
25.29	24.08	66	44.98	58.25	46
25.85	24.88	65	46.76	61.81	45
26.43	25.74	64	48.66	65.72	44
27.04	26.66	63	50.71	70.01	43
27.68	27.64	62	52.91	74.72	42
28.36	28.68	61	55.28	79.92	41
29.08	29.80	60	57.84	85.67	40
29.83	30.99	59	60.61	92.04	39
30.63	32.27	58	63.61	99.11	38
31.47	33.64	57	66.86	106.99	37
32.36	35.12	56	70.40	115.80	36
33.31	36.70	55	74.27	125.67	35
34.30	38.41	54	78.49	136.78	34
35.37	40.25	53	83.11	149.32	33
36.49	42.24	52	88.19	163.54	32
37.69	44.39	51	93.79	179.71	31

* $E' = 400$; $K_b = 0.189$; $K_x = 0.103$.

† The $\frac{D}{t}$ for the tabulated P_e nearest to the calculated P_e is selected; when the calculated P_e is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

TABLE 50.10

*Diameter-Thickness Ratios for Laying Condition Type 4**

Trench Load (P_v)—psi			Trench Load (P_v)—psi		
Bending Stress Design	Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D\dagger}{t}$ or $\frac{D}{t_1}$
5.93	9.70	310	9.95	9.97	226
6.00	9.70	308	10.08	9.98	224
6.07	9.71	306	10.21	9.99	222
6.14	9.71	304	10.35	10.01	220
6.21	9.71	302	10.49	10.02	218
6.29	9.72	300	10.62	10.03	216
6.36	9.72	298	10.77	10.05	214
6.43	9.73	296	10.91	10.06	212
6.51	9.73	294	11.05	10.08	210
6.59	9.73	292	11.20	10.09	208
6.67	9.74	290	11.35	10.11	206
6.74	9.74	288	11.50	10.13	204
6.83	9.75	286	11.66	10.15	202
6.91	9.75	284	11.81	10.17	200
6.99	9.76	282	11.97	10.19	198
7.08	9.76	280	12.13	10.21	196
7.16	9.77	278	12.29	10.23	194
7.25	9.77	276	12.45	10.25	192
7.34	9.78	274	12.62	10.27	190
7.43	9.78	272	12.79	10.30	188
7.52	9.79	270	12.96	10.32	186
7.61	9.79	268	13.13	10.35	184
7.71	9.80	266	13.30	10.37	182
7.80	9.81	264	13.48	10.40	180
7.90	9.81	262	13.66	10.43	178
8.00	9.82	260	13.84	10.46	176
8.10	9.83	258	14.02	10.50	174
8.20	9.83	256	14.20	10.53	172
8.31	9.84	254	14.39	10.57	170
8.41	9.85	252	14.48	10.59	169
8.52	9.86	250	14.57	10.60	168
8.63	9.86	248	14.67	10.62	167
8.74	9.87	246	14.76	10.64	166
8.85	9.88	244	14.86	10.66	165
8.97	9.89	242	14.96	10.69	164
9.08	9.90	240	15.05	10.71	163
9.20	9.91	238	15.15	10.73	162
9.32	9.92	236	15.25	10.75	161
9.44	9.93	234	15.34	10.78	160
9.57	9.94	232	15.44	10.80	159
			15.54	10.82	158
9.69	9.95	230	15.64	10.85	157
9.82	9.96	228	15.74	10.87	156

TABLE 50.10—(*cont.*)

Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D_t}{t}$ or $\frac{D}{t_1}$
15.84	10.90	155
15.94	10.93	154
16.04	10.96	153
16.14	10.98	152
16.24	11.01	151
16.34	11.04	150
16.45	11.07	149
16.55	11.11	148
16.65	11.14	147
16.76	11.17	146
16.86	11.21	145
16.96	11.24	144
17.07	11.28	143
17.18	11.31	142
17.28	11.35	141
17.39	11.39	140
17.50	11.43	139
17.60	11.48	138
17.71	11.52	137
17.82	11.56	136
17.93	11.61	135
18.04	11.66	134
18.15	11.71	133
18.26	11.76	132
18.37	11.81	131
18.49	11.86	130
18.60	11.92	129
18.72	11.97	128
18.83	12.03	127
18.95	12.09	126
19.06	12.15	125
19.18	12.22	124
19.30	12.28	123
19.42	12.35	122
19.54	12.42	121
19.66	12.50	120
19.78	12.57	119
19.91	12.65	118
20.04	12.73	117
20.16	12.82	116
20.29	12.91	115
20.42	13.00	114
20.55	13.09	113
20.69	13.19	112
20.82	13.29	111
20.96	13.39	110
21.10	13.50	109
21.24	13.61	108
21.39	13.73	107
21.54	13.85	106
21.69	13.98	105
21.84	14.11	104
22.00	14.24	103
22.16	14.38	102
22.32	14.53	101
22.49	14.68	100
22.66	14.84	99
22.83	15.01	98
23.01	15.18	97
23.20	15.36	96
23.38	15.55	95
23.58	15.75	94
23.78	15.95	93
23.99	16.17	92
24.20	16.39	91
24.42	16.62	90
24.64	16.87	89
24.88	17.12	88
25.12	17.39	87
25.37	17.67	86
25.63	17.97	85
25.90	18.28	84
26.18	18.60	83
26.47	18.94	82
26.77	19.30	81
27.09	19.67	80
27.42	20.07	79
27.76	20.48	78
28.11	20.92	77
28.49	21.38	76
28.87	21.87	75
29.28	22.38	74
29.70	22.93	73
30.15	23.50	72
30.62	24.11	71

TABLE 50.10—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
31.11	24.75	70	49.11	52.03	50
31.62	25.43	69	50.70	54.74	49
32.16	26.16	68	52.41	57.69	48
32.72	26.92	67	54.23	60.90	47
33.32	27.74	66	56.18	64.40	46
33.95	28.60	65	58.27	68.23	45
34.61	29.53	64	60.52	72.42	44
35.30	30.51	63	62.93	77.02	43
36.04	31.56	62	65.54	82.08	42
36.81	32.68	61	68.35	87.66	41
37.63	33.88	60	71.39	93.82	40
38.50	35.16	59	74.67	100.65	39
39.42	36.53	58	78.24	108.24	38
40.39	38.00	57	82.11	116.70	37
41.42	39.58	56	86.33	126.15	36
42.51	41.28	55	90.93	136.74	35
43.67	43.12	54	95.97	148.66	34
44.91	45.09	53	101.49	162.12	33
46.22	47.22	52	107.56	177.37	32
47.62	49.53	51	114.25	194.72	31

* $E' = 500$; $K_b = 0.157$; $K_x = 0.096$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

TABLE 50.11

*Diameter–Thickness Ratios for Laying Condition Type 5**

Trench Load (P_e)—*psi* Bending Stress Design	Trench Load (P_e)—*psi* Deflection Design	$\frac{Dt}{t}$ or $\frac{D}{t_1}$
3.06	15.09	660
3.10	15.09	655
3.15	15.09	650
3.20	15.09	645
3.25	15.09	640
3.30	15.09	635
3.35	15.09	630
3.40	15.09	625
3.46	15.09	620
3.51	15.09	615
3.57	15.10	610
3.63	15.10	605
3.68	15.10	600
3.75	15.10	595
3.81	15.10	590
3.87	15.10	585
3.94	15.10	580
4.00	15.10	575
4.07	15.10	570
4.14	15.10	565
4.21	15.10	560
4.29	15.10	555
4.36	15.10	550
4.44	15.11	545
4.52	15.11	540
4.60	15.11	535
4.69	15.11	530
4.77	15.11	525
4.86	15.11	520
4.95	15.11	515
5.05	15.11	510
5.14	15.11	505
5.24	15.12	500
5.35	15.12	495
5.45	15.12	490
5.56	15.12	485
5.67	15.12	480
5.78	15.12	475
5.90	15.13	470
6.02	15.13	465
6.15	15.13	460
6.28	15.13	455
6.41	15.13	450
6.54	15.14	445
6.68	15.14	440
6.83	15.14	435
6.98	15.14	430
7.13	15.14	425
7.29	15.15	420
7.46	15.15	415
7.63	15.15	410
7.80	15.16	405
7.98	15.16	400
8.17	15.16	395
8.36	15.17	390
8.56	15.17	385
8.77	15.17	380
8.98	15.18	375
9.20	15.18	370
9.43	15.19	365
9.66	15.19	360
9.91	15.20	355
10.16	15.20	350
10.42	15.21	345
10.69	15.22	340
10.97	15.22	335
11.26	15.23	330
11.56	15.24	325
11.87	15.24	320
12.19	15.25	315
12.52	15.26	310
12.66	15.27	308
12.80	15.27	306
12.94	15.27	304
13.08	15.28	302
13.23	15.28	300
13.37	15.29	298
13.52	15.29	296
13.67	15.30	294
13.83	15.30	292
13.98	15.30	290
14.14	15.31	288
14.30	15.31	286
14.46	15.32	284
14.62	15.33	282

TABLE 50.11—(*cont.*)

Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
14.79	15.33	280
14.96	15.34	278
15.13	15.34	276
15.30	15.35	274
15.48	15.35	272
15.65	15.36	270
15.83	15.37	268
16.02	15.37	266
16.20	15.38	264
16.39	15.39	262
16.58	15.40	260
16.77	15.40	258
16.97	15.41	256
17.16	15.42	254
17.36	15.43	252
17.57	15.44	250
17.77	15.45	248
17.98	15.45	246
18.19	15.46	244
18.40	15.47	242
18.62	15.48	240
18.84	15.49	238
19.06	15.51	236
19.28	15.52	234
19.51	15.53	232
19.73	15.54	230
19.97	15.55	228
20.20	15.57	226
20.43	15.58	224
20.67	15.59	222
20.91	15.61	220
21.16	15.62	218
21.40	15.64	216
21.65	15.65	214
21.90	15.67	212
22.15	15.69	210
22.40	15.71	208
22.66	15.73	206
22.92	15.75	204
23.18	15.77	202
23.44	15.79	200
23.70	15.81	198
23.97	15.83	196

Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
24.24	15.86	194
24.50	15.88	192
24.77	15.91	190
25.04	15.93	188
25.31	15.96	186
25.59	15.99	184
25.86	16.02	182
26.13	16.06	180
26.41	16.09	178
26.68	16.12	176
26.96	16.16	174
27.23	16.20	172
27.51	16.24	170
27.65	16.26	169
27.78	16.28	168
27.92	16.31	167
28.06	16.33	166
28.19	16.35	165
28.33	16.37	164
28.47	16.40	163
28.60	16.42	162
28.74	16.45	161
28.87	16.48	160
29.01	16.50	159
29.15	16.53	158
29.28	16.56	157
29.41	16.59	156
29.55	16.62	155
29.68	16.65	154
29.82	16.68	153
29.95	16.71	152
30.08	16.74	151
30.21	16.78	150
30.34	16.81	149
30.48	16.85	148
30.61	16.89	147
30.74	16.92	146
30.87	16.96	145
30.99	17.00	144
31.12	17.04	143
31.25	17.09	142
31.38	17.13	141

TABLE 50.11—(*cont.*)

Trench Load (P_t)—psi		
Bending Stress Design	Deflection Design	$\frac{D_t}{t}$ or $\frac{D}{t_1}$
31.50	17.17	140
31.63	17.22	139
31.76	17.27	138
31.88	17.32	137
32.01	17.37	136
32.13	17.42	135
32.25	17.47	134
32.38	17.53	133
32.50	17.58	132
32.62	17.64	131
32.75	17.70	130
32.87	17.76	129
32.99	17.83	128
33.11	17.89	127
33.23	17.96	126
33.35	18.03	125
33.47	18.11	124
33.59	18.18	123
33.71	18.26	122
33.83	18.34	121
33.95	18.42	120
34.07	18.51	119
34.19	18.60	118
34.31	18.69	117
34.43	18.78	116
34.55	18.88	115
34.68	18.98	114
34.80	19.09	113
34.92	19.20	112
35.05	19.31	111
35.17	19.43	110
35.30	19.55	109
35.43	19.68	108
35.56	19.81	107
35.69	19.95	106
35.83	20.09	105
35.96	20.24	104
36.10	20.39	103
36.25	20.55	102
36.39	20.72	101
36.54	20.89	100
36.69	21.07	99
36.85	21.26	98

Trench Load (P_t)—psi		
Bending Stress Design	Deflection Design	$\frac{D_t}{t}$ or $\frac{D}{t_1}$
37.01	21.45	97
37.17	21.66	96
37.34	21.87	95
37.52	22.09	94
37.70	22.32	93
37.89	22.56	92
38.08	22.82	91
38.28	23.08	90
38.49	23.36	89
38.71	23.65	88
38.93	23.95	87
39.17	24.27	86
39.41	24.60	85
39.67	24.95	84
39.94	25.31	83
40.22	25.70	82
40.51	26.10	81
40.82	26.52	80
41.14	26.97	79
41.48	27.44	78
41.84	27.93	77
42.21	28.46	76
42.60	29.01	75
43.02	29.59	74
43.45	30.20	73
43.92	30.85	72
44.40	31.53	71
44.91	32.26	70
45.46	33.03	69
46.03	33.85	68
46.64	34.71	67
47.28	35.63	66
47.96	36.61	65
48.68	37.65	64
49.44	38.77	63
50.25	39.95	62
51.11	41.21	61
52.02	42.57	60
52.99	44.01	59
54.02	45.56	58
55.12	47.23	57
56.28	49.01	56

TABLE 50.11—(*cont.*)

Trench Load (P_v)—*psi*			Trench Load (P_v)—*psi*		
Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$	Bending Stress Design	Deflection Design	$\frac{D}{t}$† or $\frac{D}{t_1}$
57.53	50.93	55	84.50	97.01	42
58.86	53.00	54	87.85	103.31	41
60.28	55.23	53			
61.79	57.64	52	91.47	110.27	40
63.41	60.25	51	95.40	117.98	39
65.14	63.07	50	99.67	126.56	38
67.00	66.13	49	104.32	136.11	37
68.99	69.46	48	109.40	146.78	36
71.12	73.09	47			
73.41	77.04	46	114.94	158.75	35
			121.02	172.21	34
75.88	81.36	45	127.69	187.41	33
78.54	86.10	44	135.03	204.63	32
81.40	91.29	43	143.14	224.22	31

* $E' = 700$; $K_b = 0.128$; $K_x = 0.085$.

† The $\frac{D}{t}$ for the tabulated P_v nearest to the calculated P_v is selected; when the calculated P_v is halfway between two tabulated values, the smaller $\frac{D}{t}$ should be used.

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TABLE 50.12

Thickness for Earth Load Plus Truck Load

Size in.	Depth of Cover ft	Laying Condition: Type 1 Total Calculated Thickness* in.	Type 1 Use Class	Type 2 Total Calculated Thickness* in.	Type 2 Use Class	Type 3 Total Calculated Thickness* in.	Type 3 Use Class	Type 4 Total Calculated Thickness* in.	Type 4 Use Class	Type 5 Total Calculated Thickness* in.	Type 5 Use Class
3	2.5	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	3	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	4	0.17	51	0.16	51	0.15	51	0.14	51	0.14	51
	5	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	6	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	7	0.16	51	0.16	51	0.15	51	0.14	51	0.14	51
	8	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	9	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	10	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	12	0.17	51	0.17	51	0.16	51	0.15	51	0.14	51
	14	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	16	0.18	51	0.17	51	0.17	51	0.15	51	0.14	51
	20	0.19	51	0.18	51	0.17	51	0.16	51	0.15	51
	24	0.19	51	0.19	51	0.18	51	0.16	51	0.15	51
	28	0.20	51	0.19	51	0.19	51	0.17	51	0.15	51
	32	0.21	51	0.20	51	0.19	51	0.18	51	0.15	51
4	2.5	0.19	51	0.18	51	0.17	51	0.15	51	0.15	51
	3	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	4	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	5	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	6	0.17	51	0.16	51	0.15	51	0.15	51	0.14	51
	7	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	8	0.17	51	0.16	51	0.16	51	0.15	51	0.14	51
	9	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	10	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	12	0.18	51	0.17	51	0.16	51	0.15	51	0.14	51
	14	0.19	51	0.18	51	0.17	51	0.15	51	0.15	51
	16	0.19	51	0.18	51	0.17	51	0.16	51	0.15	51
	20	0.20	51	0.19	51	0.18	51	0.16	51	0.15	51
	24	0.21	51	0.20	51	0.19	51	0.17	51	0.15	51
	28	0.22	51	0.21	51	0.20	51	0.18	51	0.15	51
	32	0.22	51	0.21	51	0.21	51	0.19	51	0.16	51
6	2.5	0.21	50	0.20	50	0.18	50	0.16	50	0.15	50
	3	0.20	50	0.19	50	0.18	50	0.16	50	0.15	50
	4	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	5	0.19	50	0.17	50	0.17	50	0.15	50	0.15	50
	6	0.19	50	0.17	50	0.17	50	0.15	50	0.15	50
	7	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	8	0.19	50	0.18	50	0.17	50	0.16	50	0.15	50
	9	0.20	50	0.18	50	0.17	50	0.16	50	0.15	50
	10	0.20	50	0.18	50	0.17	50	0.16	50	0.15	50
	12	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	14	0.21	50	0.20	50	0.18	50	0.17	50	0.15	50
	16	0.22	50	0.21	50	0.19	50	0.17	50	0.15	50
	20	0.23	50	0.22	50	0.21	50	0.18	50	0.16	50
	24	0.24	50	0.23	50	0.22	50	0.19	50	0.16	50
	28	0.25	50	0.24	50	0.23	50	0.20	50	0.16	50
	32	0.26	50	0.25	50	0.24	50	0.22	50	0.17	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

TABLE 50.12—*(cont.)*

Size *in.*	Depth of Cover *ft*	Laying Condition: Type 1 Total Calculated Thickness* *in.*	Type 1 Use Class	Type 2 Total Calculated Thickness* *in.*	Type 2 Use Class	Type 3 Total Calculated Thickness* *in.*	Type 3 Use Class	Type 4 Total Calculated Thickness* *in.*	Type 4 Use Class	Type 5 Total Calculated Thickness* *in.*	Type 5 Use Class
8	2.5	0.24	50	0.22	50	0.20	50	0.18	50	0.16	50
	3	0.23	50	0.21	50	0.19	50	0.17	50	0.16	50
	4	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	5	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	6	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	7	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	8	0.21	50	0.19	50	0.18	50	0.16	50	0.15	50
	9	0.22	50	0.20	50	0.18	50	0.17	50	0.15	50
	10	0.22	50	0.20	50	0.19	50	0.17	50	0.15	50
	12	0.23	50	0.21	50	0.19	50	0.17	50	0.16	50
	14	0.24	50	0.22	50	0.20	50	0.18	50	0.16	50
	16	0.25	50	0.23	50	0.21	50	0.18	50	0.16	50
	20	0.27	50	0.25	50	0.23	50	0.19	50	0.17	50
	24	0.28	50	0.26	50	0.24	50	0.21	50	0.17	50
	28	0.29	51	0.28	50	0.26	50	0.23	50	0.18	50
	32	0.30	51	0.29	51	0.27	50	0.24	50	0.18	50
10	2.5	0.27	50	0.25	50	0.23	50	0.20	50	0.17	50
	3	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	4	0.24	50	0.22	50	0.20	50	0.18	50	0.17	50
	5	0.23	50	0.21	50	0.20	50	0.18	50	0.17	50
	6	0.23	50	0.21	50	0.20	50	0.18	50	0.17	50
	7	0.24	50	0.21	50	0.20	50	0.18	50	0.17	50
	8	0.24	50	0.22	50	0.20	50	0.18	50	0.17	50
	9	0.25	50	0.22	50	0.20	50	0.18	50	0.17	50
	10	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	12	0.26	50	0.24	50	0.22	50	0.19	50	0.17	50
	14	0.28	50	0.25	50	0.23	50	0.20	50	0.18	50
	16	0.29	50	0.26	50	0.24	50	0.20	50	0.18	50
	20	0.31	51	0.28	50	0.26	50	0.22	50	0.18	50
	24	0.32	51	0.30	50	0.28	50	0.24	50	0.19	50
	28	0.34	52	0.32	51	0.30	50	0.26	50	0.20	50
	32	0.35	52	0.33	51	0.32	51	0.28	50	0.20	50
12	2.5	0.30	50	0.27	50	0.24	50	0.21	50	0.18	50
	3	0.28	50	0.25	50	0.23	50	0.20	50	0.18	50
	4	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	5	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	6	0.25	50	0.23	50	0.21	50	0.19	50	0.17	50
	7	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	8	0.26	50	0.23	50	0.21	50	0.19	50	0.17	50
	9	0.27	50	0.24	50	0.22	50	0.19	50	0.17	50
	10	0.27	50	0.24	50	0.22	50	0.20	50	0.18	50
	12	0.29	50	0.26	50	0.23	50	0.20	50	0.18	50
	14	0.30	50	0.27	50	0.24	50	0.21	50	0.18	50
	16	0.31	50	0.29	50	0.26	50	0.21	50	0.18	50
	20	0.34	51	0.31	50	0.28	50	0.23	50	0.19	50
	24	0.36	52	0.33	51	0.31	50	0.25	50	0.20	50
	28	0.38	52	0.35	51	0.33	51	0.28	50	0.21	50
	32	0.39	53	0.37	52	0.35	51	0.30	50	0.23	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition: Type 1 — Total Calculated Thickness* *in.*	Type 1 — Use Class	Type 2 — Total Calculated Thickness* *in.*	Type 2 — Use Class	Type 3 — Total Calculated Thickness* *in.*	Type 3 — Use Class	Type 4 — Total Calculated Thickness* *in.*	Type 4 — Use Class	Type 5 — Total Calculated Thickness* *in.*	Type 5 — Use Class
14	2.5	0.32	50	0.29	50	0.26	50	0.22	50	0.20	50
	3	0.31	50	0.27	50	0.24	50	0.21	50	0.19	50
	4	0.29	50	0.26	50	0.23	50	0.21	50	0.19	50
	5	0.28	50	0.25	50	0.23	50	0.20	50	0.19	50
	6	0.28	50	0.25	50	0.23	50	0.20	50	0.19	50
	7	0.28	50	0.25	50	0.23	50	0.21	50	0.19	50
	8	0.29	50	0.26	50	0.23	50	0.21	50	0.19	50
	9	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	10	0.31	50	0.27	50	0.24	50	0.21	50	0.19	50
	12	0.32	50	0.29	50	0.26	50	0.22	50	0.19	50
	14	0.34	50	0.30	50	0.27	50	0.23	50	0.20	50
	16	0.35	51	0.32	50	0.29	50	0.24	50	0.20	50
	20	0.38	52	0.35	51	0.32	50	0.26	50	0.21	50
	24	0.40	52	0.38	52	0.34	50	0.28	50	0.22	50
	28	0.42	53	0.40	52	0.37	51	0.31	50	0.24	50
	32	0.44	54	0.42	53	0.39	52	0.34	50	0.26	50
16	2.5	0.34	50	0.30	50	0.27	50	0.23	50	0.20	50
	3	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	4	0.30	50	0.27	50	0.24	50	0.21	50	0.19	50
	5	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	6	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	7	0.30	50	0.26	50	0.24	50	0.21	50	0.19	50
	8	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	9	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	10	0.33	50	0.29	50	0.26	50	0.22	50	0.20	50
	12	0.35	50	0.31	50	0.27	50	0.23	50	0.20	50
	14	0.36	51	0.33	50	0.29	50	0.24	50	0.20	50
	16	0.38	51	0.34	50	0.30	50	0.25	50	0.21	50
	20	0.41	52	0.38	51	0.34	50	0.27	50	0.22	50
	24	0.44	53	0.41	52	0.37	51	0.30	50	0.24	50
	28	0.46	54	0.43	53	0.40	52	0.33	50	0.27	50
	32	0.48	55	0.46	54	0.43	53	0.36	51	0.29	50
18	2.5	0.36	50	0.32	50	0.28	50	0.24	50	0.20	50
	3	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	4	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	5	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	6	0.31	50	0.27	50	0.25	50	0.22	50	0.19	50
	7	0.32	50	0.28	50	0.25	50	0.22	50	0.20	50
	8	0.33	50	0.29	50	0.26	50	0.22	50	0.20	50
	9	0.34	50	0.30	50	0.26	50	0.23	50	0.20	50
	10	0.35	50	0.30	50	0.27	50	0.23	50	0.20	50
	12	0.37	51	0.32	50	0.29	50	0.24	50	0.21	50
	14	0.39	51	0.35	50	0.30	50	0.25	50	0.21	50
	16	0.41	52	0.37	51	0.32	50	0.26	50	0.22	50
	20	0.44	53	0.40	52	0.36	50	0.29	50	0.23	50
	24	0.47	54	0.44	53	0.40	52	0.32	50	0.26	50
	28	0.50	55	0.46	54	0.43	53	0.36	50	0.29	50
	32	0.53	56	0.49	55	0.46	54	0.39	51	0.32	50

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class
20	2.5	0.38	51	0.33	50	0.29	50	0.24	50	0.21	50
	3	0.35	50	0.31	50	0.27	50	0.23	50	0.20	50
	4	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	5	0.33	50	0.28	50	0.26	50	0.23	50	0.20	50
	6	0.33	50	0.29	50	0.26	50	0.23	50	0.20	50
	7	0.34	50	0.29	50	0.26	50	0.23	50	0.20	50
	8	0.35	50	0.30	50	0.27	50	0.23	50	0.20	50
	9	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	10	0.37	50	0.32	50	0.28	50	0.24	50	0.21	50
	12	0.39	51	0.34	50	0.30	50	0.25	50	0.21	50
	14	0.41	52	0.37	50	0.32	50	0.26	50	0.22	50
	16	0.43	52	0.39	51	0.34	50	0.27	50	0.22	50
	20	0.47	54	0.43	52	0.39	51	0.31	50	0.23	50
	24	0.50	55	0.47	54	0.42	52	0.34	50	0.28	50
	28	0.54	56	0.50	55	0.46	53	0.38	51	0.31	50
	32	0.57	—	0.53	56	0.49	54	0.42	52	0.34	50
24	2.5	0.42	51	0.35	50	0.31	50	0.26	50	0.22	50
	3	0.39	50	0.33	50	0.29	50	0.25	50	0.21	50
	4	0.37	50	0.31	50	0.28	50	0.24	50	0.21	50
	5	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	6	0.36	50	0.31	50	0.28	50	0.24	50	0.21	50
	7	0.37	50	0.32	50	0.28	50	0.24	50	0.21	50
	8	0.39	50	0.33	50	0.29	50	0.25	50	0.21	50
	9	0.40	51	0.34	50	0.30	50	0.25	50	0.22	50
	10	0.41	51	0.35	50	0.31	50	0.26	50	0.22	50
	12	0.44	52	0.38	50	0.33	50	0.27	50	0.23	50
	14	0.46	53	0.41	51	0.35	50	0.28	50	0.23	50
	16	0.49	54	0.44	52	0.38	50	0.31	50	0.24	50
	20	0.54	55	0.49	54	0.43	52	0.36	50	0.25	50
	24	0.57	56	0.53	55	0.48	53	0.40	51	0.32	50
	28	0.61	—	0.57	56	0.52	55	0.43	52	0.36	50
	32	0.65	—	0.60	—	0.56	56	0.47	53	0.40	51
30	2.5	†	†	0.40	50	0.34	50	0.28	50	0.23	50
	3			0.37	50	0.32	50	0.27	50	0.23	50
	4			0.35	50	0.31	50	0.26	50	0.22	50
	5			0.35	50	0.31	50	0.26	50	0.22	50
	6			0.35	50	0.31	50	0.26	50	0.22	50
	7			0.36	50	0.31	50	0.26	50	0.23	50
	8			0.37	50	0.33	50	0.27	50	0.23	50
	9			0.39	50	0.34	50	0.28	50	0.23	50
	10			0.40	50	0.35	50	0.28	50	0.24	50
	12			0.44	51	0.37	50	0.30	50	0.24	50
	14			0.47	52	0.40	50	0.32	50	0.25	50
	16			0.51	53	0.43	51	0.37	50	0.26	50
	20			0.57	55	0.50	53	0.43	51	0.29	50
	24			0.62	56	0.56	54	0.48	52	0.37	50
	28			0.67	—	0.61	56	0.51	53	0.43	51
	32			0.71	—	0.66	—	0.55	54	0.47	52

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

TABLE 50.12—(*cont.*)

Size in.	Depth of Cover ft	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class	Total Calculated Thickness* in.	Use Class
36	2.5	†	†	0.43	50	0.37	50	0.30	50	0.25	50
	3			0.40	50	0.35	50	0.29	50	0.24	50
	4			0.39	50	0.34	50	0.28	50	0.24	50
	5			0.38	50	0.34	50	0.28	50	0.24	50
	6			0.39	50	0.34	50	0.28	50	0.24	50
	7			0.40	50	0.35	50	0.29	50	0.24	50
	8			0.42	50	0.36	50	0.30	50	0.24	50
	9			0.43	50	0.37	50	0.30	50	0.25	50
	10			0.45	50	0.38	50	0.31	50	0.25	50
	12			0.49	51	0.42	50	0.33	50	0.26	50
	14			0.54	52	0.46	51	0.37	50	0.27	50
	16			0.58	53	0.49	51	0.42	50	0.28	50
	20			0.65	54	0.57	53	0.50	51	0.33	50
	24			0.71	56	0.63	54	0.55	52	0.43	50
	28			0.77	—	0.70	55	0.60	53	0.50	51
	32			0.82	—	0.76	—	0.64	54	0.55	52
42	2.5	†	†	0.46	50	0.40	50	0.32	50	0.26	50
	3			0.44	50	0.38	50	0.31	50	0.25	50
	4			0.42	50	0.37	50	0.30	50	0.25	50
	5			0.42	50	0.37	50	0.30	50	0.25	50
	6			0.42	50	0.37	50	0.30	50	0.25	50
	7			0.44	50	0.38	50	0.31	50	0.25	50
	8			0.46	50	0.39	50	0.32	50	0.26	50
	9			0.48	50	0.41	50	0.33	50	0.26	50
	10			0.50	51	0.42	50	0.33	50	0.27	50
	12			0.55	51	0.47	50	0.35	50	0.28	50
	14			0.60	52	0.52	51	0.42	50	0.29	50
	16			0.64	53	0.56	52	0.48	50	0.30	50
	20			0.73	54	0.64	53	0.57	52	0.37	50
	24			0.80	56	0.71	54	0.63	53	0.49	50
	28			0.87	—	0.79	55	0.69	54	0.57	52
	32			0.93	—	0.86	—	0.73	54	0.63	53
48	2.5	†	†	0.50	50	0.43	50	0.35	50	0.28	50
	3			0.48	50	0.42	50	0.34	50	0.28	50
	4			0.46	50	0.40	50	0.33	50	0.27	50
	5			0.46	50	0.40	50	0.33	50	0.27	50
	6			0.47	50	0.41	50	0.33	50	0.27	50
	7			0.48	50	0.42	50	0.34	50	0.28	50
	8			0.51	50	0.44	50	0.35	50	0.28	50
	9			0.53	50	0.45	50	0.36	50	0.29	50
	10			0.56	51	0.47	50	0.37	50	0.30	50
	12			0.61	51	0.53	50	0.39	50	0.31	50
	14			0.67	52	0.59	51	0.48	50	0.32	50
	16			0.72	53	0.64	52	0.55	51	0.33	50
	20			0.82	54	0.72	53	0.65	52	0.43	50
	24			0.91	56	0.80	54	0.72	53	0.56	51
	28			0.98	—	0.89	55	0.79	54	0.65	52
	32			1.05	—	0.97	—	0.84	55	0.72	53

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

TABLE 50.12—(*cont.*)

Size *in.*	Depth of Cover *ft*	Laying Condition									
		Type 1		Type 2		Type 3		Type 4		Type 5	
		Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class	Total Calculated Thickness* *in.*	Use Class
54	2.5	†	†	0.54	50	0.46	50	0.37	50	0.30	50
	3			0.52	50	0.45	50	0.37	50	0.30	50
	4			0.51	50	0.44	50	0.36	50	0.30	50
	5			0.51	50	0.44	50	0.36	50	0.30	50
	6			0.52	50	0.45	50	0.37	50	0.30	50
	7			0.53	50	0.46	50	0.37	50	0.30	50
	8			0.56	50	0.48	50	0.38	50	0.31	50
	9			0.59	50	0.50	50	0.39	50	0.32	50
	10			0.62	51	0.52	50	0.41	50	0.32	50
	12			0.68	51	0.60	50	0.43	50	0.34	50
	14			0.74	52	0.67	51	0.54	50	0.35	50
	16			0.80	53	0.72	52	0.62	51	0.36	50
	20			0.91	54	0.81	53	0.73	52	0.48	50
	24			1.01	56	0.89	54	0.81	53	0.63	51
	28			1.09	—	0.99	55	0.88	54	0.73	52
	32			1.17	—	1.08	—	0.94	55	0.81	53

* Total calculated thickness includes service allowance and casting tolerance added to net thickness.
† For pipe 30 in. and larger, consideration should be given to laying condit ons other than Type 1.

TABLE 50.13

Thickness for Internal Pressure

Pipe Size *in.*	Rated Water Working Pressure*—*psi*									
	150		200		250		300		350	
	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class	Total Calculated Thickness *in.*†	Use Class
3	0.15	51	0.16	51	0.16	51	0.17	51	0.17	51
4	0.16	51	0.16	51	0.17	51	0.18	51	0.18	51
6	0.17	50	0.18	50	0.19	50	0.20	50	0.20	50
8	0.18	50	0.19	50	0.21	50	0.22	50	0.23	50
10	0.21	50	0.22	50	0.23	50	0.25	50	0.26	50
12	0.22	50	0.23	50	0.25	50	0.27	50	0.28	50
14	0.24	50	0.26	50	0.28	50	0.30	50	0.31	50
16	0.25	50	0.27	50	0.30	50	0.32	50	0.34	50
18	0.27	50	0.29	50	0.31	50	0.34	50	0.36	50
20	0.28	50	0.30	50	0.33	50	0.36	50	0.38	51
24	0.30	50	0.33	50	0.37	50	0.40	51	0.43	52
30	0.34	50	0.38	50	0.42	51	0.45	52	0.49	53
36	0.38	50	0.42	50	0.47	51	0.51	52	0.56	53
42	0.41	50	0.47	50	0.52	51	0.57	52	0.63	53
48	0.46	50	0.52	50	0.58	51	0.64	52	0.70	53
54	0.51	50	0.58	50	0.65	51	0.71	52	0.78	53

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi.
† Total calculated thickness includes service allowance and casting tolerance added to net thickness.

TABLE 50.14

Rated Working Pressure and Maximum Depth of Cover

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure *psi**	Laying Condition — Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
3	51	0.25	350	98	100‡	100‡	100‡	100‡
	52	0.28	350	100‡	100‡	100‡	100‡	100‡
	53	0.31	350	100‡	100‡	100‡	100‡	100‡
	54	0.34	350	100‡	100‡	100‡	100‡	100‡
	55	0.37	350	100‡	100‡	100‡	100‡	100‡
	56	0.40	350	100‡	100‡	100‡	100‡	100‡
4	51	0.26	350	76	86	96	100‡	100‡
	52	0.29	350	100‡	100‡	100‡	100‡	100‡
	53	0.32	350	100‡	100‡	100‡	100‡	100‡
	54	0.35	350	100‡	100‡	100‡	100‡	100‡
	55	0.38	350	100‡	100‡	100‡	100‡	100‡
	56	0.41	350	100‡	100‡	100‡	100‡	100‡
6	50	0.25	350	32	38	44	56	75
	51	0.28	350	49	57	64	80	100‡
	52	0.31	350	67	77	86	100‡	100‡
	53	0.34	350	91	100‡	100‡	100‡	100‡
	54	0.37	350	100‡	100‡	100‡	100‡	100‡
	55	0.40	350	100‡	100‡	100‡	100‡	100‡
	56	0.43	350	100‡	100‡	100‡	100‡	100‡
8	50	0.27	350	25	30	36	46	64
	51	0.30	350	36	42	49	61	81
	52	0.33	350	47	54	62	77	99
	53	0.36	350	64	73	82	100‡	100‡
	54	0.39	350	80	91	100‡	100‡	100‡
	55	0.42	350	98	100‡	100‡	100‡	100‡
	56	0.45	350	100‡	100‡	100‡	100‡	100‡
10	50	0.29	350	19	24	29	38	55
	51	0.32	350	27	32	38	49	66
	52	0.35	350	35	41	47	59	79
	53	0.38	350	45	52	59	74	95
	54	0.41	350	57	65	74	91	100‡
	55	0.44	350	67	77	86	100‡	100‡
	56	0.47	350	81	92	100‡	100‡	100‡
12	50	0.31	350	17	22	27	36	52
	51	0.34	350	23	28	33	43	60
	52	0.37	350	30	35	41	53	71
	53	0.40	350	36	42	49	61	81
	54	0.43	350	45	52	59	74	95
	55	0.46	350	54	62	71	87	100‡
	56	0.49	350	64	73	83	100‡	100‡

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
‡ Calculated maximum depth of cover exceeds 100 ft.

TABLE 50.14—(*cont.*)

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure *psi**	Laying Condition: Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
14	50	0.33	350	15	19	24	33	49
	51	0.36	350	19	23	28	38	55
	52	0.39	350	24	29	34	44	62
	53	0.42	350	30	35	41	53	71
	54	0.45	350	36	42	49	61	81
	55	0.48	350	43	50	57	71	92
	56	0.51	350	52	59	67	83	100‡
16	50	0.34	350	13	17	21	30	47
	51	0.37	350	16	21	25	34	51
	52	0.40	350	20	25	30	40	57
	53	0.43	350	25	30	36	46	64
	54	0.46	350	30	35	41	53	71
	55	0.49	350	35	41	47	59	79
	56	0.52	350	41	48	55	68	89
18	50	0.35	350	11	15	20	29	42
	51	0.38	350	14	19	23	32	49
	52	0.41	350	18	22	27	36	53
	53	0.44	350	22	26	31	41	58
	54	0.47	350	25	30	36	46	64
	55	0.50	350	30	35	41	53	71
	56	0.53	350	35	41	47	59	79
20	50	0.36	300	10	14	18	27	38
	51	0.39	350	13	17	21	30	44
	52	0.42	350	16	20	25	34	50
	53	0.45	350	19	23	28	38	54
	54	0.48	350	22	27	32	42	59
	55	0.51	350	26	31	37	47	65
	56	0.54	350	30	35	41	53	71
24	50	0.38	250	8	12	17	23	31
	51	0.41	300	10	15	19	27	36
	52	0.44	350	13	17	21	30	41
	53	0.47	350	15	19	24	33	47
	54	0.50	350	18	22	27	36	53
	55	0.53	350	20	25	30	40	57
	56	0.56	350	24	29	34	44	61
30	50	0.39	200	§	10	14	18	25
	51	0.43	250		12	16	21	29
	52	0.47	300		14	19	24	33
	53	0.51	350		17	21	29	38
	54	0.55	350		19	24	33	44
	55	0.59	350		22	27	36	51
	56	0.63	350		26	31	41	57

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe or working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
‡ Calculated maximum depth of cover exceeds 100 ft.
§ For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

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TABLE 50.14—(*cont.*)

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure *psi**	Laying Condition: Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
36	50	0.43	200	§	10	13	17	25
	51	0.48	250		12	16	20	28
	52	0.53	300		15	19	24	32
	53	0.58	350		17	21	28	37
	54	0.63	350		20	25	33	43
	55	0.68	350		23	28	37	50
	56	0.73	350		26	31	41	59
42	50	0.47	200	§	9	13	16	24
	51	0.53	250		12	15	19	27
	52	0.59	300		14	18	22	30
	53	0.65	350		17	22	27	35
	54	0.71	350		20	24	32	42
	55	0.77	350		23	28	38	48
	56	0.83	350		26	31	41	57
48	50	0.51	200	§	9	12	15	23
	51	0.58	250		12	14	18	26
	52	0.65	300		14	18	21	30
	53	0.72	350		17	21	25	34
	54	0.79	350		20	24	30	40
	55	0.86	350		23	28	37	47
	56	0.93	350		26	31	41	55
54	50	0.57	200	§	9	12	15	23
	51	0.65	250		12	14	18	25
	52	0.73	300		14	17	21	29
	53	0.81	350		17	21	25	34
	54	0.89	350		20	25	30	40
	55	0.97	350		23	28	37	47
	56	1.05	350		27	32	42	55

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
‡ Calculated maximum depth of cover exceeds 100 ft.
§ For pipe 30 in. and larger, consideration should be given to laying conditions other than Type 1.

3P—5M—4/78—43150

ANSI A21.4–1974
(AWWA C104–74)

Revision of
A21.4–1971
(AWWA C104–71)

AMERICAN NATIONAL STANDARD

for

CEMENT-MORTAR LINING FOR CAST-IRON AND DUCTILE-IRON PIPE AND FITTINGS FOR WATER

ADMINISTRATIVE SECRETARIAT

AMERICAN WATER WORKS ASSOCIATION

CO-SECRETARIATS

AMERICAN GAS ASSOCIATION

NEW ENGLAND WATER WORKS ASSOCIATION

Revised edition approved by American National Standards Institute, Inc., Mar. 7, 1974.

PUBLISHED BY

AMERICAN WATER WORKS ASSOCIATION

6666 West Quincy Avenue, Denver, Colo. 80235

American National Standard

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Kenneth W. Henderson, *Vice-Chairman*

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Peter E. Pallo	W. Harry Smith
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American Society of Civil Engineers	Kenneth W. Henderson
American Society of Mechanical Engineers	James S. Vanick
American Society for Testing and Materials	Albert H. Smith Jr.
American Water Works Association	Lloyd W. Weller
Cast Iron Pipe Research Association	Carl A. Henrikson
	Edward C. Sears
	W. Harry Smith
Individual Producers	Alfred F. Case
	William T. Maher
Manufacturers' Standardization Society of the Valve and Fittings Industry	Abraham Fenster
New England Water Works Association	Walter Amory
Naval Facilities Engineering Command	Stanley C. Baker
Underwriters' Laboratories, Inc.	Stanley E. Auck
Canadian Standards Association	W. F. Semenchuk*

* Liaison representative without vote.

Foreword

This foreword is for information and is not a part of ANSI A21.4–1974 (AWWA C104–74).

I—History of Standard

The first recorded installation of cement-mortar linings in cast-iron pipe was in 1922 at Charleston, S.C., under the supervision of J. E. Gibson.

From 1922 to 1929, many installations were made under various manufacturers' specifications. In 1929, ASA (now ANSI) Sectional Committee A21 issued a tentative standard for cement-mortar linings. This was published as a tentative standard by AWWA in 1932. After many revisions and refinements, it was finally adopted by ASA in 1939 under the designation A21.4—Specifications for Cement-Mortar Lining for Cast-Iron Pipe and Fittings.

During the period 1940–52, much research was done on various types of cement, methods of manufacture, and methods of curing cement mortar to improve the quality of cement-mortar linings. As a result of this research, a revised edition of the 1939 standard was approved and issued in 1953.

The centrifugal process for lining was further developed during the 1940–52 period to provide the controls and techniques necessary for assurance of uniformity of thickness throughout the length of a pipe. Another major revision recognized the ability of cure-assist bituminous materials to provide controlled curing of the mortar. The use of this method was permitted as a substitute for the moist-curing process.

In 1958, Sectional Committee A21 was reorganized and subcommittees were established to study each group of standards in accordance with ASA's review and revision policy.

Subcommittee 4 (Coatings and Linings for Cast-Iron Pipe) was organized to examine the existing ASA A21.4–1953, "Standard for Cement-Mortar Lining for Cast-Iron Pipe and Fittings." This subcommittee completed its study of A21.4–53 and submitted a proposed revision to Sectional Committee A21 in 1963. The revised third edition was approved and issued in 1964.

The 1964 standard reduced the minimum permissible thickness of the lining. This reduction was based on more than 20 years of Cast Iron Pipe Research Association (CIPRA) studies of experimental test lines having cement-mortar linings varying from $\frac{1}{32}$ in. to $\frac{1}{4}$ in. in thickness, on field tests of linings of these thicknesses that had been in service for more than 30 years, and on the assurance of uniformity of thickness afforded by improvements in the centrifugal lining process.

Two thicknesses of lining were made available, and purchasers who required a lining thickness twice the standard thickness had the option of so specifying.

The cement linings were specified for use in water lines only. This qualification was made to avoid the use of cement-mortar linings in pipe carrying aggressive liquids, which would react with the lining to produce undesirable results.

The purchaser of cement-mortar-lined pipe or fittings for use with a water that is corrosive to calcium carbonate, such as a very soft water, is advised, before specifying the omission of the seal coat, to satisfy himself by appropriate test that such a lining will not impart objectionable hardness or alkalinity to the water. The procedure outlined in Sec. 4–14.4, modified by the substitution of the water with which the pipe is to be used for distilled water, is suggested as a convenient form of test.

The 1971 revision incorporated a standard test for toxicity of the seal coat material.

This standard does not include provisions for cement-mortar lining of pipelines in place.

II—Major Revision

The title of Sec. 4–13 has been changed from Finished Lining to Lining Quality, and the entire section has been rewritten to provide new requirements of acceptable lining.

III—Options

This standard includes certain options, which, if desired, ***must*** be specified. These are:

1. *Thickness of lining.* Two thicknesses of lining are available, and purchasers who require a lining thickness twice the standard thickness have the option of so specifying (Sec. 4–10).
2. *Seal coat.* As other seal coats than bituminous ones are available, this standard makes provision for their use (Sec. 4–14).

ANSI A21.4–1974
(AWWA C104–74)

Revision of
A21.4–1971
(AWWA C104–71)

American National Standard for

Cement-Mortar Lining for Cast-Iron and Ductile-Iron Pipe and Fittings for Water

Sec. 4–1—Scope

This standard covers cement-mortar linings specified in the A21 series of ANSI Standards for Cast-Iron and Ductile-Iron Pipe and Fittings for Water and is intended for use as a supplement to those standards.

Sec. 4–2—Cement

The cement shall meet the requirements of "Standard Specifications for Portland Cement," ASTM Designation C150–73–a. The analysis and physical test records of each shipment shall be kept for reference for 1 year.

The type of cement selected shall be left to the option of the pipe and fittings manufacturer.

Sec. 4–3—Sand

4–3.1. *Type of sand.* The sand shall be well graded, from fine to coarse, and consist of inert granular material having hard, strong, durable, uncoated grains and meet the test requirements of Sec. 4–3.2.

4–3.2. *Testing of sand.* The sand shall be tested in accordance with the requirements of these sections:

4–3.2.1. *Sampling.* The sand to be tested shall be sampled according to Sections 14 and 15 of ASTM D75–71, "Standard Methods of Sampling Aggregates."

4–3.2.2. *Sieve tests.* The sand shall be tested with standard sieves, as defined in ASTM Designation E11–70, "Standard Specification for Wire-Cloth Sieves for Testing Purposes," and shall meet the requirements listed in Table 1. One sieve analysis shall be performed on each carload of sand delivered. For sand delivered by other means, one sieve analysis shall be made for each 50 tons.

4–3.2.3. *Colorimetric test.* The test for impurities shall be in accordance with ASTM C40–73, "Standard Method of Test for Organic Impurities in Sands for Concrete."

TABLE 1

Requirements for Sand Tested With Standard Sieves

Min. Thickness of Lining in.	Sieve Requirement*	
	100 Per Cent of Sand Shall Pass (Sieve No.)	75 Per Cent of Sand Shall Pass (Sieve No.)
$\frac{1}{16}$	12	20
$\frac{3}{32}$	12	16
$\frac{1}{8}$	12	†
$\frac{3}{16}$	8	†
$\frac{1}{4}$	6	†

* Not more than 10 per cent, by weight, of any sand shall pass through sieve No. 100.
† Not applicable.

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Under this test, the sand shall not produce a color darker than required in the standard. The sand shall be acceptable, however, if it is shown by adequate test that the impurities causing the color are not harmful to the strength or other specified properties of the finished lining.

The colorimetric tests of sand from an established source of supply shall be made once each 6 months. For sand from a new source, these tests shall be made not less than once a month for a period of 6 months.

4–3.2.4. *Decantation test.* The sand shall be tested according to ASTM C117–69, "Standard Method of Test for Materials Finer Than No. 200 (75-μm) Sieve in Mineral Aggregates by Washing."

At the option of the manufacturer, the clay content and sand grain fineness may be determined by using the American Foundrymen's Society procedure, described in the *Foundry Sand Handbook,* Seventh Edition, Section 5. By this latter method, the total percentage finer than No. 200 sieve, as defined in ASTM Designation C119–71, is equal to the AFS percentage of clay plus the percentage passing through the No. 200 sieve.

No more than 2 per cent shall be lost in the decantation test.

The decantation tests of sand from an established source of supply shall be made once each 6 months. For sand from a new source, these tests shall be made not less than once a month for a period of 6 months.

4–3.2.5. *Test records.* The requirements of Sec. 4–3.2.2, 4–3.2.3, and 4–3.2.4 shall be met, and the records shall be filed for reference for 1 year.

Sec. 4–4—Water

The water used for tempering the mortar shall meet the requirements of the United States Public Health Service Drinking Water Standards 1962.

Sec. 4–5—Mortar

Mortar for the lining shall be composed of cement, sand, and water. The mortar shall be well mixed and of proper consistency to produce a dense, homogeneous lining that will adhere firmly to the pipe or fitting surface. Admixtures may be used, provided the linings meet all the requirements of this standard. The cement mortar shall contain not less than one part of cement to two parts of sand, by volume.

Sec. 4–6—Preparation of Pipe and Fittings for Lining

The surface to be lined shall be free from foreign material, which would adversely affect the lining adhesion or cause inclusions, blisters, or voids in the lining. The surface shall be free from projections of iron which may protrude through the lining.

Sec. 4–7—Method of Lining

4–7.1. *Lining of pipe and fittings.* Pipe shall be lined by the centrifugal process. Fittings shall be lined by a process that will produce linings meeting the requirements of this standard.

4–7.2. *Mortar.* The waterway surfaces of pipe and fittings shall be completely covered with the specified mortar. The mortar shall be entirely free from holidays or visible bubbles of air and shall be thoroughly compacted throughout. The consistency of the mortar and the time and speed of spinning of the pipe shall be so adjusted as to minimize the segregation of the sand from the cement and to deliver the finished lining substantially free of laitance.

4–7.3. *Repair of defective or damaged areas of linings.* Defective or damaged areas of linings may be patched by cutting out the defective or damaged lining to the metal so that the edges of the lining not removed are perpendicular or slightly undercut. A stiff mortar shall be prepared in accordance with Sec. 4–5. The cut-out area and the adjoining lining shall be thoroughly wetted, and the mortar applied and troweled smooth with the adjoining lining. After any surface water has evaporated, but while the patch is still moist, it shall be cured as specified in Sec. 4–12.

Sec. 4–8—Socket

The socket shall be free of mortar.

Sec. 4–9—Protection of Work

The lined pipe and fittings shall be protected from extreme heat due to direct rays of the sun, from impact of rainfall, and from freezing temperatures until the linings have cured sufficiently to withstand these conditions.

Sec. 4–10—Thickness of Lining

4–10.1. *Standard thickness.* The thickness of linings for pipe and fittings, as determined in Sec. 4–11, shall be not less than $\frac{1}{16}$ in. for 3–12 in. pipe, $\frac{3}{32}$ in. for 14–24 in. pipe, and $\frac{1}{8}$ in. for 30–54 in. pipe.

4–10.2. *Double thickness.* Linings with thicknesses twice those specified in Sec. 4–10.1 shall be furnished if specified by the purchaser.

4–10.3. *Taper of linings.* Lining thickness may taper to less than the specified minimum thickness at the ends of the pipe or fitting. The length of the taper shall be as short as practicable and shall not exceed 2 in.

4–10.4. *Permitted tolerances.* A thickness tolerance of $+\frac{1}{8}$ in. shall be permitted on pipe and $+\frac{1}{4}$ in. on fittings.

Sec. 4–11—Determination of Thickness

Lining thickness shall be determined at intervals frequent enough to assure compliance. Thickness of lining may be determined by means of spear measurement, with a hardened-steel point not larger than $\frac{1}{16}$ in. in diameter. The inspector shall pierce the lining immediately after it is placed in the pipe or fitting and before the mortar has set. The lining shall be pierced at four equidistant points on two cross sections of the barrel at each end of the pipe or fitting. The first set shall be not more than 4 in. from the respective ends of the pipe or fitting. The second set shall be made as far into the interior of the pipe or fitting as can be readily reached without injuring the lining.

Sec. 4–12—Curing

The lining shall be cured in such a manner as to produce a properly hydrated mortar lining that is hard and durable and will otherwise meet the requirements of Sec. 4–13. The cure may be effected by the application of a seal coat to the still-moist lining.

Sec. 4–13—Lining Quality

The lining shall be free from voids, ridges, or corrugations that reduce the thickness of lining to less than the specified thickness.

Unbonded areas of cement lining in a pipe or fitting are acceptable if the dimension of any single area does not exceed the nominal diameter in the circumferential direction and in longitudinal direction does not exceed the nominal diameter or 12 in., whichever is greater.

Longitudinal cracks less than 9 in. in length or less than the nominal diameter, whichever is greater, are acceptable. Circumferential cracks of any length are acceptable. Surface crazing is acceptable.

Repair of any unacceptable condition is permitted in the field, in accordance with Sec. 4–7.3.

Sec. 4–14—Seal Coat

4–14.1. *General.* Unless otherwise specified, the cement lining shall be given a seal coat of bituminous material. Other seal coat materials may be used, but they shall be agreed upon at the time of purchase and shall be specified on the purchase order.

4–14.2. *Seal coat characteristics.* The seal coat shall be continuous and shall adhere to the mortar lining at all points. The seal coat, after drying for at least 48 hr, shall have no deleterious effect upon the quality, color, taste, or odor of potable water.

4–14.3. *Limit of toxic substances.*

4–14.3.1. *Requirements.* The seal coat material shall not yield chloroform-soluble extractives, corrected for zinc extractives as zinc oleate, in excess of 18 mg per sq in. of surface exposed or of 50 ppm by weight of the water capacity of the test container.

4–14.3.2. *Frequency of test.* The seal coat material shall be tested at sufficiently frequent intervals to determine that it meets the requirements prescribed in Sec. 4–14.3.1.

4–14.3.3. *Method of testing.* The procedure used in the determination of the amount of toxic substances shall be in accordance with the FDA "Method of Testing for Toxicity of Coating Material Intended for Use in Transporting or Holding Food or Potable Water," as described in *Food Additives Amendment and Code of Federal Regulations,* pp. 13.0 through 13.8, April 16, 1963, Food and Drug Administration, US Department of Health, Education and Welfare. The seal coat material shall be extracted with distilled or demineralized water at 120F for 24 hr.

4–14.4. *Leaching resistance.*

4–14.4.1. *Requirements.* The seal-coated pipe shall impart to the water during any 24-hr test period no more than 25 ppm of hardness or 25 ppm of total alkalinity, and shall impart no caustic alkalinity.

4–14.4.2. *Frequency of test and records.* Leaching tests shall be made at sufficiently frequent intervals to assure compliance. The results of one test each month shall be filed for reference for 1 year.

4–14.4.3. *Method of testing.* The seal-coated pipe shall be tested as follows:

The test specimen shall be at least 6 in. in length, either cut or isolated by suitable closure pieces. When a cut section is used, it shall be bedded on end in a shallow pan of molten paraffin. After the paraffin has cooled, the cut section shall be filled nearly to the top with distilled or demineralized water at laboratory temperature. The top shall be covered with a glass plate and sealed with petroleum jelly. If an isolated section is used, it shall be filled through a tap in the closure device with distilled or demineralized water at laboratory temperature.

In either case, the water in the specimen shall be changed and tested after 24-hr contact on each of 3 successive days. The methods and procedures used in the determination of hardness and alkalinity shall be those prescribed in *Standard Methods for the Examination of Water and Wastewater,* APHA, AWWA, and WPCF, thirteenth edition, 1971.

?P—10M—11 75—43104

(AWWA C151-76)
ANSI A21.51-1976

Revision of
A21.51-1971
(AWWA C151-71)

AMERICAN NATIONAL STANDARD

for

DUCTILE-IRON PIPE, CENTRIFUGALLY CAST IN METAL MOLDS OR SAND-LINED MOLDS, FOR WATER OR OTHER LIQUIDS

SECRETARIATS

AMERICAN GAS ASSOCIATION
AMERICAN WATER WORKS ASSOCIATION
NEW ENGLAND WATER WORKS ASSOCIATION

Revised edition approved by American National Standards Institute, Inc., Aug. 4, 1976

PUBLISHED BY
AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

American National Standard

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Committee Personnel

Subcommittee 1, Pipe, which reviewed this standard, had the following personnel at that time:

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WALTER AMORY, *Vice-Chairman*

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FRANK E. DOLSON	W. D. GOODE
GEORGE F. KEENAN	THOMAS D. HOLMES
LEONARD ORLANDO JR.	HAROLD KENNEDY JR.
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Standards Committee A21, Cast-Iron Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

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American Society of Mechanical Engineers	JAMES S. VANICK
American Society for Testing and Materials	H. M. COBB *
American Water Works Association	ARNOLD M. TINKEY
	LLOYD W. WELLER
Cast Iron Pipe Research Association	THOMAS D. HOLMES
	HAROLD KENNEDY JR.
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	W. HARRY SMITH
Individual Producer	ALFRED F. CASE
Manufacturers' Standardization Society of the Valve and Fittings Industry	ABRAHAM FENSTER
New England Water Works Association	WALTER AMORY
Naval Facilities Engineering Command	STANLEY C. BAKER
Underwriters' Laboratories, Inc.	JOHN E. PERRY
Canadian Standards Association	W. F. SEMENCHUK †

* Alternate
† Liaison representative without vote

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Foreword

This foreword is for information only and is not a part of ANSI A21.51 (AWWA C151).

American National Standards Committee A21 on Cast-Iron Pipe and Fittings was organized in 1926 under the sponsorship of the American Gas Association, The American Society for Testing and Materials, the American Water Works Association, and the New England Water Works Association. Since 1972, the co-secretariats have been A.G.A., AWWA, and NEWWA, with AWWA serving as the administrative secretariat. The present scope of Committee A21 activity is

> Standardization of specifications for cast-iron and ductile-iron pressure pipe for gas, water and other liquids, and fittings for use with such pipe. These specifications to include design, dimensions, materials, coatings, linings, joints, accessories and methods of inspection and test.

The work of Committee A21 is conducted by subcommittees. The directive to Subcommittee 1—Pipe is that

> The scope of the subcommittee activity shall include the periodic review of all current A21 standards for pipe, the preparation of revisions and new standards when needed, as well as other matters pertaining to pipe standards.

The first edition of A21.51, the standard for ductile-iron pipe for water and other liquids, was issued in 1965, and a revision was issued in 1971. Subcommittee 1 reviewed the 1971 edition and submitted a proposed revision to American National Standards Committee A21 in 1975.

Major Revisions

1. An additional minus tolerance of 0.02 in. is permitted along the barrel of the pipe for a distance not to exceed 12 in. The weight tolerance permitted for any single pipe is 6 per cent for pipe 12 in. or smaller and 5 per cent for pipe larger than 12 in.
2. The tables include data for the five standard laying conditions covered in A21.50–1976. Types 1, 2, and 3 replace A, B, and S, respectively, in A21.51–1971. Types 3 and 4 have been added to provide a wider selection of laying conditions.
3. The pipe thickness selection tables have been revised to reflect the changes in the 1976 edition of A21.50, the standard for thickness design of ductile-iron pipe.
4. The standard thickness classes have been renumbered. Class 1 becomes Class 51; Class 2 becomes Class 52; and so on. Class 50 has been added for 6–54-in. pipe, and Class 51 has been added for 3–12-in. pipe.
5. Pipe weights have been adjusted for 3–24-in. push-on joint pipe to reflect lighter bell weights based on push-on joint bells, which are more compatible with the barrel thicknesses of ductile-iron pipe.
6. A table (Table 3) has been added to show rated working pressure and maximum depth of cover of the standard laying conditions and standard thickness classes.

Options

This standard includes certain options that, if desired, must be specified on the purchase order. Also, a number of items must be specified to describe completely the pipe required. The following summarizes the details and available options and lists the sections of the standard where they can be found.

1. Size, joint type, thickness or class, and laying length (Tables).
2. a. Special joints (Sec. 51–3.1).
   b. Specifying ductile-iron gland, if required (Sec. 51–3.1).
3. Certification by manufacturer (Sec. 51–4.2).
4. Inspection by purchaser (Sec. 51–5).
5. a. No requirement for outside coating (Sec. 51–8.1).
   b. Cement lining (Sec. 51–8.2). Experience has indicated that bituminous inside coating is not complete protection against loss in pipe capacity caused by tuberculation. Cement linings are recommended for most waters.
   c. No requirement for inside coating (Sec. 51–8.3).
   d. Special coatings and linings (Sec. 51–8.4).
6. Special marking on pipe (Sec. 51–10).
7. Written transcripts of foundry records (Sec. 51–14).
8. Special tests (Sec. 51–15).

ANSI A21.51-1976
(AWWA C151-76)

Revision of
A21.51-1971
(AWWA C151-71)

American National Standard for

Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds, for Water or Other Liquids

Sec. 51-1—Scope

This standard covers 3-in. through 54-in. ductile-iron pipe centrifugally cast in metal molds or sand-lined molds for water or other liquids with push-on joints or mechanical joints. This standard may be used for pipe with such other types of joints as may be agreed upon at the time of purchase.

Sec. 51-2—Definitions

Under this standard, the following definitions shall apply:

51-2.1 *Purchaser.* The party entering into a contract or agreement to purchase pipe according to this standard.

51-2.2 *Manufacturer.* The party that produces the pipe.

51-2.3 *Inspector.* The representative of the purchaser, authorized to inspect on behalf of the purchaser to determine whether or not the pipe meets this standard.

51-2.4 *Ductile iron.* A cast ferrous material in which a major part of the carbon content occurs as free carbon in nodular or spheroidal form.

51-2.5 *Mechanical joint.* The gasketed and bolted joint as detailed in ANSI A21.11 (AWWA C111) of latest revision.

51-2.6 *Push-on joint.* The single rubber-gasket joint as described in ANSI A21.11 (AWWA C111) of latest revision.

Sec. 51-3—General Requirements

51-3.1 Pipe with mechanical joints or push-on joints shall conform to the applicable dimensions and weights shown in the tables in this standard and to the applicable requirements of ANSI A21.11 (AWWA C111) of latest revision. Unless otherwise specified, the mechanical-joint glands shall be cast iron in accordance with ANSI A21.11 of latest revision and bolts shall conform to the requirements of the same standard. Pipe with other types of joints shall comply with the joint dimensions and weights agreed upon at the time of purchase but in all other respects shall fulfill the requirements of this standard.

51-3.2 The nominal laying length of the pipe shall be as shown in the tables. A maximum of 20 per cent of the total number of pipe of each size specified in an order may be furnished by as much as 24 in. shorter than the nominal laying length, and an additional 10 per cent may be furnished by as much as 6 in. shorter than nominal laying length.

Sec. 51-4—Inspection and Certification by Manufacturer

51-4.1 The manufacturer shall establish the necessary quality-control and inspection practice to ensure compliance with this standard.

51-4.2 The manufacturer shall, if required on the purchase order, furnish a sworn statement that the inspection and all of the specified tests have been made and the results thereof comply with the requirements of this standard.

51-4.3 All pipe shall be clean and sound without defects that could impair service. Repairing of defects by welding or other methods shall not be allowed if such repairs could adversely affect the serviceability of the pipe or its capability to meet strength requirements of this standard.

Sec. 51-5—Inspection by Purchaser

51-5.1 If the purchaser desires to inspect pipe at the manufacturer's plant, the purchaser shall so specify on the purchase order, stating the conditions (such as time and the extent of inspection) under which the inspection shall be made.

51-5.2 The inspector shall have free access to those parts of the manufacturer's plant that are necessary to ensure compliance with this standard. The manufacturer shall make available for the inspector's use such gages as are necessary for inspection. The manufacturer shall provide the inspector with assistance as necessary for handling of pipe.

Sec. 51-6—Delivery and Acceptance

All pipe and accessories shall comply with this standard. Pipe and accessories not complying with this standard shall be replaced by the manufacturer at the agreed point of delivery. The manufacturer shall not be liable for shortages or damaged pipe after acceptance at the agreed point of delivery, except as recorded on the delivery receipt or similar document by the carrier's agent.

Sec. 51-7—Tolerances or Permitted Variations

51-7.1 *Dimensions.* The spigot end, bell, and socket of the pipe and the accessories shall be gaged with suitable gages at sufficiently frequent intervals to ensure that the dimensions comply with the requirements of this standard. The smallest inside diameter of the sockets and the outside of the spigot ends shall be tested with circular gages. Other socket dimensions shall be gaged as may be appropriate.

51-7.2 *Thickness.* Minus thickness tolerances of pipe and bell shall not exceed the following:

Size *in.*	Minus Tolerance *in.*
3-8	0.05
10-12	0.06
14-42	0.07
48	0.08
54	0.09

An additional minus tolerance of 0.02 in. shall be permitted along the barrel of the pipe for a distance not to exceed 12 in.

51-7.3 *Weight.* The weight of any single pipe shall not be less than the tabulated weight by more than 6 per cent for pipe 12 in. or smaller in diameter, or by more than 5 per cent for pipe larger than 12 in. in diameter.

Sec. 51-8—Coatings and Linings

51-8.1 *Outside coating.* The out-

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side coating for use under normal conditions shall be a bituminous coating approximately 1 mil thick. The coating shall be applied to the outside of all pipe, unless otherwise specified. The finished coating shall be continuous, smooth, neither brittle when cold nor sticky when exposed to the sun, and shall be strongly adherent to the pipe.

51–8.2 *Cement-mortar linings.* Cement linings shall be in accordance with ANSI A21.4 (AWWA C104) of latest revision. If desired by the purchaser, cement linings shall be specified in the invitation for bids and on the purchase order.

51–8.3 *Inside coating.* Unless otherwise specified, the inside coating for pipe that is not cement-lined shall be a bituminous material as thick as practicable (at least 1 mil) which conforms to all appropriate requirements for seal coat in ANSI A21.4 of latest revision.

51–8.4 *Special coatings and linings.* For special conditions, other types of coatings and linings may be available. Such special coatings and linings shall be specified in the invitation for bids and on the purchase order.

Sec. 51–9—Hydrostatic Test

Each pipe shall be subjected to a hydrostatic test of not less than 500 psi. This test may be made either before or after the outside coating and inside coating have been applied, but shall be made before the application of cement lining or of a special lining.

The pipe shall be under the full test pressure for at least 10 s. Suitable controls and recording devices shall be provided so that the test pressure and duration may be adequately ascertained. Any pipe that leaks or does not withstand the test pressure shall be rejected.

In addition to the hydrostatic test before application of a cement lining or special lining, the pipe may be retested, at the manufacturer's option, after application of such lining.

Sec. 51–10—Marking Pipe

The weight, class or nominal thickness, and casting period shall be shown on each pipe. The manufacturer's mark, the year in which the pipe was produced, and the letters "DI" or "DUCTILE" shall be cast or stamped on the pipe. When specified on the purchase order, initials not exceeding four in number shall be cast or stamped on the pipe. All required markings shall be clear and legible, and all cast marks shall be on or near the bell. All letters and numerals on pipe sizes 14 in. and larger shall be not less than ½ in. in height.

Sec. 51–11—Weighing Pipe

Each pipe shall be weighed before the application of any lining or coating other than the bituminous coating and the weight shown on the outside or inside of the bell or spigot end.

Sec. 51–12—Acceptance Tests

The standard acceptance tests for the physical characteristics of the pipe shall be as follows:

51–12.1 *Tensile test.* A tensile test specimen shall be cut longitudinally from the midsection of the pipe wall. This specimen shall be machined and tested in accordance with Fig. 1 and ASTM E8–69, "Tension Testing of Metallic Materials." The yield strength shall be determined by the 0.2 per cent offset, halt-of-pointer, or extension-under-load method. If check tests are to be made, the 0.2 per cent offset

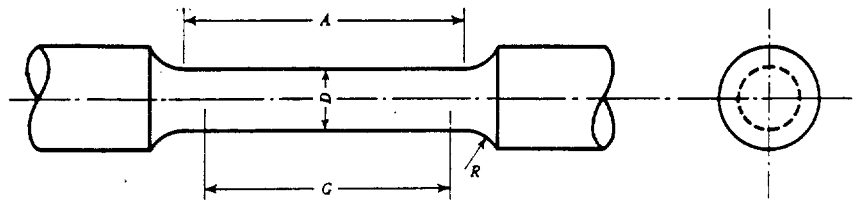

Fig. 1. Tensile-Test Specimen

The tensile-test specimen dimensions are given in the following table:

Dimension	Standard Specimen 0.500 in. round	Small-Size Specimens Proportional to Standard			
		0.350 in. round	0.250 in. round	0.175 in. round	0.125 in. round
	Dimensions—in				
T*	0.71 and greater	0.50–0.70	0.35–0.49	0.25–0.34	0.18–0.24
G	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005	0.700 ± 0.005	0.500 ± 0.005
D	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005	0.175 ± 0.005	0.125 ± 0.005
R	3/8 (min.)	1/4 (min.)	3/16 (min.)	3/32 (min.)	3/32 (min.)
A	2 1/4 (min.)	1 3/4 (min.)	1 1/4 (min.)	3/4 (min.)	5/8 (min.)

* Thickness of the section from the wall of the pipe from which the tensile specimen is to be machined.

Note. 1. The reduced section A may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. larger in diameter than the center on the standard specimen and not more than 0.003 in. larger in diameter than the center on the small size specimens.

Note. 2. If desired, on the small size specimens the length of the reduced section may be increased to accommodate an extensometer. However, reference marks for the measurement of elongation should nevertheless be spaced at the indicated gage length G.

Note. 3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. If the ends are to be held in grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

method shall be used. All specimens shall be tested at room temperature [70F ± 10 (21C ± 6)].

51–12.1.1 *Acceptance values.* The acceptance values for test specimens shall be as follows:

Grade of iron: 60–42–10

1. Minimum tensile strength: 60 000 psi.
2. Minimum yield strength: 42 000 psi.
3. Minimum elongation: 10 per cent.

51–12.2 *Impact test.* Tests shall be made in accordance with ASTM E23–72 "Notched Charpy Tests," except that specimens shall be 0.500 in. by full thickness of pipe wall. The notched impact test specimen shall be in accordance with Fig. 2. If the pipe wall thickness exceeds 0.40 in., the impact specimen may be machined to a nominal thickness of 0.40 in. In all tests, impact values are to be corrected to 0.40-in. wall thickness by calculations as follows:

Impact value (corrected)

$$= \frac{0.40}{t} \times \text{impact value (actual)}$$

in which t is the thickness of the specimen in inches (wall thickness of pipe).

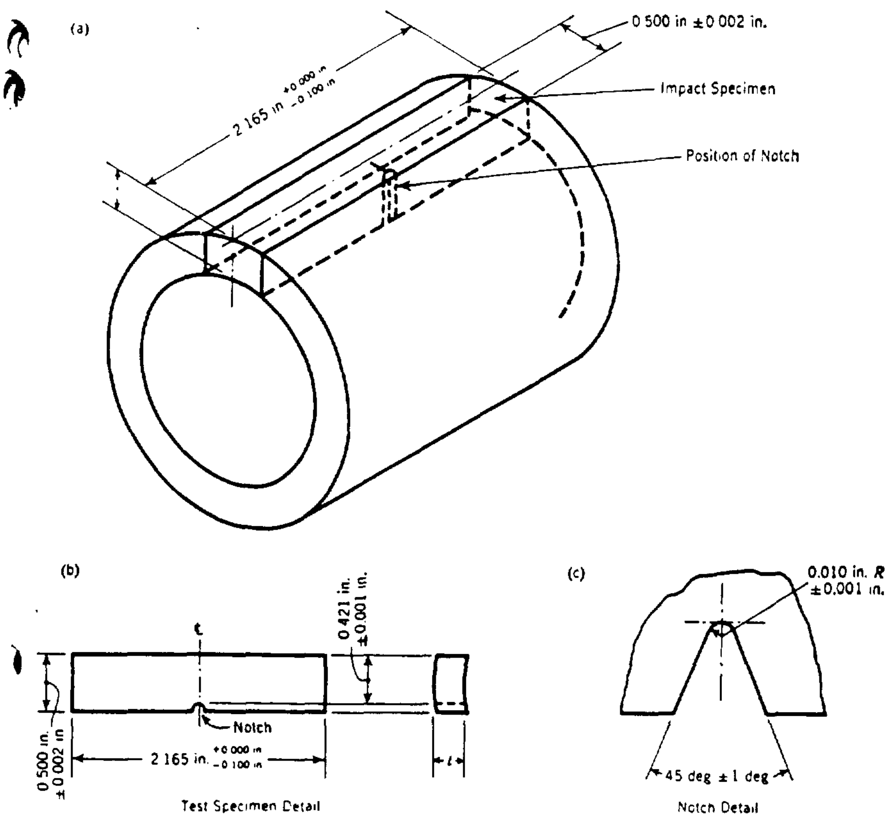

Fig. 2. Impact Test Specimen

In Diagrams (a) and (b) the symbol t *is for the pipe-wall thickness.*

The Charpy test machine anvil shall not be moved to compensate for the variation of cross section dimensions of the test specimen.

51–12.2.1 *Acceptance value.* The corrected acceptance value for notched impact test specimens shall be a minimum of 7 ft-lb for tests conducted at 70 F ± 10 (21C ± 6).

51–12.3 *Sampling.* At least one tensile and impact sample shall be taken during each casting period of approximately 3 hr. Samples shall be selected to represent extremes of pipe diameters and thicknesses properly.

Sec. 51-13—Additional Control Tests by Manufacturer

Low-temperature impact tests shall be made from at least one third of the test pipe specified in Sec. 51–12.3 to ensure compliance with a minimum corrected value of 3 ft-lb for tests conducted at −40 F (−40C). Test specimens shall be prepared and tested in accordance with Sec. 51–12.2.

In addition, the manufacturer shall conduct such other control tests as necessary to assure continuing compliance with this standard.

Sec. 51-14—Foundry Records

The results of the acceptance tests (Sec. 51-12) and low-temperature impact tests (Sec. 51-13) shall be recorded and retained for one year and shall be available to the purchaser at the foundry. Written transcripts shall be furnished, if specified on the purchase order.

Sec. 51-15—Additional Tests Required by Purchaser

When tests other than those required in this standard are required by the purchaser, such tests shall be specified in the invitation for bids and on the purchase order.

Sec. 51-16—Defective Specimens and Retests

When any physical-test specimen shows defective machining or lack of continuity of metal, it shall be discarded and replaced by another specimen. When any sound test specimen fails to meet the specified requirements, the pipe from which it was taken shall be rejected, and a retest may be made on two additional sound specimens from pipe cast in the same period as the specimen that failed. Both of the additional specimens shall meet the prescribed tests to qualify the pipe produced in that period.

Sec. 51-17—Rejection of Pipe

If the results of any physical acceptance test fail to meet the requirements of Sec. 51-12 or Sec. 51-16, the pipe cast in the same period shall be rejected, except as provided in Sec. 51-18.

Sec. 51-18—Determining Rejection

The manufacturer may determine the amount of rejection by making similar additional tests of pipe of the same size until the rejected lot is bracketed, in order of manufacture, by an acceptable test at each end of the interval in question. When pipe of one size is rejected from a casting period, the acceptability of pipe of different sizes from that same period may be established by making the acceptance tests for these sizes as specified in Sec. 51-12.

TABLE 51.1

*Standard Thickness for Earth Load Plus Truck Load**

Size in.	Depth of Cover ft.	Laying Condition									
		Type 1†		Type 2†		Type 3†		Type 4†		Type 5†	
		Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class
3	2.5	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	3	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	4	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	5	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	6	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	7	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	8	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	9	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	10	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	12	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	14	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	16	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	20	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	24	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	28	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
	32	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
4	2.5	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	3	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	4	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	5	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	6	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	7	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	8	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	9	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	10	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	12	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	14	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	16	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	20	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	24	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	28	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
	32	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
6	2.5	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	3	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	4	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	5	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	6	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	7	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	8	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	9	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	10	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	12	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	14	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	16	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	20	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	24	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	28	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	32	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
	2.5	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	3	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	4	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	5	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	6	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	7	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	8	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	9	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	10	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	12	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	14	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	16	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	20	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	24	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
	28	0.30	51	0.27	50	0.27	50	0.27	50	0.27	50
	32	0.30	51	0.30	51	0.27	50	0.27	50	0.27	50

* Truckloads used in computing this table are based on a single H-20 truck with 16 000-lb wheel load and 1.5 impact factor.

† See corresponding illustrations in Fig. 3 of types of laying conditions.

TABLE 51.1—*(cont.)*

Size in.	Depth of Cover ft.	Laying Condition									
		Type 1†		Type 2†		Type 3†		Type 4†		Type 5†	
		Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class
10	2.5	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	3	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	4	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	5	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	6	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	7	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	8	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	9	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	10	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	12	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	14	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	16	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
	20	0.32	51	0.29	50	0.29	50	0.29	50	0.29	50
	24	0.32	51	0.29	50	0.29	50	0.29	50	0.29	50
	28	0.35	52	0.32	51	0.29	50	0.29	50	0.29	50
	32	0.35	52	0.32	51	0.32	51	0.29	50	0.29	50
12	2.5	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	3	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	4	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	5	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	6	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	7	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	8	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	9	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	10	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	12	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	14	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	16	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
	20	0.34	51	0.31	50	0.31	50	0.31	50	0.31	50
	24	0.37	52	0.34	51	0.31	50	0.31	50	0.31	50
	28	0.37	52	0.34	51	0.34	51	0.31	50	0.31	50
	32	0.40	53	0.37	52	0.34	51	0.31	50	0.31	50
14	2.5	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	3	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	4	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	5	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	6	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	7	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	8	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	9	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	10	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	12	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	14	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
	16	0.36	51	0.33	50	0.33	50	0.33	50	0.33	50
	20	0.39	52	0.36	51	0.33	50	0.33	50	0.33	50
	24	0.39	52	0.39	52	0.33	50	0.33	50	0.33	50
	28	0.42	53	0.39	52	0.36	51	0.33	50	0.33	50
	32	0.45	54	0.42	53	0.39	52	0.33	50	0.33	50
16	2.5	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	3	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	4	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	5	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	6	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	7	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	8	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	9	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	10	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	12	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
	14	0.37	51	0.34	50	0.34	50	0.34	50	0.34	50
	16	0.37	51	0.34	50	0.34	50	0.34	50	0.34	50
	20	0.40	52	0.37	51	0.34	50	0.34	50	0.34	50
	24	0.43	53	0.40	52	0.37	51	0.34	50	0.34	50
	28	0.46	54	0.43	53	0.40	52	0.34	50	0.34	50
	32	0.49	55	0.46	54	0.43	53	0.37	51	0.34	50

† See corresponding illustrations in Fig. 3 of types of laying conditions.

TABLE 51.1—(*cont.*)

Size in.	Depth of Cover ft.	Laying Condition									
		Type 1†		Type 2†		Type 3†		Type 4†		Type 5†	
		Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class
18	2.5	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	3	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	4	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	5	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	6	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	7	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	8	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	9	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	10	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
	12	0.38	51	0.35	50	0.35	50	0.35	50	0.35	50
	14	0.38	51	0.35	50	0.35	50	0.35	50	0.35	50
	16	0.41	52	0.38	51	0.35	50	0.35	50	0.35	50
	20	0.44	53	0.41	52	0.35	50	0.35	50	0.35	50
	24	0.47	54	0.44	53	0.41	52	0.35	50	0.35	50
	28	0.50	55	0.47	54	0.44	53	0.35	50	0.35	50
	32	0.53	56	0.50	55	0.47	54	0.38	51	0.35	53
20	2.5	0.39	51	0.36	50	0.36	50	0.36	50	0.36	50
	3	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	4	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	5	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	6	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	7	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	8	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	9	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	10	0.36	50	0.36	50	0.36	50	0.36	50	0.36	50
	12	0.39	51	0.36	50	0.36	50	0.36	50	0.36	50
	14	0.42	52	0.36	50	0.36	50	0.36	50	0.36	50
	16	0.42	52	0.39	51	0.36	50	0.36	50	0.36	50
	20	0.48	54	0.42	52	0.39	51	0.36	50	0.36	50
	24	0.51	55	0.48	54	0.42	52	0.36	50	0.36	50
	28	0.54	56	0.51	55	0.45	53	0.39	51	0.36	50
	32	—	—	0.54	56	0.48	54	0.42	52	0.36	50
24	2.5	0.41	51	0.38	50	0.38	50	0.38	50	0.38	50
	3	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	4	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	5	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	6	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	7	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	8	0.38	50	0.38	50	0.38	50	0.38	50	0.38	50
	9	0.41	51	0.38	50	0.38	50	0.38	50	0.38	50
	10	0.41	51	0.38	50	0.38	50	0.38	50	0.38	50
	12	0.44	52	0.38	50	0.38	50	0.38	50	0.38	50
	14	0.47	53	0.41	51	0.38	50	0.38	50	0.38	50
	16	0.50	54	0.44	52	0.38	50	0.38	50	0.38	50
	20	0.53	55	0.50	54	0.44	52	0.38	50	0.38	50
	24	0.56	56	0.53	55	0.47	53	0.41	51	0.38	50
	28	—	—	0.56	56	0.53	55	0.44	52	0.38	50
	32	—	—	—	—	0.56	56	0.47	53	0.41	51
30	2.5	‡	‡	0.39	50	0.39	50	0.39	50	0.39	50
	3			0.39	50	0.39	50	0.39	50	0.39	50
	4			0.39	50	0.39	50	0.39	50	0.39	50
	5			0.39	50	0.39	50	0.39	50	0.39	50
	6			0.39	50	0.39	50	0.39	50	0.39	50
	7			0.39	50	0.39	50	0.39	50	0.39	50
	8			0.39	50	0.39	50	0.39	50	0.39	50
	9			0.39	50	0.39	50	0.39	50	0.39	50
	10			0.39	50	0.39	50	0.39	50	0.39	50
	12			0.43	51	0.39	50	0.39	50	0.39	50
	14			0.47	52	0.39	50	0.39	50	0.39	50
	16			0.51	53	0.43	51	0.39	50	0.39	50
	20			0.59	55	0.51	53	0.43	51	0.39	50
	24			0.63	56	0.55	54	0.47	52	0.39	50
	28			—	—	0.63	56	0.51	53	0.43	51
	32			—	—	—	—	0.55	54	0.47	52

† See corresponding illustrations in Fig. 3 of types of laying conditions.
‡ For pipe 30 in. and larger, consideration should be given to the use of laying conditions other than Type 1.

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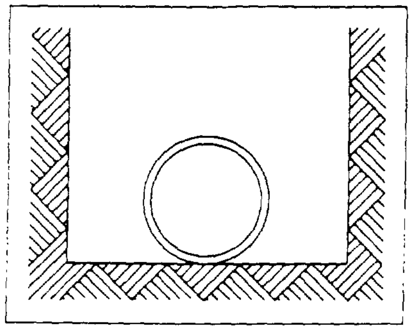
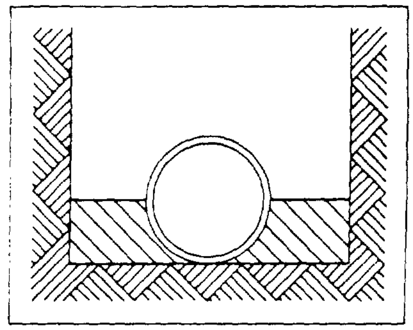
TABLE 51.1—*(cont.)*

Size in.	Depth of Cover ft.	Laying Condition									
		Type 1†		Type 2†		Type 3†		Type 4†		Type 5†	
		Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class	Thickness in.	Thickness Class
36	2.5	‡	‡	0.43	50	0.43	50	0.43	50	0.43	50
	3			0.43	50	0.43	50	0.43	50	0.43	50
	4			0.43	50	0.43	50	0.43	50	0.43	50
	5			0.43	50	0.43	50	0.43	50	0.43	50
	6			0.43	50	0.43	50	0.43	50	0.43	50
	7			0.43	50	0.43	50	0.43	50	0.43	50
	8			0.43	50	0.43	50	0.43	50	0.43	50
	9			0.43	50	0.43	50	0.43	50	0.43	50
	10			0.43	50	0.43	50	0.43	50	0.43	50
	12			0.48	51	0.43	50	0.43	50	0.43	50
	14			0.53	52	0.48	51	0.43	50	0.43	50
	16			0.58	53	0.48	51	0.43	50	0.43	50
	20			0.63	54	0.58	53	0.48	51	0.43	50
	24			0.73	56	0.63	54	0.53	52	0.43	50
	28			—	—	0.68	55	0.58	53	0.48	51
	32			—	—	—	—	0.63	54	0.53	52
42	2.5	‡	‡	0.47	50	0.47	50	0.47	50	0.47	50
	3			0.47	50	0.47	50	0.47	50	0.47	50
	4			0.47	50	0.47	50	0.47	50	0.47	50
	5			0.47	50	0.47	50	0.47	50	0.47	50
	6			0.47	50	0.47	50	0.47	50	0.47	50
	7			0.47	50	0.47	50	0.47	50	0.47	50
	8			0.47	50	0.47	50	0.47	50	0.47	50
	9			0.47	50	0.47	50	0.47	50	0.47	50
	10			0.53	51	0.47	50	0.47	50	0.47	50
	12			0.53	51	0.47	50	0.47	50	0.47	50
	14			0.59	52	0.53	51	0.47	50	0.47	50
	16			0.65	53	0.59	52	0.47	50	0.47	50
	20			0.71	54	0.65	53	0.59	52	0.47	50
	24			0.83	56	0.71	54	0.65	53	0.47	50
	28			—	—	0.77	55	0.71	54	0.59	52
	32			—	—	—	—	0.71	54	0.65	53
48	2.5	‡	‡	0.51	50	0.51	50	0.51	50	0.51	50
	3			0.51	50	0.51	50	0.51	50	0.51	50
	4			0.51	50	0.51	50	0.51	50	0.51	50
	5			0.51	50	0.51	50	0.51	50	0.51	50
	6			0.51	50	0.51	50	0.51	50	0.51	50
	7			0.51	50	0.51	50	0.51	50	0.51	50
	8			0.51	50	0.51	50	0.51	50	0.51	50
	9			0.51	50	0.51	50	0.51	50	0.51	50
	10			0.58	51	0.51	50	0.51	50	0.51	50
	12			0.58	51	0.51	50	0.51	50	0.51	50
	14			0.65	52	0.58	51	0.51	50	0.51	50
	16			0.72	53	0.65	52	0.58	51	0.51	50
	20			0.79	54	0.72	53	0.65	52	0.51	50
	24			0.93	56	0.79	54	0.72	53	0.58	51
	28			—	—	0.86	55	0.79	54	0.65	52
	32			—	—	—	—	0.86	55	0.72	53
54	2.5	‡	‡	0.57	50	0.57	50	0.57	50	0.57	50
	3			0.57	50	0.57	50	0.57	50	0.57	50
	4			0.57	50	0.57	50	0.57	50	0.57	50
	5			0.57	50	0.57	50	0.57	50	0.57	50
	6			0.57	50	0.57	50	0.57	50	0.57	50
	7			0.57	50	0.57	50	0.57	50	0.57	50
	8			0.57	50	0.57	50	0.57	50	0.57	50
	9			0.57	50	0.57	50	0.57	50	0.57	50
	10			0.65	51	0.57	50	0.57	50	0.57	50
	12			0.65	51	0.57	50	0.57	50	0.57	50
	14			0.73	52	0.65	51	0.57	50	0.57	50
	16			0.81	53	0.73	52	0.65	51	0.57	50
	20			0.89	54	0.81	53	0.73	52	0.57	50
	24			1.05	56	0.89	54	0.81	53	0.65	51
	28			—	—	0.97	55	0.89	54	0.73	52
	32			—	—	—	—	0.97	55	0.81	53

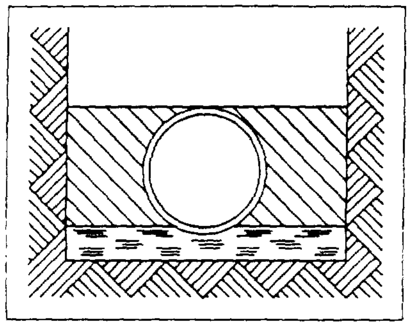
† See corresponding illustrations in Fig. 3 of types of laying conditions.
‡ For pipe 30 in. and larger, consideration should be given to the use of laying conditions other than Type 1.



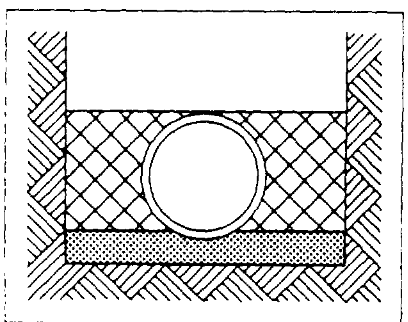
*Type 1** Flat-bottom trench.† Loose backfill.



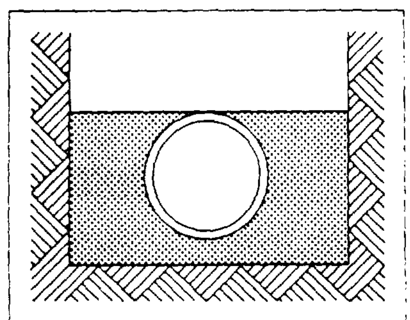
Type 2 Flat-bottom trench.† Backfill lightly consolidated to centerline of pipe.



Type 3 Pipe bedded in 4-in.-minimum loose soil.‡ Backfill lightly consolidated to top of pipe.



Type 4 Pipe bedded in sand, gravel, or crushed stone to depth of ⅛ pipe diameter, 4-in. minimum. Backfill compacted to top of pipe. (Approx. 80 per cent Standard Proctor, AASHTO § T-99)



Type 5 Pipe bedded to its centerline in compacted granular material, 4-in. minimum under pipe. Compacted granular or select ‡ material to top of pipe. (Approx. 90 per cent Standard Proctor, AASHTO § T-99)

Fig. 3. Standard Laying Conditions

* For pipe 30 in. and larger, consideration should be given to the use of laying conditions other than Type 1.
† "Flat-bottom" is defined as undisturbed earth.
‡ "Loose soil" or "select material" is defined as native soil excavated from the trench, free of rocks, foreign materials, and frozen earth.
§ American Association of State Highway and Transportation Officials, 341 National Press Bldg., Washington, D.C. 20004.

TABLE 51.2

Standard Thickness for Internal Pressure

Pipe Size *in.*	Rated Water Working Pressure*—*psi*									
	150		200		250		300		350	
	Thickness *in.*	Thickness Class	Thickness *in.*	Thickness Class	Thickness *in.*	Thickness Class	Thickness *in.*	Thickness Class	Thickness *in.*	Thickness Class
3	0.25	51	0.25	51	0.25	51	0.25	51	0.25	51
4	0.26	51	0.26	51	0.26	51	0.26	51	0.26	51
6	0.25	50	0.25	50	0.25	50	0.25	50	0.25	50
8	0.27	50	0.27	50	0.27	50	0.27	50	0.27	50
10	0.29	50	0.29	50	0.29	50	0.29	50	0.29	50
12	0.31	50	0.31	50	0.31	50	0.31	50	0.31	50
14	0.33	50	0.33	50	0.33	50	0.33	50	0.33	50
16	0.34	50	0.34	50	0.34	50	0.34	50	0.34	50
18	0.35	50	0.35	50	0.35	50	0.35	50	0.35	50
20	0.36	50	0.36	50	0.36	50	0.36	50	0.39	51
24	0.38	50	0.38	50	0.38	50	0.41	51	0.44	52
30	0.39	50	0.39	50	0.43	51	0.47	52	0.51	53
36	0.43	50	0.43	50	0.48	51	0.53	52	0.58	53
42	0.47	50	0.47	50	0.53	51	0.59	52	0.65	53
48	0.51	50	0.51	50	0.58	51	0.65	52	0.72	53
54	0.57	50	0.57	50	0.65	51	0.73	52	0.81	53

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi.

TABLE 51.3

Rated Working Pressure and Maximum Depth of Cover

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure* *psi*	Laying Condition				
				Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
3	51	0.25	350	98	100‡	100‡	100‡	100‡
	52	0.28	350	100‡	100‡	100‡	100‡	100‡
	53	0.31	350	100‡	100‡	100‡	100‡	100‡
	54	0.34	350	100‡	100‡	100‡	100‡	100‡
	55	0.37	350	100‡	100‡	100‡	100‡	100‡
	56	0.40	350	100‡	100‡	100‡	100‡	100‡
4	51	0.26	350	76	86	96	100‡	100‡
	52	0.29	350	100‡	100‡	100‡	100‡	100‡
	53	0.32	350	100‡	100‡	100‡	100‡	100‡
	54	0.35	350	100‡	100‡	100‡	100‡	100‡
	55	0.38	350	100‡	100‡	100‡	100‡	100‡
	56	0.41	350	100‡	100‡	100‡	100‡	100‡
6	50	0.25	350	32	38	44	56	75
	51	0.28	350	49	57	64	80	100‡
	52	0.31	350	67	77	86	100‡	100‡
	53	0.34	350	91	100‡	100‡	100‡	100‡
	54	0.37	350	100‡	100‡	100‡	100‡	100‡
	55	0.40	350	100‡	100‡	100‡	100‡	100‡
	56	0.43	350	100‡	100‡	100‡	100‡	100‡
8	50	0.27	350	25	30	36	46	64
	51	0.30	350	36	42	49	61	81
	52	0.33	350	47	54	62	77	99
	53	0.36	350	64	73	82	100‡	100‡
	54	0.39	350	80	91	100‡	100‡	100‡
	55	0.42	350	98	100‡	100‡	100‡	100‡
	56	0.45	350	100‡	100‡	100‡	100‡	100‡
10	50	0.29	350	19	24	29	38	55
	51	0.32	350	27	32	38	49	66
	52	0.35	350	35	41	47	59	79
	53	0.38	350	45	52	59	74	95
	54	0.41	350	57	65	74	91	100‡
	55	0.44	350	67	77	86	100‡	100‡
	56	0.47	350	81	92	100‡	100‡	100‡
12	50	0.31	350	17	22	27	36	52
	51	0.34	350	23	28	33	43	60
	52	0.37	350	30	35	41	53	71
	53	0.40	350	36	42	49	61	81
	54	0.43	350	45	52	59	74	95
	55	0.46	350	54	62	71	87	100‡
	56	0.49	350	64	73	83	100‡	100‡
14	50	0.33	350	15	19	24	33	49
	51	0.36	350	19	23	28	38	55
	52	0.39	350	24	29	34	44	62
	53	0.42	350	30	35	41	53	71
	54	0.45	350	36	42	49	61	81
	55	0.48	350	43	50	57	71	92
	56	0.51	350	52	59	67	83	100‡
15	50	0.34	350	13	17	21	30	47
	51	0.37	350	16	21	25	34	51
	52	0.40	350	20	25	30	40	57
	53	0.43	350	25	30	36	46	64
	54	0.46	350	30	35	41	53	71
	55	0.49	350	35	41	47	59	79
	56	0.52	350	41	48	55	68	89
18	50	0.35	350	11	15	20	29	42
	51	0.38	350	14	19	23	32	49
	52	0.41	350	18	22	27	36	53
	53	0.44	350	22	26	31	41	58
	54	0.47	350	25	30	36	46	64
	55	0.50	350	30	35	41	53	71
	56	0.53	350	35	41	47	59	79

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover
‡ Calculated maximum depth of cover exceeds 100 ft.

TABLE 51.3—(*cont.*)

Pipe Size *in.*	Thickness Class	Nominal Thickness *in.*	Rated Water Working Pressure* *psi*	Laying Condition: Type 1	Type 2	Type 3	Type 4	Type 5
				Maximum Depth of Cover—*ft*†				
20	50	0.36	300	10	14	18	27	38
	51	0.39	350	13	17	21	30	44
	52	0.42	350	16	20	25	34	50
	53	0.45	350	19	23	28	38	54
	54	0.48	350	22	27	32	42	59
	55	0.51	350	26	31	37	47	65
	56	0.54	350	30	35	41	53	71
24	50	0.38	250	8	12	17	23	31
	51	0.41	300	10	15	19	27	36
	52	0.44	350	13	17	21	30	41
	53	0.47	350	15	19	24	33	47
	54	0.50	350	18	22	27	36	53
	55	0.53	350	20	25	30	40	57
	56	0.56	350	24	29	34	44	61
30	50	0.39	200	§	10	14	18	25
	51	0.43	250		12	16	21	29
	52	0.47	300		14	19	24	33
	53	0.51	350		17	21	29	38
	54	0.55	350		19	24	33	44
	55	0.59	350		22	27	36	51
	56	0.63	350		26	31	41	57
36	50	0.43	200		10	13	17	25
	51	0.48	250		12	16	20	28
	52	0.53	300		15	19	24	32
	53	0.58	350		17	21	28	37
	54	0.63	350		20	25	33	43
	55	0.68	350		23	28	37	50
	56	0.73	350		26	31	41	59
42	50	0.47	200	§	9	13	16	24
	51	0.53	250		12	15	19	27
	52	0.59	300		14	18	22	30
	53	0.65	350		17	22	27	35
	54	0.71	350		20	24	32	42
	55	0.77	350		23	28	38	48
	56	0.83	350		26	31	41	57
48	50	0.51	200		9	12	15	23
	51	0.58	250		12	14	18	26
	52	0.65	300		14	18	21	30
	53	0.72	350		17	21	25	34
	54	0.79	350		20	24	30	40
	55	0.86	350		23	28	37	47
	56	0.93	350		26	31	41	55
54	50	0.57	200		9	12	15	23
	51	0.65	250		12	14	18	25
	52	0.73	300		14	17	21	29
	53	0.81	350		17	21	25	34
	54	0.89	350		20	25	30	40
	55	0.97	350		23	28	37	47
	56	1.05	350		27	32	42	55

* These pipe are adequate for the rated working pressure plus a surge allowance of 100 psi. Ductile-iron pipe for working pressures higher than 350 psi is available.
† An allowance for a single H-20 truck with 1.5 impact factor is included for all depths of cover.
§ For pipe 30 in. and larger, consideration should be given to the use of laying conditions other than Type 1

TABLE 51.4

Standard Dimensions and Weights of Push-On-Joint Ductile-Iron Pipe

Size *in.*	Thickness Class	Thickness *in.*	OD* *in.*	Wt. of Barrel Per Ft *lb*	Wt. of Bell *lb*	18-Ft Laying Length		20-Ft Laying Length	
						Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
3§	51	0.25	3.96	8.9	9	170	9.4	185	9.4
	52	0.28	3.96	9.9	9	185	10.4	205	10.4
	53	0.31	3.96	10.9	9	205	11.4	225	11.4
	54	0.34	3.96	11.8	9	220	12.3	245	12.2
	55	0.37	3.96	12.8	9	240	13.3	265	13.2
	56	0.40	3.96	13.7	9	255	14.2	285	14.2
4	51	0.26	4.80	11.3	11	215	11.9	235	11.8
	52	0.29	4.80	12.6	11	240	13.2	265	13.2
	53	0.32	4.80	13.8	11	260	14.4	285	14.4
	54	0.35	4.80	15.0	11	280	15.6	310	15.6
	55	0.38	4.80	16.1	11	300	16.7	335	16.6
	56	0.41	4.80	17.3	11	320	17.9	355	17.8
6	50	0.25	6.90	16.0	18	305	17.0	340	16.9
	51	0.28	6.90	17.8	18	340	18.8	375	18.7
	52	0.31	6.90	19.6	18	370	20.6	410	20.5
	53	0.34	6.90	21.4	18	405	22.4	445	22.3
	54	0.37	6.90	23.2	18	435	24.2	480	24.1
	55	0.40	6.90	25.0	18	470	26.0	520	25.9
	56	0.43	6.90	26.7	18	500	27.7	550	27.6
8	50	0.27	9.05	22.8	26	435	24.2	480	24.1
	51	0.30	9.05	25.2	26	480	26.6	530	26.5
	52	0.33	9.05	27.7	26	525	29.1	580	29.0
	53	0.36	9.05	30.1	26	570	31.5	630	31.4
	54	0.39	9.05	32.5	26	610	33.9	675	33.8
	55	0.42	9.05	34.8	26	650	36.2	720	36.1
	56	0.45	9.05	37.2	26	695	38.6	770	38.5
10	50	0.29	11.10	30.1	34	575	32.0	635	31.8
	51	0.32	11.10	33.2	34	630	35.1	700	34.9
	52	0.35	11.10	36.2	34	685	38.1	760	37.9
	53	0.38	11.10	39.2	34	740	41.1	820	40.9
	54	0.41	11.10	42.1	34	790	44.0	875	43.8
	55	0.44	11.10	45.1	34	845	47.0	935	46.8
	56	0.47	11.10	48.0	34	900	49.9	995	49.7

* Tolerance of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.; 30–54 in., +0.08 in., −0.06 in.

† Including bell; calculated weight of pipe rounded off to nearest 5 lb.

‡ Including bell; average weight, per foot, based on calculated weight of pipe before rounding.

§ Pipe of 3-in. size also available in 12-ft laying length with following weights:

Thickness Class	Thickness *in.*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
51	0.25	115	9.6
52	0.28	130	10.6
53	0.31	140	11.6
54	0.34	150	12.6
55	0.37	165	13.6
56	0.40	175	14.4

TABLE 51.4—(*cont.*)

Size *in.*	Thick-ness Class	Thick-ness *in.*	OD* *in.*	Wt. of Barrel Per Ft *lb*	Wt. of Bell *lb*	18-Ft Laying Length		20-Ft Laying Length	
						Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
12	50	0.31	13.20	38.4	43	735	40.8	810	40.6
	51	0.34	13.20	42.0	43	800	44.4	885	44.2
	52	0.37	13.20	45.6	43	865	48.0	955	47.8
	53	0.40	13.20	49.2	43	930	51.6	1 025	51.4
	54	0.43	13.20	52.8	43	995	55.2	1 100	55.0
	55	0.46	13.20	56.3	43	1 055	58.7	1 170	58.4
	56	0.49	13.20	59.9	43	1 120	62.3	1 240	62.0
14	50	0.33	15.30	47.5	63	920	51.0	015	50.6
	51	0.36	15.30	51.7	63	995	55.2	1 095	54.8
	52	0.39	15.30	55.9	63	1 070	59.4	1 180	59.0
	53	0.42	15.30	60.1	63	1 145	63.6	1 265	63.2
	54	0.45	15.30	64.2	63	1 220	67.7	1 345	67.4
	55	0.48	15.30	68.4	63	1 295	71.9	1 430	71.6
	56	0.51	15.30	72.5	63	1 370	76.0	1 515	75.6
16	50	0.34	17.40	55.8	76	1 080	60.0	1 190	59.6
	51	0.37	17.40	60.6	76	1 165	64.8	1 290	64.4
	52	0.40	17.40	65.4	76	1 255	69.6	1 385	69.2
	53	0.43	17.40	70.1	76	1 340	74.3	1 480	73.9
	54	0.46	17.40	74.9	76	1 425	79.1	1 575	78.7
	55	0.49	17.40	79.7	76	1 510	83.9	1 670	83.5
	56	0.52	17.40	84.4	76	1 595	88.6	1 765	88.2
18	50	0.35	19.50	64.4	87	1 245	69.2	1 375	68.8
	51	0.38	19.50	69.8	87	1 345	74.6	1 485	74.2
	52	0.41	19.50	75.2	87	1 440	80.0	1 590	79.6
	53	0.44	19.50	80.6	87	1 540	85.4	1 700	85.0
	54	0.47	19.50	86.0	87	1 635	90.8	1 805	90.4
	55	0.50	19.50	91.3	87	1 730	96.1	1 915	95.6
	56	0.53	19.50	96.7	87	1 830	101.5	2 020	101.0
20	50	0.36	21.60	73.5	97	1 420	78.9	1 565	78.4
	51	0.39	21.60	79.5	97	1 530	84.9	1 685	84.4
	52	0.42	21.60	85.5	97	1 635	90.9	1 805	90.4
	53	0.45	21.60	91.5	97	1 745	96.9	1 925	96.4
	54	0.48	21.60	97.5	97	1 850	102.9	2 045	102.4
	55	0.51	21.60	103.4	97	1 960	108.8	2 165	108.2
	56	0.54	21.60	109.3	97	2 065	114.7	2 285	114.2

* Tolerance of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.; 30–54 in., +0.08 in. −0.06 in.

† Including bell; calculated weight of pipe rounded off to nearest 5 lb.

‡ Including bell; average weight per foot, based on calculated weight of pipe before rounding.

TABLE 51.4—(*cont.*)

Size *in.*	Thickness Class	Thickness *in.*	OD* *in.*	Wt. of Barrel Per Ft *lb*	Wt. of Bell *lb*	18-Ft Laying Length		20-Ft Laying Lentgh	
						Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
24	50	0.38	25.80	92.9	120	1 790	99.6	1 980	98.9
	51	0.41	25.80	100.1	120	1 920	106.8	2 120	106.1
	52	0.44	25.80	107.3	120	2 050	114 0	2 265	113.3
	53	0.47	25 80	114.4	120	2 180	121.1	2 410	120 4
	54	0.50	25.80	121.6	120	2 310	128 3	2 550	127.6
	55	0.53	25.80	128 8	120	2 440	135 5	2 695	134.8
	56	0.56	25.80	135.9	120	2 565	142.6	2 840	141.9
30	50	0.39	32 00	118.5	**	2 350	130.5	2 535	126.6
	51	0.43	32.00	130.5		2 565	142 5	2 775	138.6
	52	0.47	32.00	142.5		2 780	154.5	3 015	150.6
	53	0.51	32.00	154.4		2 995	166.4	3 250	162.6
	54	0.55	32.00	166.3		3 210	178.3	3 490	174.4
	55	0.59	32.00	178.2		3 425	190.2	3 725	186.4
	56	0.63	32.00	190.0		3 635	202.0	3 965	198.2
36	50	0.43	38.30	156.5	††	3 110	172.7	3 345	167.3
	51	0.48	38.30	174.5		3 435	190.7	3 705	185.3
	52	0.53	38.30	192.4		3 755	208.6	4 065	203.2
	53	0.58	38.30	210.3		4 075	226.5	4 420	221.1
	54	0.63	38.30	228.1		4 400	244.3	4 780	238 9
	55	0.68	38.30	245.9		4 720	262.1	5 135	256.7
	56	0.73	38.30	263.7		5 040	279.9	5 490	274.5
42	50	0.47	44.50	198.9	261			4 240	212.0
	51	0.53	44.50	224.0	261			4 740	237.0
	52	0.59	44.50	249.1	261			5 245	262.2
	53	0.65	44.50	274.0	261			5 740	287.0
	54	0.71	44.50	298.9	261			6 240	312.0
	55	0.77	44.50	323.7	261			6 735	336.8
	56	0.83	44.50	348.4	261			7 230	361.4
48	50	0.51	50.80	246.6	316			5 250	262.4
	51	0.58	50.80	280.0	316			5 915	295.8
	52	0.65	50.80	313.4	316			6 585	329.2
	53	0.72	50.80	346.6	316			7 250	362.4
	54	0.79	50.80	379.8	316			7 910	395.6
	55	0.86	50.80	412.9	316			8 575	428.7
	56	0.93	50.80	445.9	316			9 235	461.7
54	50	0.57	57.10	309.8	370			6 565	328.3
	51	0.65	57.10	352.7	370			7 425	371.2
	52	0.73	57.10	395.6	370			8 280	414.1
	53	0.81	57.10	438.3	370			9 135	456.8
	54	0.89	57.10	480.9	370			9 990	499.4
	55	0.97	57.10	523.4	370			10 840	541.9
	56	1.05	57.10	565.8	370			11 685	584.3

* Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.; 30–54 in., +0.08 in., −0.06 in.
† Including bell; calculated weight of pipe rounded off to nearest 5 lb.
‡ Including bell; average weight per foot, based on calculated weight of pipe before rounding.
** Weight of 30-in. bell is 216 lb for 18-ft pipe and 163 lb for 20-ft pipe.
†† Weight of 36-in. bell is 292 lb for 18-ft pipe and 216 lb for 20-ft pipe.

TABLE 51.5

Standard Dimensions and Weights of Mechanical-Joint Ductile-Iron Pipe

Size *in.*	Thickness Class	Thickness *in.*	OD* *in.*	Wt. of Barrel Per Ft *lb*	Wt. of Bell *lb*	18-ft Laying Length		20-ft Laying Length	
						Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
3§	51	0.25	3.96	8.9	11	170	9.5	190	9.4
	52	0.28	3.96	9.9	11	190	10.5	210	10.4
	53	0.31	3.96	10.9	11	205	11.5	230	11.4
	54	0.34	3.96	11.8	11	225	12.4	245	12.4
	55	0.37	3.96	12.8	11	240	13.4	265	13.4
	56	0.40	3.96	13.7	11	260	14.3	285	14.2
4	51	0.26	4.80	11.3	16	220	12.2	240	12.1
	52	0.29	4.80	12.6	16	245	13.5	270	13.4
	53	0.32	4.80	13.8	16	265	14.7	290	14.6
	54	0.35	4.80	15.0	16	285	15.9	315	15.8
	55	0.38	4.80	16.1	16	305	17.0	340	16.9
	56	0.41	4.80	17.3	16	325	18.2	360	18.1
6	50	0.25	6.90	16.0	22	310	17.2	340	17.1
	51	0.28	6.90	17.8	22	340	19.0	380	18.9
	52	0.31	6.90	19.6	22	375	20.8	415	20.7
	53	0.34	6.90	21.4	22	405	22.6	450	22.5
	54	0.37	6.90	23.2	22	440	24.4	485	24.3
	55	0.40	6.90	25.0	22	470	26.2	520	26.1
	56	0.43	6.90	26.7	22	505	27.9	555	27.8
8	50	0.27	9.05	22.8	29	440	24.4	485	24.2
	51	0.30	9.05	25.2	29	485	26.8	535	26.6
	52	0.33	9.05	27.7	29	530	29.3	585	29.2
	53	0.36	9.05	30.1	29	570	31.7	630	31.6
	54	0.39	9.05	32.5	29	615	34.1	680	34.0
	55	0.42	9.05	34.8	29	655	36.4	725	36.2
	56	0.45	9.05	37.2	29	700	38.8	775	38.6
10	50	0.29	11.10	30.1	39	580	32.3	640	32.0
	51	0.32	11.10	33.2	39	635	35.4	705	35.2
	52	0.35	11.10	36.2	39	690	38.4	765	38.2
	53	0.38	11.10	39.2	39	745	41.4	825	41.2
	54	0.41	11.10	42.1	39	795	44.3	880	44.0
	55	0.44	11.10	45.1	39	850	47.3	940	47.0
	56	0.47	11.10	48.0	39	905	50.2	1 000	50.0
12	50	0.31	13.20	38.4	49	740	41.1	815	40.8
	51	0.34	13.20	42.0	49	805	44.7	890	44.4
	52	0.37	13.20	45.6	49	870	48.3	960	48.0
	53	0.40	13.20	49.2	49	935	51.9	1 035	51.6
	54	0.43	13.20	52.8	49	1 000	55.5	1 105	55.2
	55	0.46	13.20	56.3	49	1 060	59.0	1 175	58.8
	56	0.49	13.20	59.9	49	1 125	62.6	1 245	62.3
14	50	0.33	15.30	47.5	76	930	51.7	1 025	51.3
	51	0.36	15.30	51.7	76	1 005	55.9	1 110	55.5
	52	0.39	15.30	55.9	76	1 080	60.1	1 195	59.7
	53	0.42	15.30	60.1	76	1 160	64.3	1 280	63.9
	54	0.45	15.30	64.2	76	1 230	68.4	1 360	68.0
	55	0.48	15.30	68.4	76	1 305	72.6	1 445	72.2
	56	0.51	15.30	72.5	76	1 380	76.7	1 525	76.3

* Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.; 30–48 in., +0.08 in., −0.06 in.

† Including bell; calculated weight of pipe rounded off to nearest 5 lb.

‡ Including bell; average weight, per foot, based on calculated weight of pipe before rounding.

§ Pipe of 3-in. size also available in 12-ft laying length with following weights:

Thickness Class	Thickness *in.*	Wt. Per Lgth.† *lb*	Avg. Wt. Per Ft‡ *lb*
51	0.25	120	9.8
52	0.28	130	10.8
53	0.31	140	11.8
54	0.34	155	12.7
55	0.37	165	13.7
56	0.40	175	14.6

TABLE 51.5—(*cont.*)

Size *in.*	Thick-ness Class	Thick-ness *in.*	OD* *in.*	Wt. of Barrel Per Ft *lb*	Wt. of Bell†† *lb*	18-ft Laying Length Wt. Per Lgth.† *lb*	18-ft Laying Length Avg. Wt. Per Ft‡ *lb*	20-ft Laying Length Wt. Per Lgth.† *lb*	20-ft Laying Length Avg. Wt. Per Ft‡ *lb*
16	50	0.34	17.40	55.8	93	1 095	61.0	1 210	60.4
	51	0.37	17.40	60.6	93	1 185	65.8	1 305	65.2
	52	0.40	17.40	65.4	93	1 270	70.6	1 400	70.0
	53	0.43	17.40	70.1	93	1 355	75.3	1 495	74.8
	54	0.46	17.40	74.9	93	1 440	80.1	1 590	79.6
	55	0.49	17.40	79.7	93	1 530	84.9	1 685	84.4
	56	0.52	17.40	84.4	93	1 610	89.6	1 780	89.0
18	50	0.35	19.50	64.4	111	1 270	70.6	1 400	70.0
	51	0.38	19.50	69.8	111	1 365	76.0	1 505	75.4
	52	0.41	19.50	75.2	111	1 465	81.4	1 615	80.8
	53	0.44	19.50	80.6	111	1 560	86.8	1 725	86.2
	54	0.47	19.50	86.0	111	[illegible]	92.2	1 830	91.6
	55	0.50	19.50	91.3	111	1 755	97.5	1 935	96.8
	56	0.53	19.50	96.7	111	1 850	102.9	2 045	102.2
20	50	0.36	21.60	73.5	131	1 455	80.8	1 600	80.0
	51	0.39	21.60	79.5	131	1 560	86.8	1 720	86.0
	52	0.42	21.60	85.5	131	1 670	92.8	1 840	92.0
	53	0.45	21.60	91.5	131	1 780	98.8	1 960	98.0
	54	0.48	21.60	97.5	131	1 885	104.8	2 080	104.0
	55	0.51	21.60	103.4	131	1 990	110.7	2 200	110.0
	56	0.54	21.60	109.3	131	2 100	116.6	2 315	115.8
24	50	0.38	25.80	92.9	174	1 845	102.6	2 030	101.6
	51	0.41	25.80	100.1	174	1 975	109.8	2 175	108.8
	52	0.44	25.80	107.3	174	2 105	117.0	2 320	116.0
	53	0.47	25.80	114.4	174	2 235	124.1	2 460	123.1
	54	0.50	25.80	121.6	174	2 365	131.3	2 605	130.3
	55	0.53	25.80	128.8	174	2 490	138.5	2 750	137.5
	56	0.56	25.80	135.9	174	2 620	145.6	2 890	144.6
30	50	0.39	32.00	118.5	216	2 350	130.5	2 585	129.3
	51	0.43	32.00	130.5	216	2 565	142.5	2 825	141.3
	52	0.47	32.00	142.5	216	2 780	154.5	3 065	153.3
	53	0.51	32.00	154.4	216	2 995	166.4	3 305	165.2
	54	0.55	32.00	166.3	216	3 210	178.3	3 540	177.1
	55	0.59	32.00	178.2	216	3 425	190.2	3 780	189.0
	56	0.63	32.00	190.0	216	3 635	202.0	4 015	200.8
36	50	0.43	38.30	156.5	310	3 125	173.7	3 440	172.0
	51	0.48	38.30	174.5	310	3 450	191.7	3 800	190.0
	52	0.53	38.30	192.4	310	3 775	209.6	4 160	207.9
	53	0.58	38.30	210.3	310	4 095	227.5	4 515	225.8
	54	0.63	38.30	228.1	310	4 415	245.3	4 870	243.6
	55	0.68	38.30	245.9	310	4 735	263.1	5 230	261.4
	56	0.73	38.30	263.7	310	5 055	280.9	5 585	279.2
42	50	0.47	44.50	198.9	405			4 385	219.2
	51	0.53	44.50	224.0	405			4 885	244.2
	52	0.59	44.50	249.1	405			5 385	269.4
	53	0.65	44.50	274.0	405			5 885	294.2
	54	0.71	44.50	298.9	405			6 385	319.2
	55	0.77	44.50	323.7	405			6 880	344.0
	56	0.83	44.50	348.4	405			7 375	368.6
48	50	0.51	50.80	246.6	505			5 435	271.8
	51	0.58	50.80	280.0	505			6 105	305.2
	52	0.65	50.80	313.4	505			6 775	338.6
	53	0.72	50.80	346.6	505			7 435	371.8
	54	0.79	50.80	379.8	505			8 100	405.0
	55	0.86	50.80	412.9	505			8 765	438.2
	56	0.93	50.80	445.9	505			9 425	471.2

* Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.; 30–48 in., +0.08 in., −0.06 in.

†† The mechanical joint bell for 30–48 in. sizes of ductile-iron pipe have thicknesses different from those shown in ANSI A21.11 (AWWA C111), which are based on gray-iron pipe. These reduced thicknesses provide a lighter weight bell, which is compatible with the wall thicknesses of ductile-iron pipe. The internal socket dimensions, bolt circle and bolt holes of the redesigned bell remain identical to those specified in A21.11 (AWWA C111) to assure interchangeability of the joint.

† Including bell; calculated weight of pipe rounded off to nearest 5 lb.

‡ Including bell; average weight per foot, based on calculated weight of pipe before rounding.

Appendix

This appendix is for information and is not a part of ANSI A21.51 (AWWA C151).

TABLE A.1

Pipe Thicknesses Required for Different Tap Sizes as per ANSI B2.1 for Standard Taper Pipe Threads With Two, Three, and Four Full Threads

Pipe Size *in.*	No. of Threads	Tap Size—*in.*									
		½	¾	1	1¼	1½	2	2½	3	3½	4
		Pipe Thickness—*in.*									
3	2	0.18	0.21	0.28							
3	3	0.26	0.29	0.37							
3	4	0.33	0.36	0.46							
4	2	0.17	0.19	0.26	0.31						
4	3	0.25	0.27	0.35	0.40						
4	4	0.32	0.34	0.44	0.49						
6	2	0.17	0.18	0.23	0.27	0.30					
6	3	0.25	0.26	0.32	0.36	0.39					
6	4	0.32	0.33	0.41	0.45	0.48					
8	2	0.16	0.17	0.22	0.24	0.27	0.33				
8	3	0.24	0.25	0.31	0.33	0.36	0.42				
8	4	0.31	0.32	0.40	0.42	0.45	0.51				
10	2	0.15	0.17	0.21	0.23	0.25	0.30	0.44			
10	3	0.23	0.25	0.30	0.32	0.34	0.39	0.56			
10	4	0.30	0.32	0.39	0.41	0.43	0.48	0.69			
12	2	0.15	0.16	0.20	0.22	0.24	0.28	0.40	0.48		
12	3	0.23	0.24	0.29	0.31	0.33	0.37	0.52	0.60		
12	4	0.30	0.31	0.38	0.40	0.42	0.46	0.65	0.73		
14	2	0.15	0.16	0.20	0.22	0.23	0.26	0.38	0.45	0.51	0.58
14	3	0.23	0.24	0.29	0.31	0.32	0.35	0.50	0.58	0.64	0.70
14	4	0.30	0.31	0.38	0.40	0.41	0.44	0.63	0.70	0.76	0.83
16	2	0.15	0.16	0.20	0.21	0.22	0.25	0.37	0.43	0.48	0.54
16	3	0.23	0.24	0.29	0.30	0.31	0.34	0.50	0.56	0.60	0.66
16	4	0.30	0.31	0.38	0.39	0.40	0.43	0.62	0.68	0.73	0.79
18	2	0.15	0.15	0.19	0.21	0.22	0.24	0.35	0.41	0.46	0.51
18	3	0.23	0.23	0.28	0.30	0.31	0.33	0.48	0.54	0.58	0.64
18	4	0.30	0.30	0.37	0.39	0.40	0.42	0.60	0.66	0.71	0.76
20	2	0.15	0.15	0.19	0.20	0.21	0.23	0.34	0.39	0.44	0.49
20	3	0.23	0.23	0.28	0.29	0.30	0.32	0.46	0.52	0.56	0.62
20	4	0.30	0.30	0.37	0.38	0.39	0.41	0.59	0.64	0.69	0.74
24	2	0.14	0.15	0.19	0.20	0.21	0.22	0.32	0.37	0.40	0.45
24	3	0.22	0.23	0.28	0.29	0.30	0.31	0.44	0.50	0.52	0.58
24	4	0.29	0.30	0.37	0.38	0.39	0.40	0.57	0.62	0.65	0.70
30	2	0.14	0.15	0.19	0.19	0.20	0.21	0.31	0.34	0.37	0.41
30	3	0.22	0.23	0.28	0.28	0.29	0.30	0.44	0.46	0.50	0.54
30	4	0.29	0.30	0.37	0.37	0.38	0.39	0.56	0.59	0.62	0.66
36	2	0.14	0.14	0.18	0.19	0.20	0.21	0.30	0.33	0.35	0.38
36	3	0.22	0.22	0.27	0.28	0.29	0.30	0.42	0.46	0.48	0.50
36	4	0.29	0.29	0.36	0.37	0.38	0.39	0.55	0.58	0.60	0.63
42	2	0.14	0.14	0.18	0.19	0.19	0.20	0.29	0.32	0.34	0.36
42	3	0.22	0.22	0.27	0.28	0.28	0.29	0.42	0.44	0.46	0.48
42	4	0.29	0.29	0.36	0.37	0.37	0.38	0.54	0.57	0.59	0.61
48	2	0.14	0.14	0.18	0.18	0.19	0.20	0.29	0.31	0.32	0.35
48	3	0.22	0.22	0.27	0.27	0.28	0.29	0.42	0.44	0.44	0.48
48	4	0.29	0.29	0.36	0.36	0.37	0.38	0.54	0.56	0.57	0.60
54	2	0.14	0.14	0.17	0.18	0.18	0.19	0.28	0.30	0.32	0.34
54	3	0.21	0.21	0.26	0.27	0.27	0.28	0.41	0.43	0.44	0.47
54	4	0.29	0.29	0.35	0.35	0.36	0.37	0.53	0.55	0.57	0.59

TABLE A.2

Pipe Thicknesses Required for Different Tap Sizes as per AWWA C800 for Standard Corporation Stop Threads With Two, Three, and Four Full Threads*

Pipe Size in.	No. of Threads	Tap Size—in.						
		1/2	5/8	3/4	1	1 1/4	1 1/2	2
		Pipe Thickness—in.						
3	2	0.21	0.24	0.25	0.33			
3	3	0.29	0.32	0.33	0.41			
3	4	0.36	0.39	0.40	0.49			
4	2	0.19	0.22	0.23	0.30	0.36		
4	3	0.27	0.30	0.31	0.38	0.45		
4	4	0.34	0.37	0.38	0.46	0.54		
6	2	0.18	0.20	0.20	0.26	0.30	0.35	
6	3	0.26	0.28	0.28	0.34	0.39	0.44	
6	4	0.33	0.35	0.35	0.42	0.48	0.53	
8	2	0.17	0.18	0.19	0.24	0.27	0.31	0.39
8	3	0.25	0.26	0.27	0.32	0.36	0.40	0.48
8	4	0.32	0.33	0.34	0.40	0.45	0.49	0.57
10	2	0.17	0.17	0.18	0.23	0.25	0.28	0.35
10	3	0.25	0.25	0.26	0.31	0.34	0.37	0.44
10	4	0.32	0.32	0.33	0.39	0.43	0.46	0.53
12	2	0.16	0.17	0.17	0.22	0.24	0.26	0.32
12	3	0.24	0.25	0.25	0.30	0.33	0.35	0.41
12	4	0.31	0.32	0.32	0.38	0.42	0.44	0.50
14	2	0.16	0.17	0.17	0.21	0.23	0.25	0.30
14	3	0.24	0.25	0.25	0.29	0.32	0.34	0.39
14	4	0.31	0.32	0.32	0.37	0.41	0.43	0.48
16	2	0.16	0.16	0.17	0.21	0.22	0.24	0.28
16	3	0.24	0.24	0.25	0.29	0.31	0.33	0.37
16	4	0.31	0.31	0.32	0.37	0.40	0.42	0.46
18	2	0.15	0.16	0.16	0.20	0.21	0.23	0.27
18	3	0.23	0.24	0.24	0.28	0.30	0.32	0.36
18	4	0.30	0.31	0.31	0.36	0.39	0.41	0.45
20	2	0.15	0.16	0.16	0.20	0.21	0.23	0.26
20	3	0.23	0.24	0.24	0.28	0.30	0.32	0.35
20	4	0.30	0.31	0.31	0.36	0.39	0.41	0.44
24	2	0.15	0.15	0.16	0.19	0.21	0.22	0.24
24	3	0.23	0.23	0.24	0.27	0.30	0.31	0.33
24	4	0.30	0.30	0.31	0.35	0.39	0.40	0.42
30	2	0.15	0.15	0.16	0.19	0.20	0.21	0.23
30	3	0.23	0.23	0.24	0.27	0.29	0.30	0.32
30	4	0.30	0.30	0.31	0.35	0.38	0.39	0.41
36	2	0.14	0.15	0.15	0.19	0.20	0.20	0.22
36	3	0.22	0.23	0.23	0.27	0.29	0.29	0.31
36	4	0.29	0.30	0.30	0.35	0.38	0.38	0.40
42	2	0.14	0.14	0.15	0.18	0.19	0.20	0.21
42	3	0.22	0.22	0.23	0.26	0.28	0.29	0.30
42	4	0.29	0.29	0.30	0.34	0.37	0.38	0.39
48	2	0.14	0.14	0.15	0.18	0.18	0.19	0.20
48	3	0.22	0.22	0.23	0.26	0.27	0.28	0.29
48	4	0.29	0.29	0.30	0.34	0.36	0.37	0.38
54	2	0.14	0.14	0.14	0.17	0.18	0.19	0.20
54	3	0.22	0.22	0.22	0.25	0.27	0.28	0.29
54	4	0.29	0.29	0.29	0.34	0.36	0.36	0.38

* This thread is commonly known to the trade as the Mueller thread.

3P—5M—4/78—43151

ANSI A21.6–1975
(AWWA C106–75)

Revision of
A21.6–1970
(AWWA C106–70)

AMERICAN NATIONAL STANDARD

for

CAST-IRON PIPE CENTRIFUGALLY CAST IN METAL MOLDS, FOR WATER OR OTHER LIQUIDS

Administrative Secretariat
AMERICAN WATER WORKS ASSOCIATION

Co-Secretariats
AMERICAN GAS ASSOCIATION
NEW ENGLAND WATER WORKS ASSOCIATION

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Table of Contents

American National Standard

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Foreword

This foreword is provided for information only and is not a part of ANSI A21.6-1975 (AWWA C106-75).

I—History of Standard

On Sep. 10, 1902, NEWWA adopted a "Standard Specification for Cast-Iron Pipe and Special Castings," covering bell-and-spigot pit-cast pipe and fittings of ten thickness classes. The thickness classes were based on allowable internal pressures varying by increments of 50 ft of head.

On May 12, 1908, AWWA adopted a "Standard Specification for Cast-Iron Pipe and Special Castings," covering bell-and-spigot pit-cast pipe and fittings of eight classes, A through H, with allowable working pressures varying by increments of 100 ft of head from 100 to 800 ft. Dimensions and weights were given for pipe and fittings.

In 1926, ASA Sectional Committee (now American National Standards Committee) A21 on Cast-Iron Pipe and Fittings was organized under the sponsorship of A.G.A., ASTM, AWWA, and NEWWA and was assigned the following scope:

> Unification of specifications for cast-iron pipe, including materials; dimensions; pressure ratings; methods of manufacture (including such new developments as centrifugal casting) insofar as they may be necessary to secure satisfactory specifications; elimination of unnecessary sizes and varieties; consideration of the possibility of developing a coordinated scheme of metallic pipe and fittings applicable to all common mediums; and methods of making up joints insofar as they are determining as to the dimensional design of cast-iron pipe.
>
> The types of cast-iron pipe [are] to include bell-and-spigot pipe, flanged pipe, flanged and bell mouth fittings and wall castings, pipe elbows, tees, wyes, return bends, and other fittings not now included in standard lists; cast-iron pipe threaded for flanges or couplings. The standardization is not to include methods of installing pipe and similar matters, except as to the making up of joints in its relationship to the dimensional standardization of pipe and fittings, as noted above.

Sectional Committee A21 sponsored many tests of pipe and fittings; these included subjection of pipe to combined earth load and internal pressures (which form the basis of pipe thickness design), corrosion tests, measurement of hydraulic friction loss in fittings, and tests of bursting strengths of pipe and fittings. After exhaustive study of the test results and other research, the committee in 1939 issued A21.1, "American Standard Practice Manual for the Computation of Strength and Thickness of Cast Iron Pipe." The manual included nomograms and thickness tables for pit-cast pipe with 11/31* iron strength. As stated in the preface to that manual, however, the design method was applicable to pipe of any iron strength.

Discussions and interpretations of the method of design of cast-iron pipe

* The first figure designates the bursting tensile strength in units of 1 000 psi and the second figure designates the ring modulus of rupture in units of 1 000 psi.

were published in 1939 and presented to AWWA and A.G.A. As a result of these publications and because of the general acceptance of A21.1, a substantial volume of cast-iron pipe was designed by the new method and furnished to manufacturers' standards between 1939 and 1953. A standard (A21.2) for pit-cast pipe with 11/31 iron strength also was issued in 1939. Work on standards for centrifugally cast pipe with 18/40 iron strength was started after the design was completed in 1939, but, owing to the intervention of World War II and other causes, they were not formally issued until 1953.

In 1957, a revision of A21.1 was issued. In that revision, designated ASA A21.1-1957 (AWWA H1-57) the major change was the addition of a method for computing earth loads on pipe laid under embankments and of nomograms and thickness tables for centrifugally cast pipe with 18/40 iron strength.

In 1958, Sectional Committee A21 was reorganized. Subcommittees were established to study each group of standards in accordance with the review and revision policy of ASA (now ANSI). The subcommitteee on pipe (Subcommittee No. 1) was organized with the following assignment:

> The scope of the committee actitivy shall include an examination of all present A21 standards for pipe to determine what is needed to bring these up to date. The examination shall include A21.1, A21.2, A21.3, A21.6, A21.7, A21.8, and A21.9, as well as any other matters pertaining to pipe standards.

As a result of the work of Subcommittee No. 1 on this assignment, revisions of the cast-iron pipe standards A21.6(AWWA C106), A21.7, A21.8 (AWWA C108) and A21.9 were issued in 1962. A revision of A21.1-1957 (AWWA H1-57) was issued in 1967 and reaffirmed without revision in 1972. Revisions of the 1962 cast-iron pipe standards were issued in 1970. The major revisions of A21.6-1970 were: pipe with push-on joints were added; laying conditions C and D were deleted and condition F was added; and, the tables were revised to include the pipe lengths then being produced.

In 1974, Subcommittee 1 reviewed the 1970 edition and recommended minor editorial changes. Therefore, this edition is unchanged from the 1970 edition except for minor editorial changes and the updating of this foreword.

The tables and strength test requirements in this standard are for pipe with 18/40 iron strength. Advances in production technology have enabled the manufacturers to furnish pipe with greater strength. Pipe with 21/45 iron strength has been furnished for many years. Design details and standard thicknesses for pipe with 21/45 iron strength are shown in A21.1-1957 (AWWA C101-67), reaffirmed in 1972.

II—Acceptance Tests

Acceptance tests were established as routine control measures to ensure the design burst and ring strengths. The acceptance tests specified in this standard are the Talbot strip test and the hardness test. In establishing the acceptance values for the Talbot strip test, A21 Committee in the 1940s reviewed detailed data, including burst, ring, and Talbot strip tests on more than 400 pipe centrifugally cast in metal molds. Correlations of the data showed that the Talbot strip modulus of rupture and secant modulus of elasticity values specified in this standard represent acceptable pipe which meet the design burst and ring strengths.

The hardness test was specified as a means of assuring the ferritic matrix which is characteristic of the microstructure of pipe cast in metal molds. The specified acceptance values for the Talbot strip test provide additional control of the microstructure to ensure satisfactory machinability.

III—Options

This standard includes certain options which, if desired, must be specified in the invitation for bids and on the purchase order. Also, a number of items must be specified to describe completely the pipe required. The following summarizes these details and available options and lists the sections of the standard where they can be found:

1. Size, joint type, thickness or class, and laying lengths (Tables)
2. Special joints (Sec. 6–1)
3. Certification by manufacturer (Sec. 6–4)
4. Inspection by purchaser (Sec. 6–5)
5. Cement lining (Sec. 6–8.2) Experience has indicated that bituminous inside coating is not complete protection against loss in pipe capacity caused by tuberculation. Cement linings are recommended for most waters.
6. Special coatings and linings (Sec. 6–8.4)
7. Special marking on pipe (Sec. 6–10)
8. Written transcripts of foundry records (Sec. 6–15)
9. Special tests (Sec 6–16).

Committee Personnel

Subcommittee 1, Pipe, which reviewed this standard, had the following personnel at that time:

EDWARD C. SEARS, *Chairman*
WALTER AMORY, *Vice-Chairman*

User Members	*Producer Members*
ROBERT S. BRYANT	W. D. GOODE
FRANK E. DOLSON	CARL A. HENRIKSON
GEORGE F. KEENAN	THOMAS D. HOLMES
LEONARD ORLANDO JR.	SIDNEY P. TEAGUE
JOHN E. PERRY	

Standards Committee A21, Cast-Iron Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

LLOYD W. WELLER, *Chairman*
CARL A. HENRIKSON, *Vice-Chairman*
JAMES B. RAMSEY, *Secretary*

Organization Represented	*Name of Representative*
American Gas Association	LEONARD ORLANDO JR.
American Society of Civil Engineers	KENNETH W. HENDERSON
American Society of Mechanical Engineers	JAMES S. VANICK
American Society for Testing and Materials	ALBERT H. SMITH JR.
American Water Works Association	ARNOLD M. TINKEY
	LLOYD W. WELLER
Cast Iron Pipe Research Association	CARL A. HENRIKSON
	EDWARD C. SEARS
	W. HARRY SMITH
Individual Producer	ALFRED F. CASE
Manufacturers' Standardization Society of the Valve and Fittings Industry	ABRAHAM FENSTER
New England Water Works Association	WALTER AMORY
Naval Facilities Engineering Command	STANLEY C. BAKER
Underwriters' Laboratories, Inc.	JOHN E. PERRY
Canadian Standards Association	W. F. SEMENCHUK*

* Liaison representative without vote

Revision of
A21.6–1970
(AWWA C106–70)

American National Standard for

Cast-Iron Pipe Centrifugally Cast in Metal Molds, for Water or Other Liquids

Sec. 6–1—Scope

This standard covers 3-in. through 24-in. cast-iron pipe centrifugally cast in metal molds for water or other liquids. Characteristics of such pipe with push-on joints, mechanical joints and bell-and-spigot joints are given in the tables. This standard may be used for pipe with such other types of joints as may be agreed upon at the time of purchase. The thicknesses, weights, and strength test requirements shown in this standard are for pipe with 18/40 iron strength (18 000 psi minimum bursting tensile and 40 000 psi minimum ring modulus of rupture).

Sec. 6–2—Definitions

Under this standard, the following definitions shall apply:

6–2.1. *Purchaser*. The party entering into a contract or agreement to purchase pipe according to this standard.

6–2.2 *Manufacturer*. The party that produces the pipe.

6–2.3. *Inspector*. The representative of the purchaser, authorized to inspect in behalf of the purchaser to determine whether or not the pipe meet this standard.

6–2.4. *Cast iron*. The unqualified term *cast iron* shall apply to gray cast iron which is a cast ferrous material in which a major part of the carbon content occurs as free carbon in the form of flakes interspersed through the metal.

6–2.5. *Push-on joint*. The single rubber-gasket joint as described in ANSI A21.11 (AWWA C111) of latest revision.

6–2.6. *Mechanical joint*. The gasketed and bolted joint as detailed in ANSI A21.11 (AWWA C111) of latest revision.

6–2.7. *Bell-and-spigot joint*. The poured or caulked joint as detailed in Table 6.6.

Sec. 6–3—General Requirements

6–3.1. Pipe with push-on joints, mechanical joints, and bell-and-spigot joints shall conform to the applicable dimensions and weights shown in the tables in this standard and to the applicable requirements of ANSI A21.11 (AWWA C111) of latest revision. Pipe with other types of joints shall comply with the joint dimensions and weights agreed upon at the time of purchase, but in all other respects shall fulfill the requirements of this standard.

6–3.2. The nominal laying length of the pipe shall be as shown in the tables. A maximum of 10 per cent of the total number of pipe of each size specified in an order may be furnished by as much as 24 in. shorter than the nominal laying length, and an additional 10 per cent may be furnished by as much as 3 in. shorter than nominal laying length.

Sec. 6–4—Inspection and Certification by Manufacturer

6–4.1. The manufacturer shall establish the necessary quality control and inspection practice to assure compliance with this standard.

6–4.2. The manufacturer shall, if required on the purchase order, furnish a sworn statement that the inspection and all of the specified tests have been made and the results thereof comply with the requirements of this standard.

6–4.3. All pipe shall be clean and sound without defects which will impair their service. Repairing of defects by welding or other method shall not be allowed if such repairs will adversely affect the serviceability of the pipe or its capability to meet strength requirements of this standard.

Sec. 6–5—Inspection by Purchaser

6–5.1. If the purchaser desires to inspect pipe at the manufacturer's plant, the purchaser shall so specify on the purchase order, stating the conditions (such as time, and the extent of inspection) under which the inspection shall be made.

6–5.2. The inspector shall have free access to those parts of the manufacturer's plant that are necessary to assure compliance with this standard. The manufacturer shall make available for the inspector's use such gages as are necessary for inspection. The manufacturer shall provide the inspector with assistance as necessary for the handling of pipe.

Sec. 6–6—Delivery and Acceptance

All pipe and accessories shall comply with this standard. Pipe and accessories not complying with this standard shall be replaced by the manufacturer at the agreed point of delivery. The manufacturer shall not be liable for shortages or damaged pipe after acceptance at the agreed point of delivery except as recorded on the delivery receipt or similar document by the carrier's agent.

Sec. 6–7—Tolerances or Permitted Variations

6–7.1. *Dimensions.* The spigot end, bell, and socket of the pipe and the accessories shall be gaged with suitable gages at sufficiently frequent intervals to ensure that the dimensions comply with the requirements of this standard. The smallest inside diameter of the sockets and the outside of the spigot ends shall be tested with circular gages. Other socket dimensions shall be gaged as appropriate.

6–7.2. *Thickness.* Minus thickness tolerances of pipe and bell shall not exceed those shown below:

Pipe Size *in.*	Minus Tolerance *in.*
3–8	0.05
10–12	0.06
14–24	0.08

NOTE: An additional tolerance of 0.02 in. shall be permitted over areas not exceeding 8 in. in any direction.

6–7.3. *Weight.* The weight of any single pipe shall not be less than the tabulated weight by more than 5 per cent for pipe 12 in. or smaller in diameter, nor by more than 4 per cent for pipe larger than 12 in. in diameter.

Sec. 6-8—Coatings and Linings

6-8.1. *Outside coating*. The outside coating for use under normal conditions shall be a bituminous coating approximately 1 mil thick. The coating shall be applied to the outside of all pipe, unless otherwise specified. The finished coating shall be continuous, smooth, neither brittle when cold nor sticky when exposed to the sun and shall be strongly adherent to the pipe.

6-8.2. *Cement-mortar linings*. Cement linings shall be in accordance with ANSI A21.4 (AWWA C104) of latest revision. If desired, cement linings shall be specified in the invitation for bids and on the purchase order.

6-8.3. *Inside coating*. Unless otherwise specified, the inside coating for pipe not cement lined shall be a bituminous material as thick as practicable (at least 1 mil) and conforming to all appropriate requirements for seal coat in ANSI A21.4 of latest revision.

6-8.4. *Special coatings and linings*. For special conditions, other types of coatings and linings may be available. Such special coatings and linings shall be specified in the invitation for bids and on the purchase order.

Sec. 6-9—Hydrostatic Test

Each pipe shall be subjected to a hydrostatic test of not less than 500 psi. This test may be made either before or after the outside coating and the inside coating have been applied, but shall be made before the application of cement lining or of a special lining.

The pipe shall be under the full test pressure for at least 10 s. Suitable controls and recording devices shall be provided so that the test pressure and duration may be adequately ascertained. Any pipe that leaks or does not withstand the test pressure shall be rejected.

In addition to the hydrostatic test before application of a cement lining or special lining, the pipe may be retested, at the manufacturer's option, after application of such lining.

Sec. 6-10—Marking Pipe

The weight, class or nominal thickness, and sampling period shall be shown on each pipe. The manufacturer's mark and the year in which the pipe was produced shall be cast or stamped on the pipe. When specified on the purchase order, initials not exceeding four in number shall be cast or stamped on the pipe. All required markings shall be clear and legible and all cast marks shall be on or near the bell. All letters and numerals on pipe sizes 8 in. and larger shall be not less than ½ in. in height.

Sec. 6-11—Weighing Pipe

Each pipe shall be weighed before the application of any lining or coating other than the bituminous coating and the weight shall be shown on the outside or inside of the bell or spigot end.

Sec. 6-12—Acceptance Tests

The standard acceptance tests for the physical characteristics of the pipe shall be as follows:

6-12.1. *Talbot strip tests*. Talbot strip tests shall be used to determine the acceptability of 3-24 in. pipe for modulus of rupture and secant modulus of elasticity.

6-12.1.1. *Sampling*. At least one sample shall be taken during each period of approximately 3 hr. The sample for the first period shall be taken during the first hour, or if casting is direct from the melting unit, from the first ladle. Samples shall be taken so that each size of pipe continously cast for 2 hr or longer and each source of iron continuously used for 2 hr or longer shall be fairly represented.

6–12.1.2. *Acceptance values.* The modulus of rupture as determined by the Talbot strip test shall be 40 000 psi minimum.

The secant modulus of elasticity value shall not exceed 300 times the actual value of the modulus of rupture. (For example: when the modulus of rupture is 40 000 psi, the secant modulus of elasticity shall not exceed 12 000 000 psi.)

6–12.1.3. *Test method.* Talbot strips (Fig. 6.1) shall be machined

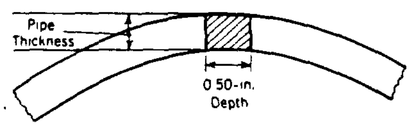

Fig. 6.1. Position From Which Talbot Strip is Cut

longitudinally from each pipe specimen selected for testing by this method. The Talbot strips may be cut from a part of the ring little stressed in the ring test—that is, near one of the elements marked *a* in the illustration of the ring test (Fig. 6.3). The strips in any case shall be in cross section as indicated in Fig. 6.1—that is, shall have for their width the thickness of the pipe and for their depth 0.50 in. Their length shall be at least 10½ in. The strips shall be tested as beams on supports 10 in. apart with loads applied perpendicularly to the machined faces at two points 3⅓ in. from the supports. The breaking load and the deflection shall be observed and recorded.

The strip shall be accurately calipered at the point of rupture and the modulus of rupture, R, shall be calculated by the usual beam formula, which for this case reduces to the expression

$$R = \frac{10W}{td^2}$$

The secant modulus of elasticity, E_s, in pounds per square inch, shall be computed by the formula

$$E_s = \frac{21.3R}{dy}$$

In the above formulas, R is the modulus of rupture (psi); E_s, the secant modulus of elasticity (psi); W, the breaking load (lb); d, the depth (in.) of the strip (intended to be 0.50 in.); t, the width (in.) of the strip (pipe thickness); and y, the deflection (in.) of the strip at the center at breaking load.

Deflection measurements shall be that of the specimen and shall not include any compression of the supports or loading blocks, or backlash or distortion of the testing machine.

6–12.2. *Hardness tests.* Hardness tests shall be made on the outside surface of pipe. A sufficient number of pipe shall be tested to assure that the hardness does not exceed Rockwell B-95, or its equivalent. Pipe may be heat-treated to meet this requirement.

For the purpose of foundry records, hardness tests shall be made on a specimen from each Talbot strip selected for testing in Sec. 6–12.11. Rockwell B hardness determinations shall be made in accordance with ASTM E18-67 on the following surfaces at their approximate centers: (a) the outside pipe surface, (b) the inside pipe surface, and (c) either of the two cut surfaces. These three determinations shall be made at three locations (1-2-3) along the length of the specimen, as shown in Fig. 6.2. The three determinations for each surface shall be averaged and no average value shall exceed Rockwell B-95. No single

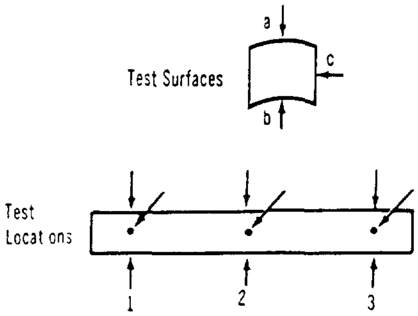

Fig. 6.2. **Location of Rockwell Hardness Tests on Talbot Strip Specimen**

determination on the Talbot strip shall exceed B-98.

Sec. 6-13—Ring Tests and Full-Length Bursting Tests

6-13.1. The manufacturer shall make bursting tests and ring tests in conjunction with strip tests so that he can certify the design values of the modulus of rupture (40 000 psi) and the bursting tensile strength of the iron in the pipe (18 000 psi). These tests shall be made in accordance with dimensions and methods given in Sec. 6-13.2 and Sec. 6-13.3. At least one pipe sample for the ring and bursting tests shall be selected from each of the following size groups from each calendar month's cast:

Group	Size in.
1	6, 8
2	10, 12
3	14, 16, 18
4	20, 24

When no pipe in a size group are manufactured during the calendar month, no tests on these sizes are required. Ring tests and bursting tests are not required on 3- and 4-in. pipe. At least three Talbot strips shall be tested from each pipe selected for bursting. Tests and records shall include the modulus of rupture of each strip and ring and the modulus of elasticity and hardness of each strip.

6-13.2. *Ring test method.* The maximum length of any ring shall not exceed 12 in.; for pipe 14 in. and larger, the minimum length shall be $10\frac{1}{2}$ in.; for pipe 12 in. and smaller, the minimum length shall be one half the nominal diameter of the pipe. Each ring shall be tested by the three-edge bearing method as indicated in Fig. 6.3. The lower bearing for the

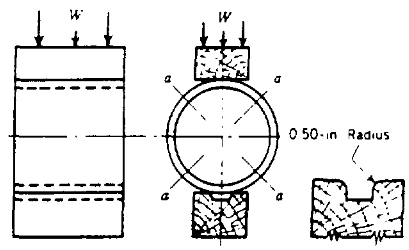

Fig. 6.3. Assembly for Ring Test

ring shall consist of two strips with vertical sides having their interior top edges rounded to a radius of approximately $\frac{1}{2}$ in. The strips shall be of hard wood or metal. If of metal, a piece of fabric or leather approximately $\frac{3}{16}$ in. thick shall be laid over them. They shall be straight and shall be securely fastened to a rigid block, with their interior vertical faces the following distances apart:

Pipe Size in.	Bearing Strip Spacing in.
6-12	$\frac{3}{4}$
14-24	1

The upper bearing shall be a hard wood block, straight and true from end to end. The upper and lower bearings shall extend the full length of the ring. The ring shall be placed symmetrically between the two bearings, and the center of application of the load shall

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be so placed that the vertical deformation at the two ends of the ring shall be approximately equal. If the ring is not uniform in thickness, it shall be so placed that the thick and thin portions are near the ends of the horizontal diameter.

For purposes of Sec. 6–15, a record of the breaking load of each ring tested shall be made. The modulus of rupture is computed from the formula

$$R = 0.954 \frac{W(d + t)}{bt^2}$$

in which R is the modulus of rupture (psi); W, the breaking load (lb); d, the average inside diameter (in.) of the ring; t, the average thickness (in.) of metal along the line of fracture; and b, the length (in.) of the ring.

6–13.3. *Burst test method.* The bursting tensile strength shall be determined by testing full-length pipe (less the amount cut off for ring and strip test specimens) to destruction by hydraulic pressure. Bells may be removed to facilitate testing. A suitable means for holding the end thrust shall be used which will not subject the pipe to endwise tension or compression, or other parasitic stresses. A calibrated pressure gage shall be used for determining the bursting pressure. The gage shall be connected to the interior of the test pipe by a separate connection from that which supplies water for the test. The unit tensile strength in bursting shall be obtained by the use of the formula

$$S = \frac{Pd}{2t}$$

in which S is the bursting tensile strength (psi) of the iron; P, the internal pressure (psi) at bursting; d, the average inside diameter (in.) of the pipe; and t, the minimum average thickness (in.) of the pipe along the principal line of break.

Measurements of thickness shall be taken along the principal line of break at 1-ft intervals.

The minimum average thickness along the principal line of break shall be obtained by averaging the measurements at the thinnest section at a weight of two and at the adjacent sections on each side at a weight of one each; or, if the thinnest section is at the end of the break, by averaging the thinnest-section measurement at a weight of two and the measurements of the adjacent section and the next section at a weight of one each.

Sec. 6–14—Chemical Analyses

Analyses of the iron shall be made at sufficiently frequent intervals to determine compliance with the following limits:

Substance	Maximum Limit *per cent*
Phosphorus	0.90
Sulfur	0.12

Control of the other chemical constituents shall be maintained to meet the physical property requirements of this standard. Samples for chemical analyses shall be representative and shall be obtained from either acceptance test specimens or specimens cast for this purpose.

Sec. 6–15—Foundry Records

The results of the following tests shall be recorded and retained for one year and shall be available to the purchaser at the foundry. Written transscripts of the results of these tests shall be furnished when specified on the purchase order:

6–15.1. Talbot strip tests (see Sec. 6–12.1)

6–15.2. Hardness tests (see Sec. 6–12.2)

6–15.3. Ring tests and full-length bursting tests (see Sec. 6–13)

6–15.4. Chemical analyses (see Sec. 6–14).

Sec. 6–16—Additional Tests Required by Purchaser

When tests other than those provided in this standard are required by the purchaser, such tests shall be specified in the invitation for bids and on the purchase order.

Sec. 6–17—Defective Specimens and Retests

When any physical test specimen shows defective machining or lack of continuity of metal, it shall be discarded and replaced by another specimen. When any sound test specimen fails to meet the specified requirements, the pipe from which it was taken shall be rejected and a retest may be made on two additional sound specimens from pipe cast in the same sampling period as the specimen which failed. Both of the additional specimens shall meet the prescribed tests to qualify the pipe produced in that sampling period.

Sec. 6–18—Rejection of Pipe

When any routine chemical analysis fails to meet the requirements of Sec. 6–14 or when any physical acceptance test fails to meet the requirements of Sec. 6–12.1, 6–12.2, or 6–17, the pipe cast in the same sampling period shall be rejected except as subject to the provision of Sec. 6–19.

Sec. 6–19—Determining Rejection

The manufacturer may determine the amount of rejection by making similar additional tests of pipe of the same size as that rejected until the rejected lot is bracketed in order of manufacture by an acceptable test at each end of the interval in question. When pipe of one size is rejected from a sampling period, the acceptability of pipe of different sizes from that same period may be established by making the routine acceptance tests for these sizes.

TABLE 6.1

Selection Table for Push-On Joint Cast-Iron Pipe§

These thicknesses and weights are for pipe laid without blocks, on flat-bottom trench, with tamped backfill (laying condition B), under 5 ft of cover. For other conditions see tables 6.3 and 6.4 hereof and ANSI A21.1 (AWWA C101).

Size	Thickness	OD	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
			Per Length†	Avg. per Foot‡	Per Length†	Avg. per Foot‡
in.			*lb*			
Working Pressure 50 psi—115 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.44	11.10	880	49.0	975	48.7
12	0.48	13.20	1,140	63.4	1,260	63.1
14	0.48	15.30	1,335	74.1	1,470	73.6
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.54	19.50	1,920	106.7	2,120	106.1
20	0.57	21.60	2,250	124.9	2,485	124.2
24	0.63	25.80	2,975	165.3	3,285	164.4
Working Pressure 100 psi—231 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.44	11.10	880	49.0	975	48.7
12	0.48	13.20	1,140	63.4	1,260	63.1
14	0.51	15.30	1,410	78.2	1,555	77.8
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.58	19.50	2,050	113.9	2,265	113.3
20	0.62	21.60	2,430	134.9	2,685	134.2
24	0.68	25.80	3,190	177.3	3,525	176.4
Working Pressure 150 psi—346 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.44	11.10	880	49.0	975	48.7
12	0.48	13.20	1,140	63.4	1,260	63.1
14	0.51	15.30	1,410	78.2	1,555	77.8
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.58	19.50	2,050	113.9	2,265	113.3
20	0.62	21.60	2,430	134.9	2,685	134.2
24	0.73	25.80	3,410	189.4	3,765	188.4
Working Pressure 200 psi—462 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.44	11.10	880	49.0	975	48.7
12	0.48	13.20	1,140	63.4	1,260	63.1
14	0.55	15.30	1,510	83.8	1,670	83.4
16	0.58	17.40	1,815	100.9	2,010	100.4
18	0.63	19.50	2,210	122.8	2,445	122.2
20	0.67	21.60	2,610	144.9	2,885	144.2
24	0.79	25.80	3,665	203.6	4,055	202.6

* Pipe of 3-in. size also available in 12-ft laying length. Weight per length† is 150 lb; average weight per foot‡ is 12.5 lb for all working pressures and heads.
† Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
‡ Including bell. Average weight per foot based on calculated weight of pipe before rounding.
§ Weights shown for push-on joint pipe are also applicable to bell-and-spigot joint pipe.

TABLE 6.1—(*contd.*)

Selection Table for Push-On Joint Cast-Iron Pipe§

These thicknesses and weights are for pipe laid without blocks, on flat-bottom trench, with tamped backfill (Laying Condition B), under 5 ft of cover. For other conditions see Tables 6.3 and 6.4 hereof and ANSI A21.1 (AWWA C101).

Size	Thickness	OD	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
			Per Length†	Avg. per Foot‡	Per Length†	Avg. per Foot‡
	in.		*lb*			
Working Pressure 250 psi—577 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.44	11.10	880	49.0	975	48.7
12	0.52	13.20	1,230	68.3	1,360	67.9
14	0.59	15.30	1,610	89.5	1,780	89.0
16	0.63	17.40	1,960	109.0	2,170	108.4
18	0.68	19.50	2,370	131.8	2,620	131.1
20	0.72	21.60	2,785	154.8	3,080	154.0
24	0.79	25.80	3,665	203.6	4,055	202.6
Working Pressure 300 psi—693 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.48	11.10	955	53.0	1,055	52.7
12	0.52	13.20	1,230	68.3	1,360	67.9
14	0.59	15.30	1,610	89.5	1,780	89.0
16	0.68	17.40	2,100	116.8	2,325	116.2
18	0.73	19.50	2,530	140.6	2,800	140.0
20	0.78	21.60	3,000	166.6	3,315	165.8
24	0.85	25.80	3,920	217.8	4,335	216.8
Working Pressure 350 psi—808 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.1	320	16.0
6	0.38	6.90	460	25.6	510	25.6
8	0.41	9.05	665	36.9	735	36.8
10	0.52	11.10	1,025	56.9	1,130	56.6
12	0.56	13.20	1,315	73.1	1,455	72.7
14	0.64	15.30	1,735	96.3	1,920	95.9
16	0.68	17.40	2,100	116.8	2,325	116.2
18	0.79	19.50	2,720	151.2	3,010	150.6
20	0.84	21.60	3,210	178.4	3,550	177.6
24	0.92	25.80	4,220	234.4	4,665	233.4

* Pipe of 3-in. size also available in 12-ft laying length. Weight per length† is 150 lb; average weight per foot‡ is 12.5 lb for all working pressures and heads.
† Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
‡ Including bell. Average weight per foot based on calculated wieght of pipe before rounding.
§ Weights shown for push-on joint pipe are also applicable to bell-and-spigot joint pipe.

TABLE 6.2

Selection Table for Mechanical-Joint Cast-Iron Pipe

These thicknesses and weights are for pipe laid without blocks, on flat-bottom trench, with tamped backfill (Laying Condition B), under 5 ft of cover. For other conditions see Tables 6.3 and 6.5 hereof and ANSI A21.1 (AWWA C101).

Size	Thickness	OD	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
			Per Length†	Avg. per Foot‡	Per Length†	Avg. per Foot‡
	in.		*lb*			
Working Pressure 50 psi—115 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.44	11.10	870	48.2	960	48.0
12	0.48	13.20	1,125	62.6	1,245	62.3
14	0.48	15.30	1,335	74.0	1,470	73.6
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.54	19.50	1,920	106.7	2,120	106.0
20	0.57	21.60	2,250	124.9	2,485	124.2
24	0.63	25.80	2,975	165.2	3,285	164.2
Working Pressure 100 psi—231 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.44	11.10	870	48.2	960	48.0
12	0.48	13.20	1,125	62.6	1,245	62.3
14	0.51	15.30	1,410	78.2	1,555	77.8
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.58	19.50	2,050	113.9	2,265	113.2
20	0.62	21.60	2,430	134.9	2,685	134.2
24	0.68	25.80	3,190	177.2	3,525	176.2
Working Pressure 150 psi—346 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.44	11.10	870	48.2	960	48.0
12	0.48	13.20	1,125	62.6	1,245	62.3
14	0.51	15.30	1,410	78.2	1,555	77.8
16	0.54	17.40	1,700	94.5	1,880	94.0
18	0.58	19.50	2,050	113.9	2,265	113.2
20	0.62	21.60	2,430	134.9	2,685	134.2
24	0.73	25.80	3,405	189.2	3,765	188.2
Working Pressure 200 psi—462 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.44	11.10	870	48.2	960	48.0
12	0.48	13.20	1,125	62.6	1,245	62.3
14	0.55	15.30	1,510	83.8	1,670	83.4
16	0.58	17.40	1,815	100.9	2,005	100.3
18	0.63	19.50	2,210	122.8	2,445	122.2
20	0.67	21.60	2,610	144.9	2,885	144.2
24	0.79	25.80	3,665	203.5	4,050	202.6

* Pipe of 3-in. size also available in 12-ft laying length. Weight per length† is 150 lb; average weight per foot‡ is 12.3 lb for all working pressures and heads.
† Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
‡ Including bell. Average weight per foot based on calculated weight of pipe before rounding.

TABLE 6.2—(*contd.*)

Selection Table for Mechanical-Joint Cast-Iron Pipe

These thicknesses and weights are for pipe laid without blocks, on flat-bottom trench, with tamped backfill (Laying Condition B), under 5 ft of cover. For other conditions see Tables 6.3 and 6.5 hereof and ANSI A21.1 (AWWA C101).

Size	Thickness	OD	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
			Per Length†	Avg. per Foot‡	Per Length†	Avg. per Foot‡
	in.		*lb*			
Working Pressure 250 psi—577 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.44	11.10	870	48.2	960	48.0
12	0.52	13.20	1,215	67.4	1,340	67.1
14	0.59	15.30	1,610	89.4	1,780	89.0
16	0.63	17.40	1,960	108.9	2,165	108.3
18	0.68	19.50	2,370	131.7	2,620	131.0
20	0.72	21.60	2,785	154.8	3,080	154.1
24	0.79	25.80	3,665	203.5	4,050	202.6
Working Pressure 300 psi—693 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.48	11.10	940	52.2	1,040	52.0
12	0.52	13.20	1,215	67.4	1,340	67.1
14	0.59	15.30	1,610	89.4	1,780	89.0
16	0.68	17.40	2,100	116.7	2,325	116.2
18	0.73	19.50	2,530	140.6	2,800	140.0
20	0.78	21.60	3,000	166.6	3,320	165.9
24	0.85	25.80	3,920	217.7	4,335	216.8
Working Pressure 350 psi—808 ft Head						
3*	0.32	3.96	215	12.0	240	11.9
4	0.35	4.80	290	16.2	320	16.1
6	0.38	6.90	460	25.5	510	25.4
8	0.41	9.05	655	36.4	725	36.2
10	0.52	11.10	1,010	56.1	1,120	55.9
12	0.56	13.20	1,300	72.2	1,440	71.9
14	0.64	15.30	1,735	96.3	1,920	95.9
16	0.68	17.40	2,100	116.7	2,325	116.2
18	0.79	19.50	2,720	151.2	3,010	150.6
20	0.84	21.60	3,210	178.3	3,550	177.6
24	0.92	25.80	4,215	234.2	4,665	233.2

* Pipe of 3-in. size also available in 12-ft laying length. Weight per length† is 150 lb; average weight per foot‡ is 12.3 lb for all working pressures and heads.
† Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
‡ Including bell. Average weight per foot based on calculated weight of pipe before rounding.

TABLE 6.3

Standard Thickness Selection Table for Cast-Iron Pipe*

Laying Condition A—flat-bottom trench, without blocks, untamped backfill
Laying Condition B—flat-bottom trench, without blocks, tamped backfill
Laying Condition F—pipe laid on gravel or sand bedding, backfill tamped

Size in.	Working Pressure psi	3½-ft Cover			5-ft Cover			8-ft Cover		
		Laying Condition			Laying Condition			Laying Condition		
		A	B	F	A	B	F	A	B	F
		Thickness*—in.								
3	50	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	100	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	150	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	200	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	250	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	300	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	350	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
4	50	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	100	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	150	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	200	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	250	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	300	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	350	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
6	50	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	100	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	150	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	200	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	250	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	300	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
	350	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
8	50	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	100	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	150	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	200	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	250	0.41	0.41	0.41	0.41	0.41	0.41	0.44	0.41	0.41
	300	0.41	0.41	0.41	0.41	0.41	0.41	0.44	0.44	0.41
	350	0.41	0.41	0.41	0.52	0.41	0.41	0.46	0.44	0.44
10	50	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	100	0.44	0.44	0.44	0.44	0.44	0.44	0.48	0.44	0.44
	150	0.44	0.44	0.44	0.44	0.44	0.44	0.48	0.44	0.44
	200	0.44	0.44	0.44	0.44	0.44	0.44	0.48	0.48	0.44
	250	0.44	0.44	0.44	0.48	0.44	0.44	0.52	0.48	0.48
	300	0.48	0.44	0.44	0.48	0.48	0.48	0.52	0.52	0.48
	350	0.48	0.48	0.48	0.52	0.52	0.48	0.56	0.52	0.52
12	50	0.48	0.48	0.48	0.48	0.48	0.48	0.52	0.48	0.48
	100	0.48	0.48	0.48	0.48	0.48	0.48	0.52	0.48	0.48
	150	0.48	0.48	0.48	0.48	0.48	0.48	0.52	0.52	0.48
	200	0.48	0.48	0.48	0.48	0.48	0.48	0.56	0.52	0.48
	250	0.52	0.48	0.48	0.52	0.52	0.48	0.56	0.56	0.52
	300	0.52	0.52	0.52	0.56	0.52	0.52	0.60	0.56	0.56
	350	0.56	0.56	0.52	0.56	0.56	0.56	0.60	0.60	0.60
14	50	0.51	0.48	0.48	0.51	0.48	0.48	0.59	0.55	0.51
	100	0.51	0.48	0.48	0.55	0.51	0.48	0.59	0.55	0.51
	150	0.55	0.51	0.48	0.55	0.51	0.48	0.64	0.59	0.55
	200	0.55	0.51	0.51	0.55	0.55	0.51	0.64	0.59	0.59
	250	0.59	0.55	0.55	0.59	0.59	0.55	0.64	0.64	0.59
	300	0.59	0.59	0.59	0.64	0.59	0.59	0.69	0.64	0.64
	350	0.64	0.64	0.64	0.64	0.64	0.64	0.75	0.69	0.64

* Thicknesses include allowances for foundry practice, corrosion, and either water hammer or truck load.

TABLE 6.3—(*contd.*)

Standard Thickness Selection Table for Cast-Iron Pipe*

Laying Condition A—flat-bottom trench, without blocks, untamped backfill
Laying Condition B—flat-bottom trench, without blocks, tamped backfill
Laying Condition F—pipe laid on gravel or sand bedding, backfill tamped

Size *in.*	Working Pressure *psi*	3½-ft Cover			5-ft Cover			8-ft Cover		
		Laying Condition			Laying Condition			Laying Condition		
		A	B	F	A	B	F	A	B	F
		Thickness*—*in.*								
16	50	0.54	0.50	0.50	0.58	0.54	0.50	0.63	0.58	0.54
	100	0.54	0.54	0.50	0.58	0.54	0.50	0.63	0.58	0.54
	150	0.58	0.54	0.50	0.58	0.54	0.54	0.68	0.63	0.58
	200	0.58	0.58	0.54	0.63	0.58	0.58	0.68	0.63	0.63
	250	0.63	0.58	0.58	0.63	0.63	0.58	0.73	0.68	0.63
	300	0.63	0.63	0.63	0.68	0.68	0.63	0.73	0.73	0.68
	350	0.68	0.68	0.68	0.73	0.68	0.68	0.79	0.73	0.73
18	50	0.58	0.54	0.54	0.58	0.54	0.54	0.68	0.63	0.58
	100	0.58	0.54	0.54	0.63	0.58	0.54	0.68	0.63	0.58
	150	0.63	0.58	0.54	0.63	0.58	0.58	0.73	0.68	0.63
	200	0.63	0.58	0.58	0.68	0.63	0.58	0.73	0.68	0.63
	250	0.68	0.63	0.63	0.68	0.68	0.63	0.79	0.73	0.68
	300	0.68	0.68	0.68	0.73	0.73	0.68	0.79	0.79	0.73
	350	0.79	0.73	0.73	0.79	0.79	0.73	0.85	0.85	0.79
20	50	0.62	0.57	0.57	0.67	0.57	0.57	0.72	0.67	0.62
	100	0.62	0.57	0.57	0.67	0.62	0.57	0.72	0.67	0.62
	150	0.67	0.62	0.57	0.67	0.62	0.62	0.78	0.72	0.67
	200	0.67	0.62	0.62	0.72	0.67	0.62	0.78	0.72	0.67
	250	0.72	0.67	0.67	0.78	0.72	0.67	0.84	0.78	0.72
	300	0.78	0.72	0.72	0.78	0.78	0.72	0.84	0.84	0.78
	350	0.84	0.78	0.78	0.84	0.84	0.78	0.91	0.84	0.84
24	50	0.68	0.63	0.63	0.73	0.63	0.63	0.79	0.73	0.68
	100	0.73	0.63	0.63	0.73	0.68	0.63	0.85	0.73	0.68
	150	0.73	0.68	0.63	0.79	0.73	0.68	0.85	0.79	0.73
	200	0.79	0.73	0.68	0.79	0.79	0.73	0.92	0.85	0.79
	250	0.79	0.79	0.73	0.85	0.79	0.79	0.92	0.85	0.85
	300	0.85	0.85	0.85	0.92	0.85	0.85	0.99	0.92	0.92
	350	0.92	0.92	0.92	0.99	0.92	0.92	1.07	0.99	0.92

* Thicknesses include allowances for foundry practice, corrosion, and either water hammer or truck load.

TABLE 6.4

Standard Dimensions and Weights of Push-On Joint Cast-Iron Pipe||

Size in.	Thickness Class	Thickness (in.)	OD† (in.)	Weight of Barrel per Foot (lb)	Weight of Bell (lb)	Weight Based on 18-ft Laying Length: Per Length‡ (lb)	Weight Based on 18-ft Laying Length: Avg. per Foot§ (lb)	Weight Based on 20-ft Laying Length: Per Length‡ (lb)	Weight Based on 20-ft Laying Length: Avg. per Foot§ (lb)
3*	22	0.32	3.96	11.4	11	215	12.0	240	11.9
	23	0.35	3.96	12.4	11	235	13.0	260	12.9
	24	0.38	3.96	13.3	11	250	13.9	275	13.8
4	22	0.35	4.80	15.3	14	290	16.1	320	16.0
	23	0.38	4.80	16.5	14	310	17.3	345	17.2
	24	0.41	4.80	17.6	14	330	18.4	365	18.3
	25	0.44	4.80	18.8	14	350	19.5	390	19.5
6	22	0.38	6.90	24.3	25	460	25.6	510	25.6
	23	0.41	6.90	26.1	25	495	27.5	545	27.4
	24	0.44	6.90	27.9	25	525	29.3	585	29.2
	25	0.48	6.90	30.2	25	570	31.7	630	31.4
	26	0.52	6.90	32.5	25	610	33.9	675	33.8
8	22	0.41	9.05	34.7	41	665	36.9	735	36.8
	23	0.44	9.05	37.1	41	710	39.4	785	39.2
	24	0.48	9.05	40.3	41	765	42.6	845	42.4
	25	0.52	9.05	43.5	41	825	45.8	910	45.6
	26	0.56	9.05	46.6	41	880	48.9	975	48.6
	27	0.60	9.05	49.7	41	935	52.0	1,035	51.8
10	22	0.44	11.10	46.0	54	880	49.0	975	48.7
	23	0.48	11.10	50.0	54	955	53.0	1,055	52.7
	24	0.52	11.10	53.9	54	1,025	56.9	1,130	56.6
	25	0.56	11.10	57.9	54	1,095	60.9	1,210	60.6
	26	0.60	11.10	61.8	54	1,165	64.8	1,290	64.5
	27	0.65	11.10	66.6	54	1,255	69.6	1,385	69.3
12	22	0.48	13.20	59.8	66	1,140	63.4	1,260	63.1
	23	0.52	13.20	64.6	66	1,230	68.3	1,360	67.9
	24	0.56	13.20	69.4	66	1,315	73.1	1,455	72.7
	25	0.60	13.20	74.1	66	1,400	77.8	1,550	77.4
	26	0.65	13.20	80.0	66	1,505	83.7	1,665	83.3
	27	0.70	13.20	85.8	66	1,610	89.5	1,780	89.1
	28	0.76	13.20	92.7	66	1,735	96.4	1,920	96.0

* Pipe of 3-in. size also available in 12-ft laying length. Weight (lb) per length‡ for thickness class 22 is 150; for 23, 160; for 24, 170. Average weight (lb) per foot§ for thickness class 22 is 12.5; for 23, 13.5; for 24, 14.3.
‡ Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
§ Including bell. Average weight per foot based on calculated weight of pipe before rounding.
† Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.
|| Weights shown for push-on joint pipe are also applicable to bell-and-spigot joint pipe.

TABLE 6.4—(*contd.*)

Standard Dimensions and Weights of Push-On Joint Cast-Iron Pipe‖

Size in.	Thickness Class	Thickness (in.)	OD† (in.)	Weight of Barrel per Foot (lb)	Weight of Bell (lb)	Weight Based on 18-ft Laying Length: Per Length‡ (lb)	Weight Based on 18-ft Laying Length: Avg. per Foot§ (lb)	Weight Based on 20-ft Laying Length: Per Length‡ (lb)	Weight Based on 20-ft Laying Length: Avg. per Foot§ (lb)
14	21	0.48	15.30	69.7	78	1,335	74.1	1,470	73.6
	22	0.51	15.30	73.9	78	1,410	78.2	1,555	77.8
	23	0.55	15.30	79.5	78	1,510	83.8	1,670	83.4
	24	0.59	15.30	85.1	78	1,610	89.5	1,780	89.0
	25	0.64	15.30	92.0	78	1,735	96.3	1,920	95.9
	26	0.69	1.530	98.8	78	1,855	103.1	2,055	102.7
	27	0.75	15.30	107.0	78	2,005	111.3	2,220	110.9
	28	0.81	15.30	115.0	78	2,150	119.3	2,380	118.9
16	21	0.50	17.40	82.8	96	1,585	88.1	1,750	87.6
	22	0.54	17.40	89.2	96	1,700	94.5	1,880	94.0
	23	0.58	17.40	95.6	96	1,815	100.9	2,010	100.4
	24	0.63	17.40	103.6	96	1,960	109.0	2,170	108.4
	25	0.68	17.40	111.4	96	2,100	116.8	2,325	116.2
	26	0.73	17.40	119.3	96	2,245	124.6	2,480	124.1
	27	0.79	17.40	128.6	96	2,410	133.9	2,670	133.4
	28	0.85	17.40	137.9	96	2,580	143.2	2,855	142.7
18	21	0.54	19.50	100.4	114	1,920	106.7	2,120	106.1
	22	0.58	19.50	107.6	114	2,050	113.9	2,265	113.3
	23	0.63	19.50	116.5	114	2,210	122.8	2,445	122.2
	24	0.68	19.50	125.4	114	2,370	131.8	2,620	131.1
	25	0.73	19.50	134.3	114	2,530	140.6	2,800	140.0
	26	0.79	19.50	144.9	114	2,720	151.2	3,010	150.6
	27	0.85	19.50	155.4	114	2,910	161.7	3,220	161.1
	28	0.92	19.50	167.5	114	3,130	173.8	3,465	173.2
20	21	0.57	21.60	117.5	133	2,250	124.9	2,485	124.2
	22	0.62	21.60	127.5	133	2,430	134.9	2,685	134.2
	23	0.67	21.60	137.5	133	2,610	144.9	2,885	144.2
	24	0.72	21.60	147.4	133	2,785	154.8	3,080	154.0
	25	0.78	21.60	159.2	133	3,000	166.6	3,315	165.8
	26	0.84	21.60	170.9	133	3,210	178.4	3,550	177.6
	27	0.91	21.60	184.5	133	3,455	191.9	3,825	191.2
	28	0.98	21.60	198.1	133	3,700	205.5	4,095	204.8
24	21	0.63	25.80	155.4	179	2,975	165.3	3,285	164.4
	22	0.68	25.80	167.4	179	3,190	177.3	3,525	176.4
	23	0.73	25.80	179.4	179	3,410	189.4	3,765	188.4
	24	0.79	25.80	193.7	179	3,665	203.6	4,055	202.6
	25	0.85	25.80	207.9	179	3,920	217.8	4,335	216.8
	26	0.92	25.80	224.4	179	4,220	234.4	4,665	233.4
	27	0.99	25.80	240.8	179	4,515	250.7	4,995	249.8
	28	1.07	25.80	259.4	179	4,850	269.3	5,365	268.4

‡ Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
§ Including bell. Average weight per foot based on calculated weight of pipe before rounding.
† Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.
‖ Weights shown for push-on joint pipe are also applicable to bell-and-spigot joint pipe.

TABLE 6.5

Standard Dimensions and Weights of Mechanical-Joint Cast-Iron Pipe

Size in.	Thickness Class	Thickness	OD†	Weight of Barrel per Foot	Weight of Bell	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
						Per Length‡	Avg. per Foot§	Per Length‡	Avg. per Foot§
		in.		lb					
3*	22	0.32	3.96	11.4	11	215	12.0	240	11.9
	23	0.35	3.96	12.4	11	235	13.0	260	12.9
	24	0.38	3.96	13.3	11	250	13.9	275	13.8
4	22	0.35	4.80	15.3	16	290	16.2	320	16.1
	23	0.38	4.80	16.5	16	315	17.4	345	17.3
	24	0.41	4.80	17.6	16	335	18.5	370	18.4
	25	0.44	4.80	18.8	16	355	19.7	390	19.6
6	22	0.38	6.90	24.3	22	460	25.5	510	25.4
	23	0.41	6.90	26.1	22	490	27.3	545	27.2
	24	0.44	6.90	27.9	22	525	29.1	580	29.0
	25	0.48	6.90	30.2	22	565	31.4	625	31.3
	26	0.52	6.90	32.5	22	605	33.7	670	33.6
8	22	0.41	9.05	34.7	30	655	36.4	725	36.2
	23	0.44	9.05	37.1	30	700	38.8	770	38.6
	24	0.48	9.05	40.3	30	755	42.0	835	41.8
	25	0.52	9.05	43.5	30	815	45.2	900	45.0
	26	0.56	9.05	46.6	30	870	48.3	960	48.1
	27	0.60	9.05	49.7	30	925	51.4	1,025	51.2
10	22	0.44	11.10	46.0	40	870	48.2	960	48.0
	23	0.48	11.10	50.0	40	940	52.2	1,040	52.0
	24	0.52	11.10	53.9	40	1,010	56.1	1,120	55.9
	25	0.56	11.10	57.9	40	1,080	60.1	1,200	59.9
	26	0.60	11.10	61.8	40	1,150	64.0	1,275	63.8
	27	0.65	11.10	66.6	40	1,240	68.8	1,370	68.6
12	22	0.48	13.20	59.8	50	1,125	62.6	1,245	62.3
	23	0.52	13.20	64.6	50	1,215	67.4	1,340	67.1
	24	0.56	13.20	69.4	50	1,300	72.2	1,440	71.9
	25	0.60	13.20	74.1	50	1,385	76.9	1,530	76.6
	26	0.65	13.20	80.0	50	1,490	82.8	1,650	82.5
	27	0.70	13.20	85.8	50	1,595	88.6	1,765	88.3
	28	0.76	13.20	92.7	50	1,720	95.5	1,905	95.2

* Pipe of 3-in. size also available in 12-ft laying length. Weight (lb) per length‡ for thickness class 22 is 150; for 23, 160; for 24, 170. Average weight (lb) per foot§ for thickness class 22 is 12.3; for 23, 13.3; for 24, 14.2.
‡ Including bell. Calculated weight of pipe rounded off to nearest 5 lb.
§ Including bell. Average weight per foot based on calculated weight of pipe before rounding.
† Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.

TABLE 6.5—(*contd.*)

Standard Dimensions and Weights of Mechanical-Joint Cast-Iron Pipe

Size in.	Thickness Class	Thickness	OD†	Weight of Barrel per Foot	Weight of Bell	Weight Based on 18-ft Laying Length		Weight Based on 20-ft Laying Length	
						Per Length‡	Avg. per Foot§	Per Length‡	Avg. per Foot§
		in.		lb					
14	21	0.48	15.30	69.7	78	1,335	74.0	1,470	73.6
	22	0.51	15.30	73.9	78	1,410	78.2	1,555	77.8
	23	0.55	15.30	79.5	78	1,510	83.8	1,670	83.4
	24	0.59	15.30	85.1	78	1,610	89.4	1,780	89.0
	25	0.64	15.30	92.0	78	1,735	96.3	1,920	95.9
	26	0.69	15.30	98.8	78	1,855	103.1	2,055	102.7
	27	0.75	15.30	107.0	78	2,005	111.3	2,220	110.9
	28	0.81	15.30	115.0	78	2,150	119.3	2,380	118.9
16	21	0.50	17.40	82.8	95	1,585	88.1	1,750	87.6
	22	0.54	17.40	89.2	95	1,700	94.5	1,880	94.0
	23	0.58	17.40	95.6	95	1,815	100.9	2,005	100.3
	24	0.63	17.40	103.6	95	1,960	108.9	2,165	108.3
	25	0.68	17.40	111.4	95	2,100	116.7	2,325	116.2
	26	0.73	17.40	119.3	95	2,240	124.6	2,480	124.0
	27	0.79	17.40	128.6	95	2,410	133.9	2,665	133.3
	28	0.85	17.40	137.9	95	2,575	143.2	2,855	142.7
18	21	0.54	19.50	100.4	113	1,920	106.7	2,120	106.0
	22	0.58	19.50	107.6	113	2,050	113.9	2,265	113.2
	23	0.63	19.50	116.5	113	2,210	122.8	2,445	122.2
	24	0.68	19.50	125.4	113	2,370	131.7	2,620	131.0
	25	0.73	19.50	134.3	113	2,530	140.6	2,800	140.0
	26	0.79	19.50	144.9	113	2,720	151.2	3,010	150.6
	27	0.85	19.50	155.4	113	2,910	161.7	3,220	161.0
	28	0.92	19.50	167.5	113	3,130	173.8	3,465	173.2
20	21	0.57	21.60	117.5	134	2,250	124.9	2,485	124.2
	22	0.62	21.60	127.5	134	2,430	134.9	2,685	134.2
	23	0.67	21.60	137.5	134	2,610	144.9	2,885	144.2
	24	0.72	21.60	147.4	134	2,785	154.8	3,080	154.1
	25	0.78	21.60	159.2	134	3,000	166.6	3,320	165.9
	26	0.84	21.60	170.9	134	3,210	178.3	3,550	177.6
	27	0.91	21.60	184.5	134	3,455	191.9	3,825	191.2
	28	0.98	21.60	198.1	134	3,700	205.5	4,095	204.8
24	21	0.63	25.80	155.4	177	2,975	165.2	3,285	164.2
	22	0.68	25.80	167.4	177	3,190	177.2	3,525	176.2
	23	0.73	25.80	179.4	177	3,405	189.2	3,765	188.2
	24	0.79	25.80	193.7	177	3,665	203.5	4,050	202.6
	25	0.85	25.80	207.9	177	3,920	217.7	4,335	216.8
	26	0.92	25.80	224.4	177	4,215	234.2	4,665	233.2
	27	0.99	25.80	240.8	177	4,510	250.6	4,995	249.7
	28	1.07	25.80	259.4	177	4,845	269.2	5,365	268.2

‡ Including bell. Calcaulated weight of pipe rounded off to nearest 5 lb.
§ Including bell. Average weight per foot based on calculated weight of pipe before rounding.
† Tolerances of OD of spigot end: 3–12 in., ±0.06 in.; 14–24 in., +0.05 in., −0.08 in.

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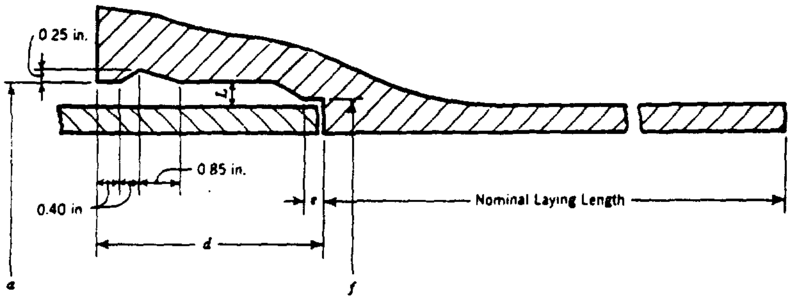

TABLE 6.6

Standard Bell-and-Spigot Joint Dimensions

For weights of bell-and-spigot joint pipe see Tables 6.1 and 6.4.

Size	Pipe OD†	Socket Diam. a†	Thickness of Joint L	Socket Depth d	Centering Shoulder Depth e	Centering Shoulder ID f†
			in.			
3	3.96	4.76	0.40	3.30	0.30	4.10
4	4.80	5.60	0.40	3.30	0.30	4.94
6	6.90	7.70	0.40	3.88	0.38	7.06
8	9.05	9.85	0.40	4.38	0.38	9.21
10	11.10	11.90	0.40	4.38	0.38	11.28
12	13.20	14.00	0.40	4.38	0.38	13.38
14	15.30	16.10	0.40	4.50	0.50	15.52
16	17.40	18.40	0.50	4.50	0.50	17.62
18	19.50	20.50	0.50	4.50	0.50	19.72
20	21.60	22.60	0.50	4.50	0.50	21.82
24	25.80	26.80	0.50	4.50	0.50	26.02

† Tolerances for outside diameter of spigot ends, socket diameter *a*, and centering shoulder inside diameter shall be ±0.06 in. for sizes 3–12 in.; ±0.08 in. for sizes 14–24 in.

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American Water Works Association

AWWA C301-72
Revision of
AWWA C301-64

AWWA STANDARD

for

PRESTRESSED CONCRETE PRESSURE PIPE, STEEL CYLINDER TYPE, FOR WATER AND OTHER LIQUIDS

First edition approved by Board of Directors Nov. 21, 1949.
This edition approved Jan. 31, 1972.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

CTD029650

Committee Personnel

Three subcommittees were instrumental in the revision of this standard.

Subcommittee on Revision of AWWA C301

T. C. Earl, *Chairman*
J. F. Wickser
R. E. Bald
W. R. Dana
S. B. Maynard

Subcommittee on Design Appendices

E. L. Wright, *Chairman*
R. A. Skinner
C. E. Beal
W. Brunzell
L. R. Keyser

Subcommittee on Standardization of Format and Terminology

L. H. Burton, *Chairman*
R. T. Tillotson
C. A. Parthum
C. B. Clinger
J. A. Willett

The Standards Committee on Concrete Pressure Pipe, which reviewed and approved this standard, had the following membership at the time of approval:

User/General Interest Members

W. K. Neubauer, *Chairman*
R. E. Morris Jr., *Vice-Chairman*

M. E. Barber	S. B. Maynard	P. M. Walker
C. E. Beal	A. C. Michael	J. F. Wickser
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Approved by the AWWA Board of Directors, Jan. 28, 1974	**Addenda to AWWA Standard for Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids and AWWA Standard for Reinforced Concrete Water Pipe—Steel Cylinder Type, Pretensioned**	**AWWA C301a–74** Supplement to C301–72 and **AWWA C303a–74** Supplement to C303–70 **American Water Works Association**

Add the following to C301, paragraph 2.7.1:

Steel sheets or coils conforming to the requirements of "Specifications for Steel, Cold-Rolled Sheet, Carbon, Structural" (ASTM Designation A611), Grade B, C or E, may also be utilized for pipe cylinders.

Add the following to C303, paragraph 2.5.1:

Steel sheets or coils conforming to the requirements of "Specifications for Steel, Cold-Rolled Sheet, Carbon, Structural" (ASTM Designation A611), Grade B or C may also be utilized for pipe cylinders.

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Table of Contents

Foreword

This foreword is for information only and is not part of AWWA C301-72

History of Standard

Prestressed-concrete steel-cylinder pipe, as described in this standard, provides an optimum utilization of steel and concrete with minimal weight under given design conditions and gives excellent performance under various internal and external pressure conditions.

There are two types of prestressed-concrete steel-cylinder pipe: (1) the lined-cylinder type with a core composed of a steel cylinder lined with concrete and subsequently wire-wrapped directly on the steel cylinder and coated with mortar; and (2) the embedded-cylinder type with a core composed of a steel cylinder encased in concrete and subsequently wire-wrapped on the exterior concrete surface and coated with concrete or mortar. The lined-cylinder type, which was first used in the US in 1942, is furnished in sizes from 16 to 48 in. The embedded-cylinder type, which was developed later and first installed in 1953, is manufactured in sizes 24 in. and larger.

Both types are designed for the specific combination of internal pressure and external load required for the project in accordance with the procedures outlined in the appendices of this standard. Lined-cylinder type is designed generally for pressures up to 250 psi and embedded-cylinder type, up to 350 psi, but both types have been designed and constructed for substantially higher pressures.

Prestressed-concrete steel-cylinder pipe is used for transmission mains, distribution feeder mains, pressure siphons (including river crossings), penstocks, industrial pressure lines, water intake lines, sewer force mains, and sewer outfall lines.

In the manufacture of lined-cylinder pipe, the first step is to make and hydraulically test the steel cylinder with joint rings attached. The cylinder is then centrifugally lined with dense concrete to constitute the core. The concrete lining is cured and high-tensile wire is wrapped around the core directly on the steel cylinder. For a selected wire size, the tension and spacing of the wire are controlled to produce a predetermined residual compression in the core to meet design requirements. The wrapped core is then covered with a dense premixed mortar coating about ¾ in. thick, applied by a mechanical impact method.

In the manufacture of embedded-cylinder pipe, the cylinder and joint rings are constructed and tested in the same manner as for lined-cylinder pipe. The cylinder is encased in concrete by vertical casting and mechanical vibration to constitute the core. After curing, the wire reinforcement is wound, under tension, in one or more layers around the outside of the concrete core containing the cylinder, instead of directly on the cylinder. The exterior coating of premixed mortar or concrete is placed by an impact method or by vertical casting. Embedded-cylinder construction has been found to be superior for large sizes and for pipe designed for comparatively high pressures.

The first edition of this standard was approved as "Tentative" on Nov. 21, 1949. It was revised and made "Standard" on Jun. 13, 1952. The second edition was approved as "Tentative" on Jun. 17, 1955, and made "Standard" on Jun. 26, 1958. Substantial changes, including the addition of combined loading procedures, were included in the third edition, which was made "Standard" as of Jan. 27, 1964.

Installation of this pipe is covered by AWWA Manual M-9, *Installation of Concrete Pipe*.

Information Regarding Use of This Standard

When purchasing pipe under the provisions of this standard, the purchaser shall furnish supplementary specifications to include specific details concerning the following:

1. Standard used; that is, AWWA C301-72
2. Type of pipe, either lined-cylinder pipe or embedded-cylinder pipe (Sec. 1.3)
3. Manner of storage and delivery, if required of the manufacturer
4. Whether there is any internal operating pressure, transient pressure, external earth load, or trench bedding condition in excess of that provided for in Sec. 3.2 (Sec. 1.2.8, 1.2.9, 1.4.1, and 1.5.2)
5. Whether pipe may not be supplied from inventory (Sec. 1.5.1)
6. Whether a tabulated layout schedule (Sec. 1.5.2) will be required
7. Identification marks required (Sec. 1.6)
8. Whether the purchaser desires to inspect the pipe and fittings at the manufacturer's plant (Sec. 1.7.1)
9. Whether steel test reports (Sec. 1.9.3) and test specimens (Sec. 1.9.4) will be required
10. Whether submission of rubber gasket material test reports (Sec. 1.9.5 and 2.11.8) will be required
11. Whether an affidavit of compliance (Sec. 1.10) will be required
12. Type of cement required, if there is a preference (Sec. 2.1.1)
13. Whether aggregate samples (Sec. 2.4) will be required
14. Whether submission of manufacturer's design calculations (Sec. 3.2.1) will be required
15. Type of protective coating on exposed portions of joint rings (Sec. 3.3)
16. Whether submission for approval of details of materials and methods of welding (Sec. 3.5.2) will be required
17. Whether a specific seal coat (Sec. 3.11) will be required
18. Details of fittings (Sec. 4.1)
19. Testing of steel cylinders for fittings (Sec. 4.2 and 4.3)
20. Whether lining and coating of structural-steel connections (Sec. 4.5) will be required

Major Revisions

The major revisions in this edition consist of the following:

1. The title has been changed to reflect the scope of the standard more accurately. The phrase "water pipe" has been changed to "pressure pipe" and the following phrase was added: "For water and other liquids"
2. The entire standard was carefully reviewed and changes were made in most of the sections to improve understanding and readability
3. Use of the standard was improved by the addition of titles to all sections

4. The scope, which formerly provided for pipe sizes from 16 in. to 96 in., was enlarged to provide for sizes from 16 to 144 in.

5. A minimum cylinder thickness of 18 gage is permitted for pipe 48 in. and smaller; and of 16 gage for pipe 54 in. and larger

6. Provision has been made that the minimum design thickness of the core, including the thickness of the cylinder, shall be $\frac{1}{16}$ of the design pipe diameter. This provision eliminates the need for Table 3 in the previous edition of AWWA C301. In that table the core thickness for embedded-cylinder pipe larger than 48 in. in diameter was based, for manufacturing reasons, on using the outside form for AWWA C300 pipe of the same diameter to cast the concrete embedment over the steel cylinder.

7. Multiple layers of circumferential reinforcement are expressly provided for in Sec. 3.8. This is necessary when high pressures are involved and the required amount of wire cannot be furnished in one layer because of insufficient space

8. The requirements for "ordinary" bedding, as specified in Sec. 3.2.2, have been provided. The previous edition specified "ordinary" bedding, but did not define the requirements

9. The extra circumferential wrap of wire required at each end of the core may now be applied at one half the design tension. This will most benefit embedded pipe where the wire anchorage has usually been embedded in the concrete and, at times, has pulled loose at the beginning of the wrapping process

10. The minimum time required for steam curing has been reduced from 32 to 24 hr. The actual time used will depend on temperature, which may vary from 110F to 150F, and other conditions. This does not relax the concrete strength requirements. The wrapping with high-tensile wire cannot begin until the concrete has reached minimum specified seven-day compressive strength and the initial compression in the concrete shall not exceed 55 per cent of the compressive strength of the concrete at the time of wrapping.

American Water Works Association

AWWA C301-72

Revision of
AWWA C301-64

AWWA Standard for

Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids

Section 1—General

Sec. 1.1—Scope

This standard covers the manufacture of circumferentially prestressed concrete water pipe with a steel cylinder and wire reinforcement in sizes from 16 to 144 in., inclusive. The standard covers two types of prestressed pipe: (1) lined-cylinder pipe with a core composed of a steel cylinder lined with concrete and subsequently wire-wrapped and coated with premixed mortar; and (2) embedded-cylinder pipe with a core in which a steel cylinder is encased in concrete and subsequently wire-wrapped and coated with premixed concrete or mortar. This standard does not include requirements for handling, delivery, laying, field testing, or disinfection of the pipe.

Sec. 1.2—Definitions

In this standard the following definitions shall apply:

1.2.1—*Purchaser.* The word "purchaser" shall mean a person, firm, corporation, or government subdivision entering into a contract or agreement to purchase pipe and fittings according to this standard.

1.2.2—*Contractor.* The word "contractor" shall mean the person, firm, or corporation executing the contract or agreement with the purchaser to furnish pipe and fittings according to this standard.

1.2.3—*Manufacturer.* The word "manufacturer" shall mean the person, firm, or corporation who actually manufactures the pipe, acting either directly as the contractor or as a subcontractor or supplier. If the manufacturer is acting as a subcontractor under the contractor or otherwise as a supplier to the contractor, the obligations of the manufacturer under this standard shall be considered as obligations of the contractor, and the contractor shall be responsible for their performance.

1.2.4—*ASTM.* The term "ASTM" shall mean the American Society for Testing and Materials. When specific ASTM specifications are cited without

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dates, the designation shall be construed to refer to the latest revision under the same specification number, or to superseding specifications under a new number, except for provisions in the revised specifications that clearly are inapplicable.

1.2.5—*ANSI*. The term "ANSI" shall mean the American National Standards Institute.

1.2.6—*Approved*. The term "approved" shall mean having received the approval of the purchaser.

1.2.7—*Design pressure*. The design pressure shall be the maximum sustained internal hydrostatic pressure to which the pipe is to be subjected. Generally, the design pressure for each pipe, or portion of the pipeline. shall be the operating pressure established by the hydraulic gradient or the static head specified by the purchaser, whichever results in the greater pressure.

1.2.8—*Surge pressures*. Surge pressures are internal pressure overloads of relatively short duration.

1.2.9—*External loads*. The term "external loads" shall mean all superimposed live and dead loads applied to the outside of the pipe after installation.

1.2.10—*Normal operating conditions*. Normal operating conditions are defined as a combination of design pressure and external dead loads.

1.2.11—*Transient conditions*. Transient conditions are conditions due to surge pressures or live loads that exceed normal operating conditions and are of short duration.

1.2.12—*Pipe diameter*. The term "pipe diameter" or "size" shall mean the design inside (waterway) diameter of the pipe.

Sec. 1.3—Essential Requirements

The pipe shall have the following principal features: a welded steel cylinder with steel joint rings welded to its ends; for lined-cylinder pipe, a core consisting of a lining of concrete within the steel cylinder, or for embedded-cylinder pipe, a core consisting of the steel cylinder encased in concrete; reinforcement consisting of high-tensile wire wound around the outside of the core in one or more layers at a predetermined stress and securely fastened at its ends; a coating of dense mortar or concrete covering the core and wire, except for the necessarily exposed surfaces of the joint rings; a self-centering joint with a preformed gasket of rubber, so designed that the joint will be watertight under all conditions of service. Lined-cylinder pipe shall be used for pipe sizes up to and including 20 in. and may be used for pipe sizes up to and including 48 in. Embedded-cylinder pipe may be used for pipe sizes 24–48 in. and shall be used for larger pipe. For embedded-cylinder pipe, at least one third of the total core thickness shall be outside the cylinder.

Sec. 1.4—Plans and Data To Be Furnished by Purchaser

1.4.1—*Design data*. The purchaser shall designate the design pressure for which the pipe shall be manufactured. If the pipe is to be used under conditions where the external loads or surge pressure will be in excess of that stated in Sec. 3.2 as provided for in the normal design of the pipe, the purchaser shall designate the external load or surge-pressure conditions for which the pipe shall be designed. For external loads in excess of those provided for in

Sec. 3.2, a statement or detail of bedding and backfilling procedures shall be included.

1.4.2—*Plans.* At least 1 month prior to manufacture, the purchaser shall furnish the contractor with plans and profiles showing: alignment and grades; location of all outlets, connections, and special appurtenances; design pressures for each part of the line; and such special details or information as are necessary for the manufacture of the pipe and fittings in accordance with this standard and with the specific requirements of the work for which the pipe is made.

Sec. 1.5—Data To Be Submitted by Manufacturer

1.5.1—*Detail drawings and schedules.* The manufacturer shall submit, for approval by the purchaser, drawings and schedules showing full details of reinforcement, concrete, and joint dimensions for the pipe and fittings. All pipe and fittings shall be fabricated in accordance with these approved drawings and schedules. Pipe may be supplied from inventory unless the purchaser has indicated otherwise.

1.5.2—*Tabulated layout schedule.* When specifically required, the data submitted by the manufacturer shall include a tabulated layout schedule, with reference to the stationing and grade line shown on the drawings supplied by the purchaser. The schedule shall show pressure zones, each of which shall be designated by the design pressure and transient pressure applicable therein, and the point of change from one zone to the next shall be clearly indicated by station number. The diameter of the pipe, the design pressure and transient pressure, and the thickness of pipe wall and area of steel (per linear foot of pipe) in the reinforcing wire and steel cylinder shall be listed for each portion of pipeline.

Sec. 1.6—Marking

Each length of straight and special pipe and each fitting shall have plainly marked inside, on the bell or spigot end, the identification marks specified by the purchaser. These shall include, as specified, either the pressure for which the pipe or fitting is designed or the area of effective circumferential reinforcement per foot of pipe wall. Special marks of identification, sufficient to show the proper location of the pipe or fitting in the line by reference to layout drawings and schedules specified under Sec. 1.5, shall be placed on the pipe if specifically required. All beveled pipe shall be marked with the amount of the bevel, and the point of maximum pipe length shall be marked on the beveled end.

Sec. 1.7—Inspection and Testing by Purchaser

1.7.1—*Inspection at manufacturer's plant.* If the purchaser desires to inspect pipe and fittings at the manufacturer's plant, he shall so specify in the contract or agreement, stating the conditions (such as time, and the extent of inspection) under which the inspection shall be made.

1.7.2—*Access to work.* The purchaser shall have free access to those parts of the manufacturer's plant that are necessary to assure compliance with this standard. The manufacturer shall make available for the purchaser's use such gages as are necessary for inspection. The manufacturer shall provide the purchaser with assistance as necessary for the handling of pipe and fittings.

1.7.3—*Responsibility*. Inspection by the purchaser, or failure of the purchaser to provide inspection, shall not relieve the contractor of his responsibility to furnish materials and to perform work in accordance with this standard.

1.7.4—*Tests*. Tests under Sec. 1.9, made by the purchaser on material samples, shall be carried out without delay. If any sample fails to meet the requirements, the manufacturer shall be notified immediately. Material affected by the test results shall be set aside pending final disposition. The manufacturer may request a review of test procedures and additional tests on the material. Duplicate samples, the number of which is to be agreed upon, should be tested by the purchaser and by the manufacturer. The manufacturer's tests shall be performed by a commercial testing laboratory or in the manufacturer's laboratory, with proper certification. Tests by either party may be witnessed by the other. If the duplicate samples meet the test requirements, the material shall be accepted. If the material is rejected after retesting, the manufacturer shall pay all costs of retesting.

1.7.5—*Rejection*. Material, fabricated parts, and pipe that are discovered to be defective, or that do not conform to the requirements of this standard, will be subject to rejection at any time prior to final acceptance of the pipe. Rejected material and pipe shall be removed promptly from the site of the work.

Sec. 1.8—Material and Workmanship

All material furnished by the manufacturer shall be new and of the quality specified. All work shall be done in a thorough, workmanlike manner by mechanics skilled in their various trades. When a lower limit or minimum dimension is given herein for a steel component, the minus tolerance (as stated in the applicable ASTM specification) for such limit or dimension shall be understood to define the true lower limit or dimension.

Sec. 1.9—Tests

1.9.1—*Cylinder assembly*. Each completed cylinder with joint rings welded to its ends shall be subjected to a hydrostatic test as specified herein under Sec. 3.5.3.

1.9.2—*Concrete*. Samples of the mixed concrete shall be taken for making compression test cylinders as specified under Sec. 3.6.5 and 3.6.6.

1.9.3—*Steel reports*. Mill test reports or plant test reports on each heat from which the steel is rolled shall be obtained by the manufacturer and made available to the purchaser on request.

1.9.4—*Steel specimens*. The manufacturer shall provide test specimens, cut from each shipment of steel for cylinders and high-tensile wire, if required by the purchaser.

1.9.5—*Gasket rubber*. Test reports showing the physical properties of rubber used in the gaskets, as specified in Sec. 2.11.8, shall be obtained by the manufacturer and shall be made available to the purchaser on request.

1.9.6—*Expense*. The expense of testing the materials and of submitting to the purchaser test reports in accordance with this standard and the purchaser's supplementary specifications referred to in the foreword, and the expense of testing the completed steel cylinder in accordance with Sec. 1.9.1 and of testing concrete in accordance with Sec. 1.9.2, shall be borne by the manufacturer. All other tests shall be made by the purchaser at the purchaser's expense, except as otherwise specifically provided.

Sec. 1.10—Affidavit of Compliance

The purchaser may require an affidavit from the manufacturer that the pipe and fittings furnished under the purchaser's contract or agreement comply with all applicable provisions of this standard.

Section 2—Material Specifications

Sec. 2.1—Cement

2.1.1—*Type.* Cement for concrete work shall conform to the "Specifications for Portland Cement" (ASTM Designation C150). Either Type I or Type II may be used unless the purchaser specifies a particular type. Sampling and testing shall conform to the individual ASTM specifications designated therein.

2.1.2—*Inspection.* Satisfactory facilities shall be provided for identifying, inspecting, and sampling cement at the mill, the warehouse, and the site of the work. The purchaser shall have the right to inspect the cement and obtain samples for testing at any of these points.

2.1.3—*Storage.* Cement shall be stored in a weathertight, dry, well-ventilated structure.

2.1.4—*Unusable.* Cement salvaged by cleaning cement sacks, mechanically or otherwise, shall not be used in the work. Cement containing lumps shall be rejected and shall immediately be removed from the site of the work.

2.1.5—*Temperature.* If the temperature of the cement exceeds 150F, it shall be stored until cooled to that temperature.

Sec. 2.2—Fine Aggregate

2.2.1—*General.* Fine aggregate for concrete and mortar shall consist of clean, hard, durable, and uncoated particles of natural sand or of sand prepared from the product obtained by crushing stone or gravel. At the time of use the fine aggregate shall be entirely free of frozen material.

2.2.2—*Gradation.* Fine aggregate shall be well graded from coarse to fine and, when tested by means of laboratory sieves in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136), shall conform to the gradation requirements in Table 1.

TABLE 1

Gradation Requirements for Fine Aggregate

Sieve Size	Total Passing, by Weight, %	
	Concrete Sand	Mortar Coating Sand
⅜ in.	100	100
No. 4	95–100	100
No. 8	65–98	93–100
No. 16	45–80	70–90
No. 30	20–70	45–65
No. 50	5–50	12–35
No. 100	2–10	3–12
No. 200	0–5	0–5

These gradation requirements represent the extreme limits for determining the suitability of fine aggregate under this standard. To maintain uniformity of gradation for aggregate from any given source, a fineness modulus determination shall be made upon representative samples from that source. Thereafter the fineness modulus of all shipments therefrom shall not vary more than ±0.20 from the fineness modulus of the representative sample, unless suitable approved mix adjustments are made.

2.2.3—*Impurities.* Fine aggregate shall be free from injurious amounts of organic impurities and shall conform to Sec. 4.2 of "Specifications for Concrete Aggregates" (ASTM Designation C33–71a).

Sec. 2.3—Coarse Aggregate

2.3.1—*General.* Coarse aggregate for concrete shall consist of hard, durable particles of crushed stone or crushed or uncrushed gravel, conforming to the requirements and tests given in Sec. 2.3.2 through 2.3.3.

2.3.2—*Gradation.* Coarse aggregate shall be well graded from coarse to fine. The maximum size and gradation shall be subject to the approval of the purchaser and shall be such that the concrete can be readily placed in the core or poured coating, by the particular method used in placing it, to provide a solid, compact, homogeneous wall with a smooth surface. Tests for gradation of coarse aggregate shall be in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136). Thin and elongated pieces, the maximum dimension of which exceeds five times the minimum, shall not be in excess of 10 per cent of the coarse aggregate by weight.

2.3.3—*Impurities.* Deleterious substances in coarse aggregate shall not exceed the amounts given in Table 2, as determined by sampling and testing procedures listed in the "Specifications for Concrete Aggregates" (ASTM Designation C33).

TABLE 2

Permissible Amounts of Deleterious Substances in Coarse Aggregate

Material	Maximum Weight Limit, %
Soft particles	5.00
Coal and lignite	0.50
Clay lumps	0.25
Material finer than 200 sieve	1.00
Combined total of above items	5.00

Sec. 2.4—Samples of Aggregates

At least 4 weeks prior to mixing concrete, the manufacturer, if required, shall provide in suitable containers, for preliminary approval, samples of not less than 1 cu ft each of fine and coarse aggregate. All samples shall be plainly labeled to indicate the source of the material, the date, and the name of the collector. Methods of sampling aggregates shall be in accordance with the "Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials" (ASTM Designation D75).

Sec. 2.5—Water

Water used for concrete and for curing pipe shall be fresh water and shall be clean and free from oil, acid, strong alkalies, or vegetable matter.

Sec. 2.6—Admixtures

At the option of the manufacturer, the concrete may contain a water-reducing, set-controlling admixture conforming to the "Specification for Chemical Admixtures for Concrete" (ASTM Designation C494). No admixture shall contain calcium chloride. The type and amount of admixture shall be subject to the purchaser's approval.

Sec. 2.7—Steel for Cylinders and Fittings

2.7.1—*Steel sheets.* Steel sheets for pipe cylinders and fittings may be in cut lengths or coils and shall meet the requirements of the "Specification for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade B or C, or "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569), except that for ASTM A569 steel, the maximum carbon content may be 0.25 per cent and the minimum yield point shall be 27,000 psi.

2.7.2—*Steel plates.* Steel plates for pipe cylinders and fittings shall conform to "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality" (ASTM Designation A283), Grade B or C.

Sec. 2.8—Steel for Wire, Bar and Wire-Mesh Reinforcement

2.8.1—*Prestressing wire.* The wire for circumferential reinforcement shall conform to "Specifications for Steel Wire, Hard-Drawn for Mechanical Springs" (ASTM Designation A227). Wire with specified minimum tensile strengths exceeding those in A227, Class II, may be used if the wire meets the other requirements for Class II in that specification, and the pipe design may be based on these higher strengths.

2.8.2—*Wire mesh.* Wire-mesh reinforcement for mortar coating for fittings shall conform to the "Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A185).

2.8.3—*Bars.* Steel-bar reinforcement for concrete for fittings shall conform to "Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 80, or to "Specifications for Deformed Billet-Steel Bars for Concrete Reinforcement" (ASTM Designation A615-68), Grade 40, except that for plain bars supplied under ASTM A615-68, (1) the requirements of Sec. 6, 7, and 14.3 shall not apply; (2) intermediate bar diameters shall meet the requirements of the next smaller bar number designation; and (3) bar diameters less than No. 3 shall meet the requirements for No. 3 bar.

Sec. 2.9—Steel for Joint Rings

Steel for bell rings less than ¼ in. thick shall conform to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade A, or to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569). Special shapes for spigot joint rings and steel for bell rings ¼ in. or more in thickness shall conform to "Specifications For Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 50, or to "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality" (ASTM Designation A283), Grade A, or to "Specifications for Merchant Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation A575), Grade 1012, or to "Specifications for Special Quality Hot-Rolled Carbon Steel Bars"

(ASTM Designation A576), Grade 1012, or to "Specifications for Steel Sheet and Strip, Carbon, Hot-Rolled Commerical Quality, Heavy-Thickness Coils (Formerly Plate)" (ASTM Designation A635).

Sec. 2.10—Steel Castings for Fittings

Steel castings for fittings shall conform to the "Specifications for Mild to Medium Strength Carbon Steel Castings for General Application" (ASTM Designation A27), Grade 70-36, normalized.

Sec. 2.11—Rubber for Gaskets

2.11.1—*General.* The gasket shall have smooth surfaces free from pitting, blisters, porosity, and other imperfections. The rubber compound shall contain not less than 50 per cent by volume of first-grade natural crude or first-grade synthetic rubber. The remainder of the compound shall consist of pulverized fillers free from rubber substitutes, reclaimed rubber, and deleterious substances. The compound shall meet the following physical requirements when tested in accordance with the indicated conditions and designated ASTM test methods.

2.11.2—*Tensile strength.* The tensile strength of the compound shall be at least 2,700 psi for natural rubber gaskets and 2,000 psi for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.3—*Elongation at rupture.* The elongation at rupture shall be at least 400 per cent for natural rubber gaskets and 350 per cent for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.4—*Specific gravity.* The specific gravity shall not vary more than ±0.05 within the range 0.95–1.45—"Methods for Chemical Analysis of Rubber Products" (ASTM Designation D297).

2.11.5—*Compression set.* The percentage of compression set shall not exceed 20. The compression set determination shall be made in accordance with "Methods of Test for Compression Set of Vulcanized Rubber" (ASTM Designation D395) Method B, with the exception that the disc shall be a ½-in.-thick section of the rubber gasket stock.

2.11.6—*Tensile strength after aging.* After being subjected to an accelerated aging test for 96 hr in air at 70C in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method" (ASTM Designation D573) or in a pressure chamber for 48 hr at 70C in an oxygen atmosphere at 300 psi in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oxygen-Pressure Method" (ASTM Designation D572), the tensile strength of the compound shall be not less than 80 per cent of the tensile strength before aging.

2.11.7—*Shore durometer.* The Shore A durometer hardness shall be in the range of 50 to 65 and shall be determined in accordance with "Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer" (ASTM Designation D2240-68) with the exception of Sec. 4 thereof. The determination shall be taken directly on the gasket.

2.11.8—*Test reports.* If required by the purchaser, the manufacturer shall submit test reports showing the physical properties of the rubber compound used in the manufacture of the gaskets.

Section 3—Design and Fabrication of Pipe

Sec. 3.1—General Requirements

3.1.1—*Minimum laying length.* In general, pipe shall have a minimum nominal laying length of 16 ft unless shorter lengths are required by weight or other considerations.

3.1.2—*Diameter tolerances.* Pipe shall be round and true and shall have a smooth and dense interior surface. The mean internal diameter of any portion of each piece of pipe shall not be less than the design diameter or size specified by more than $\frac{1}{4}$ in. for 36-in. and smaller pipe; by more than $\frac{3}{8}$ in. for 42-in. and 48-in. pipe; by more than $\frac{1}{2}$ in. for 54- to 78-in. pipe; or by more than $\frac{3}{4}$ in. for 84-in. and larger pipe.

3.1.3—*Core and coating tolerances.* The minimum design thickness of the core, including the thickness of the cylinder, shall be $\frac{1}{16}$ of the design pipe diameter for normal applications. Thickness of cores shall be not less than the design thickness by more than $\frac{1}{8}$ in. for 36-in. and smaller pipe; by more than $\frac{3}{16}$ in. for 42-in. and 48-in. pipe; by more than $\frac{1}{4}$ in. for 54- to 72-in. pipe; or by more than $\frac{3}{8}$ in. for pipe larger than 72 in. The thickness of the mortar coating shall provide a minimum cover of $\frac{5}{8}$ in. over the wire. The thickness of cast concrete coatings shall be $1\frac{1}{2}$ in. and shall provide a minimum cover of 1 in. over the core.

Sec. 3.2—Design of Pipe

3.2.1—*General.* The reinforcement of the pipe shall consist of a welded steel cylinder in the core and high-tensile wire helically wrapped around the core under measured and uniform tension after the concrete in the core has been placed and cured. The minimum thickness of the cylinder shall be 18 gage up to and including 48-in. pipe and shall be 16 gage for 54-in. pipe and larger. The size of the high-tensile wire and the spacing and tension under which it is wound shall be such that the conditions required by the design methods in Appendix A or B are met. The designs shall fully recognize all losses due to elastic and inelastic deformations, such as relaxation of the wire and plastic strains in the concrete. The average gross wrapping stress in the high-tensile wire shall not exceed 75 per cent of the minimum ultimate tensile strength of the wire. The wire shall not be smaller than 0.162 in. in diameter. The minimum centerline spacing of the wire shall be that which produces a clear distance of $\frac{3}{16}$ in. between wires in the same layer of reinforcement. The centerline spacing of the wire shall not exceed $1\frac{1}{2}$ in. For lined-cylinder pipe with wire larger than 0.192 in., the maximum centerline spacing of the wire shall be 1 in. The manufacturer shall submit design calculations for approval prior to the manufacture of any pipe, if required by the purchaser.

3.2.2—*Requirements for normal operating conditions.* Normal operating conditions shall be defined as a combination of internal design pressure (as defined in Sec. 1.2.7) and external earth (dead) load.

All pipe shall be designed for a combination of internal design pressure of at least 40 psi and at least 6 ft of earth cover with "ordinary" * bedding, or such greater pressures and earth loads

* "Ordinary" bedding is defined as Class C in "Design and Construction of Sanitary and Storm Sewers," Manual of Engineering Practice No. 37, ASCE, Rev. 1969, pp. 212-213.

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as may be specified in the supplementary specifications or as shown on the purchaser's drawings. The combination design shall be as described in either Appendix A or B in accordance with standard practice. Maximum internal design pressures for lined-cylinder pipe using minimum core thicknesses, 18-gage cylinders, and centrifugal concrete strengths required by Sec. 3.6.8 shall be 250 psi for 16- to 20-in. pipe; 200 psi for 24- to 36-in. pipe; 175 psi for 42-in. pipe; and 150 psi for 48-in. pipe. Higher internal design pressures are permissible using thicker cores, heavier cylinders, or higher concrete strengths, either singly or in combination. Maximum internal design pressures for embedded-cylinder pipe are limited only by the strength requirements of the component materials.

3.2.3—*Provisions for transient conditions.* The design methods for normal operating conditions under Appendix A or B provide for surge pressures of at least 40 per cent of design pressure and for live load (including impact) at least equal to American Assn. of State Highway Officials H20 loading. If surge pressure or live load exceeds these limits for a given design condition, such greater value shall be stated in the supplementary specifications.

In all designs the following combinations shall not exceed the design limits for the transient-condition requirements of Appendix A or B: (1) design or normal operating pressure plus surge pressure in combination with earth dead load; or (2) design or normal operating pressure in combination with earth dead load plus external live load, including impact.

Sec. 3.3—Joint Rings

The steel bell and spigot joint rings shall be so designed and fabricated that when the pipe is laid it will be self-centered. The rings shall be accurately formed and finished to obtain a close, sliding fit for the self-centered surfaces. Each ring shall be formed by one or more pieces of steel butt-welded together, either by a resistance welder or by a hand electric weld. Welds on gasket contact surfaces shall be ground smooth and flush with the adjacent surfaces. The rings shall be expanded by a press beyond their elastic limits so that they are accurately sized.

On the finished pipe, the circumference of the inside bell-ring contact surface shall not exceed the circumference of the outside spigot-ring contact surface by more than $\frac{3}{16}$ in. for gaskets $\frac{27}{32}$ in. in diameter or less and $\frac{1}{4}$ in. for gaskets greater than $\frac{27}{32}$ in. in diameter. The out-of-roundness of either contact surface, measured as the difference between the maximum and minimum joint-ring diameters, shall not exceed 0.5 per cent of the average of these diameters. The minimum thickness of the completed bell rings shall be $\frac{3}{16}$ in. for 36-in. and smaller pipe and $\frac{1}{4}$ in. for pipe larger than 36 in. The rings shall conform to the details submitted by the manufacturer and approved by the purchaser. The joint rings shall be so designed that, when the pipe is laid and the joint completed, the gasket will be enclosed on all four sides. The contact surfaces shall be such as to prevent cutting of the rubber gasket during installation. The portions of the joint rings that will be exposed on the completed pipe shall be protected from corrosion by an approved coating.

Sec. 3.4—Rubber Gaskets

Joints shall be sealed with a continuous solid-ring rubber gasket having a circular cross section with a diametral tolerance of $\pm\frac{1}{64}$ in. Gaskets shall be of sufficient volume substantially to fill the recess provided when the pipe joint is assembled, so that the gasket will be compressed to form a pressure-tight seal. The gasket shall be the sole element depended upon to make the joint watertight.

Sec. 3.5—Fabrication of Steel Cylinders

3.5.1—*General.* The cylinders shall be formed by shaping and welding together cut lengths or coils of specified material and thickness. The cylinders shall be accurately shaped to the size required and the joint rings shall be welded to the ends before testing.

3.5.2—*Welding.* Butt welding or offset lap welding of the longitudinal and circumferential or helical seams shall be used to produce a smooth and continuous external surface when wire is to be wrapped directly on the cylinder. The manufacturer may use either butt welding or lap welding for longitudinal and circumferential or helical welds, if the cylinder is encased in the concrete core. Prior to welding, the sheets shall be fitted closely and shall be held firmly during welding. The manufacturer shall submit for approval, if required, the specific details of materials and methods he proposes to use before any welding is done.

3.5.3—*Hydrostatic test.* Each steel cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test. When the cylinder is tested in a horizontal position, the stress shall be at least 20,000 psi but not greater than 25,000 psi. When the cylinder is tested in a vertical position, the stress at the lower end shall be 25,000 psi. While under pressure test, all welds shall be thoroughly inspected and all parts showing leakage shall be marked. Cylinders that show any leakage under test shall be rewelded at the points of leakage and subjected to another hydrostatic test. The finished cylinder, with joint rings attached, shall not be used in the work unless it is completely watertight under the required test pressure.

3.5.4—*Cleaning steel surfaces.* Before the concrete core and mortar coating are placed, each steel cylinder shall be cleaned to remove loose or other foreign matter that would interfere with the bonding of the concrete and mortar.

Sec. 3.6—Concrete for Pipe Core

3.6.1—*General.* The concrete in the cores may be placed by the centrifugal method, by the vertical casting method, or by other approved methods.

3.6.2—*Proportioning.* The proportions of cement, fine aggregate, coarse aggregate, and water used in concrete for pipe cores shall be subject to the approval of the purchaser. The proportions shall be determined and controlled as the work proceeds to obtain homogeneous, dense, workable, durable concrete of specified strength in the walls of the pipe and a minimum of defects in the surface of the pipe. The proportions shall be those that will give the best overall results with the particular materials and method of placing used for the work. A minimum of six bags of cement shall be used for each cubic yard of concrete. The water-cement ratio shall be such as to assure that the concrete will meet the strength requirements.

3.6.3—*Measurement of materials.* A barrel of cement shall be considered as 4 cu ft or 376 lb and a bag of cement shall be considered as 1 cu ft or 94 lb. Cement in standard sacks need not be weighed, but bulk cement shall be weighed. Water for mixing shall be measured by volume or by weight. Concrete aggregates for each batch shall be measured separately by

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weighing. The proportions of aggregates shall be computed on the saturated and surface-dry basis and the water–cement ratio shall be exclusive of water within the aggregates and absorbed by them. The equivalent unit weights for both fine and coarse aggregates shall be determined in accordance with the "Method of Test for Unit Weight of Aggregate" (ASTM Designation C29). The equipment and devices for weighing and measuring shall at all times be accurate within 1 per cent.

3.6.4—*Mixing*. The mixing shall be done thoroughly by a mixer of approved type. Mixing time shall be consistent with the type of mixer used. Transit mixing shall not be used except by written authorization and under specific requirement of the purchaser.

3.6.5—*Standard test cylinders*. A set of at least four standard test cylinders shall be taken from each day's pour of the mixed concrete for pipe cores made by the centrifugal method, the vertical casting method, or other approved methods. Standard test cylinders shall be made in conformance with the "Method for Making and Curing Concrete Compressive and Flexural Test Specimens in the Field" (ASTM Designation C31). The curing of the test cylinders shall be in conformity with the curing of the pipe cores.

3.6.6—*Centrifugal test cylinders*. Centrifugally cast test cylinders may be substituted for standard test cylinders, at the option of the manufacturer, when the centrifugal method is used for making cores. A set of at least four test cylinders shall be taken each day from the mixed concrete for cores. Test cylinders shall be centrifugally cast in 6-in.-diameter by 12-in.-long steel molds spun about their longitudinal axes, at a speed that will simulate the compaction of concrete in the cores, to produce a spun-cylinder wall thickness of about 2 in. The curing of the test cylinders shall be in conformity with the curing of the cores. The net area of the hollow cylinder shall be used to determine its compressive strength.

3.6.7—*Testing cylinders*. All test cylinders shall be tested by an approved testing laboratory at the expense of the manufacturer, unless the manufacturer has approved testing facilities at the site of the work. In such an event, the tests shall be made by and at the expense of the manufacturer in the presence of the purchaser, or, if permitted by the purchaser, certified test reports may be submitted by the manufacturer.

3.6.8.—*Strength of concrete*. Standard concrete cylinders shall attain a minimum compressive strength of 3,000 psi in seven days and 4,500 psi in 28 days. Centrifugal test specimens shall attain a minimum compressive strength of 4,000 psi in seven days and 6,000 psi in 28 days. The compressive strength at the time of wrapping shall conform to the requirements in Sec. 3.8. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the specified strength, and not more than 20 per cent of the strength tests shall have values less than the specified strength. Pipe made from concrete that does not meet the strength tests in accordance with the foregoing shall be subject to rejection.

3.6.9.—*Placing concrete by centrifugal method*. The steel pipe cylinder with joint rings attached shall be placed horizontally in a spinning machine and may be held by a spinning frame. The spinning machine shall be

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capable of revolving the cylinders at speeds that will produce concrete meeting the requirements of Sec. 3.6.8 and 3.8. The method of placing concrete in the cylinder and the speed of rotation during placing shall be such that the concrete will be evenly distributed and well compacted at the specified thickness throughout the length of the pipe. After the concrete has been deposited, the rotation shall be continued at a speed and for a length of time sufficient to provide the specified strength and sufficient compaction and bond to permit removal from the spinning machine without injury to the pipe core. Excess water and laitance shall be removed from the interior surfaces of the pipe in an approved manner so that the surface is solid, straight, and true.

3.6.10—*Placing concrete by vertical casting method.* The concrete lining or core shall be cast on end on a cast-iron or steel base ring with rigid steel collapsible forms for the concrete surfaces. The forms shall be so designed that they will have smooth contact surfaces and tight joints and will be firmly and accurately held in proper position without distortion during the placing of the concrete. The forms shall be provided with top and bottom stiffening rings and shall be designed to permit removal without injury to the inside surface of the pipe. The forms shall be thoroughly cleaned and oiled before each use. The transporting and placing of concrete shall be carried out by approved methods that will not cause the separation of concrete materials and the displacement of the steel cylinder or forms from their proper position. Approved methods of mechanical vibrating shall be used to compact the concrete in the forms and to secure satisfactory interior surfaces. Forms shall not be removed until the concrete has set sufficiently to avoid spalling or damage to the pipe during the process of form removal.

3.6.11—*Other methods of placing the lining.* If the manufacturer proposes to employ a method other than the centrifugal or vertical casting method for placing the concrete lining or core, he shall submit for approval complete details of the methods and equipment he proposes to use.

Sec. 3.7—Curing of Core

3.7.1—*General.* The purpose of curing pipe cores as specified next is to obtain concrete of the strength specified for test cylinders under Sec. 3.6.8. The cores shall be cured by steam or by water unless otherwise specifically permitted. Water and steam curing may be used interchangeably on a time ratio basis of 4 hr of water curing to 1 hr of steam curing, except that water curing may be used only if the minimum ambient temperature exceeds 40F.

3.7.2—*Steam curing.* The cores shall be placed in the steam-curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hr shall be allowed before moist steam is admitted in contact with the cores. The temperature within the enclosure shall be gradually raised to at least 110F and not more than 150F for a period of at least 24 hr. The preset time shall be included in the 24-hr period. Curing by steam shall be continuous except during a period sufficient to remove the forms or supporting rings. The forms shall not be removed until at least 6 hr after the beginning of curing. After this minimum 6-hr period, the cores may be "tipped" from their bases and curing shall be continued by either steam or water.

3.7.3—*Water curing.* The cores shall be kept moist by intermittent water spraying for a period of at least 32 hr. The water-curing period shall be continued 1 hr for each hour, in the first 24, during which the ambient temperature is below 50F. Following this minimum period, they may be "tipped" from their bases and removed to the storage yard where they shall be kept continuously moist by intermittent spraying for an additional period of at least three days.

Sec. 3.8—Placing of Wire Reinforcement

The high-tensile wire shall not be wound around the core until the concrete has reached the minimum seven-day compressive strength specified under Sec. 3.6.8 of this standard. The initial compression in the concrete shall not exceed 55 per cent of the compressive strength of the concrete at the time of wrapping. Methods and equipment for applying the wire shall be such that it will be wrapped around the core in a helical form at the designed predetermined spacing and tension for the full length of the core, except that at the ends of the core there shall be an extra complete circumferential wrap of wire that may be applied at one half the design tension. The number of coils in any 2-ft length of core shall be not less than required by the design. Wire splices shall be capable of withstanding a force equal to the minimum specified ultimate tensile strength of the wire. Anchorages of the wire at the ends of the core shall be capable of resisting a force equal to 75 per cent of the specified minimum ultimate tensile strength of the wire.

If multiple layers of circumferential reinforcement are used, each layer but the last shall be coated with cement mortar applied in accordance with Sec. 3.9 to provide a minimum cover over the reinforcement at least equal to the diameter of the wire and steam-cured in accordance with Sec. 3.10.2 for a period of not less than 8 hr. The first layer of reinforcement shall be wound on the surface of the core, and subsequent layers shall be wound over the previous layers of cement mortar as specified in this section. The final coating of cement mortar shall be applied in accordance with Sec. 3.9, shall provide the minimum cover over the reinforcement specified in Sec. 3.1.3, and shall be cured in accordance with Sec. 3.10.

Sec. 3.9—Pipe Coating

3.9.1—*General.* After the core has been wrapped with high-tensile wire, an exterior mortar or concrete coating shall be applied.

3.9.2—*Mortar coating.* Mortar for coating shall consist of one part cement to not more than three parts fine aggregate. Cement and fine aggregate shall conform to Sec. 2.1 and 2.2 herein. Rebound not to exceed one fourth of the total mix weight may be used, but the resulting mix proportions shall not be leaner than those just specified. Rebound not used within 1 hr shall be discarded. The mortar shall be thoroughly mixed, and, after mixing is completed, it shall be deposited under impact by an approved method so that a dense, durable encasement is obtained. Concurrently with the mortar coating, a cement slurry consisting of one sack of cement to not more than 8 gal of water shall be applied to the core just ahead of the mortar coating.

3.9.3—*Concrete coating.* Concrete for coating shall be of an approved mix. The proportions shall be those that will give the best overall results with the particular materials and methods of placing used for the work. A minimum of seven bags of cement shall be used for each cubic yard of concrete. The fine and coarse aggregates and cement shall meet the requirements of Sec. 2.1, 2.2 and 2.3 of this standard, except that the grading of coarse aggregate shall be such that it will all pass a $\frac{3}{4}$-in. laboratory sieve. The concrete shall be placed and compacted by approved methods and equipment to produce a dense, durable coating.

3.9.4—*Strength.* Concrete for coating shall develop a minimum compressive strength of 3,000 psi in seven days and 4,500 psi in 28 days in accordance with Sec. 3.6.8.

Sec. 3.10—Curing of Coating

3.10.1—*General.* The coating outside the core shall be cured by steam or by water unless otherwise specifically permitted. Water and steam curing may be used interchangeably on a time ratio basis of 4 hr of water curing to 1 hr of steam curing, except that water curing may be used only if the minimum ambient temperature exceeds 40F. Adequate space and facilities shall be provided for proper curing.

3.10.2—*Steam curing.* The coated pipe shall be placed in the curing chamber as soon as practicable after placing the coating and shall be steam-cured as specified under Sec. 3.7.2 for a period of at least 12 hr. The pipe shall be handled in such a manner as to avoid injury to the coating during transportation to and from the curing chamber.

3.10.3—*Water curing.* As soon as the coating has set sufficiently, it shall be kept moist by intermittent spraying for a period of at least four days. The water-curing period shall be continued 1 hr for each hour, in the first 24, during which the ambient temperature is below 50F.

Sec. 3.11—Seal Coat

If the purchaser specifically orders a bituminous seal coat, the materials and application shall comply with the appropriate provisions of AWWA C104 (ANSI A21.4) insofar as they are applicable. The material shall be applied after the pipe is cured.

Section 4—Fittings and Special Pipe

Sec. 4.1—General

Fittings and special pipe shall include closures, connections to main line valves, bends, tees, wyes, beveled pipe for curves, and pipe with outlets required for manholes, air valves, and blowoffs as shown on the purchaser's drawings or ordered by the purchaser. Fittings shall conform to the details furnished by the purchaser, or, if required, to the details furnished by the manufacturer and approved by the purchaser. Fittings shall be either type as described in Sec 4.2 or 4.3 at the option of the manufacturer and shall be designed for the same conditions as the pipe.

Sec. 4.2—Fittings (Type A)

Type A fittings are composed of steel cylinders, concrete or mortar lining, and reinforced concrete or mortar exterior coating. The steel for the cylinder shall be cut, shaped, and welded to form the properly shaped bend, tee, reducer, or fitting. The welds shall be inspected and the completed cylinder shall be tested for tightness by the dye penetrant or other approved method, if specifically required by the purchaser. A cage or cages of steel reinforcement with approved cross-sectional areas shall be formed around the cylinder and openings. Longitudinal reinforcement sufficient for additional stresses in the fitting walls shall be provided. The interior and exterior concrete or mortar shall be placed in an approved manner. Curing shall be as specified in Sec. 3.10 herein.

Sec. 4.3—Fittings (Type B)

Type B fittings are composed of cut and welded steel plate of approved thickness, with mortar coating on interior and exterior surfaces.

4.3.1—*Steel plate.* The steel for the fabricated steel plate fittings shall be cut, shaped, and welded so that the finished fitting shall have the required shape and interior dimensions. The deflection angle between adjacent segments of a bend shall be not greater than 22½ deg. Adjacent segments shall be joined by lap or butt welding. Fabrication and welding shall conform to the requirements of Sec. 3.5.1 and 3.5.2 of this standard. The welds shall be inspected and the completed cylinder shall be tested for tightness by the dye penetrant or other approved method, if specifically required by the purchaser.

4.3.2—*Reinforcement.* Wire mesh reinforcing shall be applied to the interior and exterior surfaces of the fabricated fitting. Mesh shall be 2- by 4-in. W1 welded-wire fabric, held ⅜ in. from the surfaces of the steel plate. The members on the 2-in. spacing shall extend circumferentially around the fitting with ends overlapped 4 in. and tied together. Longitudinal splices shall be staggered.

4.3.3—*Mortar.* Steel plate fittings shall be lined with mortar at least ¾ in. thick, except at adapter ends or outlets, but under no conditions shall the lining be less than ⅜ in. thick. The exterior shall be coated with mortar at least 1 in. thick. The mortar shall contain not less than one part cement to three parts sand, of a grading approved for the method of application used.

4.3.4—*Curing.* Mortar-coated fittings shall be cured by water spraying, by steam, or by curing compounds.

Sec. 4.4—Curves, Bends, and Closures

Long-radius curves and small angular changes in pipe alignment shall be formed by deflecting joints, by straight pipe with beveled ends, by bevel adapters, or by a combination of these. Pipe ends may be beveled up to 5 deg. Short-radius curves and closures shall be formed by fittings.

Sec. 4.5—Openings and Connections

Manholes and flanges, spigot or bell connections for air valves, blowoffs, or connections to other pipe shall be built into the walls of the concrete pipe at locations shown on the purchaser's drawings or ordered by the purchaser. Wall openings shall be suitably reinforced. The high-tensile wire shall be securely fastened on each side of the outlet or shall be wrapped continuously from one side of the opening to the other. The casting or fabricated outlet shall be welded to the saddle plate or saddle neck after the hole is cut through the plate, cylinder, and concrete. If required, the interior and exterior surfaces of structural-steel connections shall be lined and coated with mortar. Alternative outlet designs may be used, if specifically approved by the purchaser.

Appendix A

Cubic Parabola Design Method

This appendix is for information only and is not part of AWWA C301-72

The wire area, tension, and spacing under which the wire is wound and the core thickness shall be varied so that the specific combination of design pressure and earth load will fall on or under the design curves in Fig. A (a and b). The resulting design has a transient-load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line for surge pressure or live load until it intersects the transient-load curve. If surge pressure exceeds 40 per cent of design pressure or live load (including impact) exceeds the American Association of State Highway Officials H-20 loading, this greater value should be stated in the supplementary specifications.

The design curve is defined by the following equation:

$$w = \frac{W_o}{\sqrt[3]{P_o}}\left[\sqrt[3]{P_o - p}\right]$$

in which P_o is the internal pressure required to overcome all compression in the core concrete, exclusive of the effect of external load; W_o is nine tenths of the three-edge-bearing load producing incipient cracking in the core, with no internal pressure; p is the maximum design pressure in combination with three-edge-bearing load, w, and is not to exceed 0.8 P_o for lined cylinder pipe [Fig. A (a)]; w is the maximum three-edge-bearing load, equivalent to earth load, in combination with design pressure p.

Three-edge-bearing values of W_o used for design shall be conservatively based on the manufacturer's accumulated test results. Supporting test data shall be provided if required by the engineer.

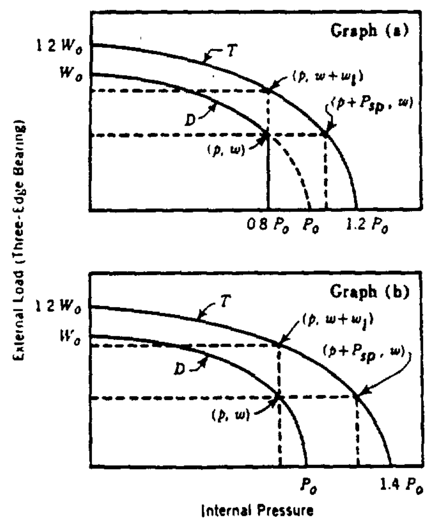

Fig. A. Design and Transient-Capacity Curves for Lined and Embedded Cylinder Pipe Using Cubic Parabola Design Method

Graph (a) is for lined- and Graph (b) for embedded-cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; w_l is for the three-edge-bearing load equivalent to live load; and P_{sp} is for surge pressure in excess of the normal operating or design pressure.

Appendix B

Stress Analysis Design Method

This appendix is for information only and is not part of AWWA C301-72

The wire area, tension, and spacing under which the wire is wound and the core thickness shall be varied so that the specific combination of design pressure and earth load will fall on or under the design curve illustrated in Fig. B (a and b). The resulting design has a transient-load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line for surge pressure or live load until it intersects the transient-load curve. If surge pressure exceeds 40 per cent of design pressure, or live load (including impact) exceeds the American Association of State Highway Officials H-20 loading, this greater value should be stated in the supplementary specifications.

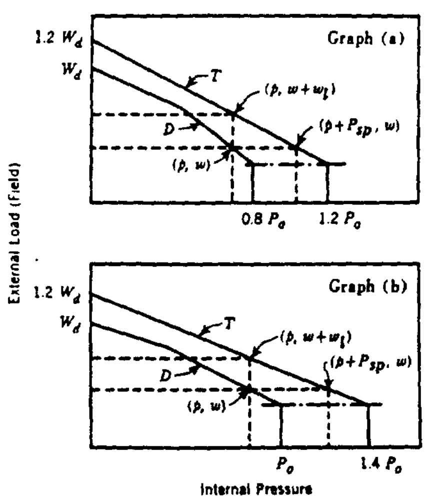

Fig. B. Design and Transient-Capacity Curves for Lined and Embedded Cylinder Pipe Using Stress Analysis Design Method

Graph (a) is for lined- and Graph (b) embedded-cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; P_o is the internal pressure required to overcome all compression in the core concrete, exclusive of the effect of external load; P_{sp} is the surge pressure in excess of the normal operating or design pressure; W_d is the maximum design field external load with internal pressure equal to zero; and w_t is the live load in excess of the external dead load.

The design curve is defined by the following equation:

$$p = \left[f_{cr} + 7.5\sqrt{f'_c} - \frac{M}{S} \pm \frac{F}{A_t}\right]\frac{A_t}{12R_s}$$

in which p is the maximum design pressure in combination with field external load, w, and is not to exceed 0.8 P_o for lined-cylinder pipe [Fig. B(a)]; f_{cr} is the resultant induced compression; $7.5\sqrt{f'_c}$ is the allowable tensile stress where f'_c is the specified 28-day compressive strength of the concrete; M is the total moment in the pipe section due to pipe weight, water weight, and external load; F is the total thrust in the pipe section due to pipe weight, water weight, and external load; S is the section modulus of the control pipe section based on the total pipe wall at the crown and invert sections and on the core only at the side section; A_t is the transformed cross-sectional area

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of the control section based on the total pipe wall at the crown and invert sections and on the core only at the side section; and R_y is the outside radius of steel cylinder.

The coefficients for moment and thrust calculations shall be from recognized and accepted theories, examples of which are to be found in "Coefficients for Large Horizontal Pipes," by J. H. Paris [*Eng. News-Record*, vol. 87, p. 768 (1921)]; and "Stress Analysis of Concrete Pipe," by H. C. Olander [Eng. Monograph No. 6 US Bureau of Reclamation, Dept. of the Interior, Washington, D.C.].

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American Water Works Association

AWWA C300-74

Revision of
AWWA C300-64

AWWA STANDARD

for

REINFORCED CONCRETE PRESSURE PIPE, STEEL CYLINDER TYPE, FOR WATER AND OTHER LIQUIDS

First edition approved by AWWA Board of Directors Dec. 11, 1947.
This edition approved Jan. 28, 1974.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colo. 80235

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Table of Contents

Foreword

This Foreword is for information and is not a part of AWWA C300-71

I—History of Standard

In April 1943, the AWWA Board of Directors authorized the preparation of "Tentative Emergency Specifications for Concrete Pressure Pipe." They covered a number of different types in a single document and served a useful purpose during the Second World War but are now obsolete and have been withdrawn.

The first standard prepared by AWWA Water Works Practice Committee 8320D—Reinforced Concrete Pipe, which was formed in 1946, covered the manufacture of reinforced concrete pipe, steel cylinder type, not prestressed. The standard is now designated AWWA C300. This type of pipe, first manufactured in 1919, consists of a welded steel cylinder with a steel joint ring welded at each end; a cage or cages of steel reinforcing bars or wire externally concentric with the cylinder; an encasing wall of dense concrete; and a preformed gasket of rubber to provide the joint seal between adjacent pipes. The pipe is manufactured in sizes ranging from 24 in. to more than 144 in. in diameter.

Reinforced concrete pipe, steel cylinder type, is designed for the specific combination of internal pressure and external load required for the project in accordance with the procedures outlined in the appendix of this standard. The pipe is normally limited in design to pressures of up to 260 psi.

This type of pipe is used for transmission mains, distribution feeder mains, pressure siphons, industrial pressure lines, sewer force mains, and sewer outfall lines.

The pipe is manufactured by first fabricating the steel cylinder and hydrostatically testing it with joint rings attached. Then, after the reinforcing cage(s) and steel cylinder have been assembled within a form, a concrete encasement is vertically cast, accompanied by mechanical vibration. Curing of the concrete is accomplished by means of water or steam. The pipe is generally made in 12- through 24-ft laying lengths. The circumferential steel of the cage provides 40 to 80 per cent of the reinforcement, depending on the conditions for which the pipe is designed.

The first edition of this standard was approved as "Tentative" on Dec. 11, 1947. It was revised and approved as "Standard" on Jan. 13, 1952. The second edition was approved as "Tentative" on Jul. 19, 1957, and made "Standard" on Jan. 27, 1964.

Installation of this pipe is covered by AWWA Manual M-9, "Installation of Concrete Pipe."

II—Information Regarding Use of This Standard

When purchasing pipe under the provisions of this standard, the purchaser shall furnish supplementary specifications that include specific details

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on the following:

1. Standard used; that is, AWWA C300–74.
2. Manner of storage and delivery if required of the manufacturer.
3. The working pressure, the transient pressure, the depth of earth cover, the trench bedding condition, and the live load for which the pipe is to be designed (Sec. 1.4.1).
4. Whether pipe may be supplied from inventory (Sec. 1.5.1).
5. Whether a tabulated layout schedule (Sec. 1.5.2) will be required.
6. Identification marks required (Sec. 1.6).
7. Whether elliptical reinforcement is acceptable (Sec. 1.6 and Appendix A4).
8. Whether the purchaser desires to inspect the pipe and fittings at the manufacturer's plant (Sec. 1.7.1).
9. Whether steel test reports (Sec. 1.9.3) and test specimens (Sec. 1.9.4) will be required.
10. Whether submission of rubber gasket material test reports (Sec. 1.9.5 and 2.11.8) will be required.
11. Testing of welds (Sec. 1.9.6) if required.
12. Whether an affidavit of compliance (Sec. 1.10) will be required.
13. Type of cement required if there is a preference (Sec. 2.1.1).
14. Whether aggregate samples (Sec. 2.4) will be required.
15. Whether submission of manufacturer's design calculations (Sec. 3.2) will be required.
16. Type of protective coating on exposed portions of joint rings (Sec. 3.3.3) if there is a preference.
17. Whether submission for approval of details of materials and methods for welding (Sec. 3.5 and 3.6) will be required.
18. Whether a specific seal coat (Sec. 3.9) will be required.
19. Details of fittings (Sec. 4.1).
20. Testing of steel cylinders for fittings (Sec. 4.2 and 4.3).
21. Whether lining and coating of structural steel connections (Sec. 4.5) will be required.
22. Variance in curing if permitted (Sec. 3.8.1).

III—Major Revisions

The major revisions in this edition consist of the following:

1. The title has been changed to reflect the scope of the standard more accurately. The phrase "water pipe" has been changed to "pressure pipe," the term "not prestressed" was eliminated as redundant, and the following phrase was added: "for water and other liquids."
2. The entire standard was carefully reviewed, and changes were made in most of the sections to improve understanding and readability.
3. Use of the standard was improved by the addition of titles to all sections.
4. The format and terminology of the standard are patterned after AWWA C301–72 to establish a consistency in concrete pressure pipe standards.
5. The scope, which formely provided for pipe in sizes from 20 in. to 96 in., was changed to provide for sizes from 24 in. to 144 in. This change was made to conform to present industry practice.
6. Concrete admixtures for reducing water content and controlling setting time may be used by the manufacturer as provided in Sec. 2.6.
7. The laying length of pipe, previously required to be nominally 12, 14, or 16 ft, is now set at a minimum of 8 ft and a maximum of 20 ft for

24-in. to 36-in. pipe and 24 ft for 39-in. pipe and larger.

8. The minimum time required for steam curing has been reduced from 32 to 24 hr. The actual time used will depend on temperature, which may vary from 110F to 150F, and other conditions. This reduction does not relax the concrete strength requirements.

9. A design appendix has been added to the standard to provide a method of designing reinforced concrete cylinder pipe to resist internal pressures and external loads. This appendix provides a uniform approach to design so that the user of the standard will find it easier to undertake the design of the pipe and to review the manufacturer's computations. By incorporating all the design considerations in the appendix, it was possible to simplify Sec. 3, Design and Fabrication of Pipe.

American Water Works Association

AWWA C300-74

Revision of
AWWA C300-64

AWWA Standard for

Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids

Section 1—General

Sec. 1.1—Scope

This standard covers the manufacture of reinforced concrete cylinder pipe that is not prestressed or pretensioned and is in sizes from 24 to 144 in., inclusive.* This type of pipe is designed for working pressures of 40 psi and higher that are combined with external loading conditions designated by the purchaser. This standard does not include requirements for handling, delivery, laying, field testing, or disinfection of the pipe.

Sec. 1.2—Definitions

In this standard, the following definitions shall apply:

1.2.1 *Purchaser.* The word "purchaser" shall mean a person, firm, corporation, or government subdivision entering into a contract or agreement to purchase pipe and fittings according to this standard.

1.2.2 *Contractor.* The word "contractor" shall mean the person, firm, or corporation executing the contract or agreement with the purchaser to furnish pipe and fittings according to this standard.

1.2.3 *Manufacturer.* The word "manufacturer" shall mean the person, firm, or corporation that actually manufactures the pipe, acting either directly as the contractor or as a subcontractor or supplier. If the manufacturer is acting as a subcontractor under the contractor or otherwise as a supplier to the contractor, the obligations of the manufacturer under this standard shall be considered as obligations of the contractor, and the contractor shall be responsible for the performance.

1.2.4 *ASTM.* The term "ASTM" does mean the American Society for Testing and Materials. When specific ASTM specifications are cited without dates, the designation shall be construed as referring either to the latest revision under the same specification number or to superseding specifications under a new number, except for provisions in the revised specifications that clearly are inapplicable.

* Pipe may be manufactured in larger diameters provided the purchaser is in full accord with the design.

1.2.5 *ANSI.* The term "ANSI" does mean the American National Standards Institute, Inc.

1.2.6 *Approved.* The term "approved" shall mean having received the approval of the purchaser.

1.2.7 *Working pressure.* The working pressure shall be the maximum sustained internal hydrostatic pressure to which the pipe is to be subjected.

1.2.8 *Transient pressures.* Transient pressures are internal pressure overloads of relatively short duration in excess of working pressure.

1.2.9 *Dead loads.* Dead loads are those loads due to the weights of the earth over the pipe, the water contained by the pipe, and the pipe itself.

1.2.10 *Live loads.* Live loads are those loads that result from the passage of vehicles over the installed pipe.

1.2.11 *Pipe diameter.* The term "pipe diameter" or "size" shall mean the design inside (waterway) diameter of the pipe.

Sec. 1.3—Essential Requirements

The pipe shall have the following principal features: a welded steel cylinder with steel joint rings welded to its ends; a reinforcing cage or cages of steel bars, wire, or welded wire fabric surrounding the steel cylinder; a wall of dense concrete covering the steel cylinder and reinforcing cage or cages inside and out; and a joint with a preformed gasket of rubber, so designed that the joint will be watertight under all conditions of service.

Sec. 1.4—Plans and Data to Be Furnished by Purchaser

1.4.1 *Design data.* The purchaser shall designate the working pressure, the transient pressure, the depth of earth cover, the trench bedding condition, and the live load for which the pipe shall be manufactured.

1.4.2 *Plans.* At least one month prior to manufacture, the purchaser shall furnish the contractor plans and profiles showing the following: alignment and grades; the location of all outlets, connections, and special appurtenances; the design pressures for each part of the line; and such special details or information as are necessary for the manufacture of the pipe and fittings in accordance with this standard and with the specific requirements of the work for which the pipe is made.

Sec. 1.5—Data to Be Submitted by Manufacturer

1.5.1 *Detailed drawings and schedules.* The manufacturer shall submit for approval of the purchaser drawings and schedules showing full details of the reinforcement, concrete, and joint dimensions for the pipe and fittings. All pipe and fittings shall be fabricated in accordance with these approved drawings and schedules. Pipe may be supplied from inventory unless the purchaser has indicated otherwise.

1.5.2 *Tabulated layout schedule.* When specifically required, the data submitted by the manufacturer shall include a tabulated layout schedule, with reference to the stationing and grade line shown on the drawings supplied by the purchaser. The schedule shall show pressure zones, and the point of change from one zone to the next shall be clearly indicated by station number. The diameter of the pipe, the working pressure and thickness of pipe wall, and the area of steel (per linear foot of pipe) in the reinforcing cage or cages and steel cylinder shall be listed for each portion of the pipeline.

Sec. 1.6—Marking

Each length of straight and special pipe and each fitting shall have plainly marked inside on the bell or spigot end the identification marks specified by the purchaser. These shall include the working pressure for which the pipe or fitting is designed. Special marks or identification sufficient to show the proper location of the pipe or fitting in the line by reference to layout drawings and schedules specified under Sec. 1.5 shall be placed on the pipe if specifically required. All beveled pipe shall be marked with the amount of the bevel, and the point of maximum pipe length shall be marked on the beveled end. If elliptical reinforcement is used, the minor axis of the reinforcement shall be identified.

Sec. 1.7—Inspection and Testing by Purchaser

1.7.1 *Inspection at manufacturer's plant.* If the purchaser desires to inspect pipe and fittings at the manufacturer's plant, the purchaser shall so specify in the contract or agreement, stating the conditions (such as the time and the extent of inspection) under which the inspection shall be made.

1.7.2 *Access to work.* The purchaser shall have free access to those parts of the manufacturer's plant that are necessary to assure compliance with this standard. The manufacturer shall make available for the purchaser's use such gages as are necessary for inspection. The manufacturer shall provide the purchaser with such assistance as is necessary for the handling of pipe and fittings.

1.7.3 *Responsibility.* Inspection by the purchaser or failure of the purchaser to provide inspection shall not relieve the manufacturer of his responsibility to furnish materials and to perform work in accordance with this standard.

1.7.4 *Tests.* Tests under Sec. 1.9 that the purchaser makes on material samples shall be made without delay. If any sample fails to meet the requirements, the manufacturer shall be notified immediately. Material affected by the test results shall be set aside pending final disposition. The manufacturer may then request a review of test procedures and additional tests on the material. Duplicate samples, the number of which is to be agreed upon, should be tested by the purchaser or his representative and by the manufacturer. The manufacturer's tests shall be performed by a commercial testing laboratory or in the manufacturer's laboratory, with proper certification. Tests by either party may be witnessed by the other. If the duplicate samples meet the test requirements, the material shall be accepted. If the material is rejected after retesting, the manufacturer shall pay all costs of retesting.

1.7.5 *Rejection.* Material, fabricated parts, and pipe that are discovered to be defective or that do not conform to the requirements of this standard will be subject to rejection at any time prior to final acceptance of the pipe. Rejected material and pipe shall be promptly removed from the site of the work.

Sec. 1.8—Material and Workmanship

All material furnished by the manufacturer shall be new and of the quality specified. All work shall be done in a thorough, workmanlike manner by mechanics skilled in their various trades. When a lower limit or minimum dimension is given herein for a steel component, the minus tolerance (as stated in the applicable ASTM specification) for such limit or dimension shall be understood to define the true lower limit or dimension.

Sec. 1.9—Tests

1.9.1 *Cylinder assembly.* Each completed cylinder with joint rings welded to its ends shall be subjected to a hydrostatic test as specified under Sec. 3.5.3.

1.9.2 *Concrete.* Samples of the mixed concrete shall be taken for making compression test cylinders as specified under Sec. 3.7.4.

1.9.3 *Steel reports.* Mill test reports or plant test reports on each heat from which the steel is rolled shall be obtained by the manufacturer and made available to the purchaser on request.

1.9.4 *Steel specimens.* If required by the purchaser, the manufacturer shall provide test specimens cut from each shipment of steel for reinforcing and for cylinders.

1.9.5 *Gasket rubber.* Test reports showing the physical properties of rubber used in the gaskets, as specified in Sec. 2.11.8, shall be obtained by the manufacturer and shall be made available to the purchaser on request.

1.9.6 *Welds in reinforcement.* If required by the purchaser, samples of welds in reinforcing bars shall be tested for conformance with Sec. 3.6.

1.9.7 *Expense.* The expense of testing materials and submitting test reports to the purchaser in accordance with this standard and the purchaser's supplementary specifications, referred to in the foreword, of testing the completed steel cylinder in accordance with Sec. 1.9.1 and of testing concrete in accordance with Sec. 1.9.2 shall be borne by the manufacturer. All other tests shall be made by the purchaser at the purchaser's expense, except as otherwise specificially provided.

Sec. 1.10—Affidavit of Compliance

The purchaser may require an affidavit from the manufacturer that the pipe and fittings furnished under the purchaser's contract or agreement comply with all applicable provisions of this standard.

Section 2—Material Specifications

Sec. 2.1—Cement

2.1.1 *Type.* Cement for concrete work shall conform to the "Specifications for Portland Cement" (ASTM Designation C150). Either Type I or Type II may be used unless the purchaser specifies a particular type. Sampling and testing shall conform to the individual ATSM specification designated therein.

2.1.2 *Inspection.* Satisfactory facilities shall be provided for identifying, inspecting, and sampling cement at the mill, the warehouse, and the site of the work. The purchaser shall have the right to inspect the cement and obtain samples for testing at any of these points.

2.1.3 *Storage.* Cement shall be stored in a weathertight, dry, well-ventilated structure.

2.1.4 *Unusable.* Cement salvaged by cleaning cement sacks, mechanically or otherwise, shall not be used in the work. Cement containing lumps shall be rejected and shall be immediately removed from the site of the work.

2.1.5 *Temperature.* If the temperature of the cement exceeds 150F, it shall be stored until cooled to that temperature.

Sec. 2.2—Fine Aggregate

2.2.1 *General.* Fine aggregate for concrete and mortar shall consist of clean, hard, durable, uncoated particles of natural sand or of sand prepared from the product obtained by crushing stone or gravel. At the time of use the fine aggregate shall be entirely free of frozen material.

2.2.2 *Gradation.* Fine aggregate shall be well graded from coarse to fine and, when tested by means of laboratory sieves in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136), shall conform to the gradation requirements in Table 1.

TABLE 1

Gradation Requirements for Fine Aggregate

Sieve Size	Total Passing, by Weight, %
⅜ In.	100
No. 4	95–100
No. 8	65– 98
No. 16	45– 80
No. 30	20– 70
No. 50	5– 50
No. 100	2– 10
No. 200	0– 5

The gradation requirements given in Table 1 represent the extreme limits for determining the suitability of fine aggregate under this standard. To maintain uniformity of gradation for aggregate from any given source, a fineness modulus determination shall be made upon representative samples from that source. Thereafter the fineness modulus of all shipments therefrom shall not vary by more than ±0.20 from the fineness modulus of the representative sample, unless suitable, approved mix adjustments are made.

2.2.3 *Impurities.* Fine aggregate shall be free from injurious amounts of organic impurities and shall conform to Sec. 4.2 of "Specifications for Concrete Aggregates" (ASTM Designation C33-71a).

Sec. 2.3—Coarse Aggregate

2.3.1 *General.* Coarse aggregate for concrete shall consist either of hard, durable particles of crushed stone or of crushed or uncrushed gravel that conforms to the requirements and tests given in Sec. 2.3.2 and 2.3.3.

2.3.2 *Gradation.* Coarse aggregate shall be well graded from coarse to fine. The maximum size and gradation shall be subject to the approval of the purchaser and shall be such that the concrete can be readily placed in the mold, by the particular method used in placing it, to provide a solid, compact, homogeneous wall with a smooth surface. Tests for gradation of coarse aggregate shall be in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136). Thin and elongated pieces, the maximum dimension of which exceeds five times the minimum, shall not be

TABLE 2

Permissible Amounts of Deleterious Substances in Coarse Aggregate

Material	Maximum Weight Limit, %
Soft particles	5.00
Coal and lignite	0.50
Clay lumps	0.25
Material finer than 200 sieve	1.00
Combined total of above items	5 00

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in excess of 10 per cent of the coarse aggregate by weight.

2.3.3 *Impurities.* Deleterious substances in coarse aggregate shall not exceed the amounts given in Table 2, as determined by sampling and testing procedures listed in the "Specifications for Concrete Aggregates" (ASTM Designation C33).

Sec. 2.4—Samples of Aggregates

At least four weeks prior to mixing concrete, the manufacturer, if required, shall provide, in suitable containers, samples of not less than 1 cu ft each of fine aggregate and coarse aggregate for preliminary approval. All samples shall be plainly labeled to indicate the source of the material, the date, and the name of the collector. Methods of sampling aggregates shall be in accordance with the "Methods of Sampling Aggregates" (ASTM Designation D75).

Sec. 2.5—Water

Water used for concrete and for curing pipe shall be fresh water and shall be clean and free from oil, acid, strong alkalies, or vegetable matter.

Sec. 2.6—Admixtures

At the option of the manufacturer, the concrete may contain a water-reducing, set-controlling admixture conforming to the "Specification for Chemical Admixtures for Concrete" (ASTM Designation C494). No admixture shall contain calcium chloride. The type and amount of admixture shall be subject to the approval of the purchaser.

Sec. 2.7—Steel for Cylinders and Fittings

2.7.1 *Steel sheets.* Steel sheets for pipe cylinders and fittings may be in cut lengths or coils and shall meet the requirements of the "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade B or C, or "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569), except that for steel covered by ASTM A569, the maximum carbon content shall be 0.25 per cent and the minimum yield shall be 27,000 psi.

2.7.2 *Steel plates.* Steel plates for pipe cylinders and fittings shall conform to the "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates for Structural Quality" (ASTM Designation A283), Grade B or C.

Sec. 2.8—Steel for Bar, Wire, and Wire Fabric Reinforcement

2.8.1 *Bars.* Steel bar reinforcement for concrete pipe or fittings shall be plain or deformed and shall conform to "Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 80, or to "Specifications for Deformed Billet-Steel Bars for Concrete Reinforcement" (ASTM Designation A615–68), Grade 40, except that for plain bars supplied under ASTM A615–68, (1) the requirements of Sections 6, 7, and 14.3 shall not apply, (2) intermediate bar diameters shall meet the requirements of the next smaller bar number designation, and (3) bar diameters less than No. 3 shall meet the requirements for No. 3 bar.

2.8.2 *Wire.* Steel wire for reinforcement of concrete pipe shall conform to the "Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (ASTM Designation A82) or to the "Specifications for Deformed Steel Wire for Concrete Reinforcement" (ASTM Designation A496). Wire used for ties may be annealed.

2.8.3 *Wire fabric.* Wire fabric reinforcement for concrete pipe or for mortar coating for fittings shall conform either to the "Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A185) or to the "Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A497).

Sec. 2.9—Steel for Joint Rings

Steel for bell rings less than ¼ in. thick shall conform to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade A, or to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569). Special shapes for spigot joint rings and steel for bell rings ¼ in. or more in thickness shall conform to "Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 50, or to "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality" (ASTM Designation A283), Grade A, or to "Specifications for Merchant Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation A575), Grade 1012, or to "Specifications for Special Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation A576), Grade 1012, or to "Specifications for Steel Sheet and Strip, Carbon, Hot-Rolled Commercial Quality, Heavy-Thickness Coils (Formerly Plate)" (ASTM Designation A635).

Sec. 2.10—Steel Castings for Fittings

Steel castings for fittings shall conform to the "Specifications for Mild to Medium Strength Carbon Steel Castings for General Application" (ASTM Designation A27), Grade 70–36, normalized.

Sec. 2.11—Rubber for Gaskets

2.11.1 *General.* The gasket shall have smooth surfaces free from pitting, blisters, porosity, and other imperfections. The rubber compound shall contain not less than 50 per cent by volume of first-grade natural crude or first-grade synthetic rubber. The remainder of the compound shall consist of pulverized fillers free from rubber substitutes, reclaimed rubber, and deleterious substances. The compound shall meet the following physical requirements when tested in accordance with the indicated conditions and designated ASTM test methods.

2.11.2 *Tensile strength.* The tensile strength of the compound shall be at least 2,700 psi for natural rubber gaskets and 2,000 psi for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.3 *Elongation at rupture.* The elongation at rupture shall be at least 400 per cent for natural rubber gaskets and 350 per cent for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.4 *Specific gravity.* The specific gravity shall not vary by more than ±0.05 within the range of 0.95–1.45—"Methods for Chemical Analysis of Rubber Products" (ASTM Designation D297).

2.11.5 *Compression set.* The percentage of compression set shall not exceed 20. The compression set determination shall be made in accordance with "Methods of Test for Compression Set of Vulcanized Rubber" (ASTM Designation D395), Method B, with the exception that the disc shall be a ½-in.-thick section of the rubber gasket stock.

2.11.6 *Tensile strength after aging.* After being subjected to an accelerated aging test for 96 hr in air at 70C in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method" (ASTM Designation D573) or in a pressure chamber for 48 hr at 70C in an oxygen atmosphere at 300 psi in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oxygen-Pressure Method" (ASTM Designation D572), the tensile strength of the compound shall be not less than 80 per cent of the tensile strength before aging.

2.11.7 *Shore durometer.* The Shore A durometer hardness shall be in the range of 50 to 65 and shall be determined in accordance with "Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer" (ASTM Designation D2240–68), with the exception of Section 4 thereof. The determination shall be taken directly on the gasket.

2.11.8 *Test reports.* If required by the purchaser, the manufacturer shall submit test reports showing the physical properties of the rubber compound used in the manufacture of the gaskets.

Section 3—Design and Fabrication of Pipe

Sec. 3.1—General Requirements

3.1.1 *Laying lengths.* In general, pipe shall have a minimum nominal laying length of 8 ft, unless shorter lengths are required by weight or other considerations. The maximum lengths shall be as follows:

Internal Diameter *in.*	Maximum Laying Length *ft*
24 to 36 inclusive	20
39 and larger	24

3.1.2 *Diameter tolerances.* Pipe shall be round and true and shall have a smooth and dense interior surface. The mean internal diameter of any portion of each piece of pipe shall be not less than the design diameter or size specified by more than ¼ in. for 36-in. pipe, and smaller; by more than ⅜ in. for 42-in. and 48-in. pipe; by more than ½ in. for 54-in. to 78-in. pipe; or by more than ¾ in. for 84-in. pipe, and larger.

3.1.3 *Wall tolerances.* The minimum design thickness of pipe wall and the minimum thickness of concrete lining for each size of pipe shall be as shown in Table 3. At the spigot section, the concrete lining thickness may be less than shown in Table 3, provided that the interior surface of the lining at the spigot shall not depart from a true right cylinder projected from the interior surface of the lining in the body of the pipe. The thickness of walls shall be not less than the design thickness by more than ⅛ in. for 36-in. pipe, and smaller; by more than $\frac{3}{16}$ in. for 42-in. and 48-in. pipe; by more than ¼ in. for 54-in. to 72-in. pipe; or by more than ⅜ in. for pipe larger than 72 in.

Sec. 3.2—Design of Pipe

The reinforcement of the pipe shall consist of a welded steel cylinder surrounded by one or more cages of welded steel hoops, helically wound steel bar or wire, or welded wire fabric

TABLE 3

*Requirements for Pipe of Various Sizes**

Pipe ID *in.*	Minimum Thickness	
	Total Pipe Wall *in*	Concrete Lining *in.*
24	$3\frac{1}{2}$	1
30	$3\frac{1}{2}$	1
36	4	1
42	$4\frac{1}{2}$	1
48	5	$1\frac{1}{4}$
54	$5\frac{1}{2}$	$1\frac{1}{4}$
60	6	$1\frac{1}{4}$
66	$6\frac{1}{2}$	$1\frac{1}{2}$
72	7	$1\frac{1}{2}$
78	$7\frac{1}{2}$	$1\frac{1}{2}$
84	8	$1\frac{1}{2}$
90	8	$1\frac{3}{4}$
96	$8\frac{1}{2}$	$1\frac{3}{4}$

* For pipe larger than 96 in. in diameter, dimensions and details of design shall be subject to approval by the purchaser.

properly spaced and supported with longitudinal reinforcing. The minimum thickness of the cylinder shall be 16 gage. The cross-sectional area of the circumferential steel in the cylinder and in the reinforcing cage or cages shall be such that the conditions required by the design methods in the appendix are met. If required by the purchaser, the manufacturer shall submit design calculations for approval prior to the manufacture of any pipe.

Sec. 3.3—Joint Rings

3.3.1 *General.* The steel bell and spigot joint rings shall be so designed and fabricated that when the pipe is laid and the joint completed, the gasket will be enclosed on four sides. Each ring shall be formed by one or more pieces of steel butt-welded together. The contact surfaces in the joint shall be such as not to cause cutting of the rubber gasket during installation. Welds on gasket contact surfaces shall be ground smooth and flush with the adjacent surfaces. The rings shall be expanded by a press beyond their elastic limits so that they are accurately sized.

3.3.2 *Tolerances.* On the finished pipe, the circumference of the inside bell ring contact surface shall not exceed the circumference of the outside spigot ring contact surface by more than $\frac{3}{16}$ in. for gaskets $\frac{21}{32}$ in. in diameter or by more than $\frac{1}{4}$ in. for gaskets greater than $\frac{21}{32}$ in. in diameter. The out-of-roundness of either contact surface, measured as the difference between the maximum and minimum joint ring diameters, shall not exceed 0.5 per cent of the average of these diameters. The minimum thickness of the completed bell rings shall be $\frac{3}{16}$ in. for 36-in. pipe, and smaller, and $\frac{1}{4}$ in. for pipe larger than 36 in. The rings shall conform to the details submitted by the manufacturer and approved by the purchaser.

3.3.3 *Protective coating.* The portions of the joint rings that will be exposed on the completed pipe shall be protected from corrosion by an approved coating.

Sec. 3.4—Rubber Gaskets

Joints shall be sealed with a continuous solid-ring rubber gasket having a circular cross section with a diametral tolerance of $\pm\frac{1}{64}$ in. Gaskets shall be of sufficient volume to fill substantially the recess provided when the pipe joint is assembled, so that the gasket will be compressed to form a pressure-tight seal. The gasket shall be the sole element depended upon to make the joint watertight.

Sec. 3.5—Fabrication of Steel Cylinders

3.5.1 *General.* The cylinders shall be formed by shaping and welding together cut lengths or coils of specified material and thickness. The cylinders shall be accurately shaped to the size required, and the joint rings shall be welded to the ends before testing.

3.5.2. *Welding.* Butt-welding, lap-welding, or offset lap-welding, shall be used for the longitudinal and circumferential or helical seams. The sheets shall be closely fitted prior to welding and shall be firmly held during welding. If required, the manufacturer shall submit for approval the specific details of materials and methods he proposes to use before any welding is done.

3.5.3 *Hydrostatic test.* Each steel cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test. When the cylinder is tested in a horizontal position, the stress shall be at least 20,000 psi, but not greater than 25,000 psi. When the cylinder is tested in a vertical position, the stress at the lower end shall be 25,000 psi. While under pressure test, all welds shall be thoroughly inspected and all parts showing leakage shall be marked. Cylinders that show any leakage under test shall be rewelded at the points of leakage and subjected to another hydrostatic test. The finished cylinder, with joint rings attached, shall not be used in the work unless it is completely watertight under the required test pressure.

3.5.4 *Cleaning steel surfaces.* Before the concrete is placed, steel surfaces shall be cleaned to remove loose or other foreign matter that would interfere with the bonding of the concrete.

Sec. 3.6—Fabrication of Reinforcement Cage

3.6.1 *Circumferential reinforcement.* The circumferential reinforcement shall either be steel bar or wire in helical or hoop form or be welded wire fabric shaped and lap- or butt-welded into cages. The quality of the welds and welding procedures shall be assured by the testing of a representative number of butt or lap welds to a test stress of 25,000 psi.

3.6.2 *Longitudinal reinforcement.* The circumferential reinforcement in cages shall be accurately spaced and rigidly assembled by the attaching of longitudinal bars securely, so that the cage is maintained in proper shape and position during the casting of the pipe.

3.6.3 *Placement.* The minimum distance between the circumferential reinforcing steel and the surface of the pipe shall be 1 in.

Sec. 3.7—Concrete for Pipe

3.7.1 *Proportioning.* The proportions of cement, fine aggregate, coarse aggregate, and water used in concrete for pipe shall be subject to the approval of the purchaser. The proportions shall be determined and controlled as the work proceeds in order to obtain homogeneous, dense, workable, durable concrete of specified strength in the wall of the pipe and a minimum of defects in the surface of the pipe. The proportions shall be those that will give the best overall results with the particular materials used for the work. A minimum of six bags of cement shall be used for each cubic yard of concrete. The water–cement ratio shall be such as to assure that the concrete will meet the strength requirements.

3.7.2 *Measurement of materials.* A barrel of cement shall be considered 4 cu ft or 376 lb, and a bag of cement shall be considered 1 cu ft or 94 lb. Cement in standard sacks need not be weighed, but bulk cement shall be weighed. Water for mixing shall be measured by volume or by weight.

Concrete aggregates for each batch shall be measured separately by weighing. The proportions of aggregates shall be computed on both the saturated and surface-dry basis, and the water-cement ratio shall exclude the water absorbed by the aggregates. The equivalent unit weights for both fine and coarse aggregates shall be determined in accordance with the "Method of Test for Unit Weight of Aggregate" (ASTM Designation C29). The equipment and devices for weighing and measuring shall at all times be accurate within 1 per cent.

3.7.3 *Mixing.* The mixing shall be thoroughly done by a mixer of accepted type. Mixing time shall be consistent with the type of mixer used. Transit mixing shall not be used except by written authorization and under specific requirement of the purchaser.

3.7.4 *Standard test cylinders.* A set of at least four standard test cylinders shall be taken from each day's pour of the mixed concrete. Standard test cylinders shall be made in conformance with the "Method for Making and Curing Concrete and Compressive and Flexural Test Specimens in the Field" (ASTM Designation C31). The curing of the test cylinders shall be in conformity with the curing of the pipe.

3.7.5 *Testing cylinders.* All test cylinders shall be tested by an approved testing laboratory at the expense of the manufacturer, unless the manufacturer has approved testing facilities at the site of the work. In such event, the tests shall be made by the manufacturer in the presence of the purchaser and at the manufacturer's expense or, if permitted by the purchaser, certified test reports may be submitted by the manufacturer.

3.7.6 *Strength of concrete.* The design strength of concrete shall be the strength used in designing the pipe by the method described in the Design Appendix. The design strength of concrete shall be not less than 4,500 psi for vertically cast concrete or 6,000 psi for centrifugally cast concrete. The compressive strength of concrete cylinders shall equal or exceed $\frac{2}{3}$ of the design strength in 7 days and the design strength in 28 days. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the design strength, and no cylinder shall have a strength less than 80 per cent of the design strength. Damaged cylinders shall be discarded. Pipe made from concrete that does not meet the strength tests in accordance with the foregoing shall be subject to rejection.

3.7.7 *Forms.* The forms shall be of steel made with butt joints throughout and with the interior surface smooth and true. The forms shall be so constructed that the inner and outer forms, joint rings, and reinforcement shall be held in position throughout placing of the concrete and so designed that the pipe can be stripped from the forms rapidly and without damage to the pipe surfaces. Forms shall be sufficiently tight to prevent leakage of mortar, and they shall be stiff enough and so braced as to withstand, without deformation, all operations incident to the pouring and setting of the concrete. Forms shall be cleaned and oiled before each use.

3.7.8 *Placing concrete.* The transporting and placing of concrete shall be carried out by methods that will not cause the separation of concrete materials or the displacement of the steel cylinder and reinforcement from their proper positions in the form. Accepted methods of mechanical vibrating shall be used to compact the concrete in the forms and to secure satisfactory interior surfaces. Forms shall not be removed until the concrete has set sufficiently to avoid spalling or damage to the pipe during removal of the form.

Sec. 3.8—Curing of Pipe

3.8.1 *General.* The purpose of curing pipe as prescribed in the following sections is to obtain concrete of the strength specified for test cylinders under Sec. 3.7.6. The pipe shall be cured by steam or by water unless otherwise specifically permitted. Water curing and steam curing may be used interchangeably on a time-ratio basis of 4 hr of water to 1 hr of steam curing except that the water curing may be used only if the minimum ambient temperature exceeds 40F.

3.8.2 *Steam curing.* The pipe shall be placed in the steam-curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hr shall be allowed before moist steam is admitted to contact the pipe. The temperature within the enclosure shall be gradually raised to at least 110F and to not more than 150F for a period of at least 24 hr. The delay period shall be included in the 24-hr period. Curing by steam shall be continuous except during a period sufficient to remove the forms or supporting rings. The forms shall not be removed until at least 6 hr after the beginning of the curing. After this minimum 6-hr period, the pipes may be "tipped" from their bases, and curing shall be continued by either steam or water.

3.8.3 *Water curing.* The pipe shall be kept moist by intermittent water spraying for a period of at least 32 hr. The water-curing period shall be extended 1 hr for each hour in the first 24 during which the ambient air temperature is below 50F. Following this minimum period, they may be "tipped" from their bases but shall be kept continuously moist by intermittent spraying for an additional period of at least 3 days.

Sec. 3.9—Seal Coat

If the purchaser specifically orders a bituminous seal coat, the materials and application shall comply with the appropriate provisions of AWWA C104 (ANSI A21.4) insofar as they are applicable. The material shall be applied after the pipe is cured.

Section 4—Fittings and Special Pipe

Sec. 4.1—General

Fittings and special pipe shall include bends, tees, wyes, connections to main-line valves, closures, beveled pipe for curves, and pipe with outlets required for manholes, air valves, and blowoffs, as shown on the purchaser's drawings or as ordered by the purchaser. Fittings shall conform to the details furnished by the purchaser or, if required, to the details furnished by the manufacturer and approved by the purchaser. Fittings shall be either type as described in Sec. 4.2 and 4.3 at the option of the manufacturer and shall be designed for the same pressures as the pipe.

Sec. 4.2—Fittings (Type A)

Type A fittings are composed of steel cylinders, concrete or mortar lining, and reinforced concrete or mortar exterior coating. The steel for the cylinder shall be cut, shaped, and welded to form the properly shaped bend, tee, reducer, or other fitting. The welds shall be inspected, and the completed cylinder shall be tested for tightness by the dye penetrant method or other approved method, if specifically required by the purchaser. A cage or cages of steel reinforcement with approved cross-sectional areas shall be formed around the cylinder and openings. Longitudinal reinforcement sufficient for the additional stresses in the fitting walls shall be provided. The interior and exterior concrete or mortar shall be placed in an accepted manner. Curing shall be as specified in Sec. 3.8.

Sec. 4.3—Fittings (Type B)

Type B fittings are composed of cut and welded steel plate of a thickness to provide the design strength, with mortar coating on interior and exterior surfaces.

4.3.1. *Steel fabrication.* The steel for the fabricated steel plate fittings shall be cut, shaped, and welded so that the finished fitting shall have the required shape and interior dimensions. The deflection angle between adjacent segments of a bend shall be no greater than 22½ deg. Adjacent segments shall be joined by lap or butt welding. Fabrication and welding shall conform to the requirements of Sec. 3.5 of this standard. The welds shall be inspected, and the completed cylinder shall be tested for tightness by the dye penetrant method or other approved method, if specifically required by the purchaser.

4.3.2 *Reinforcement.* Wire fabric reinforcing shall be applied to the interior and exterior surfaces of the fabricated fitting. The reinforcement shall be 2 × 4-in. W1 welded-wire fabric, held ⅜ in. from the surfaces of the steel plate. The members on the 2-in. spacing shall extend circumferentially around the fitting, with ends overlapped 4 in. and tied together. Longitudinal splices shall be staggered.

4.3.3 *Mortar.* Steel plate fittings shall be lined with mortar at least ¾ in. thick at adapter ends, or outlets, but under no conditions shall the lining be less than ⅜ in. thick. The exterior shall be coated with mortar at least 1 in. thick. The mortar shall contain no less than 1 part cement to 3 parts sand of a grading approved for the method of application used.

4.3.4 *Curing.* Mortar-lined and mortar-coated fittings in Sec. 4.3.3 shall be cured by water spraying, by steam, or by curing compounds. The curing compounds shall meet the requirements of "Liquid Membrane—Forming Compounds for Curing Concrete" (ASTM Designation C309), Type II, white pigmented.

Sec. 4.4—Curves, Bends, and Closures

Long radius curves and small angular changes in pipe alignment shall be formed by deflecting joints, by straight pipe with beveled ends, by bevel adapters, or by a combination of them. Pipe ends may be beveled up to 5 deg. Short-radius curves and closures shall be formed by fittings.

Sec. 4.5—Openings and Connections

Manholes and flanges, spigot or bell connections for air valves, blow offs, or connections to other pipe shall be built into the walls of the concrete pipe at locations shown on the purchaser's drawings or ordered by the purchaser. Wall openings shall be suitably reinforced. If required, the interior and exterior surfaces of structural steel connections shall be lined and coated with mortar.

Appendix A

Design Requirements

This appendix is for information and is not a part of AWWA C300-74.

A1—General

Reinforced concrete cylinder pipe covered by this standard shall be designed by the method described herein to resist the internal pressures and external loads designated by the purchaser.

A2—Hydrostatic Design

To resist internal pressure alone, the cross-sectional area of the circumferential steel reinforcement shall be no less than the maximum determined from equations (1) and (2):

$$A_s = \frac{6P_wD_y}{12{,}500} \qquad (1)$$

$$A_s = \frac{6(P_w + P_t)D_y}{16{,}500} \qquad (2)$$

A_s = Cross-sectional area of circumferential steel reinforcement, including the steel cylinder, square inches per foot of pipe wall

P_w = Working pressure, psi

P_t = Transient pressure, psi

D_y = Inside diameter of steel cylinder, inches

A3—Combined Load Design

The pipe shall be designed to resist the flexural and axial stresses from each of the following load conditions:

1. A combination of working pressure, transient pressure, and dead loads (earth, pipe, and water)
2. A combination of working pressure, dead loads, and live loads
3. Dead loads and live loads with no internal pressure.

External dead loads and live loads shall be computed in accordance with recognized and accepted theories, such as presented in *Soil Engineering* by M. G. Spangler [International Textbook Co., Scranton, Pa. (2nd ed., 1960), pp. 396–418] and in *Concrete Pipe Design Manual* [American Concrete Pipe Assn., Arlington, Va., (1970)].

The coefficients for moment and thrust shall also be from recognized and accepted theories, such as presented in "Stress Coefficients for Large Horizontal Pipes" by J. M. Paris [*Engineering News-Record*, vol. 86, p. 768 (1921)] and in "Stress Analysis of Concrete Pipe" by H. C. Olander [Eng. Monograph No. 6, US Bureau

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of Reclamation, Dept. of the Interior, Washington, D.C.]. The bedding angle used in design shall be compatible with the installation specified by the purchaser.

The reinforced concrete design shall be according to the applicable provisions of ACI Standard 318, with either the strength method or the alternate design method (working stress method) being used.

For the strength method, the load factor shall be 1.8; the capacity reduction factor, ϕ, shall be 1.0; and an equivalent rectangular concrete stress distribution shall be used. The design yield strength, f_y, shall not exceed 40,000 psi for the sides of the pipe, and the design yield strength shall not exceed the value determined by equations (3a) or (3b) for the crown and invert of the pipe.

$$f_{yi} = 27{,}000 \text{ psi, where } A_r < \tfrac{1}{3}(A_r + A_y) \quad (3a)$$

$$f_{yi} = 33{,}000 \text{ psi, where } A_r \geqq \tfrac{1}{3}(A_r + A_y) \quad (3b)$$

f_{yi} = Design yield strength for the crown and invert of the pipe, psi

A_r = Cross-sectional area of rod reinforcement in the tensile zone of the crown and invert, square inches per foot of pipe wall

A_y = Cross-sectional area of steel cylinder, square inches per foot of pipe wall

For the alternate design method, the load and ϕ factors shall each be 1.0; the calculated compressive stress in the concrete shall not exceed 0.45 f_c' (the specified 28-day compressive strength); and the allowable tensile stress in the reinforcement shall not exceed 22,000 psi at the sides of the pipe and shall not exceed the value determined by equation (4) for the crown and invert of the pipe, with the applicable value of f_{yi} from (3a) or (3b) being used.

$$f_{si} = 0.55 f_{yi} \quad (4)$$

f_{si} = Allowable tensile stress for the inner layer of steel reinforcement at the crown and invert, psi

When the transient pressure is combined with other loads, the required capacity for the strength method shall be reduced by 25 per cent, or allowable stresses for the alternate method shall be increased by one third. The provisions of this paragraph apply only to load condition 1.

A4—Reinforcement Cage Configurations

Reinforcement shall consist of a steel cylinder and one or more cages. The cages may be circular or elliptical in shape and may be used singly or in combination. The cross-sectional area of the circumferential rod reinforcement per linear foot of pipe shall be no less than 40 per cent of the total area of reinforcement per linear foot of pipe. When the reinforcement consists of a combination containing an elliptical cage, the cross-sectional area of the circular reinforcement, including the steel cylinder, shall be no less than that determined by Eq (1), with an allowable steel stress of 25,000 psi.

The design depth of the pipe wall section shall be taken to the centroid of the tensile steel. The design clear concrete cover for an outer circular cage or for the horizontal axis of an elliptical cage shall be 1½ in. For the steel cylinder, the design clear cover shall be the nominal lining thickness designated by the manufacturer but no less than the minimum lining thickness shown in Table 3 of Sec. 3.1.3.

2P-5M-7/77-43300

Transmission Pipe

American Water Works Association

AWWA C402-77

(Revision of
C402-75)

AWWA STANDARD

for

ASBESTOS-CEMENT TRANSMISSION PIPE, 18 IN. THROUGH 42 IN., FOR WATER AND OTHER LIQUIDS

First approved by AWWA Board of Directors Jan. 26, 1975.
This edition approved Jan. 30, 1977.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

Committee Personnel

The Standards Committee on Asbestos-Cement Pressure Pipe, which reviewed and approved this standard, had the following personnel at the time of approval:

R. S. Bryant, *Chairman*
J. L. Warden, *Vice-Chairman*
T. R. Gillen, *Secretary*

Consumer Members

S. C. Baker, Naval Facilities Engineering Command, Alexandria, VA	(NAVFAC)
P. J. Brady, Director of Utilities, Portsmouth, VA	(AWWA)
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*Alternate.

Table of Contents

Foreword

This foreword is for information only and is not a part of C402.

I—History of Standard

A new pipe material consisting of an intimate mixture of portland cement and asbestos fibers was introduced to the North American market in 1931 following a number of years of usage in other countries, particularly Italy.

In the ensuing years, this type of pipe gained popularity, and in 1949 AWWA established a committee on standard specifications for asbestos–cement pipe under the chairmanship of S. M. Clarke of Greeley and Hanson, Chicago.

The committee developed a standard for asbestos–cement water pipe, which was approved by the AWWA Board of Directors as a tentative standard, AWWA C400–53T, on May 15, 1953. In 1958, the committee was reactivated as Committee 8340D on Asbestos–Cement Pipe under the chairmanship of Roy H. Ritter, Whitman, Requardt and Assocs., Baltimore, to review several suggested changes and to recommend revisions to the standard. The committee produced a revised standard adopted by AWWA as C400–64T on Jan. 27, 1964. It was advanced to "standard" without revision on Jul. 2, 1965.

In early 1968, the committee was reactivated as the Standards Committee on Asbestos–Cement Pipe to review and revise all of the AWWA standards on asbestos–cement pipe. The committee produced a revised standard approved by the Board of Directors on Jan. 31, 1972, designated as "AWWA Standard for Asbestos–Cement Pressure Pipe for Water and Other Liquids, C400–72."

In the winter season of 1972–1973 the committee was reorganized and enlarged to include representation of national organizations having an interest in the scope of the committee and wishing to participate in the work. The reorganized committee reaffirmed C400–72 without revision so that it could be presented to the American National Standards Institute for designation as an American National Standard.

In 1975 the committee produced a revised standard approved by the AWWA Board of Directors Jan. 26, 1975, designated as AWWA C400–75, "Standard for Asbestos–Cement Pressure Pipe, 4 in. Through 24 in. for Water and Other Liquids." At the same time a new standard was produced by the committee and approved by the AWWA Board of Directors designated as AWWA C402–75, "Standard for Asbestos–Cement Transmission Pipe, 18 in. Through 42 in., for Water and Other Liquids."

The asbestos–cement pipe manufacturers had developed a new series of pipe classifications that was larger and designed to give greater freedom of selection to design engineers. This is of particular significance for large diameter pipeline projects where the savings in material cost can exceed the increased cost of more detailed design, better control of methods of installation, and provision of surge controls when justified.

The standard, AWWA C402–75, was developed to provide the user with a ready reference and specification for this type of pipe known as transmission pipe.

The possibility of confusion between the two standards, C400 and C402, was carefully reviewed by the committee. The result is this edition of C402, which maintains the sizes covered from 18 in. through 42 in. C400 has been revised simultaneously and covers sizes 4 in. through 16 in. There is now no overlap in sizes.

II—Information Regarding Use of This Standard

II.A *General.* When ordering pipe covered by this standard, local installation and operating conditions should be considered to determine the classification and type of pipe to specify. Also, certain other items must be specified to describe completely the pipe required.

It is recommended that, for large diameter pipeline projects, the purchaser evaluate local installation and operating conditions, operating pressures and surge pressures, trench loads, and surface loads when determining the strength classification to be used.

A proposed AWWA C403, "Standard Practice for the Selection of Asbestos-Cement Transmission Pipe," is under consideration at the present time by the committee.

Note: The purchaser is referred to AWWA C401 (formerly AWWA H2), "Standard Practice for Selection of Asbestos-Cement Distribution Pipe," for guidance in designing transmission pipe to fit his installation and operating conditions. Attention is directed to the fact that selection curves and related data in the current edition of AWWA C401 are applicable to pipe covered by AWWA C400-77, "Asbestos-Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids," not to transmission pipe covered by this standard. The purchaser is advised to consult the manufacturer pending the issuance of the proposed AWWA C403.

The purchaser is referred to AWWA C603, "Installation of Asbestos-Cement Pressure Pipe," for guidance in the laying of the pipe.

II.B *Flexural load test.* Flexural load tests are not required (Sec 2.2.1, 5.2.3). For large diameters, the wall thicknesses increase to a point at which the flexural strength is not a controlling factor, and therefore routine testing is not required.

II.C *Type of pipe.* The following criteria are presented for determining the type of pipe to be used under various soil and water conditions. Each condition should be considered separately even though each may exist in combination with others.

These criteria are based on exposures within the temperature range of 40–80F (5–28C). For pipe exposures to temperatures beyond these limits, consult the manufacturer.

The following criteria are referenced as:

1. Internal water (Table F.1).
2. External water (Table F.2).
3. Nonacid soluble sulfates—internal and external (Table F.3).
4. Acid soluble sulfates—internal and external.

II.C.1 *Internal water.* Aggressiveness of water transported through asbestos-cement pipes is related to the type-designation of asbestos-cement pipe suitable for such use in Table F.1. Aggressiveness of water is defined as follows:

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(a) Highly aggressive:
$$pH + \log (AH) < 10.0$$
(b) Moderately aggressive:
$$pH + \log (AH) = 10.0\text{-}11.9$$
(c) Nonaggressive:
$$pH + \log (AH) \geq 12.0$$

where

pH = Index of acidity (or alkalinity) of the water—standard pH units
A = Total alkalinity—ppm as $CaCO_3$
H = Calcium hardness—ppm as $CaCO_3$

It should be recognized that water that has a $pH + \log (AH)$ less than or equal to 10 is an extremely aggressive water and would be very corrosive to almost all materials found in a typical water system, including the plumbing in consumers' homes. Such waters should be treated to increase pH or hardness to protect the entire network of materials that make up the system. In the event such water treatment is not to be undertaken, the manufacturer of each item used in the water system should be consulted for recommendations regarding the use of his product in an extremely corrosive environment.

NOTE: The expression $pH + \log (AH)$ is a modification of the Langelier Index. It has been prepared so that the aggressiveness of the water may be determined easily. A reasonable comparison of the two would be as follows:

	pH + log (AH)	Langelier Index
Highly aggressive water	<10.0	< −2.0
Moderately aggressive water	10.0 to 11.9	−2.0 to −0.1
Nonaggressive water	≥12.0	≥0

TABLE F.1

Asbestos-Cement Pipe Type Recommended for Internal Water Aggressiveness

Internal Water Aggressiveness	Recommended Pipe Type*
Highly aggressive	†
Moderately aggressive	II
Nonaggressive	I and II

* Type I—no limit on uncombined calcium hydroxide; Type II—1.0 per cent or less uncombined calcium hydroxide.
† The serviceability of pipe for such applications should be established by the purchaser in conjunction with the manufacturer.

TABLE F.2

Aggressiveness of Nonsulfate Acidic Soils to Asbestos-Cement Pipe

Water Conditions Within the Soil Environment	Minimum pH of Acidic Soils When Using Asbestos-Cement Pipe	
	Type I	Type II
Essentially quiescent	5.0	4.0
Mildly fluctuating	5.5	5.0
Rapidly moving or grossly cyclic	6.3	5.5

II.C.2 *External water.* Aggressiveness of external water (water within the soil environment) in relation to asbestos-cement pipe as shown in Table F.2.

The guidelines for the use of asbestos-cement pipe in nonsulfate acidic soils are based upon minimum pH factors alone. Asbestos-cement pipe may or may not perform satisfactorily in acidic soil environments having pH values below those listed in Table F.2. To determine the suitability of asbestos-cement pipe in soils having lower pH values, each situation should be evaluated individually, taking into consideration all aspects of soil environment that affect asbestos-cement pipe corrosiveness.

Sulfate Aggressiveness Classification	Water: Water Soluble Sulfates—*ppm* SO_4	Soil: Water Soluble Neutral Sulfates—*ppm* SO_4
Nonaggressive	150 and less	1000 and less
Mildly aggressive	150–1500	1000–2000
Moderately aggressive	1500–10 000	2000–20 000
Highly aggressive	10 000 and greater	20 000 and greater

II.C.3 *Nonacid soluble sulfates—internal and external.* Aggressiveness of nonacid (pH ≥ 7.0) soluble sulfates in water and soils is related to the type-designation of asbestos-cement pipe suitable for such use in Table F.3. Sulfate aggressiveness in water and soil can be classified as indicated above.

II.C.4 *Acid soluble sulfates—internal and external.* Aggressiveness of acid (pH < 7.0) soluble sulfate waters and soils to asbestos-cement pipe must be evaluated independently. Acid sulfate soils and waters, whether the acid is inorganic or organic, must be evaluated independently of the criteria and guidelines set forth in paragraphs II.C.2 and II.C.3 and must take into consideration soil permeability and other factors. For guidance, consult the manufacturer.

II.D *Supplementary specifications.* The following information summarizes the conditions and items that the purchaser should consider when preparing his supplementary specifications and lists the sections in the standard where they may be found.

1. The standard used; that is, AWWA C402-77.
2. Affidavit of compliance, if required (Sec. 1.3).
3. Type of pipe to be furnished (Sec. 2.3 and Foreword II.C).
4. Classification of pipe (Sec. 3.1)
5. Nominal inside diameter (Sec. 3.2).
6. Lineal feet to be furnished in standard and random lengths (Sec. 3.3).
7. Number, size, type, classification, lengths, and extent of machining of special short lengths (Sec. 3.3.3).
8. Whether inspection by the purchaser (Sec. 5.1) and special marking (Sec. 6.1.4) are required.

III—Major Revisions

Major changes to the 1975 standard made in this revision are:

1. A more detailed description of aggressive soil and water criteria has been added in the Foreword, Sec. II.

TABLE F.3

Asbestos-Cement Pipe Type-Designation Chemical Resistance to Nonacid (pH = 7.0) Soluble Sulfates in Water and Soils

Type Designation	Chemical Resistance to Nonacid Soluble Sulfates in Water and Soils
I*	Will be attacked in various degrees by all but the nonaggressive levels of sulfate concentrations in waters and soils.
II	Resistant to all levels of soluble sulfates.

* The guideline criteria for sulfate resistance of Type I pipe were taken from the *Concrete Manual*, 8th edition, Bureau of Reclamation, 1974. Sulfate resistance here applies to all soluble sulfates regardless of the cation

2. The lot definition of paragraph 1.2.3 has been revised to define more clearly the quantity of pipe manufactured by size versus time.
3. Paragraph 5.2.5 *Machines for Testing* defines the machines used in the various physical tests and also allows couplings to be hydrostatically tested with a rubber bladder inside the coupling at ten times the classification of the coupling.

American Water Works Association

AWWA C402-77

(Revision of C402-75)

AWWA Standard for

Asbestos-Cement Transmission Pipe, 18 in. Through 42 in., for Water and Other Liquids

Section 1—General

Sec. 1.1—Scope

This standard covers nine pressure classifications of Type I and Type II asbestos-cement pipe, 18–42 in. in diameter, for water and other liquids, to be laid underground in public and private rights-of-way.

1.1.1 *Use.* Asbestos-cement transmission pipe is to be used in pipe systems having relatively predictable flows and few appurtenances, which permit reasonable hydraulic analyses, including those for surge pressures.

Sec. 1.2—Definitions

Under this standard, the following definitions shall apply:

1.2.1 *Inspection.* Inspection of the pipe and the tests by the inspector.

1.2.2 *Inspector.* The authorized representative of the purchaser, entrusted with the duty of inspecting pipe produced and tests performed under this standard.

1.2.3 *Lot.* A lot as used herein for pipe 20 in. in diameter and smaller is defined as all pipe of any one classification, type, and size manufactured on any one machine in 24 hr but not to exceed 300 lengths. A lot as used herein for pipe larger than 20 in. in diameter is defined as all pipe of any one classification, type, and size manufactured on any one machine during a period of consecutive working days not exceeding seven days but not to exceed 300 lengths.

1.2.4 *Manufacturer.* The person, firm, or corporation that manufactures the pipe.

1.2.5 *Purchaser.* The person, firm, corporation, or government agency entering into a contract or agreement to purchase pipe according to this standard.

Sec. 1.3—Affidavit of Compliance

The purchaser's supplemental specifications may require an affidavit of compliance from the manufacturer, whether factory inspection has been required or not, to the effect that the materials furnished under the purchaser's order comply with all applicable requirements of this standard.

Section 2—Materials

Sec. 2.1—Composition

Asbestos-cement pipe shall be composed of an intimate mixture of either: (1) portland cement or portland blast furnace slag cement and asbestos fiber with or without silica; or (2) portland pozzolana cement and asbestos fiber. Both (1) and (2) can be with or without the addition of curing agents. The pipe shall be formed under pressure and cured. The finished pipe shall be free from organic materials.

Sec. 2.2—Physical Requirements

2.2.1 *Flexural strength.* Because only improperly bedded and improperly installed small diameter pipe is susceptible to adverse flexural loading, there is no flexural requirement for large diameter pipes.

2.2.2 *Bursting strength.* Each length of pipe and each coupling sleeve shall have sufficient strength to withstand the design internal pressure indicated for its classification in Table 1 when subjected to the hydrostatic test procedure specified in this standard.

TABLE 1
Pipe Classification

Classification	Design Internal Pressure *psi*
30	300
35	350
40	400
45	450
50	500
60	600
70	700
80	800
90	900

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TABLE 2

*Design External Load**—lb/lineal ft

Pipe Size *in.*	Classification								
	30	35	40	45	50	60	70	80	90
18	2 500	3 000	4 000	5 000	6 500	8 500	11 000	14 000	18 000
20	2 500	3 500	4 500	5 500	7 100	9 500	12 000	15 000	20 000
21	2 500	3 500	4 500	5 800	7 300	9 700	12 500	16 000	21 000
24	2 800	3 800	5 000	6 200	8 100	11 000	15 000	19 000	24 000
27	3 500	4 200	5 500	7 000	8 800	12 500	16 500	20 500	27 000
30	3 500	4 500	6 000	7 500	9 700	13 500	18 000	22 500	30 000
33	3 500	5 000	6 500	8 000	10 500	14 500	19 500	24 500	33 000
36	4 000	5 000	7 000	9 000	11 200	16 000	21 000	26 000	36 000
39	4 200	5 300	7 500	9 700	12 000	17 200	22 500	28 000	39 000
42	4 300	5 700	8 000	10 500	13 000	18 500	24 000	30 000	42 000

* It is necessary to apply a load factor to the above three-edge bearing loads in order to correlate them to the field loads. (See AWWA Standard C403.)

2.2.3 *Crushing strength.* Each length of pipe shall have sufficient strength to support the design external load indicated for its classification in Table 2 when subjected to the crushing-test procedure specified in this standard.

Sec. 2.3—Chemical Requirements

Pipe shall be designated as either Type I or Type II according to its content of uncombined calcium hydroxide as determined by the test procedures in this standard for uncombined calcium hydroxide. The requirements for each type are

Type I—no limit on uncombined calcium hydroxide

Type II—1.0 per cent or less uncombined calcium hydroxide.

Section 3—Design

Sec. 3.1—Pipe Classifications

Pipe supplied under this standard shall be made in one or more of the classifications shown in Table 1. (The numerical value for each classification is equivalent to one tenth of the hydrostatic lot test pressure.)

Sec. 3.2—Pipe Diameters

Pipe shall be made with nominal inside diameters of 18, 20, 21, 24, 27, 30, 33, 36, 39, and 42 in. The average inside diameter of a standard or random pipe length shall not be less than the nominal diameter by more than 1.5 per cent.

Sec. 3.3—Pipe Lengths

Pipe shall be produced in standard, random, and short lengths. At least 90 per cent of the total footage of pipe of any classification, type, and size, excluding short lengths, shall be furnished in standard lengths. The remaining 10 per cent may be in random lengths.

3.3.1 *Standard length* shall be 13 ft ± 1 in.

3.3.2 *Random lengths* shall be cut from standard lengths and shall be not less than 7 ft long.

3.3.3 *Short lengths* for making connections to valves, fittings, or structures, and for making closures shall be furnished as specified by the purchaser.

Sec. 3.4—Couplings

A coupling shall consist of an asbestos-cement sleeve of the same type and classification as the pipe and two rubber rings or a device that has equal or better bonding characteristics, strength, and serviceability as that of an asbestos-cement coupling. The manufacturer shall submit to the purchaser for approval, prior to manufacturing, specifications and drawings of alternate couplings.

TABLE 3

Wall Thickness Tolerances

Size of Pipe in.	Wall Thickness Tolerance in.
18	−0.12
20–24	−0.14
27–30	−0.17
33–36	−0.20
39–42	−0.23

3.4.1 *One coupling* of the same size and classification as the pipe shall be furnished with each standard and random length of pipe.

3.4.2 *Rubber rings* shall conform to the requirements of the latest edition of ASTM D1869, "Rubber Rings for Asbestos-Cement Pipe."

Sec. 3.5—Joints

Joints shall be capable of withstanding, without leakage, a hydrostatic pressure test as defined in Section 5.2.2.1.

Sec. 3.6—Wall Thickness

The wall thickness of the machined portion of any length of pipe shall not be less than the manufacturer's standard by the listed tolerance in Table 3.

Section 4—Workmanship and Finish

Sec. 4.1—Imperfections

4.1.1 *Interior surfaces.* The inside surface of each length of pipe shall be free from bulges, dents, and tears that result in a variation in diameter of more than 0.20 in. from the diameter of adjacent unaffected portions of the surface.

4.1.2 *Coupling areas.* The coupling areas of the barrel of each length of pipe shall be free from dents and gouges that could cause leakage from the joint.

4.1.3 *Exterior surfaces.* Flaking on the exterior surface and edge of machined ends shall not extend back by

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more than 0.500 in. from the end, have a depth of more than 0.125 in., and shall not extend around the perimeter for more than 0.500 in. at any one location.

4.1.4 *Straightness.* Each length of pipe shall not vary in straightness by more than 0.05 in./ft of length when the variation is measured as follows:

Measure the maximum ordinate from the exterior surface of the pipe by placing a straightedge that exceeds the pipe length against the exterior surface and measure the maximum distance from the exterior pipe surface to the straightedge.

Section 5—Inspection, Testing, and Rejection

Sec. 5.1—Inspection

5.1.1 *General.* Inspection by the purchaser shall not relieve the manufacturer of the responsibility to furnish material conforming in all respects to the requirements of this standard.

5.1.2 *Notification.* If inspection is specified under Sec. 5.1.4 by the purchaser, the manufacturer shall notify the purchaser, in advance, of the date, time, and place of testing of the pipe, so that the purchaser may be represented at the test.

5.1.3 *Access.* The inspector shall have free access to those parts of the manufacturer's plant that are involved in work performed under this standard. The manufacturer shall afford the inspector, without charge, all reasonable facilities for determining whether the pipe meets the requirements of this standard.

5.1.4 *Testing.* If inspection is specified by the purchaser, the purchaser at his option may witness any or all test phases. The pipe to be tested will have passed the routine inspection and testing of this specification. The number of tests to be conducted for hydrostatic bursting strength (lot test) and, when required, crushing strength shall be limited to one per each 300 standard lengths of each size, type, and classification of pipe on the order. If uncombined calcium hydroxide tests are required, the number of tests will be one for each size, type, and classification of pipe on the order. The purchaser or his authorized inspector may select the pipe to be tested. Retesting and rejection as shown in Sec. 5.3 shall apply.

Sec. 5.2—Physical Test Requirements

5.2.1 *Test specimens.* All pipes and couplings tested under this standard shall be in a normal, air-dried condition when tested.

TABLE 4
Hydrostatic Tests

Classification	Proof Test *psi*	Lot Test *psi*
30	225	300
35	263	350
40	300	400
45	338	450
50	375	500
60	450	600
70	525	700
80	600	800
90	675	900

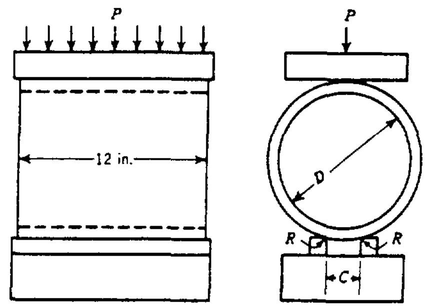

Fig. 1. Crushing Test Assembly

The diagram at the left shows a side view of the test assembly; that at the right, an end view. P *represents load;* R, *approximately 0.5 in.—the radius of the bearings;* D, *the nominal diameter of the pipe; and* C, *the clear space between supports.* C *should be approximately 1 in./ft of internal pipe diameter, but in no case less than 1 in.*

5.2.2 *Hydrostatic tests:*

5.2.2.1 Each standard, random, or short length of pipe and each coupling sleeve shall be tested under an internal hydrostatic pressure as shown for the routine proof test in Table 4. All air shall be expelled and the water pressure shall be increased to the test pressure at a uniform rate of not less than 100 psi/s. The test pressure shall be maintained for at least 5 s. Any pipe length or coupling sleeve that shows leakage, sweating, or other defects shall be rejected.

5.2.2.2 From each lot that has passed the hydrostatic proof test, a 1-ft, or longer length of pipe shall be cut from the unmachined portion of a pipe. The unmachined sample shall withstand the hydrostatic lot test shown in Table 4 when tested in the manner specified in paragraph 5.2.2.1 except that the test pressure need not be held for 5 s. If inspection by the purchaser has been specified, the length of pipe to be tested may be selected by the inspector. Each length of pipe so tested shall be retested in the manner and at the pressure specified in paragraph 5.2.2.1.

5.2.3 *Flexural testing.* No flexural testing is required.

5.2.4 *Crushing tests.* On lots containing more than 100 lengths of each size and classification, one length from each 300 lengths or fraction thereof shall be tested for crushing strength. If inspection by the purchaser has been specified, the length of pipe to be tested may be selected by the inspector. From each selected length, one unmachined length of pipe 1 ft long shall be cut. This section shall be tested by the crushing-test method shown in Fig. 1. After 75 per cent of the specified load has been reached, the loading shall be applied at a uniform rate of approximately 2 000 lb/min. The test section shall not fail until the total load applied meets or exceeds the applicable value shown in Table 2.

5.2.4.1 For this test, the two lower bearings shall consist of two straight strips with vertical sides, each strip having its interior top edge rounded to a radius of approximately 0.5 in. The

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strips shall be of hardwood or metal; if metal, a piece of leather belting 3/16 in. in thickness shall be laid over them. The strips shall be securely fastened to a rigid block, with the interior vertical faces parallel and a distance apart of approximately 1 in./ft of internal pipe diameter, but in no case less than 1 in. The upper bearing shall be a rigid wooden block, straight and true from end to end. The upper and lower bearings shall extend the full length of the test section.

5.2.4.2 For those sizes and classifications where the specified crushing load exceeds 30 000 lb/linear ft, the test length may be less than 1 ft long. In those cases, the test load shall be such as to produce an equivalent specified loading per linear foot.

5.2.5 *Machines for testing.*

5.2.5.1 The machines used for the hydrostatic proof test shall have gaskets that seal the ends of the pipe, couplings, or pipe and coupling with factory-assembled joint, but exert no end pressure. Couplings also may be hydrostatically proof tested with a rubber bladder inside of the coupling and, if so tested, each coupling shall have sufficient strength to withstand a test pressure of ten times the classification of the coupling. The machine used for hydrostatic burst testing or lot test shall have gaskets that seal against the inside of the pipe at or near the ends of the test specimen without materially counteracting the hydrostatic test pressure.

5.2.5.2 The machine used for the crushing test shall be substantial and rigid throughout so that the distribution of the load will not be appreciably affected by the deformation or yielding of any part of the machine.

Sec. 5.3—Retests (Physical) and Rejection

5.3.1 *Crushing strength.* The failure of any specimen tested for crushing strength to support 75 per cent of the crushing load required in Table 2 shall be cause for rejection of the entire lot of that size and classification manufactured during the same shift as the test specimen. If any specimen tested for crushing strength supports more than 75 per cent but less than 100 per cent of the crushing load, two additional pipe sections of the same size and classification, manufactured during the same shift, shall be subjected to the crushing test. The additional lengths may be selected by the inspector, if inspection by the purchaser has been specified. The failure of one of these additional specimens to meet the full crushing strength requirement shall be cause for rejection of the entire lot of that size and classification manufactured during the same shift as the test specimen.

5.3.2 *Hydrostatic tests.* If any pipe subjected to the hydrostatic tests specified in Sec. 5.2.2.2 fails to withstand the pressure specified in Table 4, two additional lengths of the same size and classification, manufactured during the same shift, shall be subjected to the same hydrostatic test. The additional lengths may be selected by the inspector, if inspection by the purchaser has been specified. The failure of one of these additional lengths to withstand the specified pressure shall be cause for rejection of the entire lot of that size and classification manufactured during the same shift as the test lengths.

Sec. 5.4—Test for Uncombined Calcium Hydroxide

The manufacturer shall perform this test as often as necessary to ensure

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compliance with the requirements for uncombined calcium hydroxide in Type II pipe.

5.4.1 *Reagents.*

Phenolphthalein indicator. Dissolve 1.0 g of phenolphthalein in 100.0 ml of absolute ethanol.*

Glycerol-ethanol solvent. Prepare a solution consisting of glycerol and anhydrous or absolute ethanol,* 1:2 by volume. To each litre of this solution, add 2.0 ml phenolphthalein indicator. Adjust the solvent to slightly basic with either dilute NaOH in absolute ethanol* or standard ammonium acetate, depending upon the original pH.

Strontium nitrate [$Sr(NO_3)_2$].

Standard ammonium acetate solution. Dissolve 16.0 g dry crystalline ammonium acetate in 1 l of absolute, or anhydrous, ethanol.*

Standardize the ammonium acetate solution by titrating against pure CaO that has been freshly prepared by calcining pure calcium carbonate or calcium oxalate to constant weight in a platinum crucible at 1650–1830F (900–1 000C).

When the calcined CaO has cooled in a desiccator, perform the following operations in rapid succession. Grind it in an agate mortar. Then weigh out 0.05–0.06 g CaO into a clean, dry 250-ml Erlenmeyer flask and add 60 ml of the glycerol–ethanol solvent and 2.0 g of anhydrous strontium nitrate to the flask. Place a TFE encapsulated magnetic stirring bar into the flask and attach a reflux condenser. Adjust the heating rate and stirring speed to obtain a vigorous boiling and complete agitation. Titrate the hot solution with standardized ammonium acetate solution every 5 min. The endpoint is reached when no further color appears in the solution after 10 min of boiling. Titration is to be carried out only on a hot solution. Good titration procedure is evidenced by a change to pink color upon cooling.

5.4.2 *Procedure.*

Step 1. Brush representative pieces of the pipe free of dust and drill with a clean, sharp 0.25-in. carbide-tipped drill inward from the outer surface at a rate of penetration of approximately 1 ipm until the drill point emerges from the inside wall. Catch the drillings on a clean sheet of glazed paper. Use a soft brush to collect all drillings. Screen through a 20-mesh screen immediately, and place in a weighing bottle.

Step 2. Place the bottle with top removed into a drying oven at 217F (105C) for 2 hr and then cool to room temperature in a desiccator.

Step 3. Weigh out 1 ± 0.010 g of the dried sample to the nearest 0.001 g and place in a clean, dry 250-ml Erlenmeyer flask, to which a TFE-encapsulated stirring bar, 60 ml of the glycerol-ethanol solvent, and 2.0 g $Sr(NO_3)_2$ have been added. Attach the flask to a water-cooled condenser (with a standard 24/40 glass joint) and place on a hot plate with a magnetic stirrer. Boil the solution gently for 30 min, stirring slowly. Then, remove the flask and filter the mixture, under vacuum, through a Buchner funnel. Bring the filtrate to a boil and titrate to a colorless endpoint with the standardized ammonium acetate reagent. Determine the endpoint by comparing with a similar mixture containing no phenolphthalein indicator.

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* Specially denatured alcohol No. 30, 3a, or 2b, of the US Bureau of Internal Revenue, or alcohol consisting of 95 per cent specially denatured alcohol No. 3a plus 5 per cent isopropanol, may be substituted.

5.4.3 *Calculations:*

$$E = \frac{W\text{CaO} \times 1.32}{Va}$$

where

E = the weight in grams of $Ca(OH)_2$ per millilitre of standardized ammonium acetate solution

$W\text{CaO}$ = the weight in grams of CaO in the standardized ammonium acetate solution

Va = the volume in millilitres of standardized ammonium acetate used in titration of the solution.

$$\text{Percentage uncombined } Ca(OH_2) = \frac{EV}{W} \times 100$$

where

V = the volume of standardized ammonium acetate solution required by the sample, in millilitres

W = the weight of the sample in grams.

Sec. 5.5—Test Records

The results of all tests shall be recorded and retained for one year, and shall be available to the purchaser at the place of manufacture.

Section 6–Marking and Delivery

Sec. 6.1—Marking

6.1.1 *Standard and random lengths.* Each standard or random length of pipe shall be clearly marked on the outside surface with the trade name, nominal inside diameter, classification, type, date, and shift of manufacture, and the word "Transmission."

6.1.2 *Short lengths.* Each short length of pipe shall be clearly marked on the outside surface with the nominal inside diameter, the classification, the letter T to indicate that it has been hydrostatically tested, and the word "Transmission."

6.1.3 *Couplings.* All component parts of each coupling shall be clearly marked for use with the pipe for which they are intended. Each coupling shall also be marked with the letter T to indicate that it has been hydrostatically tested.

6.1.4 *Special markings.* If factory inspection is made by the purchaser or his authorized inspector, each pipe and each coupling shall receive an additional special marking of no more than three letters, as specified by the purchaser.

Sec. 6.2—Preparation for Shipment

All pipe and couplings, unless otherwise specified, shall be prepared for standard commercial shipment.

1P—15M—7/77—43402

Designation: C 668 - 76

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Standard Specification for
ASBESTOS-CEMENT TRANSMISSION PIPE[1]

This Standard is issued under the fixed designation C 668; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers asbestos-cement transmission pipe intended for use in transmission systems that carry fluids under pressure. A transmission system consists of pipe lines which convey fluids from their source to a point of distribution or discharge. The system is characterized by relatively steady flow and few appurtenances, thereby permitting reasonable hydraulic analysis, including surge analysis.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units may be approximate.

NOTE 2—This specification is issued for product standardization and purchasing purposes only, and does not include requirements for installation or the relationships between operating conditions and the strength characteristics of the various classifications of pipe. The purchaser is cautioned that he must correlate installation and operating conditions with the specified characteristics of the pipe.

2. Applicable Documents

2.1 *ASTM Standards:*
C 500 Testing Asbestos-Cement Pipe.[2]
D 1869 Specification for Rubber Rings for Asbestos-Cement Pipe.[2]

3. Classification

3.1 Asbestos-cement pipe furnished under this specification shall be manufactured in Classifications 30, 35, 40, 45, 50, 60, 70, 80, and 90. The classifications represent one tenth of the minimum hydrostatic strength.

3.2 The types of pipe shall be known as Type I and Type II corresponding to the chemical requirements in Section 7 of this specification.

NOTE 3—To assist the purchaser in choosing the type of pipe most suitable for his use, guidelines for the definition of aggressiveness of water and of soil environments for selection of the proper type of asbestos-cement pipe are covered in Sections 19 to 25 of Methods C 500.

4. Definitions

4.1 *pipe*—asbestos-cement transmission pipe as defined in Sections 1, 3, and 5.

4.2 *coupling*—a section for joining asbestos-cement pipe that, when properly installed with the proper accessories, develops a joint equivalent in strength and serviceability to the pipe sections.

4.3 *purchaser*—the actual purchaser of the pipe or his authorized agents acting within the scope of the duties entrusted to them.

4.4 *lot*—A lot as used herein for pipe 21 in. in diameter and smaller is defined as each 300 lengths of pipe or less, of identical class and size manufactured on each machine during a 24-h period. A lot as used herein for pipe larger than 21 in. in diameter is defined as each 300 lengths of pipe or less, of identical class and size manufactured on each machine during a period of consecutive working days not exceeding 7 days.

5. Manufacture

5.1 Asbestos-cement pipe furnished under this specification shall be composed of an intimate mixture of portland cement or portland blast-furnace slag cement and asbestos fiber

[1] This specification is under the jurisdiction of ASTM Committee C-17 on Asbestos-Cement Products.
Current edition approved May 28, 1976. Published July 1976. Originally published as C 668 – 70. Last previous edition C 668 – 73b.
[2] *Annual Book of ASTM Standards*, Part 16

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with or without silica; or it shall be composed of portland-pozzolan cement and asbestos fiber. The mixture shall be free of organic additives. The material shall be of laminar construction formed under pressure to a homogeneous structure and cured to meet the physical and chemical requirements of this specification.

6. Rubber Rings

6.1 The rubber rings used to seal the joints of the asbestos-cement pipe shall conform to the requirements of the latest revision of Specification D 1869.

7. Chemical Requirements

7.1 When uncombined calcium hydroxide tests are requested, one sample shall be taken from each lot of pipe and tested in accordance with Sections 17 and 18 of Methods C 500. The sample to be tested may be taken from one of the specimens selected for the crushing test. The amount of uncombined calcium hydroxide shall not exceed 1.0 percent for Type II pipe.

NOTE 4—There are no chemical requirements for Type I pipe.

8. Hydrostatic Strength

8.1 Each standard, random, or short length of pipe (see Section 11) and each coupling sleeve, when manufactured from the same material as the pipe, shall be hydrostatically tested by the manufacturer prior to shipment and shall have sufficient strength to withstand the internal hydrostatic pressure prescribed in Table 1, when tested in accordance with Section 5 of Methods C 500.

8.2 From each lot of pipe which has passed the routine hydrostatic proof test, one length shall be selected by the inspector. A 12-in. (305-mm) or longer section of pipe cut from an unmachined portion of the selected length shall have the minimum hydrostatic strength designated in Table 2, when tested in accordance with Section 5 of Methods C 500, except that the pressure need not be held for 5 s.

9. Flexural Strength

9.1 Each length of pipe in sizes 6 and 8 in. nominal diameter having lengths 10 ft (3.05 m) or longer shall have sufficient flexural strength to withstand without failure the total load prescribed in Table 3 when tested in accordance with Section 8 of Methods C 500.

10. Crushing Strength

10.1 From each lot, one length shall be selected by the inspector. A 1-ft (305-mm) section of pipe cut from an unmachined portion of the selected length shall have the minimum crushing strength prescribed in Table 4 when tested in accordance with Section 11.1.1 of Methods C 500.

11. Dimensions and Permissible Variations

11.1 Couplings and coupling areas of pipe shall be machined or otherwise finished to such dimensions as will provide tight joints when assembled with the proper accessories and put into service for which the pipe is intended.

11.2 Pipe shall be manufactured with nominal inside diameters of 6, 8, 10, 12, 14, 15, 16, 18, 20, 21, 24, 27, 30, 33, 36, 39, and 42 in. in the classifications defined in 3.1, except 6-in. diameter pipe shall be of Classification 40 through 90 only. The average diameters of standard and random lengths may be less than the nominal inside diameter by not more than 5.0 percent, when measured approximately 3 in. (75 mm) from the end.

11.3 The standard length shall be 13 ft ± 1 in. (3.96 m ± 25 mm). Alternative stand lengths shall be 10 ft ± 1 in. (3.05 m ± 25 mm) for 6-in. pipe and 16 ft ± 1 in. (4.88 m ± 25 mm) for 14-in. and larger pipe. At least 85 percent of the total footage of pipe of any one classification, type, and size, excluding short lengths, shall be furnished in standard lengths. The remaining 15 percent may be in random lengths of not less than 7 ft (2.13 m). Short lengths, when specifically ordered, shall not exceed 6¾ ft (2.06 m).

12. Workmanship and Finish

12.1 Machined ends of the pipe that receive the coupling shall be free of dents and gouges that will affect the tightness of the joint.

12.2 Each pipe shall be free of bulges, dents, and tears in the inside surface that result in a variation in diameter of more than

$^{3}/_{16}$ in. (5 mm) from that obtained on adjacent unaffected portions of the surface.

13. Sampling

13.1 All samples shall be in a normal air-dried condition when tests are initiated.

14. Inspection and Rejection

14.1 All material furnished under this specification shall conform to the requirements stated herein and shall be subjected to the factory inspection and tests prescribed in this specification. When requested by the purchaser in his order (see Appendix X1), the manufacturer shall notify the purchaser of the time that the inspection and testing will take place so that the purchaser may arrange for witnessing such tests and inspections at his own expense. Instead of such inspection, when requested, the manufacturer shall be prepared to certify that his product conforms to the requirements of this specification.

14.2 Pipe and couplings shall be inspected by the manufacturer, before shipment, for compliance with the standards for dimensions, and workmanship, and finish (See also Sections 7 to 10).

14.3 Failure of any specimen tested for crushing strength to withstand 75 percent of the load specified in Section 10 shall be cause for rejection of the lot from which the test specimen was taken. When any specimen tested for crushing strength withstands over 75 percent but under 100 percent of the load specified in Section 10, one specimen shall be cut from each of two additional pipes of the same lot. Failure of either of these additional specimens to meet the strength requirements of Section 10 shall be cause for rejection of the entire lot from which the original sample was taken.

14.4 If any pipe subjected to the hydrostatic strength test described in 8.2 fails to withstand the pressure specified, two additional lengths of the same size and classification shall be selected from the pipe manufactured during the same shift and shall be subjected to the specified pressure. The failure of one of these additional lengths to withstand the specified pressure shall be cause for rejection of the entire lot of that size and classification manufactured during the same shift as the test lengths.

14.5 If the results of the uncombined calcium hydroxide test shows that the sample failed to meet the specification requirements, two additional specimens shall be selected and sampled for test. The failure of one of these two additional samples to meet the specification requirements of Section 7 shall be cause for rejection of the lot.

15. Marking and Shipping

15.1 Each standard and random length of pipe shall be marked by the manufacturer with the trade name, nominal size, classification, and date of manufacture. The trade name shall include, but is not limited to, the manufacturer's name or trademark and the words "Transmission Pipe." Each coupling sleeve, if made of the same material as the pipe, shall be marked by the manufacturer with the nominal size, classification, and the letter "T" to indicate that it has been hydrostatically tested.

15.2 Pipe and couplings shall be prepared for commercial shipment so as to ensure acceptance by common or other carriers.

TABLE 1 Applied Hydrostatic Proof Pressures[A]

Pipe Classification	Pressure, min psi (MPa)
30	225 (1.55)
35	262 (1.81)
40	300 (2.07)
45	337 (2.32)
50	375 (2.58)
60	450 (3.10)
70	525 (3.62)
80	600 (4.13)
90	675 (4.65)

[A] The pressures and classifications indicated apply to all sizes.

TABLE 2 Minimum Hydrostatic Strength[A]

Pipe Classification	Pressure, psi (MPa)
30	300 (2.07)
35	350 (2.41)
40	400 (2.76)
45	450 (3.10)
50	500 (3.44)
60	600 (4.13)
70	700 (4.82)
80	800 (5.51)
90	900 (6.20)

[A] The pressures and classifications indicated apply to all sizes.

TABLE 3 Minimum Applied Flexural Proof Loads, lbf (kN)

Nominal Size, in	Pipe Classification								
	30	35	40	45	50	60	70	80	90
6			2300 (10.23)	2500 (11.12)	2800 (12.45)	3200 (14.23)	3700 (16.46)	4000 (17.79)	4900 (21.80)
8	3700 (16.46)	4400 (19.57)	5100 (22.68)	5700 (25.35)	6400 (28.47)	6900 (30.69)	7600 (33.80)	8800 (39.14)	10100 (44.92)

TABLE 4 Minimum Crushing Strength, lbf/linear ft

Nominal Size, in.	Pipe Classification								
	30	35	40	45	50	60	70	80	90
6			2400	3200	4000	4700	5400	6700	9000
8	2000	2400	2800	3400	4000	4800	5500	7400	9300
10	2000	2500	3000	3500	4500	5500	7000	9000	11000
12	2000	2500	3000	4000	5200	6400	7800	10000	12200
14	2000	2500	3000	4000	5200	7000	8800	11000	13500
15	2300	2800	3300	4300	5500	7400	9300	12000	14500
16	2500	3000	3500	4500	5800	7500	9500	12400	15400
18	2500	3000	4000	5000	6500	8500	11000	14000	18000
20	2500	3500	4500	5500	7100	9500	12000	15000	20000
21	2500	3500	4500	5800	7300	9700	12500	16000	21000
24	2800	3800	5000	6200	8100	11000	15000	19000	24000
27	3500	4200	5500	7000	8800	12500	16500	20500	27000
30	3500	4500	6000	7500	9700	13500	18000	22500	30000
33	3500	5000	6500	8000	10500	14500	19500	24500	33000
36	4000	5000	7000	9000	11200	16000	21000	26000	36000
39	4200	5300	7500	9700	12000	17200	22500	28000	39000
42	4300	5700	8000	10500	13000	18500	24000	30000	42000

TABLE 4A Minimum Crushing Strength, N/linear m

Nominal Size, in.	Pipe Classification								
	30	35	40	45	50	60	70	80	90
6	...	...	35.0	46.7	58.4	68.6	78.8	97.8	131.3
8	29.2	35.0	40.9	49.6	58.4	70.1	80.3	108.0	135.7
10	29.2	36.5	43.8	51.1	65.7	80.3	102.2	131.3	160.5
12	29.2	36.5	43.8	58.4	75.9	93.4	113.8	145.9	178.0
14	29.2	36.5	43.8	58.4	75.9	102.2	128.4	160.5	197.0
15	33.6	40.9	48.2	62.8	80.3	108.0	135.7	175.1	211.6
16	36.5	43.8	51.1	65.7	84.7	109.5	138.6	181.0	224.7
18	36.5	43.8	58.4	73.0	94.9	124.0	160.5	204.3	262.7
20	36.5	51.1	65.7	80.3	103.6	138.6	175.1	218.9	291.9
21	36.5	51.1	65.7	84.6	106.5	141.6	182.4	233.5	306.5
24	40.9	55.5	73.0	90.5	118.2	160.5	218.9	277.3	350.3
27	51.1	61.3	80.3	102.2	128.4	182.4	240.8	299.2	394.0
30	51.1	65.7	87.6	109.5	141.6	197.0	262.7	328.4	437.8
33	51.1	73.0	94.9	116.8	153.2	211.6	284.6	357.6	481.6
36	58.4	73.0	102.2	131.3	163.5	233.5	306.5	379.4	525.4
39	61.3	77.3	109.5	141.6	175.1	251.0	328.4	408.6	569.2
42	62.8	83.2	116.8	153.2	189.7	270.0	350.3	437.8	612.9

APPENDIX

X1. ADDITIONAL PURCHASE ORDER OPTIONS

X1.1 It is suggested to the purchaser, without being made a part of this specification, that the purchaser may request inclusion of the following information in his order or agreement for purchase of the pipe:

X1.1.1 Any tests, in addition to those prescribed by this specification, as the special circumstances may require.

X1.1.2 The place or places where any additional tests are to be made.

X1.1.3 Description of the additional testing facilities.

X1.1.4 Who shall bear the expense of such additional tests.

X1.1.5 Whether such additional tests may be made by any sound sampling process or other method approved by the parties, and

X1.1.6 Such other matters as the parties may find desirable to include in their written agreement.

American Water Works Association

ANSI/AWWA C403-78
(First Edition)

AWWA STANDARD PRACTICE

for

THE SELECTION OF ASBESTOS-CEMENT TRANSMISSION AND FEEDER MAIN PIPE, SIZES 18 IN. THROUGH 42 IN.

AMERICAN NATIONAL STANDARD

Approved by AWWA Board of Directors Jan. 28, 1978.
Approved by American National Standards Institute, Inc., Jul. 17, 1978.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

CTD029723

Committee Personnel

The Standards Committee on Asbestos-Cement Pressure Pipe that reviewed and approved this standard had the following personnel at the time of approval:

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J. L. WARDEN, *Vice-Chairman*
T. R. GILLEN, *Secretary*

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Table of Contents

Foreword

This foreword is for information only and is not a part of AWWA C403

I. History of Standard

A new pipe material consisting of an intimate mixture of portland cement and asbestos fibers was introduced to the North American market in 1931 following several years of usage in other countries, particularly Italy.

In the ensuing years, this type of pipe gained popularity, and in 1949 AWWA established a committee on standard specifications for asbestos-cement pipe under the chairmanship of S. M. Clark of Greeley and Hanson, Chicago.

The committee developed a standard for asbestos-cement water pipe which was approved by the AWWA Board of Directors as tentative, AWWA C400-53T, May 15, 1953. In 1958, the committee was reactivated as Committee 8340D on Asbestos-Cement Pipe under the chairmanship of Roy H. Ritter, Whitman, Requardt and Assocs., Baltimore, to review several suggested changes and to recommend revisions to the standard. The committee produced a revised tentative standard adopted as AWWA C400-64T, Jan. 27, 1964. It was advanced to standard without revision Jul. 2, 1965 and designated as AWWA C400-65.

The committee concluded that an installation guide was desirable to bring to the attention of users certain important requirements on the inspection, handling, installation, and field testing of asbestos-cement pressure pipe. The committee submitted its final draft in 1963, and it received approval as tentative, AWWA C603-64T, Jan. 27, 1964. It was advanced to standard without revision Aug. 9, 1965 and designated as AWWA C603-65.

In early 1968, the committee was reactivated as the Standards Committee on Asbestos-Cement Pipe to review and revise all AWWA standards on asbestos-cement pipe. The committee produced a revised standard approved by the AWWA Board of Directors Jan. 31, 1972, designated as AWWA C400-72, "Standard for Asbestos-Cement Pressure Pipe for Water and Other Liquids."

AWWA C401-64, "Standard Practice for the Selection of Asbestos-Cement Water Pipe" (originally designated Handbook H2), was first approved by the AWWA Board of Directors Jan. 27, 1964. Although it covered pipe sizes up to and including 36 in., it was primarily intended for use with asbestos-cement pipe in smaller distribution sizes (4 through 16 in.).

In the winter of 1972-1973 the committee was reorganized and enlarged to include representatives of national organizations having an interest in the scope of the committee and wishing to participate in the work. The reorganized committee reaffirmed AWWA C400-72 without revision so that it could be presented to the American National Standards Institute for designation as an American National Standard.

In 1975 the committee produced a revised standard that was approved by the AWWA Board of Directors Jan. 26, 1975, and designated AWWA

C400-75, "Standard for Asbestos-Cement Pressure Pipe, 4 in. Through 24 in., for Water and Other Liquids."

The asbestos-cement pipe manufacturers have developed a new series of large pipe classifications, designed to give greater freedom of selection to design engineers. This is of particular significance for large diameter pipeline projects where the savings in material cost can exceed the increased cost of more detailed design, better control of methods of installation, and provision of surge controls when justified.

To provide the user with a ready reference and specification for this type of pipe, known as transmission pipe, the committee produced and the AWWA Board of Directors approved AWWA C402-75, "Standard for Asbestos-Cement Transmission Pipe, 18 in. Through 42 in., for Water and Other Liquids."

The possibility of confusion between the two 1975 standards, AWWA C400 and C402, was carefully reviewed by the committee. The results were AWWA C402-77, which covers sizes 18 through 42 in., and AWWA C400-77, which covers sizes 4 through 16 in. There is now no overlap of sizes.

Consequently, it was desirable to revise AWWA C401-64 so that it would be directly compatible with AWWA C400-77, and to develop a new pipe selection standard to be directly compatible with AWWA C402-77. AWWA C401-77 and this new standard, AWWA C403, "Standard Practice for the Selection of Asbestos-Cement Transmission and Feeder Main Pipe, Sizes 18 in. Through 42 in.," are the result.

II. Discussion

The effect of water hammer generated by the opening and closing of fire hydrants can be of significant magnitude in small distribution pipe sizes, due to the high velocities generated by open hydrant flow conditions. Furthermore, it is difficult to accurately evaluate the magnitude of these surges; and, if calculated, control through the use of surge tanks or other devices is impractical. Rather than employ a rule-of-thumb allowance for surge based upon an assumed velocity change, to compensate for undetermined surge pressures AWWA C400-77 (covering sizes 4 through 16 in.) incorporates a large fixed safety factor for each asbestos-cement pressure class.

In large transmission and feeder main pipe sizes the effect of surge pressures generated by the opening and closing of fire hydrants connected to smaller diameter distribution pipelines is of significantly lower magnitude. For example, the surge pressure generated by hard closure of a hydrant connected to a 6-in. distribution line would be nine times greater than that which would occur in an 18-in. feeder main supplying a 6-in. distribution line.

Major surge pressures in large transmission or feeder main pipelines, caused by stopping and starting pumps and similar components, are more readily calculated. It also is more economically practical to control these surges by incorporating into the system design a variety of devices which will reduce anticipated surge pressures to lower levels. This standard is based on individually evaluating all stress loadings placed on a pipe and on applying adequate safety factors commensurate with a complete review of all design criteria.

American Water Works Association

ANSI/AWWA C403-78
(First Edition)

AWWA Standard Practice for

The Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 in. Through 42 in.

Section 1—General

Sec. 1.1 Scope

This standard has been prepared so that design engineers may quickly determine the correct strength classification of asbestos–cement transmission pipe to use under various combinations of internal pressure (static, operating, and surge) and external load (earth and superimposed live loads). Combined loading curves depicting the relationship between hydrostatic loading and external loading capabilities are included to expedite the selection of the correct pipe strength classification.

NOTE: Information to assist the engineer in selecting the most economical size of pipe is in the appendices. Appendix A contains a friction loss of head chart based on the Hazen and Williams formula. Appendix B is a detailed analysis of surge pressure factors. Appendix C includes tables to assist the engineer in determining the yearly power costs to overcome friction loss of head. The appendices are for information only and are not part of AWWA C403.

1.1.1 *Pipe classifications*. The pipe strength classifications of 30, 35, 40, 45, 50, 60, 70, 80, and 90 refer to the similarly numbered classifications specified in AWWA C402, "Standard for Asbestos–Cement Transmission Pipe, 18 In. Through 42 In., for Water and Other Liquids."

1.1.2 *Installation*. Detailed coverage of the installation of asbestos–cement pipe can be found in AWWA C603, "Standard for the Installation of Asbestos–Cement Pressure Pipe."

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Section 2—General Design

Sec. 2.1 Strength and Design Factors

The strength of asbestos-cement transmission pipe must be sufficient to withstand the combined forces of all types of internal pressures (static, operating, and surge) and external loadings (earth, live, and impact). Sound engineering practice also requires that adequate safety factors be applied to strength requirements to ensure performance under other than ideal or calculated loading conditions. The magnitude of these safety factors is inversely proportional to the confifidence that the designer has in engineering estimates of actual operating conditions. Suggested safety factors based on experience are included under specific design factor subheadings.

2.1.1 *Bedding conditions.* The bedding conditions described in Fig. 1 have been selected as representative of typical installation conditions encountered in the field.

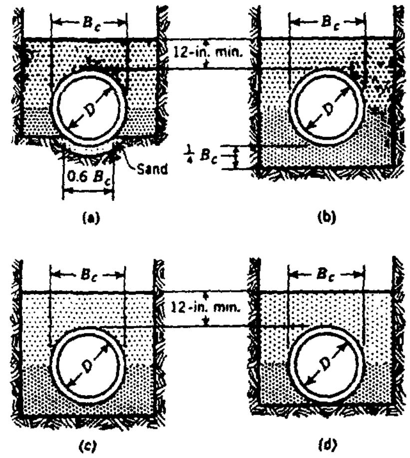

Fig. 1. Bedding Conditions

Class A bedding conditions are shown in (a) and (b). Class C conditions are shown in (c) and (d). In all four diagrams, the lightly shaded area represents approved backfill, not frozen and free from lumps, large stones, boulders, or other unsuitable substances. The heavily shaded areas represent approved backfill, carefully compacted in 4-in. layers.

In (a), a minimum of 2 in. of sand is placed in a shaped bottom under the pipe. In (b), the pipe is bedded in a gravel base. In (c), the pipe barrel rests on earth mounds and then the backfill between the earth mounds is compacted. In (d), the pipe barrel is resting on the flat bottom of the trench. Class B condition is the same as Class A, and Class D is the same as Class C except that the backfill is not compacted in B or D.

Descriptions of bedding conditions are as follows:

Class A—Gravel or sand base, backfill compacted. (Approximately 80% Standard Proctor, AASHTO T-99.)

Class B—Same as A, but backfill not compacted.

Class C—Pipe laid on earth mounds or pipe barrel on flat trench bottom with excavated coupling holes, backfill compacted. (Approximately 90% Standard Proctor, AASHTO T-9.)

Class D—Pipe barrel on flat trench bottom with excavated coupling holes, backfill not compacted.

Sec. 2.2 Combined Loading Theory

Tests of asbestos-cement pipe under various combinations of internal pressure and external crush load applied in three-edge bearing (see Sec. 2.3) indicate that there is a relationship between the combined loads at the point of pipe fracture. This relationship can be represented by a parabolic curve as shown in Fig. 2. The equation for the load pressure parabolic curve, which is known as the Schlick formula, may be expressed as:

$$w_T = W\sqrt{\frac{P - p_T}{P}} \qquad \text{Eq 1}$$

in which,

P is the internal pressure, in pounds

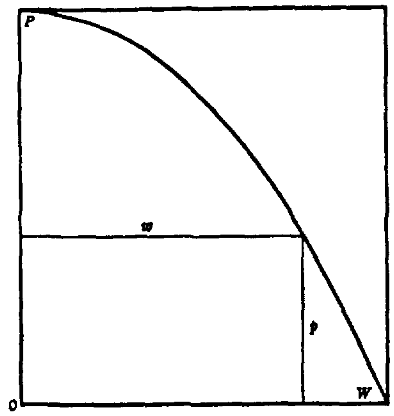

Fig. 2. Load Pressure Curve

P *represents the internal pressure;* W *the external load.*

per square inch, that will burst the pipe when no external load exists.

W is the external load, in pounds per lineal foot of pipe in the three-edge bearing test, that will crush the pipe when no internal pressure exists.

p_T is the internal pressure, in pounds per square inch which, in combination with some external load w_T applied in three-edge bearing, will fracture the pipe.

w_T is the external load, in pounds per lineal foot of pipe applied in three-edge bearing which, in combination with some internal pressure p_T, will fracture the pipe.

Sec. 2.3 Three-Edge Bearing Load

The combined loading curve shown in Fig. 2 is calculated on the basis of crush strengths determined by laboratory tests employing the three-edge bearing test method, which utilizes hardwood test blocks (Fig. 3). Because the field supporting strength of a pipe is influenced by the bedding conditions and by the lateral pressure acting against the sides of the pipe,

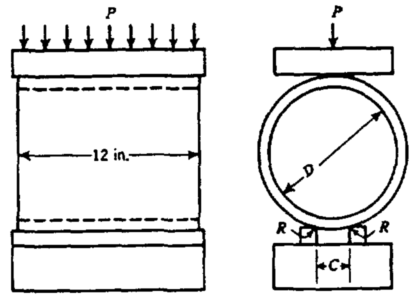

Fig. 3. Crushing Test Assembly

The diagram at the left shows a side view of the test assembly; that at the right, an end view. P *represents load;* R, *approximately 0.5 in.—the radius of the bearings;* D, *the nominal diameter of the pipe; and* C, *the clear space between supports.* C *should be approximately 1 in./ft of internal pipe diameter but in no case less than 1 in.*

it is necessary to apply a bedding load factor to the laboratory three-edge bearing loads to correlate them to the actual field loads. Since the external load equals the bedding factor times the three-edge bearing load, the bedding factor equals the external load divided by the three-edge bearing load. Table 1 shows bedding factors to be applied for each of the bedding conditions described in Fig. 1.

TABLE 1

Correlation of Bedding Conditions, Pipe Size, and Bedding Load Factors

Bedding Class	Pipe Size *in.*	Bedding Load Factor
A	18–20 24–42	1.8 2.0
B	18–42	1.5
C	18–20 24–42	1.4 1.5
D	18–42	1.1

Section 3—External Loads

Sec. 3.1 Introduction

For the design of asbestos-cement transmission pipe external loads (w_T) are defined by the following equation:

$$w_T = \frac{w_E + w_S}{B.F.}(S.F.) \qquad \text{Eq 2}$$

in which,

w_T = the total external load in pounds per linear foot of pipe applied in three-edge bearing that, in combination with some internal pressure, p_T, will fracture the pipe.

w_E = the total earth load in pounds per linear foot of pipe to which the pipe is subjected. The magnitude of this load is a direct function of the burial conditions encountered or specified (trench, embankment, tunnel, etc.).

w_S = the total superimposed load, in pounds per linear foot of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads. These loads can be static, dynamic, or a combination of both.

$B.F.$ = the bedding load factor, which is a load factor correlating three-edge bearing test loads to field loads associated with specific bedding conditions. (For a more explicit explanation see Sec. 2.3.)

$S.F.$ = the design safety factor specified by the design engineer. Safety factors are based on judgment, past experience, and sound engineering principles. For asbestos-cement transmission pipe, a design minimum safety factor of 1.5 is recommended for external loads.

Sec. 3.2 Earth Loads

Earth loads (w_E) to which pipe is subjected are a function of the soil density, pipe diameter, depth of cover, and construction techniques employed in laying the pipeline. They depend on the interplay between the weight of the prism of earth directly over the pipe, called the interior prism, and the frictional shearing forces, plus or minus, transferred to that interior prism by the adjacent outside prisms of earth. The magnitude of earth loads varies with the construction technique employed. There are two major construction techniques normally encountered: trench and embankment. Another technique, the tunnel condition, is not normally found, but nevertheless has unique design methods which make its inclusion in this discussion necessary. Fig. 4 shows these three construction techniques.

3.2.1 *Marston's equation.* For asbestos-cement transmission pipe design, earth loads are calculated by the general form of Marston's equation:

$$w_E = C w_e B^2 \qquad \text{Eq 3}$$

in which,

w_E = the total earth load transmitted to the pipe in pounds per linear foot of pipe.

w_e = the soil density in pounds per cubic foot. Soil densities range in value from 100 to 135 lb/cu ft. In the absence of accurate soil density information, a value of 120 lb/cu ft is recommended for asbestos-cement transmission pipe design.

B = the trench width or pipe diameter measured in feet. The value chosen depends on the installation conditions employed in laying the pipe.

C = a coefficient that is dependent upon

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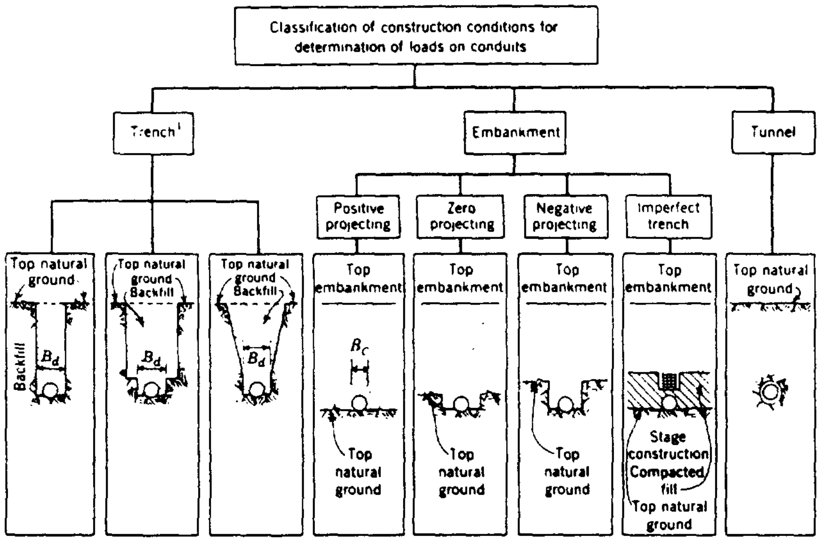

[1] B_d within required limit, otherwise conduit is positive projecting

Fig. 4. Classification of Construction Techniques

Reprinted by permission from WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers," WPCF and ASCE, 1966.

1. Ratio of the height of fill to the width of trench or pipe diameter.
2. Shearing forces between the interior and adjacent earth prisms.
3. Direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions.

The calculations used to find the value of the coefficient will depend on the installation conditions employed in laying the pipe.

Values for *B* and *C* must be determined to calculate earth loads by Eq. 3 for the trench, embankment, and tunnel construction techniques. The following subsections describe the different conditions and explain the methods for finding the values needed to use Marston's equation for soil loading.

3.2.2 *Trench condition.* A trench condition is defined as that in which the pipe is installed in a narrow trench, generally less than two to three diameters in width, cut in undisturbed ground and backfilled to the original ground surface, as illustrated in Fig. 4. For this condition, Eq 3 is rewritten as:

$$w_E = C_d w_e B_d^2 \qquad \text{Eq 4}$$

in which,

B_d = the trench width in feet, measured at the top of the pipe.

C_d = the load coefficient which is a function of the ratio H/B_d, where H is the height of the backfill in feet, measured to the top of the pipe, and B_d is the trench width as previously defined.

3.2.2.1 The values of C_d are obtained from Fig. 5, in which curves A, B, C, D, and E take into account the

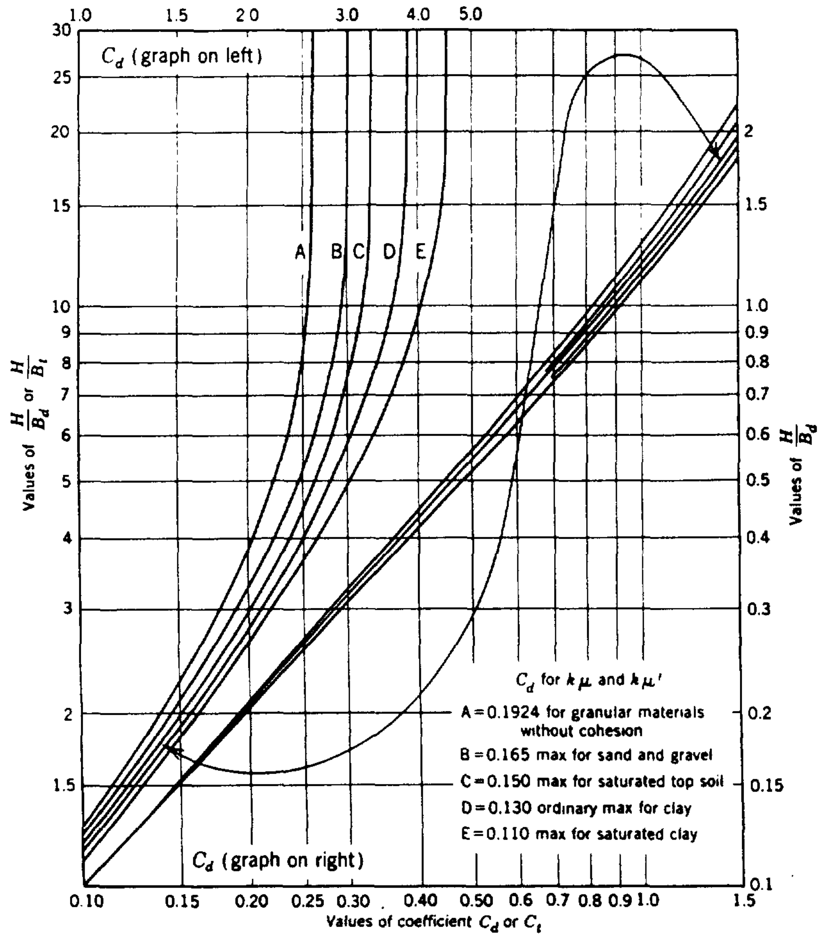

Fig. 5. Values of C_d for Trench Conditions

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friction coefficient between the backfill and the sides of the trench for the various soil compositions likely to be encountered. Curve *A* is for granular materials without cohesions. Curve *B* is for sand and gravel. Curve *C* is for saturated top soil. Curve *D* is for clay. Curve *E* is for saturated clay. Table 2 contains a series of earth load selection tables and is included as a convenience.

3.2.3 *Embankment condition.* An embankment condition is defined as either that condition where the pipe is installed in a trench that is wider than two to three pipe diameters and that is cut in undisturbed ground, or that condition where the pipe is

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TABLE 2

Earth Loads (lb/lineal ft)

NOTE: Values are for clay (part D of Fig. 9, $K\mu = K\mu' = 0.130$) with weight of earth taken as 120 lb/cu ft. Correction for other earth weights may be made by simple direct proportions. For corrections for other types of soils, refer to formulas in Sec. 3. **Boldface figures indicate maximum earth load for depth of trench.**

Pipe size 18 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	2.5	2.75	3.0	3.25	3.5	4.0	4.5	5.0	5.5	
2	**490**									2 ft 5 in.
2.5	640	**640**								2 ft 8 in.
3	810	835								2 ft 10 in.
4	1 000	1 110	**1 240**							3 ft 1 in.
5	1 200	1 320	1 450	**1 610**	**1 640**					3 ft 5 in.
6	1 350	1 520	1 700	1 865	2 050					3 ft 8 in.
7	1 500	1 690	1 900	2 090	2 300					3 ft 10 in.
8	1 600	1 850	2 100	2 320	2 525	**2 825**				4 ft 0 in.
9	1 725	2 000	2 250	2 510	2 750	3 230				4 ft 1 in.
10	1 850	2 120	2 400	2 725	2 950	3 550	**3 635**			4 ft 3 in.
12	2 050	2 360	2 675	3 020	3 300	4 000	4 440			4 ft 5 in.
14	2 200	2 570	2 900	3 280	3 600	4 400	5 220			4 ft 7 in.
16	2 300	2 720	3 100	3 515	3 900	4 800	5 640	**6 040**		4 ft 9 in.
18	2 400	2 840	3 275	3 720	4 150	5 100	6 040	6 830		5 ft 0 in.
20	2 500	3 000	3 400	3 995	4 350	5 350	6 400	7 450	**7 620**	5 ft 2 in.

Pipe size 20 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	
2	**545**									2 ft 8 in.
2.5	705									2 ft 10 in.
3	870	**890**								3 ft 0 in.
4	1 110	1 250	**1 330**							3 ft 4 in.
5	1 320	1 450	1 610	**1 750**	**1 770**					3 ft 8 in.
6	1 520	1 700	1 865	2 050	2 210	**2 220**				3 ft 11 in.
7	1 690	1 900	2 090	2 300	2 515	2 655				4 ft 1 in.
8	1 850	2 100	2 320	2 525	2 765	3 000	**3 095**			4 ft 3 in.
9	2 000	2 250	2 510	2 750	3 040	3 300	3 545			4 ft 5 in.
10	2 120	2 400	2 725	2 950	3 240	3 650	3 980			4 ft 6 in.
12	2 380	2 675	3 020	3 300	3 660	4 000	4 660	**4 310**		4 ft 10 in.
14	2 570	2 900	3 280	3 600	4 050	4 400	5 200	5 760		5 ft 1 in.
16	2 720	3 100	3 515	3 900	4 350	4 800	5 640	6 450	**6 640**	5 ft 2 in.
18	2 840	3 275	3 720	4 150	4 620	5 100	6 040	7 060	7 500	5 ft 4 in.
20	3 000	3 400	3 995	4 350	4 860	5 350	6 400	7 450	8 410	5 ft 7 in.

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TABLE 2—*Continued*

Pipe size 21 in. ID

Trench Cover ft	Trench Width—ft										Transition Width
	2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	
2	570										2 ft 9 in.
2.5	745	730									2 ft 11 in.
3	870	915									3 ft 2 in.
4	1 110	1 250	1 330	1 380							3 ft 6 in.
5	1 320	1 450	1 610	1 750	1 360						3 ft 10 in.
6	1 520	1 700	1 865	2 050	2 210	2 325					4 ft 1 in.
7	1 690	1 900	2 090	2 300	2 515	2 700	2 795				4 ft 4 in.
8	1 850	2 100	2 320	2 525	2 765	3 000	3 250				4 ft 6 in.
9	2 000	2 250	2 510	2 750	3 040	3 300	3 725				4 ft 7 in.
10	2 120	2 400	2 725	2 950	3 240	3 550	4 140	4 210			4 ft 9 in.
12	2 360	2 675	3 020	3 300	3 660	4 000	4 660	5 160			5 ft 0 in.
14	2 570	2 900	3 280	3 600	4 050	4 400	5 200	6 000	6 100		5 ft 3 in.
16	2 720	3 100	3 515	3 900	4 350	4 800	5 540	6 450	7 020		5 ft 5 in.
18	2 340	3 275	3 720	4 150	4 620	5 100	6 040	7 050	7 950		5 ft 6 in.
20	3 000	3 400	3 995	4 350	4 880	5 350	6 400	7 450	8 460	8 920	5 ft 8 in.

Pipe size 24 in. ID

Trench Cover ft	Trench Width—ft										Transition Width
	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	
2	630										3 ft 1 in.
2.5	805	810									3 ft 3 in.
3	955	1 010	1 010								3 ft 5 in.
4	1 250	1 330	1 400	1 490							3 ft 9 in.
5	1 450	1 610	1 750	1 940	2 030						4 ft 1 in.
6	1 700	1 865	2 050	2 210	2 400	2 550					4 ft 5 in.
7	1 900	2 090	2 300	2 515	2 700	3 080					4 ft 8 in.
8	2 100	2 320	2 525	2 765	3 000	3 480	3 620				4 ft 10 in.
9	2 250	2 510	2 750	3 040	3 300	3 790	4 130				5 ft 0 in.
10	2 400	2 725	2 950	3 240	3 550	4 140	4 660	4 660			5 ft 2 in.
12	2 675	3 020	3 300	3 660	4 000	4 660	5 400	5 740			5 ft 5 in.
14	2 900	3 280	3 600	4 050	4 400	5 200	6 000	6 750	6 800		5 ft 8 in.
16	3 100	3 515	3 900	4 350	4 800	5 640	6 450	7 410	7 850		5 ft 11 in.
18	3 275	3 720	4 150	4 620	5 100	6 040	7 050	8 000	8 910		6 ft 1 in.
20	3 400	3 995	4 350	4 860	5 350	6 400	7 450	8 460	9 600	10 000	6 ft 2 in.

TABLE 2—*Continued*

Pipe size 27 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
2	710										3 ft 5 in.
2.5	895	905									3 ft 6 in.
3	1 040	1 095									3 ft 8 in.
4	1 330	1 400	1 540	1 600							4 ft 1 in.
5	1 610	1 750	1 940	2 050	2 200						4 ft 6 in.
6	1 865	2 050	2 210	2 400	2 735						4 ft 8 in.
7	2 090	2 300	2 515	2 700	3 110	3 385					5 ft 1 in.
8	2 320	2 525	2 765	3 000	3 480	3 900	3 980				5 ft 3 in.
9	2 510	2 750	3 040	3 300	3 790	4 300	4 590				5 ft 6 in.
10	2 725	2 950	3 240	3 550	4 140	4 700	5 190				5 ft 7 in.
12	3 020	3 300	3 660	4 000	4 660	5 400	6 060	6 390			6 ft 0 in.
14	3 280	3 600	4 050	4 400	5 200	6 000	6 750	7 550	7 560		6 ft 3 in.
16	3 515	3 900	4 350	4 800	5 840	6 450	7 410	8 300	8 800		6 ft 6 in.
18	3 720	4 150	4 620	5 100	6 040	7 050	8 000	9 000	9 960	10 000	6 ft 8 in.
20	3 995	4 350	4 860	5 350	6 400	7 450	8 460	9 600	10 890	11 180	6 ft 10 in.

Pipe size 30 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	
2	755									3 ft 7 in.
2.5	965									3 ft 10 in.
3	1 150	1 185								3 ft 11 in.
4	1 400	1 675	1 680							4 ft 5 in.
5	1 750	2 050	2 335	2 340						4 ft 8 in.
6	2 050	2 400	2 800	3 005						5 ft 0 in.
7	2 300	2 700	3 110	3 500	3 665					5 ft 5 in.
8	2 525	3 000	3 480	3 900	4 320					5 ft 7 in
9	2 750	3 300	3 790	4 300	4 840	4 980				5 ft 10 in.
10	2 950	3 550	4 140	4 700	5 260	5 660				6 ft 1 in.
12	3 300	4 000	4 660	5 400	6 060	6 800	6 990			6 ft 5 in.
14	3 600	4 400	5 200	6 000	6 750	7 550	8 320	8 320		6 ft 9 in.
16	3 900	4 800	5 640	6 450	7 410	8 300	9 210	9 610		7 ft 0 in.
18	4 150	5 100	6 040	7 050	8 000	9 000	9 960	10 980	10 980	7 ft 3 in.
20	4 350	5 350	6 400	7 450	8 460	9 600	10 890	11 890	12 300	7 ft 5 in.

TABLE 2—*Continued*

Pipe size 33 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	3 75	4 0	4 5	5 0	5.5	6.0	6.5	7.0	7.5	8.0	
2	810										3 ft 10 in.
2.5	1 050	1 060									4 ft 1 in.
3	1 220	1 290									4 ft 3 in.
4	1 540	1 675	1 815								4 ft 6 in.
5	1 940	2 050	2 335	2 445							5 ft 1 in.
6	2 210	2 400	2 800	3 050	3 205						5 ft 5 in.
7	2 515	3 000	3 110	3 500	3 920	3 925					5 ft 8 in.
8	2 705	3 300	3 480	3 900	4 460	4 640					6 ft 1 in.
9	3 040	3 550	3 790	4 300	4 840	5 400	5 610				6 ft 3 in.
10	3 240	4 000	4 140	4 700	5 260	5 000	6 070				6 ft 5 in.
12	3 660	4 400	4 660	5 400	6 060	6 800	7 450	7 550			6 ft 10 in.
14	4 050	4 800	5 200	6 000	6 750	7 550	8 350	9 030			7 ft 2 in.
16	4 350	5 100	5 640	6 450	7 410	8 300	9 210	10 110	10 470		7 ft 5 in.
18	4 620	5 350	6 040	7 050	8 000	9 000	9 960	11 060	12 120		7 ft 9 in.
20	4 860	5 575	6 400	7 450	8 460	9 600	10 890	11 890	13 020	13 390	7 ft 11 in.

Pipe size 36 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	
2	920	925									4 ft 3 in.
2 5	1 130	1 145									4 ft 4 in.
3	1 325	1 550									4 ft 7 in.
4	1 675	1 950	1 950								4 ft 11 in.
5	2 050	2 335	2 555	2 555							5 ft 3 in.
6	2 400	2 800	3 050	3 340	3 340						5 ft 8 in.
7	2 700	3 110	3 500	3 920	4 160						6 ft 0 in.
8	3 000	3 480	3 900	4 460	4 900	4 950					6 ft 2 in.
9	3 300	3 790	4 300	4 840	5 400	5 760	5 760				6 ft 8 in.
10	3 550	4 140	4 700	5 260	5 900	6 430	6 540				6 ft 10 in.
12	4 000	4 660	5 400	6 060	6 800	7 450	8 150	8 150			7 ft 4 in.
14	4 400	5 200	6 000	6 750	7 550	8 350	9 170	9 750	9 750		7 ft 8 in.
16	4 800	5 640	6 450	7 410	8 300	9 210	10 110	11 000	11 330		7 ft 11 in.
18	5 100	6 040	7 050	8 000	9 000	9 960	11 060	12 150	12 900	12 900	8 ft 2 in.
20	5 350	6 400	7 450	8 460	9 600	10 890	11 890	13 020	14 140	14 510	8 ft 6 in.

TABLE 2—*Continued*

Pipe size 39 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	
2	990										4 ft 5 in.
2.5	1 290										4 ft 7 in.
3	1 520	1 580									4 ft 9 in.
4	1 950	2 220	2 340								5 ft 2 in.
5	2 335	2 555	2 980								5 ft 6 in.
6	2 800	3 050	3 340	3 680							5 ft 10 in.
7	3 110	3 500	3 920	4 320	4 500						6 ft 3 in.
8	3 480	3 900	4 460	4 900	5 360						6 ft 7 in.
9	3 790	4 300	4 840	5 400	5 760	6 430					6 ft 11 in.
10	4 140	4 700	5 260	5 900	6 430	7 170	7 440				7 ft 3 in.
12	4 660	5 400	6 060	6 800	7 450	8 150	8 980	9 310			7 ft 8 in.
14	5 200	6 000	6 750	7 550	8 350	9 170	9 750	11 090			8 ft 1 in.
16	5 640	6 450	7 410	8 300	9 210	10 110	11 000	11 980	12 830		8 ft 5 in.
18	6 040	7 050	8 000	9 000	9 960	11 060	12 150	12 900	14 330		8 ft 8 in.
20	6 400	7 450	8 460	9 600	10 890	11 890	13 021	14 140	15 260	16 130	8 ft 11 in.

Pipe size 42 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	
2	1 060										4 ft 8 in
2.5	1 390										4 ft 10 in.
3	1 700										5 ft 0 in.
4	2 220	2 350									5 ft 4 in.
5	2 555	3 080									5 ft 8 in.
6	3 050	3 340	3 930								6 ft 1 in.
7	3 500	3 920	4 320	4 690							6 ft 5 in.
8	3 900	4 460	4 900	5 600							6 ft 10 in.
9	4 300	4 840	5 400	5 760	6 630						7 ft 2 in.
10	4 700	5 260	5 900	6 430	7 170	7 730					7 ft 6 in.
12	5 400	6 060	6 800	7 450	8 150	8 980	9 830				8 ft 0 in.
14	6 000	6 750	7 550	8 350	9 170	9 750	10 940	11 550			8 ft 5 in.
16	6 450	7 410	8 300	9 210	10 110	11 000	11 980	13 580			8 ft 10 in.
18	7 050	8 000	9 000	9 960	11 060	12 150	12 900	14 390	15 250		9 ft 1 in.
20	7 450	8 460	9 600	10 880	11 890	13 020	14 140	15 260	16 430	16 830	9 ft 4 in.

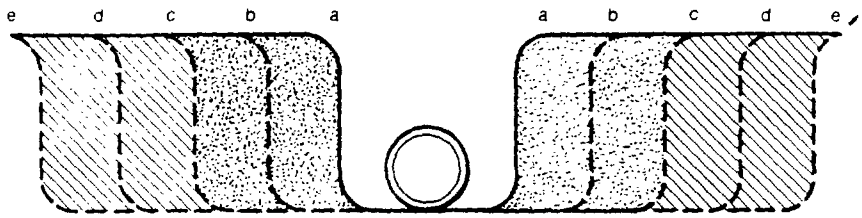

Fig. 6. Embankment Conditions

aa *and* bb *The trench width is less than the transition width; earth loads are computed by the trench equation (Eq 4).*
cc *The trench width is the transition width; earth loads are computed by either Eq 4 or Eq 5.*
dd *and* ee *The trench width is greater than the transition width; earth loads are computed by the positive projecting pipe embankment equation (Eq. 5). For a given depth of cover the earth loads resulting from trench widths* cc, dd, *and* ee *are equal.*

covered with fill above the original ground surface. Embankment conditions are further subdivided into positive and negative projecting pipe categories, depending on the location of the top of the pipe relative to the original undisturbed ground. A special case where compressible material is used as part of the backfill, called an imperfect trench, also is classified as an embankment condition. The various embankment conditions are illustrated in Fig. 6.

3.2.4 *Positive projecting pipe embankment condition.* A positive projecting pipe condition is defined as either that condition where the pipe is installed in a trench cut in undisturbed ground that is wider than two to three pipe diameters, or that condition where the top of the pipe is above the adjacent original ground surface and covered with fill above the original ground surface. For this condition, Eq 3 is rewritten as:

$$w_E = C_c w_e B_c^2 \qquad \text{Eq 5}$$

in which,

B_c = the pipe outside diameter in feet.

C_c = the load coefficient, which is a function of the ratio H/B_c, the projection ratio p, and the settlement ratio r_{sd}.

3.2.4.1 The values of C_c are obtained from Fig. 7. C_c also may be obtained from Eq 6 when the following conditions exist simultaneously:

1. The ratio H/B_c is greater than 1.3.
2. The product $p(r_{sd}) = 0.7$.

$$C_c = 1.892H/B_c - 0.96 \qquad \text{Eq 6}$$

3.2.4.2 The projection ratio p is defined as the ratio of the distance that the top of the pipe projects above the original ground surface to the pipe outside diameter. The recommended value for the settlement ratio r_{sd} is +0.7 for asbestos-cement transmission pipe design.

3.2.5 *Transition width.* It will be noted from the preceding discussion that under construction conditions where a trench is cut in undisturbed ground two methods of computing the earth load are available: (1) the trench condition, and (2) the positive projecting pipe embankment condition. The method chosen is de-

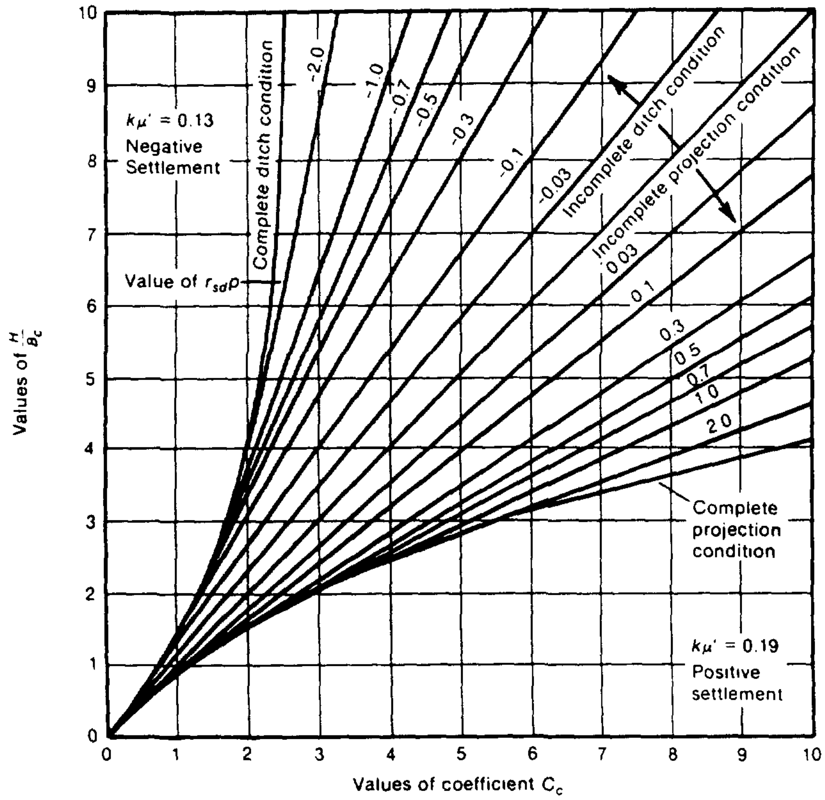

Fig. 7. Values of C_c for Positive Projecting Pipe

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pendent on the ratio of the trench width to the pipe diameter. As previously stated, when the trench width is less than two to three times the pipe diameter, earth loads are computed by the trench condition equation (Eq 4). The width of trench at which both methods of computation give equal loads is called the *transition width*. The earth load computed at the transition width is theoretically the maximum external earth load that can be transmitted to the pipe for any given depth of cover. For all trench widths greater than the transition width, earth loads are computed by the positive projecting pipe embankment condition equation (Eq 5). In this latter case and for a given depth of cover, the earth loads are equal to the load that results at the transition width and that is computed by the trench condition equation (Eq 4). [See Fig. 6.]

3.2.5.1 The transition width is determined from Fig. 8 by multiplying

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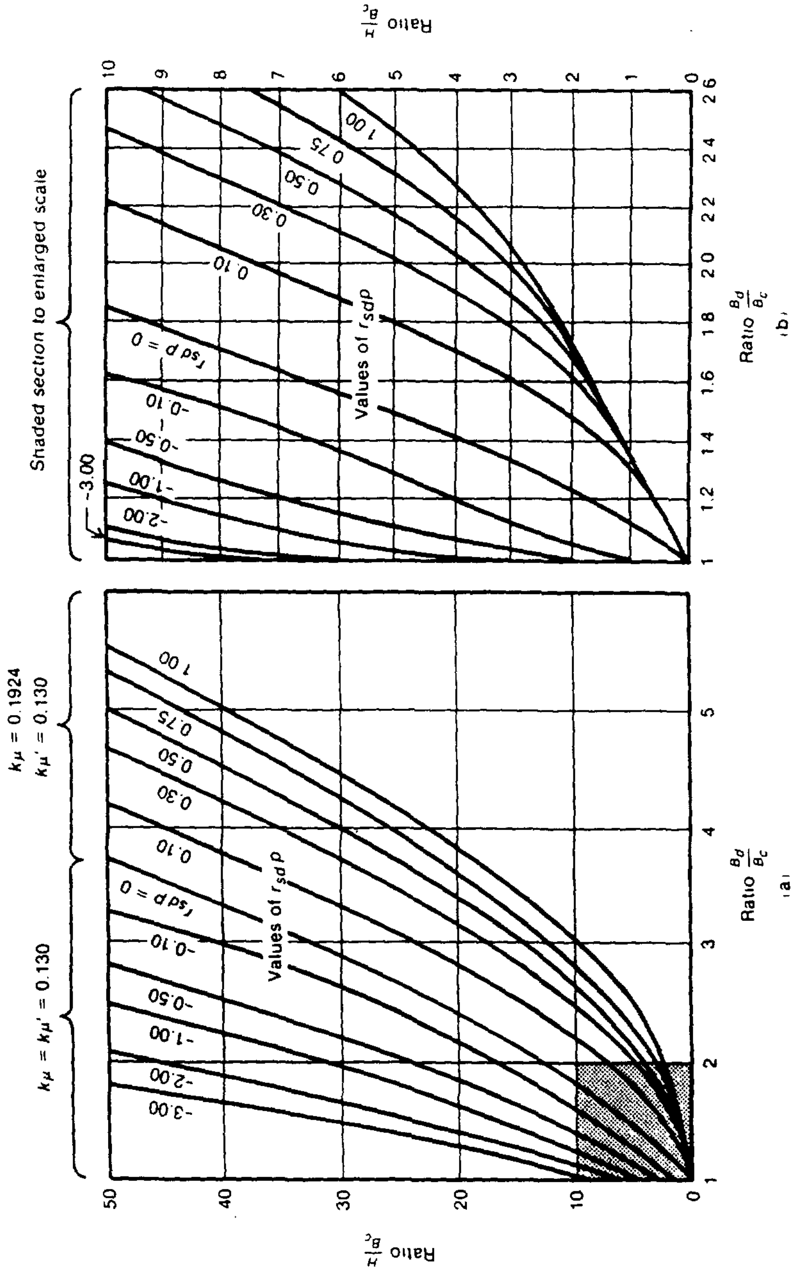

Fig. 8. Values of B_d/B_c at Which the Trench and Positive Projecting Pipe Equations Give Equal Loads

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the applicable ratio B_d/B_c by the applicable pipe outside diameter (B_c). The applicable ratio of trench width to pipe outside diameter (B_d/B_c) can be obtained from Fig. 8 for any given ratio of backfill height to pipe outside diameter (H/B_c).

3.2.6 *Negative projecting pipe embankment condition.* A negative projecting pipe condition is defined as that condition where the pipe is installed in a relatively shallow trench wherein the top of the pipe is at some elevation below the original ground surface. The trench is then backfilled and compacted, and embankment is constructed thereon to finished grade (Fig. 4). For this condition, Eq 3 is rewritten as

$$w_E = C_n w_e B_d^2 \qquad \text{Eq 7}$$

in which,

B_d = the trench width in feet, measured at the top of the pipe.

C_n = the load coefficient which is a function of the ratio H/B_d, the projection ratio p, and the settlement ratio r_{sd}.

3.2.6.1 The various values of C_n are obtained from Fig. 9. The projection ratio p is defined as the ratio of the vertical distance from the original ground surface down to the pipe top to the trench width, B_d. (See Fig. 10.) For asbestos-cement transmission pipe design the recommended value for the settlement ratio r_{sd} is zero.

3.2.6.2 When calculating earth loads under negative projecting pipe embankment conditions, consideration must be given to the transition width as defined in paragraph 3.2.5. For values of the ratio B_d/B_c less than those given in Fig. 8, the load on a pipe is determined from Eq 7 for negative projecting pipes. However, as the trench width increases and the ratio B_d/B_c becomes greater than that given in Fig. 8, the earth load should be determined from Eq 5 for positive projecting pipes. Adherence to the preceding rule will result in the most realistic earth loads for design purposes.

3.2.7 *Imperfect trench embankment condition.* The imperfect trench embankment condition occurs rather infrequently and is included for general information. The imperfect trench embankment condition refers to that construction technique wherein the pipe is first installed as a positive projecting pipe. A portion of the embankment is then built up to some elevation above the pipe top and thoroughly compacted as it is placed. A trench the same width as the pipe is then excavated directly over the pipe down to or near to its top and subsequently backfilled with loose compressible material. The remainder of the embankment is then built up to final elevation (Fig. 11). For this condition, Eq 3 is rewritten as

$$w_E = C_n w_e B_c^2 \qquad \text{Eq 8}$$

in which,

B_c = the pipe outside diameter in feet.

C_n = the load coefficient which is a function of the ratio H/B_c, the projection ratio p, and the settlement ratio r_{sd}.

3.2.7.1 The various values of C_n are obtained from Fig. 9. The projection ratio p is defined as the ratio of the vertical distance from the top of the excavated trench down to the pipe top to the pipe diameter (Fig. 11). For asbestos-cement transmission pipe design the recommended

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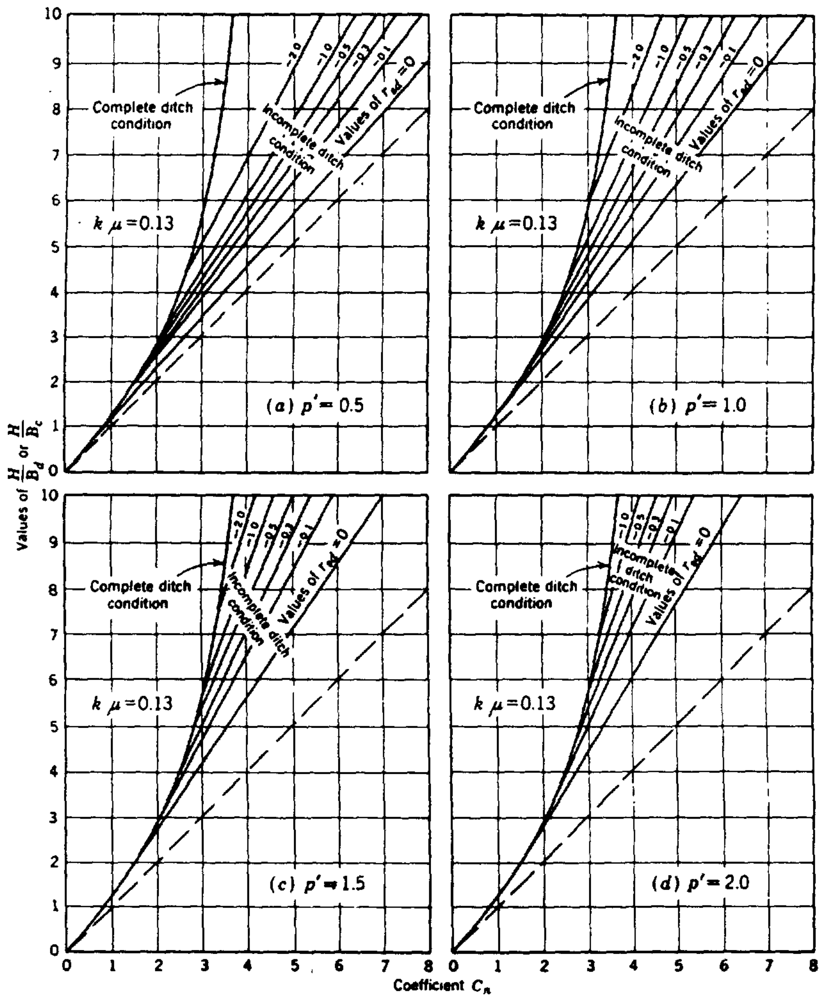

Fig. 9. Values of C_n for Negative Projecting Pipe and Imperfect Ditch Conditions

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value for the settlement ratio r_{sd} is equal to -0.3.

3.2.8 *Tunnel conditions.* There are two types of tunnel construction encountered in normal pipe laying operation.

3.2.8.1. The first type is the most frequently encountered and occurs when a sleeve of a larger diameter than the specified pipe is first jacked through an embankment. The pipe is then placed into the sleeve without

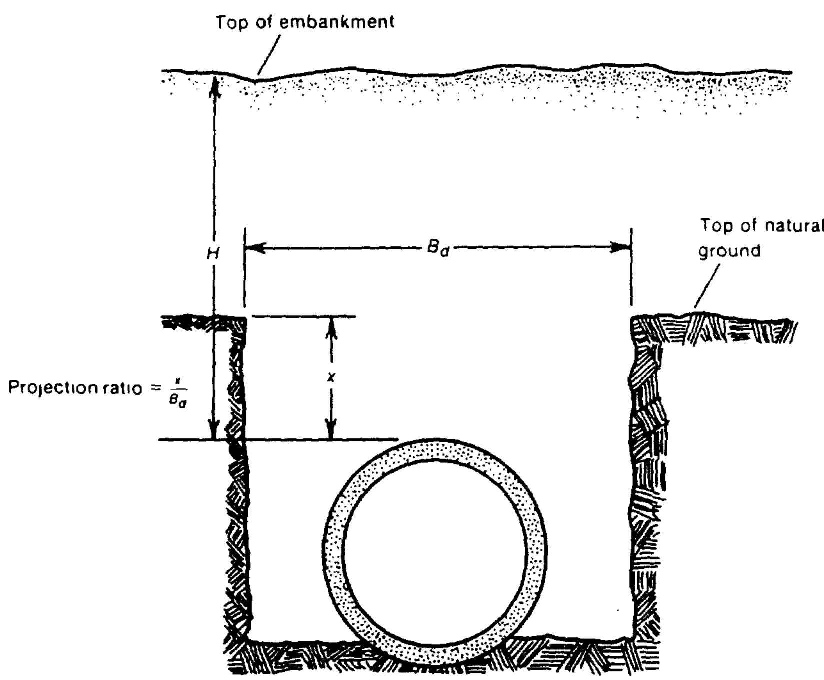

Fig. 10. Projection Ratio p for the Negative Projecting Pipe Embankment Condition

becoming an integral part of the tunnel construction. In this example the sleeve supports the entire earth load and the pipe contained therein is not subjected to crushing loads. When selecting the required pipe classification for this condition, only the internal pressure needs to be considered for design.

3.2.8.2. The second type of tunnel condition is rarely encountered in transmission work but is discussed here for completeness. It occurs when the pipe itself must carry the entire load. The area through which the pipeline must pass is bored and braced with the necessary supports. The pipe then is placed in the tunnel and the void between the pipe and tunnel braces is backfilled with compacted earth, grout, or concrete. Once this operation is completed, the earth load automatically transfers from the tunnel supports to the pipe itself. For this condition, Eq 3 is rewritten as

$$w_E = C_T B_T (w_e B_T - 2c) \qquad \text{Eq 9}$$

in which,

B_T = the maximum width of the tunnel excavation in feet.

c = the coefficient of cohesion in pounds per square foot.

C_T = the load coefficient which is a function of the coefficient of internal fraction for the material of the tunnel and of the ratio H/B_T, where H is the distance from the ground surface to the top of the tunnel in feet and B_T equals the width of the tunnel excavation in feet.

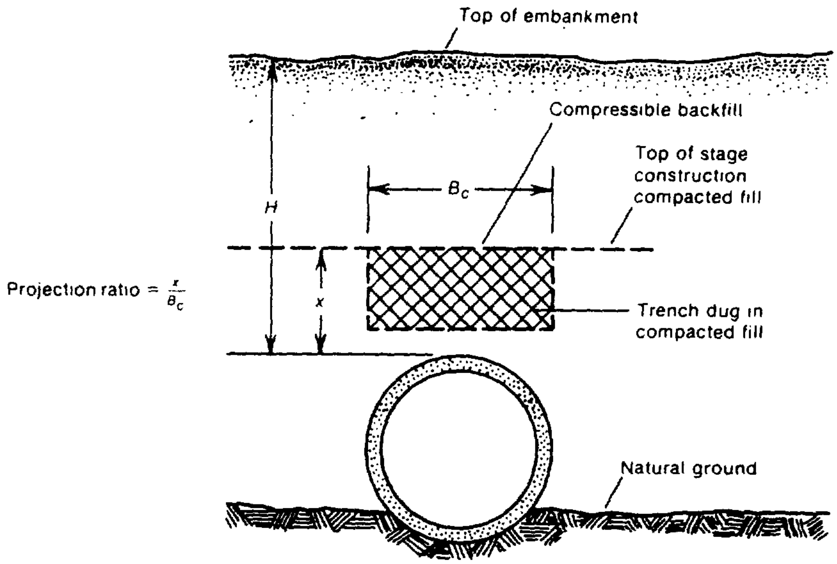

Fig. 11. Projection Ratio *p* for the Imperfect Trench Embankment Condition

3.2.8.3 Values of C_T for different types of soil are obtained from Fig. 12. If the value for the coefficient of cohesion is not available from laboratory tests, then the recommended safe design values in Table 3 are to be used.

TABLE 3

Recommended Safe Design Values of c for Tunnel Conditions

Material	Values of *c*
Clay, very soft	40
Clay, medium	250
Clay, hard	1000
Sand, loose dry	0
Sand, silty	100
Sand, dense	300
Top soil, saturated	100

3.2.8.4 When, in tunnel construction, the excavation becomes excessive, or when the void surrounding the pipe or tunnel lining is not carefully filled, or when the cohesion of the undisturbed material above the tunnel construction is destroyed by soil saturation or vibration, the earth load should be calculated by Eq 4 for trench conditions. Since it can be exceedingly difficult to either predict or assess whether the tunnel excavation is excessive, it is recommended that Eq 4 be used for most installations for safe asbestos–cement transmission pipe design.

3.2.8.5 It should be noted that the preceding discussion is based on the premise that the tunnel would be constructed in homogenenous soils that do not create unusual pressures and stresses. If the tunnel is constructed through materials that tend to squeeze or swell, such as some types of clay or shale, or through blocky and seamy rock, then methods other than tunnel construction must

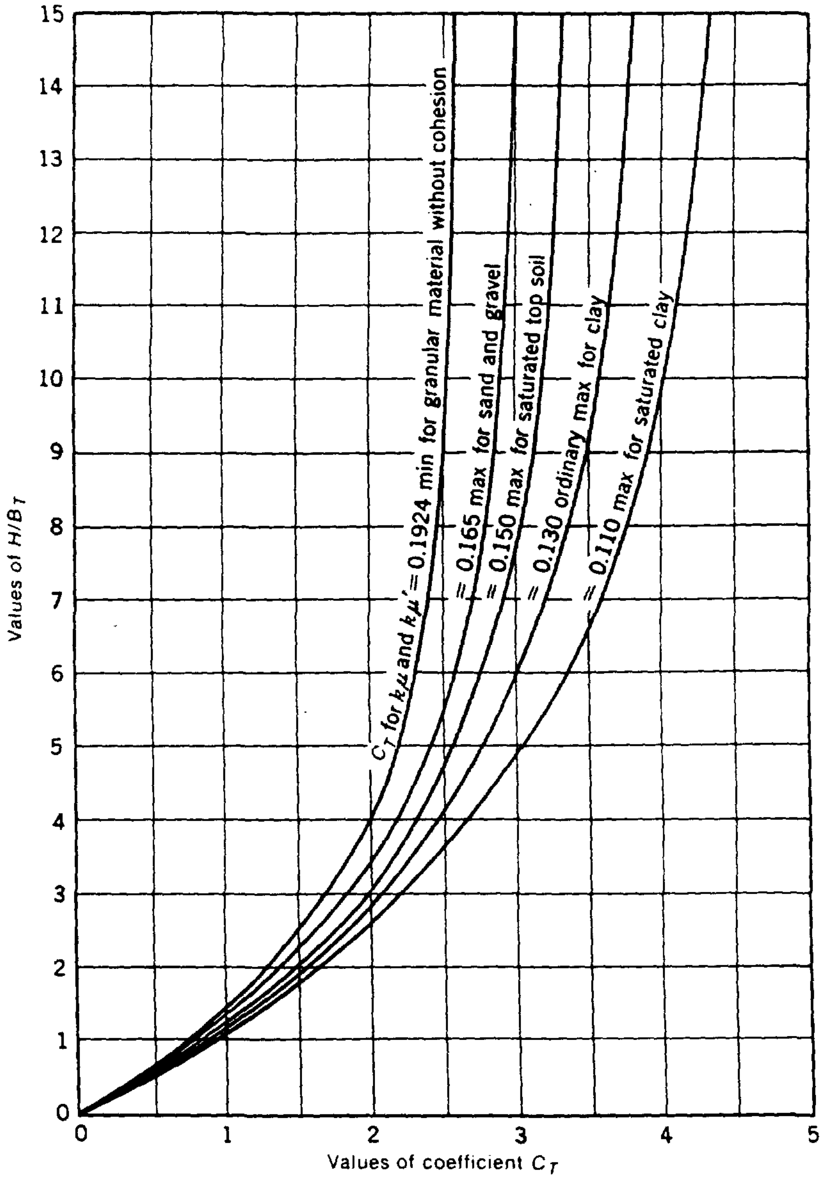

Fig. 12. Values of C_T for Tunnel Conditions

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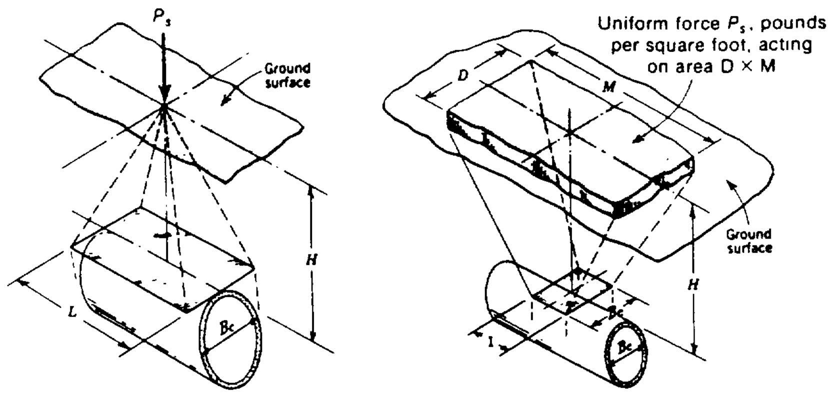

Concentrated superimposed load, w_{s1}, vertically centered over pipe.

Distributed superimposed load, w_{s2}, vertically centered over pipe.

Fig. 13. Superimposed Loads

be utilized. The method of installation that is used is the responsibility of the engineer who is in charge of construction.

Sec. 3.3 Superimposed Loads

Superimposed loads w_S are external loads other than the normal earth loads transmitted to the pipe. There are two types of superimposed loads as illustrated in Fig. 13: (1) concentrated w_{S1}, and (2) distributed w_{S2}. Superimposed loads are frequently referred to as live loads.

3.3.1 *Concentrated loads.* A concentrated load is a load caused by a single force which may be either static or dynamic in nature. In normal pipe design, vehicular wheel loads are the most frequently encountered concentrated loads. The magnitude of the load produced by concentrated superimposed forces is determined by

$$w_{S1} = \frac{C_s P_s F}{L} \qquad \text{Eq 10}$$

in which

w_{S1} = the load on a pipe caused by a concentrated superimposed force in pounds per linear foot of pipe. (For convenience, concentrated superimposed loads resulting from a 16,000-lb wheel force are presented in Table 6.)

P_s = the concentrated force in pounds. The American Association of State Highway and Transportation Officials (AASHTO) design manual gives loads for various sizes and types of vehicles.

F = the impact factor. American Association of State Highway and Transportation Officials (AASHTO) vehicular wheel loads are shown in Table 4. Impact factors vary from one locale to another and values that are consistent with local, state, and federal specifications should be chosen.

L = the effective pipe length in feet. For pipe less than three feet, the actual length of the section should be used. For all other pipe lengths an effective length of three feet should be used.

TABLE 4

Impact Factors

Depth of Cover *ft*	Impact Factor *F*
1.0–2.0	1.2
2.0—3.0	1.1
3.0 or greater	1.0

C_s = the load coefficient, which is a function of the depth of cover to the top of the pipe and the nominal inside diameter of the pipe. Values of C_s are obtained from Table 5.

3.3.2 *Distributed load.* A distributed load is a load caused by a uniform force distributed equally over a given area. The load may be either static or dynamic in nature. The magnitude of the load produced by distributed forces is determined by

$$w_{S2} = C_s P_s F B_c \qquad \text{Eq 11}$$

in which,

w_{S2} = the load on a pipe caused by distributed superimposed force in pounds per linear foot of pipe.

P_s = the intensity of the distributed force in pounds per square foot.

F = the impact factor as explained in paragraph 3.3.1.

B_c = the pipe diameter in feet.

C_s = the load coefficient, which is a function of the depth of cover to the top of the pipe and the nominal inside diameter of the pipe. Values of C_s are obtained from Table 5.

3.3.3. *Illustrative problem.* An 18-in. asbestos-cement transmission pipe is to be installed in a 3-ft wide trench under 8 ft of cover. The backfill is ordinary clay with a weight of 120 lb/cu ft. Determine the earth load on the pipe.

SOLUTION: The load must be computed two ways using the Marston equations for the trench condition and for the projecting pipe condition.

a. Trench condition Eq 4:

$$w_E = C_d w_e (B_d)^2$$

$$\frac{H}{B_d} = \frac{8}{3} = 2.7 \quad \text{(approximately 3)}$$

$$C_d = 1.9 \quad \left(\text{from Fig. 5 and } \frac{H}{B_d}\right)$$

$$w_E = (1.9)(120)(3)^2 = 2100 \text{ lb/ft}$$

TABLE 5

Values of Load Coefficients C_s for Concentrated and Distributed Superimposed Loads Centered Vertically Over Conduit

Pipe size, ID—*in.*	Depth of Cover *ft*										
	2	2½	3	4	5	6	8	10	12	16	20
18	0.391	0.289	0.221	0.136	0.092	0.066	0.038	0.025	0.017	0.010	0.006
20	0.422	0.316	0.241	0.150	0.102	0.073	0.042	0.027	0.019	0.011	0.007
21	0.436	0.327	0.251	0.157	0.107	0.077	0.044	0.029	0.020	0.012	0.007
24	0.478	0.362	0.280	0.177	0.120	0.087	0.050	0.033	0.022	0.013	0.008
27	0.510	0.392	0.306	0.195	0.133	0.096	0.056	0.037	0.025	0.014	0.008
30	0.543	0.423	0.332	0.213	0.147	0.106	0.062	0.041	0.029	0.016	0.010
33	0.563	0.446	0.353	0.230	0.159	0.115	0.067	0.045	0.032	0.018	0.011
36	0.590	0.470	0.375	0.248	0.171	0.124	0.073	0.049	0.035	0.020	0.012
39	0.615	0.502	0.404	0.272	0.191	0.140	0.083	0.054	0.041	0.026	0.015
42	0.619	0.516	0.422	0.286	0.202	0.147	0.089	0.063	0.043	0.030	0.017

NOTE: For convenience, concentrated superimposed loads resulting from a 16,000-lb wheel force are presented in Table 6.

TABLE 6

W 31

Concentrated Superimposed (Wheel) Load on Asbestos-Cement Transmission Pipe
Single Wheel = 16,000 lb (H-20 Wheel Load)

Cover Over Top of Pipe *ft*	Pipe Diameter *in.*									
	18	20	21	24	27	30	33	36	39	42
2	2083*	2251	2364	2545	2720	2896	2992	3149	3280	3301
2½	1541	1682	1728	1939	2091	2256	2368	2510	2677	2752
3	1178	1286	1334	1494	1632	1723	1878	2000	2154	2250
4	725	800	837	944	1040	1136	1224	1321	1450	1525
5	490	544	570	640	710	784	845	912	1018	1077
6	352	389	410	464	512	566	611	662	747	784
8	203	224	234	267	299	330	357	390	443	475
10	133	144	154	176	197	219	240	261	288	336
12	91	100	105	117	133	155	170	187	219	229
16	53	59	64	69	75	85	96	107	139	160
20	32	37	40	43	45	53	60	63	80	91

* Values shown are in pounds per linear foot of pipe.
NOTE: Table is based on impact factor of one. If different impact is to be used, simply multiply value from table times desired impact factor.

b. Projecting pipe condition Eq 5:

$w_E = C_c w_e (B_c)^2$
$B_c = 18$ in. pipe $OD = 1.7$ ft
$C_c = 1.892(H/B_c) - 0.96$
$= 1.892(8/1.7) - 0.96 = 8$
$w_E = (8)(120)(1.7)^2 = 2800$ lb/ft

c. The engineer, knowing the job conditions and degree of inspection, should decide which load applies.

Section 4—Hydrostatic Pressure

Sec. 4.1 Introduction

For the design of asbestos-cement transmission pipe, the internal hydrostatic pressure p_T is defined by

$$p_T = (P_o + P_s)S.F. \qquad \text{Eq 12}$$

in which,

p_T = the total internal pressure in pounds per square inch which, in combination with some external load w_T applied in three-edge bearing, will fracture the pipe.

P_o = the static or operating pressure in pounds per square inch defined by the design criteria.

P_s = the surge pressure in pounds per square inch resulting from either water hammer or other incremental pressures over and above the normal operating pressure.

$S.F.$ = the design safety factor specified by the purchaser. Safety factors are based on judgment, past experiences, and sound engineering principles. For asbestos-cement transmission pipe design, a minimum safety factor of 2.0 is recommended.

For simplicity in design and selection of asbestos-cement transmission pipe, the internal pressure may be separated into two components: (1) operating pressure, and (2) water hammer or surge pressure. Each will be determined separately.

Sec. 4.2 Operating Pressure

The operating pressure P_o is that pressure which exists under normal or steady conditions of operation. The pressure may be induced by pumps, gravity (such as the head created by a reservoir or elevated water tank), or a combination of both pumps and gravity. Under a 100 percent gravity situation, the pressure in the line at a given point is somewhat higher when there is no flow and conditions are static. Under static conditions the pressure at a given point, measured in feet of head, is equal to the difference between the elevation of that point and the water surface level at the reservoir. Under flowing conditions the pressure at a given point is reduced by the amount of friction and other energy losses resulting from the flow of water from the reservoir to that point. The magnitude of this head loss may be found by using the Hazen and Williams chart in Appendix A. In piping systems that have long runs with relatively few fittings and accessories, the recommended value of C (coefficient of flow) is 140.

Sec. 4.3 Surge Pressure

Surge pressures P_s are of a transient nature and are caused by unsteady or changing conditions in the pipeline. The terms "water hammer," "surge," or "transient pressure" are often used interchangeably to refer to these pressures, which are of brief duration but often of considerable magnitude. A variety of conditions may cause surge pressures. These include a valve opening or closing, sudden movement of air in a line, or a pump starting or stopping. Transient pressures are often a controlling factor in the selection of pipe strength. For this reason, a pipe system should always be analyzed for surge pressure determinations and the results should be used in pipe selection.

4.3.1. *Surge control.* There are numerous methods for control of surge pressures in the line. Consideration should be given to use of these methods to limit pressures to an acceptable level. Economics plays a major role in this area. Various designs may have to be balanced, depending on the complexity of the system, to yield an economical and efficient design.

4.3.1.1 Appendix B presents a discussion of water hammer with emphasis on how it may be analyzed and controlled. Although the subject is discussed in some detail, and an illustrative problem is included that involves controlling surge pressure by timing a valve closure, the subject is too complex to be thoroughly covered in this standard. It is suggested that control of surge for any transmission system be discussed with surge control equipment manufacturers or consultants in this particular field. The effects of surge in a pipeline, however, should not be ignored, as neglect of this factor may result in severe damage to the system. Also, because of the number of variables involved in creating water hammer pressures, and because of the ability to regulate their magnitude with proper controls, it is not recommended that fixed water hammer allowances based on assumed velocity changes or some other single criterion be used for the larger diameter transmission and feeder main lines.

Section 5—Pipe Selection

Sec. 5.1 Combined Loading Curves

As discussed previously, it has been demonstrated satisfactorily by tests that asbestos-cement transmission pipe conforms generally to the Schlick formula for combined loading (Sec. 2.2). Numerous tests have established values for P, internal hydrostatic design pressure with no crush load applied, and for W, external crush design load with no internal pressure applied, for all diameters and strength classifications. These values represent the end points on the combined loading curves; the intermediate points on the curves are computed by use of the Schlick formula. (It should be noted that all values used for P and W represent a conservative interpretation of the test data.) On the curves, each intermediate point—w_T, p_T—represents a combination of crush loading and internal pressure that the pipe will withstand when the loads are applied simultaneously.

5.1.1 *Selection curves.* Selection curves in Fig. 14a–14j are presented for each size of pipe from 18 through 42 in. On the graph for each pipe diameter, a combined loading curve is drawn for each strength classification of that pipe size. The vertical axis represents the internal hydrostatic design pressure P, and the horizontal axis represents the external three-edge bearing crush design load W. Table 7 lists the values of P and W for the strength classifications of each pipe size. In Sec. 5.3, Use of Selection Charts for Economical Design, the method for pipe selection is outlined.

Sec. 5.2 Safety Factors

Safety factors are normally applied by the engineer to his computed design values of crush- and internal pressure that are to be resisted by the pipe in service. These factors protect against unforeseen loads that may be placed on the line at some time in the future, and against other contingencies such as improper construction. It is the engineer's prerogative to select which safety factors he feels should apply to a given system. Considerable field experience as well as extensive laboratory work has yielded a wealth of information on the behavior of asbestos-cement transmission pipe. For this reason, suggestions for minimum safety factors are made in Table 8. Note that, since the combined loading principle is applicable, the safety factors will be applied to both hydro and crush simultaneously. Note also that water hammer and live load, which are both transient load conditions, are considered as acting simultaneously for design purposes here. Since the likelihood of both occurring at the same time is minimal, an additional conservative element is introduced into the design.

Sec. 5.3 Use of Selection Charts for Economical Design

After all loads on the pipe have been computed (operating pressure, water

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TABLE 7

Design Internal Pressure and Design External Load† Intercepts for Use With Selection Curves for the Following Pipe Classifications*

Pipe Size in.	30	35	40	45	50	60	70	80	90
	P* = 300	P = 350	P = 400	P = 450	P = 500	P = 600	P = 700	P = 800	P = 900
	W†	W	W	W	W	W	W	W	W
18	2 500	3 000	4 000	5 000	6 500	8 500	11 000	14 000	18 000
20	2 500	3 500	4 500	5 500	7 100	9 500	12 000	15 000	20 000
21	2 500	3 500	4 500	5 800	7 300	9 700	12 500	16 000	21 000
24	2 800	3 800	5 000	6 200	8 100	11 000	15 000	19 000	24 000
27	3 500	4 200	5 500	7 000	8 800	12 500	16 500	20 500	27 000
30	3 500	4 500	6 000	7 500	9 700	13 500	18 000	22 500	30 000
33	3 500	5 000	6 500	8 000	10 500	14 500	19 500	24 500	33 000
36	4 000	5 000	7 000	9 000	11 200	16 000	21 000	26 000	36 000
39	4 200	5 300	7 500	9 700	12 000	17 200	22 500	28 000	39 000
42	4 300	5 700	8 000	10 500	13 000	18 500	24 000	30 000	42 000

* *P*—*psi.*
† *W*—*lb/lin ft.*

hammer, earth load, and live load), the most economical strength of pipe to meet the service conditions should be selected. The applicable selection procedure using the suggested safety factors is:

1. Add operating pressure and water hammer, $P_o + P_s$ (Sec. 4).
2. Add earth load and live load, $w_E + w_S$ (Sec. 3).
3. Enter the combined loading graph for the appropriate pipe diameter. Plot the values from Steps 1 and 2 above as one point. When using the left-hand scales, be sure to multiply the ***operating pressure plus water hammer*** by the suggested safety factor of 2.0. When using the bottom scale, be sure to multiply the ***earth load plus live load*** by the suggested safety factor of 1.5, and then to divide it by the bedding factor (Sec. 2.3).
4. The point plotted will lie between the curves for two pipe strengths. Select the higher strength of the two. This represents the most economical selection consistent with engineering requirements.

TABLE 8

Minimum Safety Factors for Use With Asbestos-Cement Transmission Pipe Selection

Type of Load	Safety Factor	
	Hydro	Crush
Operating pressure plus water hammer, combined with earth load plus live load	2.0	1.5

Sec. 5.4 Illustrative Problem on Pipe Selection

A 24-in. asbestos-cement transmission line is to be installed in a 4-ft wide trench with 5 ft of cover. The operating pressure will be 100 psi. Surge pressures will be limited to a maximum of 50 psi. A 16,000-lb wheel load is to be assumed, with an impact factor = 1. Class C bedding will be used. Select the proper strength of pipe to be used with safety factors of 2.0 in hydro ($P_o + P_s$) and 1.5 in crush ($w_E + w_S$).

SOLUTION: Following instructions for use of selection charts with safety factors as described in Sec. 5.3 gives

1. $P_o + P_s = 100 + 50 = 150$ psi
2. $w_E + w_S = 2030 + 640$
   $= 2670$ lb/ft
3. $(P_o + P_s)(S.F.)$
   $= 150 \times 2.0 = 300$ psi
4. $\dfrac{(w_E + w_S)(S.F.)}{B.F.} = \dfrac{(2670)(1.5)}{1.5}$
   $= 2670$ lb/ft
5. Consult the combined loading chart for 24-in. pipe, using the left hand and bottom scales. Plot the two loads as a single point on the chart. The point falls between T-40 and T-45. Use T-45.

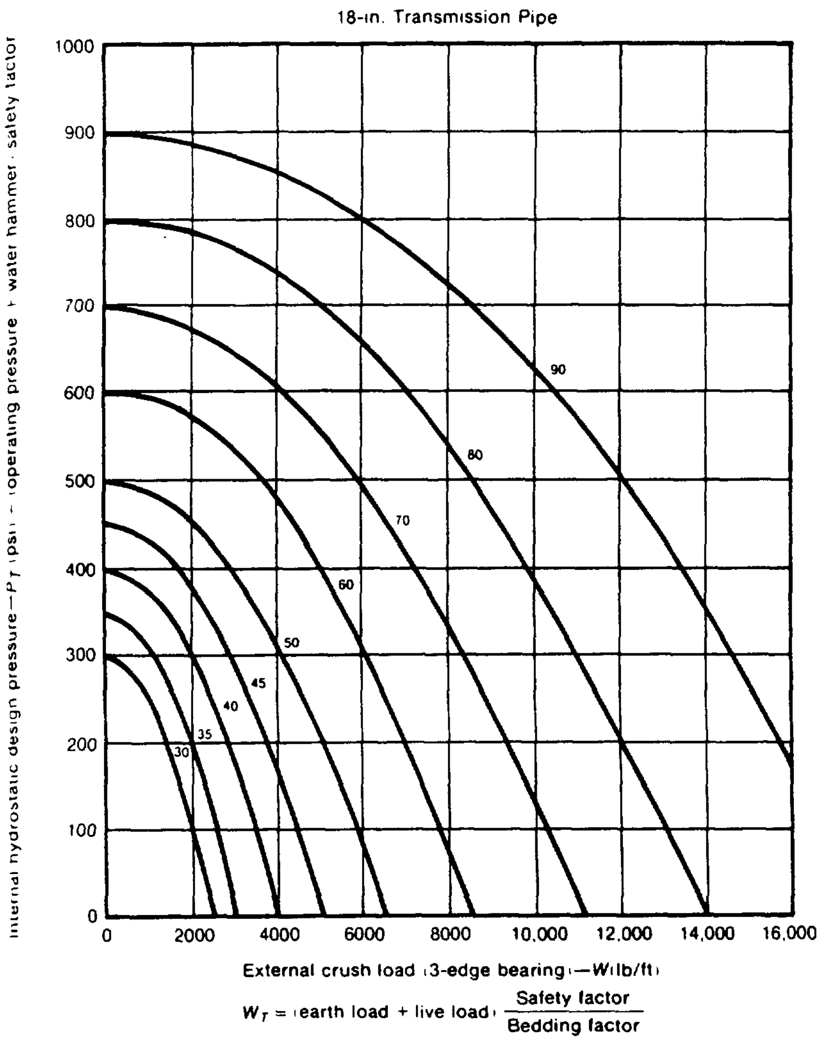

Fig. 14a. Combined Loading Curves for 18-in. Transmission Pipe

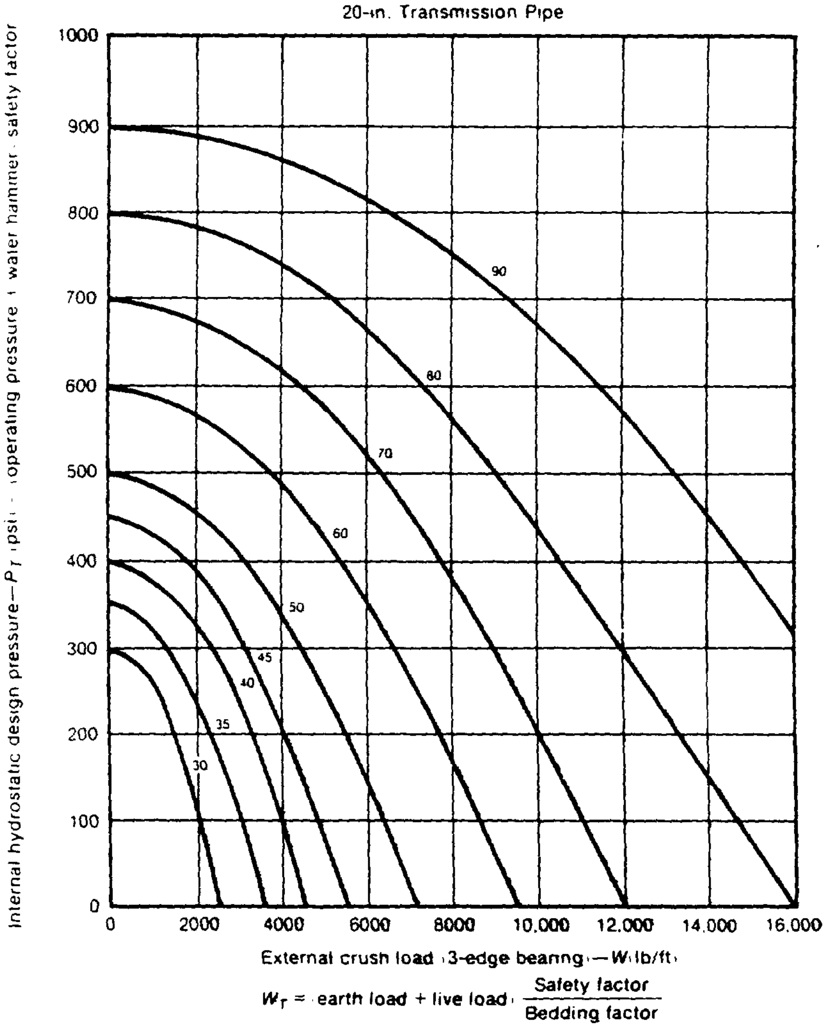

Fig. 14b. 20-in. Transmission Pipe

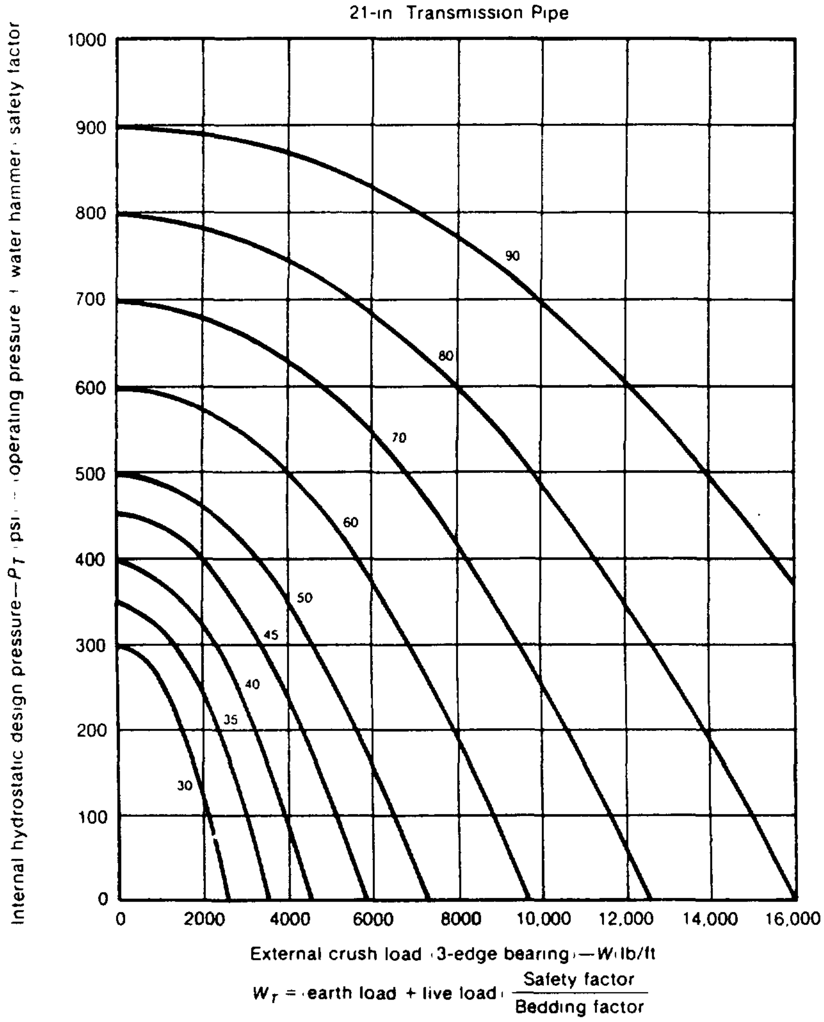

Fig. 14c. 21-in. Transmission Pipe

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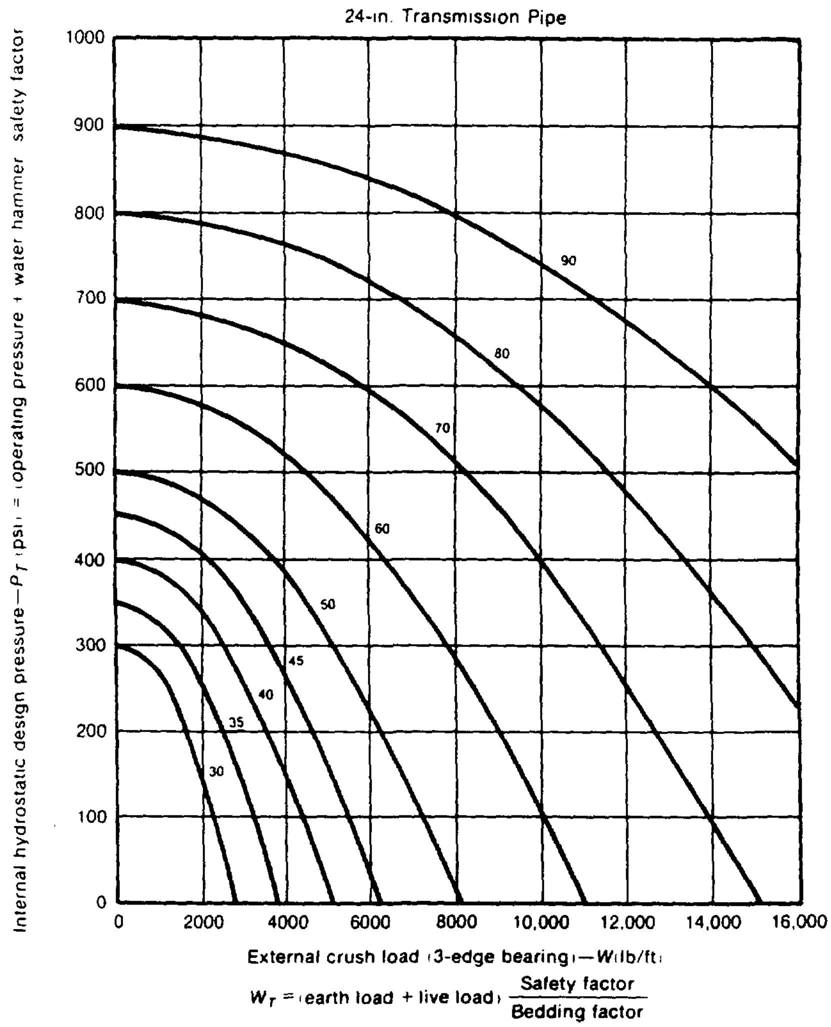

Fig. 14d. 24-in. Transmission Pipe

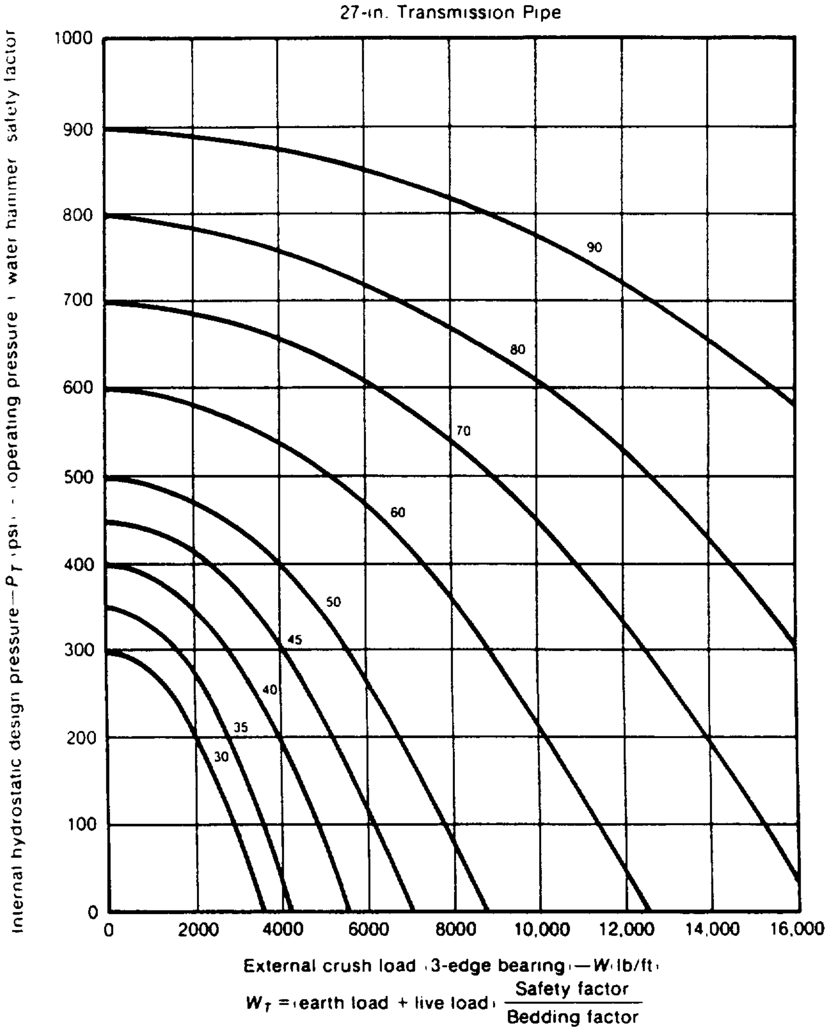

Fig. 14e. 27-in. Transmission Pipe

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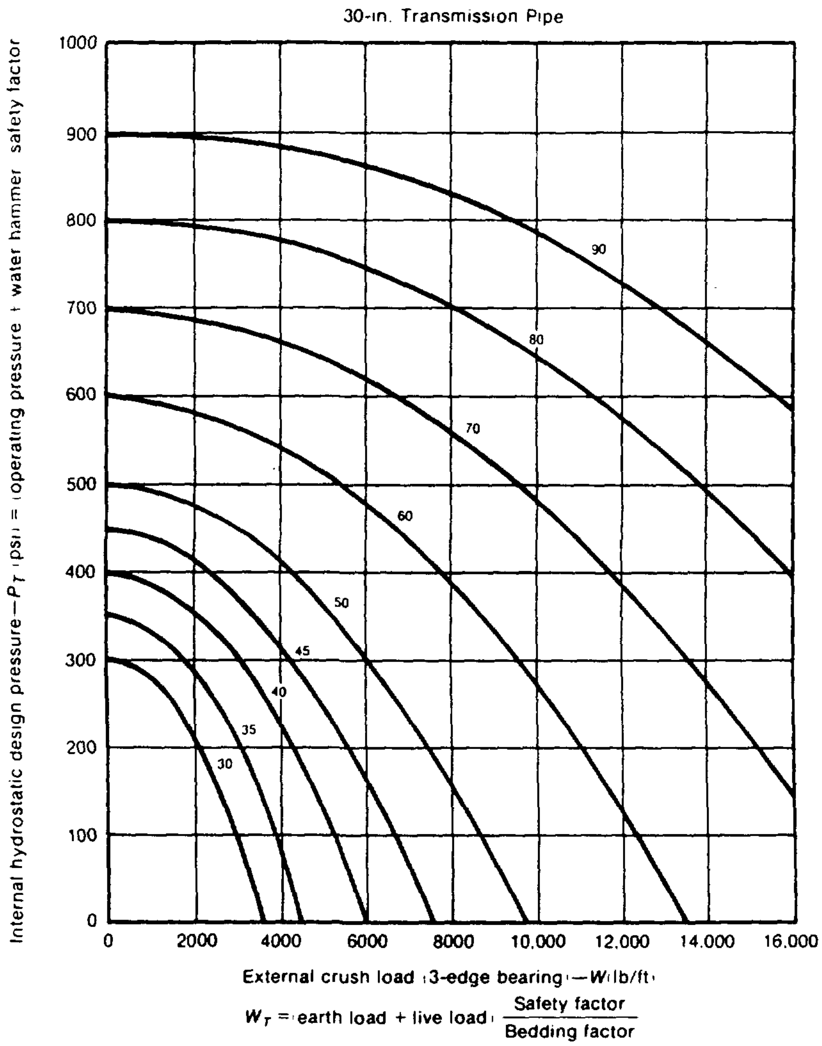

Fig. 14f. 30-in. Transmission Pipe

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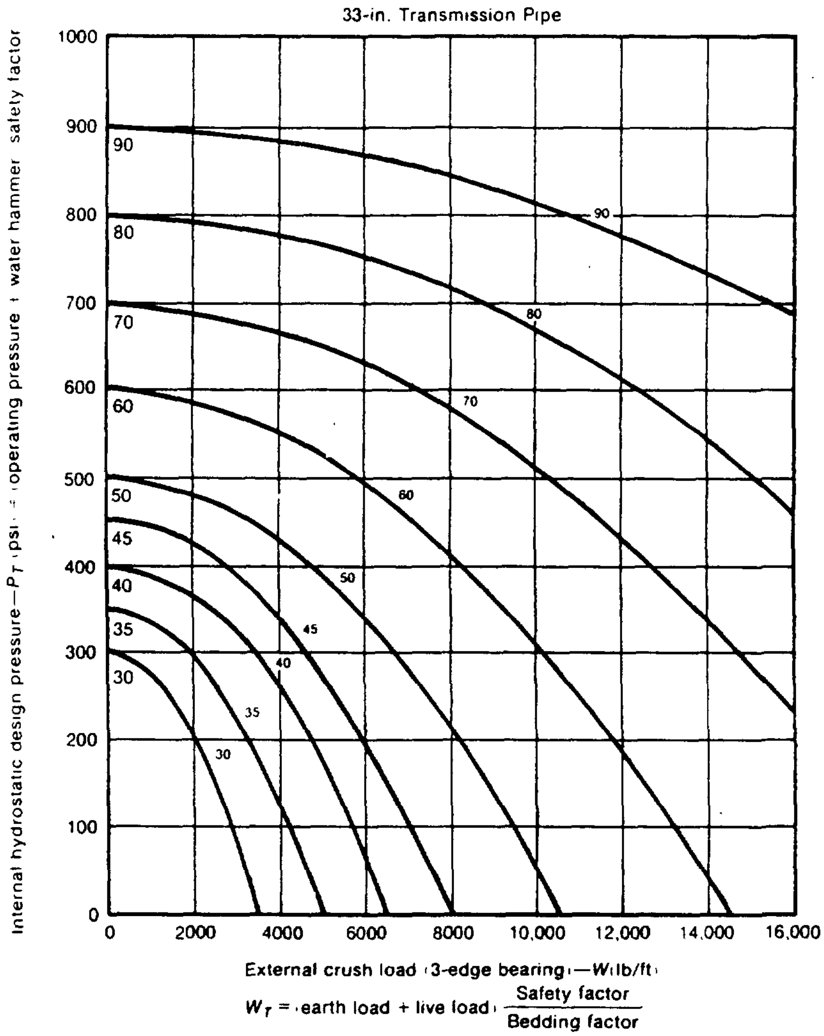

Fig. 14g. 33-in. Transmission Pipe

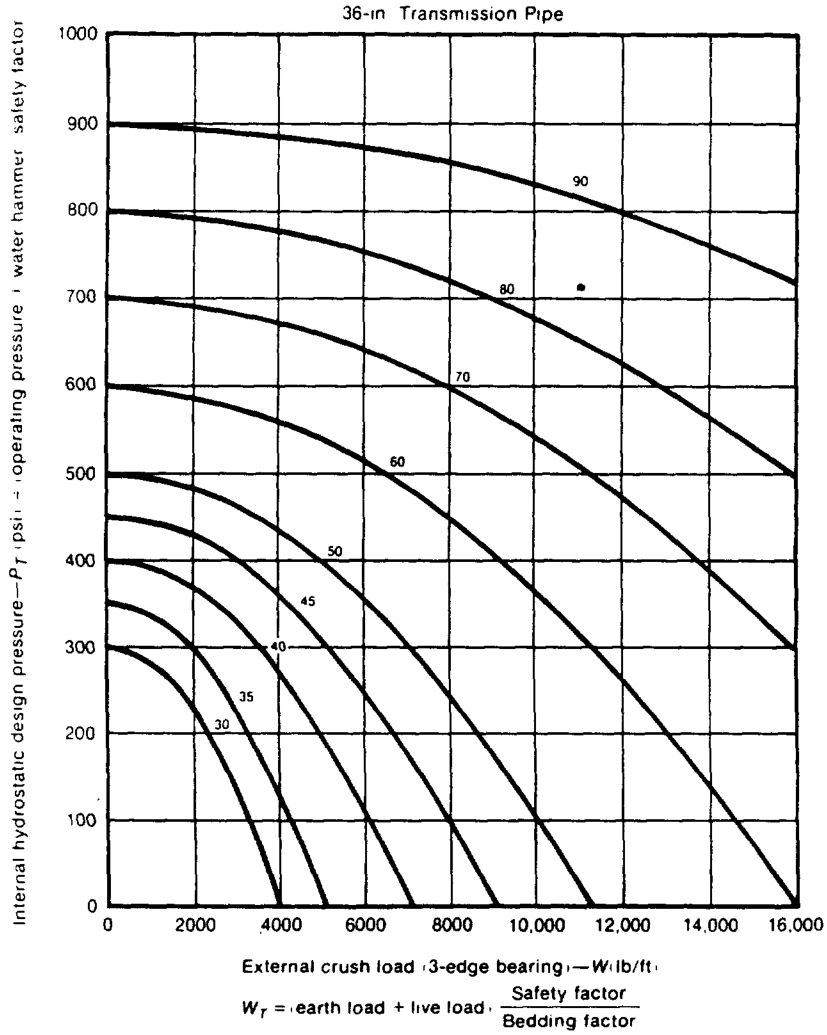

Fig. 14h. 36-in. Transmission Pipe

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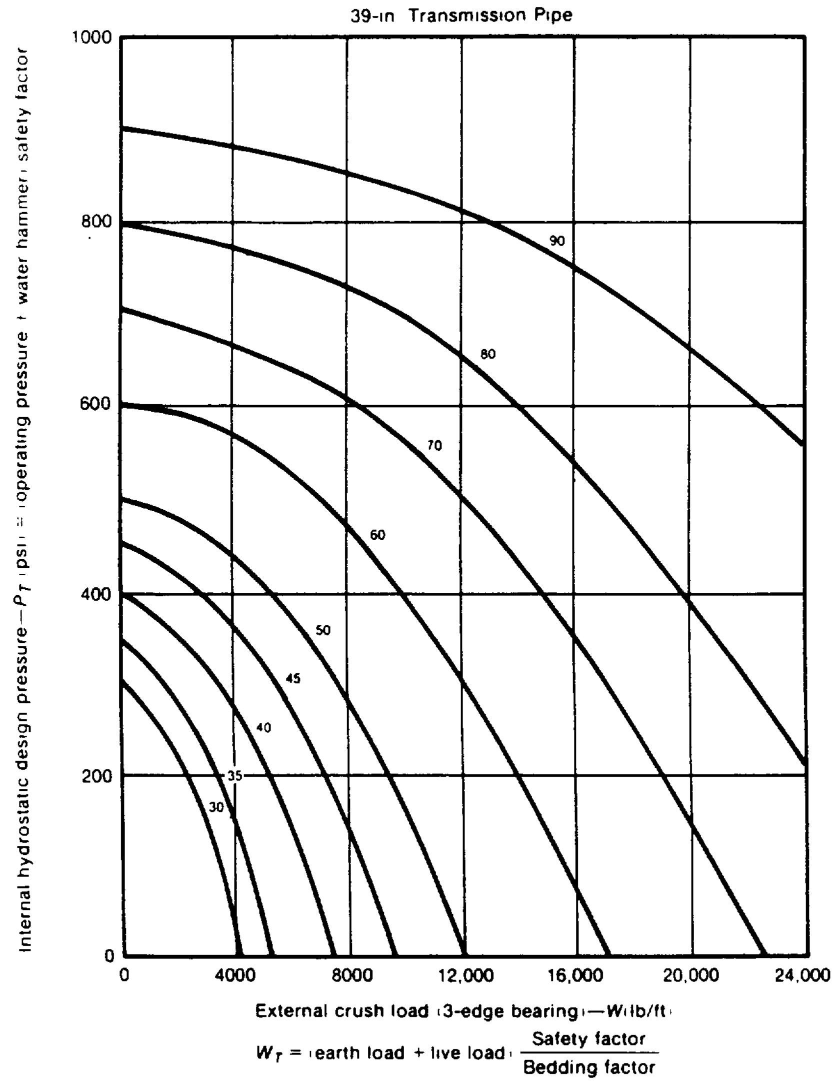

Fig. 14i. 39-in. Transmission Pipe

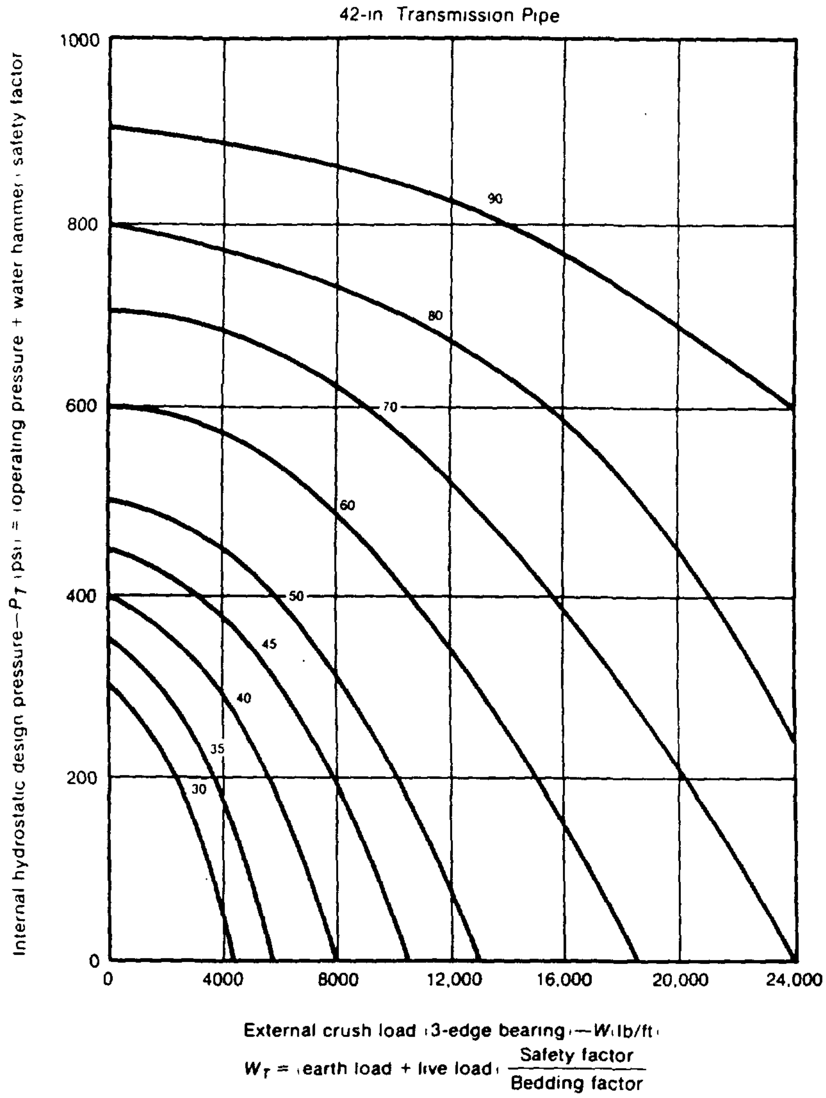

Fig. 14J—42-in. Transmission Pipe

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Appendix A

Friction Loss of Head Chart—Coefficient of Flow, $C = 140$

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Derived from the Hazen and Williams formula: $V = 1.318\ CR^{0.63}S^{0.54}$

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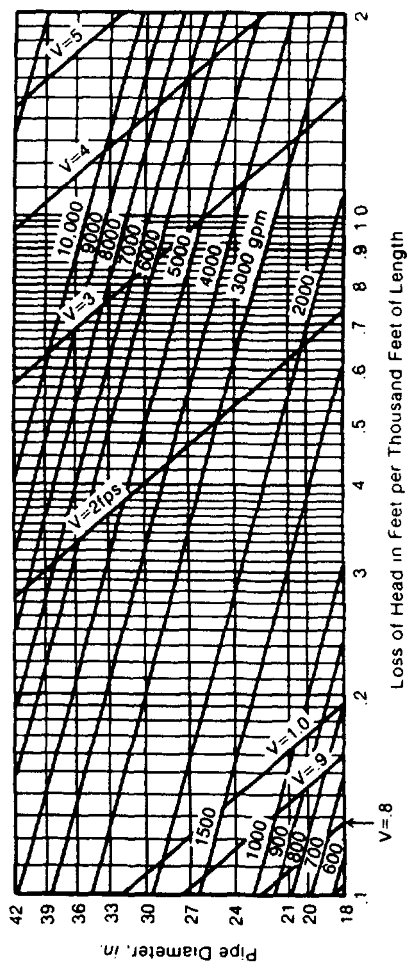
NOTE: Loss of head values derived from this chart are for coefficient of flow C = 140. They may be converted to loss of head for other coefficients of flow by means of the following multiplying factors:

1.15 for C = 130
1.34 for C = 120
1.57 for C = 110
1.86 for C = 100
2.26 for C = 90
2.83 for C = 80
4.82 for C = 60

NOTE: Diameters derived from this chart are for coefficient of flow C = 140. These may be converted to diameters for other coefficients of flow by means of the following multiplying factors:

1.033 for C = 130
1.063 for C = 120
1.100 for C = 110
1.142 for C = 100
1.185 for C = 90
1.261 for C = 80
1.365 for C = 60



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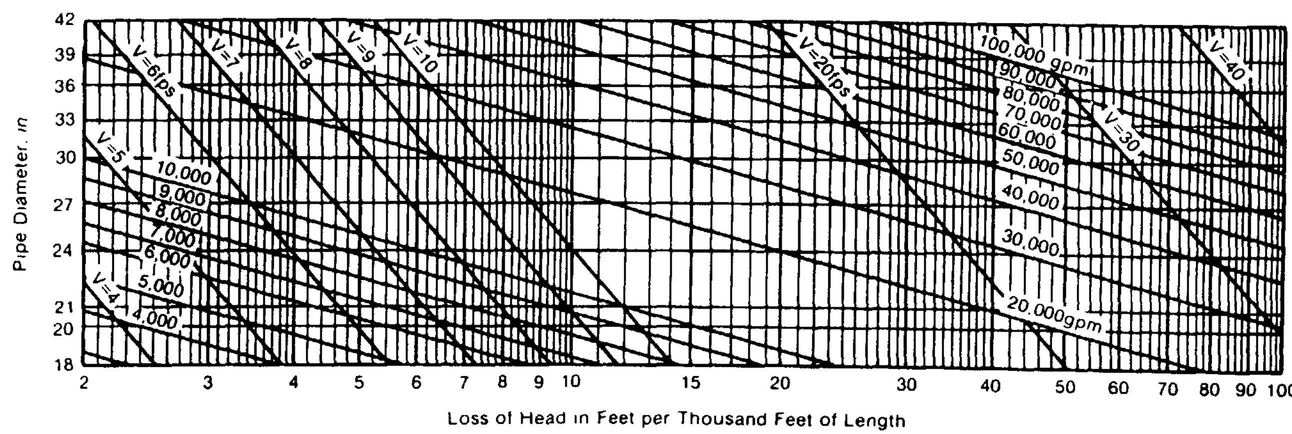
NOTE: Loss of head values derived from this chart are for coefficient of flow C = 140. They may be converted to loss of head for other coefficients of flow by means of the following multiplying factors:

1.15 for C = 130
1.34 for C = 120
1.57 for C = 110
1.86 for C = 100
2.26 for C = 90
2.83 for C = 80
4.82 for C = 60

NOTE: Diameters derived from this chart are for coefficient of flow C = 140. These may be converted to diameters for other coefficients of flow by means of the following multiplying factors:

1.033 for C = 130
1.063 for C = 120
1.100 for C = 110
1.142 for C = 100
1.185 for C = 90
1.261 for C = 80
1.365 for C = 60



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Appendix B

Surge Pressure Analysis

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B.1 Water Hammer or Surge

The slowing down or stopping of any moving mass requires a force or forces to counterbalance the kinetic energy that keeps the mass in motion. The faster a mass is decelerated and brought to a halt, the greater the force that is required.

B.1.1 *Forces involved.* It is somewhat of an oversimplification, but water hammer, or surge, can be defined in these terms: The shutting of a valve or the stopping of a pump causes a moving column of water in a pipeline to slow down and stop. The forces that bring about this deceleration are exerted radially on the moving water column by the pipeline walls. Conversely, the water exerts added pressure on the pipe, and the hoop stresses in the pipe walls thus increase over the normal operating pressure values. The faster the column of water is brought to a halt, the higher these stresses rise.

B.1.2 *Rate of velocity fluctuation.* The pipe wall stresses are thus developed by, and increase in direct proportion to, the internal pressure that builds up as the column of water decelerates. The slower the deceleration, the less the pressure builds up, and the less the pipe wall stresses increase. It is, therefore, of importance to the pipe designer to know how to control the rate of velocity fluctuation, since by controlling this rate he controls the magnitude of the pressure variations during the transitional periods. By such control he can keep the pipe wall stresses during surge to a predetermined value that will allow an economical installation.

B.1.3 *Wave motion.* Water, being liquid, will act in a fairly complex manner when undegoing acceleration or deceleration. Pressure waves are set up which move along the pipeline at a rate of 2500—4500 ft/sec, the rate depending on the pipe wall material. The waves will continue until they encounter a boundary condition, such as a reservoir, a closed valve, or a change in pipe diameter, at which point they will reflect back in the opposite direction. The wave motion will oscillate back and forth in the pipe until it is dampened out by the friction effects of the pipe walls.

B.1.4 *Causes.* The two major causes of water hammer or surge are

1. The closing or opening, fully or partially, of a valve in a pipeline system. The valve may be in the line for one of a number of purposes. It could be a gate valve, float valve, pressure reducing valve, or serve some other function.

2. The starting up or shutting down of a pump (switch or power failure). It can be seen that both of these occurrences cause changes in the velocity, and consequently in the quantity, of water flowing in the pipeline.

B.1.5. *Effects.* Ignoring the effects of surge in the pipeline can lead to difficulties after the line is in operation. Surge can result in damaged equipment and seriously reduced capacity.

B.2 Water Hammer Analysis

The elastic wave theory for surge analysis has been empirically established to be correct by many experiments, the first of which were performed as early as 1890. Its application to pipeline problems will yield results which are accurate and which may be relied upon for adequate analysis.

B.2.1 *Wave velocity*. Water hammer pressures are a function of the maximum rate of change of flow. When a valve is closed or a pump stops, a pressure wave is propagated along a pipeline. The velocity of the wave is the same as the velocity of sound in water, modified by physical characteristics of the pipeline; it is given by the following equation:

$$a = \frac{4660}{\sqrt{1 + kd/Ee}} \qquad \text{Eq B1}$$

in which,

a = pressure wave velocity, in feet per second
k = modulus of compression of water, 300,000 psi
d = internal diameter of pipe, in inches
E = modulus of elasticity of asbestos–cement pipe, 3,400,000 psi
e = wall thickness, in inches
4660 = velocity of sound in water in feet per second

B. 2. 2. *Maximum pressure*. If the pressure wave is reflected back from a boundary condition, such as a reservoir, and returns to its initial position after the flow in the line is completely stopped, then maximum water hammer pressure for those conditions will result. Stopping of the flow may be effected by closing a valve or by a pump stoppage. The magnitude of that maximum pressure is given by

$$h = \frac{aV}{g} \qquad \text{Eq B2}$$

in which,

h = surge pressure, in feet of water
V = velocity of water in the pipeline during normal conditions, in feet per second
a = velocity of pressure wave, in ft/sec
g = acceleration due to gravity, 32.2 ft/sec²

B.2.3 *Critical time*. The longest elapsed time before final flow stoppage that will still permit this maximum pressure to occur is called the critical time; it is simply the total length that the pressure wave travels in one cycle, divided by the velocity of the wave. It is given by the following equation:

$$U = \frac{2L}{a} \qquad \text{Eq B3}$$

in which,

U = the critical time, in seconds
L = distance within the pipeline that the pressure wave moves before it is reflected back by a boundary condition, in feet
a = velocity of the pressure wave in the line, in feet per second

B.3 Valve Closure

A valve in a water line may be of several different varieties, including gate, cone, and globe valves. When closing a valve, the area of the cross section of the pipeline that is progressively cut off is not generally proportional to the reduction in flow. In Fig. B1, Graph 1 presents a plot

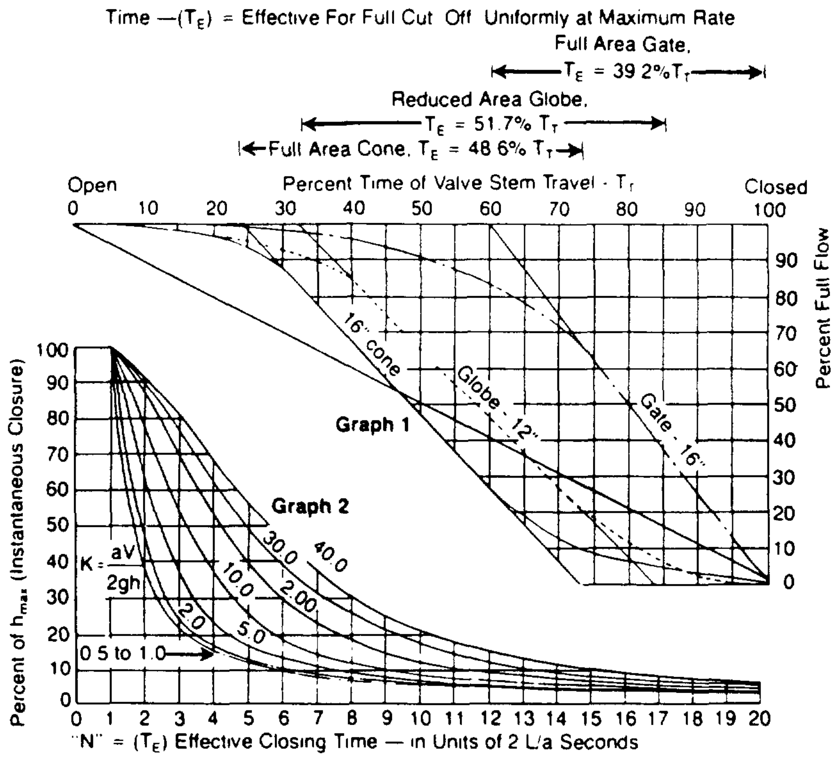

Fig. B1. Time (T_E) = Effective for Full Cut Off Uniformly at Maximum Rate

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of stem travel versus flow in the line for three types of valves. Note that the first 30–40 percent of stem travel has little effect on the flow in the pipeline.

B.3.1 *Effective time.* As stated previously, water hammer pressure is a function of the maximum rate of change of flow. Therefore, if tangents to the curves in Fig. B1 are drawn at the fastest rate of change (or steepest slope), the effective time of closure T_E is obtained. (See the curves in Fig. B1 with tangents plotted and values of T_E determined.) This effective time, T_E, is the time that is used in water hammer calculations. In most cases, it is about one half of the actual valve closing time. This indicates that if the critical time of a certain installed valve is calculated from Eq B3 and found to be x seconds, then the actual time for complete valve closure which will cause maximum pressure to occur will be approximately 2x seconds.

B.3.2 *Relation to surge control.* In the design of a water system one of the major considerations in the selection of a pipe is the design internal

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pressure that the pipe will be required to carry in service. The design internal pressure is the operating pressure plus the water hammer pressure. In order to keep the water hammer or surge pressures at a controlled level, calculations must be made to determine the valve closure times that will be required to stay within the design pressure level.

B.3.3 *Determining effective time.* Figure B1 presents a convenient three-step method for determining effective valve closure times for a given percentage of the maximum pressure (surge pressure when valve is closed in less than the critical time).

1. Determine the pipeline constant K given by

$$K = \frac{aV}{2gh_o} \qquad \text{Eq B4}$$

in which,

K = pipeline constant
a = velocity of the pressure wave in the line, in feet per second
V = velocity of water in the flow line under normal conditions, in feet per second
g = acceleration due to gravity, 32.2 ft/sec^2
h_o = operating pressure in the line under normal conditions, in feet of water

2. Determine the maximum head that might be developed from the surge by employing the formula $h_{max} = aV/g$.
3. Determine the percentage of h_{max} and find the corresponding effective closing time shown on the horizontal axis. This is given in units of $2L/a$, which represents the critical time for the pipeline. Note that the time determined is the *effective* closing time and the *actual* time of valve stem travel is about twice as long. The reason for this is that the first half of the closing of the valve has little effect on the stoppage of the flow. It is the closing of the final half of the valve stem travel which closes off the flow. The second half is the effective closing time. Therefore, two times the effective closing time is the actual time of the valve stem travel.

B.4 Pumped Systems

In relation to water hammer and surge, the most important elements in a system are pumps and valves. In a gravity system only valves have to be considered. Both pumps and valves must be considered in a pumped system.

B.3.1 *Complexity.* The surge analysis of a pumped system is more complex than in a 100 percent gravity system because

1. In a pumped system, the problem begins in the slowing down of the rising water column when the pump is shut off (because of power failure or otherwise). Consideration must be given to the time required for the pump to stop and for the flow to come to a halt. This involves the inertia of the motor and any flywheel in the assembly. Provisions normally should be made for slow opening and closing of pump control valves on pump systems. In a gravity system the hydraulic problem consists only of stopping the descending water column.
2. In a pumped system, the pipeline profile is usually irregular, with successive high and low points and with variable slopes. These conditions may give rise to water

column separation, causing severe surges and operational troubles. Surges from water column separation do not follow a standard pattern and they have been measured at many times the calculated values.

B.4.2 *Alternative layouts.* The design of a pumped system may involve the consideration of alternative layouts to keep surges and the consequent operational difficulties to a minimum. This work should be directed toward reducing the magnitude of surges and toward reducing the risk of water column separation that may be caused by the shutdown of a pump.

B.4.3 *Water column separation.* Water column separation can be serious due to the large magnitude of the surges developed when the water column rejoins. It can occur

1. At pump locations at the start of a steep main.
2. When the pressure at a high point falls below atmospheric and air enters the line through air valves that may be located at a high point.
3. When the pressure falls to below the vapor pressure of water.

B.4.4 *Entrapped air.* Water column separation can cause difficulties, not only because of the before-mentioned surges set up by the rejoining of the water column, but because of the difficulties in getting air out of the line on subsequent start-up, even with air valves. Entrapped air can cause flow fluctuations and can seriously reduce the capacity of the system.

B.5 Methods of Control

The two types of surge to be controlled are negative surge and positive surge. The type is determined, of course, by whether the surge pressures developed are below or above the normal static level.

B.5.1 *Negative surges.* Negative surges in themselves are usually not dangerous, except when they cause water column separation. If this occurs, extremely high positive surges result when the cavity closes, and this frequently causes serious problems. The control of both negative and positive surges should be given consideration.

B.5.2 *Surge control devices.* Limiting negative and positive surges is accomplished by several types of surge control devices, as follows:

1. Controlled valves. This is one of the most effective means for controlling positive surges. As explained previously, the rate of opening and closing of a valve can be calculated to allow an acceptable level of surge.
2. Flywheel on pump motor. In the event of a power outage the inertia of the flywheel will keep the pump running for a period of time, during which it will gradually slow to a stop. This means that the water column in the pipeline will also be brought to a gradual stop, thus reducing the risk of water column separation.
3. Standpipe. This is generally a tank with the surface of the water at atmospheric pressure. It is, therefore, only practical at low heads. At a pump stoppage and consequent reduced pressure, the reserve of water in the tank flows into the pipe and reduces the risk of water column separation. For positive surge control the tank

provides an outlet for the built-up pressure in the system.

4. Air vessel or surge tank. This is an enclosed vessel containing air and water. It functions similarly to a standpipe, with water reentering the line during negative surge and leaving during positive surge. The major difference is that the air in the vessel is under pressure and much higher heads can be employed in the pipe system.
5. One-way surge tank. This is an adaptation of the surge tank. It contains a check valve that permits water to enter the line during negative surge, but will not permit water to leave during positive surge. It is, therefore, only for control of negative surges and is very effective.
6. Reservoir of water. This is similar to the one way surge tank, but provides some control of positive surge by permitting the slow entrance of water into the reservoir during a positive surge.
7. Suction pipe. This is a bypass around the pump from the suction side. It contains a check valve to prevent backflow into the reservoir. It effectively reduces negative pressure adjacent to the pump.
8. Surge relief valve. This is used for controlling positive and negative surges. The valve opens at a certain pressure and discharges water to relieve a surge; positive or negative. It must be carefully designed and controlled in order to be effective.
9. Nonreturn valve. This is a check, strategically placed in a line, that can bring a small measure of relief to positive pressure. However, unless properly placed, it can lead to higher rather than lower surge.
10. Reversal of pump. At pump stoppage the column of water reverses itself. If the pump will not run backwards to permit water to flow back through it, then positive surges will be developed by the sudden stopping of the backflowing column of water. The pump should be designed to run reversed without damage to itself. Design of pumps that can run reversed without damage is a significant problem. Other measures may have to be taken.

B.5.3 *Economic considerations.* From an economic standpoint it is usually worthwhile to properly evaluate the surge potential in a system under design. The cost of control devices may be balanced against the added strength of pipe, valves, and other equipment that will be needed if surges are not controlled, and the most advantageous conclusion reached. Manufacturers of surge control equipment or consultants in this field should be sought for advice in complex situations.

B.6 Surge Calculation Example

The following example problem illustrates the calculation that may be followed to determine valve closing time for the control of surge within prescribed limits.

A 24-in. gravity transmission line is to operate at a pressure of 100 psi. Velocity in the line is to be 5 ft/sec. A valve is to be included in the line at a distance of 5000 ft from the reservoir. If positive surge pressure is to be controlled within 50 psi, determine the minimum time for valve closure. Assume that the effective closing time is one half of the actual valve stem travel time. (E for asbestos-cement pipe = 3.4×10^6, wall thickness is 1.5 in., k for water = 3×10^5)

SOLUTION

1. Determine surge wave velocity

$$a = \frac{4660}{\sqrt{1 + \frac{kd}{Ee}}} = \frac{4660}{\sqrt{1 + \frac{3 \times 10^5 \times 24}{3.4 \times 10^6 \times 1.5}}} = 3000 \text{ ft/sec.}$$

2. Determine maximum surge pressure if the valve closes within the critical time

$$h = \frac{aV}{g} = \frac{3000 \times 5}{32.2} = 465 \text{ ft of water (200 psi)}$$

3. Determine the critical time

$$C = \frac{2L}{a} = \frac{2 \times 5000}{3000} = 3.33 \text{ sec}$$

4. Determine Constant K for use in Graph 2 (Fig. B1)

$$K = \frac{aV}{2gh_o} = \frac{3000 \times 5}{2 \times 32.2 \times 231} = 1.0$$

5. Determine percent of maximum surge pressure that should not be exceeded in the system.

$$\frac{50}{200} \times 100 = 25 \text{ percent}$$

6. Enter Graph 2 (Fig. B1) with percent of h_{max} (25 percent). Go horizontally to the curves where $K = 1.0$. Read the effective closing time along the horizontal axis. This value is 2.6 and is given in units of $2L/a$ seconds. The effective closing time in seconds would be $2L/a \times 2.6 = 3.33 \times 2.6 = 8.7$ sec. The actual valve stem travel time would be twice this amount, or 17.4 sec. This calculated time (17.4 sec.), therefore, represents the fastest allowable time the valve can be closed in order to keep the surge pressure below the desired control level of 50 psi.

B.7 Air in Pipelines

Air in pipelines can cause serious operational difficulties, including reduction in capacity because of reduced cross-sectional area, and fluctuation in flow caused by expanding and contracting air in the line. These fluctuations in flow cause sudden movements of the air from one location to another, followed by slugs of water, and this can cause serious surges.

B.7.1 *Entrance of air.* Air can enter a pipeline in many ways. It may enter at the intake. Entry may be caused by release of air from water due to temperature and pressure variation, or it may be caused by draining the line, or by draining parts of the line during normal shut-down. Negative surges may cause air to enter at air valves. Air should be prevented from entering the line in the first place. This is very important in order to reduce operational difficulties. Suggested solutions for control are as follows:

1. Intake. Correct design procedures, provide low water-level pump cut-off.
2. Release of air. Air is entrained in the water at intake and its release cannot be prevented. However, the quantities are not large and provisions for exhausting can be made by means of air valves. There are various types of air valves with different

functions, and the selection of the proper type and location for installation is essential.

3. Draining the line. Air cannot be prevented from entering the line on draining, of course. Large orifice air valves should be provided for exhausting the air during refilling. Draining and then refilling does not often occur; therefore, long filling times may be satisfactory.
4. Drainage during shut down. This can be a serious problem. Open standpipes can be provided for air entry and exhaust. Sweeping air out using high velocities is also a method.
5. Negative surges. The best way to prevent air from entering under these conditions is to design out the possibility of water column separation. Large volumes of air may be involved here and can cause serious problems. Any one of the negative surge control devices described in paragraph B.5.2 will normally be adequate.

B.7.2. *Recommendations to combat air entrapment.* Colorado State University has conducted studies to determine the effect of air entrapment in pipelines. The result of the studies proved that suddenly released entrapped air, under apparently static conditions, creates a situation similar to that of classic water hammer. Pressures are generated which may be on the order of fifteen times the pipeline test pressure. Any pipeline material is seriously affected by this rapid magnitude of load increase. Hydrostatic failure due to defective pipe may in all probability be traced to suddenly released entrapped air. The initial filling and testing of a pipeline is often the most critical period of its service life. Recommendations to combat air entrapment were made as follows:

1. Pipeline should be laid to grade wherever possible.
2. Automatic continual acting air release valves should be used at all high points.
3. Air should be bled from pipeline slowly.
4. Limit filling velocity in the pipeline to one foot per second or less.
5. Use $d/D = 1/10$ to $1/100$.
   d = diameter of air release valve
   D = pipe diameter

The results of this study, together with the recommendations, have been found to be most useful to contractors in performing pipeline tests. Such recommendations also have been found to be useful to engineers from the standpoint of designing pipelines to minimize air problems.

Appendix C

Frictional Power Requirements

This appendix is for information only and is not a part of AWWA C700.

The chart shown in Fig. C1 permits rapid calculations of the yearly power costs to overcome friction loss of head. This chart is based on continuous pumping operation (24 hours per day and 365 days per year), a power cost of $0.01 per kwhr, and a motor-pump efficiency of 100 percent. For actual operating conditions and local power costs, appropriate factors must be applied to the values shown in the chart. By calculating power costs to overcome friction in two pipe sizes, or for two different types of pipe having different flow coefficients, an annual power cost savings can be determined. Economic justification for going to a larger pipe diameter with lower annual power costs can be determined by establishing the present worth of the annual savings using Table C1, which is based on the discounted cash flow method. If the present worth of the annual savings based on established interest rates exceeds the added costs for the installation of a different size or type of material, then economic justification exists for the added capital expenditure.

Nomograph values for Fig. C1 are based on the following:

Cost per 1000 ft of pipe per year—in dollars
Power cost—1¢ per kilowatt hour
Motor-pump efficiency (combined)—100 percent
Friction coefficient $C = 140$
Continuous operation

NOTE: Yearly power cost values derived in Fig. C1 are for coefficient of flow $C = 140$. They may be converted to yearly power cost values for other coefficients of flow by means of the following multiplying factors:

1.15 for $C = 130$
1.34 for $C = 120$
1.57 for $C = 110$
1.86 for $C = 100$
2.26 for $C = 90$
2.83 for $C = 80$
4.82 for $C = 60$

Diameters derived from Fig. C1 are for coefficient of flow $C = 140$. These may be converted to other diameters for other coefficients of flow by means of the following multiplying factors:

1.033 for $C = 130$
1.063 for $C = 120$
1.100 for $C = 110$
1.142 for $C = 100$
1.185 for $C = 90$
1.261 for $C = 80$
1.365 for $C = 60$

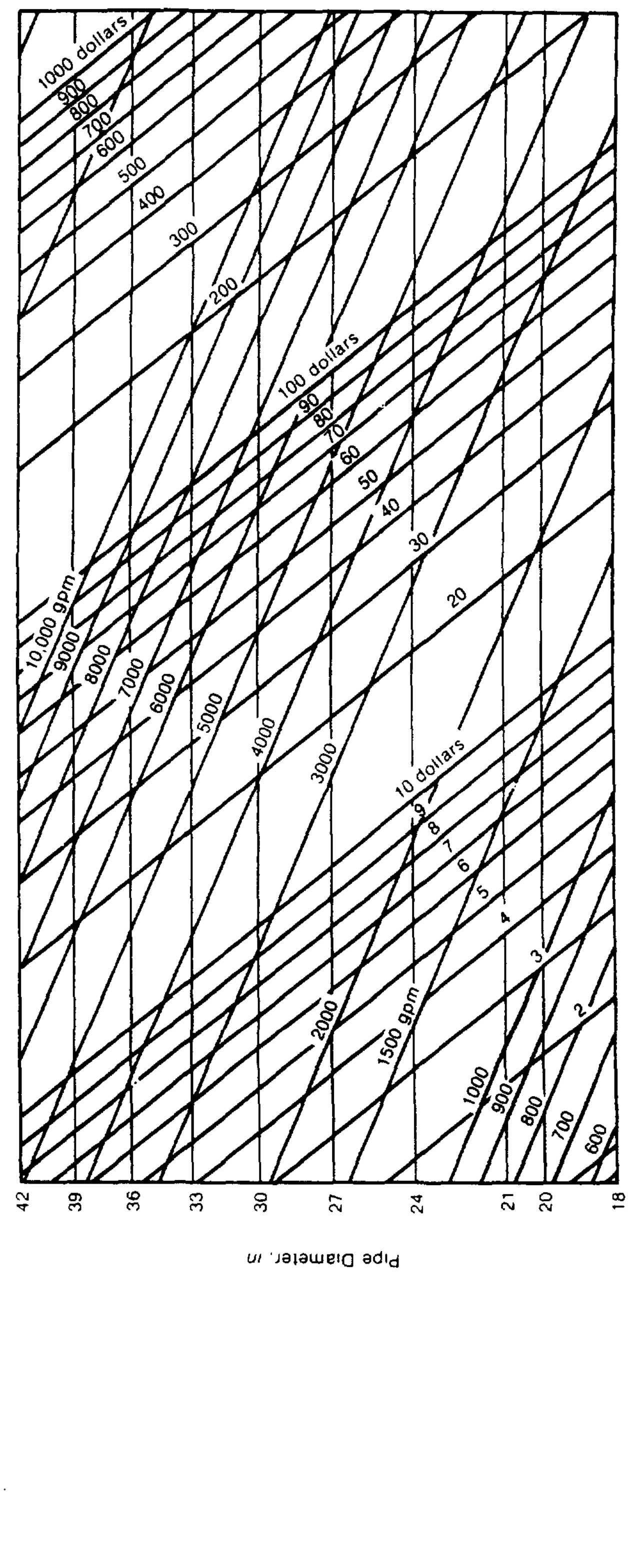

Fig. C1. Yearly Power Cost to Compensate for Friction Loss of Head * *(cont. on next page)*

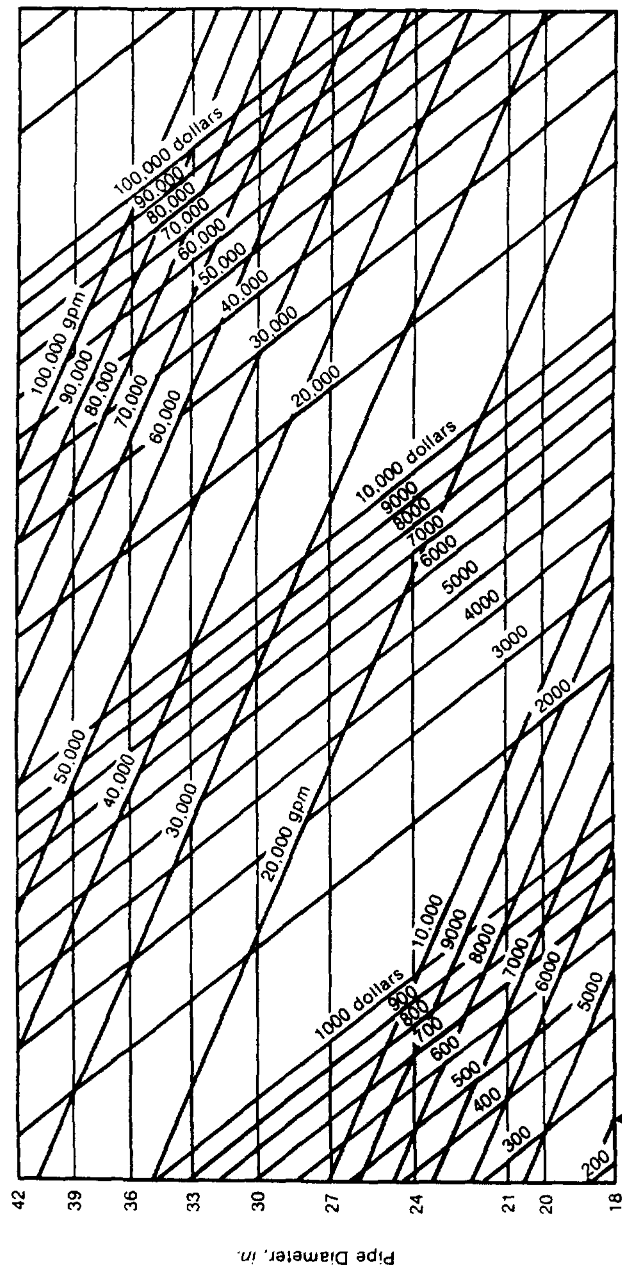

Fig. C1 (cont.)

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Table C1 *

Apply the following formula to Table C1, *Present Worth of an Income of $1.00 per Year for the Next* N *Years:*

$$\frac{(1 \div r)^N - 1}{r(1 + r)^N}$$

where

r = rate of yield in percent
N = number of years from present

Example:

When using a 10 percent rate of yield, an income of $1.00 occurring each year for the next 5 years has a present worth of $3.791; for the next 7 years, $4.868; for the next 10 years, $6.145; etc.

The present worth (*PW*) of a regular pattern of savings in the future is found as follows:

Total years of operation—25
Amount of annual savings—$5000.00
PW factor at 10 percent—9.077
Total present worth (*PW*)—$45,385.00

When expenditure, cash income, and life are known, and income is the same each year, the *PW* factor can be computed by dividing expenditure by annual cash income. Yield can then be determined by looking for the factor on the line or known life in Table C1.

* This table is reprinted by permission of the Johns-Manville Sales Corporation from their publication, "Discounted Cash Flow Method of Investment Appraisal."

TABLE C1

Present Worth of an Income of $1.00 per Year for the Next N Years

Years	.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	Years
1	.995	.990	.985	.980	.976	.971	.966	.962	.957	.952	1
2	1.985	1.970	1.956	1.942	1.927	1.913	1.900	1.886	1.873	1.859	2
3	2.970	2.941	2.912	2.884	2.856	2.829	2.802	2.775	2.749	2.723	3
4	3.950	3.902	3.854	3.808	3.762	3.717	3.673	3.630	3.588	3.546	4
5	4.926	4.853	4.783	4.713	4.646	4.580	4.515	4.452	4.390	4.329	5
6	5.896	5.795	5.697	5.601	5.508	5.417	5.329	5.242	5.158	5.076	6
7	6.862	6.728	6.598	6.472	6.349	6.230	6.115	6.002	5.893	5.786	7
8	7.823	7.652	7.486	7.325	7.170	7.020	6.874	6.733	6.596	6.463	8
9	8.779	8.566	8.361	8.162	7.971	7.786	7.608	7.435	7.269	7.108	9
10	9.730	9.471	9.222	8.983	8.752	8.530	8.317	8.111	7.913	7.722	10
11	10.68	10.37	10.07	9.787	9.514	9.253	9.002	8.760	8.529	8.306	11
12	11.62	11.26	10.91	10.58	10.26	9.954	9.663	9.385	9.119	8.863	12
13	12.56	12.13	11.73	11.35	10.98	10.64	10.30	9.986	9.683	9.394	13
14	13.49	13.00	12.54	12.11	11.69	11.30	10.92	10.56	10.22	9.899	14
15	14.42	13.87	13.34	12.85	12.38	11.94	11.52	11.12	10.74	10.38	15
16	15.34	14.72	14.13	13.58	13.06	12.56	12.09	11.65	11.23	10.84	16
17	16.26	15.56	14.91	14.29	13.71	13.17	12.65	12.17	11.71	11.27	17
18	17.17	16.40	15.67	14.99	14.35	13.75	13.19	12.66	12.16	11.69	18
19	18.08	17.23	16.43	15.68	14.98	14.32	13.71	13.13	12.59	12.09	19
20	18.99	18.05	17.17	16.35	15.59	14.88	14.21	13.59	13.01	12.46	20
21	19.89	18.86	17.90	17.01	16.19	15.42	14.70	14.03	13.41	12.82	21
22	20.78	19.66	18.62	17.66	16.77	15.94	15.17	14.45	13.78	13.16	22
23	21.68	20.46	19.33	18.29	17.33	16.44	15.62	14.86	14.15	13.49	23
24	22.56	21.24	20.03	18.91	17.89	16.94	16.06	15.25	14.50	13.80	24
25	23.45	22.02	20.72	19.52	18.42	17.41	16.48	15.62	14.83	14.09	25
26	24.32	22.80	21.40	20.12	18.95	17.88	16.89	15.98	15.15	14.36	26
27	25.20	23.56	22.07	20.71	19.46	18.33	17.29	16.33	15.45	14.64	27
28	26.07	24.31	22.73	21.28	19.97	18.76	17.67	16.66	15.74	14.90	28
29	26.93	25.07	23.38	21.84	20.45	19.19	18.04	16.98	16.02	15.14	29
30	27.79	25.81	24.02	22.40	20.93	19.60	18.39	17.29	16.29	15.37	30
31	28.65	26.54	24.65	22.94	21.40	20.00	18.74	17.59	16.54	15.59	31
32	29.50	27.27	25.27	23.47	21.85	20.39	19.07	17.87	16.79	15.80	32
33	30.35	27.99	25.88	23.99	22.29	20.77	19.39	18.15	17.02	16.00	33
34	31.20	28.70	26.48	24.50	22.72	21.13	19.70	18.41	17.25	16.19	34
35	32.04	29.41	27.08	25.00	23.15	21.49	20.00	18.67	17.46	16.37	35
36	32.87	30.11	27.66	25.49	23.56	21.83	20.29	18.91	17.67	16.55	36
37	33.70	30.80	28.24	25.97	23.96	22.17	20.57	19.14	17.86	16.71	37
38	34.53	31.49	28.81	26.44	24.35	22.49	20.84	19.37	18.05	16.87	38
39	35.35	32.16	29.37	26.90	24.73	22.81	21.10	19.58	18.23	17.02	39
40	36.17	32.84	29.92	27.36	25.10	23.12	21.36	19.79	18.40	17.16	40
41	36.99	33.50	30.46	27.80	25.47	23.41	21.60	19.99	18.57	17.29	41
42	37.80	34.16	30.99	28.24	25.82	23.70	21.84	20.19	18.72	17.42	42
43	38.61	34.81	31.52	28.66	26.17	23.98	22.06	20.37	18.87	17.55	43
44	39.41	35.46	32.04	29.08	26.50	24.25	22.28	20.55	19.02	17.66	44
45	40.21	36.09	32.55	29.49	26.83	24.52	22.50	20.72	19.16	17.77	45
46	41.00	36.73	33.06	29.89	27.15	24.78	22.70	20.89	19.29	17.88	46
47	41.79	37.35	33.55	30.29	27.47	25.03	22.90	21.04	19.42	17.98	47
48	42.58	37.97	34.04	30.67	27.77	25.27	23.09	21.20	19.54	18.08	48
49	43.36	38.59	34.53	31.05	28.07	25.50	23.28	21.34	19.65	18.17	49
50	44.14	39.20	35.00	31.42	28.36	25.73	23.46	21.48	19.76	18.26	50

TABLE C1

TABLE C1 (*continued*)

Years	5.5%	6.0%	6.5%	7.0%	7.5%	8.0%	8.5%	9.0%	9.5%	10.0%	Years
1	.948	.943	.939	.935	.930	.926	.922	.917	.913	.909	1
2	1.846	1.833	1.821	1.808	1.796	1.783	1.771	1.759	1.747	1.736	2
3	2.698	2.673	2.648	2.624	2.601	2.577	2.554	2.531	2.509	2.487	3
4	3.505	3.465	3.426	3.387	3.349	3.312	3.276	3.240	3.204	3.170	4
5	4.270	4.212	4.156	4.100	4.046	3.993	3.941	3.890	3.840	3.791	5
6	4.996	4.917	4.841	4.767	4.694	4.623	4.554	4.486	4.420	4.355	6
7	5.683	5.582	5.485	5.389	5.297	5.206	5.119	5.033	4.950	4.868	7
8	6.335	6.210	6.089	5.971	5.857	5.747	5.639	5.535	5.433	5.335	8
9	6.952	6.802	6.656	6.515	6.379	6.247	6.119	5.995	5.875	5.759	9
10	7.538	7.360	7.189	7.024	6.864	6.710	6.561	6.418	6.279	6.145	10
11	8.093	7.887	7.689	7.499	7.315	7.139	6.969	6.805	6.647	6.495	11
12	8.619	8.384	8.159	7.943	7.735	7.536	7.345	7.161	6.984	6.814	12
13	9.117	8.853	8.600	8.358	8.126	7.904	7.691	7.487	7.291	7.103	13
14	9.590	9.295	9.014	8.745	8.489	8.244	8.010	7.786	7.572	7.367	14
15	10.04	9.712	9.403	9.108	8.827	8.559	8.304	8.061	7.828	7.606	15
16	10.46	10.11	9.768	9.447	9.142	8.851	8.575	8.313	8.062	7.824	16
17	10.87	10.48	10.11	9.763	9.434	9.122	8.825	8.544	8.276	8.022	17
18	11.25	10.83	10.43	10.06	9.706	9.372	9.055	8.756	8.471	8.201	18
19	11.61	11.16	10.74	10.34	9.959	9.604	9.268	8.950	8.650	8.365	19
20	11.95	11.47	11.02	10.59	10.19	9.818	9.463	9.129	8.812	8.514	20
21	12.28	11.76	11.29	10.84	10.41	10.02	9.644	9.292	8.961	8.649	21
22	12.58	12.04	11.54	11.06	10.62	10.20	9.810	9.442	9.097	8.772	22
23	12.88	12.30	11.77	11.27	10.81	10.37	9.963	9.580	9.221	8.883	23
24	13.15	12.55	11.99	11.47	10.98	10.53	10.10	9.707	9.334	8.985	24
25	13.41	12.78	12.20	11.65	11.15	10.68	10.23	9.823	9.438	9.077	25
26	13.66	13.00	12.39	11.83	11.30	10.81	10.35	9.929	9.532	9.161	26
27	13.90	13.21	12.58	11.99	11.44	10.94	10.47	10.03	9.618	9.237	27
28	14.12	13.41	12.75	12.14	11.57	11.05	10.57	10.12	9.697	9.307	28
29	14.33	13.59	12.91	12.28	11.70	11.16	10.66	10.20	9.769	9.370	29
30	14.53	13.77	13.06	12.41	11.81	11.26	10.75	10.27	9.835	9.427	30
31	14.72	13.93	13.20	12.53	11.92	11.35	10.83	10.34	9.895	9.479	31
32	14.90	14.08	13.33	12.65	12.02	11.44	10.90	10.41	9.950	9.526	32
33	15.08	14.23	13.46	12.75	12.11	11.51	10.97	10.46	10.00	9.569	33
34	15.24	14.37	13.58	12.85	12.19	11.59	11.03	10.52	10.05	9.609	34
35	15.39	14.50	13.69	12.95	12.27	11.66	11.09	10.57	10.09	9.644	35
36	15.54	14.62	13.79	13.04	12.35	11.72	11.14	10.61	10.13	9.677	36
37	15.67	14.74	13.89	13.12	12.42	11.78	11.19	10.65	10.16	9.706	37
38	15.81	14.85	13.98	13.19	12.48	11.83	11.24	10.69	10.19	9.733	38
39	15.93	14.95	14.07	13.27	12.54	11.88	11.28	10.73	10.22	9.757	39
40	16.05	15.05	14.15	13.33	12.59	11.93	11.32	10.76	10.25	9.779	40
41	16.16	15.14	14.22	13.39	12.65	11.97	11.35	10.79	10.27	9.799	41
42	16.26	15.23	14.29	13.45	12.69	12.01	11.38	10.81	10.29	9.817	42
43	16.36	15.31	14.36	13.51	12.74	12.04	11.41	10.84	10.31	9.834	43
44	16.46	15.38	14.42	13.56	12.78	12.08	11.44	10.86	10.33	9.849	44
45	16.55	15.46	14.48	13.61	12.82	12.11	11.47	10.88	10.35	9.863	45
46	16.63	15.52	14.54	13.65	12.86	12.14	11.49	10.90	10.36	9.875	46
47	16.71	15.59	14.59	13.69	12.89	12.16	11.51	10.92	10.38	9.887	47
48	16.79	15.65	14.64	13.73	12.92	12.19	11.53	10.93	10.39	9.897	48
49	16.86	15.71	14.68	13.77	12.95	12.21	11.55	10.95	10.40	9.906	49
50	16.93	15.76	14.73	13.80	12.98	12.23	11.57	10.96	10.41	9.915	50

TABLE C1 (*continued*)

Years	10.5%	11.0%	11.5%	12.0%	12.5%	13.0%	13.5%	14.0%	14.5%	15.0%	Years
1	.905	.901	.897	.893	.889	.885	.881	.877	.873	.870	1
2	1.724	1.713	1.701	1.690	1.679	1.668	1.657	1.647	1.636	1.626	2
3	2.465	2.444	2.423	2.402	2.381	2.361	2.341	2.322	2.302	2.283	3
4	3.136	3.102	3.070	3.037	3.006	2.974	2.944	2.914	2.884	2.855	4
5	3.743	3.696	3.650	3.605	3.561	3.517	3.475	3.433	3.392	3.352	5
6	4.292	4.231	4.170	4.111	4.054	3.998	3.943	3.889	3.836	3.784	6
7	4.789	4.712	4.637	4.564	4.492	4.423	4.355	4.288	4.224	4.160	7
8	5.239	5.146	5.056	4.968	4.882	4.799	4.718	4.639	4.562	4.487	8
9	5.646	5.537	5.431	5.328	5.228	5.132	5.038	4.946	4.858	4.772	9
10	6.015	5.889	5.768	5.650	5.536	5.426	5.320	5.216	5.116	5.019	10
11	6.348	6.207	6.070	5.938	5.810	5.687	5.568	5.453	5.341	5.234	11
12	6.650	6.492	6.341	6.194	6.053	5.918	5.787	5.660	5.538	5.421	12
13	6.923	6.750	6.583	6.424	6.270	6.122	5.979	5.842	5.710	5.583	13
14	7.170	6.982	6.801	6.628	6.462	6.302	6.149	6.002	5.861	5.724	14
15	7.394	7.191	6.997	6.811	6.633	6.462	6.299	6.142	5.992	5.847	15
16	7.596	7.379	7.172	6.974	6.785	6.604	6.431	6.265	6.106	5.954	16
17	7.779	7.549	7.329	7.120	6.920	6.729	6.547	6.373	6.206	6.047	17
18	7.945	7.702	7.470	7.250	7.040	6.840	6.649	6.467	6.294	6.128	18
19	8.095	7.839	7.596	7.366	7.147	6.938	6.739	6.550	6.370	6.198	19
20	8.231	7.963	7.710	7.469	7.241	7.025	6.819	6.623	6.437	6.259	20
21	8.354	8.075	7.811	7.562	7.326	7.102	6.889	6.687	6.495	6.312	21
22	8.465	8.176	7.903	7.645	7.401	7.170	6.951	6.743	6.546	6.359	22
23	8.566	8.266	7.984	7.718	7.467	7.230	7.005	6.792	6.590	6.399	23
24	8.657	8.348	8.058	7.784	7.526	7.283	7.053	6.835	6.629	6.434	24
25	8.739	8.422	8.124	7.843	7.579	7.330	7.095	6.873	6.663	6.464	25
26	8.814	8.488	8.183	7.896	7.626	7.372	7.132	6.906	6.693	6.491	26
27	8.881	8.548	8.236	7.943	7.667	7.409	7.165	6.935	6.718	6.514	27
28	8.942	8.602	8.283	7.984	7.704	7.441	7.194	6.961	6.741	6.534	28
29	8.997	8.650	8.326	8.022	7.737	7.470	7.219	6.983	6.761	6.551	29
30	9.047	8.694	8.364	8.055	7.766	7.496	7.242	7.003	6.778	6.566	30
31	9.093	8.733	8.398	8.085	7.792	7.518	7.261	7.020	6.793	6.579	31
32	9.134	8.769	8.429	8.112	7.815	7.538	7.279	7.035	6.806	6.591	32
33	9.171	8.801	8.456	8.135	7.836	7.556	7.294	7.048	6.817	6.600	33
34	9.204	8.829	8.481	8.157	7.854	7.572	7.307	7.060	6.827	6.609	34
35	9.235	8.855	8.503	8.176	7.870	7.586	7.319	7.070	6.836	6.617	35
36	9.262	8.879	8.523	8.192	7.885	7.598	7.330	7.079	6.844	6.623	36
37	9.287	8.900	8.541	8.208	7.898	7.609	7.339	7.087	6.851	6.629	37
38	9.309	8.919	8.557	8.221	7.909	7.618	7.347	7.094	6.856	6.634	38
39	9.330	8.936	8.571	8.233	7.919	7.627	7.354	7.100	6.861	6.638	39
40	9.348	8.951	8.584	8.244	7.928	7.634	7.361	7.105	6.866	6.642	40
41	9.365	8.965	8.595	8.253	7.936	7.641	7.366	7.110	6.870	6.645	41
42	9.380	8.977	8.606	8.262	7.943	7.647	7.371	7.114	6.873	6.648	42
43	9.394	8.989	8.615	8.270	7.949	7.652	7.375	7.117	6.876	6.650	43
44	9.406	8.999	8.623	8.276	7.955	7.657	7.379	7.120	6.879	6.652	44
45	9.417	9.008	8.631	8.283	7.960	7.661	7.383	7.123	6.881	6.654	45
46	9.427	9.016	8.637	8.288	7.965	7.664	7.386	7.126	6.883	6.656	46
47	9.437	9.024	8.643	8.293	7.968	7.668	7.388	7.128	6.885	6.657	47
48	9.445	9.030	8.649	8.297	7.972	7.671	7.390	7.130	6.886	6.659	48
49	9.452	9.036	8.654	8.301	7.975	7.673	7.392	7.131	6.887	6.660	49
50	9.459	9.042	8.658	8.304	7.978	7.675	7.394	7.133	6.889	6.661	50

TABLE C1 (*continued*)

Years	15.5%	16.0%	16.5%	17.0%	17.5%	18.0%	18.5%	19.0%	19.5%	20.0%	Years
1	.866	.062	.858	.855	.851	.847	.844	.840	.837	.833	1
2	1.615	1.605	1.595	1.585	1.575	1.566	1.556	1.547	1.537	1.528	2
3	2.264	2.246	2.228	2.210	2.192	2.174	2.157	2.140	2.123	2.106	3
4	2.826	2.798	2.770	2.743	2.716	2.690	2.664	2.639	2.613	2.589	4
5	3.313	3.274	3.236	3.199	3.163	3.127	3.092	3.058	3.024	2.991	5
6	3.734	3.685	3.636	3.589	3.543	3.498	3.453	3.410	3.367	3.326	6
7	4.099	4.039	3.980	3.922	3.866	3.812	3.758	3.706	3.655	3.605	7
8	4.415	4.344	4.274	4.207	4.142	4.078	4.015	3.954	3.895	3.837	8
9	4.688	4.607	4.527	4.451	4.376	4.303	4.232	4.163	4.096	4.031	9
10	4.925	4.833	4.745	4.659	4.575	4.494	4.415	4.339	4.265	4.192	10
11	5.130	5.029	4.931	4.836	4.745	4.656	4.570	4.486	4.406	4.327	11
12	5.307	5.197	5.091	4.988	4.889	4.793	4.700	4.611	4.523	4.439	12
13	5.461	5.342	5.228	5.118	5.012	4.910	4.810	4.715	4.622	4.533	13
14	5.594	5.468	5.346	5.229	5.117	5.008	4.903	4.802	4.705	4.611	14
15	5.709	5.575	5.447	5.324	5.206	5.092	4.982	4.876	4.774	4.675	15
16	5.808	5.668	5.534	5.405	5.281	5.162	5.048	4.938	4.832	4.730	16
17	5.895	5.749	5.609	5.475	5.346	5.222	5.104	4.990	4.880	4.775	17
18	5.969	5.818	5.673	5.534	5.401	5.273	5.151	5.033	4.921	4.812	18
19	6.034	5.877	5.728	5.584	5.447	5.316	5.191	5.070	4.954	4.843	19
20	6.090	5.929	5.775	5.628	5.487	5.353	5.224	5.101	4.983	4.870	20
21	6.139	5.973	5.815	5.665	5.521	5.384	5.252	5.127	5.007	4.891	21
22	6.181	6.011	5.850	5.696	5.550	5.410	5.276	5.149	5.026	4.909	22
23	6.217	6.044	5.880	5.723	5.574	5.432	5.296	5.167	5.043	4.925	23
24	6.249	6.073	5.905	5.746	5.595	5.451	5.313	5.182	5.057	4.937	24
25	6.276	6.097	5.927	5.766	5.613	5.467	5.328	5.195	5.069	4.948	25
26	6.299	6.118	5.946	5.783	5.628	5.480	5.340	5.206	5.078	4.956	26
27	6.320	6.136	5.962	5.798	5.641	5.492	5.350	5.215	5.086	4.964	27
28	6.337	6.152	5.976	5.810	5.652	5.502	5.359	5.223	5.093	4.970	28
29	6.353	6.166	5.988	5.820	5.661	5.510	5.366	5.229	5.099	4.975	29
30	6.366	6.177	5.999	5.829	5.669	5.517	5.372	5.235	5.104	4.979	30
31	6.378	6.187	6.007	5.837	5.676	5.523	5.377	5.239	5.108	4.982	31
32	6.387	6.196	6.015	5.844	5.681	5.528	5.382	5.243	5.111	4.985	32
33	6.396	6.203	6.021	5.849	5.686	5.532	5.385	5.246	5.114	4.988	33
34	6.404	6.210	6.027	5.854	5.691	5.536	5.389	5.249	5.116	4.990	34
35	6.410	6.215	6.032	5.858	5.694	5.539	5.391	5.251	5.118	4.992	35
36	6.416	6.220	6.036	5.862	5.697	5.541	5.393	5.253	5.120	4.993	36
37	6.420	6.224	6.039	5.865	5.700	5.543	5.395	5.255	5.121	4.994	37
38	6.425	6.228	6.042	5.867	5.702	5.545	5.397	5.256	5.122	4.995	38
39	6.428	6.231	6.045	5.869	5.704	5.547	5.398	5.257	5.123	4.996	39
40	6.431	6.233	6.047	5.871	5.705	5.548	5.399	5.258	5.124	4.997	40
41	6.434	6.236	6.049	5.873	5.707	5.549	5.400	5.259	5.125	4.997	41
42	6.436	6.238	6.051	5.874	5.708	5.550	5.401	5.260	5.125	4.998	42
43	6.438	6.239	6.052	5.875	5.709	5.551	5.402	5.260	5.126	4.998	43
44	6.440	6.241	6.053	5.876	5.710	5.552	5.402	5.261	5.126	4.998	44
45	6.442	6.242	6.054	5.877	5.710	5.552	5.403	5.261	5.127	4.999	45
46	6.443	6.243	6.055	5.878	5.711	5.553	5.403	5.261	5.127	4.999	46
47	6.444	6.244	6.056	5.879	5.711	5.553	5.404	5.262	5.127	4.999	47
48	6.445	6.245	6.057	5.879	5.712	5.554	5.404	5.262	5.127	4.999	48
49	6.446	6.246	6.057	5.880	5.712	5.554	5.404	5.262	5.127	4.999	49
50	6.447	6.246	6.058	5.880	5.712	5.554	5.404	5.262	5.128	4.999	50

TABLE C1 (*continued*)

Years	21%	22%	23%	24%	25%	26%	27%	28%	29%	30%	Years
1	.826	.820	.813	.806	.800	.794	.787	.781	.775	.769	1
2	1.509	1.492	1.474	1.457	1.440	1.424	1.407	1.392	1.376	1.361	2
3	2.074	2.042	2.011	1.981	1.952	1.923	1.896	1.868	1.842	1.816	3
4	2.540	2.494	2.448	2.404	2.362	2.320	2.280	2.241	2.203	2.166	4
5	2.926	2.864	2.803	2.745	2.689	2.635	2.583	2.532	2.483	2.436	5
6	3.245	3.167	3.092	3.020	2.951	2.885	2.821	2.759	2.700	2.643	6
7	3.508	3.416	3.327	3.242	3.161	3.083	3.009	2.937	2.868	2.802	7
8	3.726	3.619	3.518	3.421	3.329	3.241	3.156	3.076	2.999	2.925	8
9	3.905	3.786	3.673	3.566	3.463	3.366	3.273	3.184	3.100	3.019	9
10	4.054	3.923	3.799	3.682	3.571	3.465	3.364	3.269	3.178	3.092	10
11	4.177	4.035	3.902	3.776	3.656	3.543	3.437	3.335	3.239	3.147	11
12	4.278	4.127	3.985	3.851	3.725	3.606	3.493	3.387	3.286	3.190	12
13	4.362	4.203	4.053	3.912	3.780	3.656	3.538	3.427	3.322	3.223	13
14	4.432	4.265	4.108	3.962	3.824	3.695	3.573	3.459	3.351	3.249	14
15	4.489	4.315	4.153	4.001	3.859	3.726	3.601	3.483	3.373	3.268	15
16	4.536	4.357	4.189	4.033	3.887	3.751	3.623	3.503	3.390	3.283	16
17	4.576	4.391	4.219	4.059	3.910	3.771	3.640	3.518	3.403	3.295	17
18	4.608	4.419	4.243	4.080	3.928	3.786	3.654	3.529	3.413	3.304	18
19	4.635	4.442	4.263	4.097	3.942	3.799	3.664	3.539	3.421	3.311	19
20	4.657	4.460	4.279	4.110	3.954	3.808	3.673	3.546	3.427	3.316	20
21	4.675	4.476	4.292	4.121	3.963	3.816	3.679	3.551	3.432	3.320	21
22	4.690	4.488	4.302	4.130	3.970	3.822	3.684	3.556	3.436	3.323	22
23	4.703	4.499	4.311	4.137	3.976	3.827	3.689	3.559	3.438	3.325	23
24	4.713	4.507	4.318	4.143	3.981	3.831	3.692	3.562	3.441	3.327	24
25	4.721	4.514	4.323	4.147	3.985	3.834	3.694	3.564	3.442	3.329	25
26	4.728	4.520	4.328	4.151	3.988	3.837	3.696	3.566	3.444	3.330	26
27	4.734	4.524	4.332	4.154	3.990	3.839	3.698	3.567	3.445	3.331	27
28	4.739	4.528	4.335	4.157	3.992	3.840	3.699	3.568	3.446	3.331	28
29	4.743	4.531	4.337	4.159	3.994	3.841	3.700	3.569	3.446	3.332	29
30	4.746	4.534	4.339	4.160	3.995	3.842	3.701	3.569	3.447	3.332	30
31	4.749	4.536	4.341	4.161	3.996	3.843	3.701	3.570	3.447	3.332	31
32	4.751	4.538	4.342	4.162	3.997	3.844	3.702	3.570	3.447	3.333	32
33	4.753	4.539	4.343	4.163	3.997	3.844	3.702	3.570	3.448	3.333	33
34	4.755	4.540	4.344	4.164	3.998	3.845	3.703	3.571	3.448	3.333	34
35	4.756	4.541	4.345	4.164	3.998	3.845	3.703	3.571	3.448	3.333	35
36	4.757	4.542	4.345	4.165	3.999	3.845	3.703	3.571	3.448	3.333	36
37	4.758	4.543	4.346	4.165	3.999	3.845	3.703	3.571	3.448	3.333	37
38	4.759	4.543	4.346	4.165	3.999	3.846	3.703	3.571	3.448	3.333	38
39	4.759	4.544	4.346	4.166	3.999	3.846	3.703	3.571	3.448	3.333	39
40	4.760	4.544	4.347	4.166	3.999	3.846	3.703	3.571	3.448	3.333	40
41	4.760	4.544	4.347	4.166	4.000	3.846	3.703	3.571	3.448	3.333	41
42	4.760	4.544	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	42
43	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	43
44	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	44
45	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	45
46	4.761	4.545	4.348	4.166	4.000	3.846	3.704	3.571	3.448	3.333	46
47	4.761	4.545	4.348	4.166	4.000	3.846	3.704	3.571	3.448	3.333	47
48	4.761	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	48
49	4.761	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	49
50	4.762	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	50

1P—25M—9/78—43403

CertainTeed

Technical Bulletin

August 30, 1977

To: All P & PG Sales & Marketing Personnel
All District Sales Managers
All Territory Managers
All Administrative Assistants
All Field Service Managers
All A/C Plant Managers
All Sales Engineers
All Quality Control Managers
All Technical Service Personnel

Fr: Roman P. Korobij - P & PG #8 RPK

Re: 18", 20", 21", and 24" Common
Groove A/C Pressure Pipe

The AWWA has recently made a few changes in the Asbestos Cement Pressure Pipe Specifications. AWWA C 400 "Standard for A/C Pressure Pipe 4" through 24" for Water"specification has been modified to include only sizes 4" through 16". AWWA C 402 " Standard for A/C Transmission Pipe 18" through 42" for Water" specification, which has been in print for some time, will be the only A/C Pressure Pipe recommended by the AWWA for those sizes.

Essentially, this means that A/C Pressure Pipe will no longer be manufactured in sizes 18" through 24" in Classes 100 and 150. Instead, we will manufacture and promote Fluid Transmission Pipe in sizes 18", 20", 21", and 24" for all pressure applications. This change will be completed as soon as our existing stock of 18", 20", 21", and 24" class pipe has been exhausted.

The large safety factors used in class pipe are not needed for transmission lines due to the fact that surge pressures for fluid transmission lines can be calculated and controlled. Small diameter class pipes which are predominately used for distribution systems, require high safety factors. Water distribution networks contain surges which are difficult to calculate and control.

Our Fluid Transmission Pipe presently has a common groove configuration in sizes 18" through 24" which uses a round rubber ring. The round rubber rings

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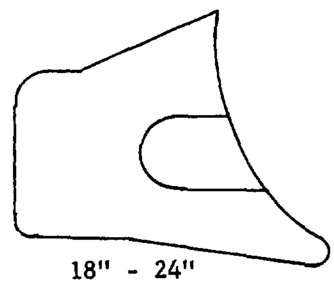
will continue to be used in the 18" - 24" sizes when used on Bureau of Reclamation funded jobs. The 18", 20", and 24" round rubber rings however, will be replaced with our common groove rubber rings (see figure) in all other applications.



Common Groove Pressure
Ring

Assembly of the new rings should follow the same procedure as applied to any large diameter pipe. The following should be observed:

1) Clean Groove before insertion of ring.

2) Run finger around inserted ring to insure that ring is properly sealed.

3) Lubricate pipe O D 1 twice.

4) Lubricate rubber ring.

5) Use feeler gauge after assembly.

Fluid Transmission Pipe with Common Groove Rings will be available in all sizes at Riverside and most sizes, at Ambler. The 18" size will also be available at Hillsboro.

Sewer

FACTS YOU SHOULD KNOW ABOUT INFILTRATION

A/C Sewer Pipe posseses a jointing system that is innately tighter than any compression joint on the market. Competitive compression joints are either cast or heat formed. The A/C joint is machined. Machining permits the use of closer tolerances than competitive pipe and this is particularly true in relation to a cast joint. Closer tolerances obviously produce tighter joints.

The ASTM C428 specification for A/C Sewer Pipe recommends an infiltration allowance of 100 gallons per inch of diameter per mile of pipe per day. The infiltration allowance generally employed by the engineering community is 250 gallons per inch of diameter per mile of pipe per day or 150 inch-gallons greater than that recommended for A/C Sewer pipe. You can get some mileage out of this difference in infiltration allowance but will have to handle it judicially so that you do not fall into the trap of facing a specification of 100 inch-gallons for A/C pipe and 250 inch-gallons for the competitive products. Obviously, if a contractor looked at this type of a specification the decision would be pretty easy for him to opt for a product that requires 250 inch-gallon test.

Secondary treatment of sewage waste has been mandated by the federal government. The present cost for secondary treatment is 55¢ per thousand gallons. Teritary treatment is rapidly becoming a reality which will probably double the cost of secondary treatment. Secondary and teritary treatment produces a strong incentive for very tight sewers.

Below we have gone through a cost exercise to show the potential savings to a community that has the benefit of a 100 inch-gallon tight sewer vs. a 250 inch-gallon not so tight sewer.

Flow Capacity

CertainTeed

Technical Bulletin

September 30, 1975

TO: VF P&PG MARKETING & SALES PERSONNEL
ALL DISTRICT MANAGERS
ALL TERRITORY MANAGERS
ALL ADMINISTRATIVE ASSISTANTS
ALL A-C & PVC PRODUCT MANAGERS
ALL FIELD SERVICE MANAGERS
ALL SALES ENGINEERS

FM: T. A. SWITALSKI T. A. Switalski

RE: A-C AND PVC SEWER PIPE FLOW CALCULATOR

Attached is our new revised Sewer Pipe Flow Calculator for use with both A-C and PVC Gravity Sewer Pipe (ASTM D 3034 SDR 35). Also enclosed is a revised instruction booklet to explain how the calculator can be used.

The flow calculator is based on the Manning Formula with a Manning Factor of n = .009 for PVC and n = .010 for A-C. Also the pipe diameters are plotted as actual internal diameters, but indicated as nominal diameters, thereby giving an exact answer for any flow calculations involving our A-C or PVC Sewer Pipe.

Note that 15" PVC Sewer Pipe (D 3034 SDR 35) is also included on the calculator even though we don't presently manufacture it. The reason is that we are planning for the future.

To distinguish this calculator from the previous one, we have inserted ASTM D 3034 (SDR 35) in bold letters on the PVC side. Don't discard your old D 3033 calculators (if you have any) since you may still get requests for them.

If further supplies are needed, contact the Advertising Department.

CTD029788

A/C & PVC SEWER PIPE FLOW CALCULATOR

In September 1975, the attached bulletin concerning the CertainTeed Sewer Pipe Flow Calculator was sent to all field personnel. Due to cost and an adequate place to carry the calculator in this binder, we have chosen not to include the calculator itself.

This calculator is still available upon request to the Advertising Department.

Competitive Products

CertainTeed

Technical Bulletin

October 31, 1975

TO: VF P&PG SALES & MARKETING PERSONNEL
DISTRICT MANAGERS
TERRITORY MANAGERS
SALES ENGINEERS
CUSTOMER SERVICE MANAGERS
ADMINISTRATIVE ASSISTANTS
FIELD SERVICE MANAGERS

Note: THIS BULLETIN IS FOR INTERNAL USE ONLY --NOT FOR GENERAL DISTRIBUTION!

FR: E. J. LAWLESS EJL

RE: TRUSS PIPE VS. A-C AND PVC

Truss Pipe was introduced in the mid 60's in Ohio and since then, has gained acceptance in many other areas. Because we can expect even greater penetration into our market areas, it would be well for our men to be familiar with the qualities of Truss Pipe. This bulletin is written for that reason.

Truss Pipe is made by Armco. There are two types of Armco Pipe; (a) the smaller sizes 4" and 6" are solid ABS Plastic and are not of the truss construction and (b) Truss Pipe in sizes of 8" through 15" which is of truss construction and consists of three elements -- an inner lining , an outer casing and a Perlite-cement filler.

Truss Pipe is made to Specification ASTM D 2680 and is considered by the manufacturer to be a flexible conduit. The inner lining is .060" thick and the outer casing is .035" thick (8" size), per ASTM 2680. The two elements are separated by a web or truss which is also quite thin and spaces in the truss construction are filled with a Perlite-cement aggregate. These three elements work in unison to give the pipe its characteristic flexibility and stiffness. We thus, have a rather complex, sophisticated pipe which was designed to be used under one of the most severe and demanding of all construction conditions; i.e., a sewer line that must perform for decades, buried in the ground under various relatively unknown conditions with the added burden of great earthload pressures. Should any one of these fragile elements fail, then the pipe fails.

The Perlite-cement aggregate serves the purpose of keeping the two shells apart. It contributes little, if any, strength of itself. Perlite-cement aggregate has a compressive strength of only 3-400 pounds per square inch (and is almost zero in tensile strength). As a frame of reference, compare this to PVC Plastic at 8500 psi, concrete at 3-400 psi, and A-C at 10-12,000 psi. Obviously, the Perlite contributes virtually nothing from a strength standpoint. Its purpose is as a "spacer". Nevertheless, its contribution as a spacer is extremely important. Should the Perlite fail--for example,

CTD029790

if there are voids in the Perlite, which would be undetectable after manufacturing (ASTM 2680 states, "Perlite--which essentially fills the truss...". Note the specification does not say "completely"), or if the inner liner is abraded away with use, then that section of the pipe will fail--if not immediately, then fail in time. Further, little is known about Perlite-cement mixtures relative to sewage. It is quite possible that sewage would adversely affect Perlite-cement (Perlite-cement is neither cement nor concrete as we know it). Perlite-cement absorbs about forty percent water. This means that if a leak should occur--particularly at an exposed end in a manhole or at a joint--then the sewage would migrate through the Perlite with unknown consequences (ASTM 2680 states under "Joint Tightness", that "Leakage through the inert filler shall not be considered a reason for rejection"). These are the risks the engineer takes when he specifies Truss Pipe.

The ABS Plastic of which the inner shell and the outer shell is composed is not only very thin, but it is not as inert as PVC. ABS is more readily attacked by more compounds than is PVC and it is an accepted fact that PVC is a superior product for sewer pipes. When plastic sewer pipe was first introduced in Germany, both ABS and polyethelene were the principal plastics used. After many years of experience, it was found that PVC was superior to both of these compounds. Accordingly, sewage systems abroad are now virtually all PVC and when plastic pipe was introduced in the United States for sewage systems, PVC quickly became the favored plastic. Please note that almost all the major manufacturers of large diameter sewer pipe produce PVC, not ABS--with the exception of the uniquely designed Armco product. ABS, on the other hand, is more widely used for DWV than is PVC. Conditions in DWV applications are far less severe than those in gravity sewer systems and for this use, ABS works quite well.

From a performance standpoint, we believe it is expecting far too much of the inner liner which can vary from only 1/16" to 3/32" to last for up to fifty years. Not only must it withstand abrasion for these many years, but it must in no way become separated from any of the other two elements. One cannot help but make the comparison between a 1/16" liner and the almost 1/4" thick PVC Sewer Pipe (SDR 35) and 3/4" thick A-C Pipe.

While Truss Pipe is considered a flexible conduit, at the same time, it is quite stiff; i.e., it has a stiffness of 200 as compared to a truly flexible conduit such as PVC at 46 (SDR 35). This would appear to be a plus for Truss; but it is not. Truss Pipe, while it is comparatively stiff, must at the same time be bedded and receive soil side support exactly the same as PVC Pipe. If Truss Pipe is bedded as a rigid conduit; that is, without side support from tamping (Armco recommended a Proctor Density of 90--the same as PVC), then it will deflect quite easily and rupture. The crushing strength of Truss Pipe is 1500 pounds per lineal foot when the pipe is vertically deflected to 7.5 percent. This means that when a Truss Pipe is placed under a load in excess of 1500 pounds, it can fail, for then the deflection would be greater than 7.5 percent. (ASTM 2680 sets 7.5 percent as a criteria and Armco recommends a maximum of 5 percent) Please note here that a trench 3 feet wide has a soil load of 1530 pounds at a burial depth of only 9 feet. In addition, if the pipe is buried without adequate side support, then due to its nature, the constant earth load will induce creeping and ultimately the pipe will rupture after a period of time. PVC, on the other hand, will not rupture under even the worst laying conditions (Our standard laboratory test requires that the sample be flattened 100 percent without splitting, cracking or other evidence of failure.).

In short, then, the stiffness of Truss Pipe is a distinct disadvantage--not an advantage as is claimed. Truss Pipe has all the disadvantages of a stiff pipe and none of the advantages of a flexible pipe. It has the disadvantages of both and the advantages of neither.

Insofar as contractor acceptance is concerned, Truss Pipe has serious drawbacks:

A. Air testing has grown extensively and we venture to say that soon virtually all sewer lines will be air tested. There are many pitfalls for Truss Pipe in air testing. The pipe as received from the manufacturer, has exposed ends. The contractor's workmen, when installing the sleeve type coupling, must be absolutely certain to thoroughly cover the exposed ends with cement. If a "holiday" is left, then air will leak through into the Perlite and depending upon the number of holidays, the line may or may not test. Additionally when saddles are placed and solvent welded on, a hole must be cut in the pipe with a saber saw. We need not point out how ragged this hole can be. The jagged edges must be thoroughly coated with cement or the line may not test. At the manholes--the exposed ends of the pipe, unless carefully coated, are subjected to sewage absorption and possible deterioration of the Perlite-cement. When an air leak or water leak does occur, due to the migration of the air or water through the truss, location of the leak is sometimes a virtual impossibility from a practical standpoint.

B. The sleeve couplings must be solvent welded. Solvent welding under laboratory or ideal conditions makes a good water-tight joint. However, in actual field conditions in wet trenches, a good solvent welded joint, in large size pipe, is at best very chancy. It is specifically for this reason that we no longer offer solvent welded joints in our sewer pipe line. A solvent welded joint is far from fool-proof and depends exclusively on the attention and care of the laborers.

C. Impact resistance is low. Truss Pipe has an impact strength of 100 ft. lbs. (per Truss literature) while PVC has an impact strength of 284 ft. lbs. (8" pipe) and 299 ft. lbs. (12" pipe)--almost three times higher. Impact resistance, for example, ability to withstand falling rocks and other rough conditions generally encountered during handling and installation, is extremely important to a contractor.

In summary, Truss Pipe does not have the inherent strength of A-C nor does it have the advantages of the flexibility of PVC. Its initial risk factor is greater and in the long term, it does not have the integrity of either. The sole advantage it does have is that of initial cost per foot--a very bad bargain for the engineer, the contractor, and the man who ultimately pays the bill--the taxpayer.

cc: R. S. Hartman VF P&PG #2
C. W. Peek, McPherson #278

CertainTeed

Technical Bulletin

May 13, 1974

TO: VF P&PG MARKETING AND SALES PERSONNEL
ALL DISTRICT MANAGERS
ALL TERRITORY MANAGERS
ALL ADMINISTRATIVE ASSISTANTS
ALL A-C PRODUCT MANAGERS
ALL FIELD SERVICE MANAGERS
ALL SALES ENGINEERS

FM: T. SWITALSKI T. Switalski

RE: CRUSHING STRENGTH OF A-C VS. CLAY SEWER PIPE

We have recently begun a series of tests to thoroughly evaluate vitrified clay sewer pipe and to compare the advantages and disadvantages of vitrified clay sewer pipe with asbestos-cement sewer pipe.

Initially, we have begun by testing our asbestos-cement pipe and clay sewer pipe in crush tests. The pipes were subjected to crush tests using the 3-edge bearing method. This test method is described in ASTM C500-73a for asbestos-cement sewer pipe and C301-72 for clay sewer pipe. The required crushing strengths are found in C644-71 and C428-73d for asbestos-cement sewer pipe and C700-71T for clay sewer pipe. These requirements are listed on the attached table.

Basically, the difference between the ASTM testing methods is that the clay sewer pipe is crush tested using rubber or plaster blocks, while asbestos-cement sewer pipe is crush tested using wood blocks. Also, the clay pipe standard specifies that a complete length of pipe be tested, usually 5 or 6 ft., while the asbestos-cement standard specifies that a 1 ft. sample be tested.

The first tests run were performed on 8 inch extra strength clay sewer pipe and 8 inch Class 2400 asbestos-cement pipe, since this is the most frequently used size and class. As a result of these tests, we have derived the equivalent crushing requirement for asbestos-cement pipe using rubber blocks and plaster blocks instead of wood blocks. Our tests show that using rubber blocks increase the crushing value of asbestos-cement pipe by 37 percent and using plaster blocks increase the crushing value of asbestos-cement pipe by 30 percent over that with wood blocks. This results in the following equivalency table:

CTD029794

Comparative Minimum Requirements of 8" A-C & Clay Sewer Pipe

Method	8" Extra Strength Clay	8" Class 2400 A-C
Wood		2400
Rubber	2200	3290
Plaster	2200	3120

Similar tests were run to determine what the requirement for clay pipe would be if wood blocks were used to test the clay pipe. The results were varied and therefore not conclusive enough to make general statements about. Also, tests were run on 8" Extra Strength Clay sewer pipe manufactured by different companies and the crushing strengths were found to vary considerably.

Tests were also run to determine the crush strength of recently manufactured 4" Vitrified Clay sewer pipe as compared to 4" VC sewer pipe which had been sitting in a distributor's yard for 6 years. The results of these tests show that the modulus of rupture for crushing strength was lower for the 6-year-old pipe by 10 percent. The 6-year-old pipe, however, still passes the minimum requirements for VC pipe. The small number of crush tests run restricts us from making this a general statement for all clay pipe. However, it is understood from various sources that clay sewer pipe does loose some degree of strength as a result of weathering.

It should be noted that vitrified clay sewer pipe would be at a disadvantage if it was tested using wood blocks since clay pipe is brittle and has an uneven surface. Wood blocks cannot fill these surface irregularities in a crush test while rubber and plaster can. These irregularities and brittleness are the reason that clay pipe comes only in short lengths and has a thicker wall than A-C pipe.

The equivalent to 8" Extra Strength Clay sewer pipe is 8" Class 2400 asbestos-cement sewer pipe and as noted in the above table, the required minimum crushing strength of the asbestos-cement pipe is greater by at least 43 percent. This relationship between the crushing strengths of A-C and clay sewer pipe is true only for 8" pipe and is a function of the diameter. Further tests are to be run to determine what the relationship is in larger sizes.

MINIMUM CRUSHING STRENGTHS, lb./linear ft.

Nominal Pipe Size, In.	Asbestos-Cement Non-Pressure Sewer Pipe C644-71, C428-73d					Clay Sewer Pipe ASTM C700-71T	
	Class 1500	Class 2400	Class 3300	Class 4000	Class 5000	Standard Strength	Extra Strength
4"	1500	2400	3300	----	----	1200	2000
5"	1500	2400	3300	----	----	----	----
6"	1500	2400	3300	----	----	1200	2000
8"	1500	2400	3300	----	----	1400	2200
10"	1500	2400	3300	4000	5000	1600	2400
12"	1500	2400	3300	4000	5000	1800	2600
14"	1500	2400	3300	4000	5000	----	----
15"	----	----	----	----	----	2000	2900
16"	1500	2400	3300	4000	5000	----	----
18"	----	2400	3300	4000	5000	2200	3300
20"	----	2400	3300	4000	5000	----	----
21"	----	----	----	----	----	2400	3850
24"	----	2400	3300	4000	5000	2600	4400

CertainTeed

Technical Bulletin

August 15, 1974

TO: VF P&PG MARKETING & SALES PERSONNEL
DISTRICT MANAGERS
TERRITORY MANAGERS
ADMINISTRATIVE ASSISTANTS
A-C PRODUCT MANAGERS
A-C FIELD SERVICE MANAGERS
SALES ENGINEERS

FM: T. SWITALSKI T. Switalski

RE: AIR TEST COMPARISON OF VITRIFIED CLAY SEWER PIPE AND ASBESTOS-CEMENT SEWER PIPE

Low pressure air testing of sewer pipe is becoming increasingly common. It is an inexpensive, easy and very reliable method of checking tightness of sewer lines. Most specifications today which specify air testing rely on the air testing procedure and standards as defined by the American Society of Civil Engineers, Low Pressure Air Test for Sanitary Services, 1964. This is the basis for our air test procedure as printed in our A-C Sewer Pipe Installation Guide.

Exfiltration air tests were run at our North Wales Facility on 8" Extra Strength Vitrified Clay Sewer Pipe with Type 3 joints (polyester groove with rubber gasket usually O ring) and on 8" Class 2400 Asbestos-Cement Sewer Pipe. The air tests were conducted to determine the loss of air through the pipe wall and to determine the loss of air through the gasketed joint.

Joint requirements for Clay Sewer Pipe are covered in ASTM C425-72a and for A-C Sewer Pipe are covered in ASTM C428-73d. In addition, our Standard Product Specifications include Joint Specifications. None of these specifications include air testing; hydrostatic testing is only considered.

The Type 3 clay pipe joints which were tested consisted of bell and spigot pipe with polyester lining the outside of the spigot and the inside of the bell. The polyester lining inside the bell seemed to be machined since the I.D. of the bell was almost perfectly round. Clay pipe as we all know, is usually oval to some degree, therefore we must conclude that the polyester in the bell is machined.

The spigot end with the polyester lining was somewhat oval. Also the spigot end had a groove in the polyester for a round rubber gasket. This is not true for all clay joints. Many clay sewer joints are used without rubber gaskets.

CTD029797

The clay pipe tests were performed in the concentric position, the angular offset position, and the lateral offset position using internal air pressures of 3 psi and 10 psi. Each of these pressures were held for 10 minutes. Although the clay sewer pipe showed a pressure drop in all tests, it did however pass the test as specified in our installation manual. In all tests, the air loss was through the pipe wall and no air leakage was evident at the joint. This was apparent when the entire pipe surface and joint was covered with a soapy solution. Bubbling was evident on the entire surface.

The moisture content in the clay pipe wall was varied from bone dry to saturated. The air loss through the pipe wall varied in each test depending on the moisture in the pipe wall. Only when the clay pipe was 100 percent saturated was there no air loss.

Similar tests were run on 8" Asbestos-Cement Sewer Pipe Class 2400 using similar conditions; that is, internal air pressures of 3 psi and 10 psi. These tests were also run in the concentric position, the angular offset position, and the lateral offset position. Each of these pressures were held for 10 minutes.

Tests were run on the A-C pipe while the pipe wall was bone dry and saturated wet. In either case, there was no drop in air pressure.

Our tests have confirmed that although our installation catalog specifies that "Wetting is necessary to minimize any loss of air through the pipe wall as a result of permeability in the dry condition", this is true only for clay sewer pipe. A-C sewer pipe, if properly installed, will have no drop in air pressure when air tested.

Many specifications state that if the ground water table is above the installed sewer line, the pressure on the outside joint due to the ground water should be added to the internal air pressure of 3.5 psi to air test the installation. This difference will have little affect on A-C sewer pipe, but may have a great affect on clay sewer pipe.

This technical bulletin is for general information and does not eliminate or supersede the policies presented in our previous Technical Bulletin Gen. 6 - Low Pressure Air Testing for Sewer Line.

Corrosion

CORROSION & SEWER PIPE

Books have been written and many lifetimes spent trying to quantify the question of corrosion and it's effects on treatment plants and piping materials utilized to meet man's waste disposal needs. Below you will find an excerpt from a paper written by Frank Duffy. The reams of technical data and years of experience needed to substantiate this data is available if needed.

No discussion of sewer pipe materials would be complete without addressing the favorite straw men of the Vitrified Clay Pipe and plastic pipe interest. Damaging ph values and H_2S generation have been played up out of all proportion to their frequency of occurence.

Asbestos Cement Sewer pipe can accommodate sewage with a ph value of 4.5. Because strong acid wastes are corrosive to sewers, structures and equipment and also harmful to biological waste water treatment processes a ph below 5.5 is considered inadmissable by the Water Pollution Control Federation. Practically all sewer ordinances require equalization by mixing or neutralization by chemical additives to produce an industrial waste with a ph value higher than 5.5. This would indicate that the problem of corrosive attack by industrial waste on Asbestos Cement Sewer pipe is controlled by sewage ordinances. The one exception would be those factories which use metal pickling or other acids in plant processes. Although the effluent from these plants is rigidly controlled human error could seriously damage a sewer line. Therefore, the use of Asbestos Cement pipe adjacent to chemical, electroplating, engraving, metal pickling plants or sulfite paper mills would be reluctantly recommended. It has been established that in sanitary sewer carrying industrial waste, there is sufficient dilution to raise the ph to acceptable levels for the intercepting sewer.

Cost Effectiveness

CertainTeed

Technical Bulletin

TO: W. A. Krivsky
All P&PG Group Officers
All A/C Marketing Personnel
All District Sales Managers
All Territory Managers
All Field Service Managers
All Sales Engineers
All A/C Plant Managers
Technical Service People
Director of Communications

FR: Norman P. Sutterer/bam NPS

RE: "ASBESTOS CEMENT SEWER PIPE - AN EVALUATION OF ITS INTEGRITY AND CAPABILITIES"

DATE: 6/12/78

Attached is a paper entitled "Asbestos Cement Sewer Pipe - An Evaluation of Its Integrity and Capabilities" which was written in 1969 by Frank T. Duffy, Marketing Manager for A/C Sewer Pipe.

The paper is an excellent overview of A/C sewer pipe and its' place in the market almost ten years ago. As you take a few minutes to read this article it will become apparent that the A/C sewer pipe of yesterday is still a viable, capable product in today's market.

It's note worthy to mention that ASTM currently has under consideration a change in the classes of sewer pipe to a three series pipe classification. You will be given more information as these developments become part of the standard.

I strongly urge you to take the time to review this bulletin as it is the perfect mini refresher course in what the A/C sewer pipe is all about.

CTD029802

ASBESTOS CEMENT SEWER PIPE

An Evaluation of Its

Integrity and Capabilities

By: Frank T. Duffy, P.E.
Marketing Manager
A/C Sewer Products
CertainTeed Corporation

Asbestos cement sewer pipe was introduced in this country in the late nineteen thirties. In the succeeding thirty some odd years it has become a preferred sewer pipe throughout the United States. This preference is predicated on its excellent flow characteristics, exceptional chemical stability and resistance to scour, highest order of structural integrity, extremely tight yet flexible joints, competitive installation and material cost, full complement of fittings, most satisfactory use experience and life expectancy equal to any sewer pipe material.

This preference is understood if one considers that asbestos cement pipe is a superior reinforced concrete pipe that is inorganic and non-metallic. Asbestos fibers are employed for tensile reinforcing rather than steel wire. These fibers possess a tensile strength of 300,000 psi as compared to the 40,000 psi to 60,000 psi strength values of steel wire. Also, these fibers are inorganic and therefore cannot corrode and lose strength.

Silica, the hardest, most durable aggregate obtainable is used in the concrete mix. The silica is ground to the consistency of flour and mixed with Portland cement, water and asbestos fibers. The mix is then laminated under tremendous pressure to produce a high density concrete that has a modulus of rupture that is well in excess of three times the modulus of rupture for concrete sewer pipe.

The superior reinforced concrete sewer pipe is then cured by high pressure steam in huge autoclaves. Ordinary concrete sewer pipe is steam cured without the benefit of pressure. High pressure steam curing accomplishes two things. It produces a 28 day strength in sixteen hours, thereby accelerating production and reducing the cost of the pipe. It also induces a chemical reaction between the free lime in the cement and the silica to reduce the free lime to less than 1%. Hence asbestos cement sewer pipe possesses extraordinary chemical stability that eliminates the problem of corrosion. It should be noted that concrete sewer pipe contains between 8% and 12% free lime and it is the free lime that permits and promotes deleterious attack on sewer pipe.

The lamination process is performed on a steel mandrel that has a trowelling effect on the interior surface of the pipe as it is withdrawn. The smooth, almost polished, surface thus produced in conjunction with pipe joints every thirteen feet creates a friction coefficient of n = 0.010. This friction coefficient was verified by R. D. Pomeroy in the field tests on asbestos cement, concrete and vitrified clay sewers. The test report was presented at the 1965 annual W.R.C.F. meeting in Atlantic City.

In this paper, Pomeroy debunked the age old myth that all sewer pipes have the same friction coefficient. He established that the innate smoothness of the pipe wall and the number of joints in the sewer line produce a marked differential in the flow capacity of various sewer pipe. This advantage in flow characteristics permits the use of 14" asbestos cement sewer pipe in lieu of 15" vitrified clay or concrete sewer pipe with the resultant first cost savings. In many instances, a 16" asbestos cement sewer pipe can be used in lieu of an 18" concrete or vitrified clay sewer pipe realizing an even greater first cost savings. There is also the advantage in situation when grade is critical, of achieving cleaning velocities at a lesser slope.

The quality of raw materials and the production techniques produce in asbestos cement sewer pipe the widest spectrum of pipe strength in the sewer pipe industry. Asbestos cement pipe offers the engineer crushing strengths of 1500 lbs./ft., 2400 lbs./ft., 3300./ft., 4000 lbs./ft. and 5000 lbs./ft. In situations of extraordinary earth or superimposed loads the wide range of pipe strengths available in asbestos cement pipe negate the necessity for concrete cradles. The substantial savings this affords is obvious.

The era of more sophisticated waste water treatment is rapidly arriving. Tertiary treatment is just around the corner. This cost of this more sophisticated treatment will preclude the luxury of exorbitant infiltration. An infiltration allowance of 250 gpd/in/mile is rapidly becoming obsolete and unacceptable. Sewers should be considered in terms of water main tightness.

The joint on asbestos cement sewer pipe is machined to tolerances of 0.04 and the dual gasket controlled gap design of the coupling produces the tightest most flexible sewer joint available. Infiltration tests on asbestos cement pipe sewer of 50 gpd/in/mile are commonplace and 150 gpd/in/mile is considered an upper limit on performance.

The cost of sewer construction is ever spiralling upward but the engineer can help hold down these costs by affording the contractor an opportunity to bid a pipe material in which he has the most confidence. Time after time, in open competition with other pipe materials, the contractor has demonstrated the most confidence in the machined dual gasket joints on asbestos cement pipe. The contractor also enjoys reduced labor costs due to the relatively long lengths and light weight of asbestos cement pipe. The pipe is handled at the trench site with ease and the long lengths permit the pipe layer to establish line and grade more readily.

Air testing sewer lines in lieu of exfiltration tests is rapidly gaining wider and wider acceptance among the contractors and engineers. Compressing air is much less costly than trucking water. Air testing is quicker and is accomplished with greater ease. At the end of the day the contractor can proof test that day's production in about fifteen minutes. It is readily seen that air testing dramatically reduces the cost of testing sewers. Obviously, if a contractor has available to him a substantially improved, although much more rigid method of testing sewers, he will select the sewer pipe with the tightest joint and the greatest structural integrity. Asbestos cement pipe has demonstrated the greatest compatability with air testing.

Although first cost is not the sole factor in determining the selection of a sewer pipe material, it is, in these inflationary times, a factor that must be seriously considered.

Asbestos cement pipe, because of its great structural integrity, ease of installation and surety of performance, is completely competitive with the other sewer pipe materials. In open competitive bidding it has been demonstrated time and again that asbestos cement pipe offers a first cost saving. We do not seek a proprietary specification, although one could be justified. We welcome competition with the full knowledge we can compete.

Asbestos cement sewer pipe is complemented by a complete line of asbestos cement sewer fittings plus the capability of field tapping the pipe without compromising the tightness of the sewer system. The asbestos cement fitting line includes a complete size range of wyes, tees, 30 degree, 45 degree and 90 degree elbows, end caps and plugs, drop manhole connections and adaptors to both cast iron soil pipe and vitrified clay sewer pipe. Because asbestos cement pipe is readily machineable virtually any special requirement can be met on request.

Also, the machineability of this pipe permits the field insertion of wye or tee branches into the wall of the existing sewer by cutting a hole to close tolerances, rather breaking an undefined hold in the side of the pipe with the resultant risk of fracturing the existing sewer pipe and great difficulty of sealing the inserted wye leg against infiltration.

No discussion of sewer pipe materials would be complete without addressing the favorite straw men of the vitrified clay pipe and plastic pipe interest. Damaging ph values and H_2S generation have been played up out of all proportion to their frequency of occurence.

Asbestos cement sewer pipe can accommodate sewage with a ph value of 4.5. Because strongly acid wastes are corrosive to sewers, structures and equipment and also harmful to biological waste water treatment processes a ph below 5.5 is considered inadmissable by the Water Pollution Control Federation. Practically all sewer ordinances require equalization by mixing or neutralization by chemical additives to produce an industrial waste with a ph value higher than 5.5. This would indicate that the problem of corrosive attack by industrial waste on asbestos cement sewer pipe is controlled by sewage ordinances. The one exception would be those factories which use metal pickling or other acids in plant processes. Although the effluent from these plants is rigidly controlled human error could seriously damage a sewer line. Therefore, the use of asbestos cement pipe adjacent to chemical, electroplating, engraving, metal pickling plants or sulfite paper mills would be reluctantly recommended. It has been established that in sanitary sewers carrying industrial waste, there is sufficient dilution to raise the ph to acceptable levels for the intercepting sewer.

Numerous tests on domestic sewage shows conclusively that dilution tends tc neutralize the sewage with slight variation back and forth on the acid and alkaline side. With the exception of highly acidic waste peculiar to a very limited number of industrial processes asbestos cement pipe can accommodate any industrial and domestic waste encountered.

Hydrogen sulfide disintegration is largely a myth. There has been no reported cases of H_2S disintegration in Ohio in the last twenty years. The reason, quite simply, is that modern sewers are so designed and constructed that they do not produce the conditions necessary for H_2S generation.

The conditions necessary for H_2S are low flows, high B.O.D., high temperatures and little ventilation. H_2S generation is a bio-chemical action promoted by the bacteria, as that of any living organism, must be supported by shelter or residence, food and oxygen.

The shelter or residence of these bacterial is the slime and sludge deposits peculiar to combined sewers with dry weather flow or sanitary sewers with less than 2 fps velocities. Cleaning velocities eliminate the breeding ground for these bacteria.

The food for these bacterial is found in the organic matter of the sewage and is most abundant in stagnant sewage. Cleaning velocities of 2fps minimizes the age of the sewage and promotes the absorption of oxygen which reduces the B.O.D. A minimum temperature of 70 degrees F. is necessary for any significant growth and reproduction of these bacteria.

The oxygen requirements are met by consuming the oxygen in the sulphates dissolved in sewage and releasing the sulphur which then combines with hydrogen to form dissolved hydrogen sulphide. Ventilation permits self-oxidation of the sewage and deters the formation of sulphides.

The modern day sanitary sewer is designed and constructed to produce a 2 fps velocity which eliminates a home for the bacteria. It also reduces the age and concentration of the sewage which diminishes the bacteria's food supply. The sewer is designed to flow half full which permits adequate ventilation to produce self-oxidation of the sewage and prevent sulphide build up. In the northern half of the United States the sewage temperatures are too moderate to promote significant bacterial growth and reproduction. For these reasons it can be stated that sewer disintegration due to H_2S build up is largely a myth.

However, because of the lack of oxygen, sewage detained in force mains or siphons can produce a serious sulphide problem. Since H_2S in solution is very corrosive to metals, engineers are well advised to specify a non-metallic pipe such as asbestos cement pressure pipe for all force mains and siphons. Not only does asbestos cement pressure pipe possess an immunity to corrosion, with the resultant reduced maintenance cost; but its high flow characteristics reduce pumping cost and its prudent design criteria affords substantial first cost reductions.

As stated in the beginning of this paper asbestos cement sewer pipe is a superior reinforced concrete pipe and as such its use experience and life expectancy can be equated to concrete sanitary sewer pipe which was developed in this country in 1840. Since asbestos cement sewer pipe is denser, stronger and smoother than ordinary concrete sewer pipe its durability and capabilities are greater than ordinary concrete sewer pipe.

A manufacturers <u>right</u> to go freely into the marketplace and compete is fundamental to our economic system. It is this competitive abrasion that assures the owner of the best possible first cost and therefore, in the owner's interest, the competitive base should be made as broad as possible.

Asbestos cement pipe offers the engineer an opportunity to broaden this competition base with a proven product that has over thirty years of us experience to support it. Asbestos cement sewer pipe will reduce maintenance and operational costs because of its high flow capabilities and tight but flexible joints. Asbestos cement sewer pipe has a life expectancy equal to or greater than any sewer pipe available on the market today.

It would be a disservice to the owner and our industry to disallow our right to compete as equals with the other sewer pipe materials available in the market.

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Installation/Testing

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Recommended Practice for
INSTALLING VITRIFIED CLAY PIPE LINES[1]

This Standard is issued under the fixed designation C 12; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This recommended practice covers the proper methods of installing vitrified clay pipe lines in order to utilize the structural properties of such pipe to their fullest advantage.

2. Applicable Documents

2.1 *ASTM Standards:*

C 425 Specification for Compression Joints for Vitrified Clay Pipe and Fittings[2]

C 700 Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated[2]

C 828 Recommended Practice for Low-Pressure Air Test of Vitrified Clay Pipe Sewer Lines (4 to 12-in.)[2]

3. Pipe Strength

3.1 The field supporting strength of vitrified clay pipe is materially affected by the methods of installation. The field supporting strength of a pipe is its ability to support dead and live loads under actual field conditions and is dependent upon two factors: (*1*) the inherent strength of the pipe and (*2*) the manner in which the pipe is bedded.

3.2 The inherent strength of the pipe is fixed by the shape of the pipe, the materials used, and the method of manufacture. The applicable ASTM pipe specification stipulates the minimum crushing strength for each type and class of pipe.

3.3 The tests used to measure crushing strength determine relative pipe strengths but do not represent actual field conditions. Therefore, an adjustment called a load factor must be introduced to convert test crushing strength to field supporting strength. The load factor depends on how the pipe is bedded. The relationship is as follows:

Field supporting strength
= three-edge-bearing strength × load factor

3.4 An appropriate factor of safety should be applied to the field supporting strength to calculate a safe supporting strength as follows:

Safe supporting strength
= (three-edge-bearing strength × load factor)/factor of safety

4. External Loads

4.1 The external loads on vitrified clay pipe are of two general types: (*1*) earth loads and (*2*) live loads.

4.2 For pipes installed in trenches, the earth load increases with the trench width measured at the top of the pipe, regardless of pipe size. Consequently, the trench width at the top of the pipe should be kept as narrow as possible, consistent with providing adequate working space at the sides of the pipe. Pipe failure may result if the design trench width is exceeded. If the trench width exceeds the width used for design, a better class of bedding or stronger pipe, or both, should be provided.

4.3 Beginning at a plane 12 in. (300 mm) or more above the top of the pipe, the trench walls can be sloped back without increasing the load imposed on the pipe.

4.4 Pipes that are installed in or beneath embankments are called projecting conduits. The earth load on a projecting conduit is influenced by the pipe diameter, the weight and character of the embankment material, the foundation material, the method of installation,

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[1] This recommended practice is under the jurisdiction of ASTM Committee C-4 on Vitrified Clay Pipe.
Current edition approved Nov 25, 1977. Published January 1978. Originally published as C 12 - 15 T. Last previous edition C 12 - 74.

[2] *Annual Book of ASTM Standards*, Part 16

and the height of the embankment above the top of the pipe.

4.5 Live loads consist of superimposed loads, such as wheel loads, which act at the ground surface and are partially transmitted to the pipe. An allowance for impact should be added to the live loads. The live load transmitted to the pipe diminishes as the depth of cover increases.

NOTE 1—For generally accepted criteria and methods for determining loads and supporting strengths see *Design and Construction of Sanitary and Storm Sewers, Water Pollution Control Federation Manual No. 9, American Society of Civil Engineers Manual No. 37.*

5. Types of Bedding

5.1 Four acceptable classes of bedding for pipe in trenches are defined herein. The load factors indicated are for conversion of three-edge-bearing strength to field supporting strength.

5.2 *Class A*—This class of bedding can be achieved with either of two construction methods:

5.2.1 *Concrete Cradle* (see Fig. 1)—The pipe shall be bedded in a monolithic cradle of plain or reinforced concrete having a thickness under the barrel of at least 4 in. (100 mm) or one fourth of the inside diameter of the pipe, whichever is greater, and extending up the sides to a height of at least one fourth of the pipe outside diameter. The cradle shall have a width at least equal to the outside diameter of the pipe plus 8 in. (200 mm) or one and one fourth of the outside diameter of the pipe, whichever is greater. Backfill above the cradle and extending 12 in. (300 mm) above the top of the pipe shall be carefully placed.

5.2.1.1 The load factor for Class A concrete cradle bedding is 2.2 for plain concrete with lightly tamped backfill; 2.8 for plain concrete with carefully tamped backfill; and up to 3.4 for reinforced concrete with $p = 0.4$ percent, where p is the percentage of the area of steel to the area of concrete at the pipe invert.

5.2.2 *Concrete Arch* (see Fig. 2)—The pipe shall be bedded in crushed stone or rounded gravel bedding material (Note 2). The bedding shall have a minimum thickness beneath the pipe of 4 in. (100 mm) or one fourth of the outside diameter of the pipe, whichever is greater, and shall extend up the sides of the pipe to the horizontal centerline. The top half of the pipe shall be covered with a monolithic plain or reinforced concrete arch having a thickness of at least 4 in. (100 mm) or one fourth of the inside diameter of the pipe, whichever is greater, at the pipe crown and a minimum width equal to the outside diameter of the pipe plus 8 in. (200 mm) or one and one fourth of the diameter of the pipe, whichever is greater.

5.2.2.1 The load factor for Class A-1 concrete arch bedding is 2.8 for plain concrete; up to 3.4 for reinforced concrete with $p = 0.4$ percent; and up to 4.8 for reinforced concrete with $p = 1.0$ percent, where p is the percentage of the area of steel to the area of concrete at the pipe crown.

NOTE 2—Because of the recent research and subsequent general acceptance of the advantages of interlocking bedding materials, this recommended practice calls special attention to the desirability of using ¾ to ¼-in. (19.0 to 6.3-mm) crushed stone bedding. Where crushed material is not readily available, rounded material is acceptable.

5.3 *Class B* (see Fig. 3)—The pipe shall be bedded in crushed stone or rounded gravel bedding material (Note 2) placed on the trench bottom. The bedding material shall have 95 percent passing a ¾-in. (19.0-mm) sieve and 95 percent retained on a No. 4 (4.75-mm) sieve. The bedding shall have a minimum thickness beneath the pipe of 4 in. (100 mm) or one eighth of the outside diameter of the pipe, whichever is greater, and shall extend up the sides of the pipe to the horizontal centerline. Backfill from pipe horizontal centerline to a level not less than 12 in. (300 mm) above the top of the pipe shall be of the bedding material or carefully placed earth. Hand placed backfill shall be finely divided materials free from debris, organic material, and stones.

5.3.1 The load factor for Class B bedding is 1.9.

5.4 *Class C* (see Fig. 4)—The pipe shall be bedded in crushed stone or rounded gravel bedding material (Note 2) placed on the trench bottom. The bedding material shall have 95 percent passing a ¾-in. (19.0-mm) sieve and 95 percent retained on a No. 4 (4.75-mm) sieve. Shells, pea gravel, sand, native soil, or other locally available and commonly used bedding materials may be specified by the engineer in place of the previously described bedding mate-

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rials. The bedding shall have a minimum thickness beneath the pipe of 4 in. (100 mm) or one eighth of the outside diameter of the pipe, whichever is greater, and shall extend up the sides of the pipe one sixth of the outside diameter of the pipe. Backfill between the bedding and a plane 12 in. (300 mm) over the top of the pipe, shall be hand placed finely divided earth free from debris and stones.

5.4.1 The load factor for Class C bedding is 1.5.

5.5 *Class D* (see Fig. 5)—The pipe shall be bedded in suitable native material on an unshaped trench bottom.

5.5.1 The load factor for Class D bedding is 1.1.

6. Concrete Encasement

6.1 Concrete encasement shall completely surround the pipe and shall have a minimum thickness at any point of one fourth of the inside diameter of the pipe or 4 in. (100 mm), whichever is greater.

6.2 In addition to providing bedding at least equivalent to Class A, concrete encasement provides additional field supporting strength. Whenever the strength of the pipe with Class A bedding is not sufficient to support the external loads, the encasement should be designed to provide the necessary additional strength.

7. Trench Excavation

7.1 Open no more trench in advance of pipe laying than is necessary to expedite the work.

7.2 Excavate trenches to a width that will provide adequate working space, but not more than the maximum design width. Do not undercut trench walls.

7.3 Excavate trenches below the pipe invert a sufficient distance to provide space for the pipe bedding. Carry trenches in ledge rock, compact rocky or gravelly soil, or other unyielding materials below the bottom of the pipe at least one fourth of the outside diameter of the pipe, or 4 in. (100 mm), whichever is greater. Refill the space beneath the pipe with bedding material as specified for Class B or Class C bedding.

7.4 Excavate bell holes at each joint to provide full-length barrel support of the pipe and to prevent point loading at the bells or couplings.

7.5 Unless trench banks above the top of the pipe are cut back on a stable slope, sheet and brace trenches as necessary to prevent caving or sliding, to provide protection for workmen and the pipe, and to protect adjacent structures and facilities. Do not remove trench sheeting unless the pipe strength is sufficient to support the external loads, including the weight of a prism of earth above the top of the pipe with trench width measured to the back of the sheeting. Do not brace sheeting against the pipe, but brace it so that no concentrated loads or horizontal thrusts are transmitted to the pipe.

8. Pipe Bedding

8.1 Carefully prepare bedding so that the pipe after installation will be true to line and grade.

8.2 Surface grade fill material or trench subgrade beneath the pipe to provide a uniform and continuous support beneath the pipe at all points between bell holes or pipe joints (see Fig. 6). Densify fill material beneath the pipe.

8.3 After each pipe has been brought to grade, aligned, and placed in final position, deposit and densify sufficient bedding material under the pipe haunches and on each side of the pipe to hold the pipe in proper position during subsequent pipe jointing, bedding, and backfilling operations. Deposit bedding material uniformly and simultaneously on each side of the pipe to prevent lateral displacement.

8.4 Place pipe that is to be bedded in a concrete cradle or encased in concrete in proper position on temporary supports consisting of preshaped wood blocks or bricks with wood wedges. When necessary, rigidly anchor or weight the pipe to prevent flotation when the concrete is placed.

8.5 Place concrete for cradles, arches, or encasement uniformly on each side of the pipe and deposit at approximately its final position. Do not move concrete more than 5 ft (1.5 m) from its point of deposit. Concrete placed beneath the pipe shall be sufficiently workable so that the entire space beneath the pipe can be filled without excessive vibration.

9. Pipe Laying

9.1 Protect pipe during handling against impact shocks and free fall. Do not permit hooks to come in contact with premolded joint surfaces.

9.2 Handle pipe having premolded joint rings or attached couplings so that no weight, including the weight of the pipe itself, will bear on or be supported by the jointing material. Take care to avoid dragging the spigot ring on the ground or allowing it to be damaged by contact with gravel, crushed stone, or other hard objects.

9.3 After delivery alongside the trench, carefully examine each piece of vitrified clay pipe for soundness and specification compliance. Acceptable pipe may be marked with paint or other permanent marking material so that the marks are plainly visible after installation in the trench and before the pipe is covered.

9.4 Clean joint contact surfaces immediately prior to jointing. Use lubricants, primers, or adhesives as recommended by the pipe or joint manufacturer.

9.5 Unless otherwise required, lay all pipe straight between changes in alignment and at uniform grade between changes in grade. Excavate bell holes for each pipe joint. When jointed in the trench, the pipe shall form a true and smooth line.

9.6 Keep trenches dry during pipe laying. Divert surface water from the trench area to the greatest extent practicable without causing damage to the adjacent property. Before pipe laying is started remove all water that may have entered the trench.

9.7 Whenever practicable, start pipe laying at the lowest point and install the pipe so that the spigot ends point in the direction of flow.

10. Backfilling Trenches

10.1 Unless other protection work is directed, backfill trenches immediately after the pipe is laid. In the case of concrete cradle bedding, delay backfilling until the concrete has set sufficiently to support the backfill load. Except for unusual circumstances (such as subaqueous installation) permit no water to rise in unbackfilled trenches after the pipe is in place.

10.2 Backfill material to be placed above pipe bedding shall be free of brush, debris, and junk. Unless specifically authorized, place no rock or rock excavation detritus in the upper 18 in. (460 mm) of the trench. Place no rock or stones having a dimension larger than 6 in. (150 mm) within 3 ft (0.9 m) of the top of the pipe. Large stones may be placed in the remainder of the trench backfill only if well separated and arranged so that no interference with backfill settlement will result.

10.3 Use puddling, jetting or water flooding for consolidating backfill material only when approved by the engineer. Particularly prone to water damage are sewers laid in heavy clay soils or during cold winter months. Water flooding or jetting in porous sand or gravel during warm periods may be recommended. In general, limit the addition of water during backfill to providing optimum moisture content for tamping procedures.

10.4 Unless otherwise required, the backfill beneath streets, pavement, drives, curbs, walks, and other surface construction shall be bedding material, sand, or tamped earth. Tamped backfill shall be placed in uniform layers and shall have a moisture content that will ensure that maximum density will be obtained with the placement method used.

11. Field Performance and Acceptance

11.1 After the pipe has been laid in the trench, the sewer shall be tested for tightness by a method specified or approved by the engineer. The test shall demonstrate tightness to the degree specified by the engineer before the line is accepted. To test an installed line for construction integrity, water or air testing is recommended depending on the conditions at the site.

11.2 Where ground water exists, the line may be tested by placing a weir in appropriate manholes and determining the quantity of water entering the system during a specified time period.

11.3 Where ground water does or does not exist either a water or low-pressure air test method is considered to be an appropriate test procedure. This will readily determine any construction deficiencies that may exist.

NOTE 3—When water or air tests are specified and the acceptance of a line depends upon satisfactory results, it should be recognized that several factors have a bearing on these results. Manhole bases, walls, and seals must be watertight. Household and commercial building and roof drains must be eliminated. Stoppers for wye and tee spur fittings must be secured sufficiently to be air or watertight.

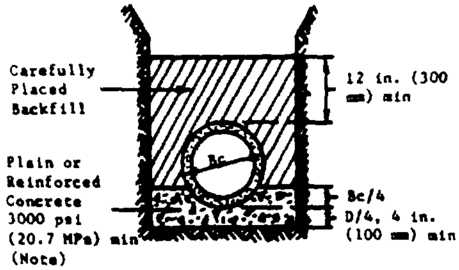
or both. Wyes and tees must be satisfactorily underbedded to prevent shear loading.

11.4 In order for the performance of the to be acceptable, all tests shall be made on pipe laid in accordance with the bedding provisions of Section 5. Jointing procedures shall follow the recommendation of the pipe manufacturer.

12. General Recommendations

12.1 Whenever a movable steel box is used in place of sheeting, take care to prevent the pipe from moving when the steel box is moved. Pipe must be secured to prevent longitudinal movement.

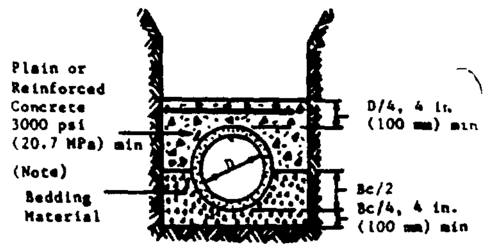
12.2 Where pipe connects with outside faces of manhole walls or the outside faces of the walls of other structures, provide a pipe joint such that slight flexibility or motion can take place in or near the plane of the wall face. It is recommended that a short pipe stub 12 to 18 in. (300 to 450 mm) be extended from manhole or other wall faces.



NOTE—Minimum width of concrete cradle or concrete arch = *Bc* + 8 in. (200 mm) or 1¼ *Bc*

Load factors
2.2 Lightly tamped
2.8 Carefully tamped
3.4 Reinforced concrete, p = 0.4 percent

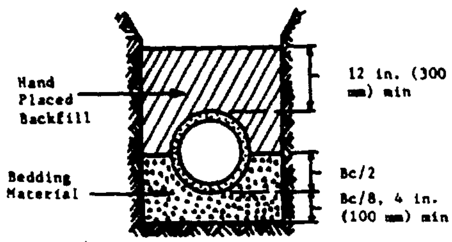
FIG. 1 Class A



NOTE—Minimum width of concrete cradle or concrete arch = *Bc* + 8 in. (200 mm) or 1¼ *Bc*

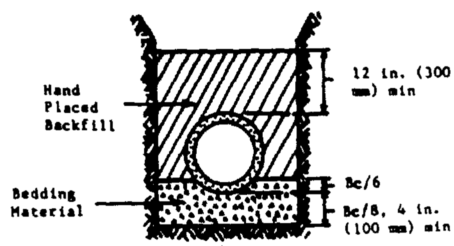
Load Factors
2.8 Plain concrete
3.4 Reinforced concrete, *p* = 0.4 percent
4.8 Reinforced concrete, *p* = 1.0 percent

FIG. 2 Class A-I



Load factor 1.9

FIG. 3 Class B



Load factor 1.5

FIG. 4 Class C

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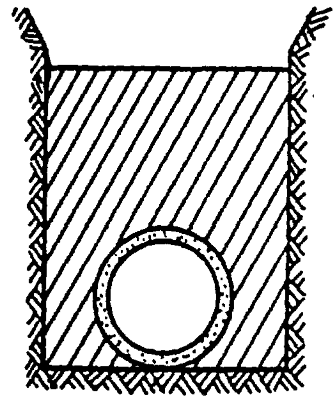

Load Factor 1.1

FIG. 5 Class D

Provide uniform and continuous
support of pipe barrel between
bell or coupling holes.

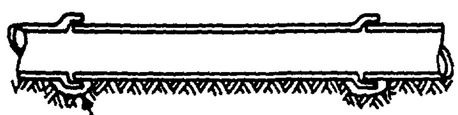

FIG. 6 Uniform Pipe Support

CertainTeed

Technical Bulletin

September 10, 1974

TO: VF P&PG MARKETING & SALES PERSONNEL
DISTRICT MANAGERS
TERRITORY MANAGERS
ADMINISTRATIVE ASSISTANTS
A-C PRODUCT MANAGERS
A-C FIELD SERVICE MANAGERS
SALES ENGINEERS

FM: T. A. SWITALSKI T. Switalski

RE: FLEXURAL STRENGTH OF ASBESTOS-CEMENT SEWER PIPE

Our competition has for many years been selling A-C sewer pipe in 10 ft. lengths. Occasionally, we still encounter claims that our 13 ft. lengths of A-C sewer pipe are more likely to result in flexural failures. No flexural failures have occurred when our pipe was installed in accordance with our installation instructions. This bulletin is being issued to show some of the merits of 13 ft. lengths vs. 10 ft. lengths of A-C sewer pipe.

Flexural strength of pipe is not only a function of the pipe's diameter and wall thickness, it is also dependent upon the quantity and quality of the fibrous re-enforcement.

The flexural strength requirements for A-C sewer pipe are specified in ASTM C 428-73d. It specifies that an 8 inch Class 2400 sewer pipe of 13 ft. length will be able to support at least 2250 pounds (third point load on a 12 ft. span) and that a 10 ft. length will be able to support at least 3000 pounds (third point load on a 9 ft. span). In effect, the same pipe or one of equal flexural strength will support 75 percent of the load on a 12 ft. span that it will on a 9 ft. span. The previous ASTM 428-67 had been based on a 12 ft. span supporting 133 percent that of a 9 ft. span, thereby requiring a 13 ft. pipe to have a unit strength of 75 percent more than that of a 10 ft. pipe. Hence, the 13 ft. pipe length by the previous ASTM had considerably higher strength than was necessary.

The flexural requirement for 13 ft. pipe of 2250 pound minimum is adequate for pipe that is properly bedded. With bell holes dug out in the trench bottom so as to allow the pipe to rest evenly on its barrel along the flat trench bottom, or with pipe laid on earth mounds and then packed in tightly between the pipe bottom and the trench bottom to give the pipe adequate support, the pipe made according to ASTM C 428-73d will not break in flexure.

The 10 ft. pipe, when placed in the ground as a loaded beam, will not bend as much as a 13 ft. pipe before breaking. For example, a 10 ft. pipe supported only on its couplings will break under an earth load of about 525 pounds, (a depth of cover of about 40") and will have a mid-point deflection of 0.17". A 13 ft. pipe so supported will break under an earth load of around 325 pounds (a depth of cover of about 26") but will have a mid-point deflection of 0.33". If the clearance under the pipe is less than 0.33" but more than 0.17"--a not unlikely possibility--than the 10 ft. pipe would break under a 40" depth of cover (525 pound load), but the 13 ft. pipe would not.

Another possibility for flex break can occur with an uneven trench bottom. As an example, say the pipe was laying over an unsupported span of 6 ft. Then the pipe would break in flex under an earth load of about 1190 pound/ft. (a depth of cover of about 8 ft.), and this would occur whether the pipe were 10 ft. long or 13 ft. long.

To further support the fact that the minimum flexural load on a 13 ft. pipe is adequate when it is 75 percent that of a 10 ft. pipe, refer to ASTM C 296, A-C Pressure Pipe. As an example with 6" Class 150 pipe, the minimum third point load on a 12 ft. span is 2100 pounds, whereas that on a 9 ft. span is 2800 pounds.

On July 16, 1973, the City of Broken Arrow, Oklahoma enacted a resolution to allow 4" and 6" A-C pipe not to exceed 10 ft. joints. In the case of Utility Supply vs. Broken Arrow, a judgement was rendered in the district court in and for Tulsa County, Oklahoma to the effect that the defendants be restrained and enjoined from enforcing the ordinance adopted by the City of Broken Arrow on July 16, 1973. The Judge in his ruling, pointed out "The court finds that the City has authority to prescribe how waterline pipe shall be laid, but the principle reason given by Defendants for not offering the 13 ft. section pipe was that the City had inadequate inspection capabilities. The court finds that when the City passes an ordinance requiring affirmative action (inspection) on its part, said City must supply that action and its failure or refusal to do so cannot form a valid basis for discriminatory practice attempted herein".

Certain-teed, from experience, has built into the pipe enough strength to take care of a certain amount of improper bedding and installation. However, such additional strength will not protect against gross mishandling or complete disregard for good bedding.

If installation is done carefully and correctly, the pipe should not be exposed to flexural stresses of unsafe magnitude. If not, then beam action causing flexural stresses will exist regardless of the length of pipe. It is unreasonable to suggest that these few improper installations will all result in 12 ft. unsupported spans.

AMERICAN NATIONAL STANDARD ANSI/ASTM C 644 - 77

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Standard Specification for
ASBESTOS-CEMENT NONPRESSURE SMALL-DIAMETER SEWER PIPE[1]

This Standard is issued under the fixed designation C 644, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers asbestos-cement nonpressure sewer pipe for conveying sanitary sewage by gravity flow from point of occupancy to system of disposal.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units given in the standard may be approximate.

NOTE 2—Rubber rings suitable for use with this pipe are covered in ASTM Specification D 1869, for Rubber Rings for Asbestos-Cement Pipe.[2]

2. Classification

2.1 Asbestos-cement sewer pipe furnished under these specifications shall be designated as Class 1500, Class 2400, and Class 3300, based on the respective crushing trengths, and furnished in 4, 5, and 6-in. (10.2, 12.7, and 15.2-cm) sizes.

2.2 The types of pipe shall be known as Type I and Type II corresponding to the chemical requirements given in Section 6 of this specification.

NOTE 3—To assist the purchaser in choosing the type of pipe most suitable for his use, guidelines for the definition of aggressiveness of water and of soil environments for selection of the proper type of asbestos-cement pipe are covered in Sections 19 to 25 ASTM Methods C 500, Testing Asbestos-Cement Pipe.[2]

3. Definitions

3.1 *pipe* — asbestos - cement nonpressure sewer pipe as defined in Sections 1, 2, and 5.

3.2 *coupling*—a coupling that is manufactured so that, when properly installed, lengths of pipe may be assembled and put into service for which they are intended.

3.3 *fittings*—wyes, tees, adaptors, etc., for use in laying asbestos-cement sewer pipe manufactured as described in Section 5 and made to such dimensions as will provide equivalent strength and tight joints when assembled with the pipe.

3.4 *purchaser*—the actual purchaser of the pipe or his authorized agents acting within the scope of the duties entrusted to them.

3.5 *lot*—those lengths of pipe of that size and class manufactured during the same shift.

4. Basis of Purchase

4.1 It is suggested to the purchaser, without being made a part of this specification, that the purchaser may request inclusion of the following information in his order or agreement for purchase of the pipe:

4.1.1 Any tests, in addition to those prescribed by this specification, as the special circumstances may require,

4.1.2 The place or places where any additional tests are to be made,

4.1.3 Description of the additional testing facilities,

4.1.4 Who shall bear the expense of such additional tests,

[1] This specification is under the jurisdiction of ASTM Committee C-17 on Asbestos-Cement Products.
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[2] *Annual Book of ASTM Standards*, Part 16

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4.1.5 Whether such additional tests may be made by any reliable sampling process or other method approved by the parties, and

4.1.6 Such other matters as the parties may find desirable to include in their written agreement.

5. Materials and Manufacture

5.1 Asbestos-cement sewer pipe shall be composed of an intimate mixture of portland cement or portland blast-furnace slag cement and asbestos fiber with or without silica, or portland-pozzolan cement and asbestos fiber. The mixture shall be free of organic additives. The material shall be of laminar construction formed under pressure to a homogeneous structure and cured to meet the physical and chemical requirements of this specification.

6. Chemical Requirements

6.1 When tested in accordance with Sections 17 and 18 of ASTM Methods C 500, the amount of uncombined calcium hydroxide shall not exceed 1.0 percent for Type II pipe.

NOTE 4—There are no chemical requirements for Type I pipe.

7. Dimensions and Permissible Variations

7.1 Couplings and coupling area of the pipe shall be machined or otherwise finished to such dimensions as will provide tight joints when assembled with proper accessories and put into service for which the pipe is intended.

7.2 The average diameter may be less than the nominal by not more than $^1/_4$ in. (0.63 cm).

7.3 The standard lengths may be 5, 6.5, 10, or 13 ft (1.52, 1.98, 3.05 or 3.96 m) ± 1 in. (2.5 cm). At least 85 percent of the total footage of any one class, type, and size, excluding short lengths, shall be furnished in standard lengths. The remaining 15 percent may be in random lengths of not less than 7 ft (2.13 m) when the standard length is 10 or 13 ft (3.05 or 3.96 m) and not less than 4 ft (1.22 m) when the standard length is 5 or 6.5 ft (1.52 or 1.98 m).

8. Workmanship

8.1 The ends of the pipe that receive the coupling shall be free of dents and gouges that will affect the tightness of the joint.

8.2 Each pipe shall be free of bulges, dents, and tears in the inside surface that result in a variation of more than $^3/_{16}$ in. (0.48 cm) from the adjacent unaffected portions of the surface.

8.3 Each length of pipe shall not vary in straightness by more than $^1/_{16}$ in./ft (5.2 mm/m) of length when the variation is measured in accordance with Section 13 of Methods C 500.

9. Sampling

9.1 For crushing tests, one full length of pipe shall be selected from each 500 lengths of 10 and 13-ft (3.05 and 3.96-m) lengths and each 1000 lengths of 5 and 6.5-ft (1.52 and 1.98-m) lengths of each size, class, and type of pipe covered by the order. One test specimen 12 in. (30.5 cm) long shall be cut from the unmachined portion of the selected length of pipe.

9.2 When uncombined calcium hydroxide tests are requested (Section 6), one sample shall be taken from each lot of pipe. The sample to be tested may be taken from any one of the specimens selected for the crushing test.

9.3 All material tested under this specification shall be in a normal air-dried condition.

10. Test Methods

10.1 *Joint Tightness:*

10.1.1 The tests outlined in this section are considered to be one-time qualification tests to establish the adequacy of the manufacturers joint design. Instead of requiring performance of these tests, the purchaser may require the manufacturer to certify that pipes and couplings equivalent in material and design have passed the tests enumerated in this section. At his own expense, however, the purchaser, by designation with his order, may require that assembled pipes and couplings pass the following performance tests without leakage:

10.1.1.1 *Straight Alignment*—Make hydrostatic pressure test on an assembly of two sections of pipe, properly connected with a coupling in accordance with the joint design. An equivalent alternative may be a single pipe with a coupling on each end. Subject the assembly to an internal hydrostatic pressure of 10 psi (69 kPa) for 10 min. Any visible water leakage shall be considered a failure of the test requirements.

10.1.1.2 *Maximum Deflected Position*—Upon completion of the test for pipes in straight alignment in accordance with 10.1.1.1, deflect the test sections 5 deg with one half of the deflection being between each pipe and the coupling and subject the test sections to an internal hydrostatic pressure of 10 psi (69 kPa) for 10 min. Any visible water leakage shall be considered a failure of the test requirements.

10.1.2 Test one sample of each size unless some other arrangement is made with the purchaser by designation with his order. At the option of the purchaser, the sample of the pipes and couplings to be tested may be selected by him.

10.2 *Flexural Strength:*

10.2.1 Each length of pipe shall have sufficient flexural strength to withstand, without failure, the total load prescribed in Table 1 when tested in accordance with Section 8 of Methods C 500.

10.3 *Crushing Strength:*

10.3.1 *Pipe*—Conduct crushing tests before shipment. One-foot (0.3 m) lengths of pipe cut from unmachined portions of the pipe shall have the minimum crushing strength prescribed in Table 2, when tested in accordance with Section 11.1.1 of Methods C 500.

10.3.2 *Couplings*—The couplings, when assembled on pipe, shall be capable of withstanding simultaneously:

10.3.2.1 The minimum crushing strength in pounds-force per linear foot prescribed in Table 2, when tested in accordance with 11.1.1 of Methods C 500, and

10.3.2.2 The hydrostatic pressure test described in 10.1.1.1 of this specification.

11. Inspection

11.1 All material furnished under this specification shall conform to the requirements stated herein and shall be subjected to the factory inspection and tests prescribed in this specification. When requested by the purchaser on his order, the manufacturer shall notify the purchaser of the time that the inspection and testing will take place so that the purchaser may arrange for witnessing such tests and inspections at his own expense. Instead of such inspection, when requested, the manufacturer shall be prepared to certify that his product conforms to the requirements of this specification.

11.2 Pipe and coupling shall be inspected by the manufacturer, before shipment, for compliance with the standards for dimensions, workmanship, and finish (see also Section 9).

12. Rejection

12.1 Failure of the specimens tested for crushing strength to withstand 75 percent of the load specified in 10.3 shall be cause for rejection of the entire lot represented by the test specimens. When the specimen tested for crushing strength withstands over 75 percent but under 100 percent of the load specified in 10.3, one specimen shall be cut from each of two additional pipes of the same size and class manufactured during the same shift. Failure of one of these additional specimens to meet the strength requirements of 10.3 shall be cause for rejection of the entire lot of that size and class manufactured during the same shift as the test specimen.

12.2 If the results of the uncombined calcium hydroxide test show the sample failed to meet the specification requirements, two additional specimens shall be selected and sampled for test. The failure of one of these two additional samples to meet the specification requirements of Section 6 shall be cause for rejection of the lot.

13. Marking and Shipping

13.1 Each standard and random length of pipe shall be marked by the manufacturer with the trade name, nominal size, class, and the date of manufacture. Each coupling sleeve shall be marked by the manufacturer with the nominal size and class for the pipe with which it shall be used.

13.2 Pipe and couplings shall be prepared for commercial shipment so as to ensure acceptance by common or other carriers.

14. Field Performance and Acceptance

14.1 All field-assembled joints for asbestos-cement nonpressure small diameter sewer pipe shall meet the requirements set forth in 14.5 for infiltration/exfiltration.

14.2 Measurements shall be based on a

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segment or segments of sewer line of asbestos-cement nonpressure small diameter sewer pipe installed separately or as a part of a sewer main system between two consecutive manholes or other similar increment of distance, rather than taken from a single joint.

14.3 Before the sewer line is backfilled and tested, all pipe shall be inspected for proper bedding to assure uniform support of the pipe, and the absence of high points and irregularities which induce beam and shear loadings on the pipe.

14.4 Final acceptance testing shall be performed on the sewer line(s) after the final backfilling has been completed.

14.5 The infiltration/exfiltration of the installed pipe shall not exceed 0.079 gal/in. of internal pipe diameter per 100 ft of pipelines, h (0.386 litre/cm of internal pipe diameter per 100 m of pipelines per hour), where the maximum hydrostatic head at the center line of the pipe does not exceed 25 ft (7.63 m) (corresponds to 100 gal/in. of pipe diameter per mile per 24 h (92.6 litres/cm of pipe diameter per 1000 m per 24 h).

TABLE 1 Applied Flexural Proof Loads

Nominal Size, in. (mm)	Total Applied Load, lbf (kN)
4 (100)	550 (2440)
5 (125)	950 (3780)
6 (150)	1500 (6680)

TABLE 2 Minimum Crushing Loads

Pipe Class	Crushing Strength, lbf/linear ft ((kN/m)
1500	1500 (21.8)
2400	2400 (35.0)
3300	3300 (48.0)

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Standard Specification for RUBBER RINGS FOR ASBESTOS-CEMENT PIPE[1]

This Standard is issued under the fixed designation D 1869; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers rubber rings used to seal the joints of asbestos-cement pipe conforming to Specifications C 296, C 428, C 644, and C 668.

1.2 A specification is given for (*1*) natural or synthetic rubber rings, or both, where resistance to oil or solvents is not required, and (*2*) synthetic rubber rings for services involving resistance to oil or solvents.

2. Applicable Documents

2.1 *ASTM Standards:*

C 296 Specification for Asbestos-Cement Pressure Pipe[2]

C 428 Specification for Asbestos-Cement Nonpressure Sewer Pipe[2]

C 644 Specification for Asbestos-Cement Nonpressure Small-Diameter Sewer Pipe[2]

C 668 Specification for Asbestos-Cement Transmission Pipe[2]

D 395 Tests for Rubber Property—Compression Set[3]

D 412 Tests for Rubber Properties in Tension[4]

D 573 Test for Rubber Deterioration in an Air Oven[3]

D 865 Test for Rubber Deterioration by Heating in a Test Tube[3]

D 1415 Test for Rubber Property—International Hardness[3]

D 2137 Test for Rubber Property—Brittleness Point of Flexible Polymers and Coated Fabrics[5]

D 2240 Test for Rubber Property—Durometer Hardness[6]

3. Composition and Manufacture

3.1 The ring shall consist of a properly vulcanized virgin rubber compound. Virgin rubber is defined as one containing no scrap, reclaim, or rubber substitutes.

3.2 If a joint is used in the manufacture of the ring, the strength of the spliced joint shall be such that the ring will withstand the stretch test described in 8.8 with no visible separation or peeling.

4. Physical Requirements

4.1 Sample rings taken from the shipment shall conform to the requirements for physical properties prescribed in Table 1 when tested in accordance with the methods specified in Section 8.

5. Dimensions and Tolerances

5.1 The rings shall conform to the dimensions specified by the manufacturer of the pipe in which the rings are to be used, with a RMA Class 3 tolerance of ±0.25 up to 25 mm (±0.010 up to 1 in.) on all cross-section dimensions, and ±1 % on all diametral dimensions, unless otherwise agreed upon by the pipe manufacturer and the ring supplier.

NOTE—The design and tolerances of asbestos-cement pipe are not sufficiently standardized to permit interchangeability of rings in many cases from pipe of one manufacturer to that of another.

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[1] This specification is under the jurisdiction of ASTM Committee D-11 on Rubber and Rubber-Like Materials and is the direct responsibility of Subcommittee D11.36 on Seals.

Current edition approved April 28, 1978. Published July 1978. Originally published as D 1869 - 61 T. Last previous edition D 1869 - 66 (1972).

[2] *Annual Book of ASTM Standards*, Part 16.

[3] *Annual Book of ASTM Standards*, Part 37.

[4] *Annual Book of ASTM Standards*, Parts 35, 37, and 38

[5] *Annual Book of ASTM Standards*, Parts 37 and 38

[6] *Annual Book of ASTM Standards*, Parts 35 and 37

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6. Workmanship

6.1 The surface shall be smooth and free of pitting, cracks, blisters, air marks, and any other imperfection that would affect its behavior in service. The body shall be free of porosity and air pockets.

6.2 The flash thickness shall not exceed 0.4 mm (0.015 in.), nor the flash width 0.8 mm (0.03 in.) at any point in the ring.

6.3 Offset, or failure of the mold to register accurately, shall not exceed 0.4 mm (0.015 in.)

7. Sampling

7.1 A number of sample rings shall be drawn at random from each shipment of rings in accordance with Table 2.

7.2 These shall be stretched and examined as specified in 8.8. A sufficient additional number of rings shall be drawn at random for the tests specified in Table 1.

8. Test Methods

8.1 *Tensile Strength, Elongation, and Stress at 300 % Elongation* – Methods D 412:

8.1.1 Cut samples for tensile strength, elongation, and stress at 300 % elongation tests from circumferential sections of the ring itself.

8.1.2 From these samples stamp dumbbell test specimens using a standard ASTM Type C dumbbell conforming to Fig. 1 of Method D 412.

8.1.3 The sections from which the dumbbells are cut may be prepared by sectioning a sample ring held rigidly in a jig, which in turn is mounted in a chuck of a machinist's lathe. A sharp, thin cutting knife should be mounted in the lathe holder and the cut made at a right angle to the jig face. The cutting site should be lubricated at all times by a jet of cool water.

8.1.4 These sections may be buffed lightly prior to cutting into dumbbell specimens in order to bring them to a uniform thickness for testing.

8.2 *Hardness:*

8.2.1 Method D 1415 shall be used as the referee method.

8.2.2 Method D 2240 may be used for quality control.

8.2.3 Hardness readings for guidance purposes may be taken directly on the ring, recognizing that those may vary slightly from those taken on dumbbell specimens.

8.3 *Air Aging: Tensile Strength, Elongation, and Hardness:*

8.3.1 Methods D 865 (preferred) or D 573, in conjunction with Methods D 412 and D 1415 or D 2240. Prepare test specimens in accordance with 8.1.

8.3.2 Age nonoil-resistant specimens for 166 ± 2 h at 70 ± 2°C.

8.3.3 Age oil-resistant specimens for 70 ± 0.7 h at 100 ± 2°C.

8.4 *Water Aging: Volume and Appearance Change:*

8.4.1 Cut one specimen 50 ± 3 mm (2.0 ± 0.1 in.) long and not less than 13 mm^2 (0.2 $in.^2$) in cross section from each of three rings.

8.4.2 Totally immerse the specimens in the siphon cup of an insulated 3-dm^3 extraction apparatus, and hold at a temperature of 100 ± 2°C for 20 consecutive days. Suspend the specimens at least 50 mm (2 in.) beneath the surface of the water in such a manner that they do not contact one another or the surface of the cup.

8.4.3. Immediately after removai from the boiling water, blot the specimens, weigh and calculate the volume increase in accordance with Method D 471.

8.4.4 Average the values obtained for the three specimens.

8.5 *Compression Set:*

8.5.1 Method B of Methods D 395, excep cut three specimens from separate rings about 75 mm (3 in.) in length and the full cross-sectional area of the ring in a compression device 50 mm long.

8.5.1.1 Place the specimens in the compression device with the inside and outside circumference sides in contact with the compression plates.

8.5.1.2 If this is impractical because of the size or shape of the specimens, they may be placed in the compression device in a manner that will give the most accurate values.

8.5.2 Make a reference measurement at any convenient point where the section is solid and compress the specimen 50 % at the reference point, using spacers.

8.5.3 Oven age nonoil-resistant specimens for 22 ± 0.25 h at 70 ± 2°C.

8.5.4 Oven age oil-resistant specimens for

22 ± 0.25 h at 100 ± 1°C.

8.6 *Low-Temperature Flexibility:*

8.6.1 Method D 2137.

8.6.2 Prepare test specimens in accordance with 8.1.2 through 8.1.5. The temperature of test shall be −25 ± 2°C.

8.7 *Oil Aging: Tensile Strength, Elongation, Hardness, and Volume Change:*

8.7.1 ASTM Method D 471.

8.7.2 Prepare test specimens for tensile strength, elongation, and hardness tests in accordance with 8.1.2 through 8.1.5.

8.7.3 Prepare specimens for the volume change test in accordance with 8.4.1.

8.7.4 Immerse the specimens in ASTM Oil No. 3 for 70 ± 0.7 h at 100 ± 2°C.

8.8 *Stretch Test for Visual Examination:*

8.8.1 Stretch the rings until the circumference has increased 50 %.

8.8.2 Inspect each ring visually for defects in accordance with 3.2 and 6.1.

8.8.3 The number of rings to be examined and the maximum number of defective rings for acceptance of the lot is shown in Table 2.

9. Markings and Color Coding

9.1 Each ring shall be marked with clearly legible letters, the size of which shall not exceed 6 mm (1/4 in.).

9.2 The markings shall include the ring manufacturer's name or symbol, the pipe manufacturer's name or symbol, the pipe size and pressure rating, and the year of manufacture.

9.3 Each oil-resistant synthetic rubber ring shall be marked with a color stripe, dot, or other identifying mark to distinguish this ring from the nonoil-resistant type.

9.3.1 The shape and color of the mark shall be as specified by the manufacturer of the pipe in which the ring is to be used.

TABLE 1 Physical Requirements of Rubber Rings for Asbestos-Cement Pipe

Test	Type of Rubber Ring	
	Nonoil-Resistant	Oil-Resistant
Original Properties:		
Tensile strength, min, MPa (psi):		
Average of three specimens	14.0 (2000)	10.5 (1500)
Lowest individual	12.5 (1800)	9.0 (1300)
Elongation, min, %:		
Average of three specimens	350	325
Lowest individual	325	300
Hardness number[A]	nominal ± 5	nominal ± 5
Stress at 300 % elongation, MPa (psi):		
Max	16.0 (2300)	16.0 (2300)
Min	8.4 (1200)	7.0 (1000)
Compression set, max, %	16	25
Low-temperature flexibility	no cracks	no cracks
After Oven Aging:		
Tensile strength, average decrease, max, %	15	20
Elongation, average decrease, max, %	25	30
Hardness, average increase, max, points	7	15
After Water Aging:		
Volume change, max, %	12	12
Apperance change	no surface degradation	no surface degradation
After Oil Aging:		
Tensile strength, average decrease, max, %	...	35
Elongation, average decrease, max, %	...	40
Hardness, average change, points	...	−10 to +2
Volume change, average, %	...	−1 to +15

[A] Nominal hardness shall be from 50 to 60 as specified by the pipe manufacturer.

TABLE 2 **Sampling Plan for Stretch Test for Visual Inspection**

Number of Rings in Shipment	Number of Rings in Sample	Maximum Number of Defectives for Acceptance
Up to 800	75	4
801 to 3 200	150	8
3 201 to 8 000	225	11
8 001 to 22 000	300	14

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Standard Specification for REINFORCED CONCRETE CULVERT, STORM DRAIN, AND SEWER PIPE[1]

This Standard is issued under the fixed designation C 76; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

NOTE 1—The values stated in either U.S. customary units or SI (metric units) are to be regarded separately as standard. The values stated in each system are not exact equivalents, therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

NOTE 2—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between earth cover load and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, controlled manufacture in the plant, and care in the eld construction work. The purchaser of the reinorced concrete pipe specified herein is cautioned that he must properly correlate the field requirements with the class of pipe specified and provide adequate inspection at the construction site.

NOTE 3—Attention is called to the specification for reinforced concrete D-load culvert, storm drain, and sewer pipe (ASTM Designation C 655).

2. Applicable Documents

2.1 *ASTM Standards:*

A 82 Specification for Cold-Drawn Steel Wire for Concrete Reinforcement[2]

A 185 Specification of Welded Steel Wire Fabric for Concrete Reinforcement[2]

A 496 Specification for Deformed Steel Wire for Concrete Reinforcement[2]

A 497 Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement[2]

A 615 Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[2]

C 14 Specification for Concrete Sewer, Storm Drain, and Culvert Pipe[3]

C 33 Specification for Concrete Aggregates[4]

C 39 Test for Compressive Strength of Cylindrical Concrete Specimens[4]

C 150 Specification for Portland Cement[4]

C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete[4]

C 497 Testing Concrete Pipe, Sections, or Tile[3]

C 595 Specification for Blended Hydraulic Cements[4]

C 822 Definitions of Terms Relating to Concrete Pipe and Related Products[2]

3. Classification

3.1 Pipe manufactured in accordance with this specification shall be of five classes identified as Class I, Class II, Class III, Class IV, and Class V. The corresponding strength requirements are prescribed in Tables 1 to 5.

4. Basis of Acceptance

4.1 Unless otherwise designated by the purchaser at the time of, or before placing an

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[1] This specification is under the jurisdiction of ASTM Committee C-13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.02 on Reinforced Sewer and Culvert Pipe.

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[2] *Annual Book of ASTM Standards*, Part 4.

[3] *Annual Book of ASTM Standards*, Part 16.

[4] *Annual Book of ASTM Standards*, Part 14.

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order, two separate and alternative bases of acceptance are permitted as follows:

4.1.1 *Acceptance on the Basis of Plant Load-Bearing Tests, Material Tests, and Inspection of Manufactured Pipe for Visual Defects and Imperfections* — Acceptability of the pipe in all diameters and classes produced in accordance with 6.1 or 6.2 shall be determined by the results of the three-edge bearing tests for either the load to produce a 0.01-in or 0.3-mm crack, or at the option of the purchaser, the load to produce a 0.01-in. or 0.3-mm crack and the ultimate strength of the pipe; by such material tests as are required in 5.1, 5.2, and 5.4; by absorption tests on selected samples of concrete from the wall of the pipe; and by visual inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

4.1.2 *Acceptance on the Basis of Material Tests and Inspection of Manufactured Pipe for Defects and Imperfections* — Acceptability of the pipe in all diameters and classes produced in accordance with 6.1 or 6.2 shall be determined by the results of such material tests as are required in 5.1, 5.2, and 5.4 by crushing tests on concrete cores or cured concrete cylinders; by absorption tests on selected samples from the wall of the pipe; and by inspection of the finished pipe including amount and placement of reinforcement to determine its conformance with the accepted design and its freedom from defects.

4.1.3 The purchaser may select and have applied the basis of acceptance in either 4.1.1 or 4.1.2.

4.2 *Age for Acceptance* — Pipe shall be considered ready for acceptance when it conforms to the requirements as indicated by the specified tests.

5. Materials

5.1 *Cement* — Portland cement shall conform to the requirements of Specification C 150 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of Specification C 595.

5.2 *Aggregates* — Aggregates shall conform to Specification C 33 except that the requirement for gradation shall not apply.

5.3 *Admixtures and Blends* — Admixtures and blends may be used with the approval of the purchaser.

5.4 *Steel Reinforcement* — Reinforcement shall consist of wire conforming to Specification A 82 or Specification A 496 or of wire fabric conforming to Specification A 185 or Specification A 497 or of bars of Grade 40 steel conforming to Specification A 615.

6. Design

6.1 *Design Tables* — The diameter, wall thickness, compressive strength of the concrete, and the amount of the circumferential reinforcement shall be as prescribed for Classes I to V in Tables 1 to 5, except as provided in 6.2.

6.1.1 Footnotes to the tables herein are intended to be amplifications of tabulated requirements and are to be considered applicable and binding as if they were contained in the body of the specification.

6.2 *Modified and Special Designs:*

6.2.1 If permitted by the purchaser the manufacturer may request approval by the purchaser of modified designs that differ from the designs in 6.1; or special designs for sizes and loads beyond those shown in Tables 1 to 5, 6.1, or special designs for pipe sizes that do not have steel reinforcement areas shown in Tables 1 to 5 of 6.1.

6.2.2 Such modified or special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of the pipe and shall fully describe to the purchaser any deviations from the requirements of 6.1. The descriptions of modified or special designs shall include the wall thickness, the concrete strength, and the area, type, placement, number of layers, and strength of the steel reinforcement.

6.2.3 The manufacturer shall submit to the purchaser proof of the adequacy of the proposed modified or special design. Such proof may comprise the submission of properly certified three-edge-bearing tests already made, which are found by the purchaser to be adequate or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the purchaser to demonstrate to the correctness and adequacy of the proposed design.

6.2.4 Such pipe must meet all of the test and performance requirements specified by the purchaser in accordance with Section 4.

6.3 *Placement of Reinforcement:*

6.3.1 Where one line of circular reinforcement is used, it shall be placed from 35 to 50 % of the wall thickness from the inner surface of the pipe except that for wall thicknesses less than 2½ in. or 63 mm, the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be ¾ in. or 19 mm. In circular pipe having two lines of circular reinforcement, each line shall be so placed that the protective covering of concrete over the circumferential reinforcement in the wall of the pipe shall be 1 in. or 25 mm. In circular pipe having elliptical reinforcement with wall thicknesses 2½ in. or 63 mm or over, the reinforcement in the wall of the pipe shall be so placed that the protective covering of concrete over the circumferential reinforcement along the vertical diameter of the pipe shall be 1 in. or 25 mm from the inside surface of the pipe, and the protective covering of the concrete over the circumferential reinforcement along the horizontal diameter of the pipe shall be 1 in. or 25 mm from the outside surface of the pipe. In all pipe 36 in. or 900 mm or more in diameter, the bell or the spigot of the joint shall contain circumferential reinforcement. For double-cage pipe, reinforcement shall be at least equal in area to that of the outside cage or line for bells or the inside cage or line for spigots. For single-cage pipe, reinforcement shall be at least equal in area to that of the cage for either the bell or the spigot. The location of the reinforcement shall be subject, however, to the permissible variations in dimensions given in 10.5.

6.3.2 A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 7 in. or 180 mm or three layers for pipe with wall thicknesses of 7 in. or 180 mm or greater. The layers shall not be separated by more than the thickness of one longitudinal plus ¼ in. or 6 mm. The multiple layers shall be fastened together to form a single rigid cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the pipe, etc., shall apply to this method of fabricating a line of reinforcement.

6.4 *Longitudinals* – Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members, extending through the wall of the pipe, to maintain the reinforcement rigidly in shape and in correct position within the form. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

6.5 *Laps, Welds, and Spacing* – If the splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire. When splices are welded and are not lapped to the minimum requirements above, pull tests of representative specimens shall develop at least 50 % of the minimum specified strength of the steel, and there shall be a minimum lap of 2 in. or 50 mm. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 % of the minimum specified strength of the steel. The spacing center to center of adjacent rings of circumferential reinforcement in a cage shall not exceed 4 in. or 100 mm for pipe up to and including pipe having a 4-in. or 100-mm wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 6 in. or 150 mm. The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe.

7. Joints

7.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that when the sections are laid together they will make a continuous line of pipe with a smooth interior free from appreciable irregularities in the flow line, all compatible with the permissible variations given in Section 10.

8. Manufacture

8.1 *Mixture* – The aggregates shall be sized, graded, proportioned, and thoroughly mixed

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in a batch mixer with such proportions of cement and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. In no case, however, shall the proportion of portland cement in the mixture be less than 564 lb/yd^3 or 330 kg/m^3 of concrete.

8.2 *Curing* — Pipe shall be subjected to any one of the methods of curing described in 8.2.1 to 8.2.4 or to any other method or combination of methods approved by the purchaser, that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength at 28 days or less.

8.2.1 *Steam Curing* — Pipe may be placed in a curing chamber, free of outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

8.2.2 *Water Curing* — Concrete pipe may be water-cured by covering with water saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

8.2.3 The manufacturer may, at his option, combine the methods described in 8.2.1 to 8.2.4 provided the required concrete compressive strength is attained.

8.2.4 A sealing membrane conforming to the requirements of Specification C 309 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 10°F or 6°C of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

8.3 *Lift Holes* — When agreed upon by the purchaser, lift eyes or holes may be provided in each pipe for the purpose of handling.

9. Physical Requirements

9.1 *Test Specimens* — The specified number of pipe required for the tests shall be furnished without charge by the manufacturer and shall be selected at random by the purchaser, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the purchaser when placing the order.

9.2 *Number and Type of Test Required for Various Delivery Schedules*:

9.2.1 *Preliminary Tests for Extended Delivery Schedules* — A purchaser of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the purchaser in Section 4, of not more than three sections of pipe covering each size in which he is interested.

9.2.2 *Additional Tests for Extended Delivery Schedules* — After the preliminary tests described in 9.2.1, a purchaser shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe tested (including preliminary tests) shall not exceed 1 % of the pipe delivered.

9.2.3 *Tests for Occasional Orders* — A purchaser who places occasional orders shall be entitled to test a number of pipe not to exceed 2 % of an order, and not to exceed five pieces of any one size; otherwise the number of pipe desired for testing shall be included in the order.

9.3 *External Load Crushing Strength Test Requirements:*

9.3.1 The load to produce a 0.01-in or 0.3-mm crack or the ultimate load, as determined by the three-edge-bearing method as described in the Methods C 497 shall be not less than that prescribed in Tables 1 to 5 for each respective class of pipe. Pipe that have been tested only to the formation of a 0.01-in. or 0.3-mm crack and that meet the 0.01-in. or 0.3-mm test load requirements shall be accepted for use.

NOTE 4 — As used in this specification, the 0.01-in. or 0.3-mm crack is a test criterion for pipe tested in three-edge bearing-test and is not intended as an indication of distress or failed pipe under installed conditions.

9.3.2 *Retests of Pipe Not Meeting the External Load Crushing Strength Test Requirements* — Pipe shall be considered as meeting the strength test requirements when all test specimens conform to the test requirements.

Should any of the test specimens fail to meet the test requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

9.4 *Concrete Test Requirements:*

9.4.1 *Compression Tests*—Compression tests for satisfying the design concrete strength may be made on either standard rodded concrete cylinders or cylinders compacted and cured in like manner as the pipe, or on cores drilled from the wall of the pipe. If cylinders are tested, they shall be tested in accordance with Method C 39. The average compressive strength of all cylinders tested shall be equal to or greater than the design strength. Not more than 10 % of the cylinders tested shall fall below the design strength. In no case shall any cylinder tested fall below 80 % of the design strength. If cores are cut from the wall of the pipe and tested they shall be cut and tested in accordance with the requirements of Methods C 497. The compressive strength of each core tested shall be equal to or greater than the design strength of the concrete. If a core does not meet the required strength, another core from the same pipe may be tested. If this core does not meet the required strength, that pipe shall be rejected. Additional tests shall be made on other pipe to determine the acceptability of the lot. When the cores cut from a section of pipe successfully meet the strength test requirement, the core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the test requirements of this specification. Pipe sections, so sealed shall be considered as satisfactory for use.

9.4.2 *Absorption Test Requirements of Concrete*—The absorption of a sample from the wall of the pipe, as determined in accordance with Methods C 497, shall not exceed 9 % of the dry mass for Method A or 8.5 % for Method B. Each Method A sample shall have a minimum mass of 0.1 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

9.4.3 *Retests of Pipe Not Meeting the Concrete Test Requirements*—When not more than 20 % of the concrete test specimens fail to pass the requirements of the specification, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the test requirements.

9.5 *Test Equipment*—Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in Methods C 497.

10. Permissible Variations

10.1 *Internal Diameter*—The internal diameter of 12 to 24-in. pipe shall vary not more than ±1.5 % from the design diameter. The internal diameter of 27-in. and larger pipe shall not vary from the design diameter by more than ± 1 % of the design diameter or ±3/8 in., whichever is greater. Permissible variations utilizing SI units are as prescribed in Table 6A.

10.2 *Wall Thickness*—The wall thickness shall not be less than that shown in the design by more than 5 % or 3/16 in. or 5 mm whichever is the greater. A wall thickness more than that required in the design shall not be a cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

10.3 *Length of Two Opposite Sides*—Variations in laying lengths (see *L* in Fig. 1 of Methods C 497) of two opposite sides of pipe shall not be more than 1/8 in./ft or 10 mm/m of diameter, with a maximum of 5/8 in. or 16 mm in any length of pipe, except where beveled end pipe for laying on curves is specified by the purchaser.

10.4 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than 1/8 in./ft or 10 mm/m with a maximum of 1/2 in. or 13 mm in any length of pipe.

10.5 *Position or Area of Reinforcement:*

10.5.1 *Position*—The maximum variation

in the position of the reinforcement shall be ± 10 % of the wall thickness or ±½ in. or ±13 mm, whichever is greater. Pipe having variations in the position of the reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than ½ in. or 13 mm as measured to the internal wall surface or the external wall surface. The preceding minimum cover limitation does not apply to mating surfaces of the joint.

10.5.2 *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of 6.1 or 6.2. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing. When inner cage and outer cage reinforcing is used, the inner cage design area may vary to the lower limit of 85 % of the elliptical design area and the outer cage design area may vary to the lower limit of 64 % of the elliptical design area provided that the total design area of the inner cage plus the outer cage shall not vary beyond the lower limit of 153 % of the elliptical design area.

11. Workmanship and Finish

11.1 Pipe shall be substantially free of fractures and surface roughness. The ends of the pipe shall be normal to the walls and center line of the pipe, within the limits of variations given in 10.3 and 10.4.

12. Repairs

12.1 Pipe may be repaired, if necessary, because of occasional imperfections in manufacture or accidental injury during handling and will be acceptable if, in the opinion of the purchaser, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of this specification.

13. Inspection

13.1 The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by an inspector employed by the purchaser.

14. Rejection

14.1 Pipe shall be subject to rejection on account of failure to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

14.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

14.1.2 Defects that indicate imperfect proportioning, mixing, and molding.

14.1.3 Surface defects indicating honeycombed or open texture.

14.1.4 Damaged or cracked ends where such damage would prevent making a satisfactory joint.

14.1.5 Any continuous crack having a surface width of 0.01 in. or 0.3 mm or more and extending for a length of 12 in. or 300 mm or more, regardless of position in the wall of the pipe.

15. Marking

15.1 The following information shall be clearly marked on each section of pipe:

15.1.1 The pipe class and specification designation,

15.1.2 The date of manufacture,

15.1.3 The name or trademark of the manufacturer, and

15.1.4 Identification of plant.

15.2 One end of each section of pipe with elliptical or quadrant reinforcement shall be clearly marked during the process of manufacturing or immediately thereafter, on the inside and the outside of opposite walls along the minor axis of the elliptical reinforcing or along the vertical axis for quadrant reinforcing.

15.3 Markings shall be indented on the pipe section or painted thereon with waterproof paint.

TABLE 1 Design Requirements for Class I Reinforced Concrete Pipe (U.S. Customary Units)[A]

NOTE—See Section 4 for basis of acceptance specified by the purchaser.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	800
D-load to produce the ultimate load	1200

Internal Designated Diameter, in.	Reinforcement, in.^{2}/linear ft of pipe wall									
	Wall A					Wall B				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
	Wall Thickness, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]		Wall Thickness, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	
60	5	0.25	0.19	0.28		6	0.21	0.16	0.23	
66	5½	0.30	0.22	0.33		6½	0.25	0.19	0.28	
72	6	0.35	0.26	0.39		7	0.29	0.22	0.32	
78	6½	0.40	0.30	0.44		7½	0.32	0.24	0.36	
84	7	0.45	0.34	0.50		8	0.37	0.28	0.41	
90	7½	0.49	0.36	0.54		8½	0.41	0.31	0.46	
96	8	0.54	0.40	0.60		9	0.46	0.35	0.51	
	Concrete Strength, 5000 psi									
102	8½	0.63	0.48	Inner Circular Plus Elliptical	0.15 0.48	9½	0.54	0.41	Inner Circular Plus Elliptical	0.13 0.41
108	9	0.68	0.51	Inner Circular Plus Elliptical	0.17 0.51	10	0.61	0.46	Inner Circular Plus Elliptical	0.15 0.46
114	[A]	...	...	...	...	[A]	...	...	...	...
120	[A]	...	...	...	...	[A]	...	...	...	...
126	[A]	...	...	...	...	[A]	...	...	...	...
132	[A]	...	...	...	...	[A]	...	...	...	...
138	[A]	...	...	...	...	[A]	...	...	...	...
144	[A]	...	...	...	...	[A]	...	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one ellipitcal cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 1A Design Requirements for Class I Reinforced Concrete Pipe (SI Units)[A]

NOTE—See Section 4 for basis of acceptance specified by purchaser.

The strength test requirements in newtons per linear metre of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear metre per millimetre of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimetres.

D-load to produce a 0.3-mm crack	40.0
D-load to produce the ultimate load	60.0

Internal Designated Diameter, mm	Reinforcement, cm^2/linear m of pipe wall									
	Wall A					Wall B				
	Concrete Strength, 27.6 MPa					Concrete Strength, 27.6 MPa				
	Wall Thickness, mm	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]		Wall Thickness, mm	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	
1500	125	5.3	4.0	5.9		150	4.4	3.4	4.9	
1650	138	6.4	4.7	7.0		163	5.3	4.0	5.9	
1800	150	7.4	5.5	8.3		175	6.1	4.7	6.8	
1950	163	8.5	6.4	9.3		188	6.8	5.1	7.6	
2100	175	9.5	7.2	10.6		200	7.8	5.9	8.7	
2250	188	10.4	7.6	11.4		213	8.7	6.6	9.7	
2400	200	11.4	8.5	12.7		225	9.7	7.4	10.8	
	Concrete Strength, 34.5 MPa									
2550	213	13.3	10.2	Inner Circular Plus Elliptical	3.2 10.2	238	11.4	8.7	Inner Circular Plus Elliptical	2.8 8.7
2700	225	14.4	10.8	Inner Circular Plus Elliptical	3.6 10.8	250	12.9	9.7	Inner Circular Plus Elliptical	3.2 9.7
2850	[A]	...	...	...	...	[A]	...	...	...	...
3000	[A]	...	...	...	...	[A]	...	...	...	...
3150	[A]	...	...	...	...	[A]	...	...	...	...
3300	[A]	...	...	...	...	[A]	...	...	...	...
3450	[A]	...	...	...	...	[A]	...	...	...	...
3600	[A]	...	...	...	...	[A]	...	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 2400 mm in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

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TABLE 2 Design Requirements for Class II Reinforced Concrete Pipe (U.S. Customary Units)[A]

NOTE—See Section 4 for basis of acceptance specified by the purchaser.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1000
D-load to produce the ultimate load	1500

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
	Wall Thickness, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]		Wall Thickness, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]		Wall Thickness, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]	
12	1 3/4	0.07[B]	...	...		2	0.07[B]	...	...		...	...	...	..	
15	1 7/8	0.07[B]	...	...		2 1/4	0.07[B]	...	...		...	...	...	..	
18	2	0.07[B]	...	0.07[B]		2 1/2	0.07[B]	...	0.07[B]		...	...	...	...	
21	2 1/4	0.12	...	0.10		2 3/4	0.07[B]	...	0.07[B]		...	...	...	...	
24	2 1/2	0.13	...	0.11		3	0.07[B]	...	0.07[B]		...	...	...	..	
27	2 5/8	0.15	...	0.13		3 1/4	0.13	...	0.11		...	...	...	...	
30	2 3/4	0.15	...	0.14		3 1/2	0.14	...	0.12		...	...	...	...	
33	2 7/8	0.16	...	0.15		3 3/4	0.15	...	0.13		...	...	...	...	
36	3	0.14	0.10	0.15		4	0.12	0.09	0.13		4 3/4	0.07	0.07	0.08	
42	3 1/2	0.16	0.12	0.18		4 1/2	0.15	0.12	0.17		5 1/4	0.10	0.08	0.11	
48	4	0.21	0.16	0.23		5	0.18	0.14	0.20		5 3/4	0.14	0.11	0.15	
54	4 1/2	0.25	0.19	0.28		5 1/2	0.22	0.16	0.24		6 1/4	0.17	0.13	0.19	
60	5	0.30	0.22	0.33		6	0.25	0.19	0.28		6 3/4	0.22	0.17	0.24	
66	5 1/2	0.35	0.26	0.39		6 1/2	0.31	0.23	0.34		7 1/4	0.25	0.19	0.28	
72	6	0.41	0.30	0.45		7	0.35	0.26	0.39		7 3/4	0.30	0.23	0.33	
78	6 1/2	0.46	0.35	0.51		7 1/2	0.40	0.30	0.44		8 1/4	0.35	0.26	0.39	
84	7	0.51	0.39	0.57		8	0.46	0.34	0.51		8 3/4	0.41	0.31	0.46	
90	7 1/2	0.57	0.43	0.63		8 1/2	0.51	0.38	0.57		9 1/4	0.48	0.36	0.53	
96	8	0.62	0.47	0.69		9	0.57	0.43	0.63		9 3/4	0.55	0.41	0.61	
	Concrete Strength, 5000 psi														
102	8 1/2	0.76	0.57	Inner Circular	0.19	9 1/2	0.68	0.51	Inner Circular	0.17	10 1/4	0.62	0.47	Inner Circular	0.15
				Plus Elliptical	0.57				Plus Elliptical	0.51				Plus Elliptical	0.47
108	9	0.85	0.64	Inner Circular	0.21	10	0.76	0.57	Inner Circular	0.19	10 3/4	0.70	0.53	Inner Circular	0.17
				Plus Elliptical	0.64				Plus Elliptical	0.57				Plus Elliptical	0.53
114	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
120	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
126	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
132	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
138	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
144	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...

See next page for footnotes.

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Table 2—*continued*

[I] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655.

Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] For these classes and sizes, the minimum practical steel reinforcement is specified. The actual ultimate strength is greater than the minimum strength specified for nonreinforced pipe of equivalent diameters in Specification C 14.

[C] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[D] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 2A Design Requirements for Class II Reinforced Concrete Pipe (SI Units)[A]

NOTE – See Section 4 for basis of acceptance specified by purchaser.

The strength test requirements in newtons per linear metre of pipe under the three-edge-bearing method shall be either the D-load (test-load expressed in newtons per linear metre per millimetre of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimetres.

D-load to produce a 0.3-mm crack	50.0
D-load to produce the ultimate load	75.0

Internal Designated Diameter, mm	Reinforcement, cm²/linear m of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa			
	Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]	Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]	Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]
300	44	1.5[B]	...	...	50	1.5[B]	...	...	...	...	...	...
375	47	1.5[B]	...	...	57	1.5[B]	...	...	...	...	...	...
450	50	1.5[B]	...	1.5[B]	63	1.5[B]	...	1.5[B]	...	...	...	...
525	57	2.5	...	2.1	69	1.5[B]	...	1.5[B]	...	...	...	...
600	63	2.8	...	2.3	75	1.5[B]	...	1.5[B]	...	...	...	...
675	66	3.2	...	2.8	82	2.8	...	2.3	...	...	...	...
750	69	3.2	...	3.0	88	3.0	...	2.5	...	...	...	...
825	72	3.4	...	3.2	94	3.2	...	2.8	...	...	...	...
900	75	3.0	2.1	3.2	100	2.5	1.9	2.8	119	1.5	1.5	1.7
1050	88	3.4	2.5	3.8	113	3.2	2.5	3.6	132	2.1	1.7	2.3
1200	100	4.5	3.4	4.9	125	3.8	3.0	4.2	144	3.0	2.3	3.2
1350	113	5.3	4.0	6.0	138	4.7	3.4	5.1	157	3.6	2.8	4.0
1500	125	6.4	4.7	7.0	150	5.3	4.0	5.9	169	4.7	3.6	5.1
1650	138	7.4	5.5	8.3	163	6.6	4.9	7.2	182	5.3	4.0	5.9
1800	150	8.7	6.4	9.5	175	7.4	5.5	8.3	194	6.4	4.9	7.0
1950	163	9.7	7.4	10.8	188	8.5	6.4	9.3	207	7.4	5.5	8.3
2100	175	10.8	8.3	12.1	200	9.7	7.2	10.8	219	8.7	6.6	9.7
2250	188	12.1	9.1	13.3	213	10.8	8.0	12.1	232	10.2	7.6	11.2
2400	200	13.1	10.0	14.6	225	12.1	9.1	13.3	244	11.6	8.7	12.9
	Concrete Strength, 34.5 MPa											
2550	213	16.1	12.1	Inner Circular 4.0 Plus Elliptical 12.1	238	14.4	10.8	Inner Circular 3.6 Plus Elliptical 10.8	257	13.1	10.0	Inner Circular 3.2 Plus Elliptical 10.0
2700	225	18.0	13.6	Inner Circular 6.6 Plus Elliptical 13.6	250	16.1	12.1	Inner Circular 4.0 Plus Elliptical 12.1	269	14.8	11.2	Inner Circular 3.6 Plus Elliptical 11.2
2850	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
3000	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
3150	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
3300	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
3450	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...
3600	[A]	...	...	... ...	[A]	...	...	... ...	[A]	...	...	... ...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655.

Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 2400 mm in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] For these classes and sizes, the minimum practical steel reinforcement is specified. The actual ultimate strength is greater than the minimum strength specified for nonreinforced pipe of equivalent diameters in Specification C 14.

[C] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[D] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 3 Design Requirements for Class III Reinforced Concrete Pipe (U.S. Customary Units)[A]

NOTE – See Section 4 for the basis of acceptance specified by the purchaser.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1350
D-load to produce the ultimate load	2000

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
	Wall Thicknesses, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]		Wall Thicknesses, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]		Wall Thicknesses, in.	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]	
12	1 3/4	0.07[B]	...	...		2	0.07[B]	...	...		...	...	...	...	
15	1 7/8	0.07[B]	...	...		2 1/4	0.07[B]	...	...		...	...	...	...	
18	2	0.07[B]	...	0.07[B]		2 1/2	0.07[B]	...	0.07[B]		...	...	...	...	
21	2 1/4	0.14	...	0.11		2 3/4	0.07[B]	..	0.07[B]		..	...	...	...	
24	2 1/2	0.17	...	0.14		3	0.07[B]	...	0.07[B]		3 3/4	0.07	...	...	
27	2 5/8	0.18	...	0.16		3 1/4	0.16	...	0.14		4	0.08	...	...	
30	2 3/4	0.19	...	0.18		3 1/2	0.18	...	0.15		4 1/4	0.10	...	...	
33	2 7/8	0.21	...	0.20		3 3/4	0.20	...	0.17		4 1/2	0.12	...	...	
36	3	0.21	0.16	0.23		4	0.17	0.13	0.19		4 3/4	0.08	0.07	0.09	
42	3 1/2	0.25	0.19	0.28		4 1/2	0.21	0.16	0.23		5 1/4	0.12	0.09	0.13	
48	4	0.32	0.24	0.35		5	0.24	0.18	0.27		5 3/4	0.16	0.12	0.18	
54	4 1/2	0.38	0.28	0.42		5 1/2	0.29	0.22	0.32		6 1/4	0.21	0.16	0.23	
60	5	0.44	0.33	0.49		6	0.34	0.26	0.38		6 3/4	0.25	0.19	0.28	
66	5 1/2	0.50	0.37	0.55		6 1/2	0.41	0.31	0.46		7 1/4	0.31	0.23	0.34	
72	6	0.57	0.43	0.63		7	0.49	0.37	0.54		7 3/4	0.36	0.27	0.40	
	Concrete Strength, 5000 psi														
78	6 1/2	0.64	0.48	0.71		7 1/2	0.57	0.43	0.63		8 1/4	0.42	0 32	0.47	
84	7	0.72	0.54	0.80		8	0.64	0.48	0.71		8 3/4	0.50	0.38	0.56	
						Concrete Strength, 5000 psi					Concrete Strength, 5000 psi				
90	7 1/2	0.81	0.61	0.90		8 1/2	0.69	0.52	0.77		9 1/4	0.59	0.45	0.66	
96	8	0.93	0.70	1.03		9	0.76	0.57	0.84		9 3/4	0.70	0.53	Inner Circular Plus Elliptical	0.17 0.53
102	8 1/2	1.03	0.77	Inner Circular Plus Elliptical	0.26 0.77	9 1/2	0.90	0.68	Inner Circular Plus Elliptical	0.22 0.68	10 1/4	0.83	0.62	Inner Circular Plus Elliptical	0.21 0.62
108	9	1.22	0.91	Inner Circular Plus Elliptical	0.31 0.91	10	1.08	0.81	Inner Circular Plus Elliptical	0.27 0.81	10 3/4	0.99	0.74	Inner Circular Plus Elliptical	0.25 0.74
114	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
120	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
126	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
132	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
138	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
144	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...

[A] See end of Table 3A for footnotes.

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TABLE 3A Design Requirements for Class III Reinforced Concrete Pipe (SI Units)[A]

Note—See Section 4 for basis of acceptance specified by purchaser.

The strength test requirements in newtons per linear metre of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear metre per millimetre of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimetres.

D-load to produce a 0.3-mm crack	65.0
D-load to produce the ultimate load	100.0

Internal Designated Diameter, mm	Reinforcement, cm²/linear m of pipe wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 27.6 MPa					Concrete Strength, 27.6 MPa					Concrete strength, 27.6 MPa				
	Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Ellipitcal Reinforcement[D]		Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Ellipitcal Reinforcement[D]		Wall Thickness, mm	Circular Reinforcement[C] Inner Cage	Circular Reinforcement[C] Outer Cage	Elliptical Reinforcement[D]	
300	44	1.5[B]	...	...		50	1.5[B]	...	...		...	...	...	...	
375	47	1.5[B]	...	...		57	1.5[B]	...	...		...	...	...	...	
450	50	1.5[B]	...	1.5[B]		63	1.5[B]	...	1.5[B]		...	...	...	...	
525	57	3.0	...	2.3		69	1.5[B]	...	1.5[B]		...	...	...	...	
600	63	3.6	...	3.0		75	1.5[B]	...	1.5[C]		94	1.5	...	...	
675	66	3.8	...	3.4		82	3.4	...	3.0		100	1.7	...	...	
750	69	4.0	...	3.8		88	3.8	...	3.2		107	2.1	...	...	
825	72	4.4	...	4.2		94	3.2	2.3	3.6		113	2.5	...	...	
900	75	4.4	3.4	4.7		100	3.6	2.8	4.0		119	1.7	1.5	1.9	
1050	88	5.3	4.0	5.9		113	4.4	3.4	4.9		132	2.5	1.9	2.8	
1200	100	6.8	5.1	7.4		125	5.1	3.8	5.7		144	3.4	2.5	3.8	
1350	113	8.0	5.9	8.9		138	6.1	4.7	6.8		157	4.4	3.4	4.9	
1500	125	9.3	7.0	10.4		150	7.2	5.5	8.0		169	5.3	4.0	5.9	
1650	138	10.6	7.8	11.6		163	9.1	6.6	9.7		182	6.6	4.9	7.2	
1800	150	12.1	9.1	13.3		175	10.4	7.8	11.4		194	7.6	5.7	8.5	
	Concrete Strength, 34.5 MPa														
1950	163	13.5	9.2	15.0		188	12.1	9.1	13 3		207	8.9	6.8	9 9	
2100	175	15.2	11.4	16.9		200	13.5	10.2	15.0		219	10.6	8.0	11 9	
						Concrete Strength, 34.5 MPa					Concrete Strength, 34.5 MPa				
2250	188	17.1	12.9	19.1		213	14.6	11.0	17.3		232	12.5	9.5	14.0	
2400	200	19.7	14.8	21.8		225	16.1	12.1	17.8		244	14.8	11.2	Inner Circular Plus Elliptical	3.6 11.2
2550	213	21.8	16.3	Inner Circular Plus Elliptical	5.5 16.3	238	19.1	14.4	Inner Circular Plus Elliptical	4.7 14.4	257	17.6	13.1	Inner Circular Plus Elliptical	4.5 13.1
2700	225	25.8	19.3	Inner Circular Plus Elliptical	6.6 19.3	250	22.9	17.1	Inner Circular Plus Elliptical	5.7 17.1	269	21.0	15.7	Inner Circular Plus Elliptical	5.3 15.7
2850	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	.
3000	[A]	...	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
3150	[A]	..	...	...	...	[A]	...	...	...	...	[A]	...	...	...	...
3300	[A]	...	..	...	...	[A]	...	...	..	...	[A]	...	...	...	...
3450	[A]	..	..	...	...	[A]	...	...	...	...	[A]	...	...	...	
3600	[A]	...	...	...	...	[A]	...	...	...	...	[A]		...	...	

[A] See next page for footnotes.

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Footnotes for Tables 3 and 3A:

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in or 2400 mm in diameter shall have two circular cages or an inner circular plus one ellipitcal cage.

[B] For these classes and sizes, the minimum practical steel reinforcement is specified. The actual ultimate strength is greater than the minimum strength specified for nonreinforced pipe of equivalent diameters in Specification C 14.

As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

[C] An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[D] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 4 Design Requirements for Class IV Reinforced Concrete Pipe (U.S. Customary Units)[A]

Note—See Section 4 for the basis of acceptance specified by the purchaser.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	2000
D-load to produce the ultimate load	3000

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 5000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
	Wall Thickness, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]
12	1 3/4	0.15	...	...	2	0.07	...	...	...	...	...	...
15	1 7/8	0.16	...	...	2 1/4	0.10	...	...	...	...	...	...
18	2	0.17	...	0.15	2 1/2	0.14	...	0.11	...	...	...	...
21	2 1/4	0.23	...	0.21	2 3/4	0.20	...	0.17	...	...	...	...
24	2 1/2	0.29	...	0.27	3	0.27	...	0.23	3 3/4	0.07	0.07	0.08
27	2 5/8	0.33	...	0.31	3 1/4	0.31	...	0.25	4	0.08	0.07	0.09
30	2 3/4	0.38	...	0.35	3 1/2	0.35	...	0.28	4 1/4	0.09	0.07	0.10
33	A	...	...	...	3 3/4	0.27	0.20	0.30	4 1/2	0.11	0.08	0.12
36	A	...	...	...	4	0.30	0.22	0.33	4 3/4	0.14	0.10	0.15
42	A	...	...	...	4 1/2	0.35	0.26	0.39	5 1/4	0.20	0.15	0.22
48	A	...	...	...	5	0.42	0.32	0.47	5 3/4	0.26	0.20	0.29
54	A	...	...	...	5 1/2	0.50	0.37	0.55	6 1/4	0.34	0.26	0.38
					Concrete Strength, 5000 psi							
60	A	...	...	...	6	0.59	0.45	0.66	6 3/4	0.41	0.31	0.46
60	A	...	...	...	6 1/2	0.69	0.52	0.77	7 1/4	0.51	0.39	0.57
									Concrete Strength, 5000 psi			
72	A	...	...	...	7	0.79	0.60	0.88	7 3/4	0.61	0.46	0.68
78	A	...	...	...	A	...	...	...	8 1/4	0.71	0.53	0.79
84	A	...	...	...	A	...	...	...	8 3/4	0.85	0.63	0.94
90	A	...	...	...	A	...	...	...	A	...	...	...
96	A	...	...	...	A	...	...	...	A	...	...	...
102	A	...	...	...	A	...	...	...	A	...	...	...
108	A	...	...	...	A	...	...	...	A	...	...	...
114	A	...	...	...	A	...	...	...	A	...	...	...
120	A	...	...	...	A	...	...	...	A	...	...	...
126	A	...	...	...	A	...	...	...	A	...	...	...
132	A	...	...	...	A	...	...	...	A	...	...	...
138	A	...	...	...	A	...	...	...	A	...	...	...
144	A	...	...	...	A	...	...	...	A	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

For Wall C, in sizes 24 to 33 in., a single circular cage with an area not less than the sum of the specified inner and outer circular reinforcement areas.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

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TABLE 4A Design Requirements for Class IV Reinforced Concrete Pipe (SI Units)[A]

NOTE—See Section 4 for basis of acceptance specified by purchaser.

The strength test requirements in newtons per linear metre of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear metre per millimetre of diameter) to produce the 0.3-mm crack or the D-loads to produce the 0.3-mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimetres.

D-load to produce a 0.3-mm crack	100.0
D-load to produce the ultimate load	150.0

Internal Designated Diameter, mm	Reinforcement, cm²/linear m of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 34.5 MPa				Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa			
	Wall Thickness, mm	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thickness, mm	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]	Wall Thickness, mm	Circular Reinforcement[B] Inner Cage	Circular Reinforcement[B] Outer Cage	Elliptical Reinforcement[C]
300	44	3.2	...	...	50	1.5	...	...	...	...	...	...
375	47	3.4	...	...	57	2.1	...	...	...	...	...	...
450	50	3.6	...	3.2	63	3.0	...	2.3	...	...	...	...
525	57	4.9	...	4.4	69	4.2	...	3.6	...	...	...	...
600	63	6.1	...	5.7	75	5.7	...	4.9	94	1.5	1.5	1.7
675	66	7.0	...	6.6	82	6.6	...	5.3	100	1.7	1.5	1.9
750	69	8.0	...	7.4	88	7.4	...	5.9	107	1.9	1.5	2.1
825	[A]	...	...	...	94	5.7	4.2	6.3	113	2.3	1.7	2.5
900	[A]	...	...	...	100	6.3	4.7	7.0	119	3.0	2.1	3.2
1050	[A]	...	...	...	113	7.4	5.5	8.3	132	4.2	3.2	4.7
1200	[A]	...	...	...	125	8.9	6.8	9.9	144	5.5	4.2	6.1
1350		...	...	...	138	10.6	7.8	11.6	157	7.2	5.5	8.0
					Concrete Strength, 34.5 MPa							
1500	[A]	...	...	...	150	12.5	9.5	14.0	169	8.7	6.6	9.7
1650	[A]	...	...	...	163	14.6	11.0	16.3	182	10.8	8.3	12.0
									Concrete Strength, 34.5 MPa			
1800	[A]	...	...	...	175	16.7	12.7	18.6	194	12.9	9.7	14.4
1950	[A]	...	...	...	[A]	...	...	...	207	15.0	11.2	16.7
2100	[A]	...	...	...	[A]	...	...	...	219	18.0	13.3	19.9
2250	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2400	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2550	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2700	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2850	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3000	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3150	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3300	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3450	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3600	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 2400 mm in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

For Wall C, in sizes 600 to 825 mm, a single circular cage with an area not less than the sum of the specified inner and outer circular reinforcement areas.

[C] Ellipitical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

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TABLE 5 Design Requirements for Class V Reinforced Concrete Pipe (U.S. Customary Units)[A]

NOTE – See Section 4 for the basis of acceptance specified by the purchaser.

The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	3000
D-load to produce the ultimate load	3750

Internal Designated Diameter, in.	Reinforcement, in.²/linear ft of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 6000 psi				Concrete Strength, 6000 psi				Concrete Strength, 6000 psi			
	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, in.	Circular Reinforcement[B]		Elliptical Reinforcement[C]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	...	...	...	...	2	0.10	...	...	...	...	...	...
15	...	...	...	...	2¼	0.14	...	...	...	...	...	...
18	...	...	...	...	2½	0.19	...	0.16	...	...	...	...
21	...	...	...	...	2¾	0.24	...	0.21	...	...	...	...
24	...	...	...	...	3	0.30	...	0.24	3¾	0.12	0.09	0.13
27	...	...	...	...	3¼	0.38	0.28	0.42	4	0.14	0.11	0.16
30	...	...	...	...	3½	0.41	0.31	0.46	4¼	0.18	0.14	0.20
33	...	...	...	...	3¾	0.46	0.35	0.51	4½	0.23	0.17	0.25
36	...	...	...	...	4	0.50	0.38	0.56	4¾	0.27	0.20	0.30
42	...	...	...	...	4½	0.60	0.45	0.67	5¼	0.36	0.27	0.40
48	...	...	...	...	5	0.73	0.55	0.81	5¾	0.47	0.35	0.52
54	...	...	...	...	...	...	...	...	6¼	0.58	0.43	0.64
60	...	...	...	...	...	...	...	...	6¾	0.70	0.53	0.78
66	...	...	...	...	...	...	...	...	7¼	0.84	0.63	0.93
72	...	...	...	...	...	...	...	...	7¾	0.99	0.74	1.10
78	...	...	...	...	...	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...	...	...	...	...	...
114	...	...	...	...	...	...	...	...	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...
126	...	...	...	...	...	...	...	...	...	...	...	...
132	...	...	...	...	...	...	...	...	...	...	...	...
138	...	...	...	...	...	...	...	...	...	...	...	...
144	...	...	...	...	...	...	...	...	...	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 5A Design Requirements for Class V Reinforced Concrete Pipe (SI Units)[A]

NOTE – See Section 4 for basis of acceptance specified by purchaser.

The strength test requirements in newtons per linear metre of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear metre per millimetre of diameter) to produce the 0.35-mm crack, or the D-loads to produce the 0.35-mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimetres

D-load to produce a 0.3-mm crack	140.0
D-load to produce the ultimate load	175.0

Internal Designated Diameter, mm	Reinforcement, cm²/linear m of pipe wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 41.4 MPa				Concrete Strength, 41.4 MPa				Concrete Strength, 41.4 MPa			
	Wall Thickness, mm	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, mm	Circular Reinforcement[B]		Elliptical Reinforcement[C]	Wall Thickness, mm	Circular Reinforcement[B]		Elliptical Reinforcement[C]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
300	[A]	...	...	...	50	2.1	...	...	...	...	...	...
375	[A]	...	...	...	57	3.0	...	...	...	...	...	...
450	[A]	...	...	...	63	4.0	...	3.4	...	...	...	...
525	[A]	...	...	...	69	5.1	...	4.4	...	...	...	...
600	[A]	...	...	...	75	6.4	...	5.1	94	2.5	1.9	2.8
675	[A]	...	...	...	82	8.0	5.9	8.9	100	3.0	2.3	3.4
750	[A]	...	...	...	88	8.7	6.6	9.7	107	3.8	3.0	4.2
825	[A]	...	...	...	94	9.7	7.4	10.8	113	4.9	3.6	5.3
900	[A]	...	...	...	100	10.6	8.0	11.9	119	5.7	4.2	6.3
1050	[A]	...	...	...	113	12.7	9.5	14.2	132	7.6	5.7	8.5
1200	[A]	...	...	...	125	15.5	11.6	17.1	144	9.9	7.4	11.0
1350	[A]	...	...	...	[A]	...	...	...	157	12.3	9.1	13.5
1500	[A]	...	...	...	[A]	...	...	...	169	14.8	11.2	16.5
1650	[A]	...	...	...	[A]	...	...	...	182	17.8	13.3	19.7
1800	[A]	...	...	...	[A]	...	...	...	194	21.0	15.7	23.3
1950	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2100	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2250	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2400	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2550	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2700	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
2850	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3000	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3150	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3300	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3450	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...
3600	[A]	...	...	...	[A]	...	...	...	[A]	...	...	...

[A] For modified or special designs see 6.2 or with the permission of the purchaser utilize the provisions of ASTM C 655.

Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe over 2400 mm in diameter shall have two circular cages or an inner circular plus one elliptical cage.

[B] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in either of the following manners:

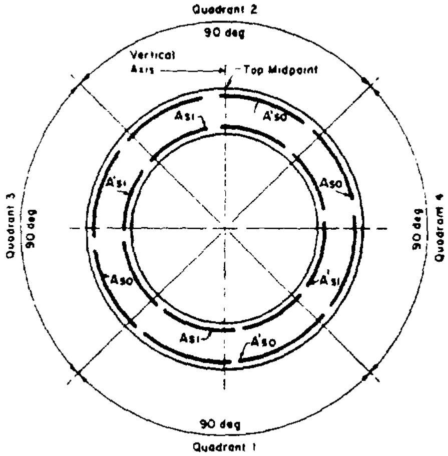
An inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table, or

An inner and outer cage plus quadrant mats in accordance with Fig. 1.

[C] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

TABLE 6A Permissible Variation in Internal Diameter (SI Units)

Designated Diameter of Pipe mm	Permissible Variation, Internal Diameter of Pipe	
	Minimum, mm	Maximum, mm
300	300	310
375	375	390
450	450	465
525	525	545
600	600	620
675	675	695
750	750	775
825	825	850
900	900	925
1050	1050	1080
1200	1200	1230
1350	1350	1385
1500	1500	1540
1650	1650	1695
1800	1800	1850
1950	1950	2000
2100	2100	2155
2250	2250	2310
2400	2400	2465
2550	2550	2620
2700	2700	2770
2850	2850	2925
3000	3000	3080
3150	3150	3235
3300	3300	3390
3450	3450	3540
3600	3600	3695



NOTE 1—The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Tables 1 to 5 or 1A to 5A

NOTE 2—The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Tables 1 to 5 or 1A to 5A.

NOTE 3—The reinforcement area (A'si) of the inner cage in Quadrants 3 and 4 shall be not less than 25 % of that specified for the inner cage in Tables 1 to 5 or 1A to 5A.

NOTE 4—The reinforcement area (A'so) of the outer cage in Quadrants 1 and 2 shall be not less than 25 % of that specified for the outer cage in Tables 1 to 5 or 1A to 5A.

FIG. 1 Quadrant Reinforcement.

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Standard Specification for CONCRETE SEWER, STORM DRAIN, CULVERT PIPE[1]

This Standard is issued under the fixed designation C 14; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification covers nonreinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, storm water, and for the construction of culverts.

NOTE 1—The values stated in either U.S. customary units or SI (metric) units are to be regarded separately as standard. The values stated in each system are not exact equivalents, therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

NOTE 2—This specification is a manufacturing and purchase specification only and does not include requirements for bedding, backfill, or the relationship between earth coverload and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, controlled manufacture in the plant, and care in the field construction work. The purchaser of the concrete pipe specified herein is cautioned that he must properly correlate the field requirements with the class of pipe specified and provide for or require adequate inspection in the manufacturing plant and at the construction site.

2. Applicable Documents

2.1 *ASTM Standards:*

- C 33 Specification for Concrete Aggregates[2]
- C 150 Specification for Portland Cement[2]
- C 309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete[2]
- C 443 Specification for Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets[3]
- C 497 Testing Concrete Pipe, Sections, or Tile[3]
- C 595 Specification for Blended Hydraulic Cements[2]
- C 822 Definitions of Terms Relating to Concrete Pipe and Related Products[3]

3. Classification

3.1 Pipe manufactured according to this specification shall be of three classes identified as "Class 1 Nonreinforced Concrete Pipe," "Class 2 Nonreinforced Concrete Pipe," and "Class 3 Nonreinforced Concrete Pipe." The corresponding strength requirements are prescribed in Tables 1 and 1A.

4. Basis of Acceptance

4.1 The acceptability of the pipe shall be determined by the results of the test prescribed in this section, when required, and by inspection to determine whether the pipe conforms to this specification as to design and freedom from defects.

4.2 *Acceptance as to Strength Properties*—Pipe shall be acceptable under the strength tests when they have met the requirements as prescribed in 9.3.

4.3 *Acceptance as to Absorption Properties*—Pipe shall be acceptable under the absorption test when they have met the requirements as prescribed in 9.4.

4.4 *Acceptance as to Permeability Properties*—Pipe shall be acceptable under the permeability test when they have met the requirements as prescribed in 9.5.

NOTE 3—Prior to purchase the purchaser may specify the hydrostatic test prescribed in 9.6 instead of the permeability test.

4.5 *Acceptance as to Hydrostatic Proper-*

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[1] This specification is under the jurisdiction of ASTM Committee C-13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.01 on Nonreinforced Sewer Pipe.

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[2] *Annual Book of ASTM Standards*, Part 14.

[3] *Annual Book of ASTM Standards*, Part 16.

ties — Pipe shall be acceptable under the hydrostatic test when they have met the requirements as prescribed in 9.6.

5. Materials

5.1 *Cement* — Portland cement shall conform to the requirements of Specification C 150 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of Specification C 595.

5.2 *Aggregates* — Aggregates shall conform to Specification C 33, except that the requirement for graduation shall not apply.

5.3 *Admixtures and Blends* — Admixtures and blends may be used with the approval of the purchaser.

6. Design

6.1 *Design Tables* — Design requirements shall be in accordance with Tables 1 and 1A. Wall thickness used may be more than but not less than the value shown, except as affected by the tolerance herein specified and by the provision for modified design.

6.2 *Modified or Special Design* — Manufacturers may submit to the purchaser for approval, prior to manufacture, wall thickness other than those shown in Tables 1 and 1A. Such pipe shall meet all of the test and performance requirements specified by the purchaser in accordance with Section 9.

7. Joints

7.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that when the sections are laid together they will make a continuous line of pipe with a smooth interior free of appreciable irregularities in the flow line, all compatible with the permissible variations given in Section 10.

8. Manufacture

8.1 *Mixture* — The aggregates shall be sized, graded, proportioned, and thoroughly mixed in a batch mixer with such proportions of cement and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. In no case, however, shall a proportion of portland cement in the mixture be less than 564 lb/yd^3 or 330 kg/m^3 of concrete.

8.2 *Curing* — Pipe shall be subjected to any one of the methods of curing described 8.2.1 through 8.2.4 or to any other method or combination of methods approved by the purchaser that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the concrete will develop the specified strength requirement at 28 days or less.

8.2.1 *Steam Curing* — Pipe may be placed in a curing chamber, free from outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

8.2.2 *Water Curing* — Concrete pipe may be water-cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

8.2.3 The manufacturer may, at his option, combine the methods described in 8.2.1 and 8.2.2 provided the specified strength is attained.

8.2.4 *Membrane Curing* — A sealing membrane conforming to the requirements Specification C 309 may be applied and le intact until the specified strength requirements are met. The concrete at the time of application shall be within 10°F or 6°C of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

8.3 *Specials:*

8.3.1 *General Requirements* — Special shapes or fittings such as wyes, tees, bends, and adapters for use with concrete pipe conforming to this specification shall conform to the applicable requirements for concrete pipe of corresponding class and internal diameter. Joints shall be compatible with those used in adjoining concrete pipes.

8.3.2 *Fabricated Branches* — Fabricated branches for wyes and tees shall be securely attached to the wall of the pipe in such a manner as not to restrict or otherwise interfere with the flow characteristics of the pipe.

9. Physical Requirements

9.1 *Test Specimen* – The pipe to be tested shall be selected by the purchaser or his representative, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the purchaser when placing the order. The test pipe shall first be freed from all visible moisture. When dry, each pipe shall be measured and inspected. The results of these observations shall be recorded.

9.2 *Number and Type of Test Specimens Required* – The manufacturer or seller shall furnish pipe for crushing and absorption tests, up to 0.5% of the number of pipe of each size included in the order, except that in no case shall less than two pipe be furnished. For the permeability test, 2 % of the number of pipe of each size included in the order, but in no case less than two pipe shall be furnished. For the hydrostatic test, 0.5% of the number of pipe of each size included in the order, but in no case less than two pipe shall be furnished.

9.3 *External Load Crushing Test Requirements* – The crushing strength of nonreinforced concrete pipe shall conform to the requirements prescribed in Tables 1 and 1A. The individual results of the various tests for each size of pipe and for each shipment and plant shall be tabulated separately so as to show the percentage that fails to conform to the requirements of each test. The crushing strength shall ordinarily be applied to not less than 75 % of the pipe received for purpose of test. All tests shall be made in accordance with Method C 497. Pipe shall be acceptable under the strength test requirements when all test pipe conform to the test requirements. Should any of the preliminary test pipe provided in 9.2 fail to meet the test requirements, then the manufacturer will be allowed a retest on two additional pipe of each pipe that failed, and the pipe shall be acceptable only when all of these retest pipe meet the strength requirements.

9.4 *Absorption Test* – When required by the purchaser, absorption shall be determined by either Method A or Method B in accordance with Methods C 497 for the boiling absorption test and shall not exceed 9 % for Method A or 8.5 % for Method B. The individual results of the various tests for each size of pipe for each shipment and plant shall be tabulated separately so as to show the percentage that fails to conform to the requirements of each test. All tests shall be made in accordance with Methods C 497. The number of absorption test specimens shall be equal to the number of pipe provided for crushing strength testing. These test specimens shall be obtained from pipe that are acceptable as to strength, and shall be taken from pipe used in making the strength test after the test is made. These specimens shall be marked with the number or identification mark of the pipe from which they were taken. Each Method A specimen shall have an area of 12 to 20 in.^{2} or 77 to 129 cm^2, as measured on one surface of the pipe, and a thickness equal to the pipe wall, and shall be free of visible cracks. Pipes shall be acceptable under the absorption test when all test pipe conform to the test requirements. When not more than 20 % of the absorption test specimens fail to pass the requirements of this section, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and they shall be acceptable if they conform to the test requirements.

9.5 *Permeability* – When subject to the permeability test as specified in Methods C 497 the outer pipe surface of not less than 80 % of the pipe tested shall show no moist or damp spots at the end of the test period due to water passing through the walls of the pipe. When more than 20 % of the test pipe fail to pass the requirements of this section, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements. If the second test fails the whole lot may be rejected.

9.6 *Hydrostatic Tests* – If subjected to the internal hydrostatic pressures of 10 psi or 70 kPa for 10 min as described in Methods C 497, the pipe shall show no leakage. Moisture appearing on the surface of the pipe in the form of patches or beads adhering to the surface shall not be considered leakage. When not more than 20 % of the test pipe fail to pass the requirements of this section, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements. If the second test fails, the whole lot may be rejected.

9.7 At the time of initial inspection, under the permeability test, if the pipe shows moist or damp spots on the outer surface of the pipe, the test shall be continued for a period not to exceed 24 h at the option of the manufacturer or seller. If the pipe shows no moist or damp spots on the outer surface of the pipe at some tme during the extended period, it shall be considered to have passed the test.

9.8 At the time of initial inspection, under the hydrostatic test, if the pipe shows leakage, the test shall be continued for a period not to exceed 24 h at the option of the manufacturer or seller. If the pipe shows no leakage, at some time during the extended period, it shall be considered to have passed the test.

9.9 When the hydrostatic test is used for acceptance of the pipe joint as specified in Section 8 of Specification C 443 the same joint test runs may be used as the basis of acceptance for the pipe hydrostatic test allowed under 4.5 and 9.6 of this specification.

9.10 *Defective Pipe*—Pipe that is observed to have cracks or other defects in form or dimensions in excess of the limits permitted in this specification, shall be discarded and replaced with additional pipe from the shipment.

10. Dimensions and Permissible Variations

10.1 *Sizes and Dimensions*—Pipe shall be furnished of the sizes, internal diameters, and dimensions prescribed in Tables 1 and 1A.

10.2 *Permissible Variations in Dimensions*—Permissible variations in dimensions shall be limited to the following:

10.2.1 *Internal Diameter*—The internal diameter shall not be more or less than the designated diameter by more than $^3/_{16}$ in. for pipe designated as 12 in. and under in diameter; by more than $^1/_4$ in. for pipe designated as 15 or 18 in. in diameter; by more than $^5/_{}$ in. for pipe designated as 21 in. in diameter; and by more than $^3/_8$ in. for pipe designated as 24 in. and over in diameter. Permissible variations utilizing SI units are as prescribed in Table 2A.

10.2.2 *Thickness of Wall*—The wall thickness shall be not less than the values shown in Table 1 or 1A or the manufacturer's designated thickness if greater than shown in Table 1 or 1A by more than $^1/_{16}$ in. or 2 mm for pipe 10 in. or 250 mm or less in diameter; by more than $^1/_8$ in. or 3 mm for pipe 12 to 24 in. or 300 to 600 mm in diameter; and by more than $^3/_{16}$ in. or 5 mm for pipe more than 24 in. or 600 mm in diameter; or by more than 5 % of the tabulated or designated wall thickness, whichever is greater. Localized variations in wall thickness exceeding those specified above shall be accepted if the physical test requirements specified herein are met.

10.2.3 *Length*—The length of any section of pipe shall vary not more than $-^1/_2$ in. or −13 mm from a specified or designated design length.

10.2.4 *Length of Two Opposite Sides*—The length of two opposite sides of any section of pipe shall vary not more than $^1/_4$ in. or 6 mm or 2 % of the designated diameter, whichever is larger.

10.2.5 *Straightness*—Pipe intended to be straight shall not vary in alignment more than $^1/_8$ in./ft or 10 mm/m of length.

11. Workmanship and Finish

11.1 Pipe shall be substantially free of fractures and excessive interior surface roughness.

11.2 The planes of the ends of the pipe shall be perpendicular to the longitudinal axis, subject to the limits of variation as shown in 10.2.4.

12. Repairs

12.1 Pipe may be repaired, if necessary, because of occasional imperfections in manufacture or injury during handling and will be acceptable if, in the opinion of the purchaser, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of this specification.

13. Inspection

13.1 The quality of all materials and the finished pipe shall be subject to inspection and approval by an inspector employed by the purchaser. Such inspection may be performed at the point of manufacture or delivery.

14. Rejection

14.1 Pipe shall be subject to rejection on account of failure to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

14.1.1 Fractures or cracks passing through the wall or joints, except that a single crack not exceeding 2 in. or 50 mm in length at either end of a pipe or a single fracture or spall in the joints not exceeding 3 in. or 75 mm around the circumference of the pipe nor 2 in. or 50 mm in length into joint shall not be considered cause for rejection unless these defects exist in more than 5 % of the entire shipment or delivery.

14.1.2 Defects that indicate imperfect mixing and molding.

14.1.3 Cracks sufficient to impair the strength, durability, or serviceability of the pipe.

15. Marking

15.1 The following information shall be clearly marked on each pipe:

15.1.1 The pipe class and specification designation,

15.1.2 The date of manufacture,

15.1.3 The name or trademark of the manufacturer, and

15.1.4 Identification of the plant.

15.2 Marking shall be indented on the pipe section or painted thereon with waterproof paint.

TABLE 1 Physical and Dimensional Requirements for Nonreinforced Concrete Pipe (U.S. Customary Units)[A]

Internal Designated Diameter, in.	Class 1		Class 2		Class 3	
	Minimum Thickness of Wall, in.	Minimum Strength, lbf/linear ft, Three-Edge Bearing	Minimum Thickness of Wall, in.	Minimum Strength, lbf/linear ft, Three-Edge Bearing	Minimum Thickness of Wall, in.	Minimum Strength, lbf/linear ft, Three-Edge Bearing
4	5/8	1500	3/4	2000	3/4	2400
6	5/8	1500	3/4	2000	7/8	2400
8	3/4	1500	7/8	2000	1 1/8	2400
10	7/8	1600	1	2000	1 1/4	2400
12	1	1800	1 3/8	2250	1 3/4	2600
15	1 1/4	2000	1 5/8	2600	1 7/8	2900
18	1 1/2	2200	2	3000	2 1/4	3300
21	1 3/4	2400	2 1/4	3300	2 3/4	3850
24	2 1/8	2600	3	3600	3 3/4	4400
27	3 1/4	2800	4	3950	4	4600
30	3 1/2	3000	4 1/4	4300	4 1/4	4750
33	3 3/4	3150	4 1/2	4400	4 1/2	4875
36	4	3300	4 3/4	4500	4 3/4	5000

[A] Subject to Tolerances in Section 10.

TABLE 1A **Physical and Dimensional Requirements for Nonreinforced Concrete Pipe (SI Units)**[A]

Internal Designated Diameter, mm	Class 1		Class 2		Class 3	
	Minimum Thickness of Wall, mm	Minimum Strength, kN/linear m, Three-Edge Bearing	Minimum Thickness of Wall, mm	Minimum Strength, kN/linear m, Three-Edge Bearing	Minimum Thickness of Wall, mm	Minimum Strength, kN/linear m, Three-Edge Bearing
100	16	22.0	19	29.0	19	35.0
150	16	22.0	19	29.0	22	35.0
200	19	22.0	22	29.0	29	35.0
250	22	23.5	25	29.0	32	35.0
300	25	26.5	35	33.0	44	38.0
375	32	29.0	41	38.0	47	42.0
450	38	32.0	50	44.0	57	48.0
525	44	35.0	57	48.0	69	56.0
600	54	38.0	75	52.5	94	64.0
675	82	41.0	100	57.5	100	67.0
750	88	44.0	107	63.0	107	69.5
825	94	46.0	113	64.0	113	71.0
900	100	48.0	119	65.5	119	73.0

[A] Subject to Tolerance in Section 10.

TABLE 2A **Permissible Variation in Internal Diameter (SI Units)**

Designated Diameter of Pipe, mm	Permissible Variation, Internal Diameter of Pipe	
	Minimum, mm	Maximum, mm
100	100	110
150	150	160
200	200	210
250	250	260
300	300	310
375	375	390
450	450	465
525	525	545
600	600	620
675	675	695
750	750	775
825	825	850
900	900	925

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for VITRIFIED CLAY PIPE, EXTRA STRENGTH, STANDARD STRENGTH, AND PERFORATED[1]

This Standard is issued under the fixed designation C 700; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification establishes the criteria for acceptance of extra strength and standard strength vitrified clay pipe and fittings to be used for the conveyance of sewage, industrial wastes, and storm water; and extra strength perforated and standard strength perforated vitrified clay pipe to be used for underdrainage, filter fields, leaching fields, and similar subdrainage installations.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

NOTE 2—Attention is called to ASTM Recommended Practice C 12, for Installing Vitrified Clay Pipe Lines,[2] ASTM Specification C 425, for Compression Joints for Vitrified Clay Pipe and Fittings,[2] and ASTM Tentative Recommended Practice C 828, for Low-Pressure Air Test of Vitrified Clay Pipe Lines (4 to 12-in.).[2]

2. Definitions

2.1 Clay, fire clay, shale, and surface clay are as defined in ASTM Definitions C 43, Terms Relating to Structural Clay Products.[2]

3. Materials and Manufacture

3.1 Vitrified clay pipe shall be manufactured from fire clay, shale, surface clay, or a combination of these materials that, when formed into pipe and fired to suitable temperatures, yields a product that is strong, durable, serviceable, free of objectionable defects, and conforms to this specification.

4. Physical and Chemical Requirements

4.1 *Crushing Strength:*

4.1.1 Pipe shall meet the crushing strength requirements of Table 1.

4.1.2 The number of specimens to be tested shall not exceed 0.5 % of the number of pipe of each size furnished, except that no less than two specimens shall be tested.

4.1.3 If any of the test specimens fail to meet the requirements, the manufacturer will be allowed a retest on two additional specimens for each one that failed. The pipe will be acceptable if all the specimens for retest meet the requirement.

4.1.4 If, subsequent to an initial pipe strength failure, the accuracy of the testing machine is questioned, at the request of the manufacturer, the machine may be recalibrated and a retest made or a retest may be made upon a machine of known accuracy.

4.2 *Absorption:*

4.2.1 The absorption of vitrified clay pipe shall not exceed 8 percent.

4.2.2 If any of the test specimens fail to meet the absorption requirements, a retest will be allowed, and the pipe accepted as provided in 4.1.3.

4.3 *Hydrostatic Pressure Test:*

4.3.1 As an alternative to the absorption test, the manufacturer may, at his option, apply a hydrostatic pressure test to all of the pipes subject to test in each size and run of the pipe.

4.3.2 When the pipe is subjected to an

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[1] This specification is under the jurisdiction of ASTM Committee C-4 on Vitrified Clay Pipe.
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[2] *Annual Book of ASTM Standards*, Part 16.

internal hydrostatic pressure of 10 psi (68.9 kPa) for the elapsed time shown in the following table, there shall be no leakage on the exterior of the pipe. Moisture appearing on the surface of the pipe in the form of beads adhering to the surface shall not be considered leakage. However, moisture which starts to run on the pipe shall be construed as leakage regardless of quantity.

Hydrostatic Pressure Test Times

Thickness of Barrel, in. (mm)	Test Time, min
Up to and including 1 (25)	7
Over 1 (25) and including 1½ (38)	9
Over 1½ (38) and including 2 (51)	12
Over 2 (51) and including 2½ (64)	15
Over 2½ (64) and including 3 (76)	18
Over 3 (76)	21

4.3.3 If any of the test specimens fail to meet the hydrostatic requirements, a retest will be allowed, and the pipe accepted as provided in 4.1.3.

4.4 *Acid Resistance:*

4.4.1 This test is used to determine the resistance of pipe to the action of acids encountered in sanitary sewers. The test shall be performed only when specified.

4.4.2 The pipe of each size and shipment shall be acceptable if the acid-soluble matter, from specimens representing such pipe, does not exceed 0.25 %. Failure of any of the specimens to meet the test shall result in the rejection of all the pipe represented by the specimen tested.

5. Sizes and Dimensions

5.1 Sizes and dimensions of pipe are as described in Table 2 (U. S. customary units) and Table 2A (SI units).

5.2 The inside diameter shall not vary from a true circle by more than 3 % of its nominal diameter.

5.3 The average inside diameter shall be determined by taking any two 90-deg (1.6-rad) opposing measurements and averaging the readings.

6. Straightness

6.1 Pipe shall not deviate from straight by more than 1/16 in./ft (5 mm/m) of length when the maximum offset is measured from the concave side of the pipe.

6.2 Measurement shall be taken by placing a straight X-edge on the concave side of the pipe's full length of the barrel, being sure not to include spigot joint material or socket, and measuring the maximum distance between the straightedge and concave side of the pip

7. Glaze

7.1 Unless otherwise specified, the manufacturer may supply either glazed or unglazed pipe. On glazed pipe, the glaze shall be a continuously uniform layer that is substantially free of imperfections. Not more than 10 % of the inner surface of any pipe barrel may be free of glaze. There shall be no well defined crazing or hairline cracks.

7.2 Glazing is not required on the outer surface of the pipe at the spigot, for a longitudinal distance equal to the depth of the socket. Glaze may be entirely absent from the inside of the socket.

7.3 When a ceramic glaze is used, it need only be applied to the inside of the pipe.

8. Blisters

8.1 Pipe of nominal sizes from 3 to 18 in., shall have no blister with a dimension exceeding 3 in. (76 mm), and no blister or pimple shall project more than 1/8 in. (3 mm) above the surface of the pipe.

8.2 Pipe of nominal sizes over 18 in., shall have no blister exceeding 2 in./ft (166 mm/m) of internal diameter, and no blister or pimple shall project above the surface of the pipe more than 1/8 in./ft (10 mm/m) of int nal diameter.

8.3 Pipe shall have no broken blisters.

9. Fractures and Cracks

9.1 There shall be no fractures or cracks passing through the barrel or socket, except that a single crack at the spigot end of the pipe not exceeding 75 % of the depth of the socket, or a single fracture in the socket not exceeding 3 in. (76 mm) around the circumference nor 2 in. (50 mm) lengthwise may be permitted.

9.2 Chips or fractures on the interior of the pipe shall not exceed 2 in. (50 mm) in length, 1 in. (25 mm) in width, and a depth of one fourth of the thickness of the barrel.

10. Finish of Ends

10.1 The ends of pipe shall be square with their longitudinal axes, within the tolerances provided in Table 2.

10.2 The inner surface of the socket and the outer surface of the spigot shall be scored ith triangular or semicircular-shaped circumferential indentations about 1/8 in. (3 mm) in depth. The minimum number of scorings shall be as follows:

Size of Pipe, in. (mm)	Number of Scorings, min
3 to 6 (75 to 150)	1
8 and 10 (200 and 250)	2
12 to 36 (300 to 900)	3

10.3 Scoring may be eliminated when it is conducive to the proper application of the joint to be used.

11. Perforations

11.1 Perforations shall be circular and cleanly cut, 1/4 in. (6 mm) in diameter, arranged approximately 3 in. (76 mm) center to center in rows parallel to the longitudinal axis of the pipe. Rows shall be arranged in two equal groups on each side of the vertical center line of the pipe. The lowermost rows of perforations shall be separated by an arc of 90 deg (1.6 rad) measured across the bottom of the pipe. The uppermost rows of perforations shall be separated by an arc of 200 deg (3.5 rad), measured across the top of the pipe. Spacing of rows between these limits shall be uniform. The total number of rows of perforations is shown in Table 3.

11.2 The spigot end of bell-and-spigot perforated pipe shall not be perforated for a distance equal to the depth of the socket.

12. Fittings

12.1 Fittings shall correspond in all respects with the dimensions specified for pipe of the corresponding size. Dimensional tolerances of fittings shall be the same as for straight pipe. All fittings shall conform to the requirements for pipe described in Sections 8 through 10.

12.2 Slants shall have their spigot ends cut at an angle of approximately 60 deg (1.0 rad) or 45 deg (0.8 rad) with the longitudinal axis.

12.3 Curves shall have arcs of approximately 90 deg (1.6 rad), 45 deg (0.8 rad), 30 deg (0.5 rad), or 22.5 deg 0.4 rad) as required.

12.4 Fittings shall be made to such lengths as will accommodate the jointing system provided. Tee and wye fittings shall be furnished with spurs of the size specified, securely and completely fastened to the barrel of the fitting in the process of manufacture. The spurs of tee fittings shall have their axes perpendicular to the longitudinal axis of the fitting. The spur of the wye fittings shall have their axes at angles of approximately 60 deg (1.0 rad), or 45 deg (0.8 rad) to the longitudinal axis of the fitting, measured from the socket or bell end of the fitting. The barrel of each spur shall be of sufficient length to permit making a proper joint.

12.5 Channel pipe and channel fittings shall be approximate half sections of the corresponding size of straight pipe and fittings.

13. Test Methods

13.1 Perform tests in accordance with Methods C 301.

14. Inspection

14.1 All pipe shall be subject to inspection by a competent inspector employed by the purchaser. Inspection may be made at the factory or promptly at the point of delivery. All pipe accepted may be plainly marked by the inspector. Rejected pipe shall not be defaced, but shall be replaced by the manufacturer or seller without additional cost, with pipe that meets the requirements of this specification.

15. Marking

15.1 Each length of pipe shall bear the initials or name of the manufacturer, and the location of the plant. The words "Extra Strength" or the symbol "ES" shall be included, when applicable, to identify the class of pipe. The markings shall be indented on the exterior of the pipe, and shall be plainly legible for identification.

TABLE 1 Minimum Crushing Strength (3-Edge Bearing Strength)

Nominal Size, in	Extra Strength Vitrified Clay Pipe		Standard Strength Vitrified Clay Pipe		Perforated Vitrified Clay Pipe			
					Extra Strength		Standard Strength	
	lbf/linear ft	kN/linear m	lbf/linear ft	kN/linear m	lbf/linear ft	kN/linear m	lbf/linear ft	kN/linear m
3	2000	29.2	...	...	...	...	...	...
4	2000	29.2	1200	17.5	1250	18.2	1000	14.6
6	2000	29.2	1200	17.5	1600	23.4	1000	14.6
8	2200	32.1	1400	20.4	1600	23.4	1000	14.6
10	2400	35.0	1600	23.4	1600	23.4	1100	16.1
12	2600	37.9	1800	26.3	1800	26.3	1200	17.5
15	2900	42.3	2000	29.2	2200	32.1	1400	20.4
18	3300	48.2	2200	32.1	2640	38.5	1700	24.8
21	3850	56.2	2400	35.0	3100	45.2	2000	29.2
24	4400	64.2	2600	37.9	3520	51.4	2400	35.0
27	4700	68.6	2800	40.9	...	...	...	...
30	5000	73.0	3300	48.2	...	...	...	...
33	5500	80.3	3600	52.5	...	...	...	...
36	6000	87.6	4000	58.4	...	...	...	...
39	6600	96.3	...	...	...	...	...	...
42	7000	102.2	...	...	...	...	...	...

TABLE 2 Dimensions of Vitrified Clay Pipe (U. S. Customary Units)

Nominal Size, in.[A]	Laying Length Limit of Minus Variation, in./ft	Difference in Length of Two Opposite Sides max, in.	Limit of Minus Variations in Average Inside Diameter, in.
3	1/4	5/16	3/16
4	1/4	5/16	3/16
6	1/4	3/8	1/4
8	1/4	7/16	5/16
10	1/4	7/16	3/8
12	1/4	7/16	7/16
15	1/4	1/2	9/16
18	1/4	1/2	11/16
21	1/4	9/16	13/16
24	3/8	9/16	15/16
27	3/8	5/8	1 1/16
30	3/8	5/8	1 3/16
33	3/8	5/8	1 5/16
36	3/8	11/16	1 7/16
39	3/8	3/4	1 7/16
42	3/8	7/8	1 7/16

[A] Specifiers should be aware that all pipe sizes are not universally available.

TABLE 2A Dimensions of Vitrified Clay Pipe (SI Units)

Nominal Size, mm.[A]	Laying Length Limit of Minus Variation, mm/m	Difference in Length of Two Opposite Sides max, mm	Limit of Minus Variations in Average Inside Diameter, mm
75	20	8	4
100	20	8	4
150	20	9	4
200	20	11	5
250	20	11	6
300	20	11	7
375	20	13	9
450	20	13	11
525	20	14	13
600	30	14	15
675	30	16	17
750	30	16	19
825	30	16	21
900	30	17	22
975	30	19	22
1050	30	23	22

[A] Specifiers should be aware that all pipe sizes are not universally available.

TABLE 3 Perforation Spacing for Perforated Vitrified Clay Pipe

Nominal Size, in.	Rows of Perfora-tions	Perforations per Row			
		2 ft (0.61 m)	3 ft (0.91 m)	4 ft (1.22 m)	5 ft (1.52 m)
4	4	7	9	11	13
6	4	7	9	11	13
8	4	7	9	11	13
10	6	7	9	11	13
12	6	7	9	11	13
15	6	...	10	14	17
18	8	...	10	14	17
21	8	...	10	14	17
24	8	...	10	14	17

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Designation: C 296 – 76

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Specification for ASBESTOS-CEMENT PRESSURE PIPE[1]

This Standard is issued under the fixed designation C 296; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This specification covers asbestos-cement pressure pipe for use in supply lines and distribution systems that carry water under pressure. The specification also covers asbestos-cement pressure pipe for use in sewer force mains which carry sewage under pressure.

2. Applicable Documents

2.1 *ASTM Standards:*

C 500 Testing Asbestos-Cement Pipe[2]

D 1869 Specification for Rubber Rings for Asbestos-Cement Pipe.[2]

3. Classification

3.1 Asbestos-cement pipe furnished under this specification shall be manufactured in the pressure class designations of Classes 100, 150, and 200. The pressure class designations shall mean that the pipe is intended for water service at operating pressures corresponding to the class designation under the conditions of installation and operation encountered in many water distribution systems.

NOTE 1—The purchaser should determine for himself the proper class of pipe to be used under the installation and operating conditions that will exist on the project on which the pipe is to be used. For this purpose, reference can be made to AWWA H2, Standard Practice for the Selection of Asbestos-Cement Water Pipe.

3.2 The types of pipe shall be known as Type I and Type II corresponding to the chemical requirements in Section 10 of this specification.

NOTE 2—To assist the purchaser in choosing the type of pipe most suitable for his use, guidelines for the definition of aggressiveness of water and of soil environments for selection of the proper type of asbestos-cement pipe are covered in Section 19 to 25 of Methods C 500.

4. Definitions

4.1 *pipe*—asbestos-cement pressure pipe as defined in Sections 1, 3, and 5.

4.2 *coupling*—a section for joining asbestos-cement pipe that, when properly installed with the proper accessories, develops a joint equivalent in strength and serviceability to the pipe sections.

4.3 *purchaser*—the actual purchaser of the pipe or his authorized agents acting within the scope of the duties entrusted to them.

4.4 *lot*—a lot as used herein for pipe 21 in. in diameter and smaller is defined as each 300 lengths of pipe or less, of identical class and size manufactured on each machine during a 24-h period. A lot as used herein for pipe larger than 21 in. in diameter is defined as each 300 lengths of pipe or less, of identical class and size manufactured on each machine during a period of consecutive working days not exceeding 7 days.

5. Manufacture

5.1 Asbestos-cement pressure pipe shall be

[1] This specification is under the jurisdiction of ASTM Committee C-17 on Asbestos-Cement Products.

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[2] *Annual Book of ASTM Standards*, Part 16.

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composed of an intimate mixture of portland cement or portland blast-furnace slag cement and asbestos fiber with or without silica; or it shall be composed of portland-pozzolan cement and asbestos fiber. The mixture shall be free of organic additives. The material shall be of laminar construction formed under pressure to a homogeneous structure and cured to meet the physical and chemical requirements of this specification.

6. Rubber Rings

6.1 The rubber rings used to seal the joints of the asbestos-cement pipe shall conform to the requirements of the latest revision of Specification D 1869.

7. Hydrostatic Strength

7.1 Each standard, random or short length of pipe (Section 12) and each coupling sleeve, when manufactured from the same material as the pipe, shall be hydrostatically tested by the manufacturer prior to shipment and shall have sufficient strength to withstand the internal hydrostatic pressure prescribed in Table 1, when tested in accordance with Section 5 of Methods C 500.

7.2 From each lot which has passed the routine hydrostatic proof test, one length shall be selected by the inspector. Each selected length shall be hydrostatically tested in accordance with Section 5 of Method C 500 to a pressure of four times the rated working pressure for the class of pipe, maintaining such pressure for not less than 5 s. The pipe shall not fail under this pressure. Each pipe so tested shall be retested in accordance with 7.1 of this specification.

8. Flexural Strength

8.1 Each length of pipe in sizes 4, 6, and 8 in. (102, 152, and 203 mm) shall have sufficient flexural strength to withstand, without failure, the total load prescribed in Table 2, when tested in accordance with Section 8 of Methods C 500.

9. Crushing Strength

9.1 When specifically requested by the purchaser in his order, crushing tests shall be conducted before shipment at the purchaser's expense. A one-foot length of pipe for each lot cut from an unmachined portion of the pipe shall have sufficient strength to resist the minimum crushing load prescribed in Table 3, when tested in accordance with Section 11.1.1 of Methods C 500.

10. Chemical Requirements

10.1 When uncombined calcium hydroxide tests are requested, one sample shall be taken from each lot of pipe and tested in accordance with Sections 14 through 18 of Methods C 500 Sample to be tested may be taken from one of the specimens selected for the crushing test. The amount of uncombined calcium hydroxide shall not exceed 1.0 % for Type II pipe.

NOTE 3—There are no chemical requirements for Type I pipe.

11. Sampling

11.1 All pipe and couplings tested under this specification shall be in a normal air-dried condition.

12. Sizes and Dimensions

12.1 Couplings and coupling areas of pipe shall be machined or otherwise finished to such dimensions as will provide tight joints when assembled with proper accessories and put into service for which the pipe is intended.

12.2 Pipe shall be manufactured with nominal inside diameters of 4, 6, 8, 10, 12, 14, 16, 18, 20, 24, 30, and 36 in. (102, 152, 203, 254, 304, 356, 406, 457, 508, 610, 762, and 914 mm) in Classes 100, 150, and 200 as defined in Section 3. The average diameters of standard and random lengths may be less than the nominal by not more than 5.0 percent, when measured approximately 3 in. (76.2 mm) from the end.

12.3 The standard length shall be 13 ft ± 1 in. (3960 ± 25 mm). Alternative lengths shall be 10 ft ± 1 in. (3050 ± 25 mm) for 4 and 6-in. (102 and 203-mm) pipe and 16 ft ± 1 in. (4880 ± 25 mm) for 14-in. (356-mm) and larger pipe. At least 85 percent of the total footage of pipe of any one class, type, and size, excluding short lengths, shall be furnished in standard lengths. The remaining 15 percent may be in random lengths of not less than 7 ft. (2.13 m). Short lengths, when specifically ordered, shall not exceed 6 ft. 9 in. (2.06 m).

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13. Workmanship and Finish

13.1 Machined ends of the pipe that receive the coupling shall be free of dents and gouges that will affect the tightness of the joint.

13.2 Each pipe shall be free of bulges, dents, and tears in the inside surface that result in a variation in diameter of more than $\frac{3}{16}$ in. (4.8 mm) from that obtained on adjacent unaffected portions of the surface.

13.3 Each length of pipe shall not vary in straightness by more than 0.05 in./ft (0.004 mm/m) of length when the variation is measured in accordance with Section 13 of Methods C 500.

14. Marking and Shipping

14.1 Each standard and random length of pipe shall be marked by the manufacturer with the trade name, nominal size, class, hydrostatic proof pressure, and date of manufacture. Each coupling sleeve, if made of the same material as the pipe, shall be marked by the manufacturer with the nominal size, class, and the letter "T" to indicate that it has been hydrostatically tested.

14.2 Pipe and couplings shall be prepared for commercial shipment so as to ensure acceptance by common or other carriers.

15. Inspection and Rejection

15.1 All material furnished under this specification shall conform to the requirements stated herein and shall be subjected to the factory inspection and tests prescribed in this specification. When requested by the purchaser in his order, the manufacturer shall notify the purchaser of the time that the inspection and testing will take place so that the purchaser may arrange for witnessing such tests and inspections at his own expense. Instead of such inspection, when requested, the manufacturer shall be prepared to certify that his product conforms to the requirements of this specification.

15.2 Each pipe and coupling shall be inspected by the manufacturer, before shipment, for compliance with the standards for dimensions, tolerances, and workmanship and finish (see also Section 11).

15.3 Failure of any specimen tested for crushing strength to withstand 75 percent of the load specified in Section 8 shall be cause for rejection of the lot from which the test specimen was taken. When any specimen tested for crushing strength withstands over 75 percent but under 100 percent of the load specified in Section 9, one specimen shall be cut from each of two additional pipes of the same lot. Failure of either of these additional specimens to meet the strength requirements of Section 9 shall be cause for rejection of the entire lot from which the original sample was taken.

15.4 If any pipe subjected to the hydrostatic test described in Section 5 of Methods C 500 fails to withstand the higher pressure specified in 7.2, two additional lengths of the same size and class shall be selected from the pipe manufactured during the same shift and shall be subjected to the higher hydrostatic test. The failure of one of these additional lengths to withstand the specified pressure shall be cause for rejection of the entire lot of that size and class manufactured during the same shift as the test lengths.

15.5 If the results of the uncombined calcium hydroxide test show that the sample failed to meet the specification requirements, two additional specimens shall be selected and sampled for test. The failure of one of these two additional samples to meet the specification requirements of Section 8 shall be cause for rejection of the lot.

TABLE 1 Applied Hydrostatic Proof Pressures

Class	Applied Pressure, psi (MPa)
100	350 (2.4)
150	525 (3.6)
200	700 (4 8)

TABLE 2 Applied Flexural Proof Loads

Nominal size, in. (mm)	Total Applied Load, lbf (kN)		
	Class 100	Class 150	Class 200
4 (101.6)	1200 (5.3)	1470 (6.6)	1 870 (8.4)
6 (152.4)	2800 (12.5)	3700 (16.5)	4 900 (21.8)
8 (203.2)	5330 (25.9)	7600 (33.8)	10 130 (45.1)

TABLE 3 Minimum Crushing Loads

Nominal Size, in. (mm)	Crushing Strength per Lineal Foot, lbf (kN/m)		
	Class 100	Class 150	Class 200
4 (102)	4 100 (59.8)	5 400 (78.8)	8 700 (126.9)
6 (152)	4 000 (58.4)	5 400 (78.8)	9 000 (131.3)
8 (203)	4 000 (58.4)	5 500 (80.2)	9 300 (135.8)
10 (254)	4 400 (64.2)	7 000 (102.1)	11 000 (160.5)
12 (304)	5 200 (75.8)	7 600 (110.8)	11 800 (172.3)
14 (356)	5 200 (75.8)	8 600 (125.5)	13 500 (197.1)
16 (406)	5 800 (84.6)	9 200 (134.2)	15 400 (224.8)
18 (457)	6 500 (94.8)	10 100 (147.4)	17 400 (254.0)
20 (508)	7 100 (103.6)	10 900 (159.0)	19 400 (283.2)
24 (610)	8 100 (118.2)	12 700 (185.3)	22 600 (329.9)
30 (762)	9 700 (141.5)	15 900 (231.9)	28 400 (414.6)
36 (914)	11 200 (163.4)	19 600 (285.9)	33 800 (493.5)

APPENDIX

A1. ADDITIONAL INFORMATION

A1.1 It is suggested to the purchaser, without being made a part of this specification, that the purchaser may request inclusion of the following information in his order or agreement for purchase of the pipe:

A1.1.1 Any tests, in addition to those prescribed by this specification, as the special circumstances may require,

A1.1.2 The place or places where any additional tests are to be made,

A1.1.3 Description of the additional testing facilities,

A1.1.4 Who shall bear the expense of such additional tests,

A1.1.5 Whether such additional tests may be made by any sound sampling process or other method approved by the parties, and

A1.1.6 Such other matters as the parties may find desirable to include in their written agreement.

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