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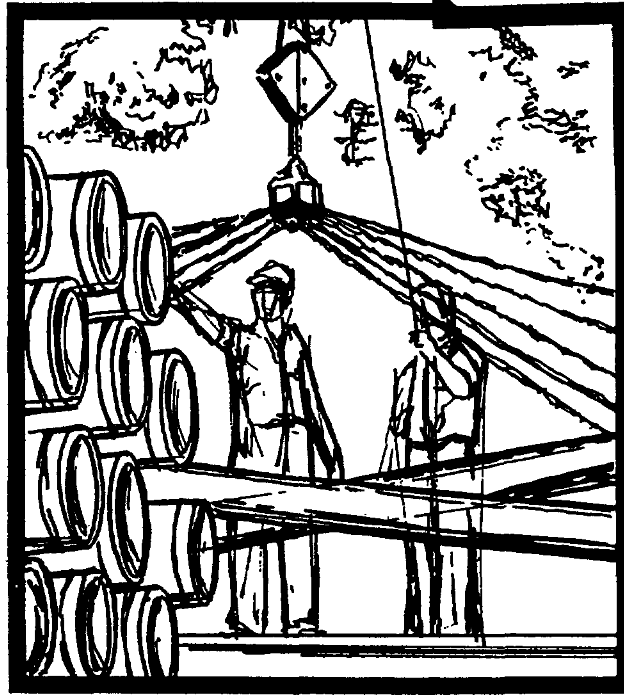

WATER SYSTEMS

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

GEORGE E. SYMONS, PH.D.

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water and wastes engineering / MANUAL OF PRACTICE NUMBER TWO

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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-

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

Group	Population	Production (gpcd) 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]

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

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.

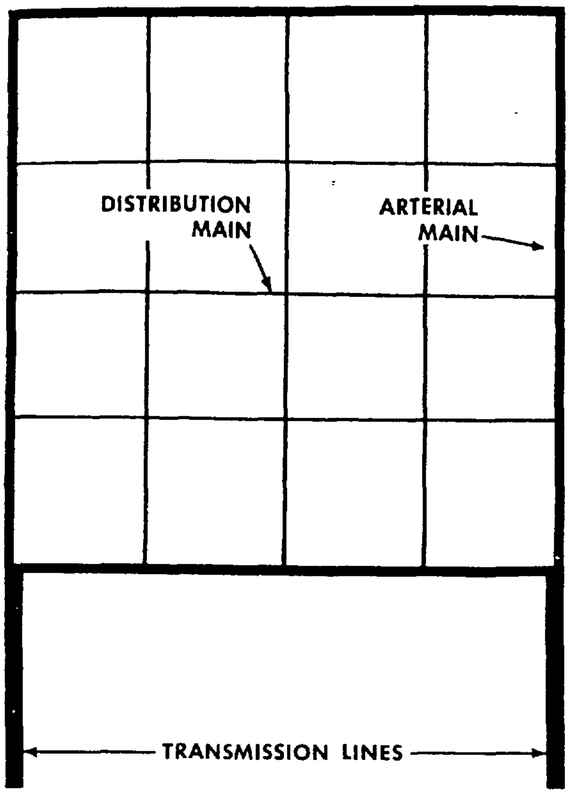


Fig. 1. Arterial loop system.

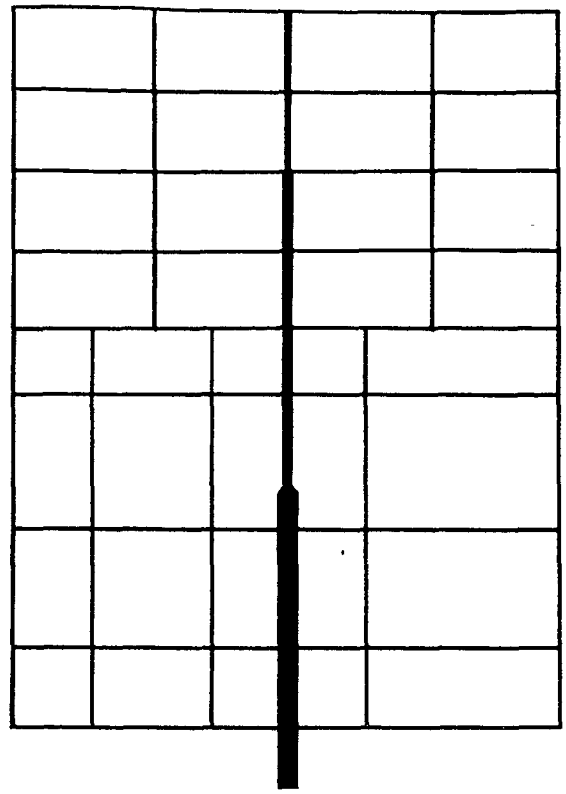


Fig. 2. Grid type of distribution system.

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:

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

where

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.

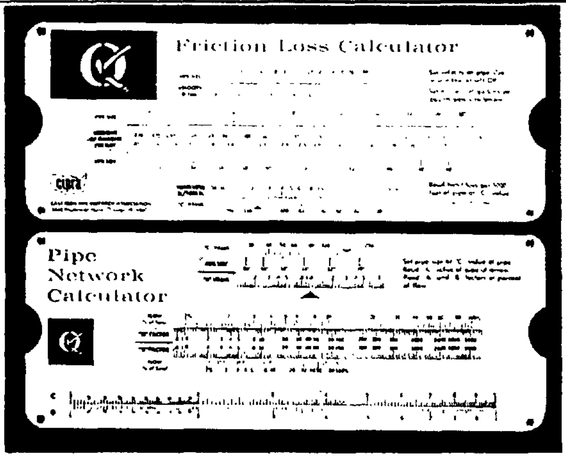
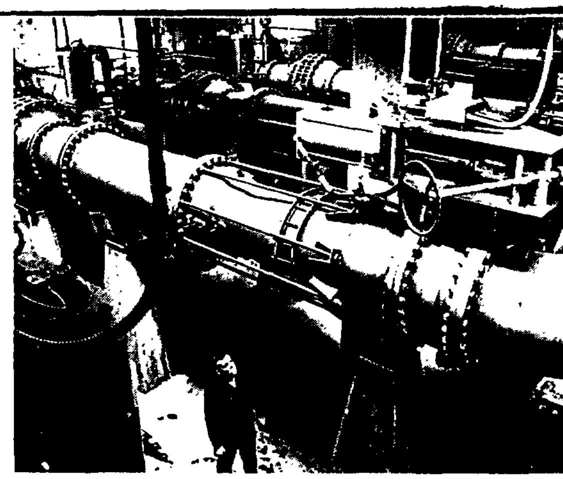


Fig. 3. Hazen-Williams slide rule.



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		100-ft line	
	1/2-in.	3/4-in.	1/2-in.	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 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.

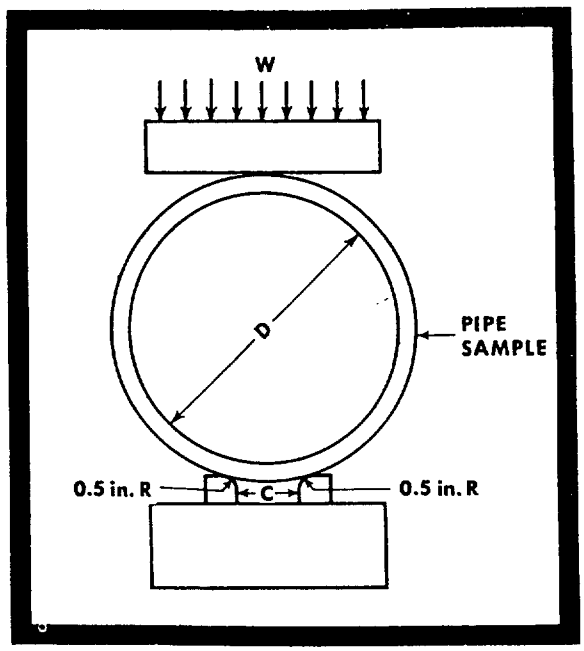


Fig. 5. Three-edge bearing test for A-C pipe. W represents load; R, approximately 0.5 in., the radius of the bearings; D, the nominal diameter of the pipe; and C, the clear space between wooden supports. C should be 0.5 in. for diameters of 12 in. and under, 1 in. for 14 to 24 in. inclusive, and 2 in.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

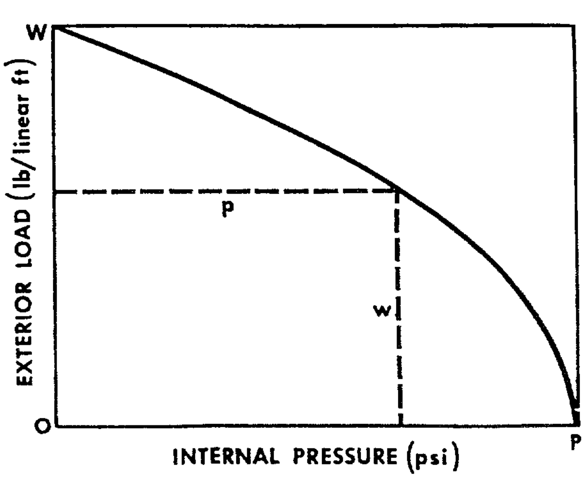


Fig. 4. Load-pressure curve for pipe.

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:

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

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

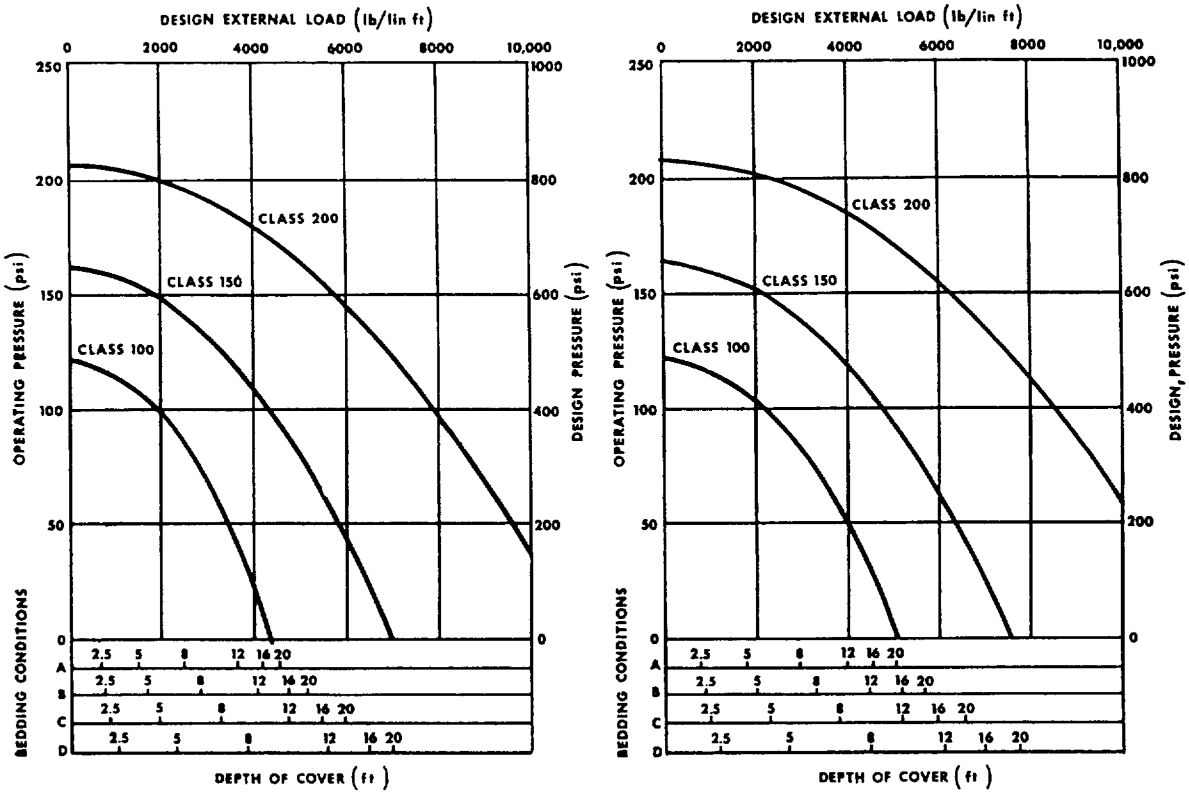


Fig. 6. Examples of A-C pipe selection curves.

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.

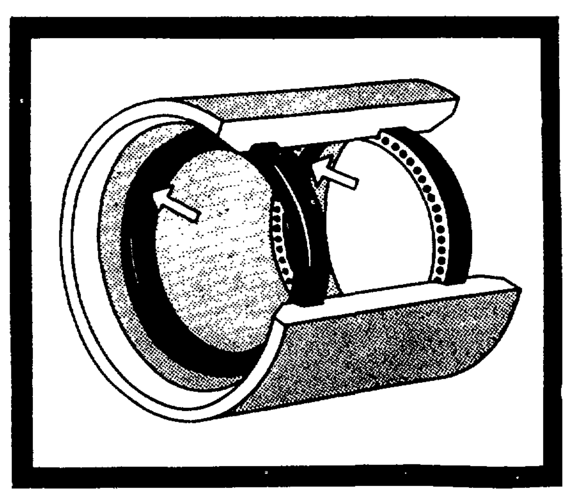


Fig. 7. Coupling for A-C pipe.

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)

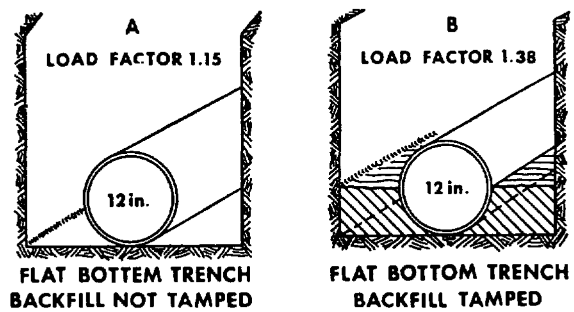


Fig. 9. Types of trench bottoms.

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.

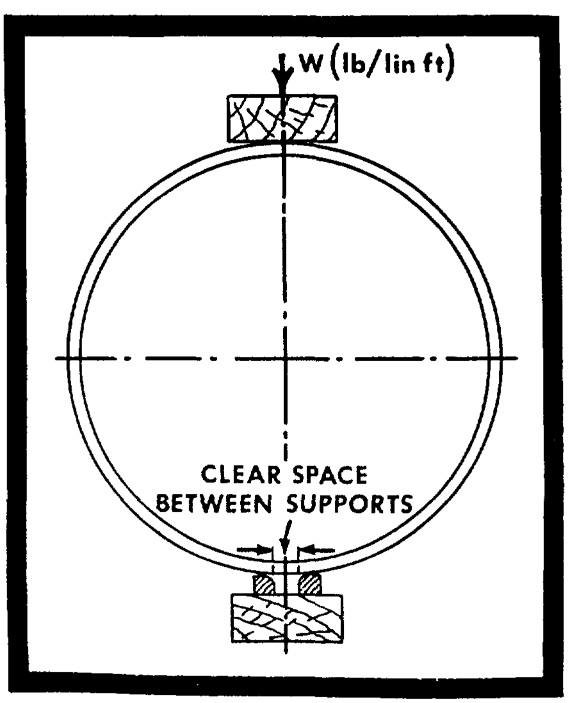
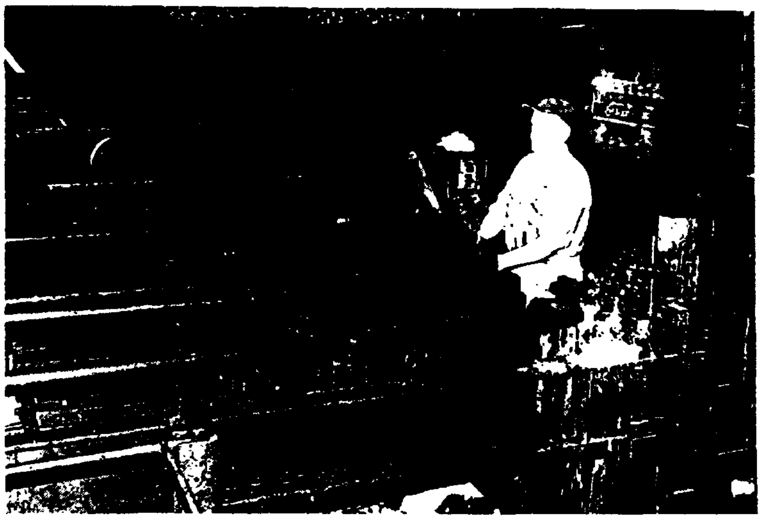


Fig. 8. Three-edge bearing test for cast iron pipe.

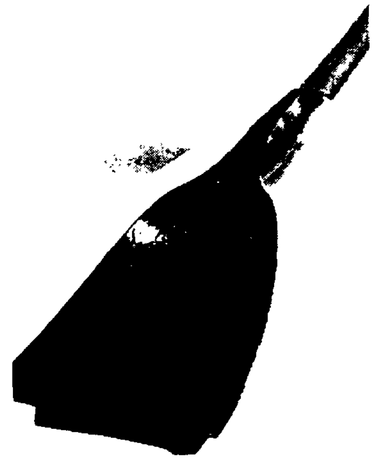
External loads. The external load on a pipe consists of two factors: weight of backfill and weight of traffic plus impact. The load-carrying capacity of a pipe is influenced by the laying conditions (see Fig. 9). The best method of laying pipe is the one that provides the highest load factor. The most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



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

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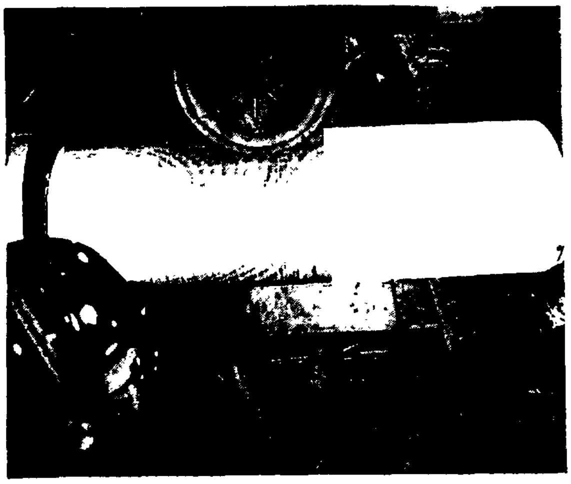

Prestressing concrete pipe.

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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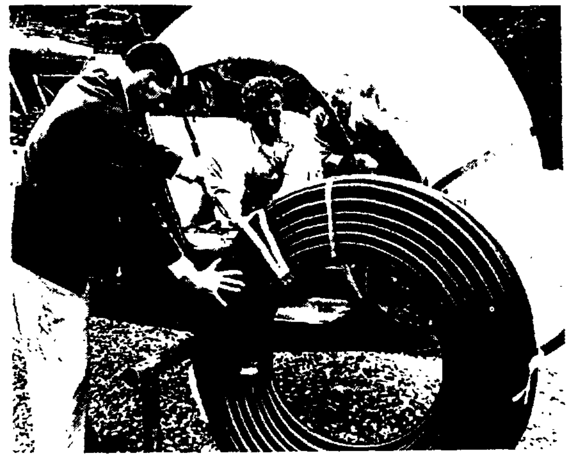
Handling cast iron pipe from railroad car to truck.



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.

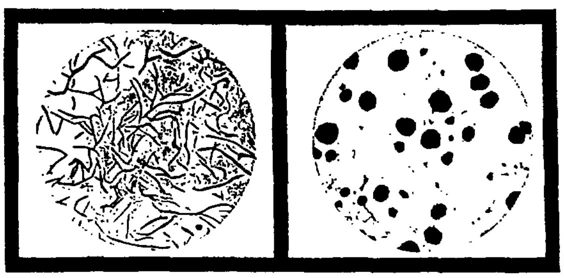


Fig. 10. Microstructure of gray iron and ductile iron at same magnification.

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.

ers. 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

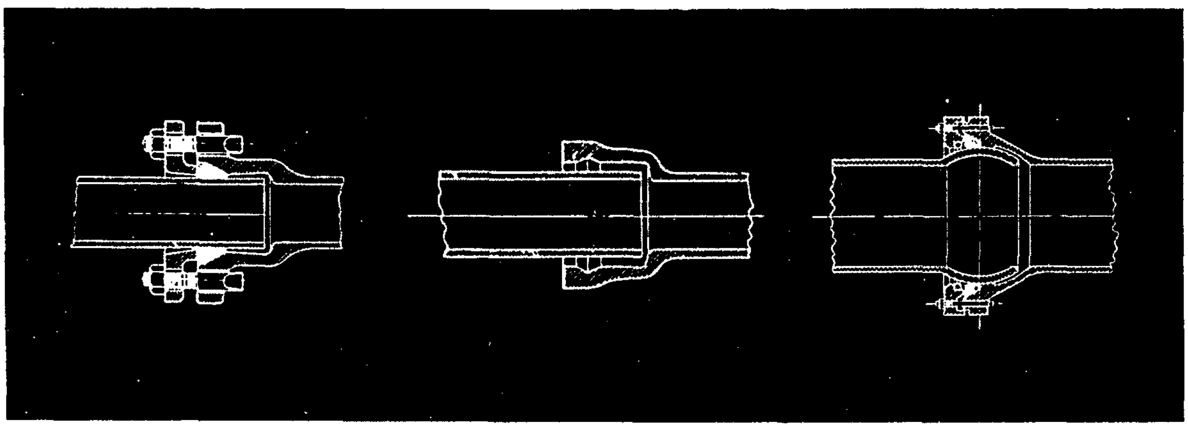


Fig. 11. Types of cast iron pipe joints. Left to right: mechanical, bell and spigot, submarine.

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 roll-

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 above-ground 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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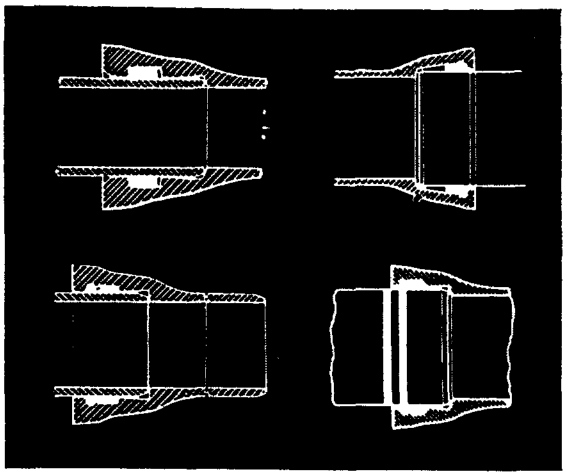


Fig. 12. Examples of slip joints for cast iron pipe joints.

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

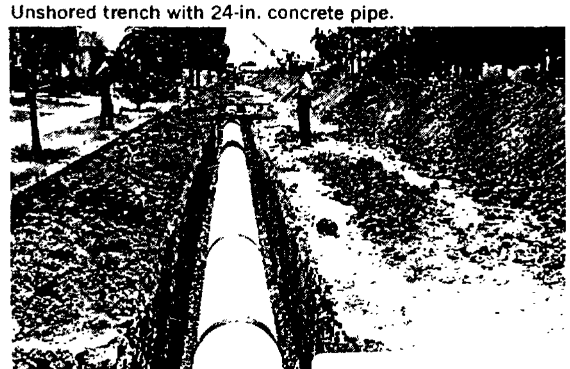
There are three types of concrete water pipe, classified according to the method of reinforcement. These types are: steel cylinder, not prestressed; steel cylinder, prestressed; and non-cylinder, not prestressed. Table 14 sets forth the general design requirements and specifications for the three types 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.



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	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 14—GENERAL DESIGN REQUIREMENTS FOR CONCRETE PIPE

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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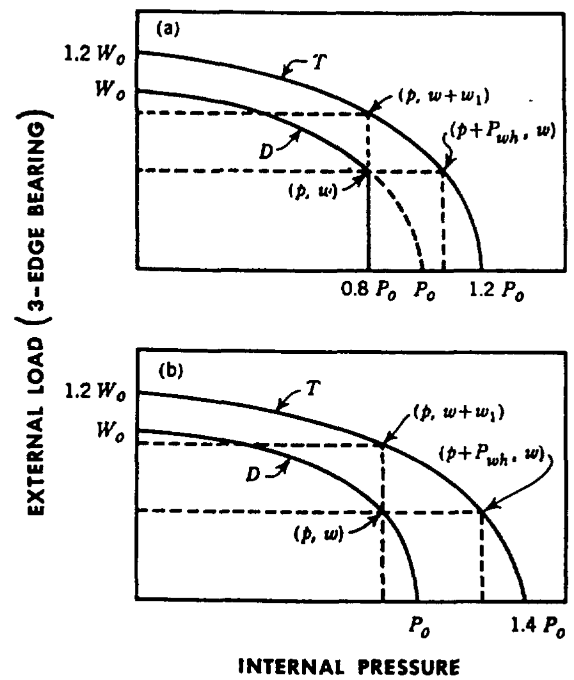


Fig. 13. Cubic parabola design curves for concrete pipe.[19] Graph (a) is for lined and Graph (b) embedded cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; w_1 is for the three-edge-bearing load equivalent to live load; and P_{wh} is for water hammer in excess 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 with lined cylinder		Pipe with embedded cylinder		Coating thickness	
Pipe ID (in.)	Core thickness (in.)	Maximum design pressure (in.)	Core thickness (in.)	Maximum design pressure (psi)	Mortar (min. thickness over the wire) (in.)	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)	6000 psi centrifugal concrete: Min. no. of cages	4500 psi poured concrete: Nominal pipe wall thickness (in)	4500 psi poured concrete: Min. no. of cages	Circumferential reinforcement spacing: Min. (in.)	Circumferential reinforcement spacing: 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		

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.

CTD000106

Lowering cast iron pipe into trench with a clamp.

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).

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

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:

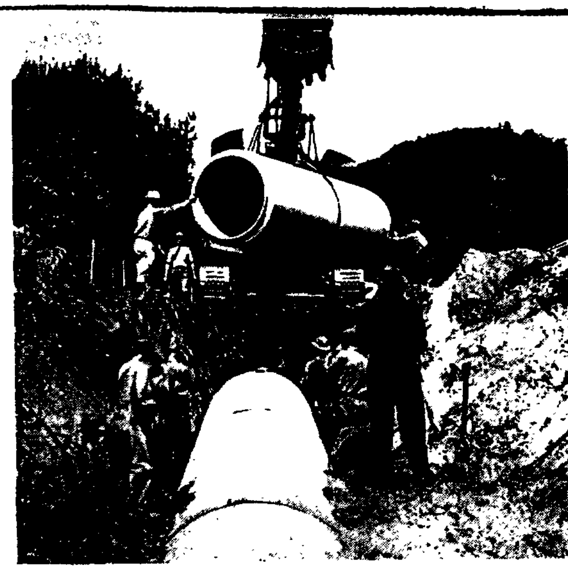
$$\frac{2S}{P} = SDR - 1 \text{ or } \frac{2S}{P} = \frac{OD}{t} - 1 \qquad \text{Eq. 11}$$

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.

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

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 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

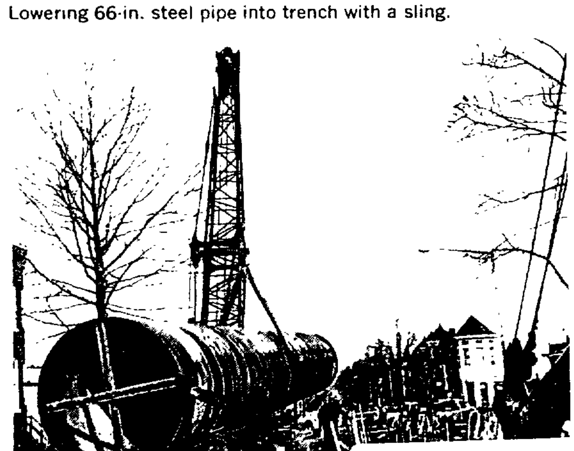
Plastic pipe is subjected to the following tests during manufacture:

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

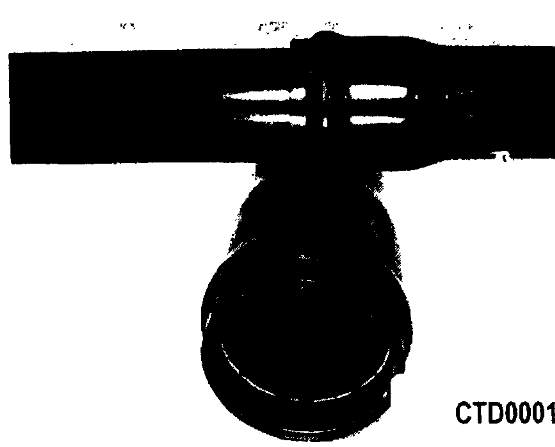


Fig. 14. PVC pipe joint for large size pipe.

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.)

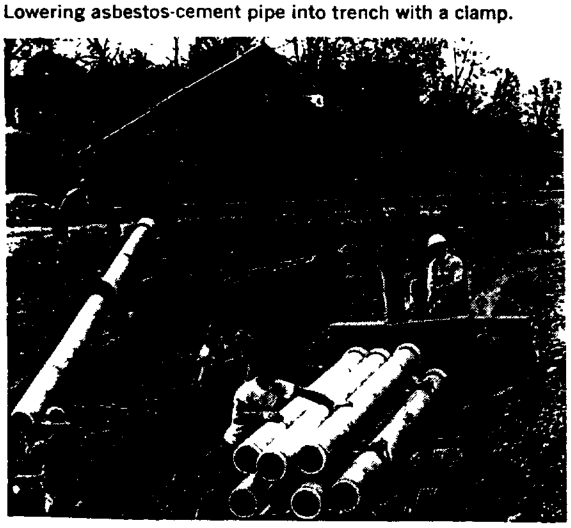
Tolerances. Manufacturing tolerances[23] are set for end, size, length, straightness, and bead.

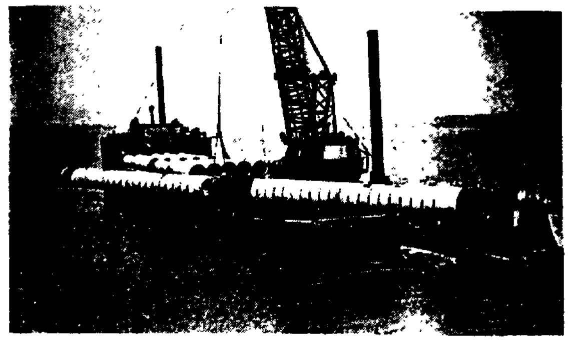
Ends. For a distance of 10 in. from the ends, both outside and inside diameters for different types of joints must be within these limits: not more than 1/16 in. smaller or more than 1/8 in. larger than the nominal circumference calculated either from the nominal outside diameter or the nominal inside 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

Lowering asbestos-cement pipe into trench with a clamp.





Underwater pipeline installation.

difference between inside diameter of the bell and outside diameter of the spigot is 0.06 in. minimum and 0.2 in. maximum.

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.)

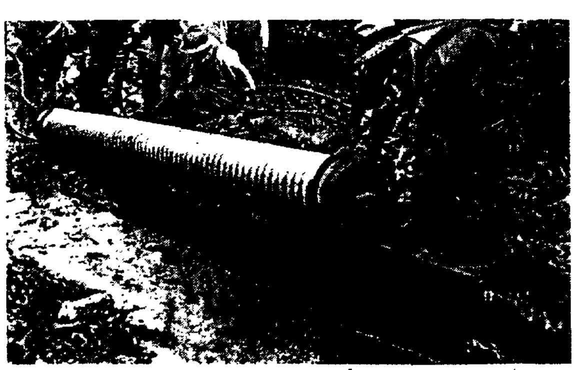
Longitudinal weld. This type of pipe is produced in a continuous straight line process. The steel skelp is drawn through a series of vertical and horizontal forming rolls that progressively form the strip of steel into a cylindrical shape. The cylinder then moves through a high-frequency resistance welder, 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.

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.



Installing pipe line in conduit under railroad.

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.

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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.

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

** 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.

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

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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).

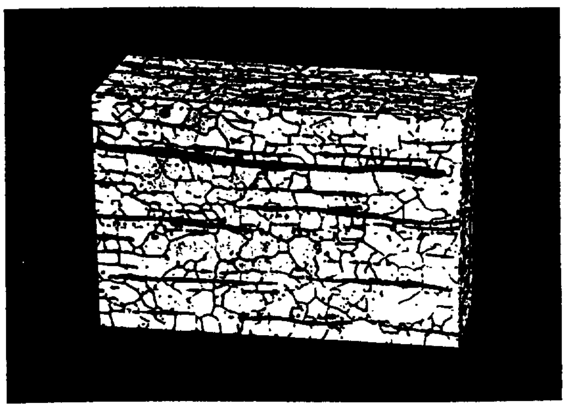

Fig. 15. Photomicrograph of wrought iron (100 X) shows glass-like siliceous fibers in metal.

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 oxyweld 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)	$7.4 \times 10X^{6}$	
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	14.000	13.000	0.500	70.68	73.04	8	1100	15.000	6-3/8
14*	14.000	13.250	0.375	53.49	56.16	8	800	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.

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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.

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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.

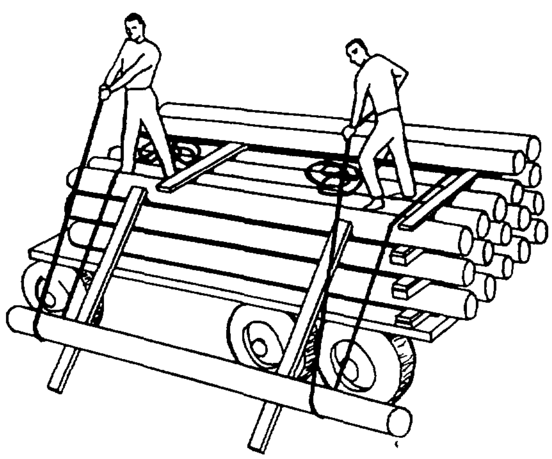

Fig. 16. Method of unloading pipe with snubbing ropes and skids.

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

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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.)	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.)	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[34]

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 9.5	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.

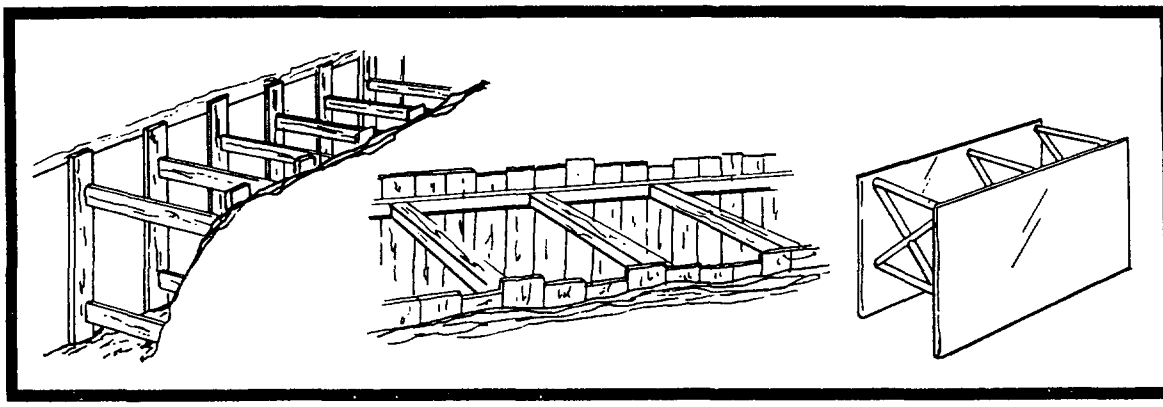

Fig. 17. Examples of trench sheeting. Left, open; center, closed; right, movable shield.

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 18—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 (pre-belled) 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 is shovel tamped. Above this point, the backfill material is placed in the trench by bulldozer or other mechanical equipment.

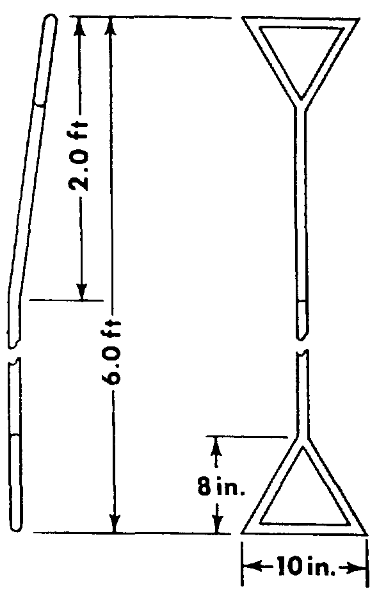

Fig. 19. Haunch hand tamping device for backfilling operations.

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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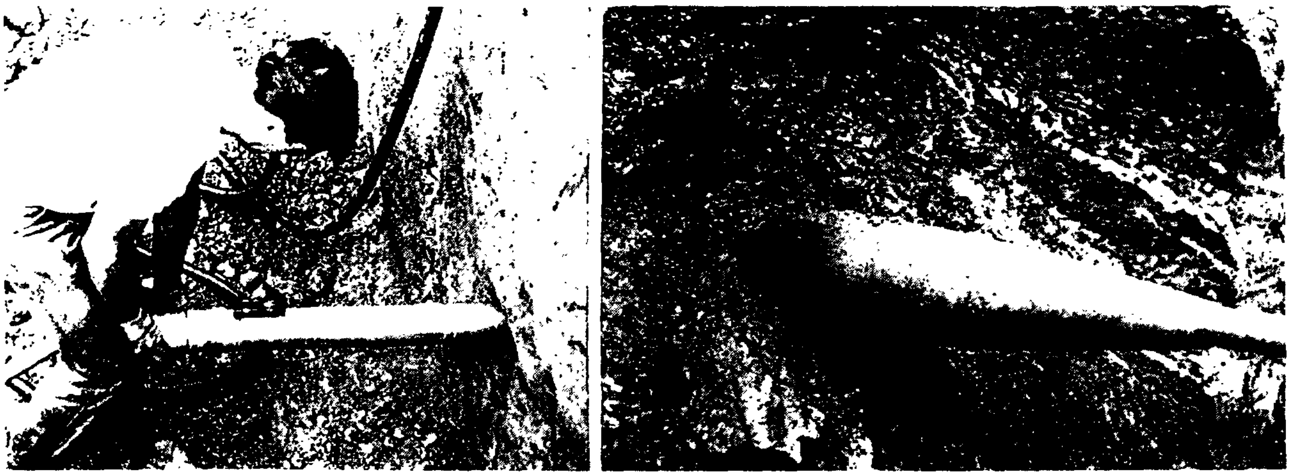

Tunneling mole for service line installation.

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.

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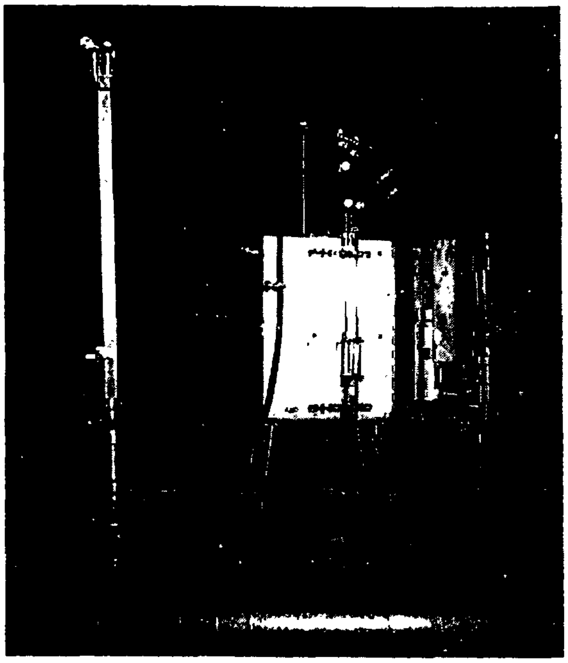

Pitometer unit for leak survey.

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

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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

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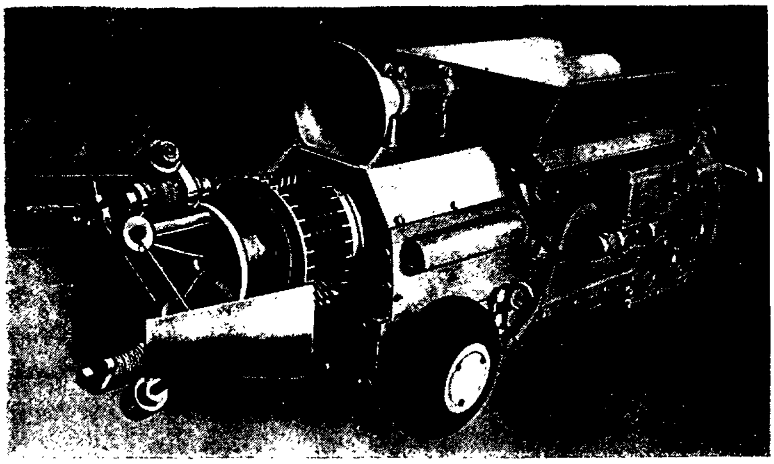

Machine for cement-mortar lining of mains in place.

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.

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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.

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