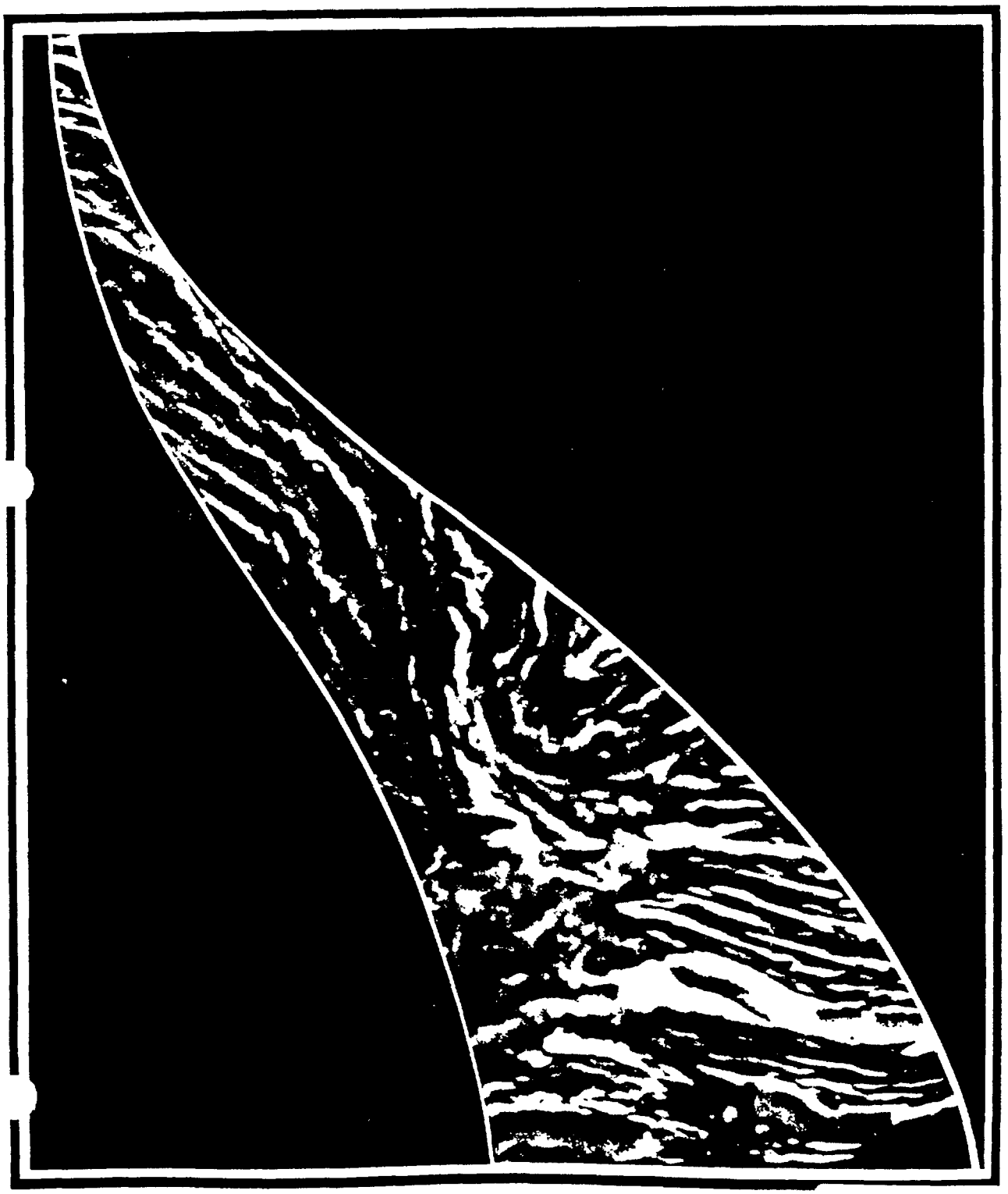
PLAINTIFF'S EXHIBIT

CT-1007

CertainTeed

FLUID TRANSMISSION

ASBESTOS-CEMENT PIPE DESIGN & SPECIFICATION MANUAL



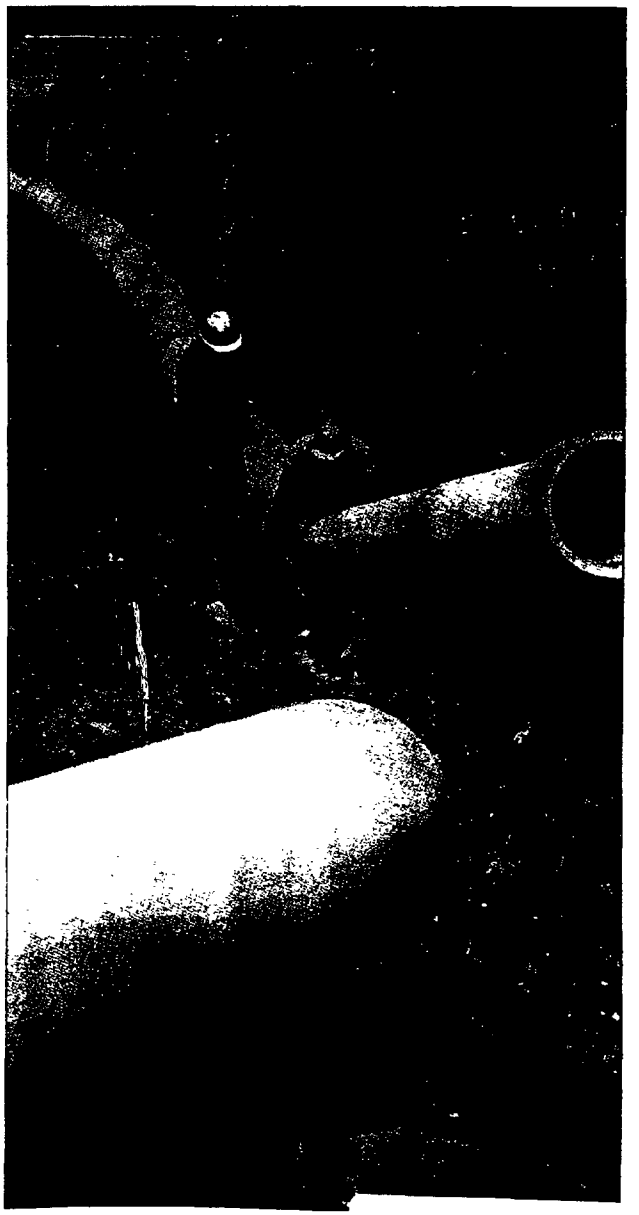
CTD032871

FLUID TRANSMISSION (FT) ASBESTOS-CEMENT PIPE

A practical lower cost way to transmit fluids over long distances



preface



Certain-teed Asbestos-Cement, Fluid Transmission, (FT) Pipe is designed and manufactured specifically for long distance transmission of fluids, such as water, under pressure, from a source to the point of distribution.

Transmission systems normally operate under steady flow and pressure conditions as contrasted with *distribution* piping systems with complex hydraulics. That is why there is a range of Certain-teed FT piping systems offered for custom engineering of transmission systems at lower cost.

The combined loading theory is utilized to design Certain-teed FT piping systems. Internal hydrostatic pressure and external loads are both considered.

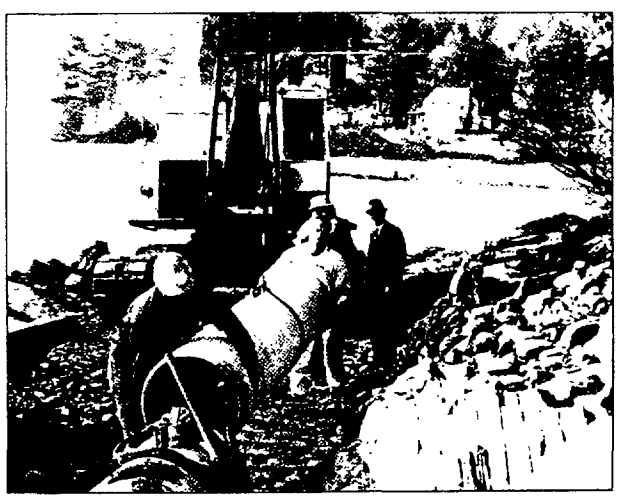
Proven fundamental practices of pipe design, contained in this manual, will enable the engineer to select the most economical Certain-teed FT pipe to do the job. There are 9 pressure classes in sizes 8" through 24" and seven pressure classes in 6" to meet almost any service requirement.

CTD032872

PROVEN IN USE

There are hundreds of miles of Certain-teed Fluid Transmission Piping in service conveying fluids from far away sources to distribution systems or reservoirs.







CTD032873

FLUID TRANSMISSION (FT) ASBESTOS CEMENT PIPE

DESCRIPTION

Certain-teed FT Asbestos Cement Pipe is composed of an intimate mixture of portland cement, asbestos fiber and silica formed under pressure and heat cured by the autoclave process.

The 13′ long sections come complete with a factory-furnished asbestos-cement coupling on one end of the pipe and two rubber gaskets to form a tight, flexible joint equivalent to or greater than the pressure rating of the pipe. Short, half section lengths are also available with coupled ends.

CUSTOM DESIGNED FOR FLUID TRANSMISSION ECONOMY

Certain-teed FT Pipe is available in 9 pressure ranges with corresponding wall thicknesses to answer the requirements of combined internal and external service loads at the most economical cost.

Engineers can design transmission systems using known conditions without the restriction of built-in general-purpose-use safety factors.

PERFORMANCE CHARACTERISTICS

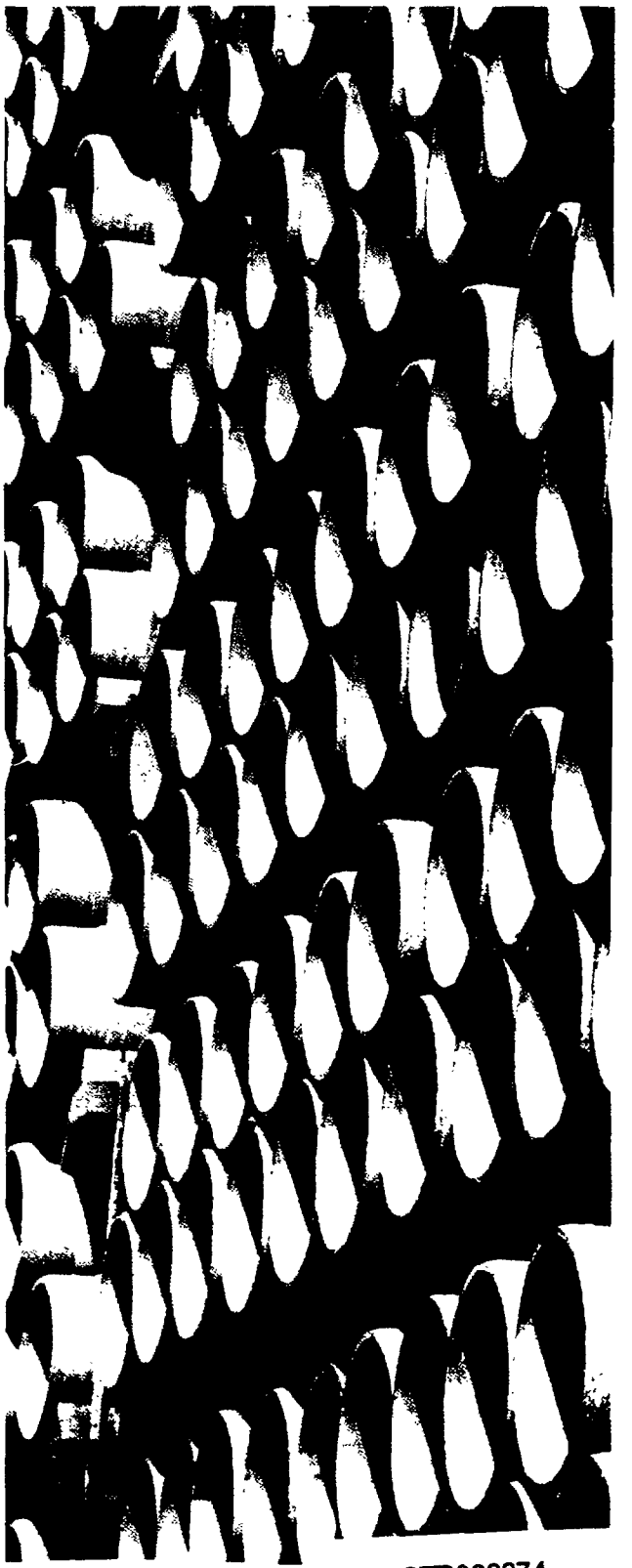
Certain-teed Fluid Transmission (FT) Asbestos Cement Pipe is continuously tested for quality consistency and performance. Dimensional tolerance checks are monitored in-line. Lab testing for burst, crushing loads, flexural strength chemical resistance are preformed before the Certain-teed mark goes on each section of pipe, coupling or fitting. Tests are performed to ASTM procedure and certified, if requested, or can be personally observed by the customer.

SIZES AND PRESSURE RATINGS

Certain-teed FT Pipe is available with nominal inside diameters of 6″, 8″, 10″, 12″, 14″, 15″, 16″, 18″, 20″, 21″ and 24″.

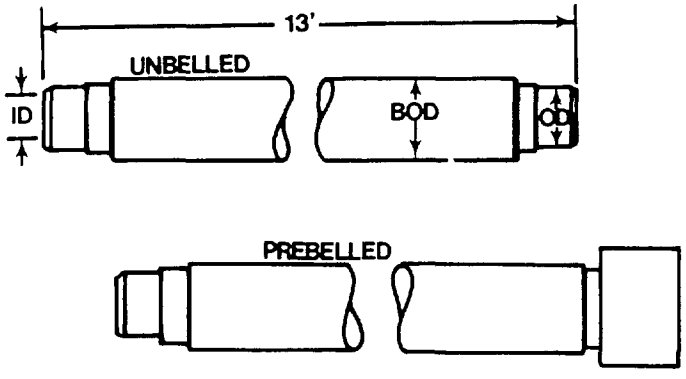
Pressure rating FT class numbers are based on one-tenth the minimum hydrostatic bursting test ratings in PSI. For instance an FT 30 pipe has a 300 psi minimum burst requirement.

Classes of FT30, FT35, FT40, FT45, FT50, FT60, FT70, FT80 and FT90 are available in sizes 8″ through 24″ and Classes FT40, FT45, FT50, FT60, FT70, FT80 and FT90 in 6″ size.

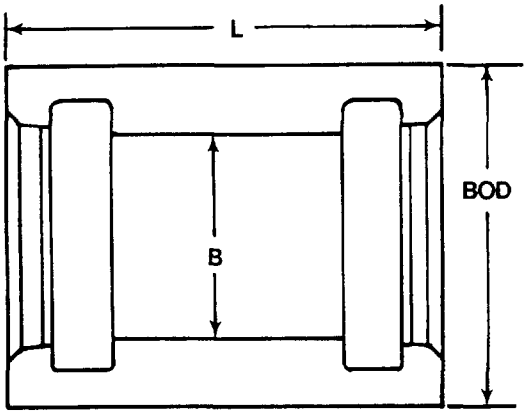


CTD032874

pipe and coupling dimensions and weight



pipe



coupling

NOM. PIPE SIZE (inches)	CLASS FT 30						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
8	8.00	9.12	8.80	8.92	10.50	7.00	13.6
10	10.00	11.08	10.89	11.01	12.50	7.00	16.2
12	12.00	13.18	12.99	13.11	14.70	8.00	21.2
14	14.00	15.38	15.07	15.20	17.60	9.00	29.8
15	15.00	16.64	16.11	16.24	18.40	9.00	36.5
16	16.00	17.58	17.15	17.28	19.31	9.00	37.5
18	18.00	19.60	19.28	19.41	21.53	10.00	43.2
20	20.00	21.76	21.44	21.57	23.83	10.00	52.6
21	21.00	22.84	22.52	22.65	25.11	10.00	57.4
24	24.00	26.08	25.76	25.89	28.43	10.00	74.2

NOM. PIPE SIZE (inches)	CLASS FT 35						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
8	8.00	9.26	8.80	8.92	10.50	7.00	15.2
10	10.00	11.18	10.89	11.01	12.75	7.00	17.8
12	12.00	13.27	12.99	13.11	15.00	8.00	22.9
14	14.00	15.44	15.07	15.20	17.60	9.00	30.9
15	15.00	16.82	16.11	16.24	18.40	9.00	40.3
16	16.00	17.94	17.15	17.28	19.80	9.00	46.1
18	18.00	19.60	19.28	19.41	21.77	10.00	43.6
20	20.00	21.76	21.44	21.57	24.01	10.00	53.0
21	21.00	22.88	22.52	22.65	25.24	10.00	58.8
24	24.00	26.08	25.76	25.89	28.65	10.00	74.8

NOM. PIPE SIZE (inches)	CLASS FT 40						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	6.00	7.06	6.69	6.81	8.18	7.00	9.7
8	8.00	9.26	8.80	8.92	10.50	7.00	15.2
10	10.00	11.30	10.89	11.01	12.75	7.00	19.5
12	12.00	13.38	12.99	13.11	15.00	8.00	24.8
14	14.00	15.44	15.07	15.20	17.60	9.00	30.9
15	15.00	16.82	16.11	16.24	18.67	9.00	40.7
16	16.00	17.94	17.15	17.28	19.80	9.00	46.1
18	18.00	20.14	19.90	20.03	22.82	10.00	58.7
20	20.00	22.38	22.12	22.25	25.24	10.00	72.3
21	21.00	23.72	23.28	23.41	26.79	10.00	86.2
24	24.00	26.82	26.48	26.61	29.98	10.00	102.0

NOM. PIPE SIZE (inches)	CLASS FT 45						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	6.00	7.06	6.69	6.81	8.18	7.00	9.7
8	8.00	9.36	8.80	8.92	10.67	7.00	16.4
10	10.00	11.46	11.24	11.36	13.30	7.00	22.3
12	12.00	13.70	13.44	13.56	15.55	8.00	30.9
14	14.00	15.75	15.50	15.63	18.20	9.00	37.6
15	15.00	17.05	16.68	16.81	19.51	9.00	46.9
16	16.00	17.99	17.74	17.87	20.42	9.00	48.4
18	18.00	20.14	19.90	20.03	23.20	10.00	59.4
20	20.00	22.38	22.12	22.25	25.66	10.00	73.2
21	21.00	23.72	23.28	23.41	26.93	10.00	86.5
24	24.00	26.82	26.48	26.61	30.52	10.00	103.0

pipe and coupling dimensions and weight (con't.)

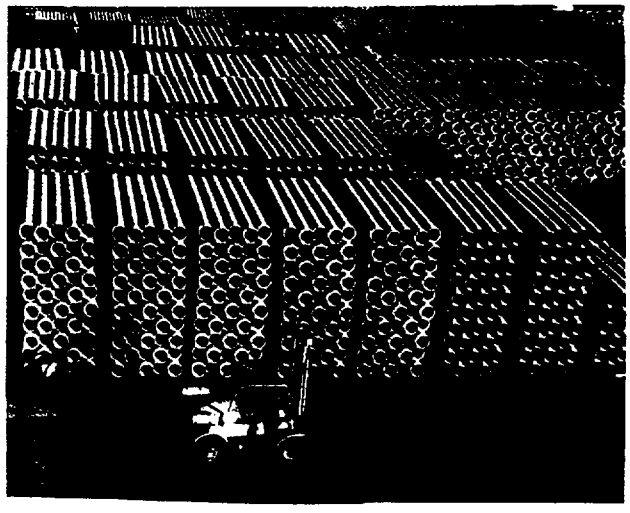
NOM. PIPE SIZE (inches)	CLASS FT 50						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	6.00	7.16	6.91	7.03	8.40	7.00	10.8
8	8.00	9.38	9.11	9.23	10.90	7.00	16.9
10	10.00	11.52	11.24	11.36	13.30	7.00	23.3
12	12.00	13.76	13.44	13.56	15.76	8.00	32.1
14	14.00	15.87	15.50	15.63	18.49	9.00	40.4
15	15.00	17.36	16.68	16.81	19.82	9.00	53.8
16	16.00	18.22	17.74	17.87	20.69	9.00	53.9
18	18.00	20.44	19.90	20.03	23.30	10.00	67.1
20	20.00	22.56	22.12	22.25	25.78	10.00	78.4
21	21.00	23.84	23.28	23.41	27.07	10.00	90.3
24	24.00	27.25	26.48	26.61	30.66	10.00	118.0

NOM. PIPE SIZE (inches)	CLASS FT 60						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	5.80	7.12	6.91	7.03	8.76	7.00	12.1
8	7.80	9.32	9.11	9.23	11.32	7.00	18.6
10	10.00	11.85	11.66	11.78	14.36	7.00	28.9
12	12.00	14.11	13.92	14.04	17.00	8.00	39.6
14	14.00	16.41	16.22	16.35	19.80	9.00	53.2
15	15.00	17.81	17.28	17.41	21.02	9.00	65.5
16	16.00	18.65	18.46	18.59	22.28	9.00	66.3
18	18.00	20.94	20.50	20.63	24.79	10.00	82.8
20	20.00	23.26	22.83	22.96	27.49	10.00	102.0
21	21.00	24.44	23.96	24.09	28.79	10.00	112.0
24	24.00	27.96	27.42	27.55	32.47	10.00	147.0

NOM. PIPE SIZE (inches)	CLASS FT 70						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	5.80	7.12	6.91	7.03	8.76	7.00	12.1
8	7.80	9.32	9.11	9.23	11.32	7.00	18.6
10	10.00	11.93	11.66	11.78	14.36	7.00	30.1
12	12.00	14.35	13.92	14.04	17.13	8.00	44.0
14	13.60	16.44	16.22	16.35	20.26	9.00	61.7
15	14.44	17.66	17.28	17.41	21.52	9.00	73.8
16	16.00	19.09	18.46	18.59	22.54	9.00	77.0
18	18.00	21.48	20.94	21.07	26.00	10.00	99.4
20	20.00	23.60	23.28	23.41	28.78	10.00	114.0
21	21.00	25.10	24.38	24.51	30.03	10.00	135.0
24	24.00	28.60	27.96	28.09	34.34	10.00	174.0

NOM. PIPE SIZE (inches)	CLASS FT 80						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	5.70	7.36	6.91	7.03	9.35	7.00	15.7
8	7.60	9.46	9.11	9.23	12.00	7.00	23.3
10	9.60	11.88	11.66	11.78	15.15	7.00	35.7
12	11.44	14.11	13.92	14.04	17.90	8.00	49.3
14	13.60	16.50	16.22	16.35	20.50	9.00	63.3
15	15.00	18.43	17.99	18.12	22.46	9.00	81.7
16	15.50	18.95	18.46	18.59	23.20	9.00	85.3
18	18.00	21.92	20.94	21.07	26.68	10.00	112.0
20	20.00	24.36	23.28	23.41	29.52	10.00	139.0
21	21.00	25.60	24.38	24.51	30.81	10.00	153.0
24	24.00	29.22	27.96	28.09	35.22	10.00	199.0

NOM. PIPE SIZE (inches)	CLASS FT 90						WGT. PRE-BELLED
	PIPE			COUPLING			
	I.D.	B.O.D.	O.D.	B	B.O.D.	L	
6	5.70	7.38	6.91	7.03	9.35	7.00	15.9
8	7.60	9.62	9.11	9.23	12.00	7.00	25.2
10	9.60	12.34	11.66	11.78	15.15	7.00	42.6
12	11.44	14.52	13.92	14.04	17.90	8.00	56.5
14	13.60	16.92	16.22	16.35	21.06	9.00	72.8
15	14.44	18.28	17.99	18.12	23.01	9.00	90.0
16	15.50	19.52	18.46	18.59	23.47	9.00	99.3
18	18.00	22.60	22.18	22.31	28.29	10.00	135.0
20	20.00	25.16	24.66	24.79	31.41	10.00	168.0



CTD032876

FLUID TRANSMISSION (FT) ASBESTOS CEMENT PIPE

SECTION 1 — GENERAL

Sec. 1.1 Scope — This specification designates the requirements for Certain-teed Asbestos-Cement Fluid Transmission Pipe manufactured for use in transmission systems which carry water under pressure. Certain-teed Asbestos-Cement Fluid Transmission Pipe will be designated as FT Pipe. Pipe manufactured in accordance with this specification will conform to ASTM C668 latest issue.

SECTION 2 — GENERAL REQUIREMENTS

Sec. 2.1 Sizes — FT Pipe shall be manufactured with nominal inside diameters of 6", 8", 10", 12", 14", 15", 16", 18", 20", 21" and 24".

Sec. 2.2 Classes — FT Pipe shall be manufactured in classes FT30, FT35, FT40, FT45, FT50, FT60, FT70, FT80 and FT90 in sizes 8" through 24" and classes FT40, FT45, FT50, FT60, FT70, FT80 and FT90 in size 6".

Sec. 2.3 Lengths —

2.3.1 The standard length of FT Pipe shall be 13 feet in all classes and sizes. A maximum of 15 percent of the total footage of any one size or class for any one order may be furnished in random pipe lengths shorter than 13 feet but not less than 7 feet. The tolerance for the standard length of 13 feet is plus 0 or minus 1 inch. Random lengths are furnished in increments of 0.5 feet with a tolerance of plus or minus 1 inch.

2.3.2 **Short Lengths** — Short lengths for use in making connections to valves, fittings and structures, and for making closures shall not exceed 6'6". Standard lengths are ½ lengths (6'6" ±1" or 6'0" ±1") machined ends only (MEO) and ¼ lengths (3'3" ±1") fully machined (FM). Short lengths are available for all sizes and classes of FT Pipe.

Sec. 2.4 Couplings — Couplings shall be designed to provide tight joints when subjected to the same hydrostatic test as designated for the same size or class of pipe. One coupling of the same composition as the pipe shall be furnished with each standard, random and short length of pipe. It shall consist of an asbestos-cement sleeve and two rubber gaskets suitable for use with the particular size and class of pipe with which it is supplied.

Sec. 2.5 Materials —

2.5.1 **Pipe and Couplings** — Asbestos-Cement FT Pipe and Couplings shall be composed of an intimate mixture of portland cement, asbestos fiber and silica, and shall be free from organic additives. The material shall be formed under pressure and cured by autoclave process to meet the physical and chemical requirements of the specification.

2.5.2 **Rubber Gaskets** — Rubber Sealing Gaskets shall conform to the requirements of ASTM D-1869 latest issue. The gaskets shall be fabricated from a properly vulcanized elastomeric compound as specificied by the manufacturer.

SECTION 3 — DETAIL REQUIREMENTS

Sec. 3.1 Pipe —

3.1.1 **Description** — Asbestos-Cement FT Pipe shall be made to the manufacturer's standard dimensions and tolerances. The pipe shall be machined on each end to properly receive the coupling and gasket.

3.1.2 **Hydrostatic Proof Test** — Each standard, random or short length of pipe and each coupling for the corresponding pipe shall withstand, without leakage, a hydrostatic proof test of not less than the pressure indicated in the following table when tested in accordance with Section 4.2.1.

MINIMUM HYDROSTATIC PROOF TEST, PSI

ALL PIPE SIZES	PIPE CLASS								
	FT30	FT35	FT40	FT45	FT50	FT60	FT70	FT80	FT90
	225	262	300	337	375	450	525	600	675

3.1.3 **Hydrostatic Bursting Test** — In conjunction with the minimum hydrostatic proof test, certain lengths of pipe shall be subjected to and be able to withstand the minimum bursting pressure indicated in the following table when tested in accordance with Section 4.2.2.

MINIMUM HYDROSTATIC BURSTING TEST, PSI

ALL PIPE SIZES	PIPE CLASS								
	FT30	FT35	FT40	FT45	FT50	FT60	FT70	FT80	FT90
	300	350	400	450	500	600	700	800	900

3.1.4 **Crushing Strength** — Each pipe when tested shall have sufficient strength to support not less than the loads indicated in the following table when tested in accordance with Section 4.2.3.

MINIMUM CRUSH STRENGTH, LBS/FT

PIPE SIZE SIZES	PIPE CLASS								
	FT30	FT35	FT40	FT45	FT50	FT60	FT70	FT80	FT90
6			2400	3200	4000	4700	5400	6700	9000
8	2000	2400	2800	3400	4000	4800	5500	7400	9300
10	2000	2500	3000	3500	4500	5500	7000	9000	11000
12	2000	2500	3000	4000	5200	6400	7800	10000	12200
14	2000	2500	3000	4000	5200	7000	8800	11000	13500
15	2300	2800	3300	4300	5500	7400	9300	12000	14500
16	2500	3000	3500	4500	5800	7500	9500	12400	15400
18	2500	3000	4000	5000	6500	8500	11000	14000	18000
20	2500	3500	4500	5500	7100	9500	12000	15000	20000
21	2500	3500	4500	5800	7300	9700	12500	16000	21000
24	2800	3800	5000	6200	8100	11000	15000	19000	24000

3.1.5 **Flexure Proof Test** — Each pipe in sizes 6" and 8" shall have sufficient strength to withstand without failure the total applied load indicated in the following table when tested in accordance with Section 4.2.4.

MINIMUM FLEXURAL LOADS, LBS.

PIPE SIZE INCHES	PIPE CLASS								
	FT30	FT35	FT40	FT45	FT50	FT60	FT70	FT80	FT90
6			1700	1900	2100	2400	2800	3000	3700
8	2800	3300	3800	4300	4800	5200	5700	6600	7600

3.1.6 **Workmanship**

3.1.6.1 **Inside Surface** — Each pipe shall be uniform in quality and shall be free from bulges, dents, fractures, and tears on the inside surface which result in variation in diameter greater than 3/16 of an inch from that obtained on adjacent unaffected portions of the surface. The pipe shall also be free from excessive interior surface flaking and roughness.

3.1.6.2 **Ends** — Machined ends of the pipe that receive the coupling shall be free from dents and gouges that will affect the tightness of the joint.

3.1.6.3 **Diameter** — The internal diameter of the pipe shall not vary from the manufacturer's standard diameter as approved, by more than the following:

Diameter of Pipe	Permissible Variation in Diameter (Plus or Minus)
21 inch and smaller	1/4 inch
24 inch and larger	5/16 inch

3.1.6.4 **Wall Thickness** — The wall thickness at the machined portions of any pipe shall not be less than the manufacturer's standard by more than 0.08 inch for pipe 15 inches or less in diameter and 0.12 inch for pipe 16 inches in diameter and larger.

Sec. 3.2 Couplings — Asbestos-Cement Couplings shall be machined on the inside surface so that the gaskets are retained in the proper position to make a tight seal.

Sec. 3.3 Rubber Gaskets — The Rubber Gaskets shall conform to the manufacturer's standard.

Sec. 3.4 Chemical Requirements —

3.4.1 **Uncombined Calcium Hydroxide Test** — The Uncombined Calcium Hydroxide in FT Pipe and Couplings shall not be greater than 1 percent when tested in accordance with Section 4.2.5.

SECTION 4 — INSPECTION TESTS AND REJECTIONS

Sec. 4.1 General — All material furnished under this specification shall be inspected and tested in accordance with this specification. All material shall be in a normal processed condition prior to test for conformance to the requirements stated in previous sections. When requested on his order, the purchaser may witness inspection and test procedures at his own expense. In lieu of this witnessing, he may request the manufacturer to submit a certificate certifying the product meets the requirements of the specification. To insure the purchaser that all pipe purchased under this specification conforms to the standards herein required and for the convenience of the purchaser or his representative, all tests must be conducted in the Continental United States.

Sec. 4.2 Tests —

4.2.1 **Hydrostatic Proof Test** — Each pipe unit, each standard coupling, and all pipe used in fabricating bends, tees, and other fittings, shall withstand without leakage a hydrostatic proof test of not less than the pressure designated in the table in Section 3.1.2. Standard couplings may be tested with a rubber bladder inside of the coupling and, if so tested, each coupling shall have sufficient strength to withstand a hydrostatic proof test of 1.5 times the pressure designated in the table. Fittings not requiring the hydrostatic proof test shall be manufactured of the same materials and by the same method as used in manufacturing the pipe that is tested. The test shall be performed in accordance with ASTM C500. Any pipe length or coupling showing leakage, sweating or other defect shall be rejected.

4.2.2 **Hydrostatic Bursting Test** — A one foot or longer length of unmachined pipe shall be cut from a standard pipe unit and shall be subjected to and withstand the minimum bursting pressure designated in the table in Section 3.1.3. The test specimen shall be selected from each 300 standard lengths, or fraction thereof, of each size and class of pipe manufactured on each machine during each shift. The test shall be conducted in accordance with ASTM C500, except maintaining the 5 second dwell is not required. (This is an instantaneous test.) Specimens passing this bursting test may be included in the order, provided the specimen, when retested after machine, meets the hydrostatic proof load test.

4.2.3 **Crushing Strength** — One foot lengths of pipe cut from unmachined portions of the pipe shall withstand the minimum crushing strength designated in the table in Section 3.1.4. On lots containing more than 100 lengths of each size and class, the test specimen shall be cut from a standard pipe length selected from each 300 lengths, or fraction thereof, of each size and class of pipe manufactured on each machine during each shift. The test shall be performed in accordance with ASTM C500.

4.2.4 **Flexural Strength** — Flexure proof tests shall be conducted on each standard length of 6" or 8" diameter pipe. The tests shall be performed in accordance with ASTM C500. Each pipe shall support the applicable total load designated in the table in Section 3.1.5 without evidence of cracks or other defects.

4.2.5 **Uncombined Calcium Hydroxide Test** — The manufacturer shall conduct periodic Uncombined Calcium Hydroxide Tests, the results of which must meet the requirements specified under Section 3.4.1. The test shall be performed in accordance with ASTM C500.

Sec. 4.3 Rejection —

4.3.1 **Hydrostatic Bursting Test** — In the event that a test specimen fails to withstand the hydrostatic bursting test specified in Section 3.1.3, the manufacturer will be allowed to test two additional specimens of the same size and class manufactured on the same machine during the same shift. If either of the two additional specimens fail to pass the test, the entire lot of pipe represented by the test specimen shall be rejected.

4.3.2 **Crushing** — In the event that a test specimen fails to withstand the crushing strength specified in Section 3.1.4, the manufacturer will be allowed to test two additional specimens of the same size and class manufactured on the same machine during the same shift. If either of the two additional specimens fail to pass the test, the entire lot of pipe represented by the test specimen shall be rejected.

SECTION 5 — MARKING

Sec. 5.1 Pipe and Coupling — Each length of pipe, each coupling and each tee, cross or bend shall be clearly marked with the size and class of pipe, name of manufacturer or trademark, and the date of manufacture.

Sec. 5.2 Gaskets — Each rubber gasket shall be marked with the manufacturer's identification, the size and year of manufacture.

Sec. 5.3 Additional Marking — When factory inspection is made by the purchaser, each pipe and each coupling may receive an additional special marking of no more than three letters as required by the purchaser.

SECTION 6 — PREPARATION FOR SHIPMENT

Sec. 6.1 General — All pipe, couplings and gaskets shall, unless otherwise specified, be prepared for standard commercial shipment, so as to insure acceptance by common or other carriers.

SECTION 7 — SUPPLEMENTARY DETAILS TO BE PROVIDED BY PURCHASER

Sec. 7.1 General — When purchasing FT Pipe under these specifications, it will be necessary for the purchaser to make specific statements for each lot of pipe.

Sec. 7.2 Size — The purchaser shall state the pipe size or sizes required.

Sec. 7.3 Class — The purchaser shall state the class or classes of pipe required.

Sec. 7.4 Standard Lengths — The purchaser shall state the total footage of 13 foot lengths required.

Sec. 7.5 Short Lengths — The purchaser shall state the total footage of 6'6" and 3'3" lengths required.

Sec. 7.6 Inspection and Tests —

7.6.1 **Crushing Tests** — The purchaser shall state on his order when Crushing Tests are required.

7.6.2 **Uncombined Calcium Hydroxide Tests** — The purchaser shall state on his order when the Uncombined Calcium Hydroxide Test is required.

7.6.3 **Certificate of Tests** — The purchaser shall state on his order when a certificate of tests in lieu of inspection is required.

Sec. 7.7 Definitions — Under these specifications the following definitions will apply:

7.7.1 **Purchaser** — The person, firm, corporation or governmental subdivision entering into a contract or agreement to purchase pipe according to these specifications.

7.7.2 **Manufacturer** — The person, firm or corporation who manufactures the pipe.

7.7.3 **Inspector** — The representative of the purchaser, properly authorized and limited by the duties entrusted to him.

7.7.4 **Performance Requirements** — The performance requirements of FT Pipe are developed jointly by the purchaser and manufacturer in accordance with the combined loading theory, utilizing as a basis of design the minimum hydrostatic burst and the minimum crush strength values specified in Sections 3.1.3 and 3.1.4 respectively.

FLUID TRANSMISSION (FT) ASBESTOS CEMENT PIPE

SECTION 1 — INTRODUCTION

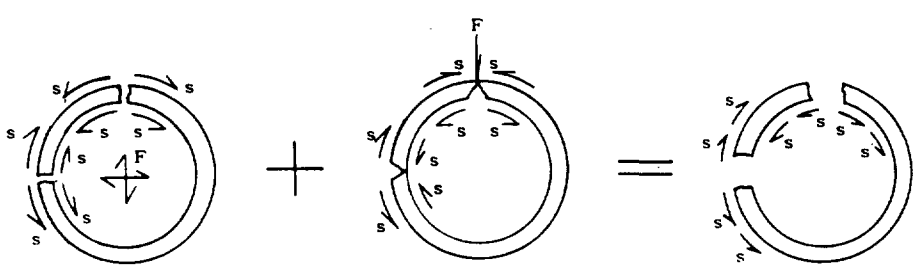
Sec. 1.1 Definition — A transmission system consists of pipelines which convey a fluid, such as water, from its source to a point of distribution or distributing reservoir. Transmission systems differ from distribution systems.

In comparison, a distribution system consists of numerous branches, connections and appurtenances. Large variations in flow and surge pressures can be expected in a distribution system due to the number of unknown factors involved.

Transmission systems have relatively fewer branches and appurtenances and the unknown factors are reduced to a minimum. The hydraulic analysis is simpler, permitting reasonable control of surge pressures and the use of lower safety factors. Because of the better control, piping material can be selected to meet the specific requirements of the system, thereby reducing overall costs.

Sec. 1.2 Design Principles — The serviceability of Certain-teed Asbestos-Cement Fluid Transmission (FT) Pipe is its ability to withstand the combined stresses developed by internal hydrostatic pressure and external crushing loads. Typical stresses encountered are schematically shown in Figure 1.

FIGURE 1 — COMBINED STRESS



Internal Hydrostatic Pressure | External Crushing Load | Combined Stress

The net effect on the pipe resulting from the combined loading shown above can be mathematically determined by the Schlick Formula:

$$w_T = W\sqrt{\frac{P - p_T}{P}} \qquad (1)$$

Where P = the hydrostatic pressure in pounds per square inch that will burst the pipe when no external load exists.

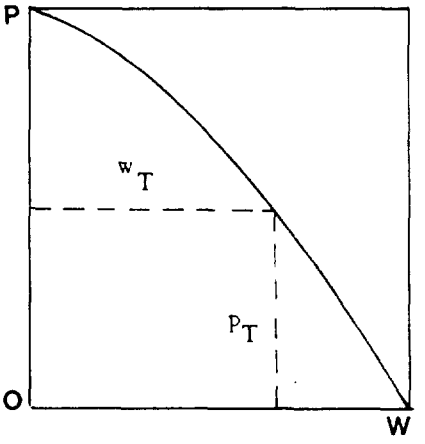
W = the external load in pounds per linear foot of pipe, in the three-edge bearing test, that will crush the pipe when no hydrostatic pressure exists.

p_T = the total internal pressure in pounds per square inch which, in combination with some external load, w_T, applied in three-edge bearing, will fracture the pipe.

w_T = the total external load in pounds per linear foot of pipe applied in three-edge bearing which, in combination with some internal pressure, p_T, will fracture the pipe.

Resolution of Eq. 1 will result in a parabolic curve as shown in Figure 2. This relationship shows the allowable internal pressure, p_T, for a fixed external load, w_T, or conversely the allowable external load, w_T, for a fixed internal pressure, p_T.

FIGURE 2 — LOAD PRESSURE CURVE



Once the design criteria is established for a particular pipe installation, it is possible by the utilization of the combined loading principle to select the proper class of FT Pipe. Combined loading curves for each size and class of FT Pipe are presented in Section IV. Each curve is based on the Schlick Formula, utilizing the hydrostatic burst value P and the crush value W desinated in Sections 3.1.3 and 3.1.4 of the specifications for that particular size and class of pipe. The internal pressure p_T and the external load w_T will be taken from the design criteria. A more detailed explanation of p_T and w_T is given in the following sections.

SECTION 2 — DETERMINATION OF INTERNAL HYDROSTATIC PRESSURE (p_T)

Sec. 2.1 Introduction — For the design of FT Pipe, the internal hydrostatic pressure, p_T, is defined by the following equation:

$$p_T = (P_o + P_s)\ S.\ F. \qquad (2)$$

Where p_T = the total internal pressure in pounds per square inch which, in combination with some external load, w_T, applied in three-edge bearing, will fracture the pipe.

P_o = the static or operating pressure in pounds per square inch defined by the design criteria.

P_s = the surge pressure in pounds per square inch resulting from either water hammer or other incremental pressures over and above the normal operating pressure.

Note: For the engineer's convenience, Section VI of this manual contains a discussion on operating static and surge pressures.

S. F. = The design safety factor specified by the purchaser. Factors of safety are based on judgment, past experiences and sound engineering principles.

For FT Pipe design minimum safety factor of 2.0 is recommended.

SECTION 3 — EXTERNAL LOADS (wT)

Sec. 3.1 Introduction — For the design of FT Pipe external loads, wT, are defined by the following equation:

$$w_T = \frac{W_E + W_S}{B.F.} \text{ S. F.} \qquad (3)$$

Where w_T = the total external load in pounds per linear foot of pipe applied in three-edge bearing which, in combination with some internal pressure, p_T, will fracture the pipe.

W_E = the total earth load in pounds per linear foot of pipe to which the pipe is subjected. The magnitude of this load is a direct function of the burial conditions encountered or specified (e.g., trench, embankment, tunnel, etc.)

W_S = the total superimposed load in pounds per linear foot of pipe transmitted through the burial environment to the pipe by factors other than the earth loads. These loads can be either of a static or dynamic character or combination of both.

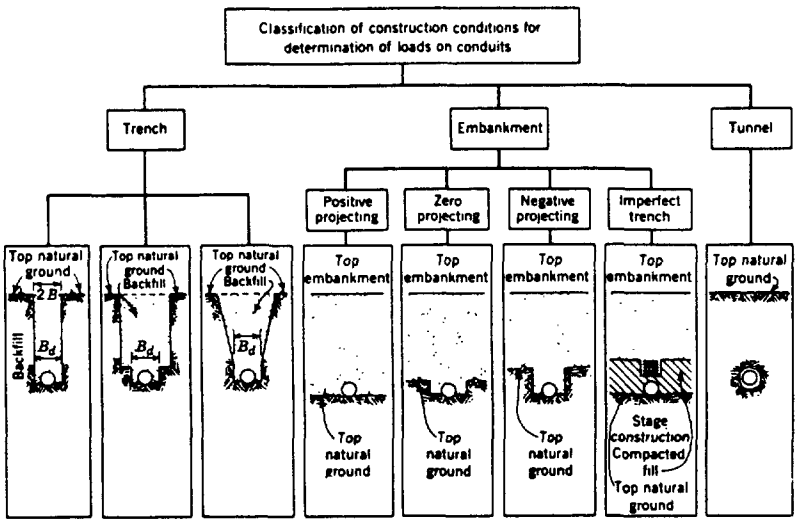
S. F. = the design safety factor specified by the purchaser. Factors of safety are based on judgment, past experiences and sound engineering principles. For FT Pipe design, the factor of safety shall be chosen such that the ratio of safety factor shall not be less than unity (i.e. $\frac{S.F.}{B.F.} \geq 1$). However, in this computation, the safety factor itself shall never be less than 1.5.

B. F. = the bedding factor which is a load factor correlating three-edge bearing test loads to field loads associated with specific bedding conditions. (For a more explicit explanation see Sec. 3.4.)

Methods for determining W_E, W_S and B.F. are given in the following sections Determination of S.F. is governed by the limitations previously discussed.

Sec. 3.2 Earth Loads (W_E) — Earth loads to which the pipe is subjected are a function of the soil density, the pipe diameters, depth of cover and the construction techniques employed in laying the pipeline. They depend on the interplay between the weight of the prism of earth directly over the pipe, called the interior prism, and the frictional shearing forces, plus or minus, transferred to that interior prism by the adjacent outside prisms of earth. The magnitude of earth loads vary with the construction technique employed. There are two major construction techniques normally encountered; namely, trench and embankment Another technique, the tunnel condition is not normally found, but nevertheless it has unique design methods which make it necessary to be included in this discussion Figure 3 shows these three construction techniques.

FIGURE 3 — CLASSIFICATION OF CONSTRUCTION TECHNIQUES



Reprinted from Fig. 59, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

For FT Pipe design, earth loads are calculated by the general form of Marston's Equation, given below.

$$W_E = C\ w_e\ B^2 \qquad (4)$$

Where W_E = the total earth load transmitted to the pipe in pounds per linear foot of pipe.

w_e = the soil density in pounds per cubic foot. Soil densities range in value from 100 to 135 pounds per cubic foot. In the absence of accurate soil density information, *a value of 120 pounds per cubic foot is recommended for FT Pipe design.*

B = the trench width or pipe diameter measured in feet. The value chosen depends on the installation conditions employed in laying the pipe.

C = a coefficient that is dependent on (1) ratio of the height of fill to the width of trench or pipe diameter; (2) shearing forces between the interior and adjacent earth prisms and (3) direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions. The calculations used to find the value of the coefficient will depend on the installation conditions employed in laying the pipe.

To calculate earth loads by Eq. 4 for the above mentioned major construction techniques (trench, embankment and tunnel) values for B and C must be determined. The following sections describe the different conditions and explain the methods for finding the values needed to use Marston's equation for soil loading.

3.2.1 **Trench Condition** — Trench conditions are defined as those in which the pipe is installed in a narrow trench, generally less than two (2) pipe diameters in width, cut in undisturbed ground and backfilled to the original ground surface, as illustrated in Figure 3. For this application, Eq. 4 is rewritten as:

$$W_E = C_d \, w_e \, B_d^2 \qquad (5)$$

Where

B_d = the width of the trench in feet, measured at the top of the pipe.

C_d = the load coefficient which is a function of the ratio $\frac{H}{B_d}$, where H is the height of the backfill in feet, measured to the top of the pipe and B_d is the trench width as previously defined.

The values of C_d are obtained from Figure 4 in which curves A, B, C, D and E take into account the friction coefficient between the backfill and the sides of the trench for the various soil compositions likely to be encountered.

Curve A is for granular materials without cohesion.

Curve B is for sand and gravel.

Curve C is for saturated top soil.

Curve D is for clay.

Curve E is for saturated clay.

For the engineer's convenience, earth load selection tables for the trench condition are presented at the end of this section.

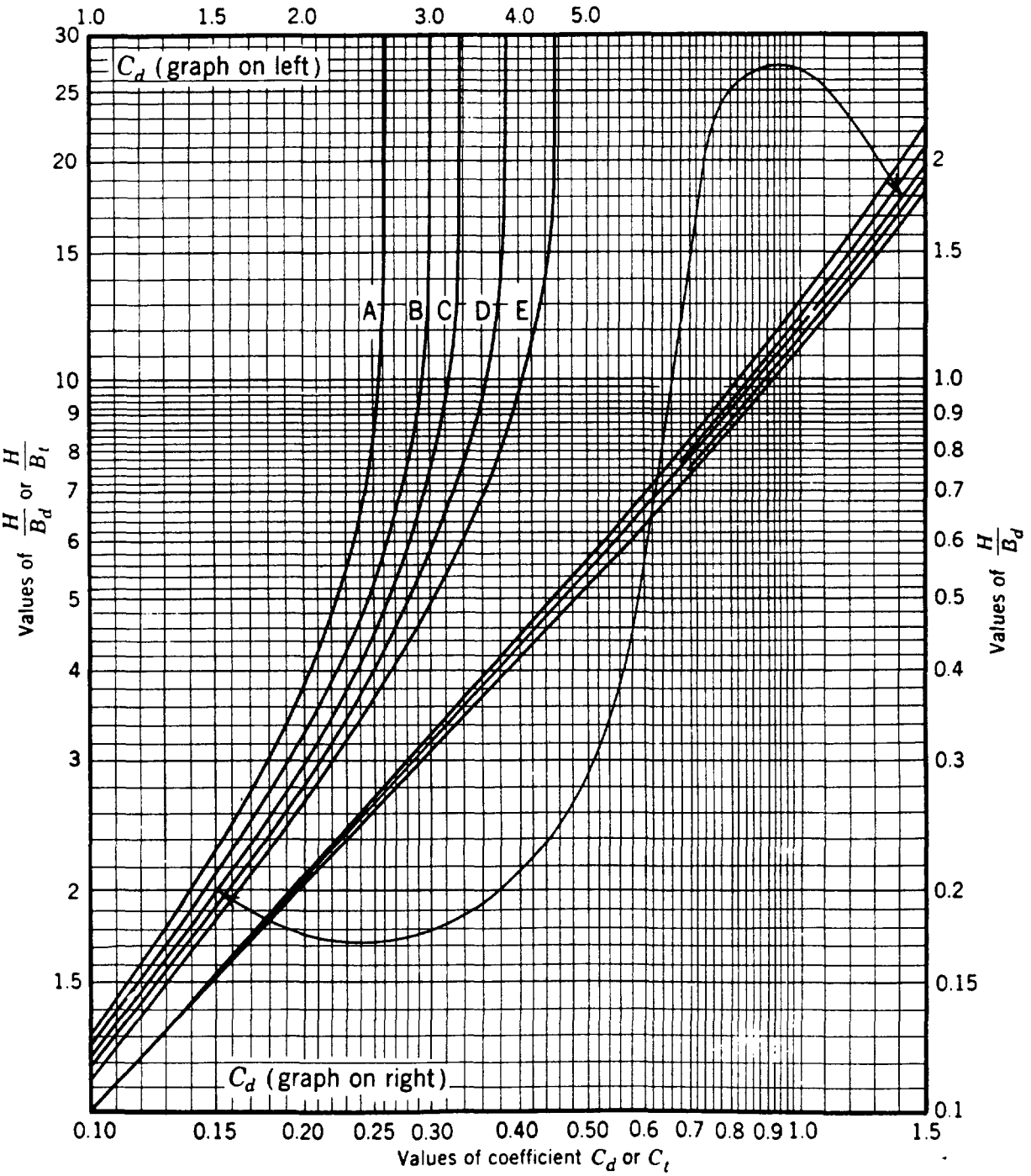
Sec. 3.2.2. Embankment Condition — Embankment conditions are defined as either that condition where the pipe is installed in a trench cut in undisturbed ground which is wider than two (2) to three (3) pipe diameters or that condition where the pipe is covered with fills above the original ground surface. Embankment conditions can be further subdivided into positive and negative projecting depending on the location of the top of the pipe relative to the original undisturbed ground. A special case, called the imperfect trench, where compressible material is used as a part of the backfill is also classified as an embankment condition.
The various embankment conditions described above are diagrammatically presented in Figure 3.

Sec. 3.2.2 (a) Embankment — Positive Projecting Pipe — Under embankment conditions, a positive projecting pipe is defined as either that condition where the pipe is installed in a trench cut in undisturbed ground which is wider than two (2) to three (3) pipe diameters or that condition where the top of the pipe is above the adjacent original ground surface and covered with fills above the original ground surface. For this condition, Eq. 4 is rewritten as:

$$W_E = C_c \, W_e \, B_c^2 \qquad (6)$$

Where B_c = the outside diameter of the pipe in feet.

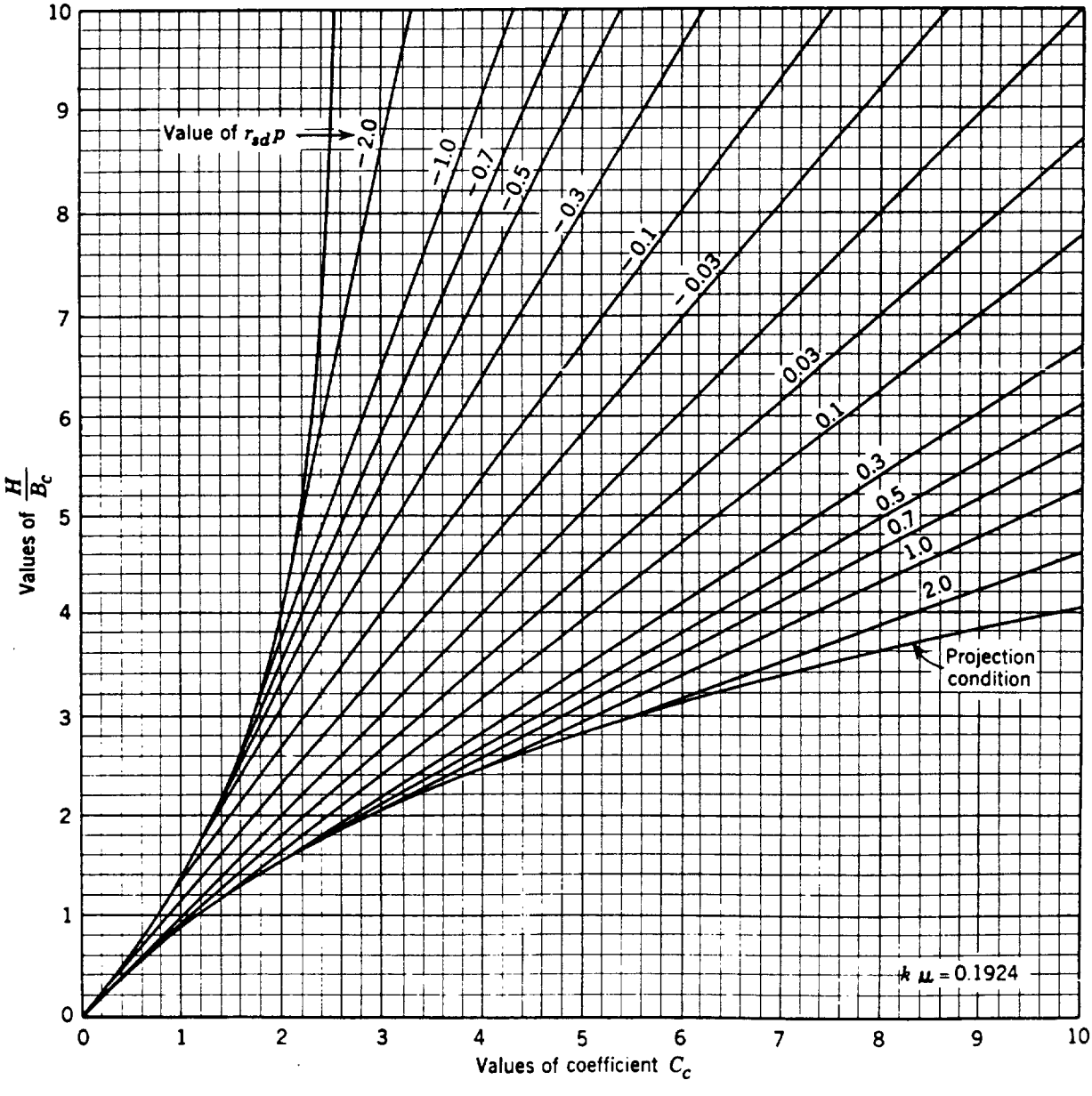
FIGURE 4. — VALUES OF C_d FOR TRENCH CONDITIONS



Reprinted from Fig. 61, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

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FIGURE 5 — VALUES OF C_c FOR POSITIVE PROJECTING PIPES



Reprinted from Fig. 65, Chapter IX, WPCF Manual of Practice No 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

C_c = the load coefficient which is a function of the ratio $\frac{H}{B_c}$, the projection ratio p, and the settlement ratio r_{sd}.
The values of C_c are obtained from Figure 5. The projection ratio, p, is defined as the ratio of the distance that the top of the pipe projects above the original ground surface to the outside diameter of the pipe. (See Figure 5)

For FT Pipe design the recommended value for the settlement ratio r_{sd} is $+0.7$.

C_c may also be obtained from Equation 7 when the following conditions exist simultaneously:

(1) The ratio $\frac{H}{B_c}$ is greater than 1.3.

(2) The product $r_{sd} \times p = 0.7$.

$$C_c = 1.892 \frac{H}{B_c} - 0.96 \qquad (7)$$

Sec. 3.2.2 (b) Transition Width — It will be noted from the preceding discussion that under construction conditions where a trench is cut in undisturbed ground two methods of computing the earth load are available; namely, the trench condition and the positive projection embankment condition. The method chosen is dependent on the ratio of the trench width to the pipe diameter. As previously stated, when the trench width is less than two (2) to three (3) times the pipe diameter, earth loads are computed by the trench condition (Equation 5). When the trench width is greater than two (2) to three (3) times the pipe diameter, earth loads are computed by the positive projection embankment condition (Equation 6). The width of trench at which both methods of computations give equal loads is called the "transition width." *The earth load computed at the "transition width" is theoretically the maximum external earth load that can be transmitted to the pipe for any given depth of cover.* For all widths of trench greater than the "transition width" earth loads are computed by the positive projection embankment condition (Equation 6). For a given depth of cover these earth loads are equal to the load resulting at the "transition width." For all widths of trench less than the "transition width," the earth loads are computed by the trench condition (Equation 5). See Figure 6:

(c) — trench width is the "transition width." Earth loads are computed by either Equation 5 or 6.

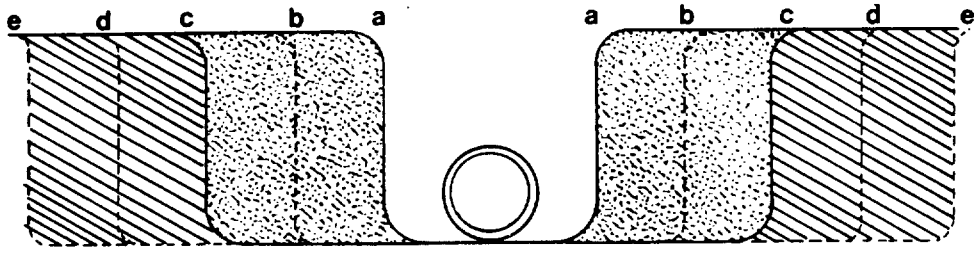
(a), (b) — Earth loads are computed by the trench equation (Equation 5), because the width of trench is less than the transition width.

(d), (e) — Earth loads are computed by the positive projection embankment formula (Equation 6). For a stated depth of cover the earth loads resulting from trench widths c, d and e are equal.

The "transition width" is determined from Figure 7. The ratio of the "transition width" of trench to the outside diameter of pipe ($\frac{B_d}{B_c}$) can be obtained from Figure 7 for any given ratio of $\frac{H}{B_c}$. By multiplying the ratio $\frac{B_d}{B_c}$ by the applicable outside diameter of pipe (B_c) the "transition width" is determined.

For the engineer's convenience earth load selection tables for trench condition and positive projection embankment condition are given at the end of this section. The earth loads at the transition width for corresponding depths of cover are shown in bold type.

FIGURE 6



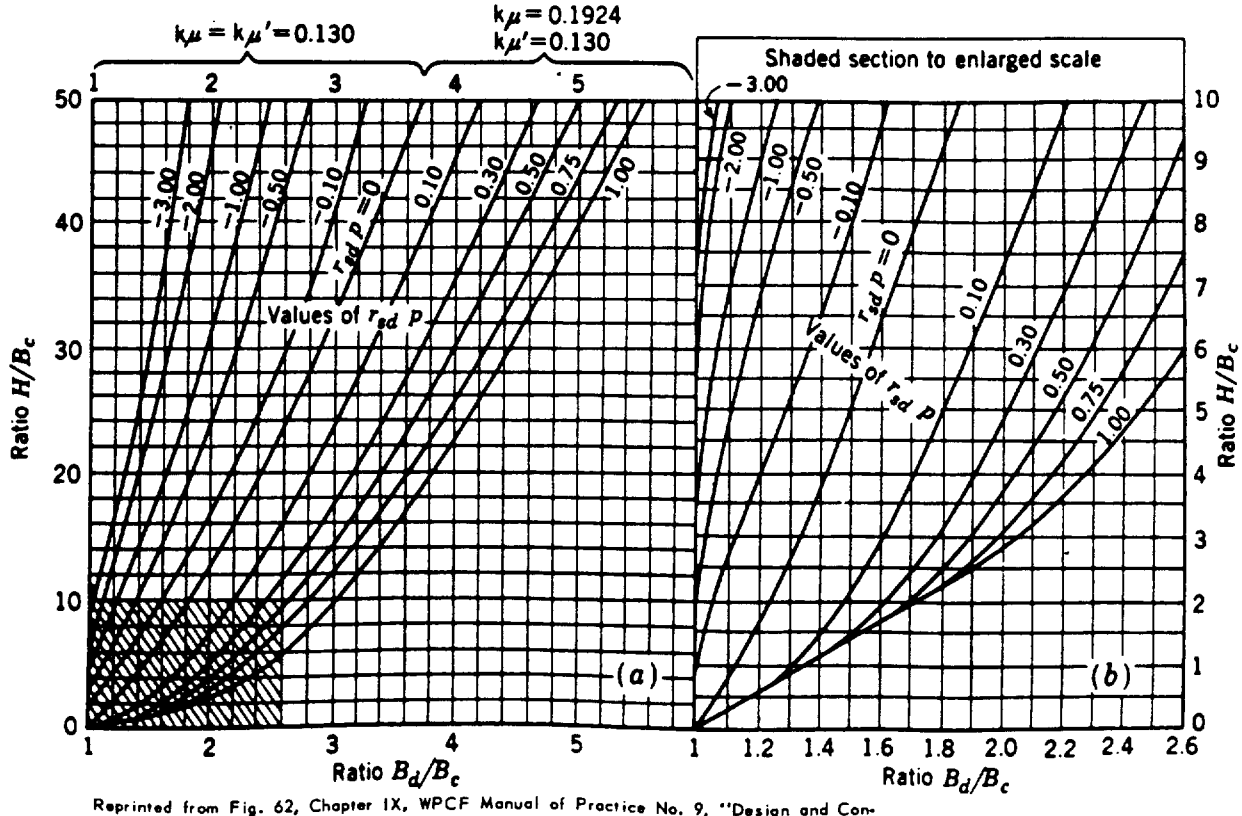
Sec. 3.2.2 (c) Embankment — Negative Projecting Pipe — A negative projecting pipe is defined as that condition where the pipe is installed in a relatively shallow trench wherein the top of the pipe is at some elevation below the original ground surface. The trench is then backfilled and compacted and an embankment is constructed thereon to finished grade (Figure 3). For the negative projecting pipe condition, Equation 4 is rewritten as:

$$W_E = C_n w_e B_d^2 \qquad (8)$$

Where B_d = the width of the trench in feet.

C_n = the load coefficient which is a function of $\frac{H}{B_d}$ the projection ratio p, and the settlement ratio r_{sd}. The various values of C_n are obtained from Figure 10. The projection ratio, p, is defined as the ratio of the vertical distance from the original ground surface down to the top of the pipe to the width of the trench, B_d (See Figure 8).

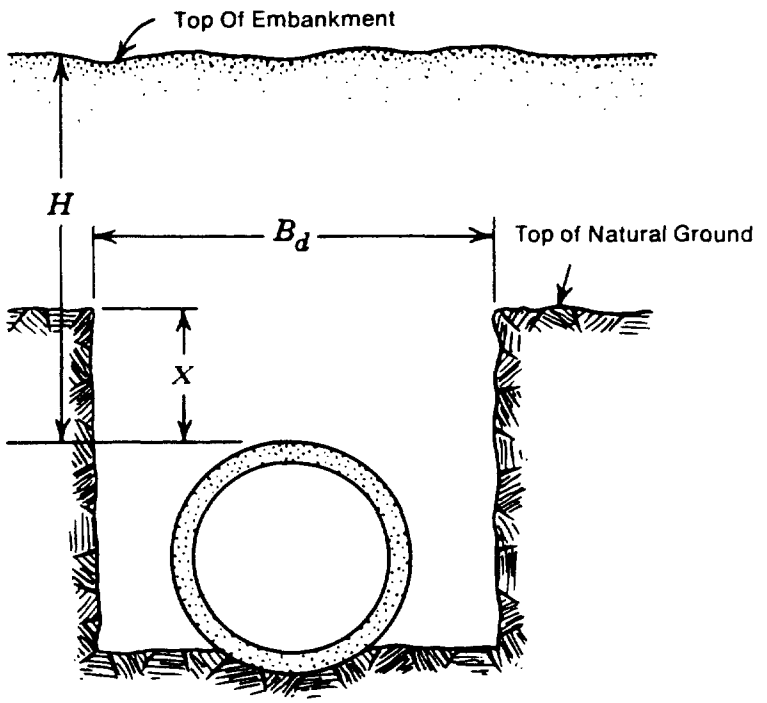
FIGURE 7 — VALUES OF $\frac{B_c}{B_d}$ AT WHICH THE TRENCH AND POSITIVE PROJECTING PIPE EQUATIONS GIVE EQUAL LOADS



Reprinted from Fig. 62, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

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FIGURE 8 — PROJECTION RATIO (p) FOR THE NEGATIVE PROJECTION EMBANKMENT CONDITION



For FT Pipe design the recommended value for the settlement ratio (rsd) is equal to zero.

Projection Ratio = $\frac{X}{B_d}$

When calculating earth loads under negative projecting embankment conditions, consideration must be given to the "transition width" as defined in Sec. 3.2.2(b). For values of the ratio $\frac{B_d}{B_c}$, less than those given in Figure 6, the load on a pipe is determined from Equation 8 for negative projecting pipes. However, as the trench width increases and consequently the ratio $\frac{B_d}{B_c}$, becomes greater than that given in Figure 7, the earth load should be determined from Equation 6 for positive projecting pipe. Adherence to the preceding rule will result in the most realistic earth loads for design purposes.

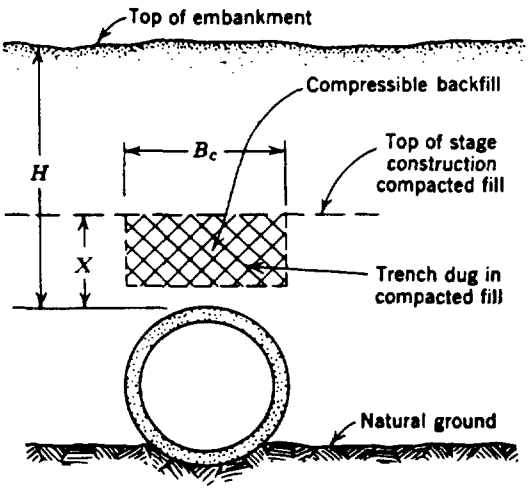
Sec. 3.2.2 (d) Embankment — Imperfect Ditch Condition — The imperfect ditch condition occurs rather infrequently and is included in this design manual for the engineer's general information. The imperfect ditch condition refers to that construction technique wherein the pipe is first installed as a positive projecting pipe. A portion of the embankment is then built up to some elevation above the top of the pipe and thoroughly compacted as it is placed. A trench the same width as the pipe is then excavated directly over the pipe down to or near its top and subsequently backfilled with *loose, compressible* material. The remainder of the embankment is then built up to final elevation (Figure 3). For the imperfect ditch condition, Equation 4 is rewritten as:

$$W_E = C_n \, w_e \, B_c^2 \qquad (9)$$

Where B_c = the outside diameter of the pipe in feet.

C_n = the load coefficient which is a function of $\frac{H}{B_c}$, the projection ratio p, and the settlement ratio, r_{sd}. The various values of C_n are obtained from Figure 10. The projection ratio, p, is defined as the ratio of the vertical distance from the top of the excavated trench down to the top of the pipe to the diameter of the pipe (See Figure 9). *For FT Pipe design the recommended value for the settlement ratio r_{sd}, is equal to -0.3.*

FIGURE 9 — PROJECTION RATIO (p) FOR THE IMPERFECT DITCH CONDITION



Projection Ratio = $\frac{X}{B_c}$

Sec. 3.2.2 (e) Tunnel Conditions — There are two types of tunnel construction encountered in normal pipe laying operation. The first type, which is the most frequently encountered, occurs when a sleeve of a larger diameter than the specified pipe is first "jacked" through an embankment. The pipe is then placed into the sleeve without becoming an integral part of the tunnel construction. In this instance the sleeve supports the entire earth load and the pipe contained therein is not subjected to crushing loads. When selecting the required class of pipe for this condition, only the internal pressures need to be considered for design.

The second type of tunnel condition is rarely encountered in transmission work, but is included in this design manual in event of its occurring. It is that condition wherein the pipe itself must carry the entire load. The area through which the pipeline must pass is bored and braced with the necessary supports. The pipe is then placed in the tunnel and the void between the pipe and tunnel braces is backfilled with compacted earth, grout or concrete. Once this operation is completed, the earth load automatically transfers from the tunnel supports to the pipe itself. For this condition Equation 4 is rewritten as:

$$W_E = C_T B_T (w_e B_T - 2c) \qquad (10)$$

Where B_T = the maximum width of the tunnel excavation in feet.

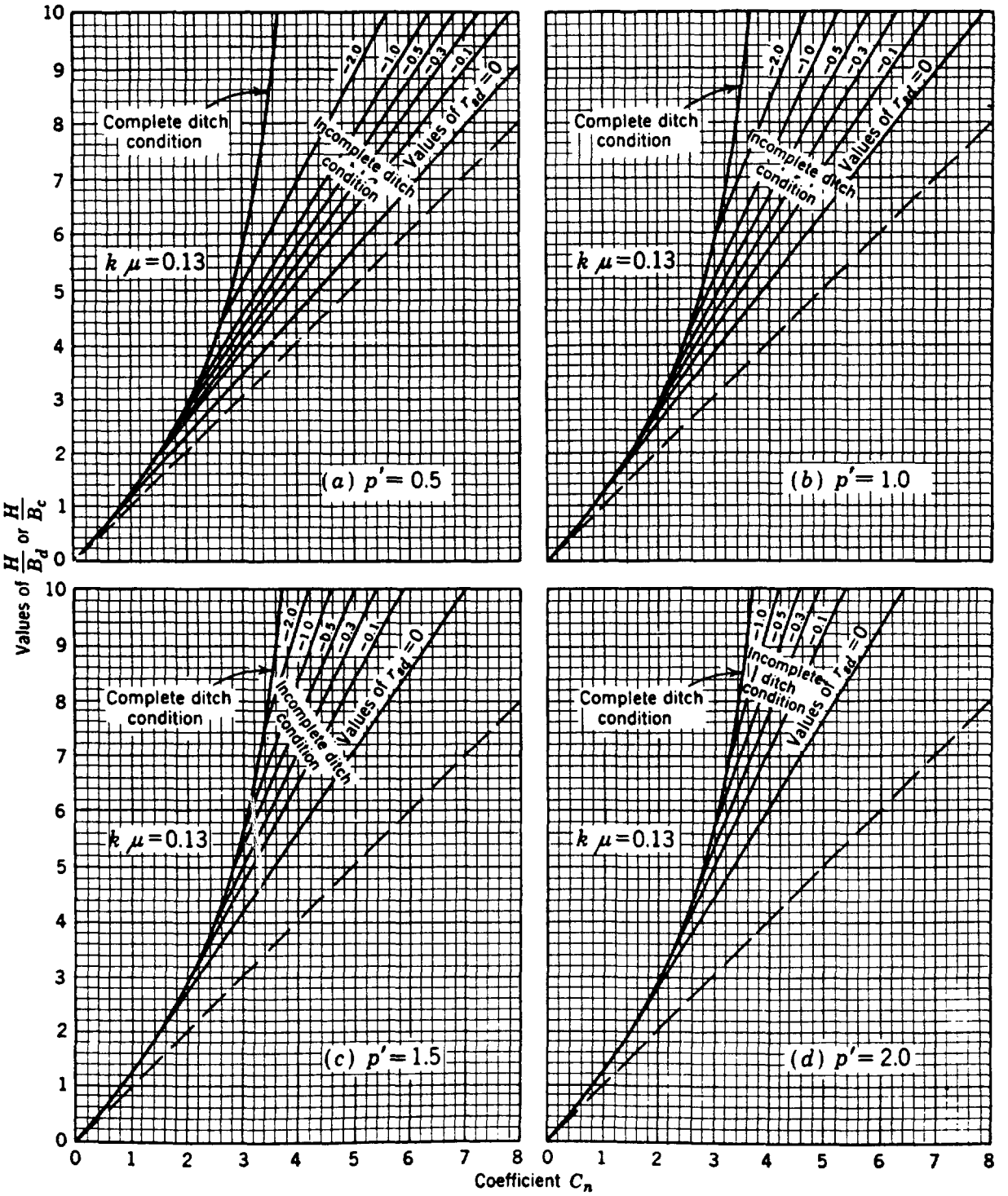
c = the coefficient of cohesion in pounds per square foot.

C_T = the load coefficient which is a function of the coefficient of internal friction for the material of the tunnel and of the ratio $\frac{H}{B_T}$, where H is the distance from the ground surface to the top of the tunnel in feet and B_T equals the width of the tunnel excavation in feet. Values of C_T for different types of soils are obtained from Figure 11.

If the value for the coefficient of cohesion is not available from laboratory tests, the following recommended safe design values are to be used:

Material	Values of c
Clay, very soft	40
Clay, medium	250
Clay, hard	1000
Sand, loose dry	0
Sand, silty	100
Sand, dense	300
Top Soil, saturated	100

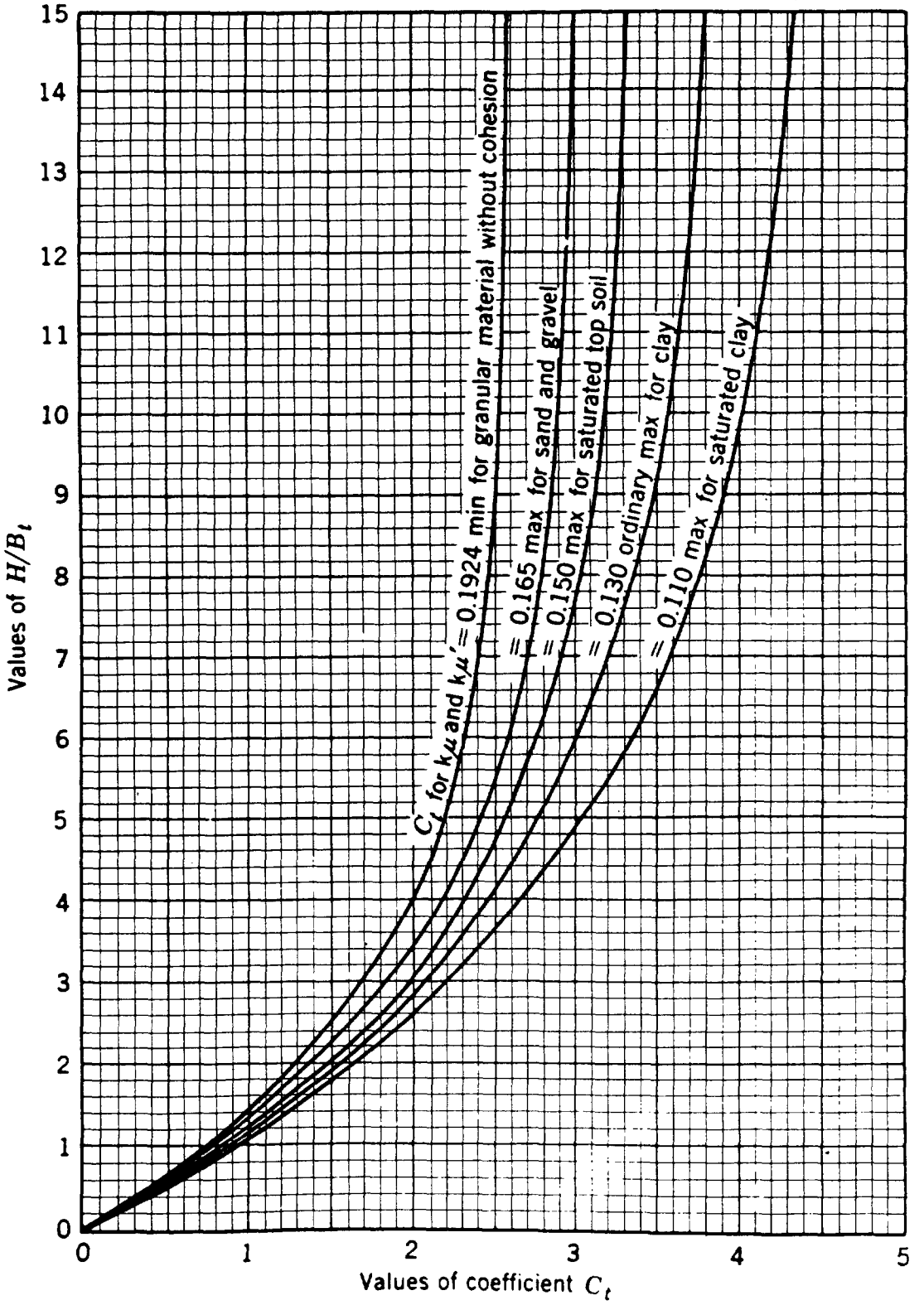
FIGURE 10 — VALUES OF C_n FOR NEGATIVE PROJECTING PIPES AND IMPERFECT DITCH CONDITIONS



Reprinted from Fig. 68, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

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FIGURE 11 — VALUES OF C_t FOR TUNNEL CONDITIONS



Reprinted from Fig. 71, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

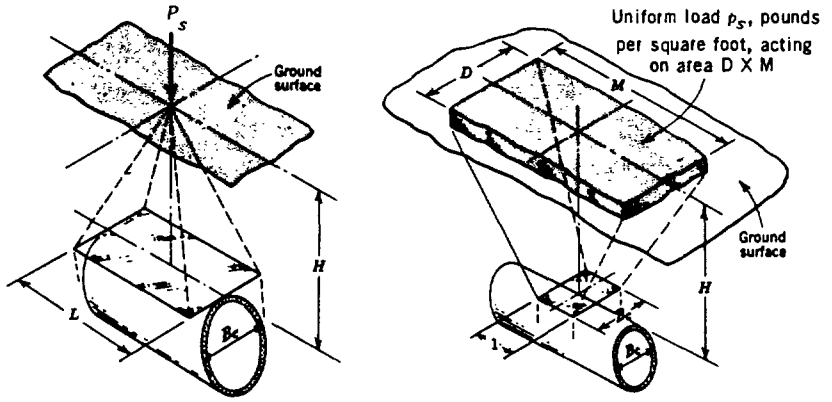
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When in tunnel construction, the excavation becomes excessive, or when the void surrounding the pipe or tunnel lining is not carefully filled, or when the cohesion of the undisturbed material above the tunnel construction is destroyed by soil saturation or vibration, the earth load should be calculated by Equation 5 for trenching conditions. Since it can be exceedingly difficult to either predict or assess whether the tunnel excavation is excessive, it is recommended for safe FT Pipe design that Equation 5 be used for most installations.

It should be pointed out that the preceding discussion was based on the premise that the tunnel would be constructed in homogenous soils which do not create unusual pressures and stresses. If the tunnel is constructed through materials which tend to squeeze or swell, such as some types of clays or shales, or through blocky and seamy rock, methods other than tunnel construction must be utilized. The method of installation used is the responsibility of the engineer in charge of construction.

Sec. 3.3 Superimposed Loads (W_s) — Superimposed loads are external loads other than the normal earth loads transmitted to the pipe. There are two types of superimposed loads; namely, concentrated $W_{s\,1}$, and distributed $W_{s\,2}$, as illustrated in Figure 12. Superimposed loads are frequently referred to as live loads.

FIGURE 12 — SUPERIMPOSED LOADS



Concentrated Superimposed Load Vertically Centered Over the Pipe

Distributed Superimposed Load Vertically Centered Over the Pipe

Reprinted from Fig. 72, Chapter IX, WPCF Manual of Practice No. 9, "Design and Construction of Sanitary and Storm Sewers", prepared by A Joint Committee of the WPCF and the ASCE, 1966.

Sec. 3.3.1 Concentrated Loads — A concentrated load is a load caused by a single force which may be either static or dynamic in nature. In normal pipe design vehicular wheel loads are the most frequently encountered concentrated loads. The magnitude of the force produced by concentrated loads is determined by the following equation:

$$W_{s\,1} = C_S \frac{P_s F}{L} \qquad (11)$$

Where W_{s1} = the force on a pipe caused by a concentrated superimposed load in pounds per foot of pipe.

P_s = the concentrated load in pounds. The AASHO* design manual gives loads for various sizes and types of vehicles.

F = the impact factor. AASHO* recommended values for vehicular wheel loads are as follows:

Depth of Cover	Impact Factor (F)
1.0 – 2.0 feet	1.2
2.0 – 3.0 feet	1.1
3.0 feet or greater	1.0

Impact factors vary from one locale to another and values should be chosen which are consistent with local, state and federal specifications.

*American Association of State Highway Officials

L = the effective length of the pipe in feet. For pipe less than three (3) feet, use the actual length of the section. For all other pipe lengths, use an effective length of three (3) feet.

C_s = the load coefficient which is a function of the depth of cover to the top of the pipe and the nominal inside diameter of the pipe. Values of C_s are obtained from Table 1.

TABLE 1 – VALUES OF C_s FOR CONCENTRATED SUPERIMPOSED LOADS VERTICALLY CENTERED OVER THE PIPE.

Depth of Cover to Top of Pipe (feet)	PIPE DIAMETER (INCHES)										
	6	8	10	12	14	15	16	18	20	21	24
2.0	.147	.191	0.237	0.279	0.317	.336	0.354	0.391	0.422	.437	0.478
2.5	.106	.137	0.174	0.202	0.232	.247	0.259	0.289	0.316	.328	0.362
3.0	.078	.102	0.129	0.153	0.175	.186	0.197	0.221	0.241	.250	0.280
4.0	.046	.061	0.078	0.092	0.106	.114	0.121	0.136	0.150	.156	0.177
5.0	.031	.041	0.052	0.062	0.071	.077	0.081	0.092	0.102	.106	0.120
6.0	.023	.029	0.037	0.044	0.050	.054	0.057	0.066	0.073	.076	0.087
8.0	.013	.017	0.022	0.025	0.030	.032	0.034	0.038	0.042	.043	0.050
10.0	.008	.010	0.013	0.016	0.018	.020	0.021	0.025	0.027	.029	0.033
12.0	.006	.008	0.009	0.011	0.013	.015	0.015	0.017	0.019	.021	0.022
16.0	.003	.004	0.006	0.007	0.008	.008	0.009	0.010	0.011	.012	0.013
20.0	.002	.003	0.0035	0.004	0.005	.005	0.005	0.006	0.007	.007	0.008

For the engineer's convenience concentrated superimposed loads resulting from a 10,000 pound wheel load are presented at the end of this section. Also included are conversion factors for other frequently encountered wheel loads.

Sec. 3.3.2 Distributed Load — A distributed load is a load caused by a uniform force distributed equally over a given area; the load may be either static or dynamic in nature. In such cases, the following equation is used:

$$W_{s2} = C_s P_s F B_c \qquad (12)$$

Where W_{s2} = the force on a pipe caused by distributed superimposed load in pounds per foot of pipe.

P_s = the intensity of the distributed load in pounds per square foot.

F = the impact factor as explained in Section 3.3.1.

B_c = the diameter of the pipe in feet.

C_s = the load coefficient which is a function of the ratio $\frac{D}{2H}$ and $\frac{M}{2H}$.

H is the height of the fill from the top of the pipe to the ground surface in feet and D and M are the width and length respectively of the area over which the distributed load acts, in feet.

Values of C_s are obtained from Table 1.

Sec. 3.4 Bedding Factor (B.F.) — The bedding factor is a load factor which is defined as the ratio of the crushing strength of the pipe under field bedding conditions to the crushing strength as determined by the three-edge bearing test. Because the crushing strength of a pipe in the field is influenced by the bedding condition and the lateral support exerted on the sides of the pipe, it is necessary to use this load factor to correlate field loads to three-edge bearing test loads. This relationship is expressed as the external field load equaling the load factor times the three-edge bearing load. An illustration of the different bedding conditions is shown in Figure 13. Recommended load factors for various bedding conditions are given in Table 2.

TABLE 2

CORRELATION OF BEDDING CONDITIONS, PIPE SIZES, AND LOAD FACTORS

Bedding Condition (Class)	Description	Pipe Size Inches	Load Factor
A	Gravel or Sand Base - Backfill Tamped	6 - 12	1.7
		14 - 20	1.8
		21, 24	2.0
B	Same as A, But Backfill Not Tamped	6 - 24	1.5
C	Pipe Laid on Earth Mounds or Pipe Barrel on Flat Trench Bottom With Excavated Coupling Holes - Backfill Tamped	6 - 12	1.3
		14 - 20	1.4
		21, 24	1.5
D	Same as C, But Backfill Not Tamped	6 - 24	1.1

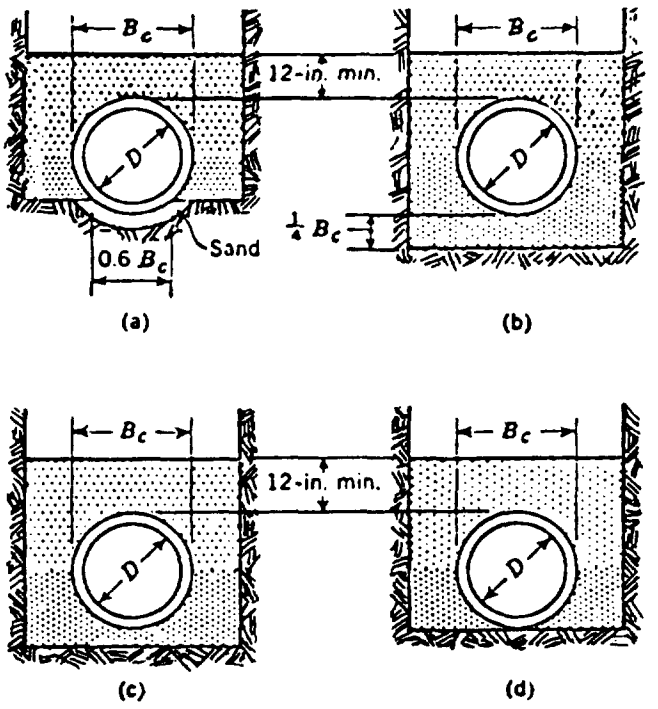


Fig. 13 Bedding Conditions Illustrated — Class A bedding conditions are shown in (a) and (b). Class C conditions are shown in (c) and (d). In all four diagrams, the lightly shaded area represents approved backfill, not frozen and free from lumps, large stones, boulders, or other unsuitable substances. The heavily shaded areas represent approved backfill, carefully tamped in 4 in. layers. In (a), a minimum of 2 in. of sand is placed in a shaped bottom under the pipe. In (b), the pipe is bedded in a gravel base. In (c), the pipe barrel rests on earth mounds. In (d), the pipe barrel is resting on the flat bottom of the trench. Class B condition is the same as Class A, and Class D is the same as Class C except that the backfill is not tamped in B or D.

6 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		1'9"	2'0"	2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"					
2'	GRANULAR MATERIAL	230														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	300														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	370														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
4'	GRANULAR MATERIAL	510														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
5'	GRANULAR MATERIAL	640														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
6'	GRANULAR MATERIAL	700	780													
	SAND & GRAVEL	750														
	SATURATED TOP SOIL	780														
	CLAY															
	SATURATED CLAY															
7'	GRANULAR MATERIAL	750	920													
	SAND & GRAVEL	820														
	SATURATED TOP SOIL	880														
	CLAY	920														
	SATURATED CLAY															
8'	GRANULAR MATERIAL	790	990	1050												
	SAND & GRAVEL	880	1050													
	SATURATED TOP SOIL	920														
	CLAY	990														
	SATURATED CLAY	1050														
9'	GRANULAR MATERIAL	830	1030	1190												
	SAND & GRAVEL	920	1130													
	SATUPATED TOP SOIL	970	1190													
	CLAY	1050														
	SATURATED CLAY	1110														
10'	GRANULAR MATERIAL	860	1060	1280	1330											
	SAND & GRAVEL	950	1180	1330												
	SATURATED TOP SOIL	1020	1270													
	CLAY	1100	1330													
	SATURATED CLAY	1210														
12'	GRANULAR MATERIAL	890	1130	1370	1600											
	SAND & GRAVEL	1000	1270	1520												
	SATURATED TOP SOIL	1070	1350	1600												
	CLAY	1180	1470													
	SATURATED CLAY	1320	1590													
14'	GRANULAR MATERIAL	920	1180	1430	1730	1870										
	SAND & GRAVEL	1040	1320	1610	1870											
	SATURATED TOP SOIL	1120	1420	1730												
	CLAY	1250	1560	1870												
	SATURATED CLAY	1400	1730													
16'	GRANULAR MATERIAL	930	1200	1490	1790	2110	2150									
	SAND & GRAVEL	1070	1350	1670	2010	2150										
	SATURATED TOP SOIL	1160	1460	1790	2150											
	CLAY	1310	1630	2010												
	SATURATED CLAY	1450	1820	2150												
18'	GRANULAR MATERIAL	940	1220	1520	1830	2180	2420									
	SAND & GRAVEL	1080	1390	1700	2060	2420										
	SATURATED TOP SOIL	1180	1510	1890	2240											
	CLAY	1330	1680	2070	2420											
	SATURATED CLAY	1490	1880	2310												
20'	GRANULAR MATERIAL	945	1230	1550	1880	2210	2600	2690								
	SAND & GRAVEL	1090	1410	1730	2110	2520	2690									
	SATURATED TOP SOIL	1190	1530	1910	2290	2690										
	CLAY	1350	1730	2130	2550											
	SATURATED CLAY	1510	1940	2340	2690											

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

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8 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH													
		2'0"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"		
2'	GRANULAR MATERIAL	290													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
2'6"	GRANULAR MATERIAL	370													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
3'	GRANULAR MATERIAL	460													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
4'	GRANULAR MATERIAL	640													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
5'	GRANULAR MATERIAL	770	820												
	SAND & GRAVEL	820													
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
6'	GRANULAR MATERIAL	840	1000												
	SAND & GRAVEL	890													
	SATURATED TOP SOIL	960													
	CLAY	1000													
	SATURATED CLAY														
7'	GRANULAR MATERIAL	910	1090	1180											
	SAND & GRAVEL	1010	1150												
	SATURATED TOP SOIL	1060													
	CLAY	1110	1180												
	SATURATED CLAY	1150													
8'	GRANULAR MATERIAL	990	1150												
	SAND & GRAVEL	1060	1280	1360											
	SATURATED TOP SOIL	1130	1340												
	CLAY	1200	1360												
	SATURATED CLAY	1270													
9'	GRANULAR MATERIAL	1030	1250	1430	1530										
	SAND & GRAVEL	1130	1340												
	SATURATED TOP SOIL	1200	1430	1530											
	CLAY	1270	1520												
	SATURATED CLAY	1350	1530												
10'	GRANULAR MATERIAL	1060	1280	1540	1710										
	SAND & GRAVEL	1180	1400	1650											
	SATURATED TOP SOIL	1270	1520												
	CLAY	1350	1610	1710											
	SATURATED CLAY	1440	1700												
12'	GRANULAR MATERIAL	1130	1370	1650	1910	2070									
	SAND & GRAVEL	1270	1520	1800											
	SATURATED TOP SOIL	1350	1640	1950	2070										
	CLAY	1470	1730	2060											
	SATURATED CLAY	1590	1910	2070											
14'	GRANULAR MATERIAL	1180	1430	1730	2020	2320	2420								
	SAND & GRAVEL	1320	1610	1940	2270	2420									
	SATURATED TOP SOIL	1420	1730	2060	2410										
	CLAY	1560	1880	2210	2420										
	SATURATED CLAY	1730	2070	2420											
16'	GRANULAR MATERIAL	1200	1490	1790	2110	2450	2780								
	SAND & GRAVEL	1350	1670	2010	2360	2700									
	SATURATED TOP SOIL	1460	1790	2150	2540	2780									
	CLAY	1630	2010	2330	2720										
	SATURATED CLAY	1820	2220	2590	2780										
18'	GRANULAR MATERIAL	1220	1520	1830	2180	2540	2920	3140							
	SAND & GRAVEL	1390	1700	2060	2450	2860	3140								
	SATURATED TOP SOIL	1510	1890	2240	2630	3030									
	CLAY	1680	2070	2460	2890	3140									
	SATURATED CLAY	1880	2310	2720	3140										
20'	GRANULAR MATERIAL	1230	1550	1880	2210	2600	2980	3410	3490						
	SAND & GRAVEL	1410	1730	2110	2520	2930	3350	3490							
	SATURATED TOP SOIL	1530	1910	2290	2700	3130	3490								
	CLAY	1730	2130	2550	3000	3450									
	SATURATED CLAY	1940	2340	2840	3290	3490									

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

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10 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		2'0"	2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"					
2'	GRANULAR MATERIAL	340														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	450														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	560														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
4'	GRANULAR MATERIAL	650	790													
	SAND & GRAVEL	700														
	SATURATED TOP SOIL	720														
	CLAY	790														
	SATURATED CLAY															
5'	GRANULAR MATERIAL	770	880	1010												
	SAND & GRAVEL	820	940													
	SATURATED TOP SOIL	840	970													
	CLAY	870	1010													
	SATURATED CLAY	890														
6'	GRANULAR MATERIAL	840	1000	1160	1240											
	SAND & GRAVEL	890	1060	1240												
	SATURATED TOP SOIL	960	1120													
	CLAY	1010	1150													
	SATURATED CLAY	1060	1240													
7'	GRANULAR MATERIAL	910	1090	1280	1460											
	SAND & GRAVEL	1010	1150	1370												
	SATURATED TOP SOIL	1060	1250	1460												
	CLAY	1110	1310													
	SATURATED CLAY	1150	1330													
8'	GRANULAR MATERIAL	990	1150	1390	1590	1690										
	SAND & GRAVEL	1060	1280	1460	1690											
	SATURATED TOP SOIL	1130	1340	1560												
	CLAY	1200	1400	1640												
	SATURATED CLAY	1270	1460	1690												
9'	GRANULAR MATERIAL	1030	1250	1430	1710	1890	1910									
	SAND & GRAVEL	1130	1340	1580	1820	1910										
	SATURATED TOP SOIL	1200	1430	1650	1910											
	CLAY	1270	1520	1730												
	SATURATED CLAY	1350	1610	1800												
10'	GRANULAR MATERIAL	1060	1280	1540	1770	2030	2140									
	SAND & GRAVEL	1180	1400	1650	1910	2140										
	SATURATED TOP SOIL	1270	1520	1760	2020											
	CLAY	1350	1610	1880	2140											
	SATURATED CLAY	1440	1700	1990												
12'	GRANULAR MATERIAL	1130	1370	1650	1910	2210	2470	2580								
	SAND & GRAVEL	1270	1520	1800	2090	2380	2580									
	SATURATED TOP SOIL	1350	1640	1950	2220	2540										
	CLAY	1470	1730	2060	2360	2580										
	SATURATED CLAY	1590	1910	2210	2520											
14'	GRANULAR MATERIAL	1180	1430	1730	2020	2320	2660	3030								
	SAND & GRAVEL	1320	1610	1940	2270	2570	2920									
	SATURATED TOP SOIL	1420	1730	2060	2410	2750	3030									
	CLAY	1560	1880	2210	2570	2920										
	SATURATED CLAY	1730	2070	2420	2800	3030										
16'	GRANULAR MATERIAL	1200	1490	1790	2110	2450	2810	3150	3480							
	SAND & GRAVEL	1350	1670	2010	2360	2700	3090	3480								
	SATURATED TOP SOIL	1460	1790	2150	2540	2920	3320									
	CLAY	1630	2010	2330	2720	3120	3480									
	SATURATED CLAY	1820	2220	2590	3000	3400										
18'	GRANULAR MATERIAL	1220	1520	1830	2180	2540	2920	3310	3710	3930						
	SAND & GRAVEL	1390	1700	2060	2450	2860	3250	3680	3930							
	SATURATED TOP SOIL	1510	1890	2240	2630	3030	3490	3930								
	CLAY	1680	2070	2460	2890	3290	3740									
	SATURATED CLAY	1880	2310	2710	3180	3620	3930									
20'	GRANULAR MATERIAL	1230	1550	1880	2210	2600	2980	3410	3830	4260	4380					
	SAND & GRAVEL	1410	1730	2110	2520	2930	3350	3820	4220	4380						
	SATURATED TOP SOIL	1530	1910	2290	2700	3130	3610	4090	4380							
	CLAY	1730	2130	2550	3000	3450	3930	4380								
	SATURATED CLAY	1930	2340	2840	3290	3800	4320									

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

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12 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		2'0"	2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"			
2'	GRANULAR MATERIAL	370														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	460	510													
	SAND & GRAVEL	480														
	SATURATED TOP SOIL	510														
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	560	640													
	SAND & GRAVEL	580														
	SATURATED TOP SOIL	600														
	CLAY	630														
	SATURATED CLAY	640														
4'	GRANULAR MATERIAL	650	790	910												
	SAND & GRAVEL	700	820													
	SATURATED TOP SOIL	720	850													
	CLAY	770	880													
	SATURATED CLAY	800	910													
5'	GRANULAR MATERIAL	770	880	1010	1180											
	SAND & GRAVEL	820	940	1090												
	SATURATED TOP SOIL	840	970	1130												
	CLAY	870	1040	1180												
	SATURATED CLAY	890	1070													
6'	GRANULAR MATERIAL	840	1000	1160	1320	1450										
	SAND & GRAVEL	890	1060	1240	1410											
	SATURATED TOP SOIL	960	1120	1300												
	CLAY	1010	1150	1350	1450											
	SATURATED CLAY	1060	1220	1390												
7'	GRANULAR MATERIAL	910	1090	1280	1450	1630	1710									
	SAND & GRAVEL	1010	1150	1370	1540	1710										
	SATURATED TOP SOIL	1060	1250	1440	1630											
	CLAY	1110	1310	1500	1690											
	SATURATED CLAY	1150	1370	1560	1710											
8'	GRANULAR MATERIAL	990	1150	1390	1590	1780	1980									
	SAND & GRAVEL	1060	1280	1460	1700	1890										
	SATURATED TOP SOIL	1130	1340	1560	1790	1980										
	CLAY	1200	1390	1640	1860											
	SATURATED CLAY	1270	1460	1690	1950											
9'	GRANULAR MATERIAL	1030	1250	1430	1710	1890	2160	2250								
	SAND & GRAVEL	1130	1340	1580	1820	2000	2250									
	SATURATED TOP SOIL	1200	1430	1650	1920	2160										
	CLAY	1270	1520	1730	2020	2250										
	SATURATED CLAY	1350	1610	1800	2100											
10'	GRANULAR MATERIAL	1060	1280	1540	1770	2030	2280	2520								
	SAND & GRAVEL	1180	1400	1650	1910	2160	2430									
	SATURATED TOP SOIL	1270	1520	1760	2020	2300	2520									
	CLAY	1350	1610	1880	2130	2410										
	SATURATED CLAY	1440	1700	1990	2220	2520										
12'	GRANULAR MATERIAL	1130	1370	1650	1910	2210	2470	2790	3050							
	SAND & GRAVEL	1270	1520	1800	2090	2380	2670	3000								
	SATURATED TOP SOIL	1350	1640	1950	2220	2540	1850	3050								
	CLAY	1470	1730	2060	2360	2700	2980									
	SATURATED CLAY	1590	1910	2210	2520	2860	3050									
14'	GRANULAR MATERIAL	1180	1430	1730	2020	2320	2660	3010	3320	3590						
	SAND & GRAVEL	1320	1610	1940	2270	2570	2920	3230	3590							
	SATURATED TOP SOIL	1420	1730	2060	2410	2750	3110	3460								
	CLAY	1560	1880	2210	2570	2920	3300	3590								
	SATURATED CLAY	1730	2060	2420	2800	3130	3520									
16'	GRANULAR MATERIAL	1200	1490	1790	2110	2450	2810	3150	3510	3940	4130					
	SAND & GRAVEL	1350	1670	2010	2360	2700	3090	3460	3850	4130						
	SATURATED TOP SOIL	1460	1790	2150	2540	2920	3320	3680	4080							
	CLAY	1630	2010	2330	2720	3120	3550	3940	4130							
	SATURATED CLAY	1820	2220	2590	3000	3400	3803	4130								
18'	GRANULAR MATERIAL															
	SAND & GRAVEL	1390	1700	2060	2450	2860	3250	3680	4050	4510	4660					
	SATURATED TOP SOIL	1510	1890	2240	2630	3030	3490	3930	4390	4660						
	CLAY	1680	2070	2460	2890	3290	3740	4190	4640							
	SATURATED CLAY	1880	2310	2720	3180	3620	4080	4560	4660							
20'	GRANULAR MATERIAL															
	SAND & GRAVEL	1410	1730	2110	2520	2930	3360	3820	4220	4710	5190					
	SATURATED TOP SOIL	1530	1910	2290	2700	3130	3610	4090	4560	5050						
	CLAY	1730	2130	2550	3000	3460	3930	4410	4880	5200						
	SATURATED CLAY	1940	2340	2840	3290	3800	4320	4820	5200							

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

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14 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH													
		2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"		
2'	GRANULAR MATERIAL	410													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
2'6"	GRANULAR MATERIAL	520	560												
	SAND & GRAVEL	560													
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
3'	GRANULAR MATERIAL	640	690	720											
	SAND & GRAVEL	670	720												
	SATURATED TOP SOIL	690													
	CLAY	720													
	SATURATED CLAY														
4'	GRANULAR MATERIAL	790	900	1000	1040										
	SAND & GRAVEL	820	940												
	SATURATED TOP SOIL	850	980	1040											
	CLAY	880	1000												
	SATURATED CLAY	910	1040												
5'	GRANULAR MATERIAL	880	1010	1180	1330	1350									
	SAND & GRAVEL	940	1090	1230											
	SATURATED TOP SOIL	970	1130	1270	1350										
	CLAY	1040	1200	1320											
	SATURATED CLAY	1070	1240	1350											
6'	GRANULAR MATERIAL	1000	1160	1320	1460										
	SAND & GRAVEL	1060	1240	1410	1570	1660									
	SATURATED TOP SOIL	1120	1300	1450	1620										
	CLAY	1150	1350	1540	1660										
	SATURATED CLAY	1220	1390	1590											
7'	GRANULAR MATERIAL	1090	1280	1450	1630	1840	1970								
	SAND & GRAVEL	1150	1370	1540	1750										
	SATURATED TOP SOIL	1250	1440	1630	1840	1970									
	CLAY	1310	1500	1690	1910										
	SATURATED CLAY	1370	1560	1740	1970										
8'	GRANULAR MATERIAL	1150	1390	1590	1780	1990	2210	2290							
	SAND & GRAVEL	1280	1460	1700	1890	2120	2290								
	SATURATED TOP SOIL	1340	1560	1790	2000	2240									
	CLAY	1390	1640	1860	2080	2290									
	SATURATED CLAY	1460	1690	1950	2150										
9'	GRANULAR MATERIAL	1250	1430	1710	1890	2160	2400	2600							
	SAND & GRAVEL	1340	1580	1820	2000	2280	2530								
	SATURATED TOP SOIL	1430	1650	1920	2160	2410	2600								
	CLAY	1520	1730	2020	2270	2510									
	SATURATED CLAY	1610	1800	2100	2380	2600									
10'	GRANULAR MATERIAL	1280	1540	1770	2030	2280	2560	2780	2920						
	SAND & GRAVEL	1400	1650	1910	2160	2430	2710	2920							
	SATURATED TOP SOIL	1520	1760	2020	2300	2570	2850								
	CLAY	1610	1880	2130	2410	2700	2920								
	SATURATED CLAY	1700	1990	2220	2520	2810									
12'	GRANULAR MATERIAL	1370	1650	1910	2210	2470	2790	3120	3360	3540					
	SAND & GRAVEL	1520	1800	2090	2380	2670	3000	3290	3540						
	SATURATED TOP SOIL	1640	1950	2220	2540	2850	3190	3510							
	CLAY	1730	2060	2360	2700	2980	3350	3540							
	SATURATED CLAY	1910	2210	2520	2860	3170	3480								
14'	GRANULAR MATERIAL	1430	1730	2020	2320	2660	3010	3320	3650	4080	4160				
	SAND & GRAVEL	1610	1940	2270	2570	2920	3230	3630	4030	4160					
	SATURATED TOP SOIL	1730	2060	2410	2750	3110	3460	3850	4160						
	CLAY	1880	2210	2570	2920	3300	3680	4050							
	SATURATED CLAY	2070	2420	2800	3130	3520	3900	4160							
16'	GRANULAR MATERIAL	1490	1790	2110	2450	2810	3150	3510	3940	4290	4620	4790			
	SAND & GRAVEL	1670	2010	2360	2700	3090	3460	3850	4220	4660	4790				
	SATURATED TOP SOIL	1790	2150	2540	2920	3320	3680	4080	4510	4790					
	CLAY	2010	2330	2720	3120	3550	3940	4390	4790						
	SATURATED CLAY	2220	2590	3000	3400	3800	4200	4640							
18'	GRANULAR MATERIAL	1520	1830	2180	2540	2920	3310	3710	4130	4530	4980	5420			
	SAND & GRAVEL	1700	2060	2450	2860	3250	3680	4050	4510	4940	5350				
	SATURATED TOP SOIL	1890	2240	2630	3030	3490	3930	4390	4800	5200	5420				
	CLAY	2070	2460	2890	3290	3740	4190	4640	5090	5420					
	SATURATED CLAY	2310	2720	3180	3620	4080	4560	4980	5420						
20'	GRANULAR MATERIAL	1550	1880	2210	2600	2980	3410	3830	4260	4730	5180	5630	6040		
	SAND & GRAVEL	1730	2110	2520	2930	3360	3820	4220	4710	5200	5600	6040			
	SATURATED TOP SOIL	1910	2290	2700	3130	3610	4090	4560	5050	5570	6040				
	CLAY	2130	2550	3000	3450	3930	4410	4880	5380	5920					
	SATURATED CLAY	2340	2840	3290	3820	4320	4820	5320	5820	6040					

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032904

15 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH													
		2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	
2'	GRANULAR MATERIAL	420													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
2'6"	GRANULAR MATERIAL	520	590												
	SAND & GRAVEL	550													
	SATURATED TOP SOIL	550													
	CLAY	570													
	SATURATED CLAY	590													
3'	GRANULAR MATERIAL	640	690	760											
	SAND & GRAVEL	670	760												
	SATURATED TOP SOIL	690	740	760											
	CLAY	710	760												
	SATURATED CLAY	730													
4'	GRANULAR MATERIAL	790	900	1000	1090										
	SAND & GRAVEL	820	940	1090											
	SATURATED TOP SOIL	850	980												
	CLAY	880	1000												
	SATURATED CLAY	910	1030												
5'	GRANULAR MATERIAL	880	1010	1180	1330	1430									
	SAND & GRAVEL	940	1090	1230	1430										
	SATURATED TOP SOIL	970	1130	1270											
	CLAY	1040	1200	1320											
	SATURATED CLAY	1070	1240	1360											
6'	GRANULAR MATERIAL	1000	1160	1320	1460	1650	1770								
	SAND & GRAVEL	1060	1240	1410	1570	1710									
	SATURATED TOP SOIL	1120	1300	1450	1620	1770									
	CLAY	1150	1350	1520	1730										
	SATURATED CLAY	1220	1390	1590	1700										
7'	GRANULAR MATERIAL	1090	1280	1450	1630	1840	2060								
	SAND & GRAVEL	1150	1370	1540	1750	1970									
	SATURATED TOP SOIL	1250	1440	1630	1840	2060									
	CLAY	1310	1500	1680	1910										
	SATURATED CLAY	1370	1560	1740	1980										
8'	GRANULAR MATERIAL	1150	1390	1590	1780	1990	2210	2440							
	SAND & GRAVEL	1280	1460	1700	1890	2120	2350								
	SATURATED TOP SOIL	1340	1560	1790	2000	2240	2440								
	CLAY	1390	1640	1860	2080	2320									
	SATURATED CLAY	1460	1690	1950	2150	2410									
9'	GRANULAR MATERIAL	1250	1430	1710	1890	2160	2400	2780							
	SAND & GRAVEL	1340	1580	1820	2000	2280	2530								
	SATURATED TOP SOIL	1430	1650	1920	2160	2410	2680								
	CLAY	1520	1730	2020	2270	2510	2760								
	SATURATED CLAY	1610	1800	2100	2380	2600	2780								
10'	GRANULAR MATERIAL	1280	1540	1770	2030	2280	2560	2780	3110						
	SAND & GRAVEL	1400	1650	1910	2160	2430	2710	2950							
	SATURATED TOP SOIL	1520	1760	2020	2300	2570	2850	3110							
	CLAY	1610	1880	2160	2410	2700	2970								
	SATURATED CLAY	1700	1990	2220	2520	2810	3090								
12'	GRANULAR MATERIAL	1370	1650	1910	2210	2470	2790	3120	3360	3250	3790				
	SAND & GRAVEL	1520	1800	2090	2380	2670	3000	3290	3550	3790					
	SATURATED TOP SOIL	1640	1950	2220	2540	2850	3190	3510	3790						
	CLAY	1730	2060	2360	2700	2980	3350	3680							
	SATURATED CLAY	1910	2210	2520	2860	3170	3480	3790							
14'	GRANULAR MATERIAL	1430	1730	2020	2320	2660	3010	3320	3650	4080	4460				
	SAND & GRAVEL	1610	1940	2270	2570	2920	3230	3630	4030	4340					
	SATURATED TOP SOIL	1730	2060	2410	2750	3190	3460	3850	4220	4460					
	CLAY	1880	2210	2560	2920	3300	3680	4050	4420						
	SATURATED CLAY	2070	2420	2800	3130	3520	3900	4250	4460						
16'	GRANULAR MATERIAL	1490	1790	2110	2450	2810	3150	3510	3940	4290	4620	5140			
	SAND & GRAVEL	1670	2010	2360	2700	3090	3460	3850	4220	4660	5100				
	SATURATED TOP SOIL	1790	2150	2540	2920	3320	3680	4080	4510	4960	5140				
	CLAY	2010	2330	2720	3120	3550	3940	4390	4800	5140					
	SATURATED CLAY	2220	2590	3000	3400	3800	4200	4640	5090						
18'	GRANULAR MATERIAL	1520	1830	2180	2540	2920	3310	3710	4130	4530	4980	5420	5790	5810	
	SAND & GRAVEL	1700	2060	2450	2860	3250	3680	4050	4510	4940	5350	5810			
	SATURATED TOP SOIL	1890	2240	2630	3030	3490	3930	4390	4800	5200	5120				
	CLAY	2070	2460	2860	3290	3740	4190	4640	5090	5570	5810				
	SATURATED CLAY	2310	2720	3180	3620	4080	4560	4980	5470	5810					
20'	GRANULAR MATERIAL	1550	1880	2210	2600	2980	3410	3830	4260	4730	5180	5630	6120 -	6480	
	SAND & GRAVEL	1730	2110	2520	2930	3360	3820	4220	4710	5200	5600	6170	6480		
	SATURATED TOP SOIL	1910	2290	2700	3130	3610	4090	4560	5050	5570	6080	6480			
	CLAY	2130	2550	3000	3450	3930	4410	4880	5380	5920	6440				
	SATURATED CLAY	2340	2840	3290	3800	4320	4820	5320	5820	6350	6480				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032905

16 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH													
		2'3"	2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	5'6"
2'	GRANULAR MATERIAL	430													
	SAND & GRAVEL														
	SATURATED TOP SOIL														
	CLAY														
	SATURATED CLAY														
2'6"	GRANULAR MATERIAL	520													
	SAND & GRAVEL	550													
	SATURATED TOP SOIL	550	610												
	CLAY	570													
	SATURATED CLAY	580													
3'	GRANULAR MATERIAL	640	690												
	SAND & GRAVEL	670	720	780											
	SATURATED TOP SOIL	690	740												
	CLAY	710													
	SATURATED CLAY	730	780												
4'	GRANULAR MATERIAL	790	900	1000	1110	1130									
	SAND & GRAVEL	820	940	1040	1130										
	SATURATED TOP SOIL	850	980	1090											
	CLAY	880	1000	1130											
	SATURATED CLAY	910	1030												
5'	GRANULAR MATERIAL	880	1010	1180	1330	1460	1490								
	SAND & GRAVEL	940	1090	1230	1380	1490									
	SATURATED TOP SOIL	970	1130	1270	1440										
	CLAY	1040	1200	1320	1490										
	SATURATED CLAY	1070	1240	1360											
6'	GRANULAR MATERIAL	1000	1160	1320	1460	1650									
	SAND & GRAVEL	1060	1240	1410	1570	1710	1850								
	SATURATED TOP SOIL	1120	1300	1450	1620	1780									
	CLAY	1150	1350	1540	1730	1850									
	SATURATED CLAY	1220	1390	1590	1780										
7'	GRANULAR MATERIAL	1100	1280	1450	1630	1840	1990	2200							
	SAND & GRAVEL	1150	1370	1540	1750	1970	2130								
	SATURATED TOP SOIL	1250	1440	1630	1840	2030	2200								
	CLAY	1310	1500	1690	1910	2160									
	SATURATED CLAY	1370	1560	1740	1980	2200									
8'	GRANULAR MATERIAL	1150	1390	1590	1780	1990	2210	2450	2560						
	SAND & GRAVEL	1280	1460	1700	1890	2120	2350	2560							
	SATURATED TOP SOIL	1340	1560	1790	2000	2240	2470								
	CLAY	1390	1640	1860	2080	2320	2560								
	SATURATED CLAY	1460	1690	1950	2150	2410									
9'	GRANULAR MATERIAL	1250	1430	1710	1890	2160	2400	2620	2880	2910					
	SAND & GRAVEL	1340	1580	1820	2000	2280	2530	2780	2910						
	SATURATED TOP SOIL	1430	1650	1920	2160	2410	2680								
	CLAY	1520	1730	2020	2270	2510	2760	2910							
	SATURATED CLAY	1610	1800	2100	2380	2600	2850								
10'	GRANULAR MATERIAL	1280	1540	1770	2030	2280	2560	2780	3070	3260					
	SAND & GRAVEL	1400	1650	1910	2160	2430	2710	2950	3260						
	SATURATED TOP SOIL	1520	1760	2020	2300	2570	2850	3120							
	CLAY	1610	1880	2130	2410	2700	2970	3260							
	SATURATED CLAY	1700	2000	2220	2520	2810	3090								
12'	GRANULAR MATERIAL	1370	1650	1910	2210	2470	2790	3120	3360	3750	3970				
	SAND & GRAVEL	1520	1800	2090	2380	2670	3000	3290	3550	3970					
	SATURATED TOP SOIL	1640	1950	2220	2540	2850	3190	3510	3840						
	CLAY	1730	2060	2360	2700	2980	3350	3680	3970						
	SATURATED CLAY	1910	2210	2520	2860	3170	3480	3800							
14'	GRANULAR MATERIAL	1430	1730	2020	2320	2660	3010	3320	3650	4080	4370	4680			
	SAND & GRAVEL	1610	1940	2270	2570	2920	3230	3630	4030	4340	4620				
	SATURATED TOP SOIL	1730	2060	2410	2750	3110	3460	3850	4220	4620	4680				
	CLAY	1880	2210	2570	2920	3300	3680	4050	4420	4680					
	SATURATED CLAY	2070	2420	2800	3130	3520	3900	4250	4610						
16'	GRANULAR MATERIAL	1490	1790	2110	2450	2810	3150	3510	3940	4290	4620	5090	5390		
	SAND & GRAVEL	1670	2010	2360	2700	3090	3460	3850	4220	4660	5100	5390			
	SATURATED TOP SOIL	1790	2150	2540	2920	3320	3680	4080	4510	4960	5350				
	CLAY	2010	2330	2720	3120	3550	3940	4390	4800	5200	5390				
	SATURATED CLAY	2220	2590	3000	3400	3800	4200	4640	5090	5390					
18'	GRANULAR MATERIAL	1520	1830	2180	2540	2920	3310	3710	4130	4530	4980	5420	5790	6100	
	SAND & GRAVEL	1700	2060	2450	2860	3250	3680	4050	4510	4940	5350	5820	6100		
	SATURATED TOP SOIL	1890	2240	2630	3030	3490	3930	4390	4800	5200	5720	6100			
	CLAY	2070	2460	2890	3300	3740	4190	4640	5090	5570	6080				
	SATURATED CLAY	2310	2720	3180	3620	4080	4560	4980	5470	5960	6100				
20'	GRANULAR MATERIAL	1550	1880	2210	2600	2980	3410	3830	4260	4730	5180	5630	6120	6620	6800
	SAND & GRAVEL	1730	2110	2520	2930	3360	3820	4220	4710	5200	5600	6170	6620	6800	
	SATURATED TOP SOIL	1910	2290	2700	3130	3610	4090	4560	5050	5570	6080	6530	6800		
	CLAY	2130	2550	3000	3450	3930	4410	4880	5380	5920	6440	6800			
	SATURATED CLAY	2340	2840	3290	3800	4320	4820	5320	5820	6350	6800				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032906

18 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		2'6"	2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	5'6"	5'9"	6'0"
2'	GRANULAR MATERIAL	440														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	620	640													
	SAND & GRAVEL															
	SATURATED TOP SOIL	640														
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	690	770	830												
	SAND & GRAVEL	720														
	SATURATED TOP SOIL	740	830													
	CLAY	790														
	SATURATED CLAY	830														
4'	GRANULAR MATERIAL	900	1000	1110	1200	1230										
	SAND & GRAVEL	940	1040	1170	1230											
	SATURATED TOP SOIL	980	1090	1210												
	CLAY	1000	1120	1230												
	SATURATED CLAY	1030	1150													
5'	GRANULAR MATERIAL	1010	1180	1330	1460	1620										
	SAND & GRAVEL	1090	1230	1380	1560											
	SATURATED TOP SOIL	1130	1270	1440												
	CLAY	1200	1320	1480	1620											
	SATURATED CLAY	1240	1360	1530												
6'	GRANULAR MATERIAL	1160	1320	1460	1650	1850										
	SAND & GRAVEL	1240	1410	1570	1710	1910	2020									
	SATURATED TOP SOIL	1300	1450	1620	1780	2000										
	CLAY	1350	1540	1730	1840	2020										
	SATURATED CLAY	1390	1590	1780	1900											
7'	GRANULAR MATERIAL	1280	1450	1630	1840	1990	2240	2420								
	SAND & GRAVEL	1370	1540	1750	1970	2130	2360									
	SATURATED TOP SOIL	1440	1630	1840	2030	2210	2420									
	CLAY	1500	1690	1910	2160	2350										
	SATURATED CLAY	1560	1740	1980	2220	2420										
8'	GRANULAR MATERIAL	1390	1590	1780	1990	2210	2450	2590	2810							
	SAND & GRAVEL	1460	1700	1890	2120	2350	2510	2780								
	SATURATED TOP SOIL	1560	1790	2000	2240	2470	2700	2810								
	CLAY	1640	1860	2080	2320	2570	2780									
	SATURATED CLAY	1690	1950	2150	2410	2660	2810									
9'	GRANULAR MATERIAL	1430	1700	1890	2160	2400	2620	2880	3140	3200						
	SAND & GRAVEL	1580	1820	2000	2280	2530	2780	3010	3200							
	SATURATED TOP SOIL	1650	1920	2160	2410	2680	2920	3170								
	CLAY	1730	2020	2270	2510	2760	3040	3200								
	SATURATED CLAY	1800	2100	2380	2600	2850	3120									
10'	GRANULAR MATERIAL	1540	1770	2030	2280	2560	2780	3070	3320	3520	3600					
	SAND & GRAVEL	1650	1910	2160	2430	2710	2950	3260	3510	3600						
	SATURATED TOP SOIL	1760	2020	2300	2570	2850	3120	3360								
	CLAY	1880	2130	2410	2700	2970	3260	3460	3600							
	SATURATED CLAY	1990	2220	2520	2810	3090	3360	3550								
12'	GRANULAR MATERIAL	1650	1910	2210	2470	2790	3120	3360	3750	4010	4390					
	SAND & GRAVEL	1800	2090	2380	2670	3000	3290	3550	3970	4250						
	SATURATED TOP SOIL	1950	2220	2540	2850	3190	3510	3840	4180	4390						
	CLAY	2060	2360	2700	2980	3350	3680	4030	4340							
	SATURATED CLAY	2210	2520	2860	3170	3480	3800	4220	4390							
14'	GRANULAR MATERIAL	1730	2020	2320	2660	3010	3320	3650	4080	4370	4790	5100	5180			
	SAND & GRAVEL	1940	2270	2570	2920	3230	3630	4030	4340	4620	5090	5180				
	SATURATED TOP SOIL	2060	2410	2750	3110	3460	3850	4220	4620	4980	5180					
	CLAY	2210	2570	2920	3300	3680	4050	4420	4830	5180						
	SATURATED CLAY	2420	2800	3130	3520	3900	4250	4610	5050							
16'	GRANULAR MATERIAL	1790	2110	2450	2810	3150	3510	3940	4290	4620	5090	5490	5950	5970		
	SAND & GRAVEL	2010	2360	2700	3090	3460	3850	4220	4660	5100	5470	5850	5970			
	SATURATED TOP SOIL	2150	2540	2920	3320	3680	4080	4510	4960	5350	5820	5970				
	CLAY	2330	2720	3120	3550	3940	4390	4800	5200	5590	5970					
	SATURATED CLAY	2590	3000	3400	3800	4200	4640	5090	5480	5830						
18'	GRANULAR MATERIAL	1830	2180	2540	2920	3310	3710	4130	4530	4980	5420	5720	6280	6760		
	SAND & GRAVEL	2060	2450	2862	3250	3680	4050	4510	4940	5350	5820	6300	6760			
	SATURATED TOP SOIL	2240	2630	3030	3490	3930	4390	4800	5200	5720	6230	6660				
	CLAY	2460	2890	3300	3740	4190	4640	5090	5570	6080	6500	6760				
	SATURATED CLAY	2720	3180	3620	4080	4560	4980	5470	5960	6440	6760					
20'	GRANULAR MATERIAL	1880	2210	2600	2980	3410	3830	4260	4730	5180	5630	6120	6620	7080		
	SAND & GRAVEL	2110	2520	2930	3360	3820	4220	4710	5200	5600	6170	6620	7180	7550		
	SATURATED TOP SOIL	2290	2700	3130	3610	4090	4560	5050	5570	6080	6530	7080	7550			
	CLAY	2550	3000	3450	3930	4410	4880	5380	5920	6440	6960	7500				
	SATURATED CLAY	2840	3290	3800	4320	4820	5320	5820	6350	6850	7450	7550				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032907

20 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		2'9"	3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	5'6"	5'9"	6'0"	6'3"
2'	GRANULAR MATERIAL	450														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	670														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	770	880													
	SAND & GRAVEL	820														
	SATURATED TOP SOIL	830														
	CLAY	850														
	SATURATED CLAY	**880**														
4'	GRANULAR MATERIAL	1000	1110	1200	1320											
	SAND & GRAVEL	1040	1170	1270												
	SATURATED TOP SOIL	1090	1210	1300												
	CLAY	1120	1240	**1320**												
	SATURATED CLAY	1150	1300													
5'	GRANULAR MATERIAL	1180	1330	1460	1620	1740	**1760**									
	SAND & GRAVEL	1230	1380	1560	1690	**1760**										
	SATURATED TOP SOIL	1270	1440	1610	**1760**											
	CLAY	1320	1480	1650												
	SATURATED CLAY	1360	1530	1710												
6'	GRANULAR MATERIAL	1320	1460	1650	1850	2030	**2200**									
	SAND & GRAVEL	1410	1570	1710	1910	2110										
	SATURATED TOP SOIL	1450	1620	1780	2000	**2200**										
	CLAY	1540	1730	1840	2060											
	SATURATED CLAY	1590	1780	1900	2100											
7'	GRANULAR MATERIAL	1450	1630	1840	1990	2240	2460	**2640**								
	SAND & GRAVEL	1540	1750	1970	2130	2360	2550									
	SATURATED TOP SOIL	1630	1840	2030	2210	2410										
	CLAY	1690	1910	2160	2350	2480	**2640**									
	SATURATED CLAY	1740	1980	2220	2430	2580										
8'	GRANULAR MATERIAL	1590	1780	1990	2210	2450	2590	2930	**3080**							
	SAND & GRAVEL	1700	1890	2120	2350	2570	2780	3040								
	SATURATED TOP SOIL	1790	2000	2240	2470	2700	2880	**3080**								
	CLAY	1860	2080	2320	2570	2780	**3080**									
	SATURATED CLAY	1950	2150	2410	2660	2900										
9'	GRANULAR MATERIAL	1710	1890	2160	2400	2620	2880	3140	3280	**3510**						
	SAND & GRAVEL	1820	2000	2280	2530	2780	3010	3250	**3510**							
	SATURATED TOP SOIL	1920	2160	2410	2680	2920	3170	3450								
	CLAY	2020	2270	2510	2760	3040	3320	**3510**								
	SATURATED CLAY	2100	2380	2600	2850	3120	3420									
10'	GRANULAR MATERIAL	1770	2030	2280	2560	2780	3070	3320	3520	3930	**3950**					
	SAND & GRAVEL	1910	2160	2430	2710	2950	3260	3510	3770	**3950**						
	SATURATED TOP SOIL	2020	2300	2570	2850	3120	3360	3690	3890							
	CLAY	2130	2410	2700	2970	3260	3460	3860	**3950**							
	SATURATED CLAY	2220	2520	2810	3090	3360	3550	**3950**								
12'	GRANULAR MATERIAL	1910	2210	2470	2790	3120	3360	3750	4010	4390	4650	**4830**				
	SAND & GRAVEL	2090	2380	2670	3000	3290	3550	3970	4250	4660	**4830**					
	SATURATED TOP SOIL	2220	2540	2850	3190	3510	3840	4180	4500	**4830**						
	CLAY	2360	2700	2980	3350	3680	4030	4340	4620							
	SATURATED CLAY	2520	2860	3170	3480	3800	4220	4510	**4830**							
14'	GRANULAR MATERIAL	2020	2320	2660	3010	3320	3650	4080	4370	4790	5100	5460	5700			
	SAND & GRAVEL	2270	2570	2920	3230	3630	4030	4340	4620	5090	5490	**5700**				
	SATURATED TOP SOIL	2410	2750	3110	3460	3850	4220	4620	4980	5390	**5700**					
	CLAY	2570	2920	3300	3680	4050	4420	4830	5230	5630						
	SATURATED CLAY	2800	3130	3520	3900	4250	4610	5050	5470	**5700**						
16'	GRANULAR MATERIAL	2110	2450	2810	3150	3510	3940	4290	4620	5090	5490	5950	6390	6580		
	SAND & GRAVEL	2360	2700	3090	3460	3850	4220	4660	5100	5470	5850	6350	**6580**			
	SATURATED TOP SOIL	2540	2920	3320	3680	4080	4510	4960	5350	5820	6240	**6580**				
	CLAY	2720	3120	3550	3940	4390	4800	5200	5590	6090	6540					
	SATURATED CLAY	3000	3400	3800	4200	4640	5090	5480	5830	6360	**6580**					
18'	GRANULAR MATERIAL	2180	2540	2920	3310	3710	4130	4530	4980	5420	5790	6280	6750	7260	7460	
	SAND & GRAVEL	2450	2860	3250	3680	4050	4510	4940	5340	5820	6300	6750	7190	**7460**		
	SATURATED TOP SOIL	2630	3030	3490	3930	4390	4800	5200	5720	6230	6660	7180	**7460**			
	CLAY	2890	3300	3740	4190	4640	5090	5510	6080	6500	6990	**7460**				
	SATURATED CLAY	3180	3620	4080	4560	4980	5470	5960	6440	6900	7290					
20'	GRANULAR MATERIAL	2210	2600	2980	3410	3830	4260	4730	5180	5630	6120	6620	7080	7620	8120	8330
	SAND & GRAVEL	2520	2930	3360	3820	4220	4710	5200	5600	6170	6620	7180	7620	8130	**8330**	
	SATURATED TOP SOIL	2700	3130	3610	4090	4560	5050	5570	6080	6530	7080	7610	8100	**8330**		
	CLAY	3000	3450	3930	4410	4880	5380	5920	6440	6960	7500	8000	**8330**			
	SATURATED CLAY	3290	3800	4320	4820	5320	5820	6350	6850	7450	7950	**8330**				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032908

21 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH														
		3'0"	3'3"	3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	5'6"	5'9"	6'0"	6'3"	6'6"
2'	GRANULAR MATERIAL	450														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	680														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	920														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
4'	GRANULAR MATERIAL	1110	1200	1310	1380											
	SAND & GRAVEL	1170	1270	1380												
	SATURATED TOP SOIL	1210	1300													
	CLAY	1240	1380													
	SATURATED CLAY	1300														
5'	GRANULAR MATERIAL	1330	1460	1620	1740	1820	1850									
	SAND & GRAVEL	1380	1560	1690												
	SATURATED TOP SOIL	1440	1610	1760	1850											
	CLAY	1480	1650	1810												
	SATURATED CLAY	1530	1710	1850												
6'	GRANULAR MATERIAL	1460	1650	1850	2030	2210	2320									
	SAND & GRAVEL	1570	1710	1910	2120											
	SATURATED TOP SOIL	1620	1780	2000	2190	2320										
	CLAY	1730	1840	2060	2240											
	SATURATED CLAY	1780	1900	2100	2320											
7'	GRANULAR MATERIAL	1630	1840	1990	2440	2460	2640	2790								
	SAND & GRAVEL	1750	1970	2130	2360	2550	2750									
	SATURATED TOP SOIL	1840	2030	2210	2410	2630	2790									
	CLAY	1910	2160	2350	2480	2750										
	SATURATED CLAY	1980	2220	2430	2580	2790										
8'	GRANULAR MATERIAL	1780	1990	2210	2450	2590	2930	3160	3260							
	SAND & GRAVEL	1890	2120	2350	2570	2780	3040	3260								
	SATURATED TOP SOIL	2000	2240	2470	2700	2880	3140									
	CLAY	2080	2320	2570	2780	3070	3210									
	SATURATED CLAY	2150	2410	2660	2900	3170	3260									
9'	GRANULAR MATERIAL	1890	2160	2400	2620	2880	3140	3280	3660	3730						
	SAND & GRAVEL	2000	2280	2530	2780	3010	3250	3520	3730							
	SATURATED TOP SOIL	2160	2410	2680	2920	3170	3450	3650								
	CLAY	2270	2510	2760	3040	3320	3580	3730								
	SATURATED CLAY	2380	2600	2850	3120	3420	3690									
10'	GRANULAR MATERIAL	2030	2280	2560	2780	3070	3320	3520	3930	4050	4200					
	SAND & GRAVEL	2160	2430	2710	2950	3260	3510	3770	4060	4200						
	SATURATED TOP SOIL	2300	2570	2850	3120	3360	3690	3890	4200							
	CLAY	2410	2700	2970	3260	3460	3860	4130								
	SATURATED CLAY	2520	2810	3090	3360	3550	3970	4200								
12'	GRANULAR MATERIAL	2210	2470	2790	3120	3360	3750	4010	4390	4650	4960	5140				
	SAND & GRAVEL	2380	2670	3000	3290	3550	3970	4250	4660	4950	5140					
	SATURATED TOP SOIL	2540	2850	3190	3510	3840	4180	4500	4930	5140						
	CLAY	2700	2980	3350	3680	4030	4340	4620	5060							
	SATURATED CLAY	2860	3170	3480	3800	4220	4510	4860	5140							
14'	GRANULAR MATERIAL	2320	2660	3010	3320	3650	4080	4370	4790	5100	5460	5810	6080			
	SAND & GRAVEL	2570	2920	3230	4630	4030	4340	4620	5090	5490	5790	6080				
	SATURATED TOP SOIL	2750	3110	3460	3850	4220	4620	4980	5390	5760	6080					
	CLAY	2920	3300	3680	4050	4460	4830	5230	5630	6000						
	SATURATED CLAY	3130	3520	3900	4250	4610	5050	5470	5820	6080						
16'	GRANULAR MATERIAL	2450	2810	3150	3510	3940	4290	4620	5090	5490	5950	6390	6750	7020		
	SAND & GRAVEL	2700	3090	3460	3850	4220	4660	5100	5470	5850	6350	6790	7020			
	SATURATED TOP SOIL	2920	3320	3680	4080	4510	4960	5350	5820	6240	6710	7020				
	CLAY	3120	3550	3940	4390	4800	5200	5590	6090	6540	7020					
	SATURATED CLAY	3400	3800	4200	4640	5090	5480	5830	6360	6750						
18'	GRANULAR MATERIAL	2540	2920	3310	3710	4130	4530	4980	5420	5790	6280	6750	7260	7780	7950	
	SAND & GRAVEL	2860	3250	3680	4050	4510	4940	5340	5820	6300	6750	7190	7700	7950		
	SATURATED TOP SOIL	3030	3490	3930	4390	4800	5200	5720	6230	6660	7180	7620	7950			
	CLAY	3300	3740	4190	4640	5090	5510	6080	6500	6990	7540	7950				
	SATURATED CLAY	3620	4080	4560	4980	5470	5960	6440	6900	7290	7840					
20'	GRANULAR MATERIAL	2600	2980	3410	3830	4260	4730	5180	5630	6120	6620	7080	7620	8120	8670	8890
	SAND & GRAVEL	2930	3360	3820	4220	4710	5200	5600	6170	6620	7180	7620	8130	8640	8890	
	SATURATED TOP SOIL	3130	3610	4090	4560	5050	5570	6080	6530	7080	7610	8100	8650	8890		
	CLAY	3450	3930	4410	4880	5380	5920	6440	6960	7500	8000	8530	8890			
	SATURATED CLAY	3800	4320	4820	5320	5820	6350	6850	7450	7950	8500	8890				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032909

24 inches—pipe size EARTH LOAD (lbs./lin. ft.)

Depth of Cover	TYPE OF SOIL	WIDTH OF TRENCH													
		3'6"	3'9"	4'0"	4'3"	4'6"	4'9"	5'0"	5'3"	5'6"	5'9"	6'0"	6'3"	6'6"	6'9"	7'0"
2'	GRANULAR MATERIAL	430														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
2'6"	GRANULAR MATERIAL	700														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
3'	GRANULAR MATERIAL	960														
	SAND & GRAVEL															
	SATURATED TOP SOIL															
	CLAY															
	SATURATED CLAY															
4'	GRANULAR MATERIAL	1310	1430	1480												
	SAND & GRAVEL	1370	1480													
	SATURATED TOP SOIL	1410														
	CLAY	1440														
	SATURATED CLAY	1470														
5'	GRANULAR MATERIAL	1620	1740	1820	1950	2020										
	SAND & GRAVEL	1690	1820	1920	2020											
	SATURATED TOP SOIL	1760	1890	2020												
	CLAY	1810	1940													
	SATURATED CLAY	1850	2020													
6'	GRANULAR MATERIAL	1850	2030	2210	2340	2500	2550									
	SAND & GRAVEL	1910	2120	2300	2470	2550										
	SATURATED TOP SOIL	2000	2190	2400	2550											
	CLAY	2060	2240	2500												
	SATURATED CLAY	2100	2310	2550												
7'	GRANULAR MATERIAL	1990	2240	2460	2640	2820	3030	3070								
	SAND & GRAVEL	2130	2360	2550	2750	2990	3070									
	SATURATED TOP SOIL	2210	2410	2630	2880											
	CLAY	2350	2480	2750	2950	3070										
	SATURATED CLAY	2430	2580	2800	3040											
8'	GRANULAR MATERIAL	2210	2450	2590	2930	3160	3330	3600								
	SAND & GRAVEL	2350	2570	2780	3040	3280	3470									
	SATURATED TOP SOIL	2470	2700	2880	3140	3400	3600									
	CLAY	2570	2780	3070	3210	3520										
	SATURATED CLAY	2660	2900	3170	3340	3600										
9'	GRANULAR MATERIAL	2400	2620	2880	3140	3280	3660	3900	4120							
	SAND & GRAVEL	2530	2780	3010	3250	3520	3700	4080								
	SATURATED TOP SOIL	2680	2920	3170	3450	3650	3930	4120								
	CLAY	2760	3040	3320	3580	3890	4010									
	SATURATED CLAY	2850	3120	3420	3690	4010	4120									
10'	GRANULAR MATERIAL	2560	2780	3070	3320	3520	3930	4050	4500	4640						
	SAND & GRAVEL	2710	2950	3260	3510	3770	4060	4350	4640							
	SATURATED TOP SOIL	2850	3120	3360	3690	3890	4310	4500								
	CLAY	2970	3260	3460	3860	4130	4470	4640								
	SATURATED CLAY	3090	3360	3550	3970	4250	4600									
12'	GRANULAR MATERIAL	2790	3120	3360	3750	4010	4390	4650	4960	5260	5670	5700				
	SAND & GRAVEL	3000	3290	3550	3970	4250	4660	4950	5290	5630	5700					
	SATURATED TOP SOIL	3190	3510	3840	4180	4500	4930	5190	5560	5700						
	CLAY	3350	3680	4030	4340	4620	5060	5400	5700							
	SATURATED CLAY	3480	3800	4220	4510	4860	5230	5550								
14'	GRANULAR MATERIAL	3010	3320	3650	4080	4370	4790	5100	5460	5810	6190	6520	6660	6750		
	SAND & GRAVEL	3230	3630	4030	4340	4620	5090	5490	5790	6170	6550	6750				
	SATURATED TOP SOIL	3460	3850	4220	4620	4980	5390	5760	6120	6530	6750					
	CLAY	3680	4050	4420	4830	5230	5630	6000	6280	6750						
	SATURATED CLAY	3900	4250	4610	5050	5470	5820	6240	6620							
16'	GRANULAR MATERIAL	3150	3510	3940	4290	4620	5090	5490	5950	6390	6750	7130	7500	7760	7810	
	SAND & GRAVEL	3460	3580	4220	4660	5100	5470	5850	6350	6790	7140	7600	7810			
	SATURATED TOP SOIL	3680	4080	4510	4960	5350	5820	6240	6710	7150	7540	7810				
	CLAY	3940	4390	4800	5200	5590	6090	6540	7050	7440	7810					
	SATURATED CLAY	4200	4640	5090	5480	5830	6360	6750	7260	7810						
18'	GRANULAR MATERIAL	3310	3710	4130	4530	4980	5420	5790	6280	6750	7260	7780	8160	8620	8800	8860
	SAND & GRAVEL	3680	4050	4510	4940	5350	5820	6300	6750	7190	7700	8210	8670	8770	8860	
	SATURATED TOP SOIL	3930	4390	4800	5200	5720	6230	6660	7180	7620	8130	8640	8860			
	CLAY	4190	4640	5090	5570	6080	6500	6990	7540	7990	8530	8860				
	SATURATED CLAY	4560	4980	5470	5960	6440	6900	7290	7840	8350	8860					
20'	GRANULAR MATERIAL	3410	3830	4260	4730	5180	5630	6120	6620	7080	7620	8120	8670	9130	9400	9920
	SAND & GRAVEL	3820	4220	4710	5200	5600	6170	6620	7180	7620	8130	8640	9140	9730	9910	
	SATURATED TOP SOIL	4090	4560	5050	5570	6080	6530	7080	7610	8100	8650	9200	9750	9910		
	CLAY	4410	4880	5380	5920	6440	6960	7500	8000	8530	9130	9630	9910			
	SATURATED CLAY	4820	5320	5820	6350	6850	7450	7950	8500	8890	9520	9910				

Bold-face numbers represent EARTH-LOAD at the transition width. Refer to Sec. 3.2.2 (b) Transition Width for detailed explanation.

CTD032910

CONCENTRATED SUPERIMPOSED LOADS (LBS/LIN. FT)
SINGLE WHEEL LOAD = 10,000 LBS*

Depth Of Cover Feet	PIPE DIAMETER (INCHES)										
	6	8	10	12	14	15	16	18	20	21	24
2'-0''	490	640	790	930	1060	1120	1180	1300	1410	1450	1590
2'-6''	350	460	580	670	770	830	860	960	1050	1090	1210
3'-0''	260	340	430	510	580	620	660	740	800	840	930
4'-0''	150	200	260	310	350	380	400	450	500	520	590
5'-0''	100	140	170	210	240	250	270	310	340	350	400
6'-0''	80	100	120	150	170	180	190	220	240	250	290
8'-0''	40	60	70	80	100	110	110	130	140	150	170
10'-0''	30	30	40	50	60	70	70	80	90	90	110
12'-0''	20	30	30	40	40	50	50	60	60	70	70
16'-0''	10	10	20	20	30	30	30	30	40	40	40
20'-0''	10	10	10	10	20	20	20	20	20	20	30

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* Conversion Factors for Concentrated Loads other than 10,000 lbs.
9,000 lbs. = 0.90
12,000 lbs. = 1.20
14,000 lbs. = 1.40
16,000 lbs. = 1.60

Selection Table is based on an impact factor equal to one. If Impact Factors other than one are required, multiply the loads in the Selection Table by the desired Impact Value.

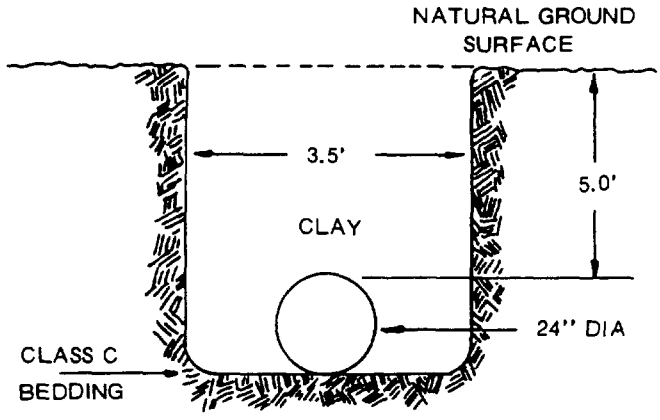
FLUID TRANSMISSION (FT) ASBESTOS CEMENT PIPE

TYPICAL DESIGN EXAMPLES

Example 1

Select the proper class FT Pipe to satisfy the following conditions.

Pipe size — 24 inch
Operating pressure — 100 psi
Surge pressure — 50 psi
Type of soil — Clay
Depth of cover — 5 feet
Width of trench — 3.5 feet
Bedding — Class C
Safety factor (Hydro) — 2.0
Safety factor (Crush) — 1.5



Solution

(a) Solve ratio Bd/Bc

Bd = 3.5 feet
Bc is unknown*

*Note — When Bc is unknown for FT design problems, use the B.O.D. for Class FT70 as initial assumption. Therefore, $Bc = \frac{28.22}{12} = 2.35$

$Bd/Bc = \frac{3.5}{2.35} = 1.49$

from Figure 7, Section 3.2.2(b) determine the transition value of Bd/Bc where

$H/Bc = \frac{5}{2.35} = 2.13$

$p = \frac{2.35}{2.35} = 1.0$

$r_{sd} = 0.70$ (assumed)

$(r_{sd})\, p = 0.70$

Answer Bd/Bc = 1.75

Since the actual value (1.49) is less than the transition value (1.75) the trench condition prevails. Use Equation 5.

(b) Determine earth load (W_E) from Equation 5 Section III, Page 7.

$$W_E = C_d\, W_e\, B_d^2$$

From Figure 4 Section III determine C_d for clay where

$$H/Bd = \frac{5}{3.5} = 1.42$$

Answer $C_d = 1.23$

$$W_E = 1.23 \times 120 (3.5)^2$$

$$W_E = 1808 \text{ lbs./ft.}$$

Note: Steps (a) and (b) can be eliminated by using the earth load table in Section III for 24-inch pipe and clay soil. The value given in the table is 1810 lbs./ft.

(c) Determine W_T from Equation 3 Section III.

$$W_T = \frac{(W_E + W_S)\ S.F.}{B.F.}$$

From Section III Table 2 for Class C Bedding and 24-inch Pipe B. F. = 1.5

$$W_T = \frac{(1808 + 0)\ 1.5}{1.5}$$

$$W_T = 1808 \text{ lbs./ft.}$$

(d) Determine p_T from Equation 2 Section III.

$$p_T = (P_o + P_s)\ S.\ F.$$

$$p_T = (100 + 50)\ 2.0$$

$$p_T = 300 \text{ psi}$$

(e) From the combined loading curve for 24-inch FT Pipe, determine the point of intersection for the values of pT = 300 psi, and WT = 1808 lbs./ft. Select that class of FT Pipe whose combined loading curve is above this point of intersection. The answer is FT40.

Note: Since the B.O.D. for the FT Pipe selected is less than the value of B.O.D. assumed in step (a); i.e., 2.23 ft. < 2.35 ft., the design calculation is acceptable. If it had been greater than the assumed value, the design would have to be recalculated utilizing the B.O.D. of the selected Class FT40 pipe.

(f) The actual safety factors resulting from the selection of FT40 Pipe for the above example are as follows:

Hydrostatic Pressure — From the combined loading curve the maximum pressure (p_T) = 345 psi for an external load (W_T) = 1808 lbs./ft.

Therefore $S.F. = \frac{345}{150} = 2.30$

Crush — From the combined loading curve, the maximum allowable crush (W_T) is 2500 lbs./ft. when the total internal pressure (p_T) = 300 psi.

Therefore $S.\ F. = \frac{W_T \times B.\ F.}{(W_E + W_S)}$

$$S.\ F. = \frac{2500 \times 1.5}{(1808 + 0)}$$

$$S.\ F. = 2.07$$

Example 2

Select the proper class FT Pipe to satisfy the following conditions.

Pipe size — 14 inch
Operating pressure — 100 psi
Surge pressure — 50 psi
Type of soil — clay
Bedding — Class C
Trench Width — 4 feet
Depth of cover — 6.0 feet
Wheel load — 10,000 lbs.
Impact factor — 1.0
Safety Factor (Hydro) — 2.0
Safety Factor (Crush) — 1.5

Solution

(a) Solve ratio Bd/Bc

Bd = 4.0 feet
Bc is unknown

Use B.O.D. for Class FT70 as initial assumption.

Therefore $Bc = \frac{16.41}{12} = 1.37$

$$Bd/Bc = \frac{4.0}{1.37} = 2.92$$

From Figure 7, Section 3.2.2(b) determine the transition value of Bd/Bc where

$$H/Bc = \frac{6.0}{1.37} = 4.38$$

$$p = \frac{1.37}{1.37} = 1.0$$

$r_{sd} = 0.70$ (assumed)

$(r_{sd})\ p = 0.70$

Answer Bd/Bc = 2.21

Since the actual value (2.92) is more than the transition value (2.21), the positive projecting embankment condition prevails. Use Equation 6.

(b) Determine earth load (W_E) from Equation 6 Section III where

$$W_E = C_C\ w_e\ B_c^2$$

Since r_{sd} is 0.70 and H/Bc $>$ 1.3, use Equation 7 for C_C where

$$C_C = 1.892\ H/Bc - 0.96$$

$$C_C = 7.33$$

$$W_E = 7.33 \times 120 \times (1.37)^2$$

$$W_E = 1651 \text{ lbs./ft.}$$

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Note: Steps (a) and (b) can be eliminated by using the earth load in Section III for 14-inch pipe and clay soil. The value given in the table is 1660 lbs./ft.

(c) Determine superimposed load (W_S). In this instance $W_S = W_{S1}$ From Equation 11 Section III.

$$W_S = W_{S1} = C_S \frac{P_S F}{L}$$

$L = *3.0$ feet

*Note — For FT Pipe design the effective length (L) is always equal to 3.0 feet.

From Section III Table 1 determine C_S where

$$Bc/2H = \frac{1.37}{12} = .114$$

$$L/2H = \frac{3}{12} = .25$$

Answer $C_S = .051$

$$W_S = W_{S1} = \frac{.051 \times 10{,}000 \times 1.0}{3}$$

$W_S = W_{S1} = 167$ lbs./ft.

Note: Step (c) can be eliminated by using the concentrated load table in Section III. The value given in the table is 170 lbs./ft.

(d) Determine W_T from Equation 3 Section III

$$W_T = \frac{(W_E + W_S)\ S.F.}{B.F.}$$

From Section III Table 2 for Class C Bedding and 14 inch pipe B.F. = 1.4

$$W_T = \frac{(1651 + 167)\ 1.5}{1.4}$$

$W_T = 1948$ lbs./ft.

(e) Determine p_T from Equation 2 Section III.

$$p_T = (P_0 + P_S)\ S.F.$$

$$p_T = (100 + 50)\ 2.0$$

$p_T = 300$ psi

(f) From the combined loading curve for 14 inch FT Pipe determine the point of intersection for the values of $p_T = 300$ psi and $W_T = 1948$ lbs./ft. Select that class of FT Pipe whose combined loading curve is above this point of intersection. The answer is FT45.

(g) The actual safety factors resulting from the selection of FT45 Pipe for the above example are as follows:

Hydrostatic pressure — From the combined loading curve the maximum pressure (P_T) = 337 psi for an external load (W_T) = 1948 lbs./ft.

Therefore $S.F. = \frac{337}{150} = 2.25$

Crush — From the combined loading curve, the maximum allowable crush (W_T) is 2300 lbs./ft. when the total internal pressure (P_T) = 300 psi.

Therefore

$$S.F. = \frac{W_T \times B.F.}{(W_E + W_S)}$$

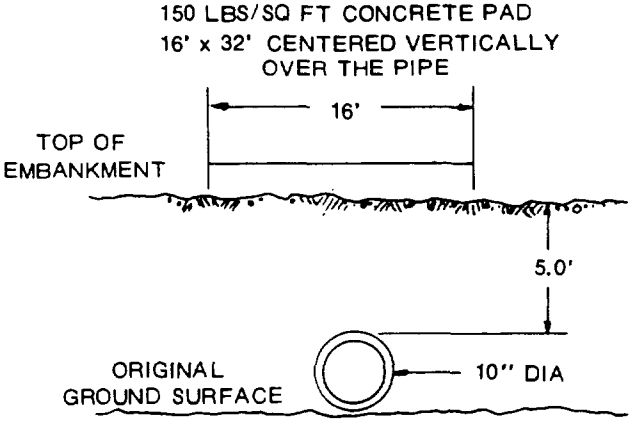
$$S.F. = \frac{2300 \times 1.4}{(1651 + 167)}$$

$$S.F. = 1.77$$

Example 3

Select the proper class FT Pipe to satisfy the following conditions.

Pipe Size — 10 inch
Operating Pressure — 100 psi
Surge Pressure — 50 psi
Type Soil — Clay
Depth of Cover — 5.0 feet
Bedding — Class C
Impact Factor — 1.0
Safety Factor (Hydro) — 2.5
Safety Factor (Crush) — 2.0



Solution

(a) Determine earth load from Equation 6 Section III for embankment condition.

$$W_E = C_c \, W_e \, B_c^2$$

$$B_c = \frac{11.85}{12} \text{ (FT70 assumed)} = .99$$

from Equation 7

$$C_c = 1.892 \, \frac{H}{B_c} - 0.96$$

$$C_c = 1.892 \times \frac{5.0}{.99} - 0.96$$

$$C_c = 8.60$$

$$W_E = 8.60 \times 120 \times (.99)^2$$

$$W_E = 1011 \text{ lbs./ft.}$$

Note: Step (a) can be eliminated by using the earth load table in Section III for 10 inch pipe, clay soil and embankment. The value given in the table is 1010 lbs./ft.

(b) Determine superimposed load (W_S). In this instance $W_S = W_{S2}$ from Equation 12 Section III.

$$W_S = W_{S2} = C_S\ p_s\ F\ B_c$$

From Section III Table 1 determine C_S where

$$\frac{D}{2H} = \frac{16}{2 \times 5} = 1.60$$

$$\frac{M}{2H} = \frac{32}{2 \times 5} = 3.20$$

Answer - $C_S = .910$

$W_{S2} = .910 \times 150 \times 1.0 \times .99$

$W_{S2} = 135$ lbs./ft.

(c) Determine W_T from Equation 3 Section III

$$W_T = \frac{(W_E + W_S)}{B.F.}\ S.F.$$

From Section III Table 2 for Class C bedding and 10 inch pipe B.F. = 1.3

$$W_T = \frac{(1011 + 135)\ 2.0}{1.3}$$

$W_T = 1763$ lbs./ft.

(d) Determine P_T from Equation 2 Section III

$P_T = (P_O + P_S)\ S.F.$

$P_T = (100 + 50)\ 2.5$

$P_T = 375$ psi

(e) From the combined loading curve for 10 inch FT Pipe, determine the point of intersection for the values of $P_T = 375$ psi and $W_T = 1763$ lbs./ft. Select that class of FT Pipe whose combined loading curve is above this point of intersection. The answer is FT 50.

(f) The actual safety factors resulting from the selection of FT 50 pipe for the above example are as follows:

Hydrostatic Pressure — From the combined loading curve the maximum pressure (P_T) = 420 psi for an external load (W_T) = 1763 lbs./ft.

Therefore $S.F. = \frac{420}{150} = 2.80$

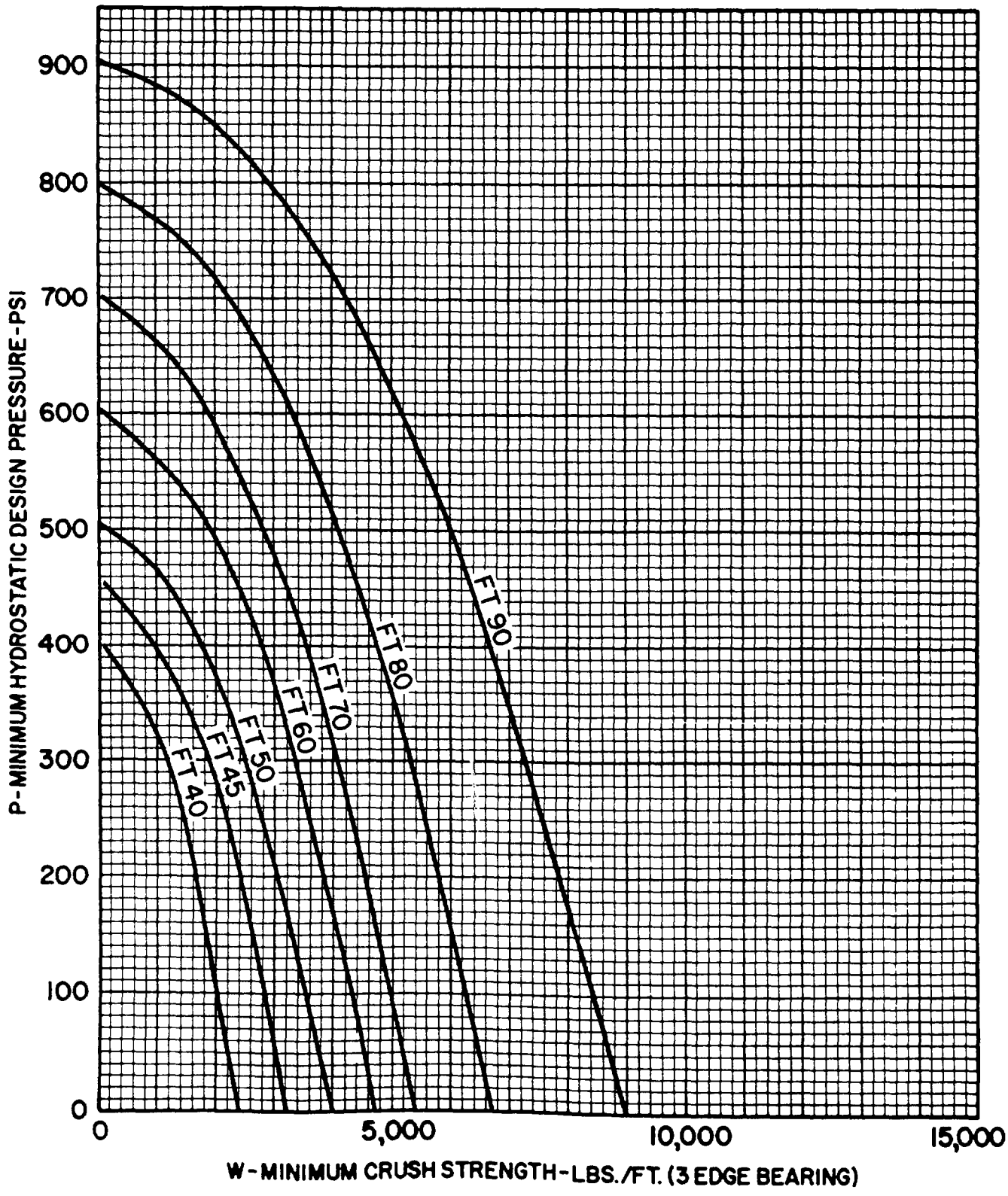
Crush — From the combined loading curve, the maximum allowable crush (W_T) is 2250 lbs./ft. when the internal pressure (P_T) = 375 psi.

Therefore $S.F. = \frac{W_T \times B.F.}{(W_E + W_S)}$

$$S.F. = \frac{2250 \times 1.3}{(1011 + 135)}$$

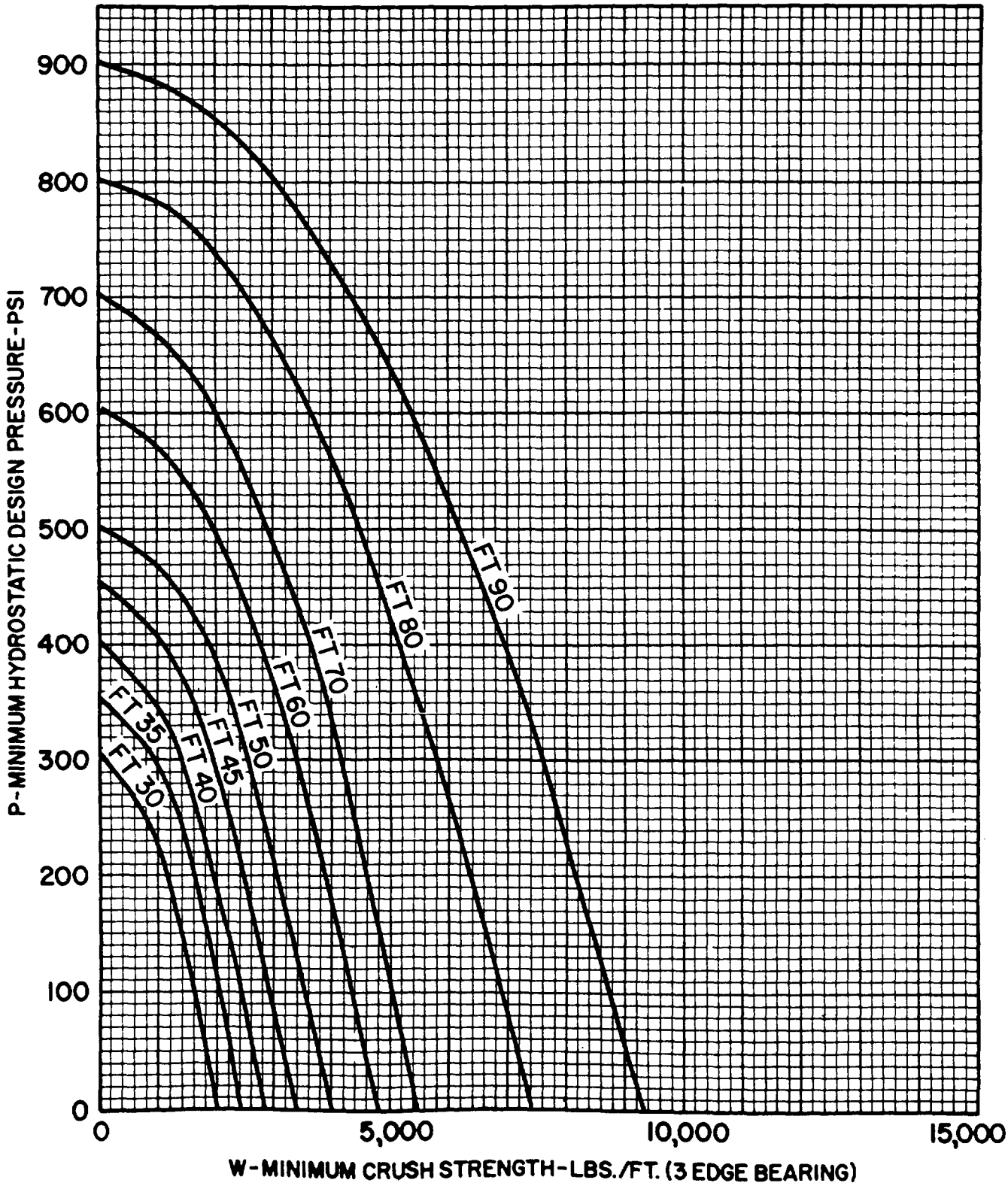
$S.F. = 2.55$

CERTAIN-TEED
COMBINED LOADING CURVES FOR 6 INCH FT PIPE



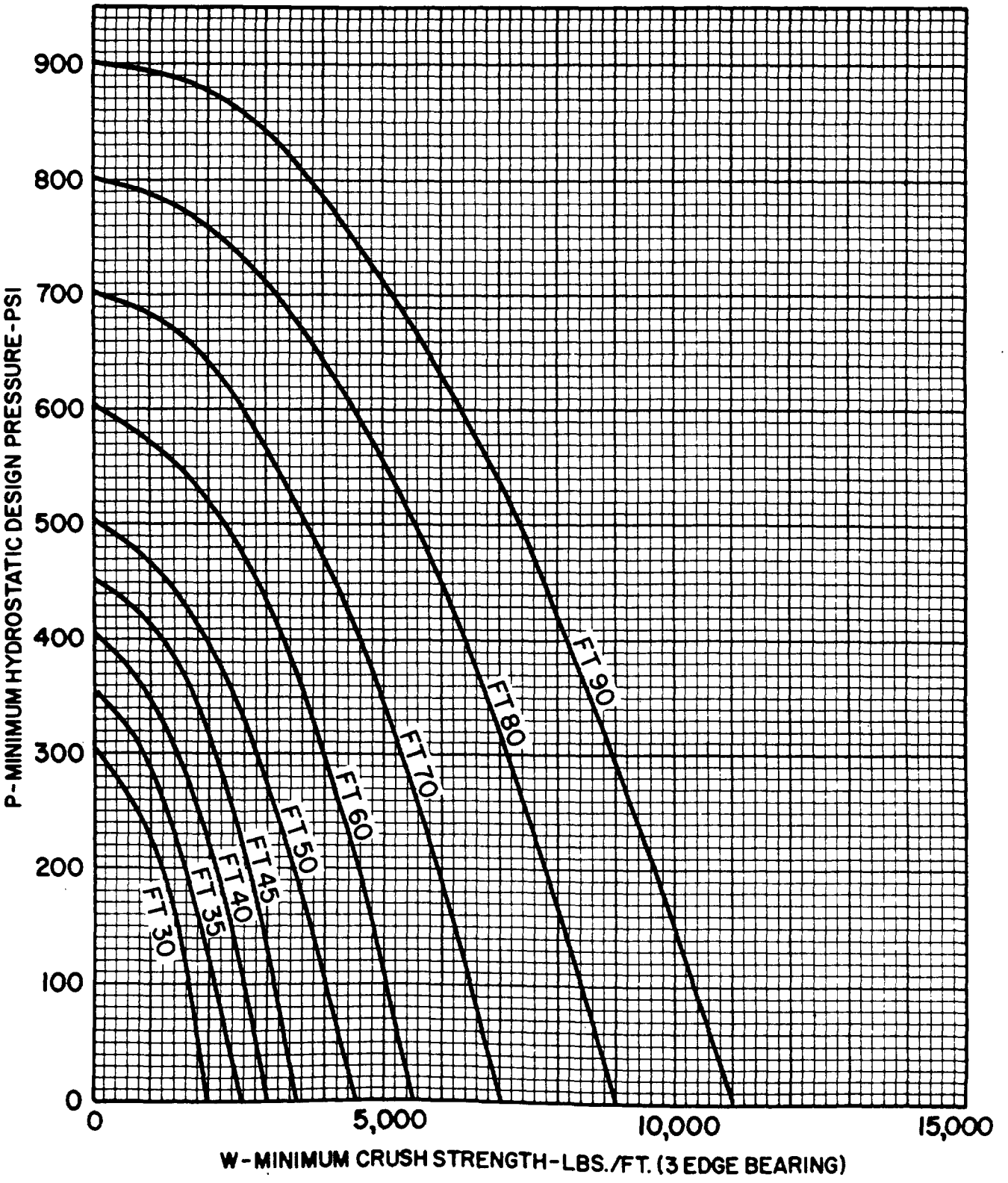
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 8 INCH FT PIPE



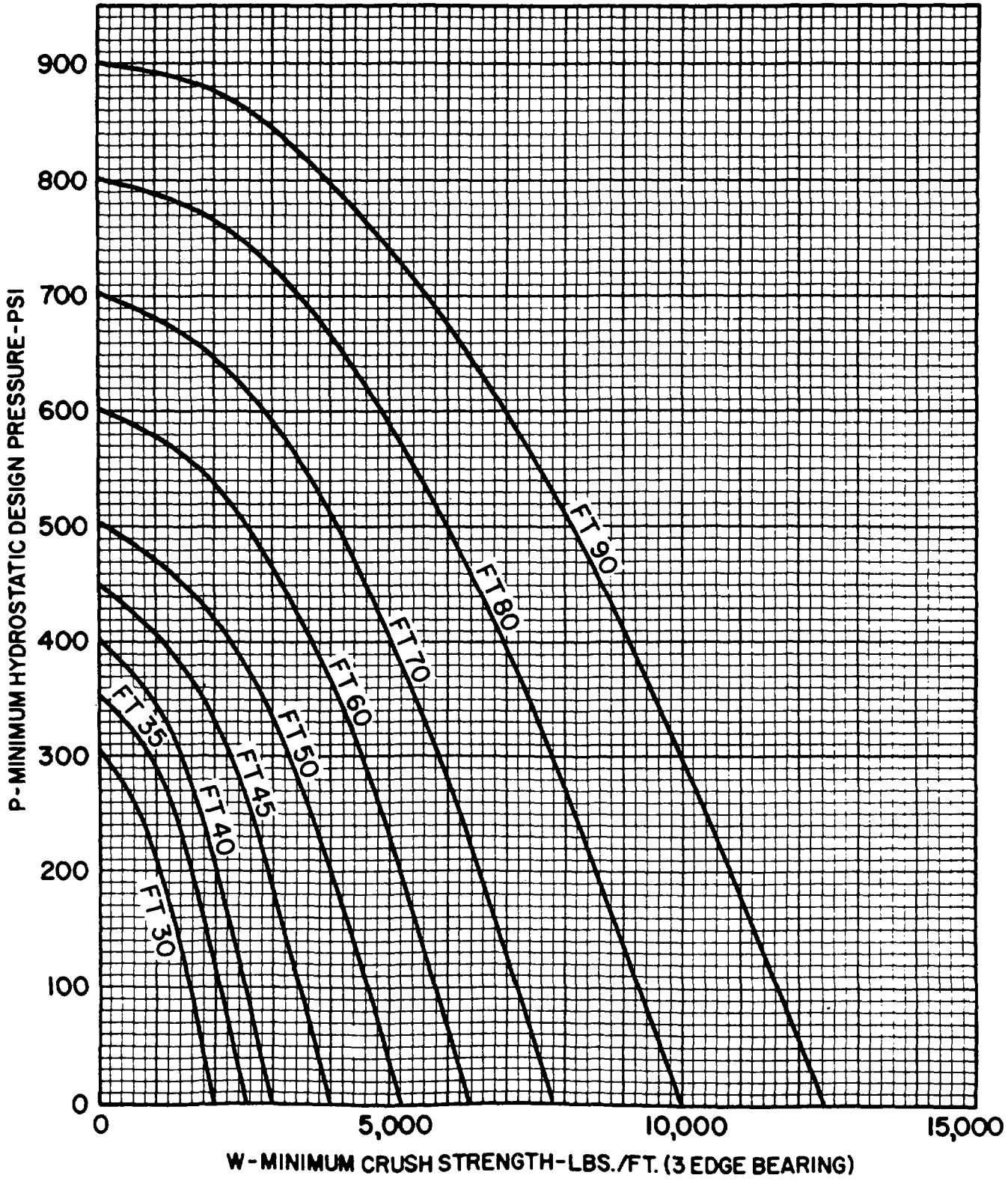
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 10 INCH FT PIPE



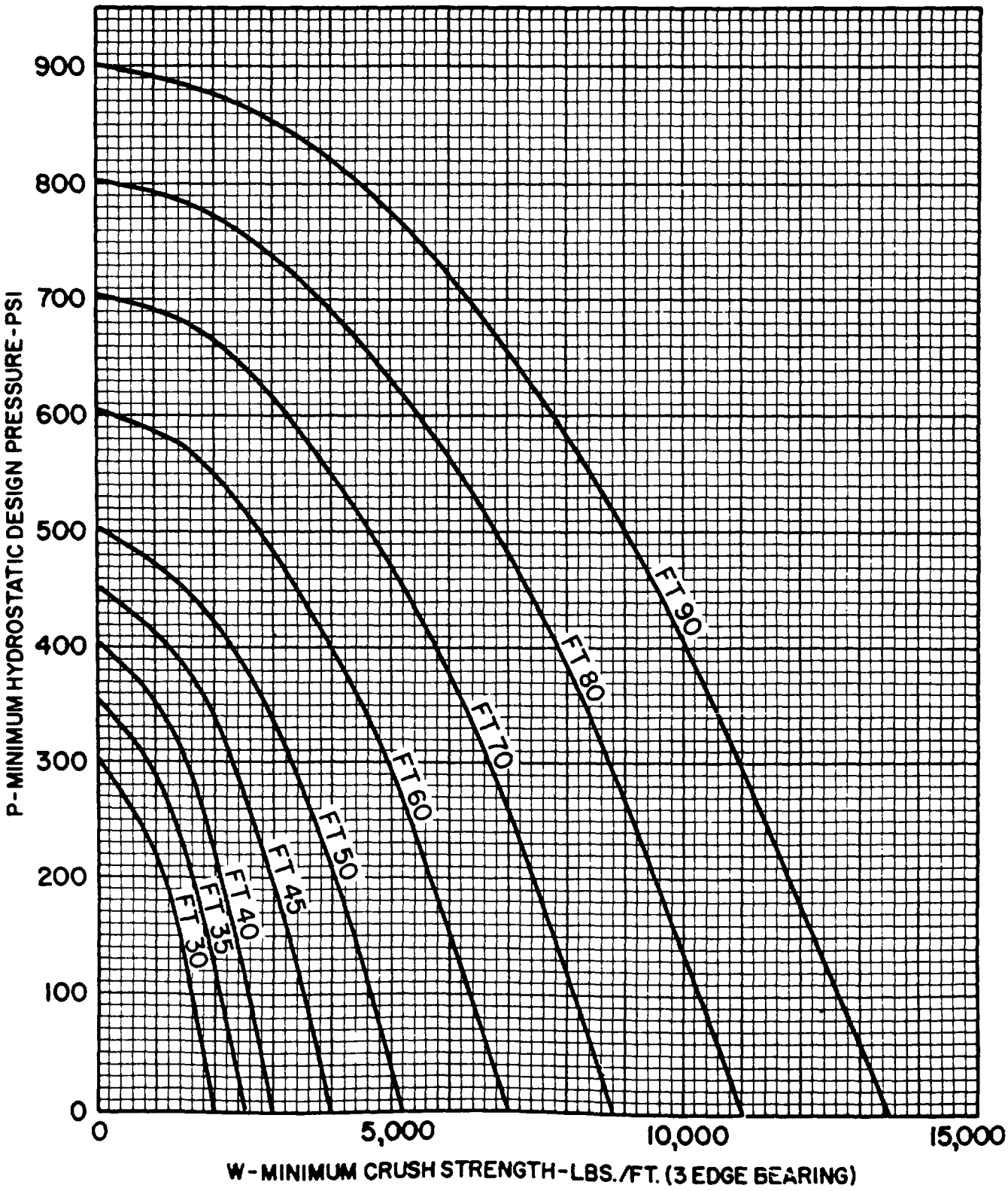
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CERTAIN-TEED
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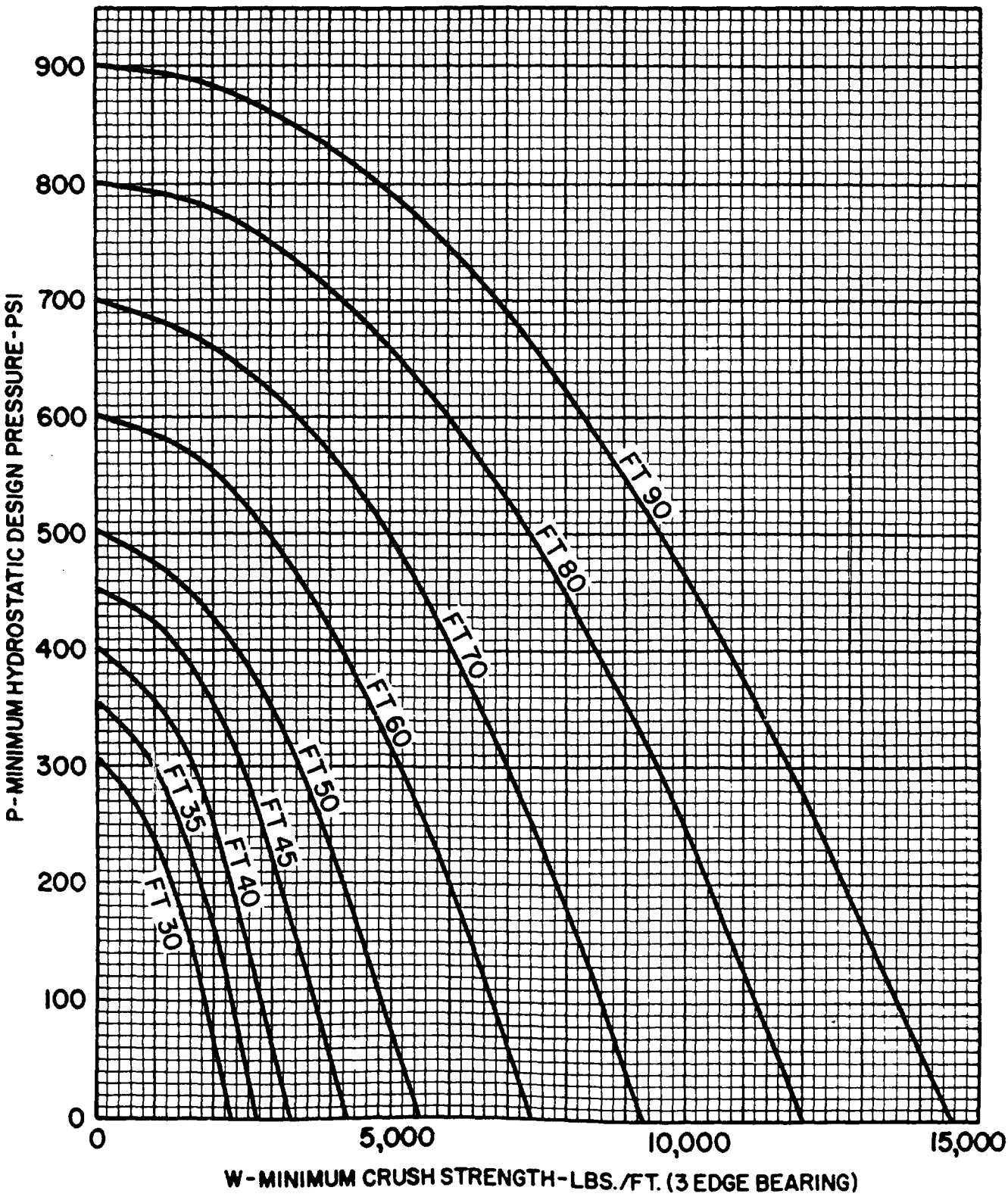
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 14 INCH FT PIPE



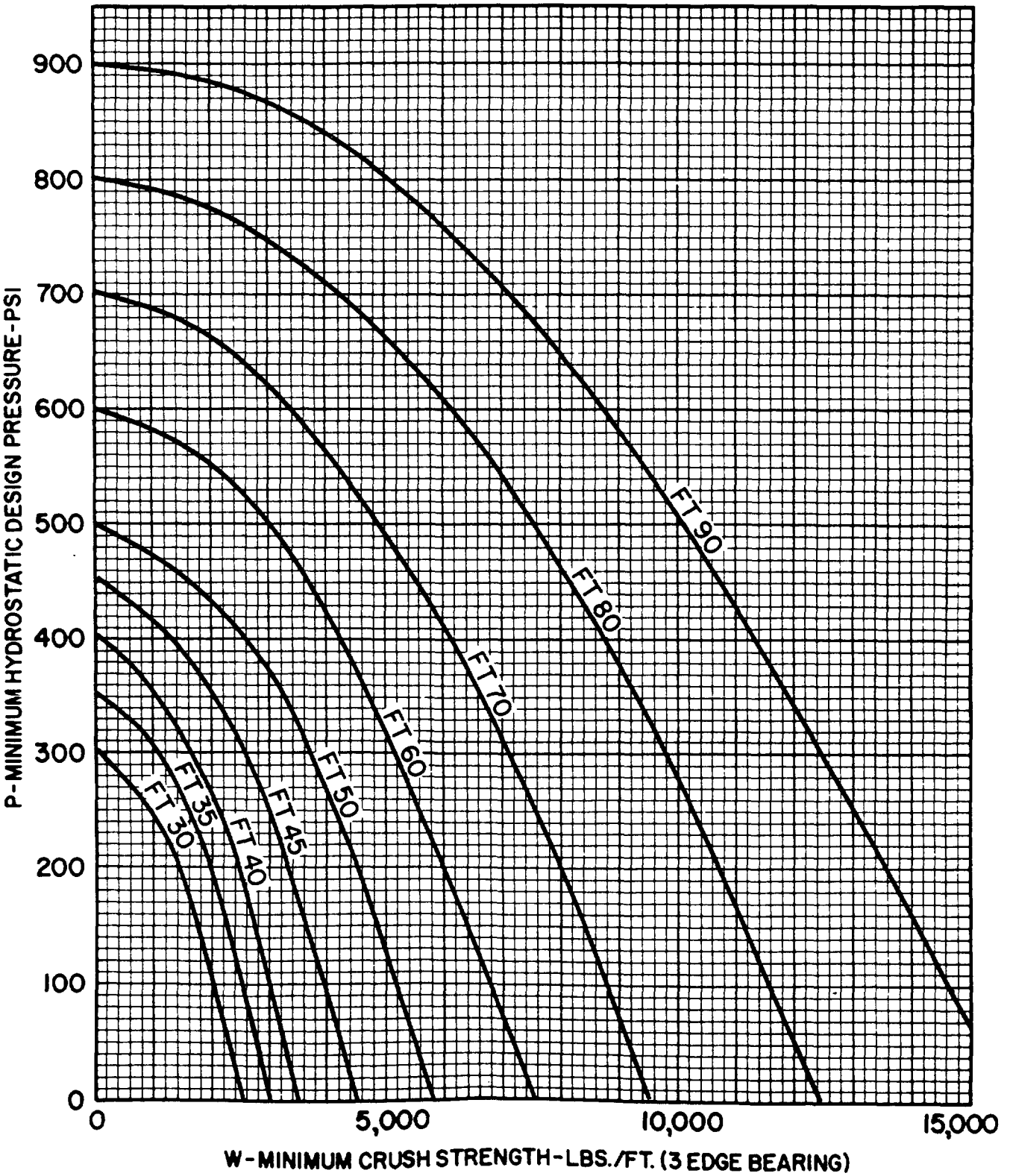
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 15 INCH FT PIPE



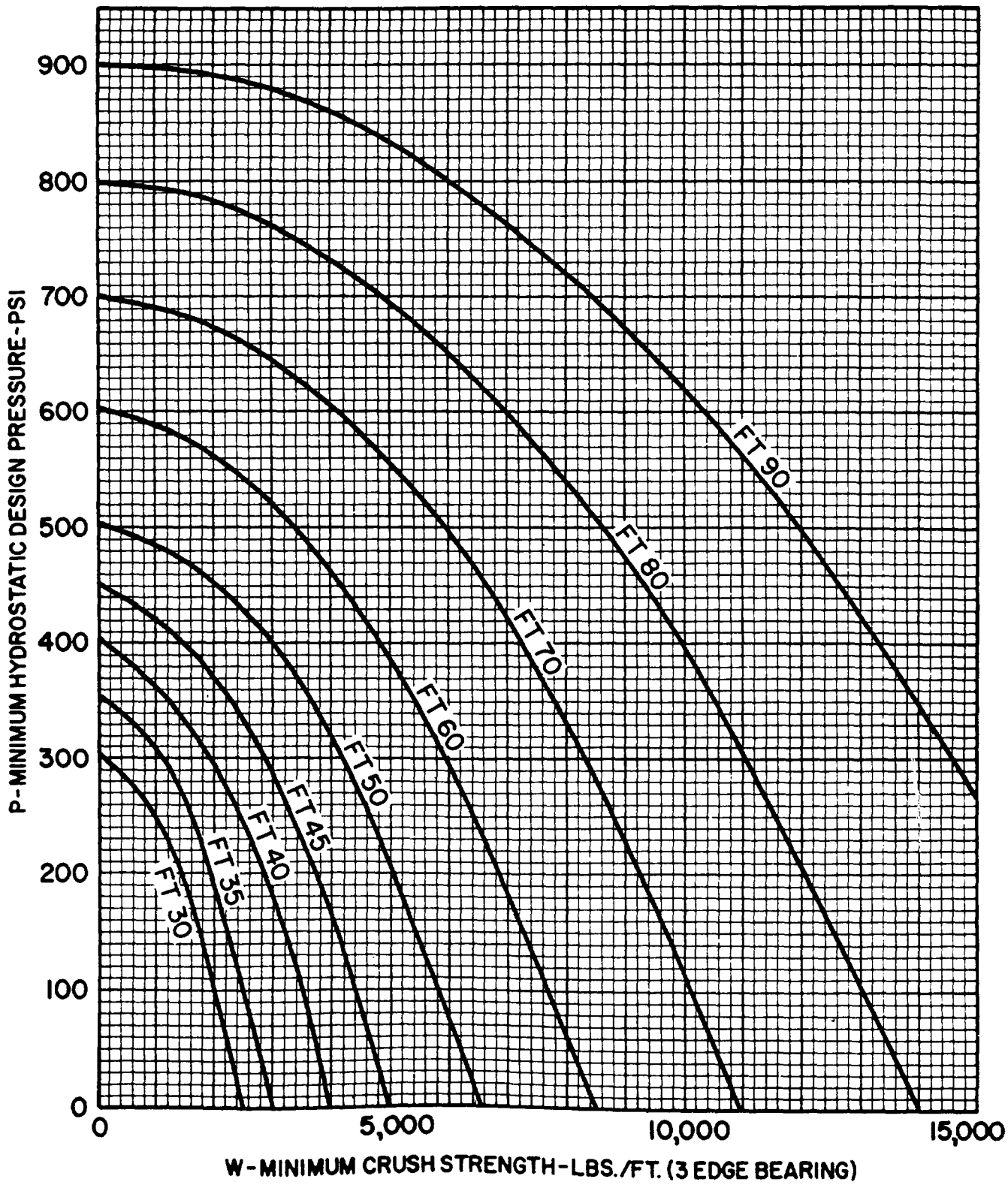
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 16 INCH FT PIPE



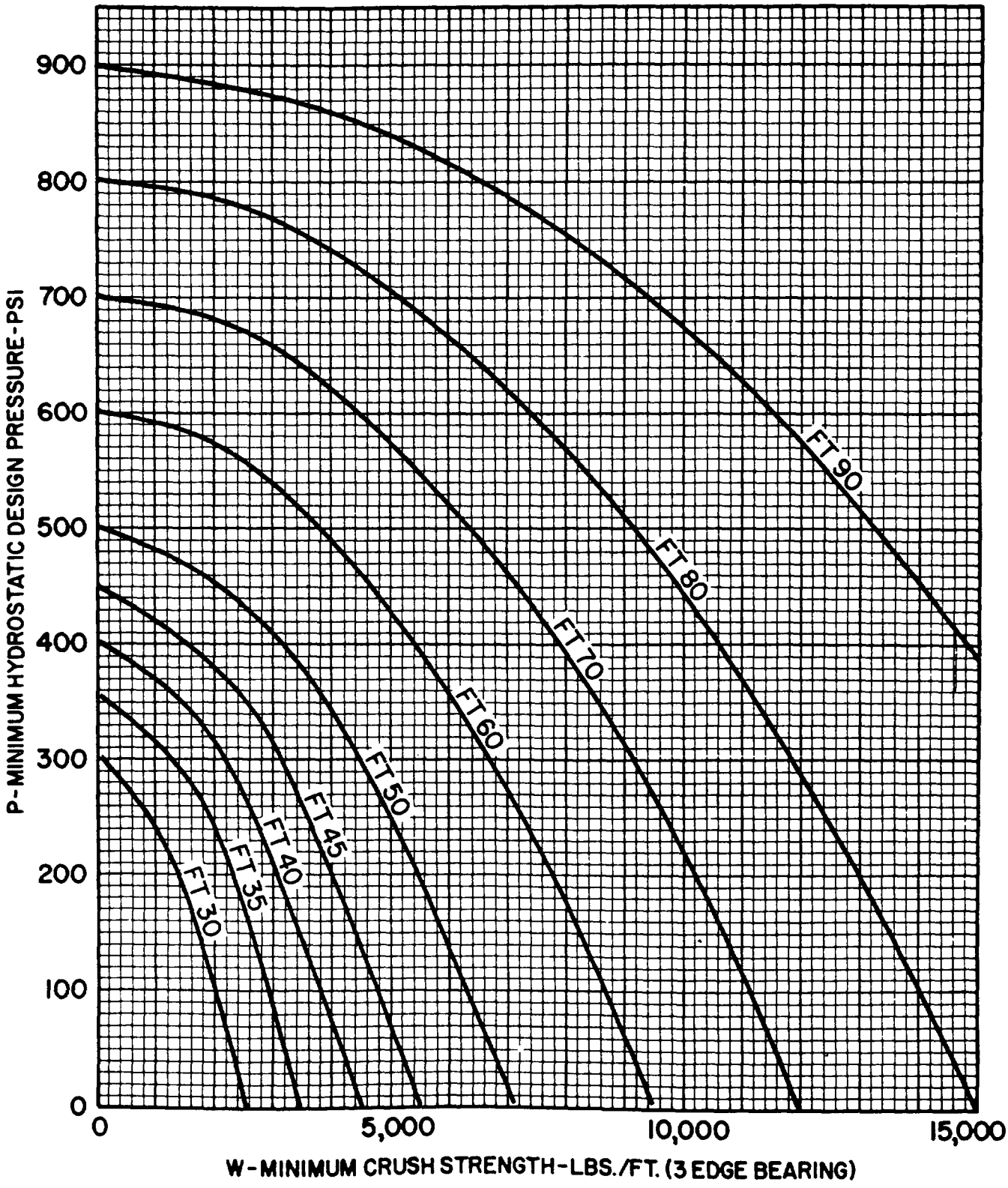
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 18 INCH FT PIPE



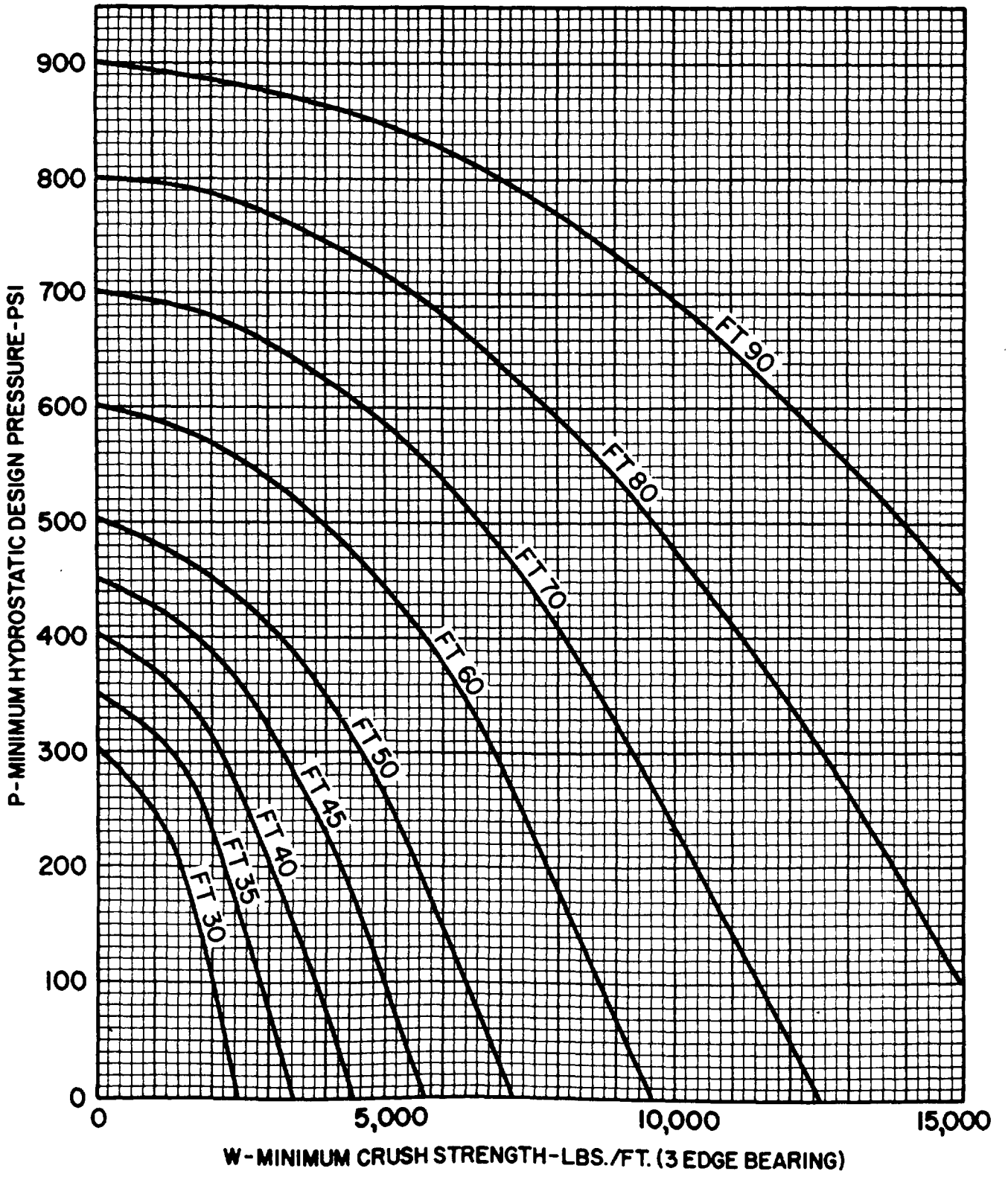
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 20 INCH FT PIPE



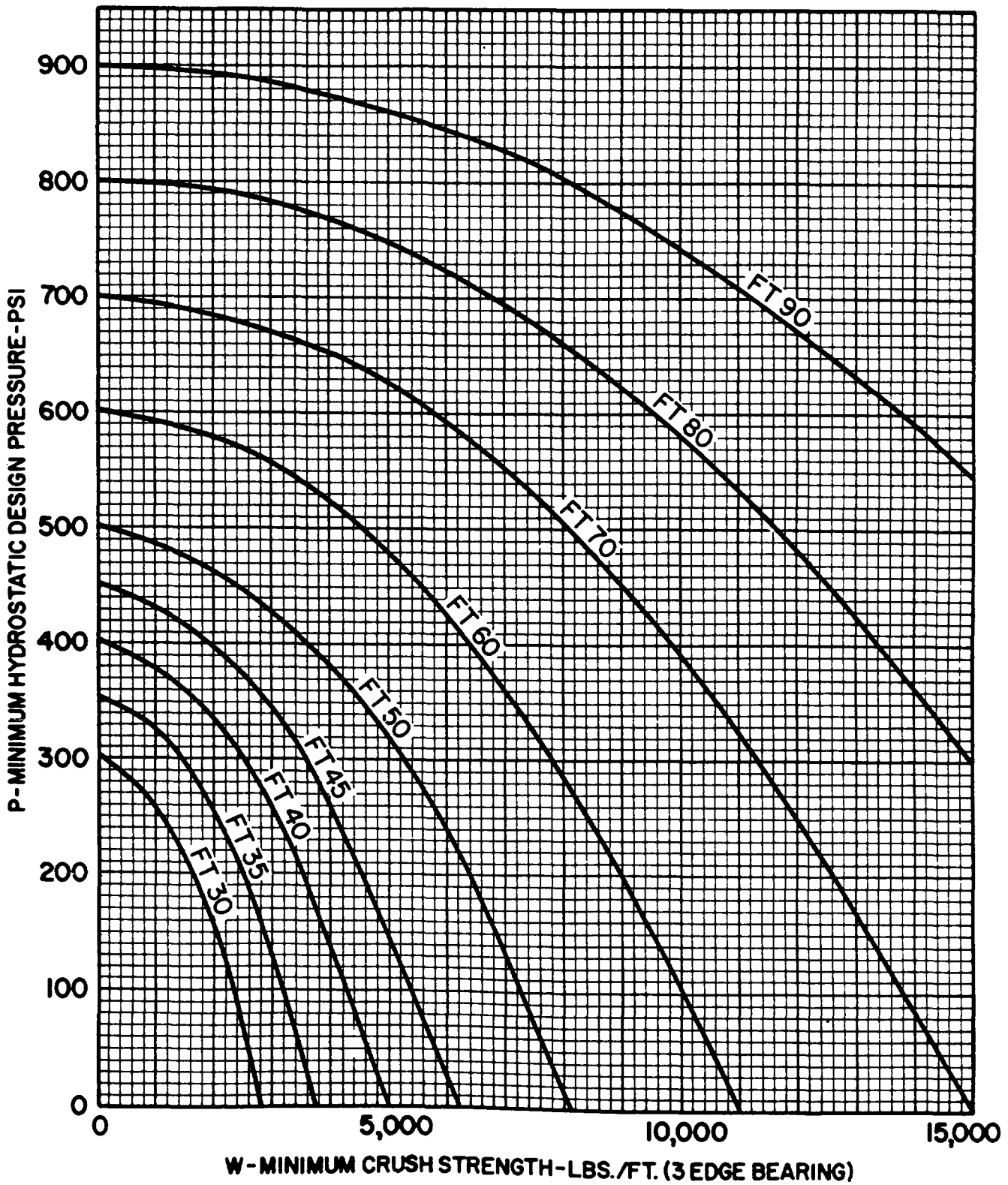
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CERTAIN-TEED
COMBINED LOADING CURVES FOR 21 INCH FT PIPE



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CERTAIN-TEED
COMBINED LOADING CURVES FOR 24 INCH FT PIPE



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FLUID TRANSMISSION (FT)
ASBESTOS CEMENT PIPE

INTRODUCTION

To design a hydraulic system there are a number of conditions to be determined. These conditions are:

(a) Flow rate
(b) Pipe size
(c) Velocity
(d) Pressures (operating, static and surge)
(e) Friction loss
(f) Elevation

Most of the conditions are commonly determined by the Hazen and Williams Formula

$$V = 0.0131\ CH^{0.54}\ D^{0.632}$$
$$Q = 0.0103\ CH^{0.54}\ D^{2.63}$$

Where

V = velocity of the fluid in the pipe, feet per second
C = roughness coefficient of the pipe. For Asbestos-Cement Pipe, C = 140.
H = head loss due to friction, feet per 1,000 feet of straight pipe.
D = diameter of pipe, feet.
Q = rate of flow, cubic feet per second

The Hazen and Williams Formula is difficult to use for ordinary calculations, therefore, a nomograph of the formula is presented in figure 1, page 61. It is based on the roughness coefficient (C) for Asbestos-Cement Pipe, equal to 140. By proper utilization of the nomograph the following may be determined.

(a) Loss of head (H) and velocity of flow (V) for a known pipe size (D) and fixed rate of flow (Q).
(b) Pipe size (D) for known values for both loss of head (H) and rate of flow (Q).

OPERATING PRESSURE

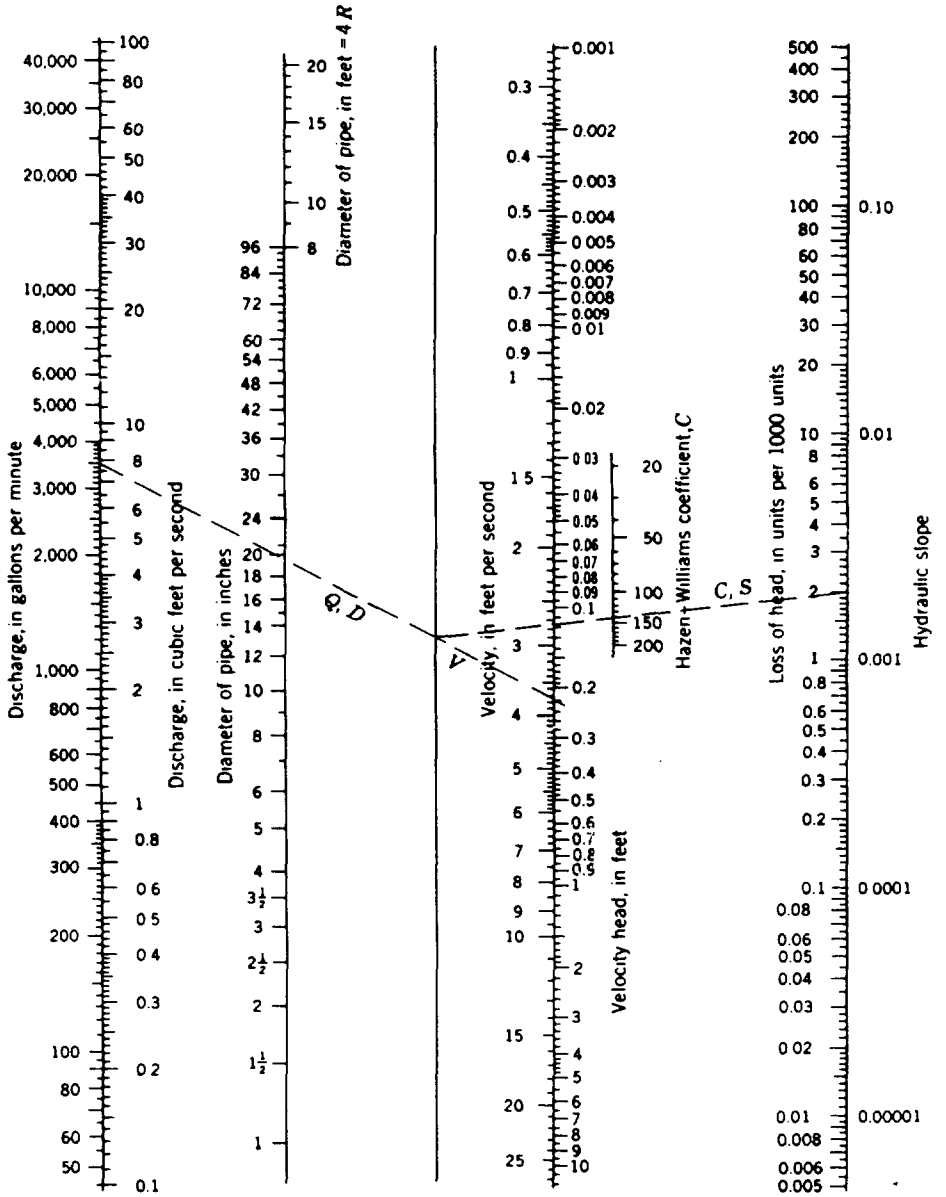
Operating pressures are pressure heads which occur in normal piping systems under steady operating conditions. They occur in both gravity flow systems and pumped systems. For determining these normal pressure heads the general energy equation, better known as Bernoulli's theorem is utilized, which is as follows:

$$h_1 + z_1 + \frac{V_1^2}{2g} = h_2 + z_2 + \frac{V_2^2}{2g} + hf \qquad \text{(eq. 1)}$$

Where

h_1 = pressure head at reference point 1, ft.
z_1 = elevation head at reference point 1, ft.
V_1 = velocity of flow at reference point 1, ft./sec.
g = acceleration due to gravity, 32.2 ft./sec.^{2}
h_2 = pressure head at reference point 2, ft.
z_2 = elevation head at reference point 2, ft.
V_2 = velocity of flow at reference point 2, ft./sec.
hf = friction head, ft.

FIGURE 1 HAZEN-WILLIAMS NOMOGRAPH



Alignment chart for Hazen-Williams formula for pipe flow

Example: As shown in figure 2 water is flowing by gravity from a reservoir at a rate of 3500 gallons per minute to a distribution system. The required pressure at point 2 is 100 psi (230'). Determine the size of pipe required.

Solution: Determine allowable head loss

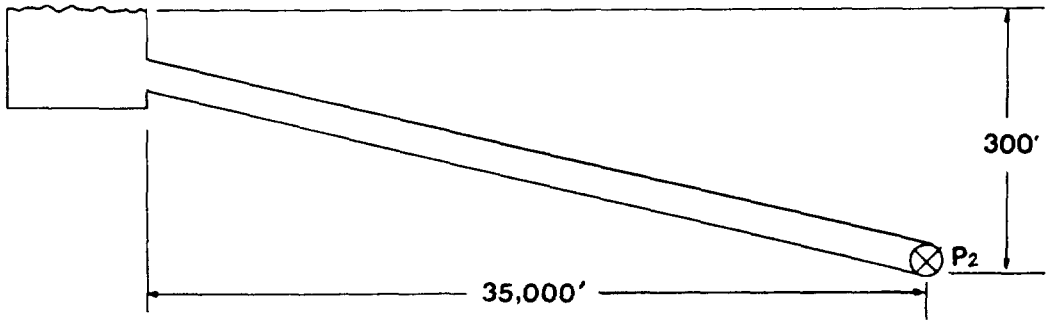
$300' - 230' = 70'$

Allowable head loss per 1000 ft. of pipe

$$\frac{70'}{35'} = 2 \text{ ft./1000 ft.}$$

Enter nomograph figure 1 using a head loss of 2 ft./1000 ft. and C of 140. From the nomograph it is found that 20-inch pipe is required.

FIGURE 2



STATIC PRESSURE

Static pressure is the pressure at a point in the undisturbed stream of a liquid. The static pressure is usually calculated from a datum or reference line and is a function of height and specific weight of the liquid. The datum is usually a point in the stream where the pressure is known. Static pressures are calculated from the equation

$$p_2 - p_1 = \frac{\gamma h}{144} \quad \text{or} \quad p = \frac{\gamma h}{144} \qquad \text{(eq. 2)}$$

Where

p = pressure difference, lbs./in.^{2}

γ = specific weight of the liquid, lbs./ft.^{3}

h = elevation, feet (commonly referred to as pressure head, expressed as feet of water, inches of mercury, etc.

Example: Assume in figure 2 a valve at point 2 is closed and the water is in static equilibrium. Determine the pressure at point 2

Using eq 2

$$p_2 - p_1 = \frac{\gamma h}{144}$$

$$p_2 - 0 = \frac{62.4 \times 300}{144}$$

$$p_2 = 130 \text{ psi}$$

SURGE PRESSURE OR WATER HAMMER

Surge pressure, commonly called water hammer, is a pulsation of pressures above and below the operating or normal pressure, resulting from rapid deceleration or acceleration in the velocity of a liquid flowing through a pipeline. Surge pressure is of large magnitude and short

duration. The main causes of water hammer or surge are the quick opening or closing of valves or gates and the sudden starting, stopping or variation in speed of pumps. The effect of water hammer is increased stress on pipe walls and fittings, which is in excess of the stress caused by the normal operating pressure.

Like any mass in motion, water flowing through a pipeline possesses both static and kinetic energy. Any change in the velocity of a moving mass will produce a force. If both the pipeline and the water are assumed to be incompressible, a change in velocity relative to time, the acceleration or deceleration of the mass, would produce a force equal to $F = MA$,

Where F = the force.
M = the mass of the material.
A = the change in velocity relative to time or the acceleration or deceleration of the mass.

Since neither the water nor the pipe are actually incompressible, the formula $F = MA$ is not accurate for determining the force created by surge pressures. Factors such as the elasticity and frictional resistance of the material must be incorporated into an equation that will give the actual force or increase in pressure caused by water hammer. Because there are so many variables involved in solving for the actual value of water hammer, a number of empirical equations have been formulated for different conditions. An actual theoretical equation involves such factors as the speed of sound waves in the liquid, roughness factors and elasticity of materials and are not practical for normal engineering use.

However, for the determination of water hammer in most systems, the elastic wave theory has been proven to be the most accurate, yet still being relatively easy to use. A discussion of the elastic wave theory is given below.

ELASTIC WAVE THEORY

The maximum increase in pressure due to the change in velocity of water is equal to $h = \frac{av}{g}$,

Where h = the increase in pressure (feet of water).
a = the velocity of pressure wave in ft./sec.
v = the velocity of flow during normal conditions in ft./sec.
g = acceleration due to gravity (32.2 ft./sec.^{2}).

When interference is placed in a flowing line or the velocity is changed in some manner, a pressure wave is induced in the line. The velocity of the pressure wave is the speed of sound in water, damped by the physical characteristics of the pipeline. The actual velocity of the pressure wave (a) is equal to

$$\frac{4660 \text{ ft./sec.}}{\sqrt{1 + \frac{Kd}{Ee}}}$$

Where
4660 = the speed of sound in water in ft./sec.
K = the modulus of compression for water (300×10^3 psi).
d = the internal diameter of the pipe in inches.
E = the modulus of elasticity of the pipe material (3.4×10^6 psi for A-C Pipe).
e = the wall thickness of the pipe in inches.

As the above formula may become cumbersome for repeated use, pressure wave velocities for various ratios of pipe diameter to wall thickness d are given in Table 1.

d/e	Pressure Wave Velocities
5	3883
10	3400
15	3054
20	2807
25	2603
30	2440

Table 1 – Pressure Wave Velocities for Corresponding ratios of Pipe Diameter to Wall Thickness ($\frac{d}{e}$).

The pressure wave travels along the pipeline until it reaches a reflection boundary such as a reservoir and is reflected back to its initial or starting point. If by the time the reflected wave reaches its starting point, flow is completely stopped, maximum water hammer occurs and, as was stated above, is equal to $\frac{av}{g}$. The total length of time it takes for the wave to travel to the reflecting surface and back to its initial point is simply $\frac{2L}{a}$,

Where L = the distance between the initial point and the reflecting surface in feet.
a = the wave velocity in ft./sec.

This time is called the critical time. If flow stoppage is obtained within this time, maximum water hammer will occur. By regulating the time it takes to stop flow, the maximum water hammer can be proportionately reduced. There are charts and graphs available for determining the length of time necessary to stop flow for various valves and flow conditions that will give a calculated acceptable water hammer value. Given below is a graph which can be used to find the minimum time required for flow stoppage to obtain a given percent of the maximum water hammer force $\frac{av}{g}$. To use the graph a value for K, the pipeline constant must be obtained. The formula for K is given below:

$$K = \frac{aV}{2gho}$$

Where K = pipeline constant.
a = velocity of the pressure wave in the line (ft./sec.).
V = velocity of flow under normal conditions (ft./sec.).
ho = operating pressure in the line under normal conditions (feet of water).
g = acceleration due to gravity (32.2 ft./sec.^{2}).

Figure 3 – At right. Approximate tests of various types of valves showing the flow vs the time of valve stem travel (tr)

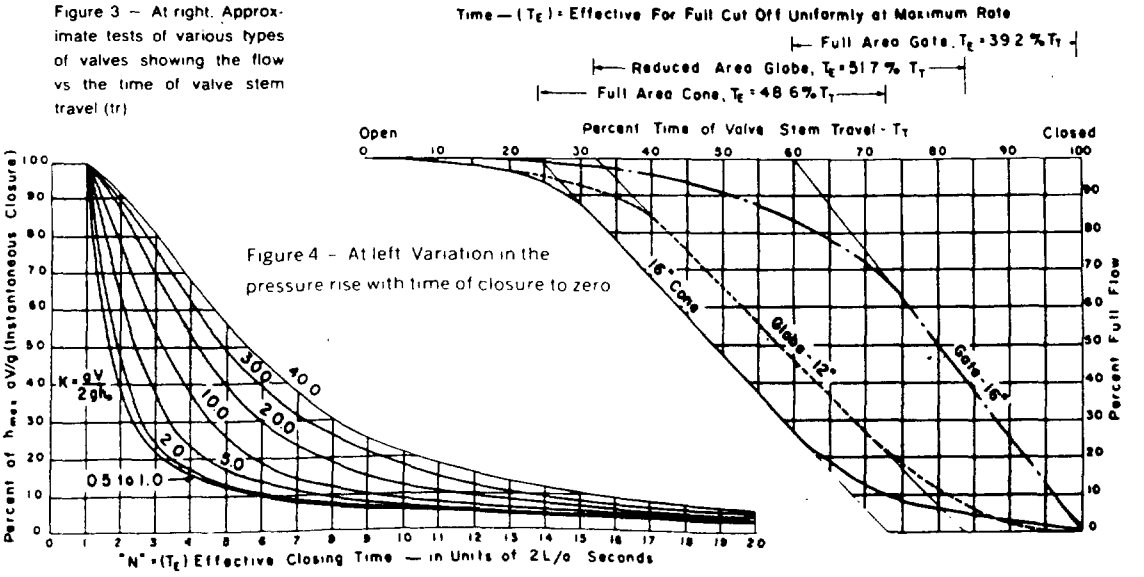


Figure 4 – At left Variation in the pressure rise with time of closure to zero

(Reprinted from May, 1958 Issue, Consulting Engineering)

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The desired allowable surge pressure is then computed as a percentage of the maximum surge pressure. Entering the graph with the pipe factor K and the percentage of the maximum surge pressure desired the effective time of valve closure can be found. The effective time is given in units of $\frac{2L}{A}$, so the value obtained from the graph must be multiplied by the critical time, $\frac{2L}{A}$ to get the total effective time in seconds.

The actual closing time for valves is approximately twice the effective time. Manufacturer's data for a particular valve should be checked to obtain the accurate relationship of effective closing time to actual closing time.

As was previously stated, the common causes of water hammer are the sudden opening or closing of valves, and the starting or stopping of pumps. By controlling the time in which valves are opened or closed, and pumps started and stopped, the rate of velocity change can be controlled so that no great force is imposed on the pipeline or appurtenances. Control of pumps and valves is necessary if water hammer is to be minimized. There are, however, control devices such as check valves and air chambers which can be incorporated into the line to compensate or alleviate the force created by water hammer. A description of the more common devices for alleviating the forces associated with water hammer are given below. The use of control devices as opposed to strengthening pipe and fittings is an economic decision based on appropriate costs.

CONTROL

Relief Valves — Relief valves are actuated by a slight increase in pressure. They open wide in a few seconds in order to discharge water to waste to relieve an increase in pressure.

Air Inlet Valves — Used to control negative surges. They are designed to open at a slight pressure, below normal, to admit air and avoid the creation of a partial vacuum.

Air Chambers — Used to relieve either positive or negative surge pressures. They must be filled with air at the time they are called on to function; therefore, they should be set on a high point on the pipeline to permit the accumulation of air in the chambers.

Surge Tower — Used for either positive or negative surge. They are connected to a pipeline to take water from it in the event of positive surge or to deliver water to it during negative surge.

Flywheel on a Pump — Water hammer or surge resulting from the sudden cutting off of power from a pump may be diminished by increasing the inertia of the moving parts of the pump so that, acting as a flywheel, the pump is brought more slowly to a stop.

Reversal of Pump — When a pump stops operating, if it is able to reverse itself without damage, the positive surge pressure set up will be lessened.

Since there are many appurtenances and varying flow conditions associated with a pipeline system, the calculations for determination and control of water hammer can be quite complex. Analysis and treatment of the problem must be based on experience and judgment. Included in this section was a discussion of the elastic wave theory, one of the most common methods for determining the magnitude of water hammer. The discussion of the elastic wave theory was limited to its application to lines containing valves and gates. The determination of water hammer for lines containing pumps or turbines is very complex and cannot be adequately discussed within the scope of this manual.

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CTD032935

Printed in U.S.A.