American Water Works Association

ANSI/AWWA C403-78
(First Edition)

AWWA STANDARD PRACTICE

for

THE SELECTION OF ASBESTOS-CEMENT TRANSMISSION AND FEEDER MAIN PIPE, SIZES 18 IN. THROUGH 42 IN.

AMERICAN NATIONAL STANDARD

Approved by AWWA Board of Directors Jan. 28, 1978.

Approved by American National Standards Institute, Inc., Jul. 17, 1978.

AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

Committee Personnel

The Standards Committee on Asbestos–Cement Pressure Pipe that reviewed and approved this standard had the following personnel at the time of approval:

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T. R. Gillen, *Secretary*

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Foreword

This foreword is for information only and is not a part of AWWA C403

I. History of Standard

A new pipe material consisting of an intimate mixture of portland cement and asbestos fibers was introduced to the North American market in 1931 following several years of usage in other countries, particularly Italy.

In the ensuing years, this type of pipe gained popularity, and in 1949 AWWA established a committee on standard specifications for asbestos-cement pipe under the chairmanship of S. M. Clark of Greeley and Hanson, Chicago.

The committee developed a standard for asbestos-cement water pipe which was approved by the AWWA Board of Directors as tentative, AWWA C400-53T, May 15, 1953. In 1958, the committee was reactivated as Committee 8340D on Asbestos-Cement Pipe under the chairmanship of Roy H. Ritter, Whitman, Requardt and Assocs., Baltimore, to review several suggested changes and to recommend revisions to the standard. The committee produced a revised tentative standard adopted as AWWA C400-64T, Jan. 27, 1964. It was advanced to standard without revision Jul. 2, 1965 and designated as AWWA C400-65.

The committee concluded that an installation guide was desirable to bring to the attention of users certain important requirements on the inspection, handling, installation, and field testing of asbestos-cement pressure pipe. The committee submitted its final draft in 1963, and it received approval as tentative, AWWA C603-64T, Jan. 27, 1964. It was advanced to standard without revision Aug. 9, 1965 and designated as AWWA C603-65.

In early 1968, the committee was reactivated as the Standards Committee on Asbestos-Cement Pipe to review and revise all AWWA standards on asbestos-cement pipe. The committee produced a revised standard approved by the AWWA Board of Directors Jan. 31, 1972, designated as AWWA C400-72, "Standard for Asbestos-Cement Pressure Pipe for Water and Other Liquids."

AWWA C401-64, "Standard Practice for the Selection of Asbestos-Cement Water Pipe" (originally designated Handbook H2), was first approved by the AWWA Board of Directors Jan. 27, 1964. Although it covered pipe sizes up to and including 36 in., it was primarily intended for use with asbestos-cement pipe in smaller distribution sizes (4 through 16 in.).

In the winter of 1972-1973 the committee was reorganized and enlarged to include representatives of national organizations having an interest in the scope of the committee and wishing to participate in the work. The reorganized committee reaffirmed AWWA C400-72 without revision so that it could be presented to the American National Standards Institute for designation as an American National Standard.

In 1975 the committee produced a revised standard that was approved by the AWWA Board of Directors Jan. 26, 1975, and designated AWWA

C400–75, "Standard for Asbestos–Cement Pressure Pipe, 4 in. Through 24 in., for Water and Other Liquids."

The asbestos–cement pipe manufacturers have developed a new series of large pipe classifications, designed to give greater freedom of selection to design engineers. This is of particular significance for large diameter pipeline projects where the savings in material cost can exceed the increased cost of more detailed design, better control of methods of installation, and provision of surge controls when justified.

To provide the user with a ready reference and specification for this type of pipe, known as transmission pipe, the committee produced and the AWWA Board of Directors approved AWWA C402–75, "Standard for Asbestos–Cement Transmission Pipe, 18 in. Through 42 in., for Water and Other Liquids."

The possibility of confusion between the two 1975 standards, AWWA C400 and C402, was carefully reviewed by the committee. The results were AWWA C402–77, which covers sizes 18 through 42 in., and AWWA C400–77, which covers sizes 4 through 16 in. There is now no overlap of sizes.

Consequently, it was desirable to revise AWWA C401-64 so that it would be directly compatible with AWWA C400–77, and to develop a new pipe selection standard to be directly compatible with AWWA C402–77. AWWA C401–77 and this new standard, AWWA C403, "Standard Practice for the Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 in. Through 42 in.," are the result.

II. Discussion

The effect of water hammer generated by the opening and closing of fire hydrants can be of significant magnitude in small distribution pipe sizes, due to the high velocities generated by open hydrant flow conditions. Furthermore, it is difficult to accurately evaluate the magnitude of these surges; and, if calculated, control through the use of surge tanks or other devices is impractical. Rather than employ a rule-of-thumb allowance for surge based upon an assumed velocity change, to compensate for undetermined surge pressures AWWA C400–77 (covering sizes 4 through 16 in.) incorporates a large fixed safety factor for each asbestos–cement pressure class.

In large transmission and feeder main pipe sizes the effect of surge pressures generated by the opening and closing of fire hydrants connected to smaller diameter distribution pipelines is of significantly lower magnitude. For example, the surge pressure generated by hard closure of a hydrant connected to a 6-in. distribution line would be nine times greater than that which would occur in an 18-in. feeder main supplying a 6-in. distribution line.

Major surge pressures in large transmission or feeder main pipelines, caused by stopping and starting pumps and similar components, are more readily calculated. It also is more economically practical to control these surges by incorporating into the system design a variety of devices which will reduce anticipated surge pressures to lower levels. This standard is based on individually evaluating all stress loadings placed on a pipe and on applying adequate safety factors commensurate with a complete review of all design criteria.

American Water Works Association

ANSI/AWWA C403-78
(First Edition)

AWWA Standard Practice for

The Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 in. Through 42 in.

Section 1—General

Sec. 1.1 Scope

This standard has been prepared so that design engineers may quickly determine the correct strength classification of asbestos–cement transmission pipe to use under various combinations of internal pressure (static, operating, and surge) and external load (earth and superimposed live loads). Combined loading curves depicting the relationship between hydrostatic loading and external loading capabilities are included to expedite the selection of the correct pipe strength classification.

NOTE: Information to assist the engineer in selecting the most economical size of pipe is in the appendices. Appendix A contains a friction loss of head chart based on the Hazen and Williams formula. Appendix B is a detailed analysis of surge pressure factors. Appendix C includes tables to assist the engineer in determining the yearly power costs to overcome friction loss of head. The appendices are for information only and are not part of AWWA C403.

1.1.1 *Pipe classifications.* The pipe strength classifications of 30, 35, 40, 45, 50, 60, 70, 80, and 90 refer to the similarly numbered classifications specified in AWWA C402, "Standard for Asbestos-Cement Transmission Pipe, 18 In. Through 42 In., for Water and Other Liquids."

1.1.2 *Installation.* Detailed coverage of the installation of asbestos–cement pipe can be found in AWWA C603, "Standard for the Installation of Asbestos-Cement Pressure Pipe."

Section 2—General Design

Sec. 2.1 Strength and Design Factors

The strength of asbestos-cement transmission pipe must be sufficient to withstand the combined forces of all types of internal pressures (static, operating, and surge) and external loadings (earth, live, and impact). Sound engineering practice also requires that adequate safety factors be applied to strength requirements to ensure performance under other than ideal or calculated loading conditions. The magnitude of these safety factors is inversely proportional to the confifidence that the designer has in engineering estimates of actual operating conditions. Suggested safety factors based on experience are included under specific design factor subheadings.

2.1.1 *Bedding conditions.* The bedding conditions described in Fig. 1 have been selected as representative of typical installation conditions encountered in the field.

Descriptions of bedding conditions are as follows:

Class A—Gravel or sand base, backfill compacted. (Approximately 80% Standard Proctor, AASHTO T-99.)

Class B—Same as A, but backfill not compacted.

Class C—Pipe laid on earth mounds or pipe barrel on flat trench bottom with excavated coupling holes, backfill compacted. (Approximately 90% Standard Proctor, AASHTO T-9.)

Class D—Pipe barrel on flat trench bottom with excavated coupling holes, backfill not compacted.

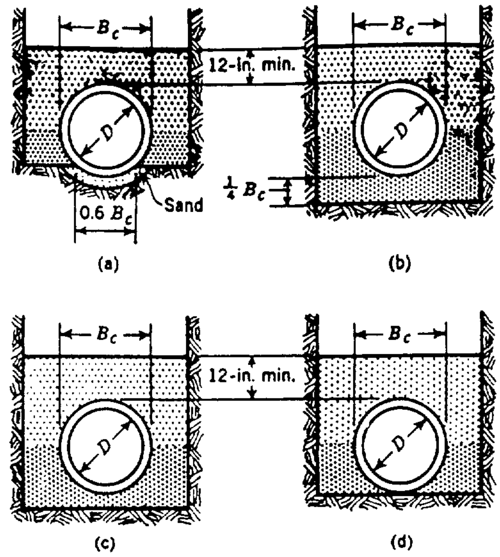


Fig. 1. Bedding Conditions

Class A bedding conditions are shown in (a) and (b). Class C conditions are shown in (c) and (d). In all four diagrams, the lightly shaded area represents approved backfill, not frozen and free from lumps, large stones, boulders, or other unsuitable substances. The heavily shaded areas represent approved backfill, carefully compacted in 4-in. layers.

In (a), a minimum of 2 in. of sand is placed in a shaped bottom under the pipe. In (b), the pipe is bedded in a gravel base. In (c), the pipe barrel rests on earth mounds and then the backfill between the earth mounds is compacted. In (d), the pipe barrel is resting on the flat bottom of the trench. Class B condition is the same as Class A, and Class D is the same as Class C except that the backfill is not compacted in B or D.

Sec. 2.2 Combined Loading Theory

Tests of asbestos-cement pipe under various combinations of internal pressure and external crush load applied in three-edge bearing (see Sec. 2.3) indicate that there is a relationship between the combined loads at the point of pipe fracture. This relationship can be represented by a parabolic curve as shown in Fig. 2. The equation for the load pressure parabolic curve, which is known as the Schlick formula, may be expressed as:

$$w_T = W\sqrt{\frac{P - p_T}{P}} \qquad \text{Eq 1}$$

in which,

P is the internal pressure, in pounds

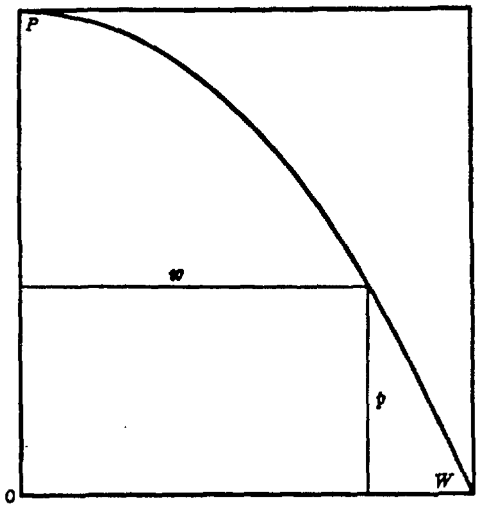


Fig. 2. Load Pressure Curve

P *represents the internal pressure;* W *the external load.*

per square inch, that will burst the pipe when no external load exists.

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

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

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

Sec. 2.3 Three-Edge Bearing Load

The combined loading curve shown in Fig. 2 is calculated on the basis of crush strengths determined by laboratory tests employing the three-edge bearing test method, which utilizes hardwood test blocks (Fig. 3). Because the field supporting strength of a pipe is influenced by the bedding conditions and by the lateral pressure acting against the sides of the pipe,

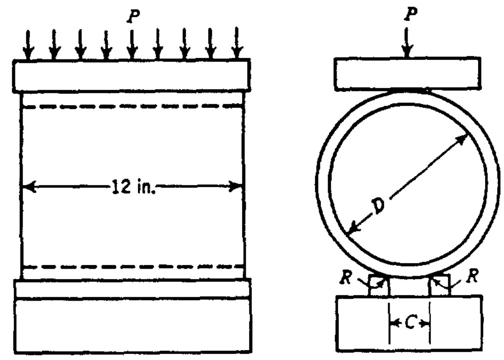


Fig. 3. Crushing Test Assembly

The diagram at the left shows a side view of the test assembly; that at the right, an end view. P *represents load;* R, *approximately 0.5 in.—the radius of the bearings;* D, *the nominal diameter of the pipe; and* C, *the clear space between supports.* C *should be approximately 1 in./ft of internal pipe diameter but in no case less than 1 in.*

it is necessary to apply a bedding load factor to the laboratory three-edge bearing loads to correlate them to the actual field loads. Since the external load equals the bedding factor times the three-edge bearing load, the bedding factor equals the external load divided by the three-edge bearing load. Table 1 shows bedding factors to be applied for each of the bedding conditions described in Fig. 1.

TABLE 1

Correlation of Bedding Conditions, Pipe Size, and Bedding Load Factors

Bedding Class	Pipe Size *in.*	Bedding Load Factor
A	18–20	1.8
	24–42	2.0
B	18–42	1.5
C	18–20	1.4
	24–42	1.5
D	18–42	1.1

Section 3—External Loads

Sec. 3.1 Introduction

For the design of asbestos-cement transmission pipe external loads (w_T) are defined by the following equation:

$$w_T = \frac{w_E + w_S}{B.F.}(S.F.) \qquad \text{Eq 2}$$

in which,

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

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

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

B.F. = the bedding load factor, which is a load factor correlating three-edge bearing test loads to field loads associated with specific bedding conditions. (For a more explicit explanation see Sec. 2.3.)

S.F. = the design safety factor specified by the design engineer. Safety factors are based on judgment, past experience, and sound engineering principles. For asbestos-cement transmission pipe, a design minimum safety factor of 1.5 is recommended for external loads.

Sec. 3.2 Earth Loads

Earth loads (w_E) to which pipe is subjected are a function of the soil density, pipe diameter, depth of cover, and construction techniques employed in laying the pipeline. They depend on the interplay between the weight of the prism of earth directly over the pipe, called the interior prism, and the frictional shearing forces, plus or minus, transferred to that interior prism by the adjacent outside prisms of earth. The magnitude of earth loads varies with the construction technique employed. There are two major construction techniques normally encountered: trench and embankment. Another technique, the tunnel condition, is not normally found, but nevertheless has unique design methods which make its inclusion in this discussion necessary. Fig. 4 shows these three construction techniques.

3.2.1 *Marston's equation.* For asbestos-cement transmission pipe design, earth loads are calculated by the general form of Marston's equation:

$$w_E = C w_e B^2 \qquad \text{Eq 3}$$

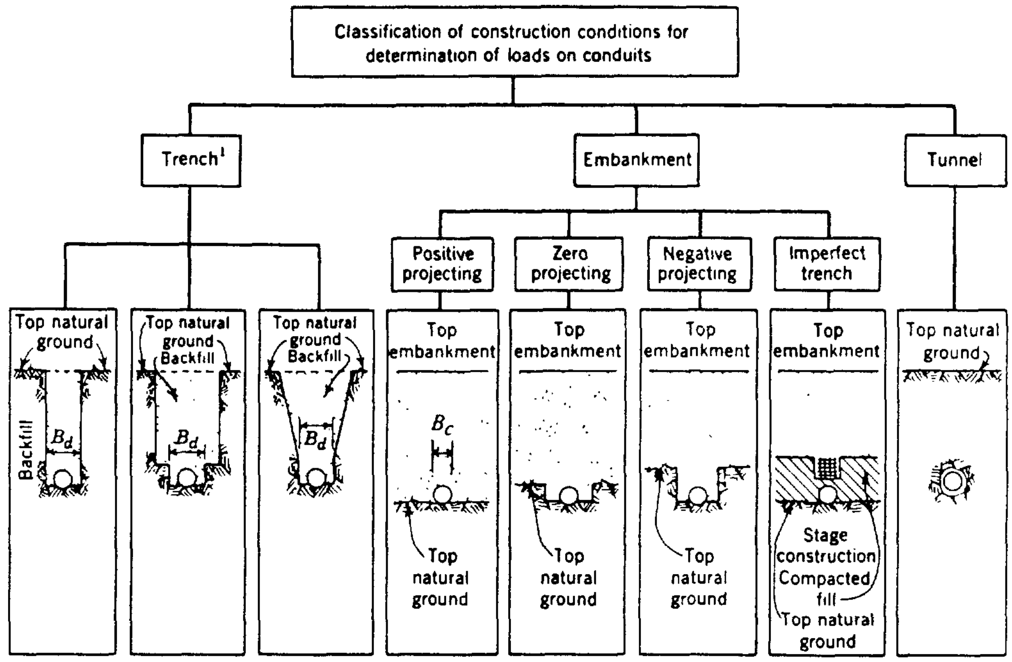
in which,

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

w_e = the soil density in pounds per cubic foot. Soil densities range in value from 100 to 135 lb/cu ft. In the absence of accurate soil density information, a value of 120 lb/cu ft is recommended for asbestos-cement transmission pipe design.

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

C = a coefficient that is dependent upon



[1] B_d within required limit, otherwise conduit is positive projecting

Fig. 4. Classification of Construction Techniques

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1. Ratio of the height of fill to the width of trench or pipe diameter.
2. Shearing forces between the interior and adjacent earth prisms.
3. Direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions.

The calculations used to find the value of the coefficient will depend on the installation conditions employed in laying the pipe.

Values for B and C must be determined to calculate earth loads by Eq. 3 for the trench, embankment, and tunnel construction techniques. The following subsections describe the different conditions and explain the methods for finding the values needed to use Marston's equation for soil loading.

3.2.2 *Trench condition.* A trench condition is defined as that in which the pipe is installed in a narrow trench, generally less than two to three diameters in width, cut in undisturbed ground and backfilled to the original ground surface, as illustrated in Fig. 4. For this condition, Eq 3 is rewritten as:

$$w_E = C_d w_e B_d^2 \qquad \text{Eq 4}$$

in which,

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

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

3.2.2.1 The values of C_d are obtained from Fig. 5, in which curves A, B, C, D, and E take into account the

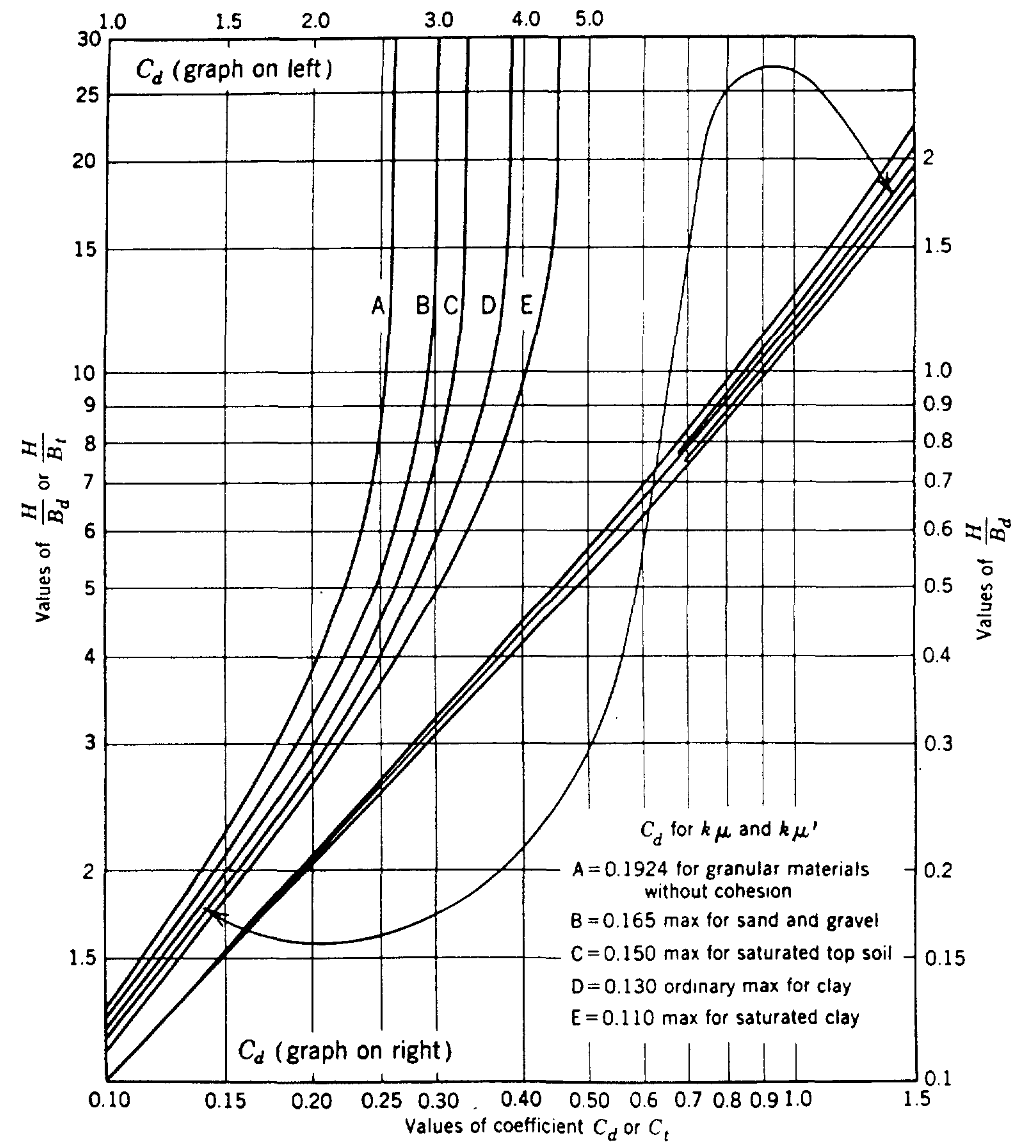

Fig. 5. Values of C_d for Trench Conditions

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friction coefficient between the backfill and the sides of the trench for the various soil compositions likely to be encountered. Curve *A* is for granular materials without cohesions. Curve *B* is for sand and gravel. Curve *C* is for saturated top soil. Curve *D* is for clay. Curve *E* is for saturated clay. Table 2 contains a series of earth load selection tables and is included as a convenience.

3.2.3 *Embankment condition.* An embankment condition is defined as either that condition where the pipe is installed in a trench that is wider than two to three pipe diameters and that is cut in undisturbed ground, or that condition where the pipe is

TABLE 2

Earth Loads (lb/lineal ft)

Note: Values are for clay (part D of Fig. 9, $K\mu = K\mu' = 0.130$) with weight of earth taken as 120 lb/cu ft. Correction for other earth weights may be made by simple direct proportions. For corrections for other types of soils, refer to formulas in Sec. 3. **Boldface** figures indicate maximum earth load for depth of trench.

Pipe size 18 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	2.5	2.75	3.0	3.25	3.5	4.0	4.5	5.0	5.5	
2	**490**									2 ft 5 in.
2.5	640	**640**								2 ft 8 in.
3	810	835								2 ft 10 in.
4	1 000	1 110	**1 240**							3 ft 1 in.
5	1 200	1 320	1 450	1 610	**1 640**					3 ft 5 in.
6	1 350	1 520	1 700	1 865	2 050					3 ft 8 in.
7	1 500	1 690	1 900	2 090	2 300					3 ft 10 in.
8	1 600	1 850	2 100	2 320	2 525	**2 825**				4 ft 0 in.
9	1 725	2 000	2 250	2 510	2 750	3 230				4 ft 1 in.
10	1 850	2 120	2 400	2 725	2 950	3 550	**3 635**			4 ft 3 in.
12	2 050	2 360	2 675	3 020	3 300	4 000	4 440			4 ft 5 in.
14	2 200	2 570	2 900	3 280	3 600	4 400	5 220			4 ft 7 in.
16	2 300	2 720	3 100	3 515	3 900	4 800	5 640	**6 040**		4 ft 9 in.
18	2 400	2 840	3 275	3 720	4 150	5 100	6 040	6 830		5 ft 0 in.
20	2 500	3 000	3 400	3 995	4 350	5 350	6 400	7 450	**7 620**	5 ft 2 in.

Pipe size 20 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	
2	**545**									2 ft 8 in.
2.5	705									2 ft 10 in.
3	870	**890**								3 ft 0 in.
4	1 110	1 250	**1 330**							3 ft 4 in.
5	1 320	1 450	1 610	**1 750**	**1 770**					3 ft 8 in.
6	1 520	1 700	1 865	2 050	2 210	**2 220**				3 ft 11 in.
7	1 690	1 900	2 090	2 300	2 515	2 655				4 ft 1 in.
8	1 850	2 100	2 320	2 525	2 765	3 000	**3 095**			4 ft 3 in.
9	2 000	2 250	2 510	2 750	3 040	3 300	3 545			4 ft 5 in.
10	2 120	2 400	2 725	2 950	3 240	3 650	3 980			4 ft 6 in.
12	2 380	2 675	3 020	3 300	3 660	4 000	4 660	**4 310**		4 ft 10 in.
14	2 570	2 900	3 280	3 600	4 050	4 400	5 200	5 760		5 ft 1 in.
16	2 720	3 100	3 515	3 900	4 350	4 800	5 640	6 450	**6 640**	5 ft 2 in.
18	2 840	3 275	3 720	4 150	4 620	5 100	6 040	7 060	7 500	5 ft 4 in.
20	3 000	3 400	3 995	4 350	4 860	5 350	6 400	7 450	8 410	5 ft 7 in.

TABLE 2—*Continued*

Pipe size 21 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	
2	**570**										2 ft 9 in.
2.5	745	**730**									2 ft 11 in.
3	870	915									3 ft 2 in.
4	1 110	1 250	**1 330**	**1 380**							3 ft 6 in.
5	1 320	1 450	1 610	1 750	**1 360**						3 ft 10 in.
6	1 520	1 700	1 865	2 050	2 210	**2 325**					4 ft 1 in.
7	1 690	1 900	2 090	2 300	2 515	2 700	**2 795**				4 ft 4 in.
8	1 850	2 100	2 320	2 525	2 765	3 000	3 250				4 ft 6 in.
9	2 000	2 250	2 510	2 750	3 040	3 300	3 725				4 ft 7 in.
10	2 120	2 400	2 725	2 950	3 240	3 550	4 140	**4 210**			4 ft 9 in.
12	2 360	2 675	3 020	3 300	3 660	4 000	4 660	5 160			5 ft 0 in.
14	2 570	2 900	3 280	3 600	4 050	4 400	5 200	6 000	**6 100**		5 ft 3 in.
16	2 720	3 100	3 515	3 900	4 350	4 800	5 540	6 450	7 020		5 ft 5 in.
18	2 340	3 275	3 720	4 150	4 620	5 100	6 040	7 050	7 950		5 ft 6 in.
20	3 000	3 400	3 995	4 350	4 880	5 350	6 400	7 450	8 460	**8 920**	5 ft 8 in.

Pipe size 24 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	
2	**630**										3 ft 1 in.
2.5	805	**810**									3 ft 3 in.
3	955	1 010	**1 010**								3 ft 5 in.
4	1 250	1 330	1 400	**1 490**							3 ft 9 in.
5	1 450	1 610	1 750	1 940	2 030						4 ft 1 in.
6	1 700	1 865	2 050	2 210	2 400	**2 550**					4 ft 5 in.
7	1 900	2 090	2 300	2 515	2 700	3 080					4 ft 8 in.
8	2 100	2 320	2 525	2 765	3 000	3 480	**3 620**				4 ft 10 in.
9	2 250	2 510	2 750	3 040	3 300	3 790	4 130				5 ft 0 in.
10	2 400	2 725	2 950	3 240	3 550	4 140	4 660	**4 660**			5 ft 2 in.
12	2 675	3 020	3 300	3 660	4 000	4 660	5 400	5 740			5 ft 5 in.
14	2 900	3 280	3 600	4 050	4 400	5 200	6 000	6 750	**6 800**		5 ft 8 in.
16	3 100	3 515	3 900	4 350	4 800	5 640	6 450	7 410	7 850		5 ft 11 in.
18	3 275	3 720	4 150	4 620	5 100	6 040	7 050	8 000	8 910		6 ft 1 in.
20	3 400	3 995	4 350	4 860	5 350	6 400	7 450	8 460	9 600	**10 000**	6 ft 2 in.

TABLE 2—*Continued*

Pipe size 27 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
2	**710**										3 ft 5 in.
2.5	895	**905**									3 ft 6 in.
3	1 040	1 095									3 ft 8 in.
4	1 330	1 400	**1 540**	**1 600**							4 ft 1 in.
5	1 610	1 750	1 940	2 050	**2 200**						4 ft 6 in.
6	1 865	2 050	2 210	2 400	2 735						4 ft 8 in.
7	2 090	2 300	2 515	2 700	3 110	**3 385**					5 ft 1 in.
8	2 320	2 525	2 765	3 000	3 480	3 900	**3 980**				5 ft 3 in.
9	2 510	2 750	3 040	3 300	3 790	4 300	4 590				5 ft 6 in.
10	2 725	2 950	3 240	3 550	4 140	4 700	5 190				5 ft 7 in.
12	3 020	3 300	3 660	4 000	4 660	5 400	6 060	6 390			6 ft 0 in.
14	3 280	3 600	4 050	4 400	5 200	6 000	6 750	7 550	**7 560**		6 ft 3 in.
16	3 515	3 900	4 350	4 800	5 840	6 450	7 410	8 300	8 800		6 ft 6 in.
18	3 720	4 150	4 620	5 100	6 040	7 050	8 000	9 000	9 960	10 000	6 ft 8 in.
20	3 995	4 350	4 860	5 350	6 400	7 450	8 460	9 600	10 890	11 180	6 ft 10 in.

Pipe size 30 in. ID

Trench Cover *ft*	Trench Width—*ft*									Transition Width
	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	
2	**755**									3 ft 7 in.
2.5	965									3 ft 10 in.
3	1 150	**1 185**								3 ft 11 in.
4	1 400	1 675	**1 680**							4 ft 5 in.
5	1 750	2 050	2 335	**2 340**						4 ft 8 in.
6	2 050	2 400	2 800	3 005						5 ft 0 in.
7	2 300	2 700	3 110	3 500	**3 665**					5 ft 5 in.
8	2 525	3 000	3 480	3 900	4 320					5 ft 7 in.
9	2 750	3 300	3 790	4 300	4 840	**4 980**				5 ft 10 in.
10	2 950	3 550	4 140	4 700	5 260	5 660				6 ft 1 in.
12	3 300	4 000	4 660	5 400	6 060	6 800	6 990			6 ft 5 in.
14	3 600	4 400	5 200	6 000	6 750	7 550	8 320	8 320		6 ft 9 in.
16	3 900	4 800	5 640	6 450	7 410	8 300	9 210	9 610		7 ft 0 in.
18	4 150	5 100	6 040	7 050	8 000	9 000	9 960	10 980	10 980	7 ft 3 in.
20	4 350	5 350	6 400	7 450	8 460	9 600	10 890	11 890	12 300	7 ft 5 in.

TABLE 2—*Continued*

Pipe size 33 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	
2	**810**										3 ft 10 in.
2.5	1 050	**1 060**									4 ft 1 in.
3	1 220	1 290									4 ft 3 in.
4	1 540	1 675	**1 815**								4 ft 6 in.
5	1 940	2 050	2 335	**2 445**							5 ft 1 in.
6	2 210	2 400	2 800	3 050	**3 205**						5 ft 5 in.
7	2 515	3 000	3 110	3 500	3 920	**3 925**					5 ft 8 in.
8	2 705	3 300	3 480	3 900	4 460	**4 640**					6 ft 1 in.
9	3 040	3 550	3 790	4 300	4 840	5 400	**5 610**				6 ft 3 in.
10	3 240	4 000	4 140	4 700	5 260	5 000	6 070				6 ft 5 in.
12	3 660	4 400	4 660	5 400	6 060	6 800	7 450	**7 550**			6 ft 10 in.
14	4 050	4 800	5 200	6 000	6 750	7 550	8 350	9 030			7 ft 2 in.
16	4 350	5 100	5 640	6 450	7 410	8 300	9 210	10 110	**10 470**		7 ft 5 in.
18	4 620	5 350	6 040	7 050	8 000	9 000	9 960	11 060	12 120		7 ft 9 in.
20	4 860	5 575	6 400	7 450	8 460	9 600	10 890	11 890	13 020	**13 390**	7 ft 11 in.

Pipe size 36 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	
2	**920**	**925**									4 ft 3 in.
2.5	1 130	1 145									4 ft 4 in.
3	1 325	1 550									4 ft 7 in.
4	1 675	1 950	**1 950**								4 ft 11 in.
5	2 050	2 335	2 555	**2 555**							5 ft 3 in.
6	2 400	2 800	3 050	3 340	**3 340**						5 ft 8 in.
7	2 700	3 110	3 500	3 920	4 160						6 ft 0 in.
8	3 000	3 480	3 900	4 460	4 900	**4 950**					6 ft 2 in.
9	3 300	3 790	4 300	4 840	5 400	5 760	**5 760**				6 ft 8 in.
10	3 550	4 140	4 700	5 260	5 900	6 430	6 540				6 ft 10 in.
12	4 000	4 660	5 400	6 060	6 800	7 450	8 150	**8 150**			7 ft 4 in.
14	4 400	5 200	6 000	6 750	7 550	8 350	9 170	9 750	**9 750**		7 ft 8 in.
16	4 800	5 640	6 450	7 410	8 300	9 210	10 110	11 000	11 330		7 ft 11 in.
18	5 100	6 040	7 050	8 000	9 000	9 960	11 060	12 150	12 900	**12 900**	8 ft 2 in.
20	5 350	6 400	7 450	8 460	9 600	10 890	11 890	13 020	14 140	14 510	8 ft 6 in.

TABLE 2—*Continued*

Pipe size 39 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	
2	**990**										4 ft 5 in.
2.5	1 290										4 ft 7 in.
3	1 520	**1 580**									4 ft 9 in.
4	1 950	2 220	**2 340**								5 ft 2 in.
5	2 335	2 555	2 980								5 ft 6 in.
6	2 800	3 050	3 340	**3 680**							5 ft 10 in.
7	3 110	3 500	3 920	4 320	**4 500**						6 ft 3 in.
8	3 480	3 900	4 460	4 900	5 360						6 ft 7 in.
9	3 790	4 300	4 840	5 400	5 760	**6 430**					6 ft 11 in.
10	4 140	4 700	5 260	5 900	6 430	7 170	**7 440**				7 ft 3 in.
12	4 660	5 400	6 060	6 800	7 450	8 150	8 980	9 310			7 ft 8 in.
14	5 200	6 000	6 750	7 550	8 350	9 170	9 750	11 090			8 ft 1 in.
16	5 640	6 450	7 410	8 300	9 210	10 110	11 000	11 980	**12 830**		8 ft 5 in.
18	6 040	7 050	8 000	9 000	9 960	11 060	12 150	12 900	14 330		8 ft 8 in.
20	6 400	7 450	8 460	9 600	10 890	11 890	13 021	14 140	15 260	**16 130**	8 ft 11 in.

Pipe size 42 in. ID

Trench Cover *ft*	Trench Width—*ft*										Transition Width
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	
2	**1 060**										4 ft 8 in.
2.5	1 390										4 ft 10 in.
3	1 700										5 ft 0 in.
4	2 220	**2 350**									5 ft 4 in.
5	2 555	3 080									5 ft 8 in.
6	3 050	3 340	**3 930**								6 ft 1 in.
7	3 500	3 920	4 320	**4 690**							6 ft 5 in.
8	3 900	4 460	4 900	5 600							6 ft 10 in.
9	4 300	4 840	5 400	5 760	**6 630**						7 ft 2 in.
10	4 700	5 260	5 900	6 430	7 170	**7 730**					7 ft 6 in.
12	5 400	6 060	6 800	7 450	8 150	8 980	9 830				8 ft 0 in.
14	6 000	6 750	7 550	8 350	9 170	9 750	10 940	11 550			8 ft 5 in.
16	6 450	7 410	8 300	9 210	10 110	11 000	11 980	13 580			8 ft 10 in.
18	7 050	8 000	9 000	9 960	11 060	12 150	12 900	14 390	**15 250**		9 ft 1 in.
20	7 450	8 460	9 600	10 880	11 890	13 020	14 140	15 260	16 430	**16 830**	9 ft 4 in.

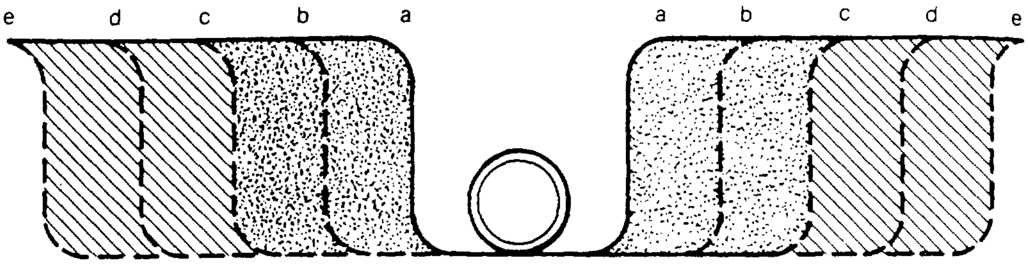

Fig. 6. Embankment Conditions

aa *and* bb *The trench width is less than the transition width; earth loads are computed by the trench equation (Eq 4).*
cc *The trench width is the transition width; earth loads are computed by either Eq 4 or Eq 5.*
dd *and* ee *The trench width is greater than the transition width; earth loads are computed by the positive projecting pipe embankment equation (Eq. 5). For a given depth of cover the earth loads resulting from trench widths* cc, dd, *and* ee *are equal.*

covered with fill above the original ground surface. Embankment conditions are further subdivided into positive and negative projecting pipe categories, depending on the location of the top of the pipe relative to the original undisturbed ground. A special case where compressible material is used as part of the backfill, called an imperfect trench, also is classified as an embankment condition. The various embankment conditions are illustrated in Fig. 6.

3.2.4 *Positive projecting pipe embankment condition.* A positive projecting pipe condition is defined as either that condition where the pipe is installed in a trench cut in undisturbed ground that is wider than two to three pipe diameters, or that condition where the top of the pipe is above the adjacent original ground surface and covered with fill above the original ground surface. For this condition, Eq 3 is rewritten as:

$$w_E = C_c w_e B_c^2 \qquad \text{Eq 5}$$

in which,

B_c = the pipe outside diameter in feet.

C_c = the load coefficient, which is a function of the ratio H/B_c, the projection ratio p, and the settlement ratio r_{sd}.

3.2.4.1 The values of C_c are obtained from Fig. 7. C_c also may be obtained from Eq 6 when the following conditions exist simultaneously:

1. The ratio H/B_c is greater than 1.3.
2. The product $p(r_{sd}) = 0.7$.

$$C_c = 1.892H/B_c - 0.96 \qquad \text{Eq 6}$$

3.2.4.2 The projection ratio p is defined as the ratio of the distance that the top of the pipe projects above the original ground surface to the pipe outside diameter. The recommended value for the settlement ratio r_{sd} is +0.7 for asbestos-cement transmission pipe design.

3.2.5 *Transition width.* It will be noted from the preceding discussion that under construction conditions where a trench is cut in undisturbed ground two methods of computing the earth load are available: (1) the trench condition, and (2) the positive projecting pipe embankment condition. The method chosen is de-

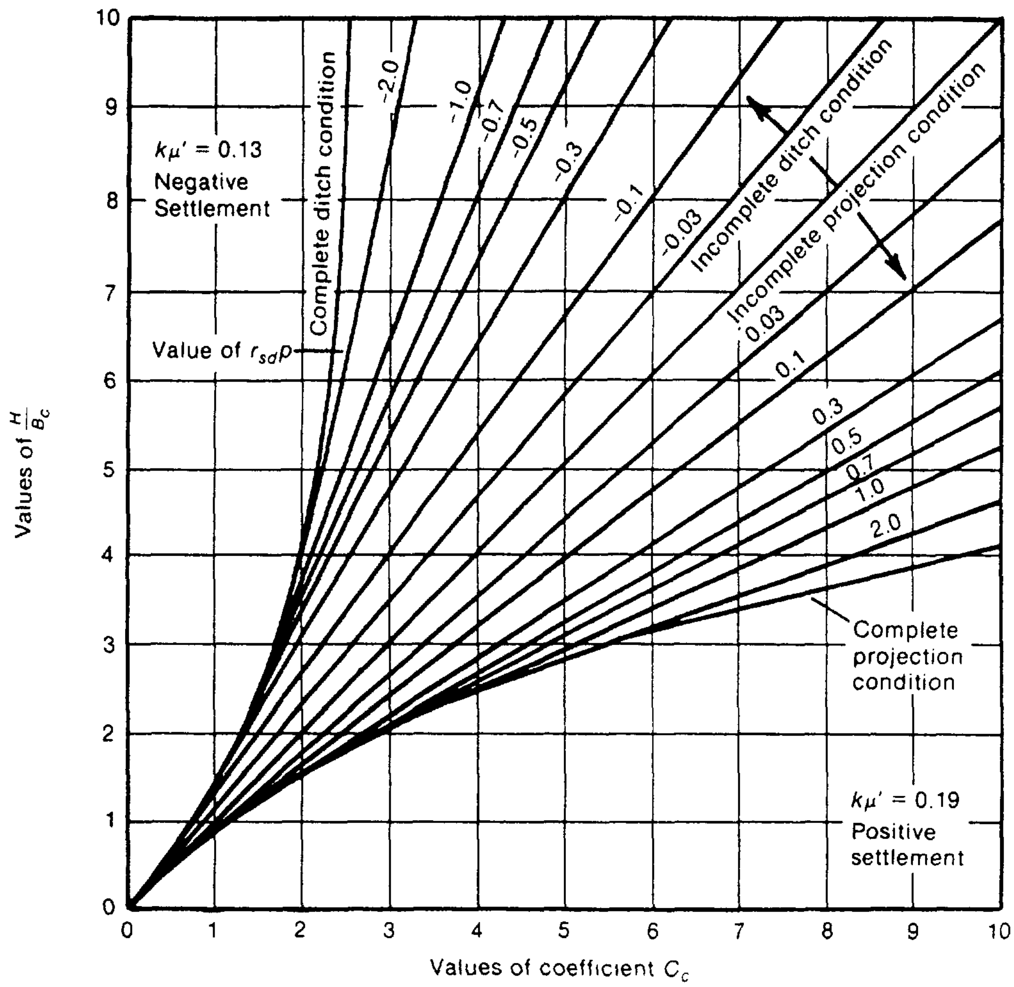

Fig. 7. Values of C_c for Positive Projecting Pipe

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pendent on the ratio of the trench width to the pipe diameter. As previously stated, when the trench width is less than two to three times the pipe diameter, earth loads are computed by the trench condition equation (Eq 4). The width of trench at which both methods of computation give equal loads is called the *transition width*. The earth load computed at the transition width is theoretically the maximum external earth load that can be transmitted to the pipe for any given depth of cover. For all trench widths greater than the transition width, earth loads are computed by the positive projecting pipe embankment condition equation (Eq 5). In this latter case and for a given depth of cover, the earth loads are equal to the load that results at the transition width and that is computed by the trench condition equation (Eq 4). [See Fig. 6.]

3.2.5.1 The transition width is determined from Fig. 8 by multiplying

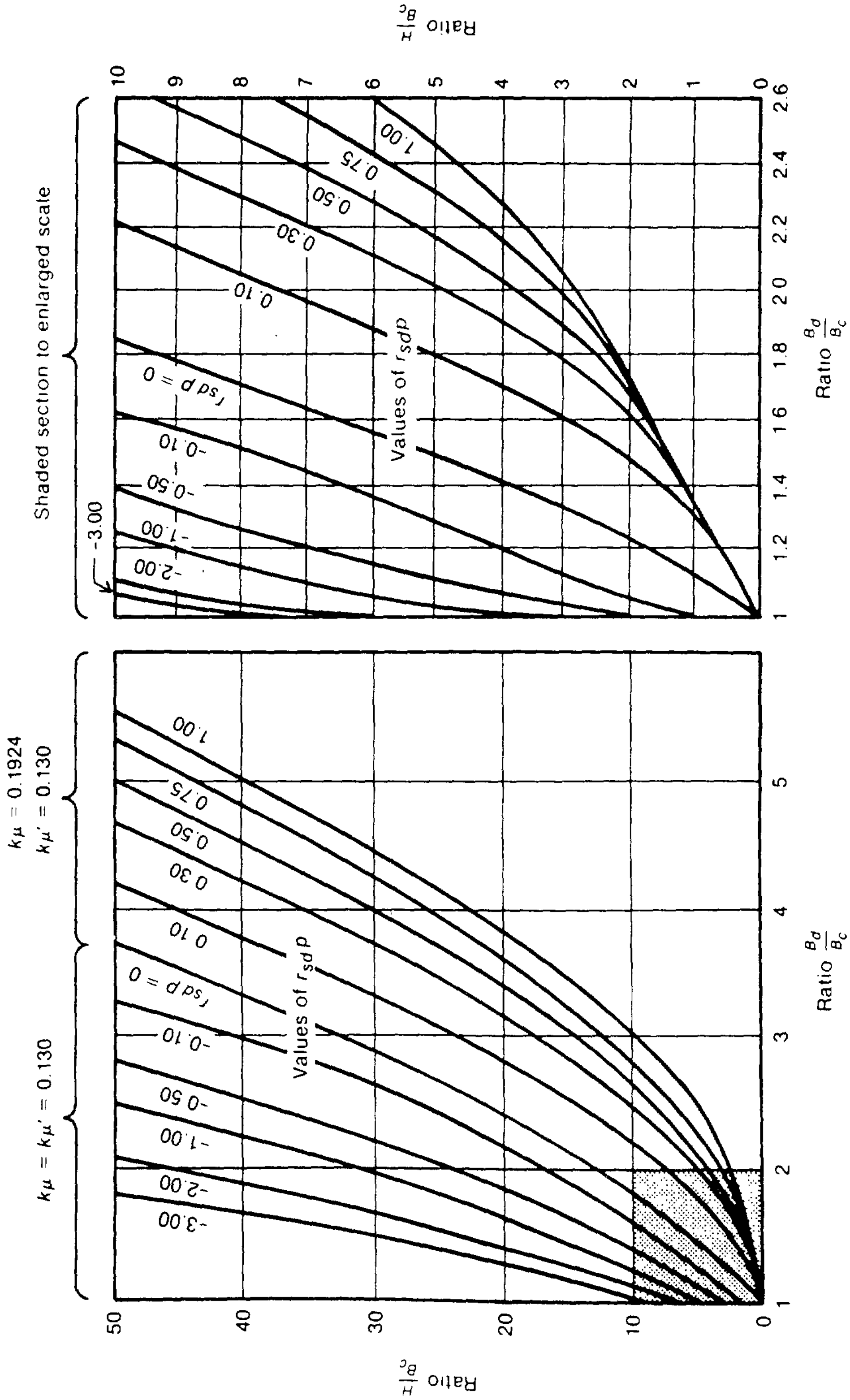

Fig. 8. Values of B_c/B_d at Which the Trench and Positive Projecting Pipe Equations Give Equal Loads

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the applicable ratio B_d/B_c by the applicable pipe outside diameter (B_c). The applicable ratio of trench width to pipe outside diameter (B_d/B_c) can be obtained from Fig. 8 for any given ratio of backfill height to pipe outside diameter (H/B_c).

3.2.6 *Negative projecting pipe embankment condition.* A negative projecting pipe condition is defined as that condition where the pipe is installed in a relatively shallow trench wherein the top of the pipe is at some elevation below the original ground surface. The trench is then backfilled and compacted, and embankment is constructed thereon to finished grade (Fig. 4). For this condition, Eq 3 is rewritten as

$$w_E = C_n w_e B_d^2 \qquad \text{Eq 7}$$

in which,

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

C_n = the load coefficient which is a function of the ratio H/B_d, the projection ratio p, and the settlement ratio r_{sd}.

3.2.6.1 The various values of C_n are obtained from Fig. 9. The projection ratio p is defined as the ratio of the vertical distance from the original ground surface down to the pipe top to the trench width, B_d. (See Fig. 10.) For asbestos-cement transmission pipe design the recommended value for the settlement ratio r_{sd} is zero.

3.2.6.2 When calculating earth loads under negative projecting pipe embankment conditions, consideration must be given to the transition width as defined in paragraph 3.2.5. For values of the ratio B_d/B_c less than those given in Fig. 8, the load on a pipe is determined from Eq 7 for negative projecting pipes. However, as the trench width increases and the ratio B_d/B_c becomes greater than that given in Fig. 8, the earth load should be determined from Eq 5 for positive projecting pipes. Adherence to the preceding rule will result in the most realistic earth loads for design purposes.

3.2.7 *Imperfect trench embankment condition.* The imperfect trench embankment condition occurs rather infrequently and is included for general information. The imperfect trench embankment condition refers to that construction technique wherein the pipe is first installed as a positive projecting pipe. A portion of the embankment is then built up to some elevation above the pipe top and thoroughly compacted as it is placed. A trench the same width as the pipe is then excavated directly over the pipe down to or near to its top and subsequently backfilled with loose compressible material. The remainder of the embankment is then built up to final elevation (Fig. 11). For this condition, Eq 3 is rewritten as

$$w_E = C_n w_e B_c^2 \qquad \text{Eq 8}$$

in which,

B_c = the pipe outside diameter in feet.

C_n = the load coefficient which is a function of the ratio H/B_c, the projection ratio p, and the settlement ratio r_{sd}.

3.2.7.1 The various values of C_n are obtained from Fig. 9. The projection ratio p is defined as the ratio of the vertical distance from the top of the excavated trench down to the pipe top to the pipe diameter (Fig. 11). For asbestos-cement transmission pipe design the recommended

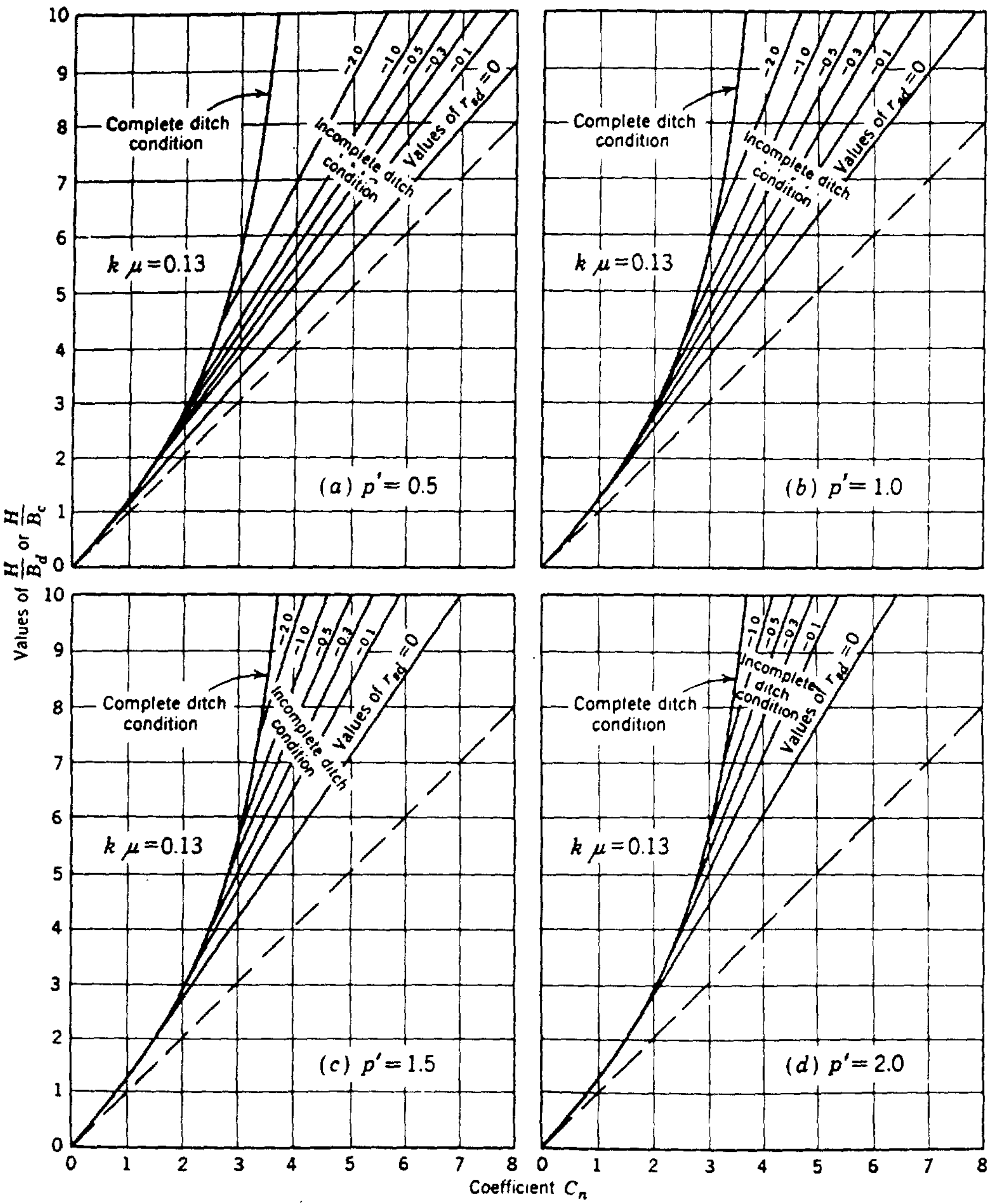

Fig. 9. Values of C_n for Negative Projecting Pipe and Imperfect Ditch Conditions

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value for the settlement ratio r_{sd} is equal to -0.3.

3.2.8 *Tunnel conditions.* There are two types of tunnel construction encountered in normal pipe laying operation.

3.2.8.1. The first type is the most frequently encountered and occurs when a sleeve of a larger diameter than the specified pipe is first jacked through an embankment. The pipe is then placed into the sleeve without

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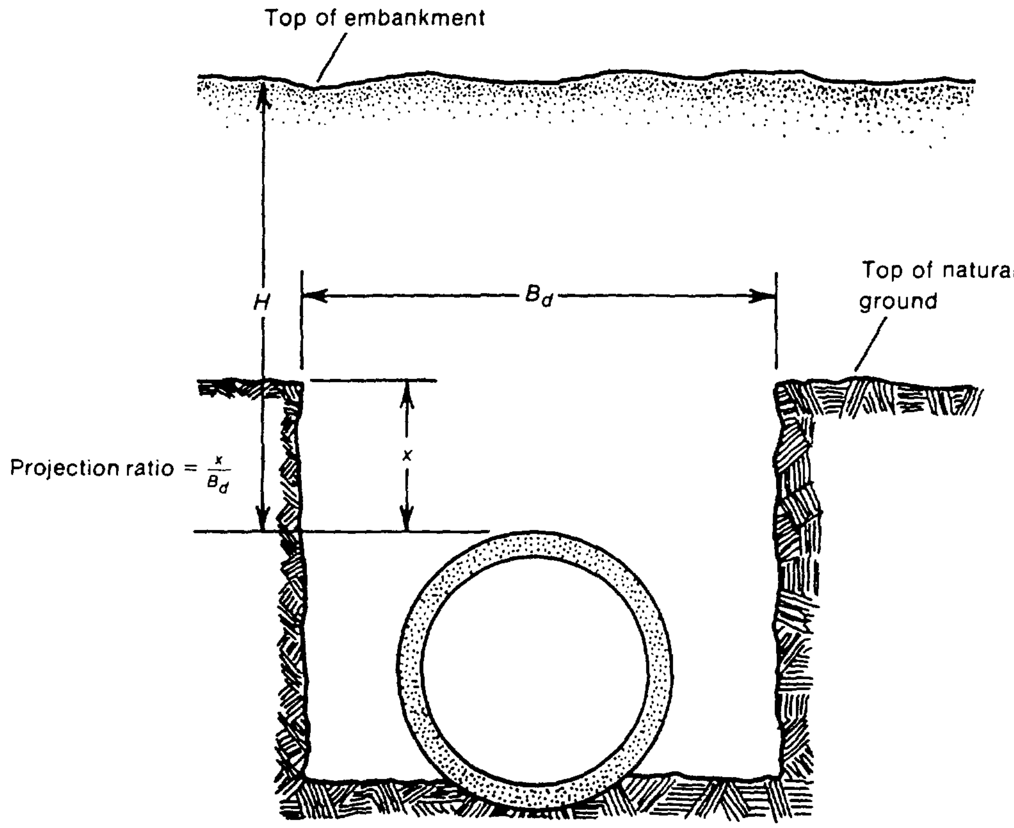

Fig. 10. Projection Ratio p for the Negative Projecting Pipe Embankment Condition

becoming an integral part of the tunnel construction. In this example the sleeve supports the entire earth load and the pipe contained therein is not subjected to crushing loads. When selecting the required pipe classification for this condition, only the internal pressure needs to be considered for design.

3.2.8.2. The second type of tunnel condition is rarely encountered in transmission work but is discussed here for completeness. It occurs when the pipe itself must carry the entire load. The area through which the pipeline must pass is bored and braced with the necessary supports. The pipe then is placed in the tunnel and the void between the pipe and tunnel braces is backfilled with compacted earth, grout, or concrete. Once this operation is completed, the earth load automatically transfers from the tunnel supports to the pipe itself. For this condition, Eq 3 is rewritten as

$$w_E = C_T B_T (w_e B_T - 2c) \qquad \text{Eq 9}$$

in which,

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

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

C_T = the load coefficient which is a function of the coefficient of internal fraction for the material of the tunnel and of the ratio H/B_T, where H is the distance from the ground surface to the top of the tunnel in feet and B_T equals the width of the tunnel excavation in feet.

Projection ratio = $\frac{x}{B_c}$

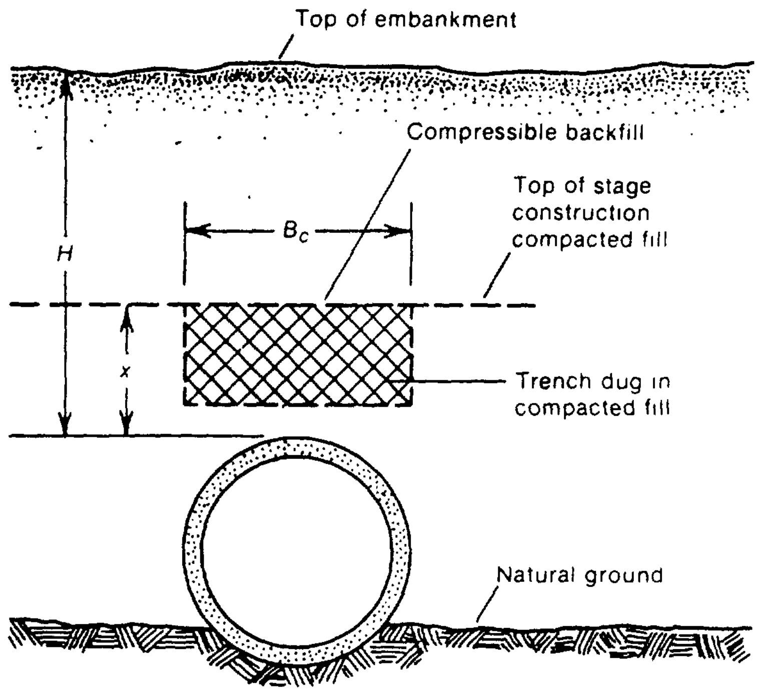

Fig. 11. Projection Ratio *p* for the Imperfect Trench Embankment Condition

3.2.8.3 Values of C_T for different types of soil are obtained from Fig. 12. If the value for the coefficient of cohesion is not available from laboratory tests, then the recommended safe design values in Table 3 are to be used.

TABLE 3

Recommended Safe Design Values of c *for Tunnel Conditions*

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

3.2.8.4 When, in tunnel construction, the excavation becomes excessive, or when the void surrounding the pipe or tunnel lining is not carefully filled, or when the cohesion of the undisturbed material above the tunnel construction is destroyed by soil saturation or vibration, the earth load should be calculated by Eq 4 for trench conditions. Since it can be exceedingly difficult to either predict or assess whether the tunnel excavation is excessive, it is recommended that Eq 4 be used for most installations for safe asbestos–cement transmission pipe design.

3.2.8.5 It should be noted that the preceding discussion is based on the premise that the tunnel would be constructed in homogenenous soils that do not create unusual pressures and stresses. If the tunnel is constructed through materials that tend to squeeze or swell, such as some types of clay or shale, or through blocky and seamy rock, then methods other than tunnel construction must

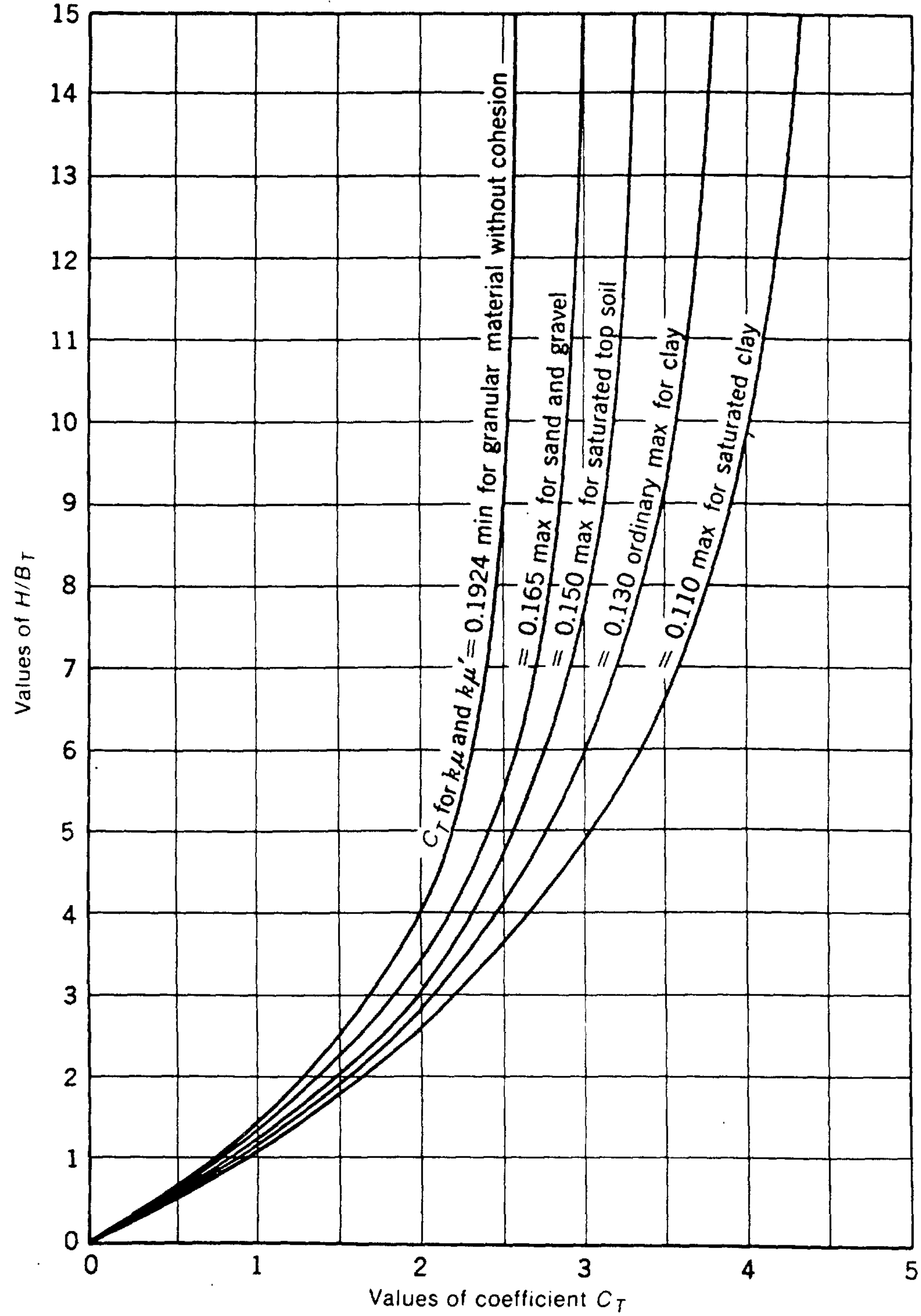

Fig. 12. Values of C_T for Tunnel Conditions

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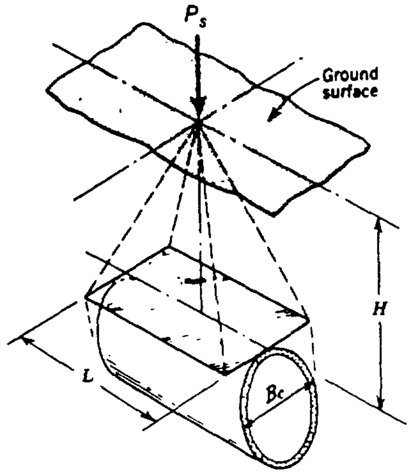
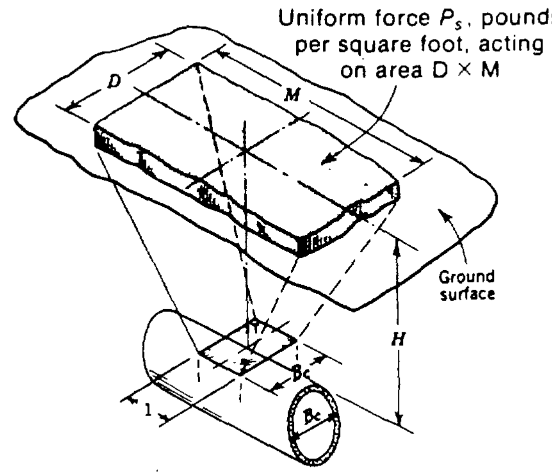


Concentrated superimposed load, w_{S1}, vertically centered over pipe.



Distributed superimposed load, w_{S2}, vertically centered over pipe.

Fig. 13. Superimposed Loads

be utilized. The method of installation that is used is the responsibility of the engineer who is in charge of construction.

Sec. 3.3 Superimposed Loads

Superimposed loads w_S are external loads other than the normal earth loads transmitted to the pipe. There are two types of superimposed loads as illustrated in Fig. 13: (1) concentrated w_{S1}, and (2) distributed w_{S2}. Superimposed loads are frequently referred to as live loads.

3.3.1 *Concentrated loads.* A concentrated load is a load caused by a single force which may be either static or dynamic in nature. In normal pipe design, vehicular wheel loads are the most frequently encountered concentrated loads. The magnitude of the load produced by concentrated superimposed forces is determined by

$$w_{S1} = \frac{C_s P_t F}{L} \qquad \text{Eq 10}$$

in which

w_{S1} = the load on a pipe caused by a concentrated superimposed force in pounds per linear foot of pipe. (For convenience, concentrated superimposed loads resulting from a 16,000-lb wheel force are presented in Table 6.)

P_t = the concentrated force in pounds. The American Association of State Highway and Transportation Officials (AASHTO) design manual gives loads for various sizes and types of vehicles.

F = the impact factor. American Association of State Highway and Transportation Officials (AASHTO) vehicular wheel loads are shown in Table 4. Impact factors vary from one locale to another and values that are consistent with local, state, and federal specifications should be chosen.

L = the effective pipe length in feet. For pipe less than three feet, the actual length of the section should be used. For all other pipe lengths an effective length of three feet should be used.

TABLE 4

Impact Factors

Depth of Cover *ft*	Impact Factor *F*
1.0–2.0	1.2
2.0—3.0	1.1
3.0 or greater	1.0

C_s = the load coefficient, which is a function of the depth of cover to the top of the pipe and the nominal inside diameter of the pipe. Values of C_s are obtained from Table 5.

3.3.2 *Distributed load.* A distributed load is a load caused by a uniform force distributed equally over a given area. The load may be either static or dynamic in nature. The magnitude of the load produced by distributed forces is determined by

$$w_{S2} = C_s P_s F\ B_c \qquad \text{Eq 11}$$

in which,

w_{S2} = the load on a pipe caused by distributed superimposed force in pounds per linear foot of pipe.

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

F = the impact factor as explained in paragraph 3.3.1.

B_c = the pipe diameter in feet.

C_s = the load coefficient, which is a function of the depth of cover to the top of the pipe and the nominal inside diameter of the pipe. Values of C_s are obtained from Table 5.

3.3.3. *Illustrative problem.* An 18-in. asbestos-cement transmission pipe is to be installed in a 3-ft wide trench under 8 ft of cover. The backfill is ordinary clay with a weight of 120 lb/cu ft. Determine the earth load on the pipe.

SOLUTION: The load must be computed two ways using the Marston equations for the trench condition and for the projecting pipe condition.

a. Trench condition Eq 4:

$$w_E = C_d w_e (B_d)^2$$

$$\frac{H}{B_d} = \frac{8}{3} = 2.7 \quad \text{(approximately 3)}$$

$$C_d = 1.9 \quad \left(\text{from Fig. 5 and } \frac{H}{B_d}\right)$$

$$w_E = (1.9)(120)(3)^2 = 2100 \text{ lb/ft}$$

TABLE 5

Values of Load Coefficients C_s for Concentrated and Distributed Superimposed Loads Centered Vertically Over Conduit

Pipe size, ID—*in.*	Depth of Cover *ft*										
	2	2½	3	4	5	6	8	10	12	16	20
18	0.391	0.289	0.221	0.136	0.092	0.066	0.038	0.025	0.017	0.010	0.006
20	0.422	0.316	0.241	0.150	0.102	0.073	0.042	0.027	0.019	0.011	0.007
21	0.436	0.327	0.251	0.157	0.107	0.077	0.044	0.029	0.020	0.012	0.007
24	0.478	0.362	0.280	0.177	0.120	0.087	0.050	0.033	0.022	0.013	0.008
27	0.510	0.392	0.306	0.195	0.133	0.096	0.056	0.037	0.025	0.014	0.008
30	0.543	0.423	0.332	0.213	0.147	0.106	0.062	0.041	0.029	0.016	0.010
33	0.563	0.446	0.353	0.230	0.159	0.115	0.067	0.045	0.032	0.018	0.011
36	0.590	0.470	0.375	0.248	0.171	0.124	0.073	0.049	0.035	0.020	0.012
39	0.615	0.502	0.404	0.272	0.191	0.140	0.083	0.054	0.041	0.026	0.015
42	0.619	0.516	0.422	0.286	0.202	0.147	0.089	0.063	0.043	0.030	0.017

NOTE: For convenience, concentrated superimposed loads resulting from a 16,000-lb wheel force are presented in Table 6.

TABLE 6

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Concentrated Superimposed (Wheel) Load on Asbestos-Cement Transmission Pipe
Single Wheel = 16,000 lb (H-20 Wheel Load)

Cover Over Top of Pipe *ft*	Pipe Diameter *in.*									
	18	20	21	24	27	30	33	36	39	42
2	2083*	2251	2364	2545	2720	2896	2992	3149	3280	3301
2½	1541	1682	1728	1939	2091	2256	2368	2510	2677	2752
3	1178	1286	1334	1494	1632	1723	1878	2000	2154	2250
4	725	800	837	944	1040	1136	1224	1321	1450	1525
5	490	544	570	640	710	784	845	912	1018	1077
6	352	389	410	464	512	566	611	662	747	784
8	203	224	234	267	299	330	357	390	443	475
10	133	144	154	176	197	219	240	261	288	336
12	91	100	105	117	133	155	170	187	219	229
16	53	59	64	69	75	85	96	107	139	160
20	32	37	40	43	45	53	60	63	80	91

* Values shown are in pounds per linear foot of pipe.
NOTE: Table is based on impact factor of one. If different impact is to be used, simply multiply value from table times desired impact factor.

b. Projecting pipe condition Eq 5:

$$w_E = C_c w_e (B_c)^2$$
$$B_c = 18 \text{ in. pipe } OD = 1.7 \text{ ft}$$
$$C_c = 1.892(H/B_c) - 0.96$$
$$= 1.892(8/1.7) - 0.96 = 8$$
$$w_E = (8)(120)(1.7)^2 = 2800 \text{ lb/ft}$$

c. The engineer, knowing the job conditions and degree of inspection, should decide which load applies.

Section 4—Hydrostatic Pressure

Sec. 4.1 Introduction

For the design of asbestos-cement transmission pipe, the internal hydrostatic pressure p_T is defined by

$$p_T = (P_o + P_s)S.F. \qquad \text{Eq 12}$$

in which,

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

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

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

$S.F.$ = the design safety factor specified by the purchaser. Safety factors are based on judgment, past experiences, and sound engineering principles. For asbestos-cement trans-

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mission pipe design, a minimum safety factor of 2.0 is recommended.

For simplicity in design and selection of asbestos-cement transmission pipe, the internal pressure may be separated into two components: (1) operating pressure, and (2) water hammer or surge pressure. Each will be determined separately.

Sec. 4.2 Operating Pressure

The operating pressure P_o is that pressure which exists under normal or steady conditions of operation. The pressure may be induced by pumps, gravity (such as the head created by a reservoir or elevated water tank), or a combination of both pumps and gravity. Under a 100 percent gravity situation, the pressure in the line at a given point is somewhat higher when there is no flow and conditions are static. Under static conditions the pressure at a given point, measured in feet of head, is equal to the difference between the elevation of that point and the water surface level at the reservoir. Under flowing conditions the pressure at a given point is reduced by the amount of friction and other energy losses resulting from the flow of water from the reservoir to that point. The magnitude of this head loss may be found by using the Hazen and Williams chart in Appendix A. In piping systems that have long runs with relatively few fittings and accessories, the recommended value of C (coefficient of flow) is 140.

Sec. 4.3 Surge Pressure

Surge pressures P_s are of a transient nature and are caused by unsteady or changing conditions in the pipeline. The terms "water hammer," "surge," or "transient pressure" are often used interchangeably to refer to these pressures, which are of brief duration but often of considerable magnitude. A variety of conditions may cause surge pressures. These include a valve opening or closing, sudden movement of air in a line, or a pump starting or stopping. Transient pressures are often a controlling factor in the selection of pipe strength. For this reason, a pipe system should always be analyzed for surge pressure determinations and the results should be used in pipe selection.

4.3.1. *Surge control.* There are numerous methods for control of surge pressures in the line. Consideration should be given to use of these methods to limit pressures to an acceptable level. Economics plays a major role in this area. Various designs may have to be balanced, depending on the complexity of the system, to yield an economical and efficient design.

4.3.1.1 Appendix B presents a discussion of water hammer with emphasis on how it may be analyzed and controlled. Although the subject is discussed in some detail, and an illustrative problem is included that involves controlling surge pressure by timing a valve closure, the subject is too complex to be thoroughly covered in this standard. It is suggested that control of surge for any transmission system be discussed with surge control equipment manufacturers or consultants in this particular field. The effects of surge in a pipeline, however, should not be ignored, as neglect of this factor may result in severe damage to the system. Also, because of the number of variables involved in creating water hammer pressures, and because of the ability to regulate their magnitude with proper controls, it is not recommended that fixed water hammer allowances based on assumed velocity changes or some other single criterion be used for the larger diameter transmission and feeder main lines.

Section 5—Pipe Selection

Sec. 5.1 Combined Loading Curves

As discussed previously, it has been demonstrated satisfactorily by tests that asbestos-cement transmission pipe conforms generally to the Schlick formula for combined loading (Sec. 2.2). Numerous tests have established values for P, internal hydrostatic design pressure with no crush load applied, and for W, external crush design load with no internal pressure applied, for all diameters and strength classifications. These values represent the end points on the combined loading curves; the intermediate points on the curves are computed by use of the Schlick formula. (It should be noted that all values used for P and W represent a conservative interpretation of the test data.) On the curves, each intermediate point—w_T, p_T—represents a combination of crush loading and internal pressure that the pipe will withstand when the loads are applied simultaneously.

5.1.1 *Selection curves.* Selection curves in Fig. 14a–14j are presented for each size of pipe from 18 through 42 in. On the graph for each pipe diameter, a combined loading curve is drawn for each strength classification of that pipe size. The vertical axis represents the internal hydrostatic design pressure P, and the horizontal axis represents the external three-edge bearing crush design load W. Table 7 lists the values of P and W for the strength classifications of each pipe size. In Sec. 5.3, Use of Selection Charts for Economical Design, the method for pipe selection is outlined.

Sec. 5.2 Safety Factors

Safety factors are normally applied by the engineer to his computed design values of crush- and internal pressure that are to be resisted by the pipe in service. These factors protect against unforeseen loads that may be placed on the line at some time in the future, and against other contingencies such as improper construction. It is the engineer's prerogative to select which safety factors he feels should apply to a given system. Considerable field experience as well as extensive laboratory work has yielded a wealth of information on the behavior of asbestos-cement transmission pipe. For this reason, suggestions for minimum safety factors are made in Table 8. Note that, since the combined loading principle is applicable, the safety factors will be applied to both hydro and crush simultaneously. Note also that water hammer and live load, which are both transient load conditions, are considered as acting simultaneously for design purposes here. Since the likelihood of both occurring at the same time is minimal, an additional conservative element is introduced into the design.

Sec. 5.3 Use of Selection Charts for Economical Design

After all loads on the pipe have been computed (operating pressure, water

TABLE 7

Design Internal Pressure and Design External Load† Intercepts for Use With Selection Curves for the Following Pipe Classifications*

Pipe Size in.	30	35	40	45	50	60	70	80	90
	$P^* = 300$	$P = 350$	$P = 400$	$P = 450$	$P = 500$	$P = 600$	$P = 700$	$P = 800$	$P = 900$
	W†	W	W	W	W	W	W	W	W
18	2 500	3 000	4 000	5 000	6 500	8 500	11 000	14 000	18 000
20	2 500	3 500	4 500	5 500	7 100	9 500	12 000	15 000	20 000
21	2 500	3 500	4 500	5 800	7 300	9 700	12 500	16 000	21 000
24	2 800	3 800	5 000	6 200	8 100	11 000	15 000	19 000	24 000
27	3 500	4 200	5 500	7 000	8 800	12 500	16 500	20 500	27 000
30	3 500	4 500	6 000	7 500	9 700	13 500	18 000	22 500	30 000
33	3 500	5 000	6 500	8 000	10 500	14 500	19 500	24 500	33 000
36	4 000	5 000	7 000	9 000	11 200	16 000	21 000	26 000	36 000
39	4 200	5 300	7 500	9 700	12 000	17 200	22 500	28 000	39 000
42	4 300	5 700	8 000	10 500	13 000	18 500	24 000	30 000	42 000

* *P*—psi.
† *W*—lb/lin ft.

hammer, earth load, and live load), the most economical strength of pipe to meet the service conditions should be selected. The applicable selection procedure using the suggested safety factors is:

1. Add operating pressure and water hammer, $P_o + P_s$ (Sec. 4).
2. Add earth load and live load, $w_E + w_S$ (Sec. 3).
3. Enter the combined loading graph for the appropriate pipe diameter. Plot the values from Steps 1 and 2 above as one point. When using the left-hand scales, be sure to multiply the *operating pressure plus water hammer* by the suggested safety factor of 2.0. When using the bottom scale, be sure to multiply the *earth load plus live load* by the suggested safety factor of 1.5, and then to divide it by the bedding factor (Sec. 2.3).
4. The point plotted will lie between the curves for two pipe strengths. Select the higher strength of the two. This represents the most economical selection consistent with engineering requirements.

TABLE 8

Minimum Safety Factors for Use With Asbestos-Cement Transmission Pipe Selection

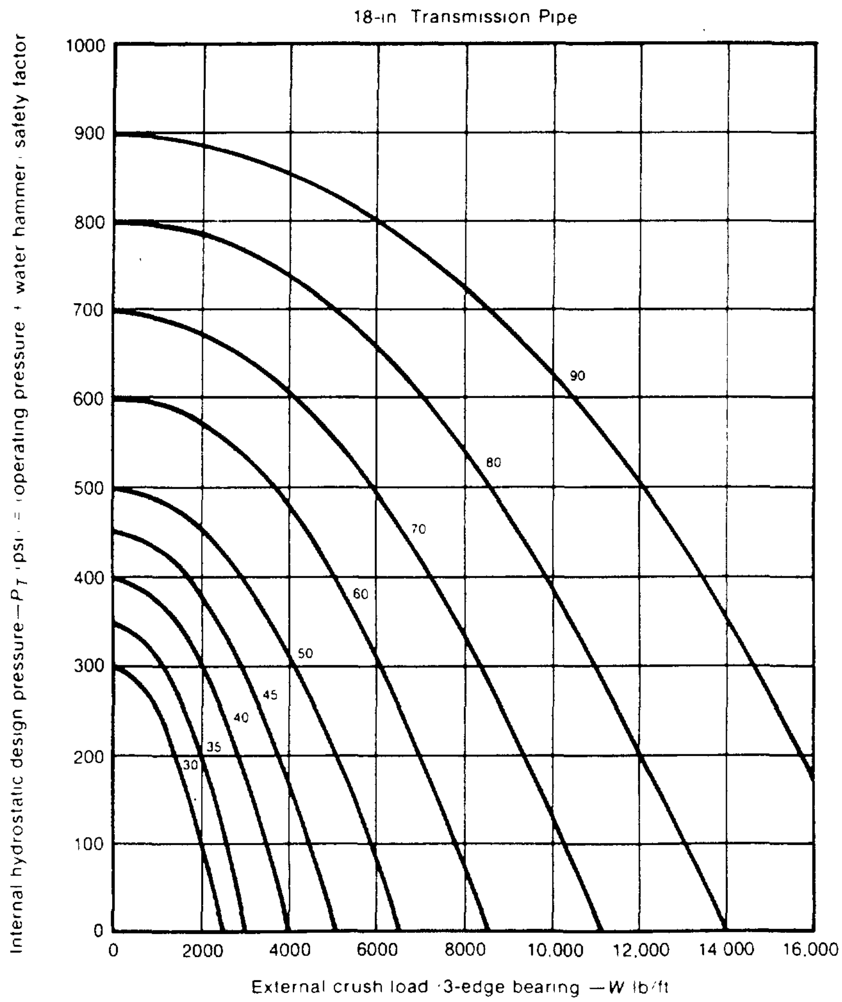
Type of Load	Safety Factor	
	Hydro	Crush
Operating pressure plus water hammer, combined with earth load plus live load	2.0	1.5

Sec. 5.4 Illustrative Problem on Pipe Selection

A 24-in. asbestos-cement transmission line is to be installed in a 4-ft wide trench with 5 ft of cover. The operating pressure will be 100 psi. Surge pressures will be limited to a maximum of 50 psi. A 16,000-lb wheel load is to be assumed, with an impact factor = 1. Class C bedding will be used. Select the proper strength of pipe to be used with safety factors of 2.0 in hydro ($P_o + P_s$) and 1.5 in crush ($w_E + w_S$).

Solution: Following instructions for use of selection charts with safety factors as described in Sec. 5.3 gives

1. $P_o + P_s = 100 + 50 = 150$ psi
2. $w_E + w_S = 2030 + 640 = 2670$ lb/ft
3. $(P_o + P_s)(S.F.) = 150 \times 2.0 = 300$ psi
4. $\dfrac{(w_E + w_S)(S.F.)}{B.F.} = \dfrac{(2670)(1.5)}{1.5} = 2670$ lb/ft
5. Consult the combined loading chart for 24-in. pipe, using the left hand and bottom scales. Plot the two loads as a single point on the chart. The point falls between T-40 and T-45. Use T-45.



W_T = earth load + live load $\frac{\text{Safety factor}}{\text{Bedding factor}}$

Fig. 14a. Combined Loading Curves for 18-in. Transmission Pipe

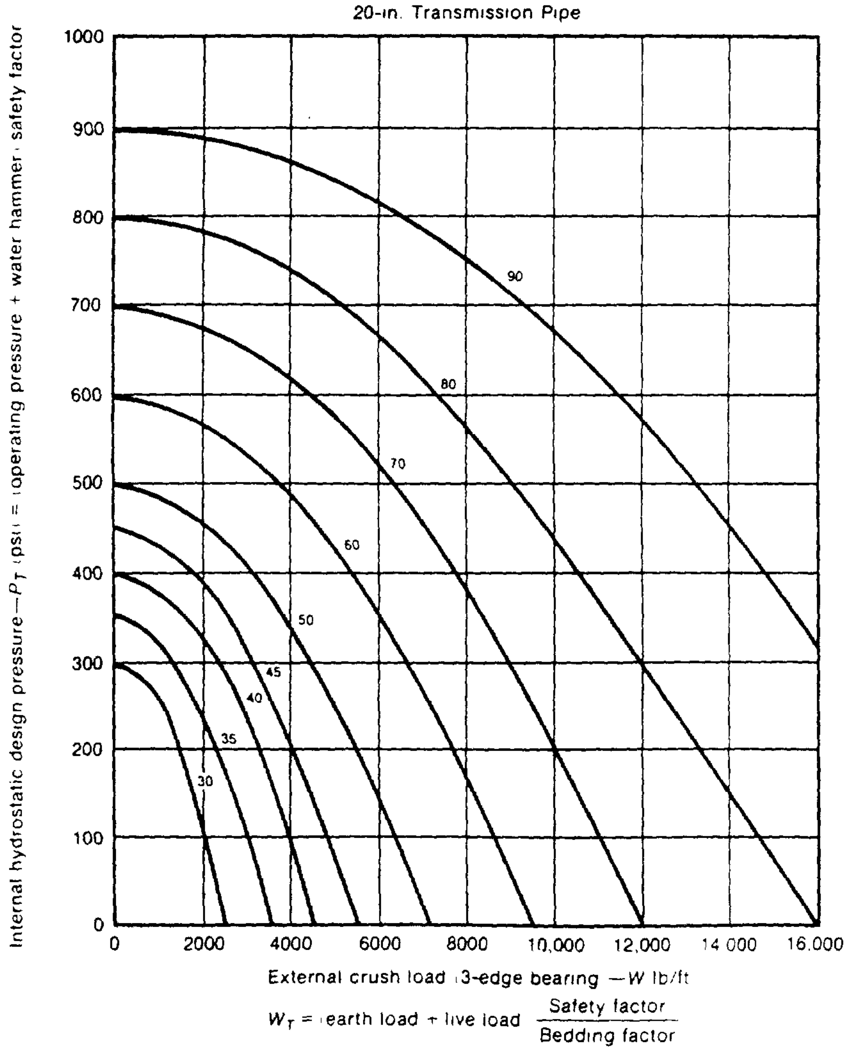


Fig. 14b. 20-in. Transmission Pipe

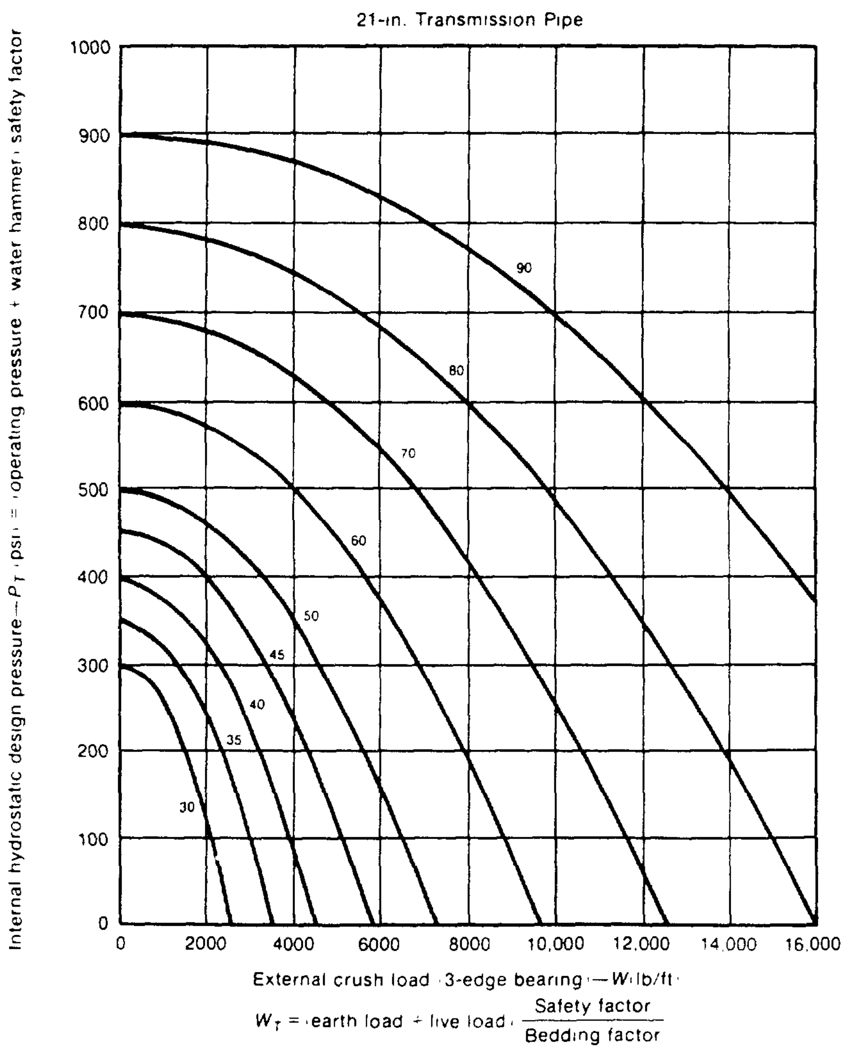


Fig. 14c. 21-in. Transmission Pipe

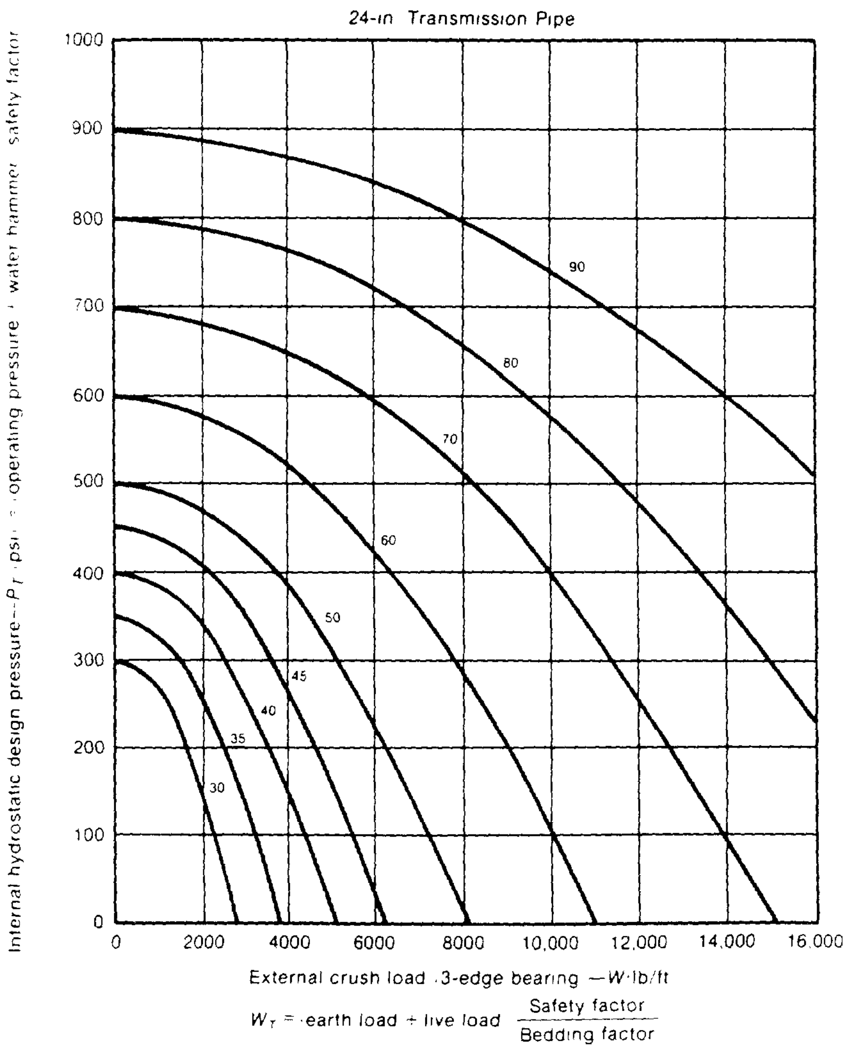
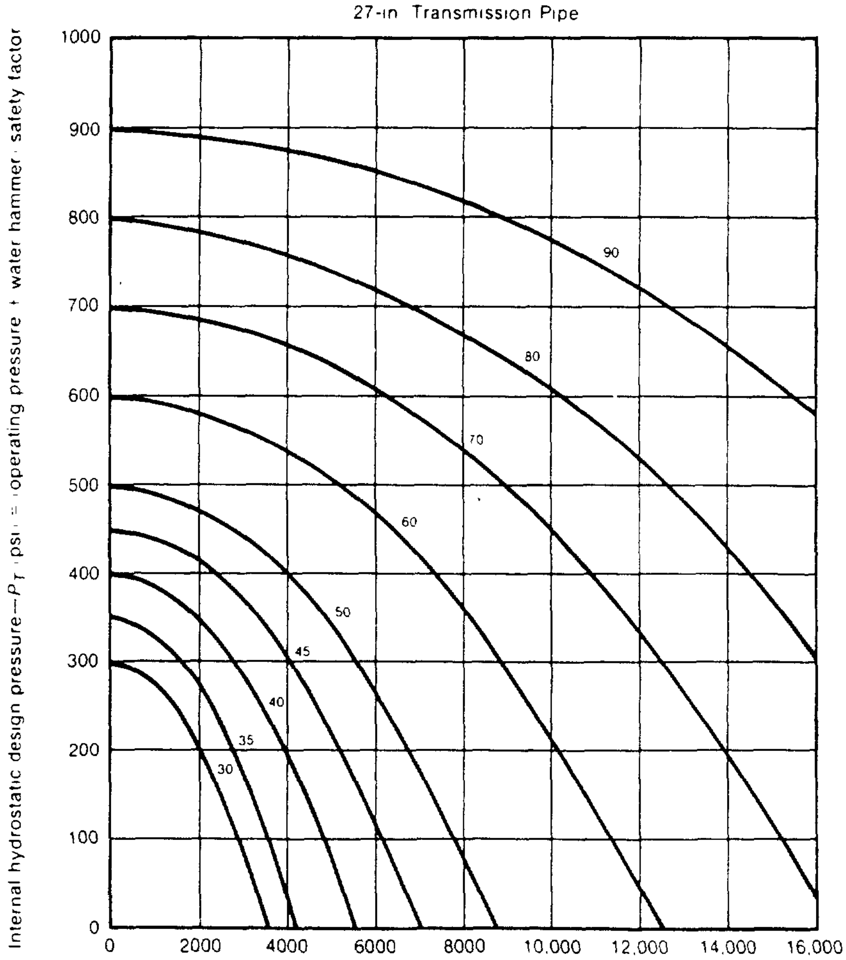


Fig. 14d. 24-in. Transmission Pipe

27-in Transmission Pipe



W_T = (earth load + live load) $\frac{\text{Safety factor}}{\text{Bedding factor}}$

Fig. 14e. 27-in. Transmission Pipe

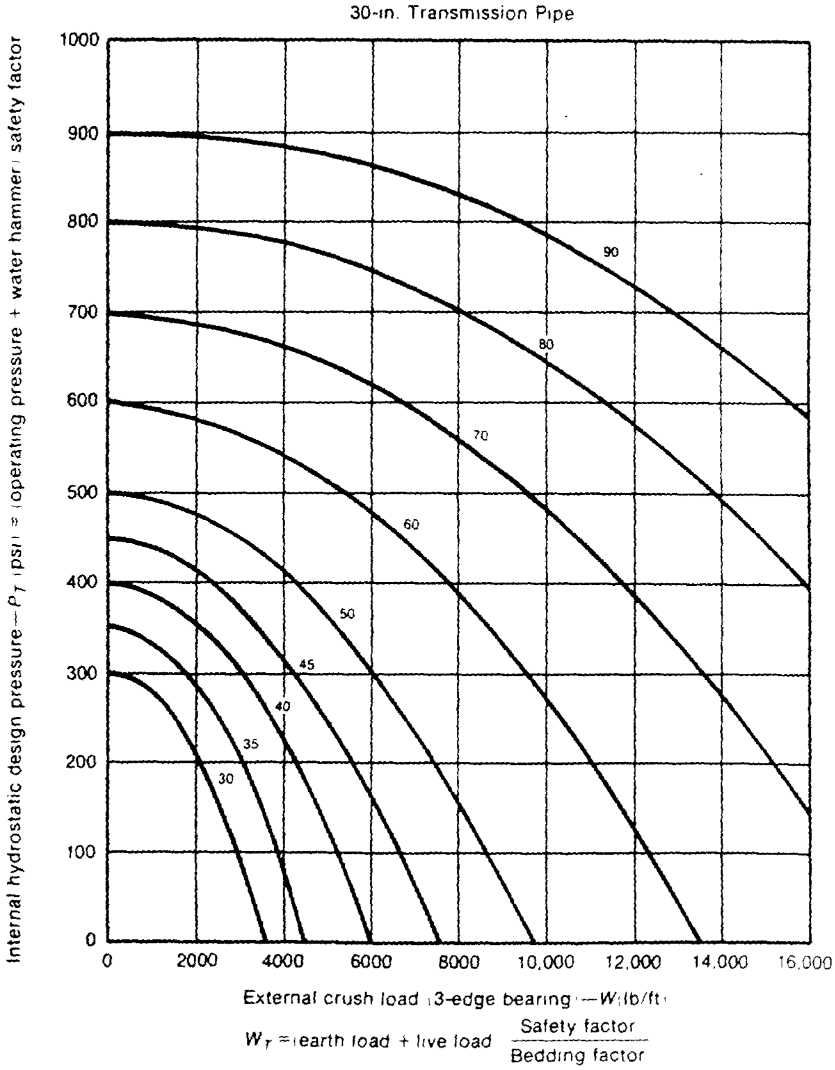


Fig. 14f. 30-in. Transmission Pipe

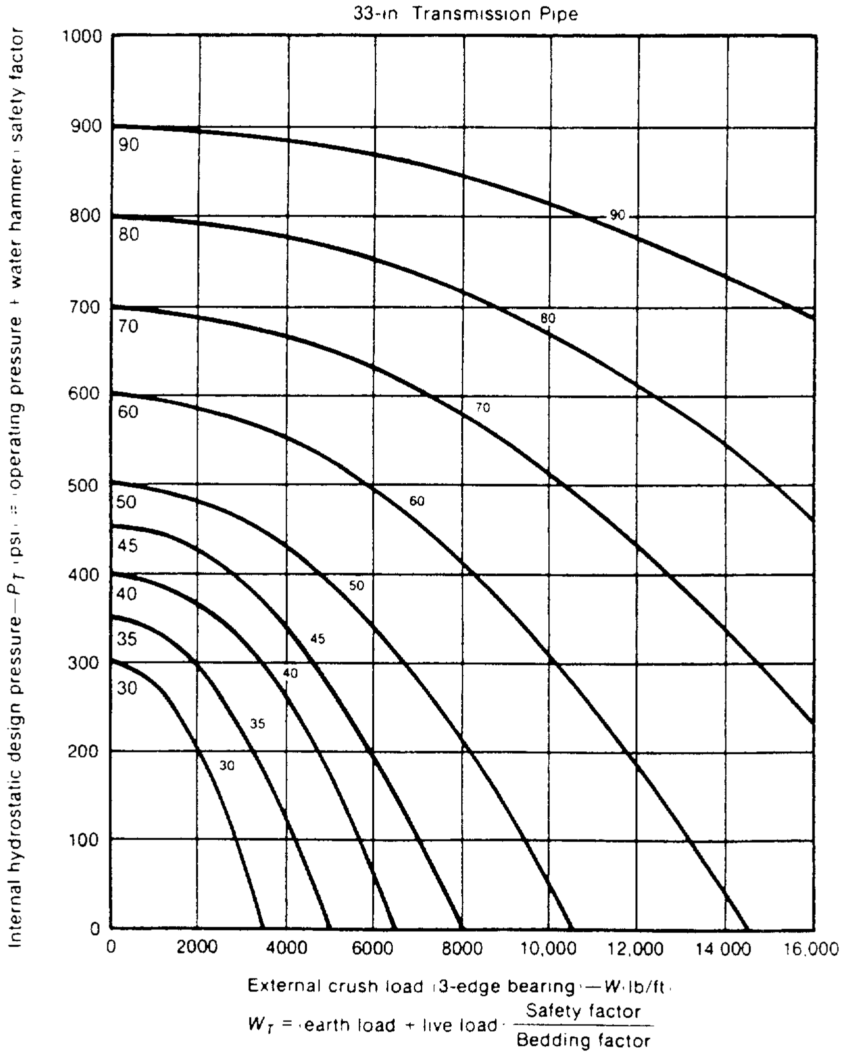


Fig. 14g. 33-in. Transmission Pipe

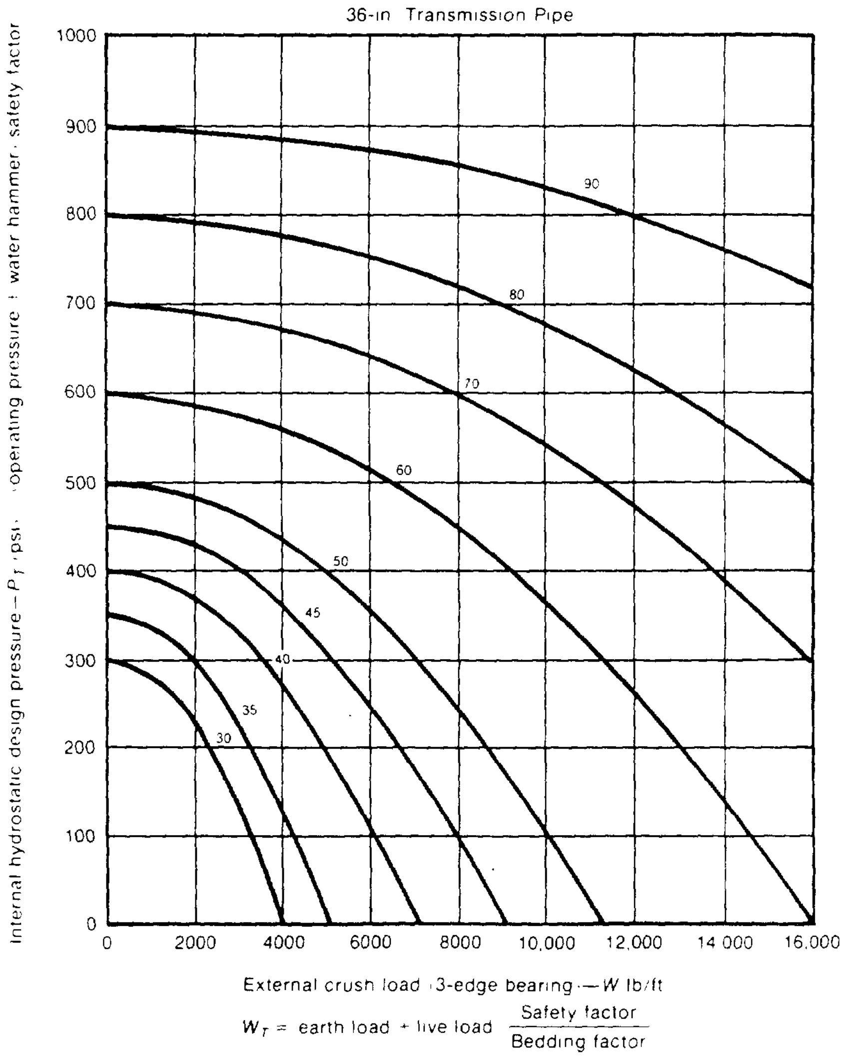


Fig. 14h. 36-in. Transmission Pipe

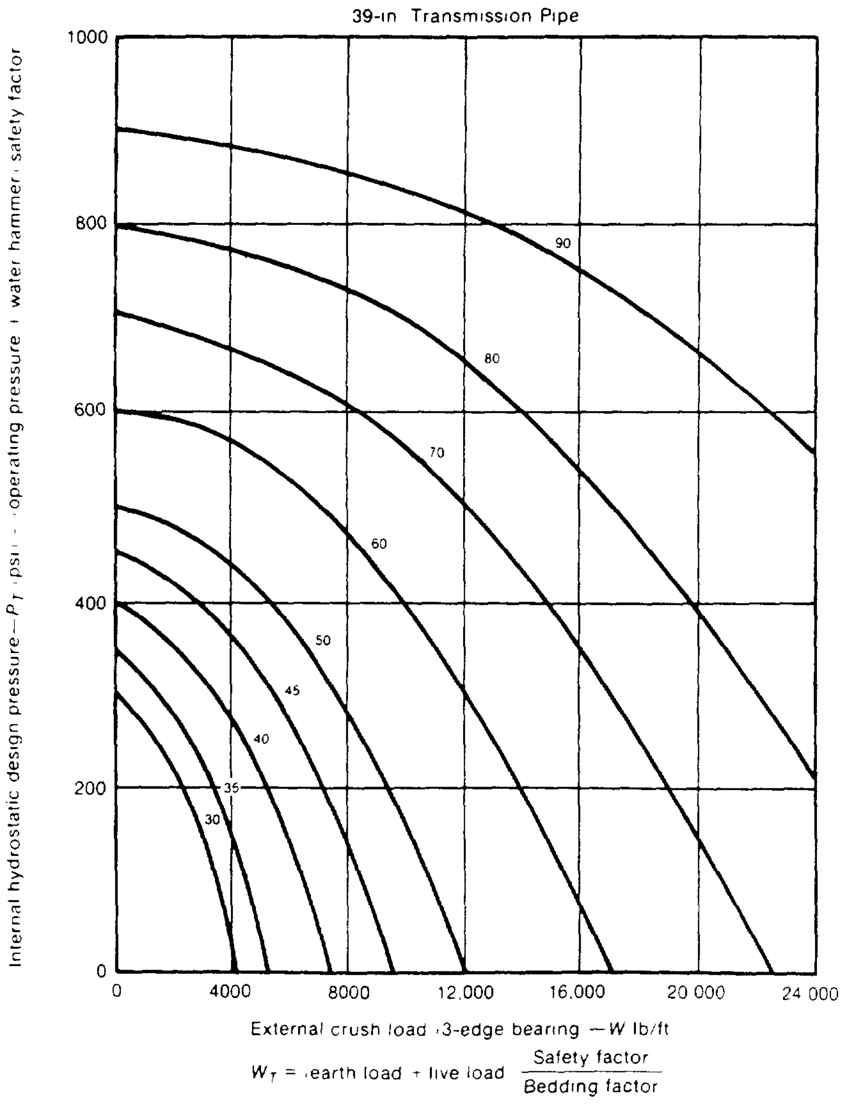


Fig. 14i. 39-in. Transmission Pipe

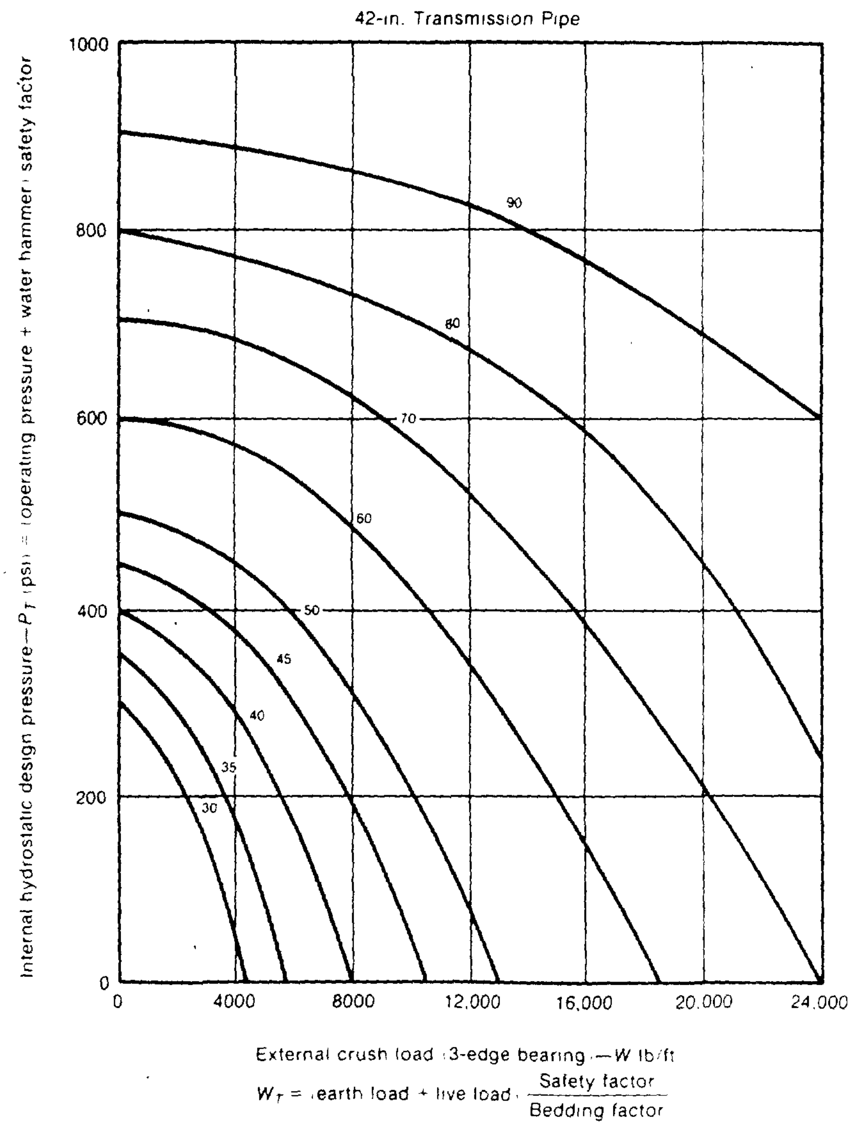


Fig. 14j—42-in. Transmission Pipe

Appendix A

Friction Loss of Head Chart—Coefficient of Flow, C = 140

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Derived from the Hazen and Williams formula: $V = 1.318\, C R^{0.63} S^{0.54}$

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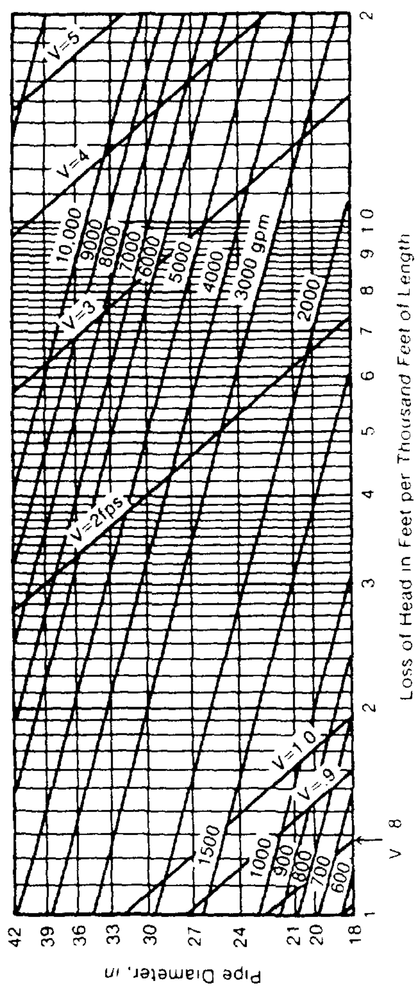
NOTE. Loss of head values derived from this chart are for coefficient of flow C = 140. They may be converted to loss of head for other coefficients of flow by means of the following multiplying factors:

1.15 for C = 130
1.34 for C = 120
1.57 for C = 110
1.86 for C = 100
2.26 for C = 90
2.83 for C = 80
4.82 for C = 60

NOTE: Diameters derived from this chart are for coefficient of flow C = 140. These may be converted to diameters for other coefficients of flow by means of the following multiplying factors:

1.033 for C = 130
1.063 for C = 120
1.100 for C = 110
1.142 for C = 100
1.185 for C = 90
1.261 for C = 80
1.365 for C = 60



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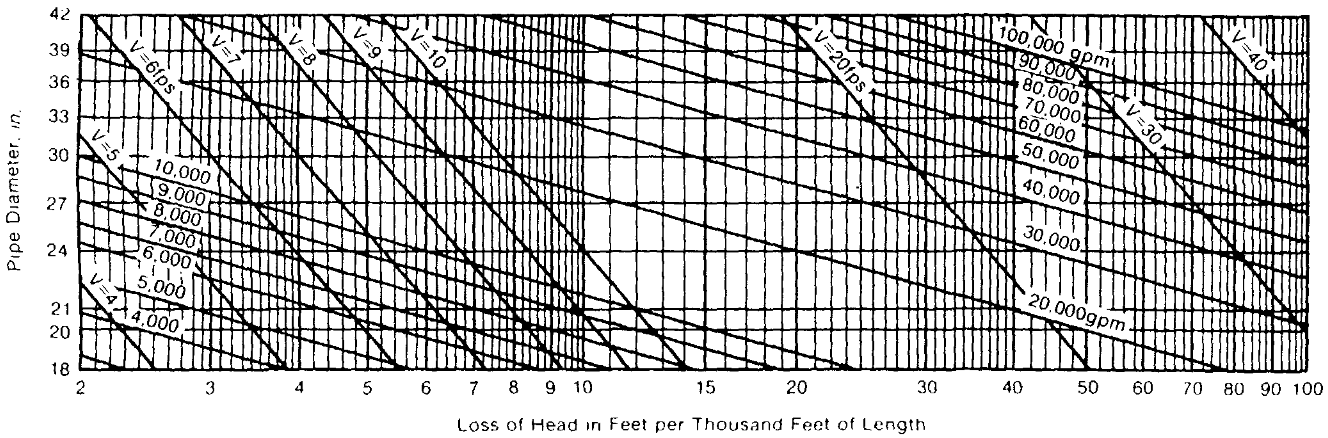
1.185 for C = 90
1.261 for C = 80
1.365 for C = 60



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Appendix B

Surge Pressure Analysis

This appendix is for information only and is not a part of AWWA C403.

B.1 Water Hammer or Surge

The slowing down or stopping of any moving mass requires a force or forces to counterbalance the kinetic energy that keeps the mass in motion. The faster a mass is decelerated and brought to a halt, the greater the force that is required.

B.1.1 *Forces involved.* It is somewhat of an oversimplification, but water hammer, or surge, can be defined in these terms: The shutting of a valve or the stopping of a pump causes a moving column of water in a pipeline to slow down and stop. The forces that bring about this deceleration are exerted radially on the moving water column by the pipeline walls. Conversely, the water exerts added pressure on the pipe, and the hoop stresses in the pipe walls thus increase over the normal operating pressure values. The faster the column of water is brought to a halt, the higher these stresses rise.

B.1.2 *Rate of velocity fluctuation.* The pipe wall stresses are thus developed by, and increase in direct proportion to, the internal pressure that builds up as the column of water decelerates. The slower the deceleration, the less the pressure builds up, and the less the pipe wall stresses increase. It is, therefore, of importance to the pipe designer to know how to control the rate of velocity fluctuation, since by controlling this rate he controls the magnitude of the pressure variations during the transitional periods. By such control he can keep the pipe wall stresses during surge to a predetermined value that will allow an economical installation.

B.1.3 *Wave motion.* Water, being liquid, will act in a fairly complex manner when undegoing acceleration or deceleration. Pressure waves are set up which move along the pipeline at a rate of 2500—4500 ft/sec, the rate depending on the pipe wall material. The waves will continue until they encounter a boundary condition, such as a reservoir, a closed valve, or a change in pipe diameter, at which point they will reflect back in the opposite direction. The wave motion will oscillate back and forth in the pipe until it is dampened out by the friction effects of the pipe walls.

B.1.4 *Causes.* The two major causes of water hammer or surge are

1. The closing or opening, fully or partially, of a valve in a pipeline system. The valve may be in the line for one of a number of purposes. It could be a gate valve, float valve, pressure reducing valve, or serve some other function.

2. The starting up or shutting down of a pump (switch or power failure) It can be seen that both of these occurrences cause changes in the velocity, and consequently in the quantity, of water flowing in the pipeline.

B.1.5. *Effects.* Ignoring the effects of surge in the pipeline can lead to difficulties after the line is in operation. Surge can result in damaged equipment and seriously reduced capacity.

B.2 Water Hammer Analysis

The elastic wave theory for surge analysis has been empirically established to be correct by many experiments, the first of which were performed as early as 1890. Its application to pipeline problems will yield results which are accurate and which may be relied upon for adequate analysis.

B.2.1 *Wave velocity.* Water hammer pressures are a function of the maximum rate of change of flow. When a valve is closed or a pump stops, a pressure wave is propagated along a pipeline. The velocity of the wave is the same as the velocity of sound in water, modified by physical characteristics of the pipeline; it is given by the following equation:

$$a = \frac{4660}{\sqrt{1 + kd/Ee}} \qquad \text{Eq B1}$$

in which,

a = pressure wave velocity, in feet per second
k = modulus of compression of water, 300,000 psi
d = internal diameter of pipe, in inches
E = modulus of elasticity of asbestos-cement pipe, 3,400,000 psi
e = wall thickness, in inches
4660 = velocity of sound in water in feet per second

B. 2. 2. *Maximum pressure.* If the pressure wave is reflected back from a boundary condition, such as a reservoir, and returns to its initial position after the flow in the line is completely stopped, then maximum water hammer pressure for those conditions will result. Stopping of the flow may be effected by closing a valve or by a pump stoppage. The magnitude of that maximum pressure is given by

$$h = \frac{aV}{g} \qquad \text{Eq B2}$$

in which,

h = surge pressure, in feet of water
V = velocity of water in the pipeline during normal conditions, in feet per second
a = velocity of pressure wave, in ft/sec
g = acceleration due to gravity, 32.2 ft/sec²

B.2.3 *Critical time* The longest elapsed time before final flow stoppage that will still permit this maximum pressure to occur is called the critical time; it is simply the total length that the pressure wave travels in one cycle, divided by the velocity of the wave. It is given by the following equation:

$$U = \frac{2L}{a} \qquad \text{Eq B3}$$

in which,

U = the critical time, in seconds
L = distance within the pipeline that the pressure wave moves before it is reflected back by a boundary condition, in feet
a = velocity of the pressure wave in the line, in feet per second

B.3 Valve Closure

A valve in a water line may be of several different varieties, including gate, cone, and globe valves. When closing a valve, the area of the cross section of the pipeline that is progressively cut off is not generally proportional to the reduction in flow. In Fig. B1, Graph 1 presents a plot

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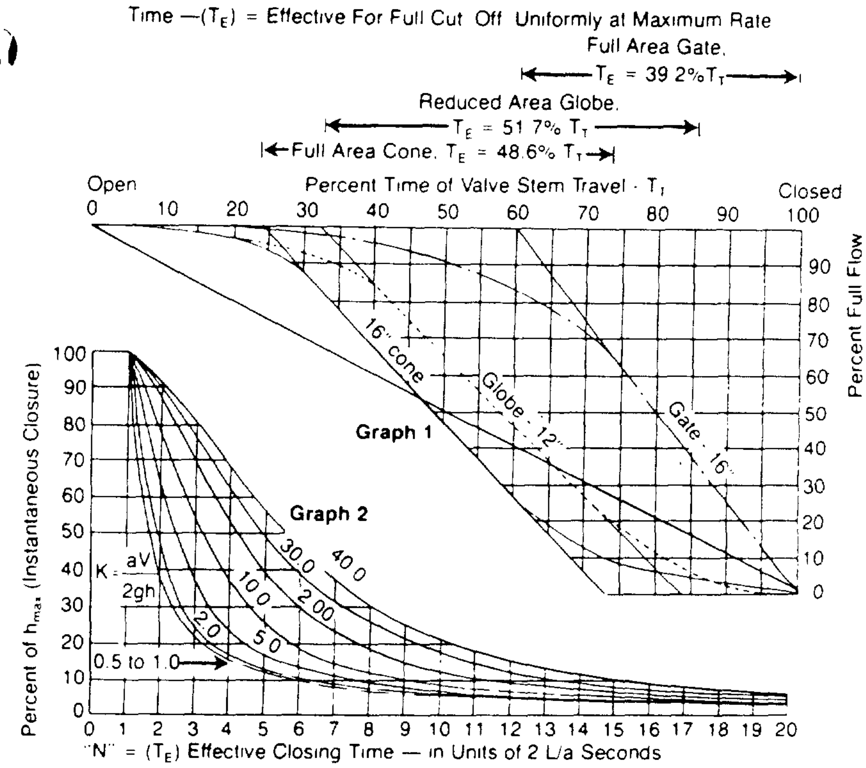

Fig. B1. Time (T_L) = Effective for Full Cut Off Uniformly at Maximum Rate

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of stem travel versus flow in the line for three types of valves. Note that the first 30–40 percent of stem travel has little effect on the flow in the pipeline.

B.3.1 *Effective time.* As stated previously, water hammer pressure is a function of the maximum rate of change of flow. Therefore, if tangents to the curves in Fig. B1 are drawn at the fastest rate of change (or steepest slope), the effective time of closure T_E is obtained. (See the curves in Fig. B1 with tangents plotted and values of T_E determined.) This effective time, T_E, is the time that is used in water hammer calculations. In most cases, it is about one half of the actual valve closing time. This indicates that if the critical time of a certain installed valve is calculated from Eq B3 and found to be x seconds, then the actual time for complete valve closure which will cause maximum pressure to occur will be approximately 2x seconds.

B.3.2 *Relation to surge control.* In the design of a water system one of the major considerations in the selection of a pipe is the design internal

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pressure that the pipe will be required to carry in service. The design internal pressure is the operating pressure plus the water hammer pressure. In order to keep the water hammer or surge pressures at a controlled level, calculations must be made to determine the valve closure times that will be required to stay within the design pressure level.

B.3.3 *Determining effective time.* Figure B1 presents a convenient three-step method for determining effective valve closure times for a given percentage of the maximum pressure (surge pressure when valve is closed in less than the critical time).

1. Determine the pipeline constant K given by

$$K = \frac{aV}{2gh_o} \qquad \text{Eq B4}$$

in which,

K = pipeline constant
a = velocity of the pressure wave in the line, in feet per second
V = velocity of water in the flow line under normal conditions, in feet per second
g = acceleration due to gravity, 32.2 ft/sec^2
h_o = operating pressure in the line under normal conditions, in feet of water

2. Determine the maximum head that might be developed from the surge by employing the formula $h_{max} = aV/g$.
3. Determine the percentage of h_{max} and find the corresponding effective closing time shown on the horizontal axis. This is given in units of $2L/a$, which represents the critical time for the pipeline. Note that the time determined is the *effective* closing time and the *actual* time of valve stem travel is about twice as long. The reason for this is that the first half of the closing of the valve has little effect on the stoppage of the flow. It is the closing of the final half of the valve stem travel which closes off the flow. The second half is the effective closing time. Therefore, two times the effective closing time is the actual time of the valve stem travel.

B.4 Pumped Systems

In relation to water hammer and surge, the most important elements in a system are pumps and valves. In a gravity system only valves have to be considered. Both pumps and valves must be considered in a pumped system.

B.3.1 *Complexity.* The surge analysis of a pumped system is more complex than in a 100 percent gravity system because

1. In a pumped system, the problem begins in the slowing down of the rising water column when the pump is shut off (because of power failure or otherwise). Consideration must be given to the time required for the pump to stop and for the flow to come to a halt. This involves the inertia of the motor and any flywheel in the assembly. Provisions normally should be made for slow opening and closing of pump control valves on pump systems. In a gravity system the hydraulic problem consists only of stopping the descending water column.
2. In a pumped system, the pipeline profile is usually irregular, with successive high and low points and with variable slopes. These conditions may give rise to water

column separation, causing severe surges and operational troubles. Surges from water column separation do not follow a standard pattern and they have been measured at many times the calculated values.

B.4.2 *Alternative layouts.* The design of a pumped system may involve the consideration of alternative layouts to keep surges and the consequent operational difficulties to a minimum. This work should be directed toward reducing the magnitude of surges and toward reducing the risk of water column separation that may be caused by the shutdown of a pump.

B.4.3 *Water column separation.* Water column separation can be serious due to the large magnitude of the surges developed when the water column rejoins. It can occur

1. At pump locations at the start of a steep main.
2. When the pressure at a high point falls below atmospheric and air enters the line through air valves that may be located at a high point.
3. When the pressure falls to below the vapor pressure of water.

B.4.4 *Entrapped air.* Water column separation can cause difficulties, not only because of the before-mentioned surges set up by the rejoining of the water column, but because of the difficulties in getting air out of the line on subsequent start-up, even with air valves. Entrapped air can cause flow fluctuations and can seriously reduce the capacity of the system.

B.5 Methods of Control

The two types of surge to be controlled are negative surge and positive surge. The type is determined, of course, by whether the surge pressures developed are below or above the normal static level.

B.5.1 *Negative surges.* Negative surges in themselves are usually not dangerous, except when they cause water column separation. If this occurs, extremely high positive surges result when the cavity closes, and this frequently causes serious problems. The control of both negative and positive surges should be given consideration.

B.5.2 *Surge control devices.* Limiting negative and positive surges is accomplished by several types of surge control devices, as follows:

1. Controlled valves. This is one of the most effective means for controlling positive surges. As explained previously, the rate of opening and closing of a valve can be calculated to allow an acceptable level of surge.
2. Flywheel on pump motor. In the event of a power outage the inertia of the flywheel will keep the pump running for a period of time, during which it will gradually slow to a stop. This means that the water column in the pipeline will also be brought to a gradual stop, thus reducing the risk of water column separation.
3. Standpipe. This is generally a tank with the surface of the water at atmospheric pressure. It is, therefore, only practical at low heads. At a pump stoppage and consequent reduced pressure, the reserve of water in the tank flows into the pipe and reduces the risk of water column separation. For positive surge control the tank

provides an outlet for the built-up pressure in the system.

4. Air vessel or surge tank. This is an enclosed vessel containing air and water. It functions similarly to a standpipe, with water reentering the line during negative surge and leaving during positive surge. The major difference is that the air in the vessel is under pressure and much higher heads can be employed in the pipe system.
5. One-way surge tank. This is an adaptation of the surge tank. It contains a check valve that permits water to enter the line during negative surge, but will not permit water to leave during positive surge. It is, therefore, only for control of negative surges and is very effective.
6. Reservoir of water. This is similar to the one way surge tank, but provides some control of positive surge by permitting the slow entrance of water into the reservoir during a positive surge.
7. Suction pipe. This is a bypass around the pump from the suction side. It contains a check valve to prevent backflow into the reservoir. It effectively reduces negative pressure adjacent to the pump.
8. Surge relief valve. This is used for controlling positive and negative surges. The valve opens at a certain pressure and discharges water to relieve a surge; positive or negative. It must be carefully designed and controlled in order to be effective.
9. Nonreturn valve. This is a check, strategically placed in a line, that can bring a small measure of relief to positive pressure However, unless properly placed, it can lead to higher rather than lower surge.
10. Reversal of pump. At pump stoppage the column of water reverses itself. If the pump will not run backwards to permit water to flow back through it, then positive surges will be developed by the sudden stopping of the backflowing column of water. The pump should be designed to run reversed without damage to itself. Design of pumps that can run reversed without damage is a significant problem. Other measures may have to be taken.

B.5.3 *Economic considerations.* From an economic standpoint it is usually worthwhile to properly evaluate the surge potential in a system under design. The cost of control devices may be balanced against the added strength of pipe, valves. and other equipment that will be needed if surges are not controlled, and the most advantageous conclusion reached. Manufacturers of surge control equipment or consultants in this field should be sought for advice in complex situations.

B.6 Surge Calculation Example

The following example problem illustrates the calculation that may be followed to determine valve closing time for the control of surge within prescribed limits.

A 24-in gravity transmission line is to operate at a pressure of 100 psi. Velocity in the line is to be 5 ft/sec. A valve is to be included in the line at a distance of 5000 ft from the reservoir. If positive surge pressure is to be controlled within 50 psi, determine the minimum time for valve closure. Assume that the effective closing time is one half of the actual valve stem travel time. (E for asbestos–cement pipe = 3.4×10^6, wall thickness is 1.5 in., k for water = 3×10^5)

SOLUTION

1. Determine surge wave velocity

$$a = \frac{4660}{\sqrt{1 + \frac{kd}{Ee}}} = \frac{4660}{\sqrt{1 + \frac{3 \times 10^5 \times 24}{3.4 \times 10^6 \times 1.5}}} = 3000 \text{ ft/sec.}$$

2. Determine maximum surge pressure if the valve closes within the critical time

$$h = \frac{aV}{g} = \frac{3000 \times 5}{32.2} = 465 \text{ ft of water (200 psi)}$$

3. Determine the critical time

$$U = \frac{2L}{a} = \frac{2 \times 5000}{3000} = 3.33 \text{ sec}$$

4. Determine Constant K for use in Graph 2 (Fig. B1)

$$K = \frac{aV}{2gh_o} = \frac{3000 \times 5}{2 \times 32.2 \times 231} = 1.0$$

5. Determine percent of maximum surge pressure that should not be exceeded in the system.

$$\frac{50}{200} \times 100 = 25 \text{ percent}$$

6. Enter Graph 2 (Fig. B1) with percent of h_{max} (25 percent). Go horizontally to the curves where $K = 1.0$. Read the effective closing time along the horizontal axis. This value is 2.6 and is given in units of $2L/a$ seconds. The effective closing time in seconds would be $2L/a \times 2.6 = 3.33 \times 2.6 = 8.7$ sec. The actual valve stem travel time would be twice this amount, or 17.4 sec. This calculated time (17.4 sec.), therefore, represents the fastest allowable time the valve can be closed in order to keep the surge pressure below the desired control level of 50 psi.

B.7 Air in Pipelines

Air in pipelines can cause serious operational difficulties, including reduction in capacity because of reduced cross-sectional area, and fluctuation in flow caused by expanding and contracting air in the line. These fluctuations in flow cause sudden movements of the air from one location to another, followed by slugs of water, and this can cause serious surges.

B.7.1 *Entrance of air.* Air can enter a pipeline in many ways. It may enter at the intake. Entry may be caused by release of air from water due to temperature and pressure variation, or it may be caused by draining the line, or by draining parts of the line during normal shut-down. Negative surges may cause air to enter at air valves. Air should be prevented from entering the line in the first place. This is very important in order to reduce operational difficulties. Suggested solutions for control are as follows:

1. Intake. Correct design procedures, provide low water-level pump cut-off.
2. Release of air. Air is entrained in the water at intake and its release cannot be prevented. However, the quantities are not large and provisions for exhausting can be made by means of air valves. There are various types of air valves with different

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functions, and the selection of the proper type and location for installation is essential.

3. Draining the line. Air cannot be prevented from entering the line on draining, of course. Large orifice air valves should be provided for exhausting the air during refilling. Draining and then refilling does not often occur; therefore, long filling times may be satisfactory.
4. Drainage during shut down. This can be a serious problem. Open standpipes can be provided for air entry and exhaust. Sweeping air out using high velocities is also a method.
5. Negative surges. The best way to prevent air from entering under these conditions is to design out the possibility of water column separation. Large volumes of air may be involved here and can cause serious problems. Any one of the negative surge control devices described in paragraph B.5.2 will normally be adequate.

B.7.2. *Recommendations to combat air entrapment.* Colorado State University has conducted studies to determine the effect of air entrapment in pipelines. The result of the studies proved that suddenly released entrapped air, under apparently static conditions, creates a situation similar to that of classic water hammer. Pressures are generated which may be on the order of fifteen times the pipeline test pressure. Any pipeline material is seriously affected by this rapid magnitude of load increase. Hydrostatic failure due to defective pipe may in all probability be traced to suddenly released entrapped air. The initial filling and testing of a pipeline is often the most critical period of its service life. Recommendations to combat air entrapment were made as follows:

1. Pipeline should be laid to grade wherever possible.
2. Automatic continual acting air release valves should be used at all high points.
3. Air should be bled from pipeline slowly.
4. Limit filling velocity in the pipeline to one foot per second or less.
5. Use $d/D = 1/10$ to $1/100$.
   d = diameter of air release valve
   D = pipe diameter

The results of this study, together with the recommendations, have been found to be most useful to contractors in performing pipeline tests. Such recommendations also have been found to be useful to engineers from the standpoint of designing pipelines to minimize air problems.

Appendix C

Frictional Power Requirements

This appendix is for information only and is not a part of AWWA C700.

The chart shown in Fig. C1 permits rapid calculations of the yearly power costs to overcome friction loss of head. This chart is based on continuous pumping operation (24 hours per day and 365 days per year), a power cost of $0.01 per kwhr, and a motor-pump efficiency of 100 percent. For actual operating conditions and local power costs, appropriate factors must be applied to the values shown in the chart. By calculating power costs to overcome friction in two pipe sizes, or for two different types of pipe having different flow coefficients, an annual power cost savings can be determined. Economic justification for going to a larger pipe diameter with lower annual power costs can be determined by establishing the present worth of the annual savings using Table C1, which is based on the discounted cash flow method. If the present worth of the annual savings based on established interest rates exceeds the added costs for the installation of a different size or type of material, then economic justification exists for the added capital expenditure.

Nomograph values for Fig. C1 are based on the following:

- Cost per 1000 ft of pipe per year—in dollars
- Power cost—1¢ per kilowatt hour
- Motor-pump efficiency (combined)—100 percent
- Friction coefficient $C = 140$
- Continuous operation

NOTE: Yearly power cost values derived in Fig. C1 are for coefficient of flow $C = 140$. They may be converted to yearly power cost values for other coefficients of flow by means of the following multiplying factors:

- 1.15 for $C = 130$
- 1.34 for $C = 120$
- 1.57 for $C = 110$
- 1.86 for $C = 100$
- 2.26 for $C = 90$
- 2.83 for $C = 80$
- 4.82 for $C = 60$

Diameters derived from Fig. C1 are for coefficient of flow $C = 140$. These may be converted to other diameters for other coefficients of flow by means of the following multiplying factors:

- 1.033 for $C = 130$
- 1.063 for $C = 120$
- 1.100 for $C = 110$
- 1.142 for $C = 100$
- 1.185 for $C = 90$
- 1.261 for $C = 80$
- 1.365 for $C = 60$

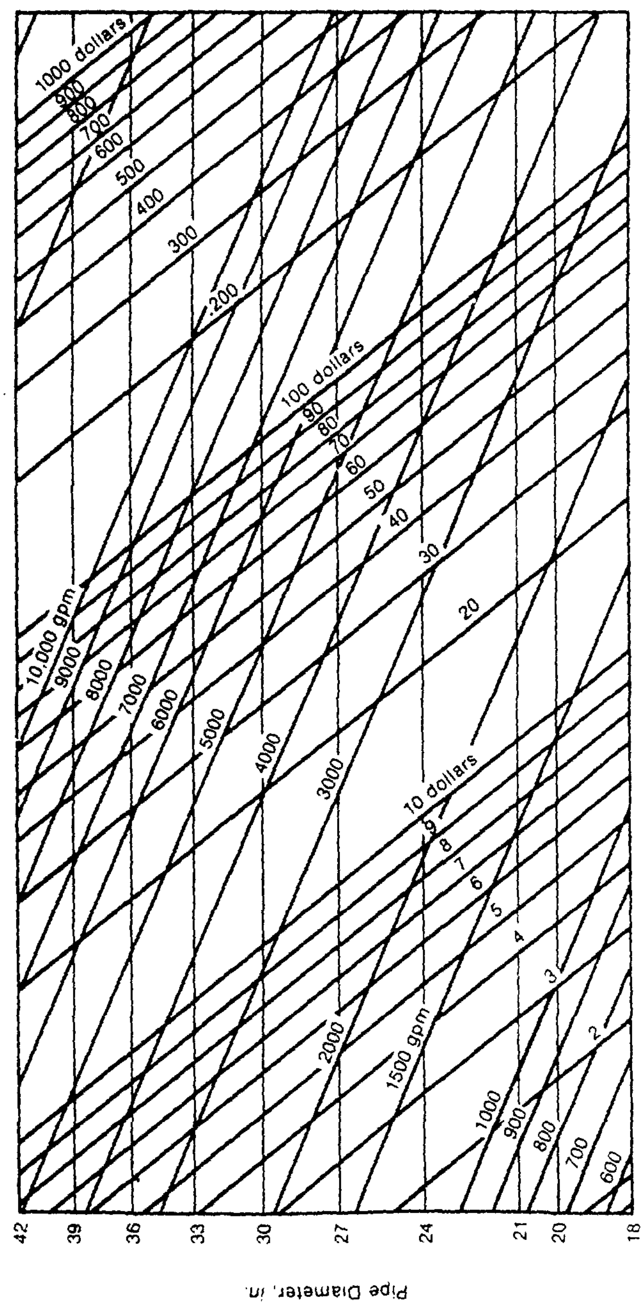

Fig. C1. Yearly Power Cost to Compensate for Friction Loss of Head * *(cont. on next page)*

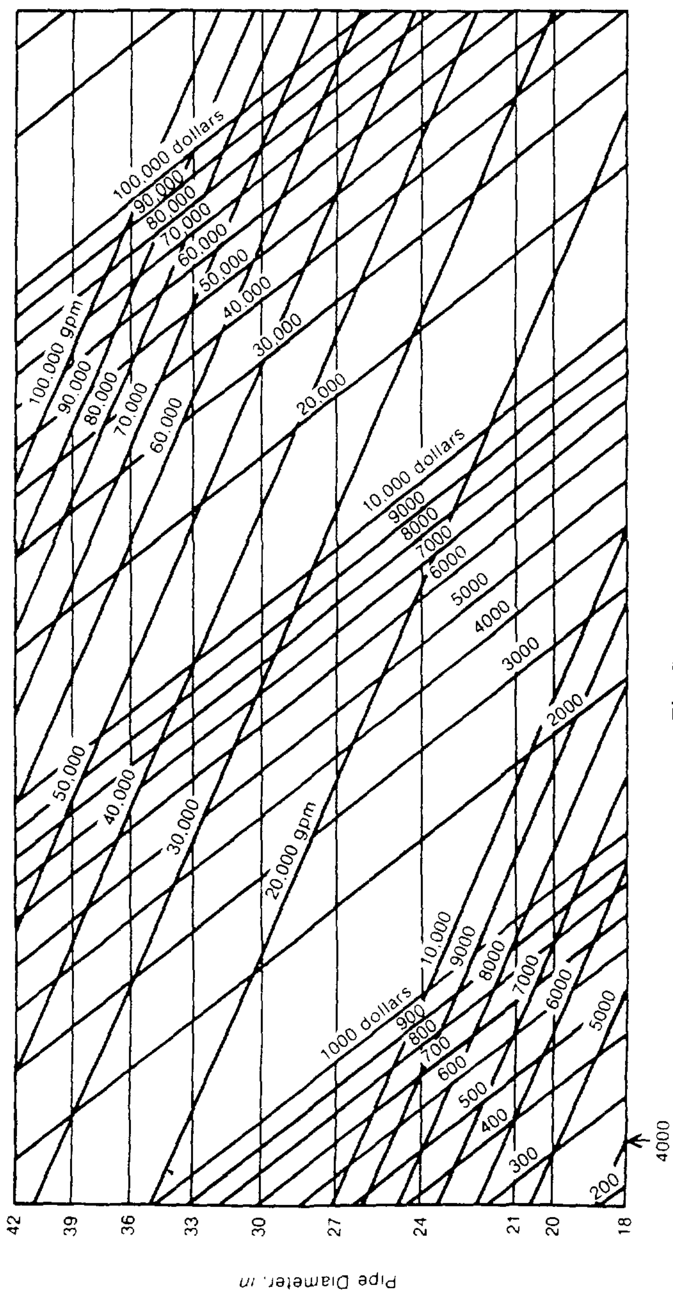

Fig. C1 (*cont.*)

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Table C1 *

Apply the following formula to Table C1, *Present Worth of an Income of $1.00 per Year for the Next* N *Years:*

$$\frac{(1 + r)^N - 1}{r(1 + r)^N}$$

where

r = rate of yield in percent
N = number of years from present

Example:

When using a 10 percent rate of yield, an income of $1.00 occurring each year for the next 5 years has a present worth of $3.791; for the next 7 years, $4.868; for the next 10 years, $6.145; etc.

The present worth (*PW*) of a regular pattern of savings in the future is found as follows.

Total years of operation—25
Amount of annual savings—$5000.00
PW factor at 10 percent—9.077
Total present worth (*PW*)—$45,385.00

When expenditure, cash income, and life are known, and income is the same each year, the *PW* factor can be computed by dividing expenditure by annual cash income. Yield can then be determined by looking for the factor on the line or known life in Table C1.

* This table is reprinted by permission of the Johns-Manville Sales Corporation from their publication, "Discounted Cash Flow Method of Investment Appraisal."

TABLE C1

Present Worth of an Income of $1.00 per Year for the Next N Years

Years	.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	Years
1	.995	.990	.985	.980	.976	.971	.966	.962	.957	.952	1
2	1.985	1.970	1.956	1.942	1.927	1.913	1.900	1.886	1.873	1.859	2
3	2.970	2.941	2.912	2.884	2.856	2.829	2.802	2.775	2.749	2.723	3
4	3.950	3.902	3.854	3.808	3.762	3.717	3.673	3.630	3.588	3.546	4
5	4.926	4.853	4.783	4.713	4.646	4.580	4.515	4.452	4.390	4.329	5
6	5.896	5.795	5.697	5.601	5.508	5.417	5.329	5.242	5.158	5.076	6
7	6.862	6.728	6.598	6.472	6.349	6.230	6.115	6.002	5.893	5.786	7
8	7.823	7.652	7.486	7.325	7.170	7.020	6.874	6.733	6.596	6.463	8
9	8.779	8.566	8.361	8.162	7.971	7.786	7.608	7.435	7.269	7.108	9
10	9.730	9.471	9.222	8.983	8.752	8.530	8.317	8.111	7.913	7.722	10
11	10.68	10.37	10.07	9.787	9.514	9.253	9.002	8.760	8.529	8.306	11
12	11.62	11.26	10.91	10.58	10.26	9.954	9.663	9.385	9.119	8.863	12
13	12.56	12.13	11.73	11.35	10.98	10.64	10.30	9.986	9.683	9.394	13
14	13.49	13.00	12.54	12.11	11.69	11.30	10.92	10.56	10.22	9.899	14
15	14.42	13.87	13.34	12.85	12.38	11.94	11.52	11.12	10.74	10.38	15
16	15.34	14.72	14.13	13.58	13.06	12.56	12.09	11.65	11.23	10.84	16
17	16.26	15.56	14.91	14.29	13.71	13.17	12.65	12.17	11.71	11.27	17
18	17.17	16.40	15.67	14.99	14.35	13.75	13.19	12.66	12.16	11.69	18
19	18.08	17.23	16.43	15.68	14.98	14.32	13.71	13.13	12.59	12.09	19
20	18.99	18.05	17.17	16.35	15.59	14.88	14.21	13.59	13.01	12.46	20
21	19.89	18.86	17.90	17.01	16.19	15.42	14.70	14.03	13.41	12.82	21
22	20.78	19.66	18.62	17.66	16.77	15.94	15.17	14.45	13.78	13.16	22
23	21.68	20.46	19.33	18.29	17.33	16.44	15.62	14.86	14.15	13.49	23
24	22.56	21.24	20.03	18.91	17.89	16.94	16.06	15.25	14.50	13.80	24
25	23.45	22.02	20.72	19.52	18.42	17.41	16.48	15.62	14.83	14.09	25
26	24.32	22.80	21.40	20.12	18.95	17.88	16.89	15.98	15.15	14.38	26
27	25.20	23.56	22.07	20.71	19.46	18.33	17.29	16.33	15.45	14.64	27
28	26.07	24.31	22.73	21.28	19.97	18.76	17.67	16.66	15.74	14.90	28
29	26.93	25.07	23.38	21.84	20.45	19.19	18.04	16.98	16.02	15.14	29
30	27.79	25.81	24.02	22.40	20.93	19.60	18.39	17.29	16.29	15.37	30
31	28.65	26.54	24.65	22.94	21.40	20.00	18.74	17.59	16.54	15.59	31
32	29.50	27.27	25.27	23.47	21.85	20.39	19.07	17.87	16.79	15.80	32
33	30.35	27.99	25.88	23.99	22.29	20.77	19.39	18.15	17.02	16.00	33
34	31.20	28.70	26.48	24.50	22.72	21.13	19.70	18.41	17.25	16.19	34
35	32.04	29.41	27.08	25.00	23.15	21.49	20.00	18.67	17.46	16.37	35
36	32.87	30.11	27.66	25.49	23.56	21.83	20.29	18.91	17.67	16.55	36
37	33.70	30.80	28.24	25.97	23.96	22.17	20.57	19.14	17.86	16.71	37
38	34.53	31.49	28.81	26.44	24.35	22.49	20.84	19.37	18.05	16.87	38
39	35.35	32.16	29.37	26.90	24.73	22.81	21.10	19.58	18.23	17.02	39
40	36.17	32.84	29.92	27.36	25.10	23.12	21.36	19.79	18.40	17.16	40
41	36.99	33.50	30.46	27.80	25.47	23.41	21.60	19.99	18.57	17.29	41
42	37.80	34.16	30.99	28.24	25.82	23.70	21.84	20.19	18.72	17.42	42
43	38.61	34.81	31.52	28.66	26.17	23.98	22.06	20.37	18.87	17.55	43
44	39.41	35.46	32.04	29.08	26.50	24.25	22.28	20.55	19.02	17.66	44
45	40.21	36.09	32.55	29.49	26.83	24.52	22.50	20.72	19.16	17.77	45
46	41.00	36.73	33.06	29.89	27.15	24.78	22.70	20.89	19.29	17.88	46
47	41.79	37.35	33.55	30.29	27.47	25.03	22.90	21.04	19.42	17.98	47
48	42.58	37.97	34.04	30.67	27.77	25.27	23.09	21.20	19.54	18.08	48
49	43.36	38.59	34.53	31.05	28.07	25.50	23.28	21.34	19.65	18.17	49
50	44.14	39.20	35.00	31.42	28.36	25.73	23.46	21.48	19.76	18.26	50

TABLE C1 *(continued)*

Years	5.5%	6.0%	6.5%	7.0%	7.5%	8.0%	8.5%	9.0%	9.5%	10.0%	Years
1	.948	.943	.939	.935	.930	.926	.922	.917	.913	.909	1
2	1.846	1.833	1.821	1.808	1.796	1.783	1.771	1.759	1.747	1.736	2
3	2.698	2.673	2.648	2.624	2.601	2.577	2.554	2.531	2.509	2.487	3
4	3.505	3.465	3.426	3.387	3.349	3.312	3.276	3.240	3.204	3.170	4
5	4.270	4.212	4.156	4.100	4.046	3.993	3.941	3.890	3.840	3.791	5
6	4.996	4.917	4.841	4.767	4.694	4.623	4.554	4.486	4.420	4.355	6
7	5.683	5.582	5.485	5.389	5.297	5.206	5.119	5.033	4.950	4.868	7
8	6.335	6.210	6.089	5.971	5.857	5.747	5.639	5.535	5.433	5.335	8
9	6.952	6.802	6.656	6.515	6.379	6.247	6.119	5.995	5.875	5.759	9
10	7.538	7.360	7.189	7.024	6.864	6.710	6.561	6.418	6.279	6.145	10
11	8.093	7.887	7.689	7.499	7.315	7.139	6.969	6.805	6.647	6.495	11
12	8.619	8.384	8.159	7.943	7.735	7.536	7.345	7.161	6.984	6.814	12
13	9.117	8.853	8.600	8.358	8.126	7.904	7.691	7.487	7.291	7.103	13
14	9.590	9.295	9.014	8.745	8.489	8.244	8.010	7.786	7.572	7.367	14
15	10.04	9.712	9.403	9.108	8.827	8.559	8.304	8.061	7.828	7.606	15
16	10.46	10.11	9.768	9.447	9.142	8.851	8.575	8.313	8.062	7.824	16
17	10.87	10.48	10.11	9.763	9.434	9.122	8.825	8.544	8.276	8.022	17
18	11.25	10.83	10.43	10.06	9.706	9.372	9.055	8.756	8.471	8.201	18
19	11.61	11.16	10.74	10.34	9.959	9.604	9.268	8.950	8.650	8.365	19
20	11.95	11.47	11.02	10.59	10.19	9.818	9.463	9.129	8.812	8.514	20
21	12.28	11.76	11.29	10.84	10.41	10.02	9.644	9.292	8.961	8.649	21
22	12.58	12.04	11.54	11.06	10.62	10.20	9.810	9.442	9.097	8.772	22
23	12.88	12.30	11.77	11.27	10.81	10.37	9.963	9.580	9.221	8.883	23
24	13.15	12.55	11.99	11.47	10.98	10.53	10.10	9.707	9.334	8.985	24
25	13.41	12.78	12.20	11.65	11.15	10.68	10.23	9.823	9.438	9.077	25
26	13.66	13.00	12.39	11.83	11.30	10.81	10.35	9.929	9.532	9.161	26
27	13.90	13.21	12.58	11.99	11.44	10.94	10.47	10.03	9.618	9.237	27
28	14.12	13.41	12.75	12.14	11.57	11.05	10.57	10.12	9.697	9.307	28
29	14.33	13.59	12.91	12.28	11.70	11.16	10.66	10.20	9.769	9.370	29
30	14.53	13.77	13.06	12.41	11.81	11.26	10.75	10.27	9.835	9.427	30
31	14.72	13.93	13.20	12.53	11.92	11.35	10.83	10.34	9.895	9.479	31
32	14.90	14.08	13.33	12.65	12.02	11.44	10.90	10.41	9.950	9.526	32
33	15.08	14.23	13.46	12.75	12.11	11.51	10.97	10.46	10.00	9.569	33
34	15.24	14.37	13.58	12.85	12.19	11.59	11.03	10.52	10.05	9.609	34
35	15.39	14.50	13.69	12.95	12.27	11.66	11.09	10.57	10.09	9.644	35
36	15.54	14.62	13.79	13.04	12.35	11.72	11.14	10.61	10.13	9.677	36
37	15.67	14.74	13.89	13.12	12.42	11.78	11.19	10.65	10.16	9.706	37
38	15.81	14.85	13.98	13.19	12.48	11.83	11.24	10.69	10.19	9.733	38
39	15.93	14.95	14.07	13.27	12.54	11.88	11.28	10.73	10.22	9.757	39
40	16.05	15.05	14.15	13.33	12.59	11.93	11.32	10.76	10.25	9.779	40
41	16.16	15.14	14.22	13.39	12.65	11.97	11.35	10.79	10.27	9.799	41
42	16.26	15.23	14.29	13.45	12.69	12.01	11.38	10.81	10.29	9.817	42
43	16.36	15.31	14.36	13.51	12.74	12.04	11.41	10.84	10.31	9.834	43
44	16.46	15.38	14.42	13.56	12.78	12.08	11.44	10.86	10.33	9.849	44
45	16.55	15.46	14.48	13.61	12.82	12.11	11.47	10.88	10.35	9.863	45
46	16.63	15.52	14.54	13.65	12.86	12.14	11.49	10.90	10.36	9.875	46
47	16.71	15.59	14.59	13.69	12.89	12.16	11.51	10.92	10.38	9.887	47
48	16.79	15.65	14.64	13.73	12.92	12.19	11.53	10.93	10.39	9.897	48
49	16.86	15.71	14.68	13.77	12.95	12.21	11.55	10.95	10.40	9.906	49
50	16.93	15.76	14.73	13.80	12.98	12.23	11.57	10.96	10.41	9.915	50

TABLE C1 (*continued*)

Years	10.5%	11.0%	11.5%	12.0%	12.5%	13.0%	13.5%	14.0%	14.5%	15.0%	Years
1	.905	.901	.897	.893	.889	.885	.881	.877	.873	.870	1
2	1.724	1.713	1.701	1.690	1.679	1.668	1.657	1.647	1.636	1.626	2
3	2.465	2.444	2.423	2.402	2.381	2.361	2.341	2.322	2.302	2.283	3
4	3.136	3.102	3.070	3.037	3.006	2.974	2.944	2.914	2.884	2.855	4
5	3.743	3.696	3.650	3.605	3.561	3.517	3.475	3.433	3.392	3.352	5
6	4.292	4.231	4.170	4.111	4.054	3.998	3.943	3.889	3.836	3.784	6
7	4.789	4.712	4.637	4.564	4.492	4.423	4.355	4.288	4.224	4.160	7
8	5.239	5.146	5.056	4.968	4.882	4.799	4.718	4.639	4.562	4.487	8
9	5.646	5.537	5.431	5.328	5.228	5.132	5.038	4.946	4.858	4.772	9
10	6.015	5.889	5.768	5.650	5.536	5.426	5.320	5.216	5.116	5.019	10
11	6.348	6.207	6.070	5.938	5.810	5.687	5.568	5.453	5.341	5.234	11
12	6.650	6.492	6.341	6.194	6.053	5.918	5.787	5.660	5.538	5.421	12
13	6.923	6.750	6.583	6.424	6.270	6.122	5.979	5.842	5.710	5.583	13
14	7.170	6.982	6.801	6.628	6.462	6.302	6.149	6.002	5.861	5.724	14
15	7.394	7.191	6.997	6.811	6.633	6.462	6.299	6.142	5.992	5.847	15
16	7.596	7.379	7.172	6.974	6.785	6.604	6.431	6.265	6.106	5.954	16
17	7.779	7.549	7.329	7.120	6.920	6.729	6.547	6.373	6.206	6.047	17
18	7.945	7.702	7.470	7.250	7.040	6.840	6.649	6.467	6.294	6.128	18
19	8.095	7.839	7.596	7.366	7.147	6.938	6.739	6.550	6.370	6.198	19
20	8.231	7.963	7.710	7.469	7.241	7.025	6.819	6.623	6.437	6.259	20
21	8.354	8.075	7.811	7.562	7.326	7.102	6.889	6.687	6.495	6.312	21
22	8.465	8.176	7.903	7.645	7.401	7.170	6.951	6.743	6.546	6.359	22
23	8.566	8.266	7.984	7.718	7.467	7.230	7.005	6.792	6.590	6.399	23
24	8.657	8.348	8.058	7.784	7.526	7.283	7.053	6.835	6.629	6.434	24
25	8.739	8.422	8.124	7.843	7.579	7.330	7.095	6.873	6.663	6.464	25
26	8.814	8.488	8.183	7.896	7.626	7.372	7.132	6.906	6.693	6.491	26
27	8.881	8.548	8.236	7.943	7.667	7.409	7.165	6.935	6.718	6.514	27
28	8.942	8.602	8.283	7.984	7.704	7.441	7.194	6.961	6.741	6.534	28
29	8.997	8.650	8.326	8.022	7.737	7.470	7.219	6.983	6.761	6.551	29
30	9.047	8.694	8.364	8.055	7.766	7.496	7.242	7.003	6.778	6.566	30
31	9.093	8.733	8.398	8.085	7.792	7.518	7.261	7.020	6.793	6.579	31
32	9.134	8.769	8.429	8.112	7.815	7.538	7.279	7.035	6.806	6.591	32
33	9.171	8.801	8.456	8.135	7.836	7.556	7.294	7.048	6.817	6.600	33
34	9.204	8.829	8.481	8.157	7.854	7.572	7.307	7.060	6.827	6.609	34
35	9.235	8.855	8.503	8.176	7.870	7.586	7.319	7.070	6.836	6.617	35
36	9.262	8.879	8.523	8.192	7.885	7.598	7.330	7.079	6.844	6.623	36
37	9.287	8.900	8.541	8.208	7.898	7.609	7.339	7.087	6.851	6.629	37
38	9.309	8.919	8.557	8.221	7.909	7.618	7.347	7.094	6.856	6.634	38
39	9.330	8.936	8.571	8.233	7.919	7.627	7.354	7.100	6.861	6.638	39
40	9.348	8.951	8.584	8.244	7.928	7.634	7.361	7.105	6.866	6.642	40
41	9.365	8.965	8.595	8.253	7.936	7.641	7.366	7.110	6.870	6.645	41
42	9.380	8.977	8.606	8.262	7.943	7.647	7.371	7.114	6.873	6.648	42
43	9.394	8.989	8.615	8.270	7.949	7.652	7.375	7.117	6.876	6.650	43
44	9.406	8.999	8.623	8.276	7.955	7.657	7.379	7.120	6.879	6.652	44
45	9.417	9.008	8.631	8.283	7.960	7.661	7.383	7.123	6.881	6.654	45
46	9.427	9.016	8.637	8.288	7.965	7.664	7.386	7.126	6.883	6.656	46
47	9.437	9.024	8.643	8.293	7.968	7.668	7.388	7.128	6.885	6.657	47
48	9.445	9.030	8.649	8.297	7.972	7.671	7.390	7.130	6.886	6.659	48
49	9.452	9.036	8.654	8.301	7.975	7.673	7.392	7.131	6.887	6.660	49
50	9.459	9.042	8.658	8.304	7.978	7.675	7.394	7.133	6.889	6.661	50

TABLE C1 (*continued*)

Years	15.5%	16.0%	16.5%	17.0%	17.5%	18.0%	18.5%	19.0%	19.5%	20.0%	Years
1	.866	.862	.858	.855	.851	.847	.844	.840	.837	.833	1
2	1.615	1.605	1.595	1.585	1.575	1.566	1.556	1.547	1.537	1.528	2
3	2.264	2.246	2.228	2.210	2.192	2.174	2.157	2.140	2.123	2.106	3
4	2.826	2.798	2.770	2.743	2.716	2.690	2.664	2.639	2.613	2.589	4
5	3.313	3.274	3.236	3.199	3.163	3.127	3.092	3.058	3.024	2.991	5
6	3.734	3.685	3.636	3.589	3.543	3.498	3.453	3.410	3.367	3.326	6
7	4.099	4.039	3.980	3.922	3.866	3.812	3.758	3.706	3.655	3.605	7
8	4.415	4.344	4.274	4.207	4.142	4.078	4.015	3.954	3.895	3.837	8
9	4.688	4.607	4.527	4.451	4.376	4.303	4.232	4.163	4.096	4.031	9
10	4.925	4.833	4.745	4.659	4.575	4.494	4.415	4.339	4.265	4.192	10
11	5.130	5.029	4.931	4.836	4.745	4.656	4.570	4.486	4.406	4.327	11
12	5.307	5.197	5.091	4.988	4.889	4.793	4.700	4.611	4.523	4.439	12
13	5.461	5.342	5.228	5.118	5.012	4.910	4.810	4.715	4.622	4.533	13
14	5.594	5.468	5.346	5.229	5.117	5.008	4.903	4.802	4.705	4.611	14
15	5.709	5.575	5.447	5.324	5.206	5.092	4.982	4.876	4.774	4.675	15
16	5.808	5.668	5.534	5.405	5.281	5.162	5.048	4.938	4.832	4.730	16
17	5.895	5.749	5.609	5.475	5.346	5.222	5.104	4.990	4.880	4.775	17
18	5.969	5.818	5.673	5.534	5.401	5.273	5.151	5.033	4.921	4.812	18
19	6.034	5.877	5.728	5.584	5.447	5.316	5.191	5.070	4.954	4.843	19
20	6.090	5.929	5.775	5.628	5.487	5.353	5.224	5.101	4.983	4.870	20
21	6.139	5.973	5.815	5.665	5.521	5.384	5.252	5.127	5.007	4.891	21
22	6.181	6.011	5.850	5.696	5.550	5.410	5.276	5.149	5.026	4.909	22
23	6.217	6.044	5.880	5.723	5.574	5.432	5.296	5.167	5.043	4.925	23
24	6.249	6.073	5.905	5.746	5.595	5.451	5.313	5.182	5.057	4.937	24
25	6.276	6.097	5.927	5.766	5.613	5.467	5.328	5.195	5.069	4.948	25
26	6.299	6.118	5.946	5.783	5.628	5.480	5.340	5.206	5.078	4.956	26
27	6.320	6.136	5.962	5.798	5.641	5.492	5.350	5.215	5.086	4.964	27
28	6.337	6.152	5.976	5.810	5.652	5.502	5.359	5.223	5.093	4.970	28
29	6.353	6.166	5.988	5.820	5.661	5.510	5.366	5.229	5.099	4.975	29
30	6.366	6.177	5.999	5.829	5.669	5.517	5.372	5.235	5.104	4.979	30
31	6.378	6.187	6.007	5.837	5.676	5.523	5.377	5.239	5.108	4.982	31
32	6.387	6.196	6.015	5.844	5.681	5.528	5.382	5.243	5.111	4.985	32
33	6.396	6.203	6.021	5.849	5.686	5.532	5.385	5.246	5.114	4.988	33
34	6.404	6.210	6.027	5.854	5.691	5.536	5.389	5.249	5.116	4.990	34
35	6.410	6.215	6.032	5.858	5.694	5.539	5.391	5.251	5.118	4.992	35
36	6.416	6.220	6.036	5.862	5.697	5.541	5.393	5.253	5.120	4.993	36
37	6.420	6.224	6.039	5.865	5.700	5.543	5.395	5.255	5.121	4.994	37
38	6.425	6.228	6.042	5.867	5.702	5.545	5.397	5.256	5.122	4.995	38
39	6.428	6.231	6.045	5.869	5.704	5.547	5.398	5.257	5.123	4.996	39
40	6.431	6.233	6.047	5.871	5.705	5.548	5.399	5.258	5.124	4.997	40
41	6.434	6.236	6.049	5.873	5.707	5.549	5.400	5.259	5.125	4.997	41
42	6.436	6.238	6.051	5.874	5.708	5.550	5.401	5.260	5.125	4.998	42
43	6.438	6.239	6.052	5.875	5.709	5.551	5.402	5.260	5.126	4.998	43
44	6.440	6.241	6.053	5.876	5.710	5.552	5.402	5.261	5.126	4.998	44
45	6.442	6.242	6.054	5.877	5.710	5.552	5.403	5.261	5.127	4.999	45
46	6.443	6.243	6.055	5.878	5.711	5.553	5.403	5.261	5.127	4.999	46
47	6.444	6.244	6.056	5.879	5.711	5.553	5.404	5.262	5.127	4.999	47
48	6.445	6.245	6.057	5.879	5.712	5.554	5.404	5.262	5.127	4.999	48
49	6.446	6.246	6.057	5.880	5.712	5.554	5.404	5.262	5.127	4.999	49
50	6.447	6.246	6.058	5.880	5.712	5.554	5.404	5.262	5.128	4.999	50

TABLE C1 *(continued)*

Years	21%	22%	23%	24%	25%	26%	27%	28%	29%	30%	Years
1	.826	.820	.813	.806	.800	.794	.787	.781	.775	.769	1
2	1.509	1.492	1.474	1.457	1.440	1.424	1.407	1.392	1.376	1.361	2
3	2.074	2.042	2.011	1.981	1.952	1.923	1.896	1.868	1.842	1.816	3
4	2.540	2.494	2.448	2.404	2.362	2.320	2.280	2.241	2.203	2.166	4
5	2.926	2.864	2.803	2.745	2.689	2.635	2.583	2.532	2.483	2.436	5
6	3.245	3.167	3.092	3.020	2.951	2.885	2.821	2.759	2.700	2.643	6
7	3.508	3.416	3.327	3.242	3.161	3.083	3.009	2.937	2.868	2.802	7
8	3.726	3.619	3.518	3.421	3.329	3.241	3.156	3.076	2.999	2.925	8
9	3.905	3.786	3.673	3.566	3.463	3.366	3.273	3.184	3.100	3.019	9
10	4.054	3.923	3.799	3.682	3.571	3.465	3.364	3.269	3.178	3.092	10
11	4.177	4.035	3.902	3.776	3.656	3.543	3.437	3.335	3.239	3.147	11
12	4.278	4.127	3.985	3.851	3.725	3.606	3.493	3.387	3.286	3.190	12
13	4.362	4.203	4.053	3.912	3.780	3.656	3.538	3.427	3.322	3.223	13
14	4.432	4.265	4.108	3.962	3.824	3.695	3.573	3.459	3.351	3.249	14
15	4.489	4.315	4.153	4.001	3.859	3.726	3.601	3.483	3.373	3.268	15
16	4.536	4.357	4.189	4.033	3.887	3.751	3.623	3.503	3.390	3.283	16
17	4.576	4.391	4.219	4.059	3.910	3.771	3.640	3.518	3.403	3.295	17
18	4.608	4.419	4.243	4.080	3.928	3.786	3.654	3.529	3.413	3.304	18
19	4.635	4.442	4.263	4.097	3.942	3.799	3.664	3.539	3.421	3.311	19
20	4.657	4.460	4.279	4.110	3.954	3.808	3.673	3.546	3.427	3.316	20
21	4.675	4.476	4.292	4.121	3.963	3.816	3.679	3.551	3.432	3.320	21
22	4.690	4.488	4.302	4.130	3.970	3.822	3.684	3.556	3.436	3.323	22
23	4.703	4.499	4.311	4.137	3.976	3.827	3.689	3.559	3.438	3.325	23
24	4.713	4.507	4.318	4.143	3.981	3.831	3.692	3.562	3.441	3.327	24
25	4.721	4.514	4.323	4.147	3.985	3.834	3.694	3.564	3.442	3.329	25
26	4.728	4.520	4.328	4.151	3.988	3.837	3.696	3.566	3.444	3.330	26
27	4.734	4.524	4.332	4.154	3.990	3.839	3.698	3.567	3.445	3.331	27
28	4.739	4.528	4.335	4.157	3.992	3.840	3.699	3.568	3.446	3.331	28
29	4.743	4.531	4.337	4.159	3.994	3.841	3.700	3.569	3.446	3.332	29
30	4.746	4.534	4.339	4.160	3.995	3.842	3.701	3.569	3.447	3.332	30
31	4.749	4.536	4.341	4.161	3.996	3.843	3.701	3.570	3.447	3.332	31
32	4.751	4.538	4.342	4.162	3.997	3.844	3.702	3.570	3.447	3.333	32
33	4.753	4.539	4.343	4.163	3.997	3.844	3.702	3.570	3.448	3.333	33
34	4.755	4.540	4.344	4.164	3.998	3.845	3.703	3.571	3.448	3.333	34
35	4.756	4.541	4.345	4.164	3.998	3.845	3.703	3.571	3.448	3.333	35
36	4.757	4.542	4.345	4.165	3.999	3.845	3.703	3.571	3.448	3.333	36
37	4.758	4.543	4.346	4.165	3.999	3.845	3.703	3.571	3.448	3.333	37
38	4.759	4.543	4.346	4.165	3.999	3.846	3.703	3.571	3.448	3.333	38
39	4.759	4.544	4.346	4.166	3.999	3.846	3.703	3.571	3.448	3.333	39
40	4.760	4.544	4.347	4.166	3.999	3.846	3.703	3.571	3.448	3.333	40
41	4.760	4.544	4.347	4.166	4.000	3.846	3.703	3.571	3.448	3.333	41
42	4.760	4.544	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	42
43	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	43
44	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	44
45	4.761	4.545	4.347	4.166	4.000	3.846	3.704	3.571	3.448	3.333	45
46	4.761	4.545	4.348	4.166	4.000	3.846	3.704	3.571	3.448	3.333	46
47	4.761	4.545	4.348	4.166	4.000	3.846	3.704	3.571	3.448	3.333	47
48	4.761	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	48
49	4.761	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	49
50	4.762	4.545	4.348	4.167	4.000	3.846	3.704	3.571	3.448	3.333	50

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