American Water Works Association
ANSI/AWWA C403-89
(Revision of ANSI/AWWA C403-84)

AWWA STANDARD

FOR

THE SELECTION OF ASBESTOS-CEMENT TRANSMISSION AND FEEDER MAIN PIPE, SIZES 18 IN. THROUGH 42 IN. (450 mm THROUGH 1050 mm)

AMERICAN NATIONAL STANDARD

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AMERICAN WATER WORKS ASSOCIATION

6666 West Quincy Avenue, Denver, Colorado 80235

AWWA Standard

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Committee Personnel

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

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*Alternate

†Liaison, nonvoting

Contents

Foreword

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

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

In the ensuing years, this type of pipe gained popularity. In 1949, AWWA established a committee, chaired by S.M. Clark of Greeley and Hanson, Chicago, Ill., on standard specifications for asbestos–cement pipe.

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

The committee concluded that an installation guide was desirable to bring certain important requirements on the inspection, handling, installation, and field testing of asbestos–cement pressure pipe to the attention of users. The committee submitted its final draft in 1963, and it received approval as tentative, AWWA C603-64T, on Jan. 27, 1964. It was advanced to standard without revision on 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 on Jan. 31, 1972, and 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 AWWA Handbook H2), was first approved by the AWWA Board of Directors on Jan. 27, 1964. Although it covered pipe sizes up to and including 36 in. (900 mm), it was primarily intended for use with asbestos–cement pipe in smaller distribution sizes (4 in. through 16 in. [100 mm through 400 mm]).

In the winter of 1972–73, the committee was reorganized and enlarged to include representatives of national organizations having an interest in the scope of the committee and wanting 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 on 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 developed a new series of large pipe classifications, designed to give greater freedom of selection to design engineers. This was of particular significance for large-diameter pipeline projects where the savings in material cost can exceed the increased cost resulting from 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 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 AWWA C402, was carefully reviewed by the committee. The results were AWWA C402-77, which covers sizes 18 in. through 42 in. (450 mm through 1050 mm), and AWWA C400-77, which covers sizes 4 in. through 16 in. (100 mm through 400 mm). There is now no overlap of sizes.

Consequently, it was desirable to revise AWWA C401-64 so that it would be compatible with AWWA C400-77 and to develop a new pipe selection standard to be compatible with AWWA C402-77. AWWA C401-77, Standard Practice for the Selection of Asbestos–Cement Distribution Pipe, 4 In. Through 16 In., for Water and Other Liquids, and AWWA C403-78, Standard Practice for the Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 In. Through 42 In., were approved in May 1977 and January 1978, respectively. The 1978 edition of this standard was revised to include the three-edge, vee-shaped bearing method for crush testing, revision of bedding condition descriptions and load factors used in calculating earth loads to correspond with those contained in ASCE Manual of Practice 37, *Design and Construction of Sanitary and Storm Sewers,** and revision of the crush values for pipe. That revision was approved by AWWA Board of Directors on Jan. 30, 1984, and designated AWWA C403-84.

II. Major Revisions. Major changes made to this revision of the standard include:

1. A statement concerning potential permeation of pipe materials by low molecular weight petroleum products or organic solvents was added as Sec. 1.4.
2. A footnote concerning derivation of equivalent metric pressures was added to Table 6.
3. Sec. B.1.4 was revised to discuss three major causes of water hammer: (1) valve closure or opening, (2) pump start-up or shutdown, and (3) entrapped air.

III. Metrication. Metric conversions of all dimensions and physical requirements have been included in this standard (Table F.1). Metric dimensions are direct conversions of US customary inch-pound units and are not those specified in International Organization for Standardization (ISO) standards.

IV. Information Regarding Use of This Standard. This standard provides for pipe sizes ranging from 18 in. (450 mm) through 42 in. (1050 mm). However, current production in the United States is limited to a maximum size of 24 in. (600 mm).

Effective July 21, 1986, the Occupational Safety and Health Administration (OSHA) revised its standards for workplace exposure to airborne asbestos particles. The current standard makes the employer responsible for ensuring that employee exposures to airborne asbestos fiber concentrations do not exceed stringent exposure limits. The OSHA construction standard on asbestos, 29 CFR 1926, prescribes initial air monitoring and other compliance measures. The OSHA requirements apply to

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*Available from American Society of Chemical Engineers, 345 East 47th St., New York, NY 10017.

Table F.1 Conversion Factors*

US Customary Unit	Conversion Factor	Metric Equivalent
inch (in.)	× 25.4	= millimetre (mm)
foot (ft)	× 0.3048	= metre (m)
pounds per square inch (psi)	× 6.894757	= kilopascals (kPa)
pound (lb)	× 0.4536	= kilogram (kg)
pounds per square foot (lb/ft^2)	× 0.0478803	= kilonewtons per square metre (kN/m^2)
pounds per cubic foot (lb/ft^3)	× 16.0185	= kilograms per cubic metre (kg/m^3)

*Metric pipe inside diameter sizes are nominal and may not directly convert from the equivalent inches.

the manufacture, shipping, handling, installation, and repair of asbestos–cement pipe and appurtenances. It is recommended that users and prospective users of asbestos–cement pipe familiarize themselves with the current OSHA asbestos work practice standards.

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AWWA STANDARD FOR

THE SELECTION OF ASBESTOS–CEMENT TRANSMISSION AND FEEDER MAIN PIPE, SIZES 18 IN. THROUGH 42 IN. (450 mm THROUGH 1050 mm)

SECTION 1: GENERAL

Sec. 1.1 Scope

This standard has been prepared so that design engineers may determine the correct pressure 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 loss of head due to friction. The Appendices are for information only and are not a part of AWWA C403-89.

1.1.1 *Pressure classes.* The pipe strength classifications of 30, 35, 40, 45, 50, 60, 70, 80, and 90 refer to the similarly numbered classes specified in AWWA C402, Standard for Asbestos–Cement Transmission Pipe, 18 In. Through 42 In. (450 mm Through 1050 mm), 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 Installation of Asbestos–Cement Pressure Pipe.

Sec. 1.2 References

This standard references the following documents. They form a part of this standard to the extent specified herein. In any case of conflict, the requirements of this standard shall prevail.

ASTM* C500—Standard Test Method for Asbestos–Cement Pipe (Rev. A).

AWWA C403-84—Standard Practice for the Selection of Asbestos–Cement Distribution Pipe, 4 In. Through 16 In. (100 mm Through 400 mm), for Water and Other Liquids.

Design and Construction of Sanitary and Storm Sewers. Manual of Engrg. Prac. No. 37. Amer. Soc. Civ. Engrg., New York (1976).

KERR, S.L. Practical Aspects of Water Hammer. *Jour. AWWA*, 40:6:699 (June 1948).

MARSTON, ANSON. The Theory of External Loads on Closed Conduits in the Light of Latest Experiments. Bull. 96. Iowa State Col. Engrg. Exp. Sta., Ames, Iowa (1930).

SCHLICK, W.J. Supporting Strengths for Cast-Iron Pipe for Water and Gas Service. Bull. 146. Iowa State Col. Engrg. Exp. Sta., Ames, Iowa (June 1940).

Sec. 1.3 Symbols and Abbreviations

B_c = outside diameter of a pipe, in feet (metres).

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

B.F. = bedding factor, which is a load factor correlating three-edge, vee-shaped bearing test loads to field loads associated with specific bedding conditions.

B_T = maximum width of a tunnel excavation, in feet (metres).

c = coefficient of soil cohesion, in pounds per square foot (kilonewtons per square metre).

C_c = load coefficient for the positive projecting embankment condition. It is a function of the ratio H/B_c, the projection ratio p, and the settlement ratio r_{sd}.

C_d = load coefficient for the trench condition. It is a function of the ratio H/B_d and the backfill material.

C_n = load coefficient for the negative projecting embankment condition, as well as the imperfect trench condition. It is a function of the ratio H/B_d, the projection ratio p', and the settlement ratio r_{sd}.

C_s = load coefficient for concentrated or distributed superimposed loads. It is a function of the ratio $B_c/2H$ and the ratio $L/2H$ for concentrated loads, or the ratio $D/2H$ and the ratio $M/2H$ for distributed loads.

C_T = load coefficient for tunnel conditions. It is a function of the ratio H/B_T and the type of soil surrounding the tunnel.

*American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

D = width of the area over which the distributed superimposed load acts, in feet (metres).
F = impact factor.
H = depth of cover, in feet (metres), for all conditions except the tunnel condition. For the tunnel condition, H is the distance from the ground surface to the top of the tunnel excavation, in feet (metres).
k = Rankine's ratio of lateral earth pressure to vertical pressure.
L = effective length of the pipe, in feet (metres). For pipe less than 3 ft (1 m), the actual length of the section should be used. For all other lengths, an effective length of 3 ft (1 m) should be used.
M = length of the area over which the distributed superimposed load acts, in feet (metres).
P = internal pressure, in pounds per square inch (kilopascals), that the pipe will withstand when no external load exists.
P_c = concentrated load, in pounds (kilonewtons*).
P_d = distributed load, in pounds per square foot (kilonewtons pounds per square metre*).
P_o = static, working, or operating pressure, in pounds per square inch (kilopascals).
P_s = surge pressure or water hammer, in pounds per square inch (kilopascals).
P_T = total internal pressure, in pounds per square inch (kilopascals), above which, in combination with some external load W_T applied in three-edge, vee-shaped bearing, the pipe will withstand.
p = projection ratio for the positive projecting embankment condition. It is defined as the ratio of the distance that the top of the pipe projects above the original ground surface, in feet (metres), to the outside diameter of the pipe, in feet (metres) (see Figure 10A, page 19).
p' = projection ratio for the negative projecting and imperfect trench condition. It is defined as the ratio of the vertical distance from the original ground surface down to the top of the pipe, in feet (metres), divided by the width of the trench, in feet (metres), for negative projection, and as the ratio of the vertical distance from the top of the excavated trench down to the top of the pipe, in feet (metres), divided by the diameter of the pipe, in feet (metres), for the imperfect trench condition (see Figures 10B and 11, pages 19 and 21).
r_{sd} = settlement ratio for positive projection, negative projection, and imperfect trench conditions.
S.F. = safety factor.
μ = coefficient of internal friction of backfill material.
μ' = coefficient of friction between backfill material and the trench wall.
W = external load, in pounds per linear foot (kilonewtons per metre) of pipe, in the three-edge, vee-shaped bearing test that the pipe will withstand when no hydrostatic pressure exists.

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*NOTE: P_c and P_d are loads measured as a mass. However, to use them in equations using SI units, the mass unit must be converted to force by multiplying by 9.8062 (g, the acceleration of gravity).

W_E = total earth load, in pounds per linear foot (kilonewtons per metre), to which the pipe is subjected.

W_s = total superimposed load, in pounds per linear foot (kilonewtons per metre) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_{sc} = concentrated superimposed load, in pounds per linear foot (kilonewtons per metre) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_{sd} = distributed superimposed load, in pounds per linear foot (kilonewtons per metre) of pipe, transmitted through the burial environment to the pipe by factors other than the earth loads.

W_T = total external load, in pounds per linear foot (kilonewtons per metre) of pipe, applied in three-edge, vee-shaped bearing above which, in combination with some internal pressure P_T, the pipe will withstand.

w_e = weight of earth, in pounds per cubic foot (kilonewtons per cubic metre*).

Sec. 1.4 Permeation

The selection of materials is critical for water service and distribution piping in locations where there is likelihood the pipe will be exposed to significant concentrations of pollutants comprised of low molecular weight petroleum products or organic solvents or their vapors. Research has documented that pipe materials such as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement; and elastomers, such as used in jointing gaskets and packing glands, may be subject to permeation by lower molecular weight organic solvents or petroleum products. If a water pipe must pass through such a contaminated area or an area subject to contamination, consult with the manufacturer regarding permeation of pipe walls, jointing materials, and so forth, *before* selecting materials for use in that area.

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 confidence that the designer has in engineering estimates of actual operating conditions. Safety factors are included in Sec. 5.

*Density, as used in the equations in this standard, refers to force exerted per unit volume under the acceleration of gravity, rather than mass per unit volume. Where true density is known in pounds per cubic foot, that value should be used in equations using US customary units; where true density is known in kilograms per cubic metre, it must be converted to newtons per cubic metre by multiplying by 9.8062 (g, the acceleration of gravity) before the value is used in equations using SI units.

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

2.1.1.1 Class A—concrete cradle or concrete arch bedding. This class of bedding may take either of two forms:

2.1.1.1.1 Concrete cradle. The pipe shall be bedded in a monolithic cradle of plain or reinforced concrete having a minimum thickness of one fourth the outside pipe diameter (minimum of 4 in. [100 mm]) under the barrel and extending up the sides for a height equal to one fourth the outside diameter. The cradle shall have a width at least equal to the outside diameter of the pipe barrel plus 8 in. (200 mm). Backfill shall be compacted above the cradle and extending to 12 in. (300 mm) above the crown of the pipe. The load factor for class A concrete cradle bedding is 2.2 for plain concrete with lightly compacted (85 percent to 95 percent proctor or 40 percent to 70 percent relative density) backfill; 2.8 for plain concrete with carefully compacted (95 percent proctor or 70 percent relative density) backfill; and 3.4 for reinforced concrete with $p = 0.4$ percent, in which p is the ratio of the contact area of steel to the area at the invert.

2.1.1.1.2 Concrete arch. The pipe shall be embedded in carefully compacted granular material having a minimum thickness of one fourth the outside diameter between barrel and bottom of trench excavation and extending halfway up the sides of the pipe. The top half of the pipe shall be covered with a monolithic plain or reinforced concrete arch having a minimum thickness of one fourth the outside diameter (minimum of 4 in. [100 mm]) at the crown and having a minimum width equal to the outside pipe diameter plus 8 in. (200 mm). The load factor for class A concrete arch-type bedding is 2.8 for plain concrete; 3.4 for reinforced concrete with $p = 0.4$ percent; and 4.8 for reinforced concrete with $p = 1.0$ percent, in which p is the ratio of the area of steel to the contact area of concrete at the crown.

2.1.1.2 Class B—first class bedding. Class B bedding may be achieved by either of two construction methods:

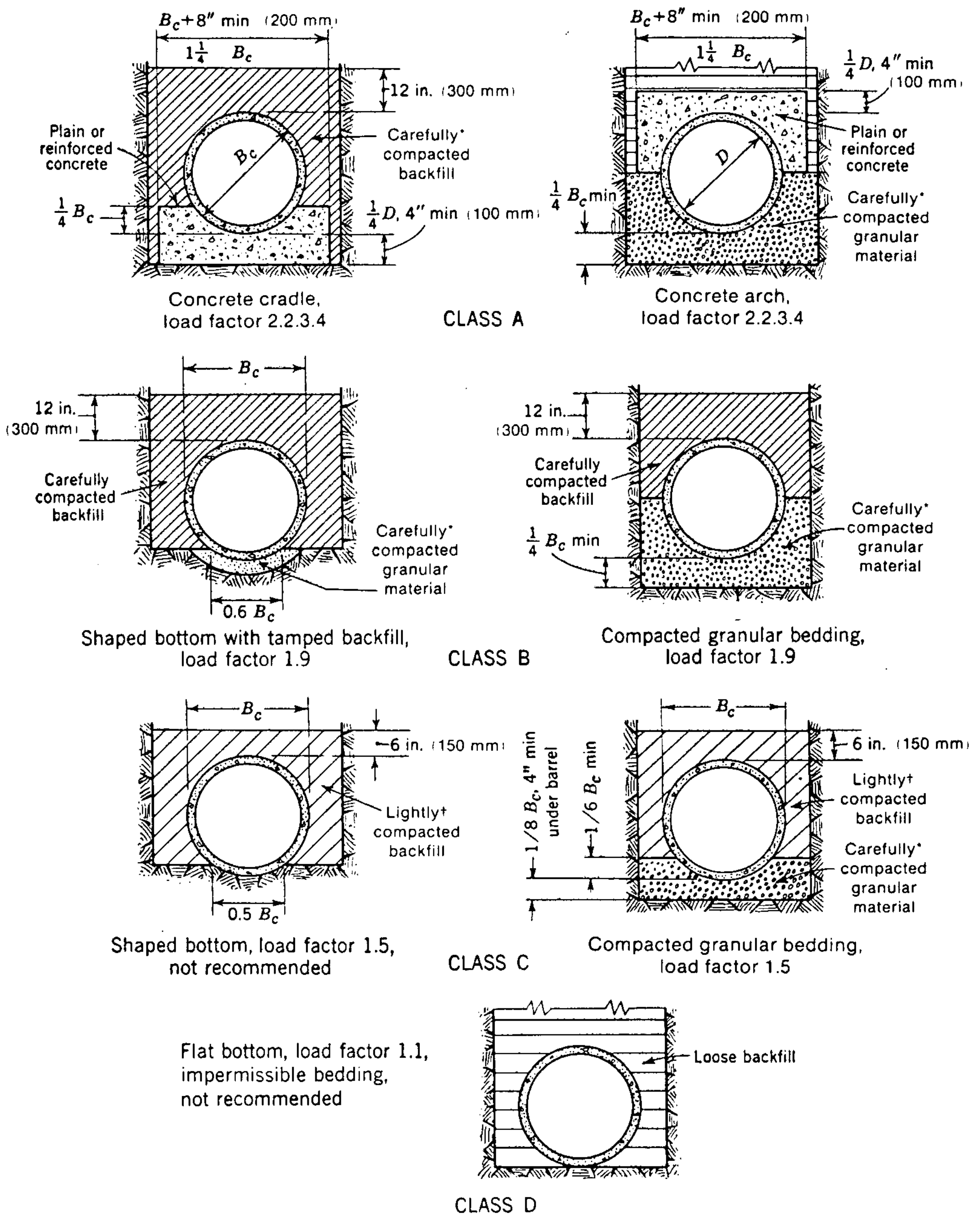
2.1.1.2.1 Shaped bottom with carefully compacted backfill. The bottom of the trench excavation shall be shaped to conform to a cylindrical surface with a radius at least 2 in. (50 mm) greater than the radius to the outside of the pipe and with a width sufficient to allow six tenths of the width of the pipe barrel to be bedded in fine granular fill placed in the shaped excavation. Carefully compacted backfill shall be placed at the sides of the pipe to a thickness of at least 12 in. (300 mm) above the top of the pipe. Shaped trench bottoms are difficult to achieve under current construction techniques.

2.1.1.2.2 Compacted granular bedding with carefully compacted backfill. The pipe shall be bedded in compacted granular material placed on a flat trench bottom. The granular bedding shall have a minimum thickness of one fourth the outside pipe diameter (minimum of 4 in. [100 mm]) and shall extend halfway up the pipe barrel at the side. The remainder of the side fills and a minimum depth of 12 in. (300 mm) over the top of the pipe shall be filled with carefully compacted material.

2.1.1.2.3 The load factor for either construction method is 1.9.

2.1.1.3 Class C—ordinary bedding. Class C ordinary bedding may be achieved by either of two construction methods:

2.1.1.3.1 Shaped bottom. The pipe shall be bedded with “ordinary” care in an earth foundation formed in the trench bottom by a shaped excavation that will fit the pipe barrel with reasonable closeness for a width of at least 50 percent of the outside pipe diameter. The side fills and area over the pipe to a minimum depth of



NOTE: In rock trench, excavate at least 6 in. (150 mm) below the coupling of the pipe except where concrete cradle is used.

* Carefully compacted backfill or granular material: 95% proctor or 70% relative density.

† Lightly compacted backfill: 85-90% proctor or 40-70% relative density.

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Figure 1 Classes of bedding for conduits in trench.

6 in. (150 mm) above the top of the pipe shall be filled with lightly compacted fill. The shaped bottom bedding is not recommended for pipeline construction because it is impractical and costly.

2.1.1.3.2 Compacted granular bedding with a lightly compacted backfill. The pipe shall be bedded in compacted granular material placed on a flat trench bottom. The granular bedding shall have a minimum thickness of 4 in. (100 mm) under the barrel and shall extend one tenth to one sixth of the outside diameter up the pipe barrel at the sides. The remainder of the side fills and a minimum depth of 6 in. (150 mm) over the top of the pipe shall be filled with lightly compacted backfill.

2.1.1.3.3 The load factor for either construction method is 1.5.

2.1.1.4 Class D—flat bottom trench, impermissible bedding. In this class of bedding, the bottom of the trench is left flat, and no care is taken to secure compaction of backfill at the sides and immediately over the pipe. The load factor for class D bedding is 1.1. Class D bedding is not recommended for pipeline construction. Under present construction conditions, class B or class C bedding with a compacted granular bedding is generally a more practical and economical method of installation.

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, vee-shaped 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 Figure 2. The equation for the load pressure parabolic curve, which is known as the Schlick formula, may be expressed as

$$W_T = W\sqrt{\frac{P - P_T}{P}} \qquad \text{(Eq 1)}$$

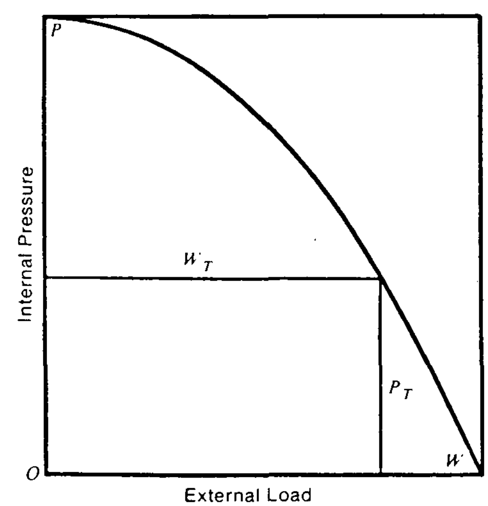

Figure 2 Load pressure curve.

Sec. 2.3 Three-Edge, Vee-Shaped Bearing Load

The combined loading curve shown in Figure 2 is calculated on the basis of crush strengths determined by laboratory tests employing the three-edge, vee-shaped bearing test method (see ASTM C500 and Figure 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, it is necessary to apply a bedding load factor to the laboratory three-edge, vee-shaped bearing loads to correlate them to the actual field loads. Since the external load equals the bedding factor times the vee-shaped bearing load, the bedding factor equals the external load divided by the three-edge, vee-shaped bearing load. Figure 1 shows the load factors to be applied for each bedding class.

SECTION 3: EXTERNAL LOADS

Sec. 3.1 Introduction

For the design of asbestos–cement distribution pipe, external loads W_T are defined by the following equation:

$$W_T = \frac{W_E + W_s}{(\text{B.F.})} \times (\text{S.F.}) \qquad \text{(Eq 2)}$$

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

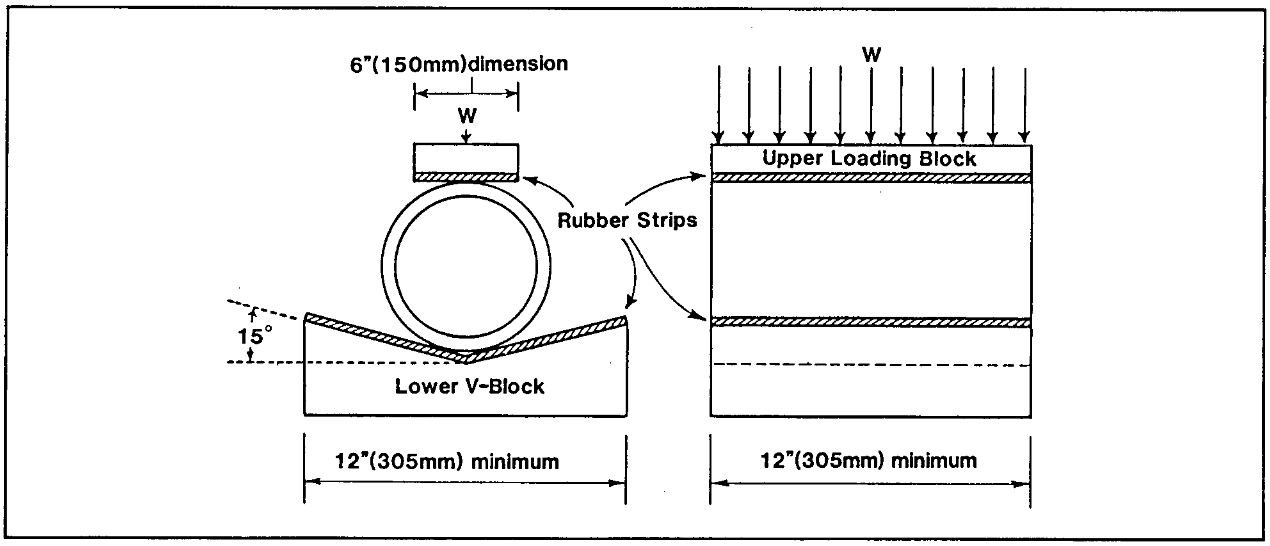

Figure 3 Assembly for three-edge, vee-shaped crushing strength test.

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 that make its inclusion in this discussion necessary. Figure 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

$$W_E = C w_e B_d^2 \qquad \text{(Eq 3)}$$

NOTE: Density as used in this equation and the following equations actually refers to force exerted per unit volume (pounds per cubic foot or kilonewtons per metre) under the acceleration of gravity, rather than mass per unit volume. Where true density is known in pounds per cubic foot, that value should be used in equations using US customary units; where true density is known in kilograms per cubic metre, it must be converted to newtons per cubic metre by multiplying times 9.8062 (g, the acceleration of gravity) before the value is used in equations using SI units.

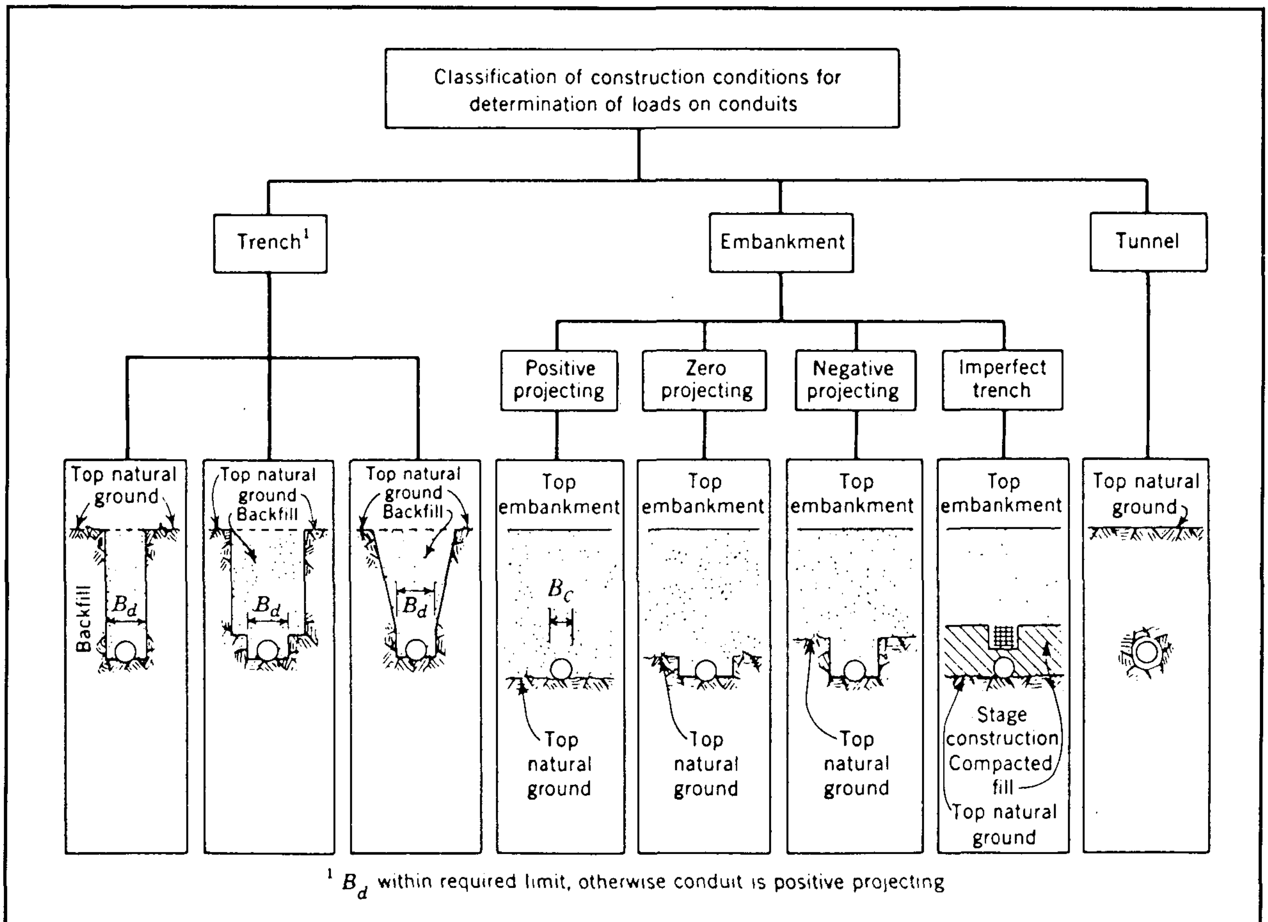

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Figure 4 Classification of construction techniques.

Soil densities w_e range in value from 100 to 135 lb/ft^3 (16 to 21 kN/m^3). In the absence of actual site information, a value of 120 lb/ft^3 (19 kN/m^3) is recommended for asbestos–cement transmission pipe design.

3.2.1.1 *C* is a coefficient that is dependent on the following:

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.

3.2.1.2 Values for B_d 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 Figure 4. For this condition, Eq 3 is rewritten as:

$$W_E = C_d w_e B_d^2 \qquad \text{(Eq 4)}$$

3.2.2.1 The values of C_d are obtained from Figure 5, in which curves A, B, C, D, and E take into account the friction coefficient between the backfill and the sides of the trench for the various soil compositions likely to be encountered. Curve A is for granular materials without cohesion. Curve B is for sand and gravel. Curve C is for saturated top soil. Curve D is for clay. Curve E is for saturated clay. Table 1 (pages 12–16) contains a series of earth-load selection tables.

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 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, is also classified as an embankment condition. The various embankment conditions are illustrated in Figures 4 and 6.

3.2.4 *Positive projecting pipe 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

$$W_E = C_c w_e B_c^2 \qquad \text{(Eq 5)}$$

3.2.4.1 The values of C_c are obtained from Figure 7 (page 17). C_c may also 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 $p(r_{sd}) = 0.7$.

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

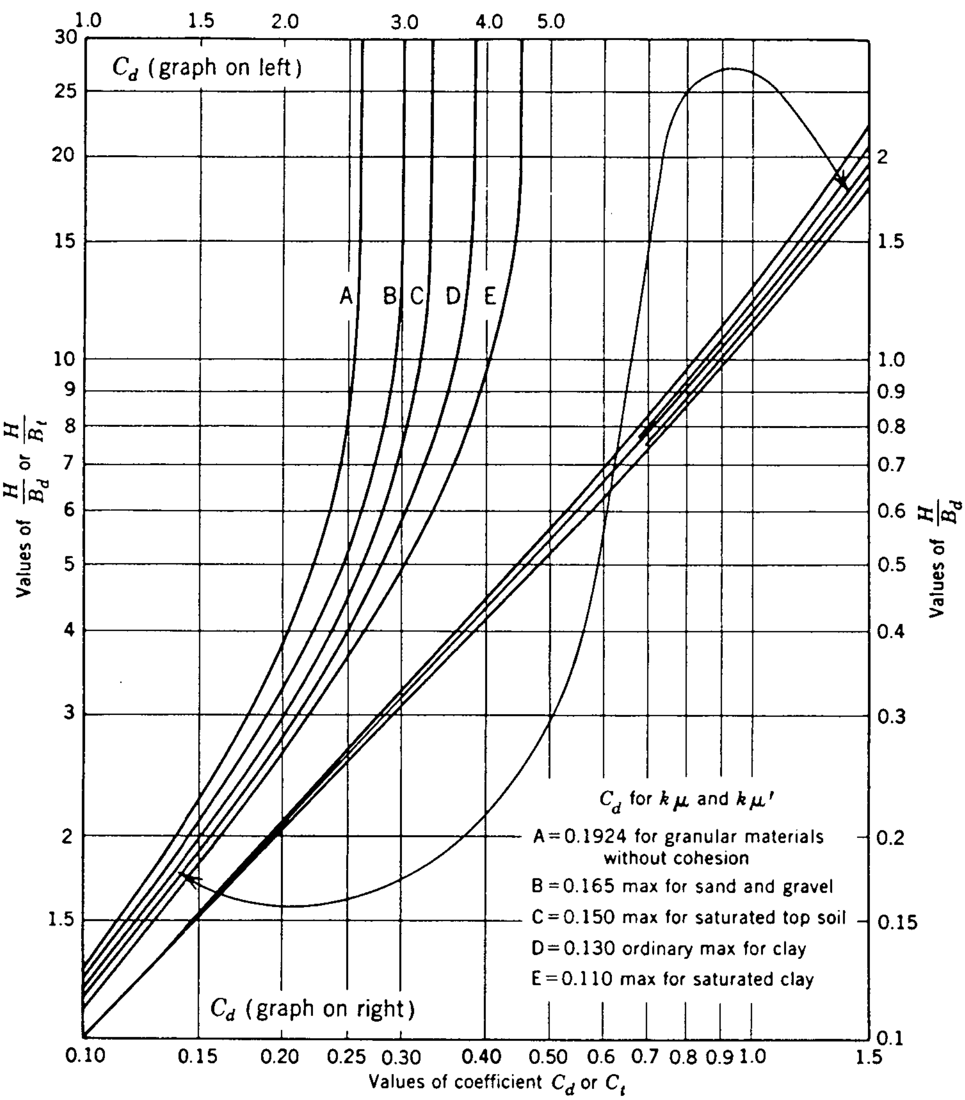

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Figure 5 Values of C_d for trench conditions.

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, the following 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 dependent 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

Table 1 Earth Loads (*lb/lin ft*)

Pipe size 18 in. ID

Trench Cover *ft*	Trench Width—*ft* 2.5	2.75	3.0	3.25	3.5	4.0	4.5	5.0	5.5	Transition Width
2	**490**									2 ft 5 in.
2.5	640	**640**								2 ft 8 in.
3	810	835								2 ft 10 in.
4	1000	1110	**1240**							3 ft 1 in.
5	1200	1320	1450	**1610**	**1640**					3 ft 5 in.
6	1350	1520	1700	1865	2050					3 ft 8 in.
7	1500	1690	1900	2090	2300					3 ft 10 in.
8	1600	1850	2100	2320	2525	**2825**				4 ft 0 in.
9	1725	2000	2250	2510	2750	3230				4 ft 1 in.
10	1850	2120	2400	2725	2950	3550	**3635**			4 ft 3 in.
12	2050	2360	2675	3020	3300	4000	4440			4 ft 5 in.
14	2200	2570	2900	3280	3600	4400	5220			4 ft 7 in.
16	2300	2720	3100	3515	3900	4800	5640	**6040**		4 ft 9 in.
18	2400	2840	3275	3720	4150	5100	6040	6830		5 ft 0 in.
20	2500	3000	3400	3995	4350	5350	6400	7450	**7620**	5 ft 2 in.

Pipe size 20 in. ID

Trench Cover *ft*	Trench Width—*ft* 2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	Transition Width
2	**545**									2 ft 8 in.
2.5	705									2 ft 10 in.
3	870	**890**								3 ft 0 in.
4	1110	1250	**1330**							3 ft 4 in.
5	1320	1450	1610	**1750**	**1770**					3 ft 8 in.
6	1520	1700	1865	2050	2210	**2220**				3 ft 11 in.
7	1690	1900	2090	2300	2515	2655				4 ft 1 in.
8	1850	2100	2320	2525	2765	3000	**3095**			4 ft 3 in.
9	2000	2250	2510	2750	3040	3300	3545			4 ft 5 in.
10	2120	2400	2725	2950	3240	3650	3980			4 ft 6 in.
12	2380	2675	3020	3300	3660	4000	4660	**4310**		4 ft 10 in.
14	2570	2900	3280	3600	4050	4400	5200	5760		5 ft 1 in.
16	2720	3100	3515	3900	4350	4800	5640	6450	**6640**	5 ft 2 in.
18	2840	3275	3720	4150	4620	5100	6040	7060	7500	5 ft 4 in.
20	3000	3400	3995	4350	4860	5350	6400	7450	8410	5 ft 7 in.

Pipe size 21 in. ID

Trench Cover *ft*	Trench Width—*ft* 2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	Transition Width
2	**570**										2 ft 9 in.
2.5	745	**730**									2 ft 11 in.
3	870	915									3 ft 2 in.
4	1110	1250	**1330**	**1380**							3 ft 6 in.
5	1320	1450	1610	1750	**1360**						3 ft 10 in.

Table continued next page

Table 1 (continued)

Pipe size 21 in. ID

Trench Cover *ft*	Trench Width—*ft* 2.75	3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	Transition Width
6	1520	1700	1865	2050	2210	**2325**					4 ft 1 in.
7	1690	1900	2090	2300	2515	2700	**2795**				4 ft 4 in.
8	1850	2100	2320	2525	2765	3000	3250				4 ft 6 in.
9	2000	2250	2510	2750	3040	3300	3725				4 ft 7 in.
10	2120	2400	2725	2950	3240	3550	4140	**4210**			4 ft 9 in.
12	2360	2675	3020	3300	3660	4000	4660	5160			5 ft 0 in.
14	2570	2900	3280	3600	4050	4400	5200	6000	**6100**		5 ft 3 in.
16	2720	3100	3515	3900	4350	4800	5540	6450	7020		5 ft 5 in.
18	2340	3275	3720	4150	4620	5100	6040	7050	7950		5 ft 6 in.
20	3000	3400	3995	4350	4880	5350	6400	7450	8460	**8920**	5 ft 8 in.

Pipe size 24 in. ID

Trench Cover *ft*	Trench Width—*ft* 3.0	3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	Transition Width
2	**630**										3 ft 1 in.
2.5	805	**810**									3 ft 3 in.
3	955	1010	**1010**								3 ft 5 in.
4	1250	1330	1400	**1490**							3 ft 9 in.
5	1450	1610	1750	1940	**2030**						4 ft 1 in.
6	1700	1865	2050	2210	2400	**2550**					4 ft 5 in.
7	1900	2090	2300	2515	2700	3080					4 ft 8 in.
8	2100	2320	2525	2765	3000	3480	**3620**				4 ft 10 in.
9	2250	2510	2750	3040	3300	3790	4130				5 ft 0 in.
10	2400	2725	2950	3240	3550	4140	4660	**4660**			5 ft 2 in.
12	2675	3020	3300	3660	4000	4660	5400	5740			5 ft 5 in.
14	2900	3280	3600	4050	4400	5200	6000	6750	**6800**		5 ft 8 in.
16	3100	3515	3900	4350	4800	5640	6450	7410	7850		5 ft 11 in.
18	3275	3720	4150	4620	5100	6040	7050	8000	8910		6 ft 1 in.
20	3400	3995	4350	4860	5350	6400	7450	8460	9600	**10,000**	6 ft 2 in.

Pipe size 27 in. ID

Trench Cover *ft*	Trench Width—*ft* 3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	Transition Width
2	**710**										3 ft 5 in.
2.5	895	**905**									3 ft 6 in.
3	1040	1095									3 ft 8 in.
4	1330	1400	**1540**	**1600**							4 ft 1 in.
5	1610	1750	1940	2050	**2200**						4 ft 6 in.
6	1865	2050	2210	2400	2735						4 ft 8 in.
7	2090	2300	2515	2700	3110	**3385**					5 ft 1 in.
8	2320	2525	2765	3000	3480	3900	**3980**				5 ft 3 in.
9	2510	2750	3040	3300	3790	4300	4590				5 ft 6 in.
10	2725	2950	3240	3550	4140	4700	5190				5 ft 7 in.

NOTE: Values are for clay (part D of Figure 5, $k\mu = k\mu' = 0.130$) with weight of earth taken as 120 lb/ft^3 (1922 k/m^3). Correction for other earth weights may be made by simple direct proportions. For corrections of other types of soils, refer to formulas in Sec. 3. **Boldface** figures indicate maximum earth load for depth of trench. To obtain earth loads in kilonewtons per metre, multiply by 0.014594.

Table continued next page

Table 1 (continued)

Pipe size 27 in. ID

Trench Cover *ft*	Trench Width—*ft* 3.25	3.5	3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	Transition Width
12	3020	3300	3660	4000	4660	5400	6060	**6390**			6 ft 0 in.
14	3280	3600	4050	4400	5200	6000	6750	7550	**7560**		6 ft 3 in.
16	3515	3900	4350	4800	5840	6450	7410	8300	8800		6 ft 6 in.
18	3720	4150	4620	5100	6040	7050	8000	9000	9960	**10,000**	6 ft 8 in.
20	3995	4350	4860	5350	6400	7450	8460	9600	10,890	11,180	6 ft 10 in.

Pipe size 30 in. ID

Trench Cover *ft*	Trench Width—*ft* 3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	Transition Width
2	**755**									3 ft 7 in.
2.5	965									3 ft 10 in.
3	1150	**1185**								3 ft 11 in.
4	1400	1675	**1680**							4 ft 5 in.
5	1750	2050	2335	**2340**						4 ft 8 in.
6	2050	2400	2800	3005						5 ft 0 in.
7	2300	2700	3110	3500	**3665**					5 ft 5 in.
8	2525	3000	3480	3900	4320					5 ft 7 in.
9	2750	3300	3790	4300	4840	**4980**				5 ft 10 in.
10	2950	3550	4140	4700	5260	5660				6 ft 1 in.
12	3300	4000	4660	5400	6060	6800	**6990**			6 ft 5 in.
14	3600	4400	5200	6000	6750	7550	8320	**8320**		6 ft 9 in.
16	3900	4800	5640	6450	7410	8300	9210	9610		7 ft 0 in.
18	4150	5100	6040	7050	8000	9000	9960	10,980	**10,980**	7 ft 3 in.
20	4350	5350	6400	7450	8460	9600	10,890	11,890	12,300	7 ft 5 in.

Pipe size 33 in. ID

Trench Cover *ft*	Trench Width—*ft* 3.75	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	Transition Width
2	**810**										3 ft 10 in.
2.5	1050	**1060**									4 ft 1 in.
3	1220	1290									4 ft 3 in.
4	1540	1675	**1815**								4 ft 6 in.
5	1940	2050	2335	**2445**							5 ft 1 in.
6	2210	2400	2800	3050	**3205**						5 ft 5 in.
7	2515	3000	3110	3500	3920	**3925**					5 ft 8 in.
8	2705	3300	3480	3900	4460	4640					6 ft 1 in.
9	3040	3550	3790	4300	4840	5400	**5610**				6 ft 3 in.
10	3240	4000	4140	4700	5260	5260	6070				6 ft 5 in.
12	3660	4400	4660	5400	6060	6800	7450	**7550**			6 ft 10 in.
14	4050	4800	5200	6000	6750	7550	8350	9030			7 ft 2 in.
16	4350	5100	5640	6450	7410	8300	9210	10,110	**10,470**		7 ft 5 in.
18	4620	5350	6040	7050	8000	9000	9960	11,060	12,120		7 ft 9 in.
20	4860	5575	6400	7450	8460	9600	10,890	11,890	13,020	**13,390**	7 ft 11 in.

Table continued next page

Table 1 (continued)

Pipe size 36 in. ID

Trench Cover *ft*	Trench Width—*ft* 4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	Transition Width
2	**920**	**925**									4 ft 3 in.
2.5	1130	1145									4 ft 4 in.
3	1325	1550									4 ft 7 in.
4	1675	1950	**1950**								4 ft 11 in.
5	2050	2335	2555	**2555**							5 ft 3 in.
6	2400	2800	3050	3340	**3340**						5 ft 8 in.
7	2700	3110	3500	3920	4160						6 ft 0 in.
8	3000	3480	3900	4460	4900	**4950**					6 ft 2 in.
9	3300	3790	4300	4840	5400	5760	**5760**				6 ft 8 in.
10	3550	4140	4700	5260	5900	6430	6540				6 ft 10 in.
12	4000	4660	5400	6060	6800	7450	8150	**8150**			7 ft 4 in.
14	4400	5200	6000	6750	7550	8350	9170	9750	**9750**		7 ft 8 in.
16	4800	5640	6450	7410	8300	9210	10,110	11,000	11,330		7 ft 11 in.
18	5100	6040	7050	8000	9000	9960	11,060	12,150	12,900	**12,900**	8 ft 2 in.
20	5350	6400	7450	8460	9600	10,890	11,890	13,020	14,140	14,510	8 ft 6 in.

Pipe size 39 in. ID

Trench Cover *ft*	Trench Width—*ft* 4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	Transition Width
2	**990**										4 ft 5 in.
2.5	1290										4 ft 7 in.
3	1520	**1580**									4 ft 9 in.
4	1950	2220	**2340**								5 ft 2 in.
5	2335	2555	2980								5 ft 6 in.
6	2800	3050	3340	**3680**							5 ft 10 in.
7	3110	3500	3920	4320	**4500**						6 ft 3 in.
8	3480	3900	4460	4900	5360						6 ft 7 in.
9	3790	4300	4840	5400	5760	**6430**					6 ft 11 in.
10	4140	4700	5260	5900	6430	7170	**7440**				7 ft 3 in.
12	4660	5400	6060	6800	7450	8150	8980	**9310**			7 ft 8 in.
14	5200	6000	6750	7550	8350	9170	9750	11,090			8 ft 1 in.
16	5640	6450	7410	8300	9210	10,110	11,000	11,980	**12,830**		8 ft 5 in.
18	6040	7050	8000	9000	9960	11,060	12,150	12,900	14,330		8 ft 8 in.
20	6400	7450	8460	9600	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* 5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	Transition Width
2	**1060**										4 ft 8 in.
2.5	1390										4 ft 10 in.
3	1700										5 ft 0 in.
4	2220	**2350**									5 ft 4 in.
5	2555	3080									5 ft 8 in.

NOTE: Values are for clay (part D of Figure 5, $k\mu = k\mu' = 0.130$) with weight of earth taken as 120 lb/ft^3 (1922 k/m^3). Correction for other earth weights may be made by simple direct proportions. For corrections of other types of soils, refer to formulas in Sec. 3. **Boldface** figures indicate maximum earth load for depth of trench. To obtain earth loads in kilonewtons per metre, multiply by 0.014594.

Table continued next page

Table 1 (continued)

Trench Cover *ft*	Pipe size 42 in. ID — Trench Width—*ft* 5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	Transition Width
6	3050	3340	**3930**								6 ft 1 in.
7	3500	3920	4320	**4690**							6 ft 5 in.
8	3900	4460	4900	5600							6 ft 10 in.
9	4300	4840	5400	5760	**6630**						7 ft 2 in.
10	4700	5260	5900	6430	7170	**7730**					7 ft 6 in.
12	5400	6060	6800	7450	8150	8980	**9830**				8 ft 0 in.
14	6000	6750	7550	8350	9170	9750	10,940	**11,550**			8 ft 5 in.
16	6450	7410	8300	9210	10,110	11,000	11,980	13,580			8 ft 10 in.
18	7050	8000	9000	9960	11,060	12,150	12,900	14,390	**15,250**		9 ft 1 in.
20	7450	8460	9600	10,880	11,890	13,020	14,140	15,260	16,430	**16,830**	9 ft 4 in.

NOTE: Values are for clay (part D of Figure 5, $k\mu = k\mu' = 0.130$) with weight of earth taken as 120 lb/ft^3 (1922 k/m^3). Correction for other earth weights may be made by simple direct proportions. For corrections of other types of soils, refer to formulas in Sec. 3. **Boldface** figures indicate maximum earth load for depth of trench. To obtain earth loads in kilonewtons per metre, multiply by 0.014594.

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 Figure 6).

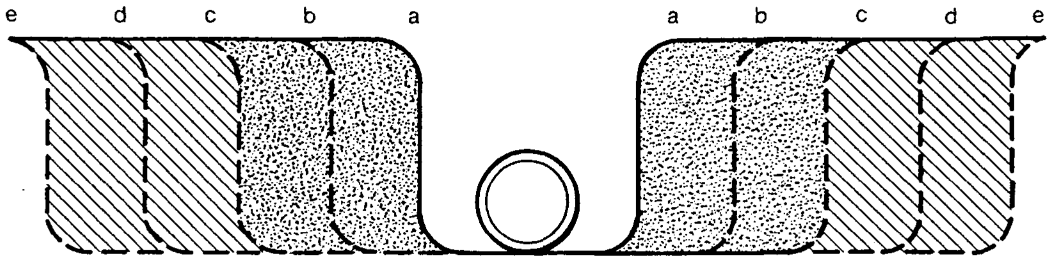
3.2.5.1 The transition width is determined from Figure 8 (page 18) by multiplying the applicable ratio B_d/B_c by the applicable pipe outside diameter B_c. The applicable ratio of trench width to pipe outside diameter B_d/B_c can be obtained from Figure 8 for any given ratio of backfill height to pipe 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 (Figure 4). For this condition, Eq 3 is rewritten as

$$W_E = C_n w_e B_d^2 \qquad \text{(Eq 7)}$$

3.2.6.1 The various values of C_n are obtained from Figure 9 (page 19). 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 (Figure 10B [page 19]). For asbestos–cement 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 Sec. 3.2.5. For values of the ratio B_d/B_c less than those given in Figure 8, the load on a pipe is determined from Eq 7 for negative projecting pipes. However, as the



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.

Figure 6 Embankment conditions.

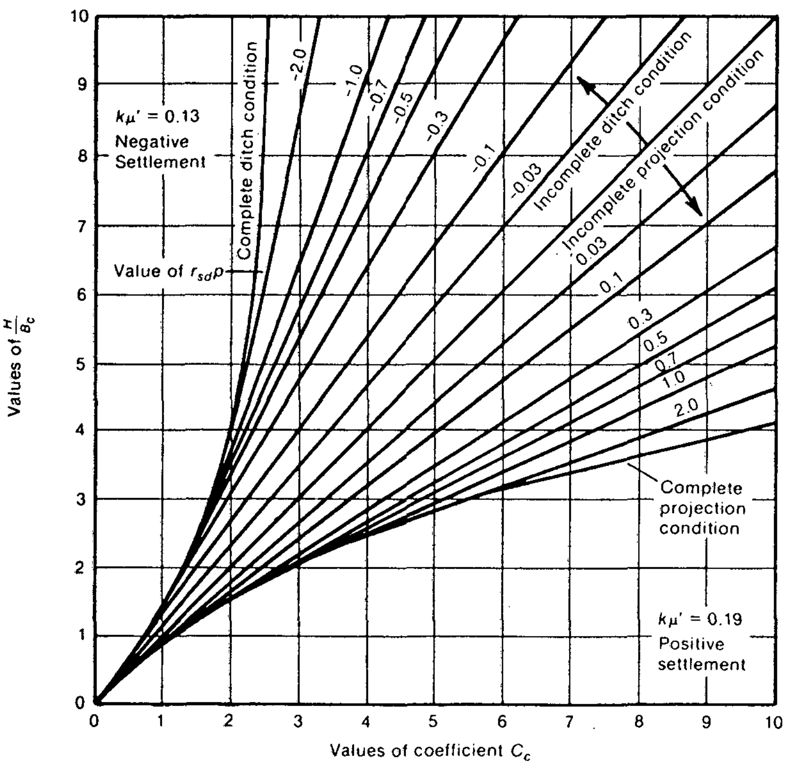


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Figure 7 Values of C_c for positive projecting pipe.

trench width increases and the ratio B_d/B_c becomes greater than that given in Figure 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 condition.* The imperfect trench 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 (Figure 11 [page 21]). For this condition, Eq 3 is rewritten as

$$W_e = C_n w_e B_c^2 \qquad \text{(Eq 8)}$$

3.2.7.1 The various values of C_n are obtained from Figure 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 (Figure 11). For asbestos–cement pipe design the recommended value for the settlement ratio r_{sd} is equal to –0.3.

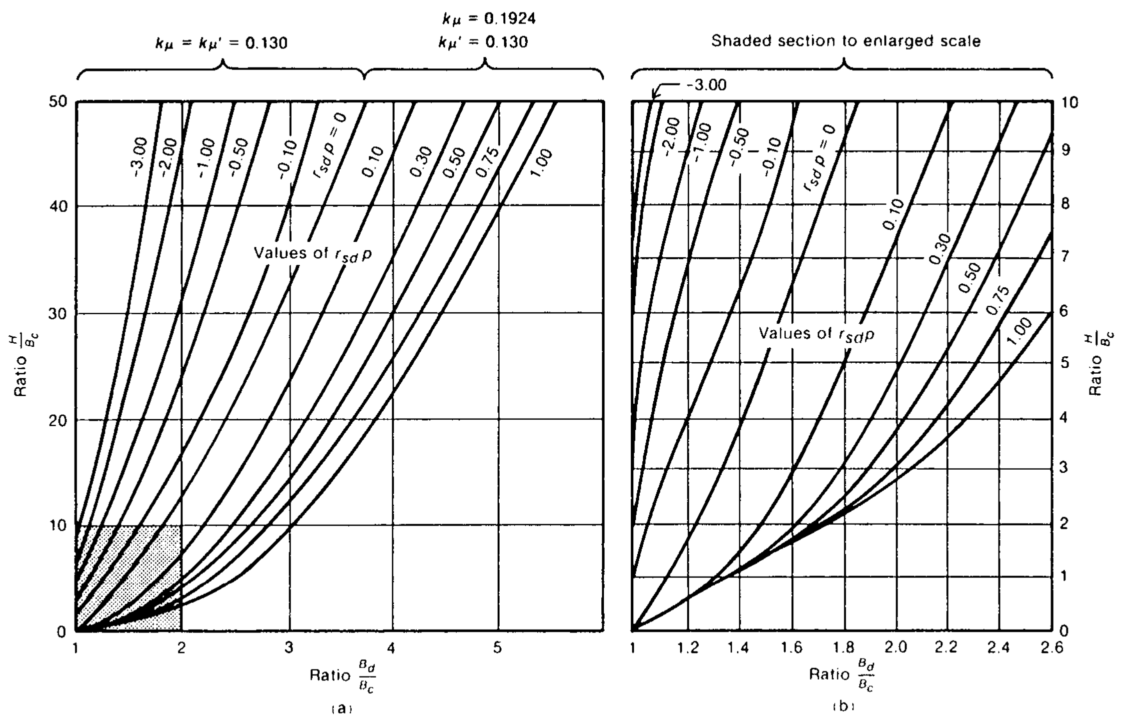

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Figure 8 Values of B_d/B_c at which the trench and positive projecting pipe equations give equal loads.

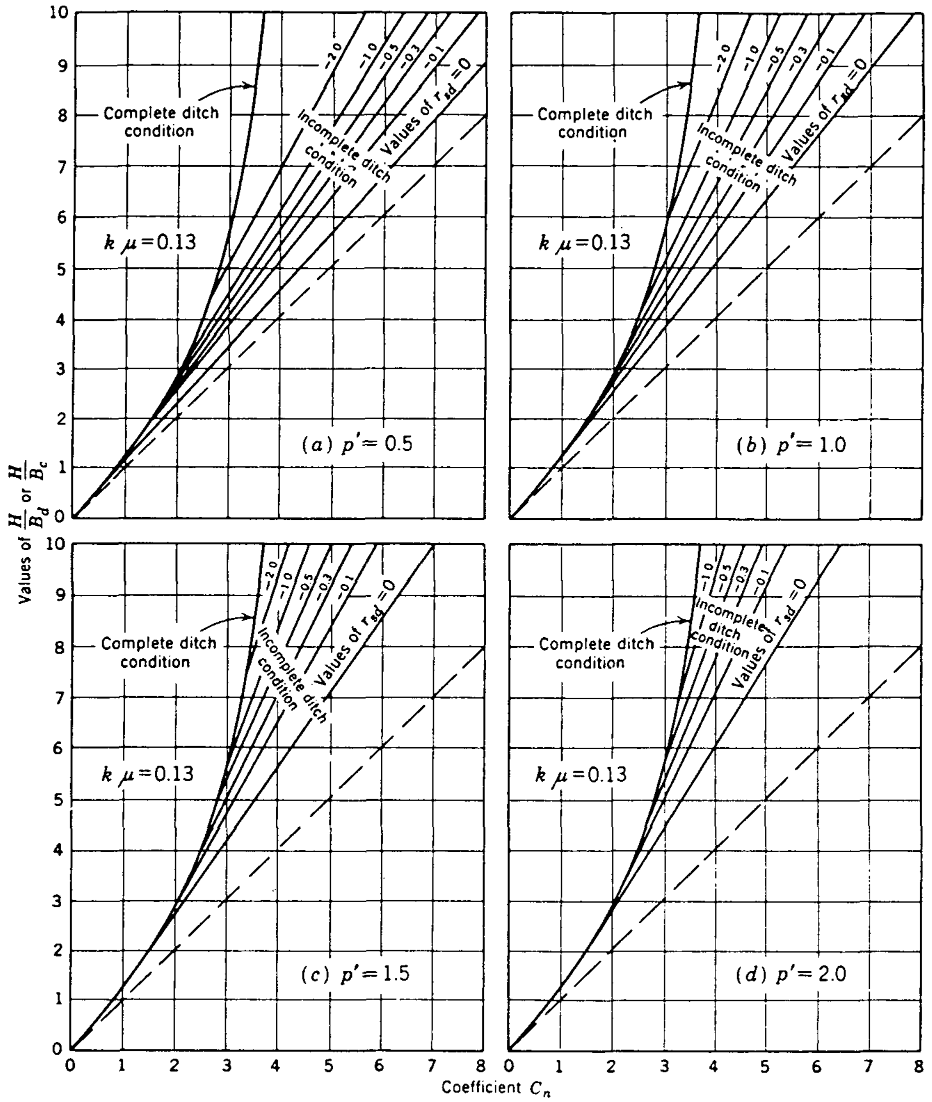

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Figure 9 Values of C_n for negative projecting pipe and imperfect ditch conditions.

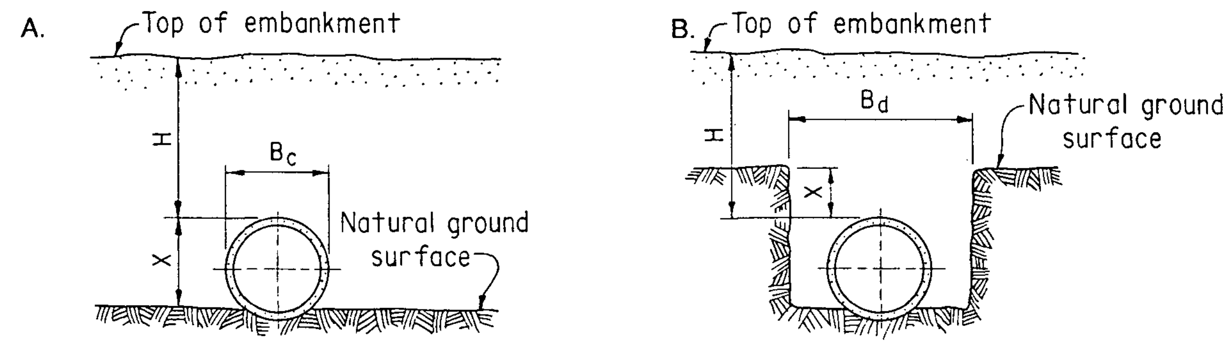

Figure 10A Positive projecting pipe projection ratio = x/B_c; Figure 10B Negative projecting pipe projection ratio = x/B_d.

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 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 distribution pipe 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 is then placed in the tunnel, and the void between the pipe and tunnel braces is backfilled with compacted earth, grout, or concrete. Once this operation is completed, the earth load automatically transfers from the tunnel supports to the pipe itself. For this condition, Eq 3 is rewritten as

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

3.2.8.3 Values of C_T for different types of soil are obtained from Figure 12 (page 22). If the value for the coefficient of cohesion is not available from laboratory tests, then the recommended safe design values in Table 2 are to be used.

3.2.8.4 In tunnel construction, when 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 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 homogenous soils that do not create unusual pressures and stresses. The tunnel construction method described in Sec. 3.2.8.2 (unsleeved tunnels) should not be used through materials that tend to squeeze or swell, such as some types of clay or shale, or through blocky and seamy rock. Under these conditions, the construction method described in Sec. 3.2.8.1 is recommended.

Table 2 Recommended Safe Design Values of *c* for Tunnel Conditions

Materials	Values of *c* lb/ft^2	(kN/m^2)
Clay, very soft	40	(1.63)
Clay, medium	250	(10.19)
Clay, hard	1000	(40.77)
Sand, loose dry	0	(0)
Sand, silty	100	(4.007)
Sand, dense	300	(12.23)
Top soil, saturated	100	(4.007)

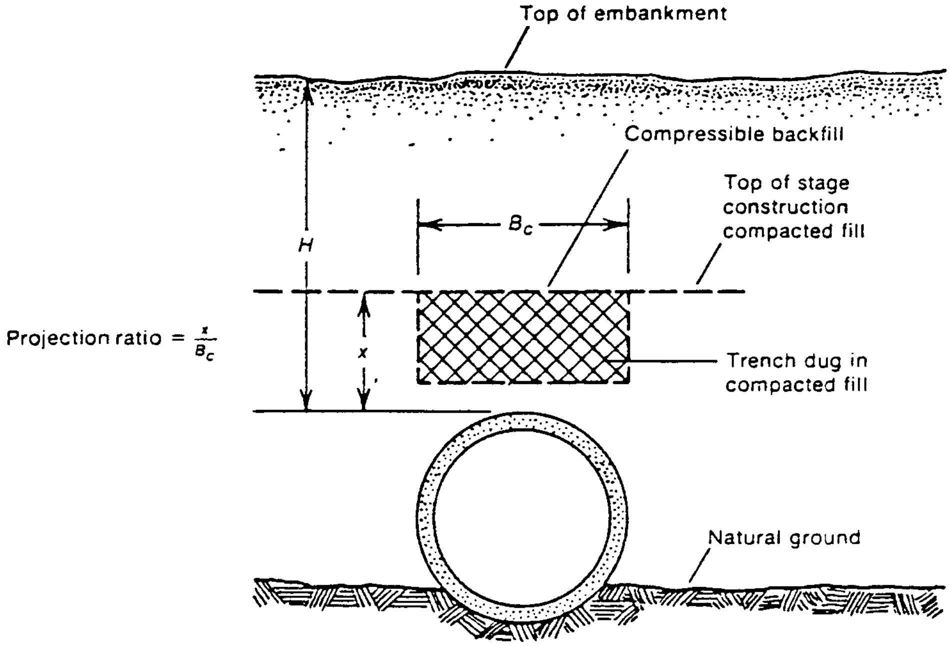

Figure 11 Projection ratio p' for the imperfect trench embankment condition.

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 Figure 13 (page 24): (1) concentrated W_{S_1} and (2) distributed W_{S_2}. Superimposed loads are frequently referred to as live loads.

3.3.1 *Concentrated load.* 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

$$W_{sc} = \frac{C_s P_c F}{L} \qquad \text{(Eq 10)}$$

See Tables 3, 4, and 5 (page 23).

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

$$W_{sd} = C_s P_d F B_c \qquad \text{(Eq 11)}$$

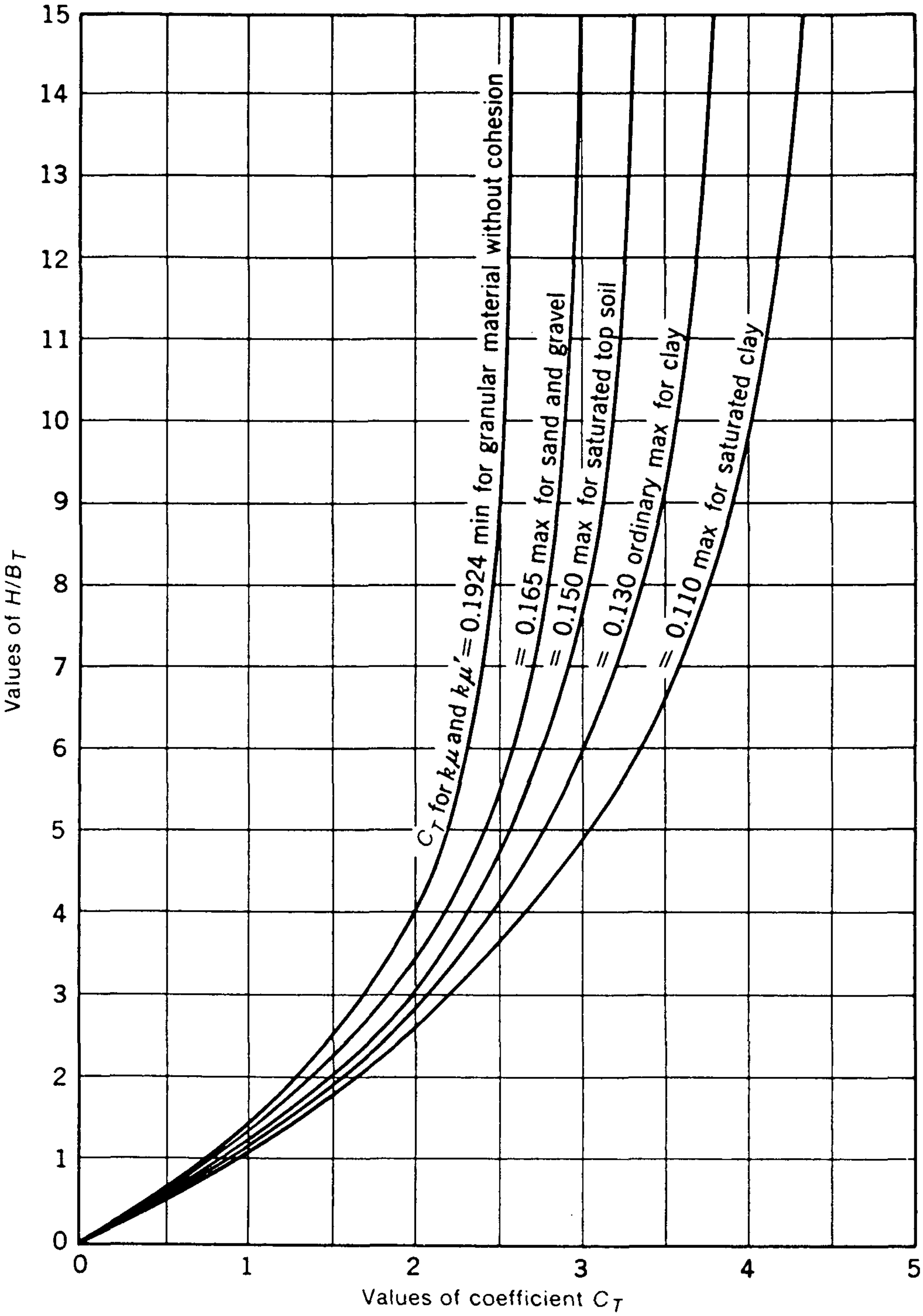

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Figure 12 Values of C_T for tunnel conditions.

Table 3 Impact Factors *F*

Depth of Cover *ft(m)*	Impact Factor *F*
1.0–2.0 (0.3–0.6)	1.2
2.0–3.0 (0.6–1.0)	1.1
3.0 or greater (1.0 or greater)	1.0

Table 4 Values of Load Coefficients C_S for Concentrated Superimposed Loads Centered Vertically Over Conduit*

Pipe Size	Depth of Cover *ft (m)*										
ID *in. (mm)*	2 (0.6)	2½ (0.76)	3 (0.91)	4 (1.21)	5 (1.52)	6 (1.83)	8 (2.44)	10 (3.05)	12 (3.66)	16 (4.89)	20 (6.09)
18 (450)	0.391	0.289	0.221	0.136	0.092	0.066	0.038	0.025	0.017	0.010	0.006
20 (500)	0.422	0.316	0.241	0.150	0.102	0.073	0.042	0.027	0.019	0.011	0.007
21 (525)	0.436	0.327	0.251	0.157	0.107	0.077	0.044	0.029	0.020	0.012	0.007
24 (600)	0.478	0.362	0.280	0.177	0.120	0.087	0.050	0.033	0.022	0.013	0.008
27 (675)	0.510	0.392	0.306	0.195	0.133	0.096	0.056	0.037	0.025	0.014	0.008
30 (750)	0.543	0.423	0.332	0.213	0.147	0.106	0.062	0.041	0.029	0.016	0.010
33 (825)	0.563	0.446	0.353	0.230	0.159	0.115	0.067	0.045	0.032	0.018	0.011
36 (900)	0.590	0.470	0.375	0.248	0.171	0.124	0.073	0.049	0.035	0.020	0.012
39 (975)	0.615	0.502	0.404	0.272	0.191	0.140	0.083	0.054	0.041	0.026	0.015
42 (1050)	0.619	0.506	0.422	0.286	0.202	0.147	0.089	0.063	0.043	0.030	0.017

*For convenience, concentrated superimposed loads resulting from a 16,000-lb (7250-kg) wheel force are presented in Table 5.

Table 5 Concentrated Superimposed Wheel Load *L* (Measured in *lb/ft* [*kN/m*]) on Asbestos-Cement Transmission Pipe—Single Wheel = 16,000 lb (7250 kg)

Cover Over Top of Pipe	Pipe Diameter *in. (mm)*									
ft (m)	18 (450)	20 (500)	21 (525)	24 (600)	27 (675)	30 (750)	33 (875)	36 (900)	39 (975)	42 (1050)
2 (0.61)	2083 (30.4)	2251 (37.2)	2364 (34.5)	2545 (37.1)	2720 (39.7)	2896 (42.3)	2992 (43.7)	3149 (45.9)	3280 (47.9)	3301 (48.2)
2.5 (0.76)	1541 (22.5)	1682 (24.5)	1728 (25.2)	1939 (28.3)	2091 (30.5)	2256 (33.0)	2368 (34.6)	2510 (36.6)	2677 (39.1)	2752 (40.2)
3 (0.91)	1178 (17.2)	1286 (18.7)	1334 (19.5)	1494 (21.9)	1632 (23.8)	1723 (25.1)	1878 (27.4)	2000 (29.2)	2154 (31.4)	2250 (32.8)
4 (1.22)	725 (10.6)	800 (11.7)	837 (12.2)	944 (13.8)	1040 (15.2)	1136 (16.6)	1224 (17.9)	1321 (19.3)	1450 (21.2)	1525 (22.2)
5 (1.52)	490 (7.2)	544 (7.9)	570 (8.3)	640 (9.3)	710 (10.4)	784 (11.4)	845 (12.3)	912 (13.3)	1018 (14.8)	1077 (15.7)
6 (1.83)	352 (5.1)	389 (5.7)	410 (6.0)	464 (6.8)	512 (7.5)	466 (8.3)	611 (8.9)	662 (9.7)	747 (10.9)	784 (11.4)
8 (2.44)	203 (2.9)	224 (3.3)	234 (3.4)	267 (3.9)	299 (4.4)	330 (4.8)	357 (5.2)	390 (5.7)	443 (6.5)	475 (6.9)
10 (3.05)	133 (1.9)	144 (2.1)	154 (2.2)	176 (2.4)	197 (2.9)	219 (3.2)	240 (3.5)	261 (3.8)	288 (4.2)	336 (4.9)
12 (3.66)	91 (1.3)	100 (1.5)	105 (1.5)	117 (1.7)	133 (1.9)	155 (2.3)	170 (2.5)	187 (2.7)	219 (3.2)	229 (3.3)
16 (4.87)	53 (0.8)	59 (0.8)	64 (0.9)	69 (1.0)	75 (1.1)	85 (1.2)	96 (1.4)	107 (1.67)	139 (2.0)	160 (2.3)
20 (6.09)	32 (0.5)	37 (0.5)	40 (0.6)	43 (0.6)	45 (0.6)	53 (0.8)	60 (0.9)	63 (0.9)	80 (1.2)	91 (1.3)

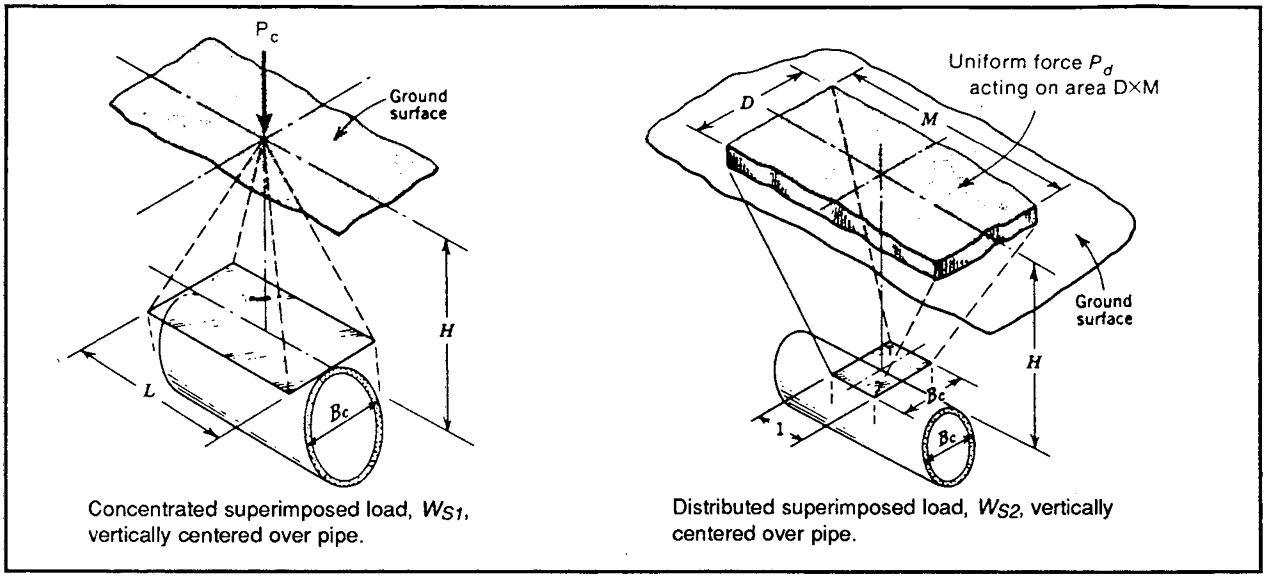


Figure 13 Superimposed loads.

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

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

The S.F. is the design safety factor. Safety factors are based on judgment, past experiences, and sound engineering principles. For asbestos–cement transmission pipe, a safety factor of 2 is recommended when surge or water hammer are calculated and added to operating pressure.

Sec. 4.2 Operating Pressure

The operating pressure P_o is the pressure that 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 (metres) 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 in the larger transmission main sizes are less affected by high and uncontrolled surges generated by rapid closing of fire hydrants. For example, a 6-in. (150-mm) hydrant flowing at 6 ft/s (1.8 m/s) could cause a surge in a 6-in. (150-mm) distribution line of more than 270 psi (1860 kPa). At the same flow rate, this change in velocity of 6 ft/s (1.8 m/s) would only change velocity in an 18-in. (450-mm) transmission pipe by 0.7 ft/s (0.2 m/s), with a resultant surge pressure of only 30 psi (207 kPa). The primary cause of surge pressure in transmission mains is the stopping and starting of pumps and opening or closing of line valves. The surge pressures resulting from these operations are more readily controlled by design of the system, and the magnitude of the surge is subject to more precise calculation than is possible by the opening and closing of hydrant valves. Appendix B presents a discussion of water hammer and how it may be controlled.

SECTION 5: DESIGN CRITERIA AND USE OF PIPE SELECTION CHARTS

Sec. 5.1 Combined Loading Curves

Extensive testing and application of statistical analyses have shown that the strength characteristics of asbestos–cement pipe conform to the principles of the combined loading theory developed by the late W.J. Schlick. This theory, commonly discussed in terms of the Schlick formula, represented graphically as a parabola, is used as the basis for the design and class selection of asbestos–cement transmission pipe (See Figures 14A–14J [pages 28–37] and Figures 14A(m)–14J(m) [pages 38–47].).

5.1.1 *Curve development*. The families of selection curves presented in this standard were developed using the Schlick formula, which establishes a functional relationship between external load and internal pressure. The external and internal load intercepts are tabulated in Table 6. These values represent the end points of 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. Selection curves in Figures 14A–14J and Figures 14A(m)–14J(m) are presented for each size of pipe from 18 in. through 42 in. and 450 mm through 1050 mm. 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 vee-shaped bearing crush design load W. Table 6 lists the values of P and W for the strength classifications of each pipe size. The method for pipe selection is outlined in Sec. 5.3.

Sec. 5.2 Safety Factors

Safety factors are normally applied by the engineer to the 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 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 7. 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. 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 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).

Table 6 Design Internal Pressure and Design External Load Intercepts for Use With Selection Curves for Transmission Pipe

Pipe Size	Class 30 300 psi (2100 kPa)*	Class 35 350 psi (2400 kPa)*	Class 40 400 psi (2800 kPa)*	Class 45 450 psi (3100 kPa)*	Class 50 500 psi (3400 kPa)*	Class 60 600 psi (4100 kPa)*	Class 70 700 psi (4800 kPa)*	Class 80 800 psi (5500 kPa)*	Class 90 900 psi (6200 kPa)*
in. (mm)	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*	*lb/ft (kN/m)*
18 (450)	2800 (41)	3300 (48)	4600 (67)	5700 (83)	7000 (102)	9000 (131)	11,500 (168)	14,700 (215)	18,900 (276)
20 (500)	3100 (45)	3900 (57)	5300 (77)	6400 (93)	7900 (115)	10,000 (146)	12,600 (184)	15,800 (231)	21,000 (306)
21 (525)	3150 (46)	4100 (60)	6000 (87)	6700 (98)	8000 (117)	10,200 (149)	13,200 (193)	16,800 (245)	22,000 (321)
24 (600)	3500 (51)	4500 (66)	6600 (96)	7500 (109)	9000 (131)	11,600 (169)	15,700 (229)	20,000 (292)	25,900 (378)
27 (675)	4400 (64)	5300 (77)	7000 (102)	8000 (117)	9700 (142)	13,200 (193)	17,400 (255)	21,500 (314)	28,300 (413)
30 (750)	4600 (67)	5600 (82)	7800 (114)	8700 (127)	10,200 (149)	14,100 (206)	18,900 (276)	23,600 (344)	32,000 (467)
33 (825)	5000 (73)	6000 (87)	8700 (127)	9600 (140)	11,200 (163)	15,200 (222)	20,500 (299)	25,800 (377)	34,500 (504)
36 (900)	5300 (77)	6300 (92)	9100 (133)	10,400 (152)	12,300 (180)	16,800 (245)	22,000 (321)	27,300 (398)	37,800 (552)
39 (975)	5500 (80)	6600 (96)	9500 (139)	11,100 (162)	13,200 (193)	18,000 (263)	23,600 (344)	29,400 (429)	40,900 (597)
42 (1050	5600 (82)	7200 (105)	10,000 (146)	12,600 (184)	14,300 (209)	20,000 (292)	25,200 (368)	31,500 (460)	44,100 (644)

*kPa values were converted from pounds per square inch and rounded to the nearest hundred.

Table 7 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

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 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.

Sec. 5.4 Discussion

AWWA C401-83 is a standard containing information similar to that contained herein, but dealing with smaller diameter pipes. The effect of water hammer generated by the opening and closing of fire hydrants can be of significant magnitude in small distribution pipe sizes because of 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 on an assumed velocity change to compensate for undetermined surge pressures, AWWA C401 incorporates a large fixed safety factor for each asbestos–cement pressure class. In the larger sizes covered in this standard, the design is based on an evaluation of surge pressure that can be controlled in design. Calculated surge pressure is added to operating pressure before a safety factor of 2 is applied. For external loads, AWWA C401 considers only earth loads, and a recommended safety factor of 2.5 is applied. In this standard, both earth loads and live loads are added before a factor of safety of 1.5 is applied to the combination of these external loads.

In summary, design using this standard is based on a more detailed evaluation of the magnitude of surge pressure and live loadings, and safety factors based on this more precise knowledge of actual operating conditions are applied.

Sec. 5.5 Illustrative Problem on Pipe Selection

Problem. A 24-in. asbestos–cement transmission pipeline 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 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 the instructions for use of selection charts with safety factors as described in Sec. 5.3:

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. $$\frac{W_E + W_S \text{ (S.F.)}}{\text{B.F.}} = \frac{(2670)(1.5)}{1.5} = 2670 \text{ lb/ft}$$

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-35 and T-40. Use T-40.

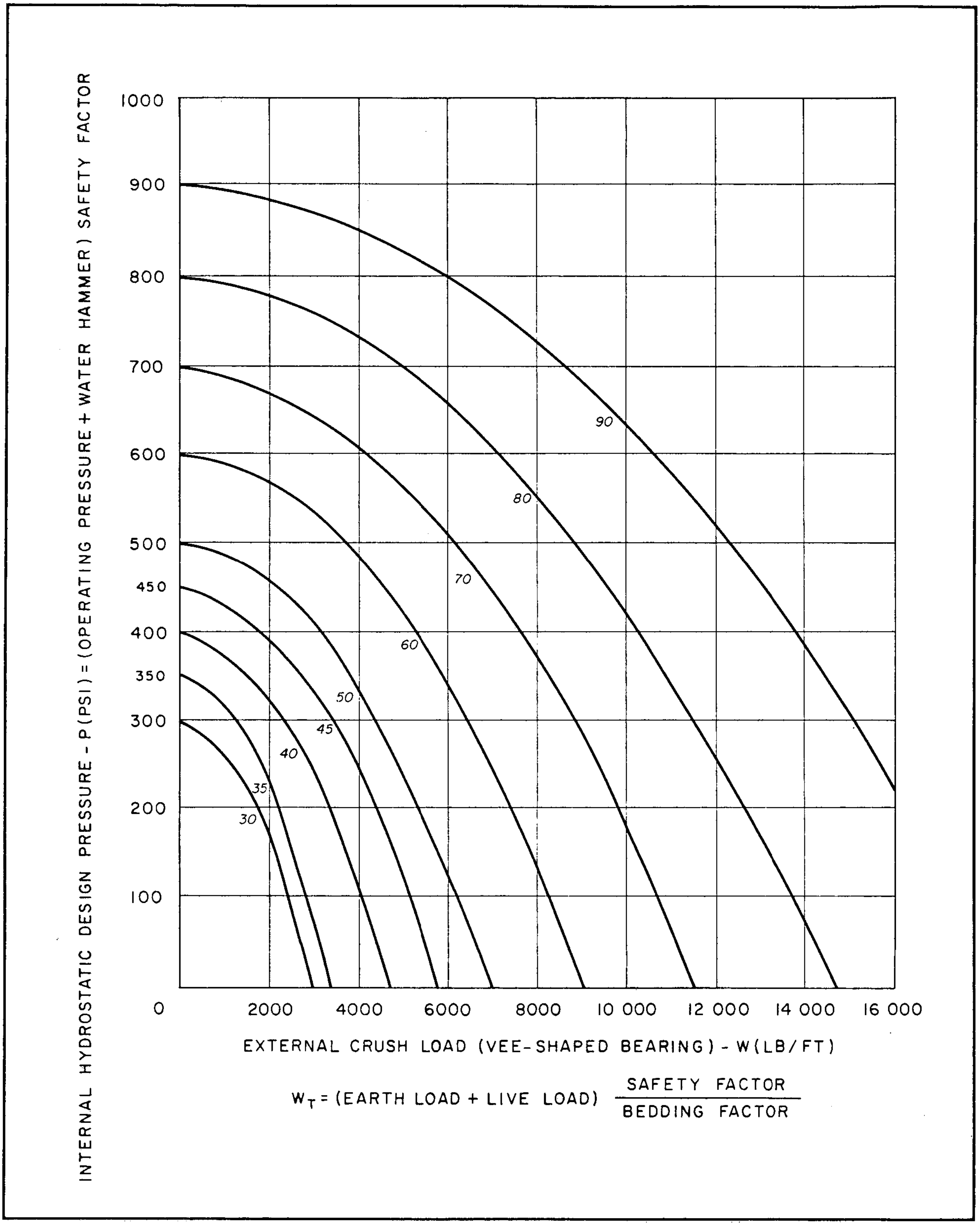


Figure 14A Combined loading curves for 18-in. transmission pipe.

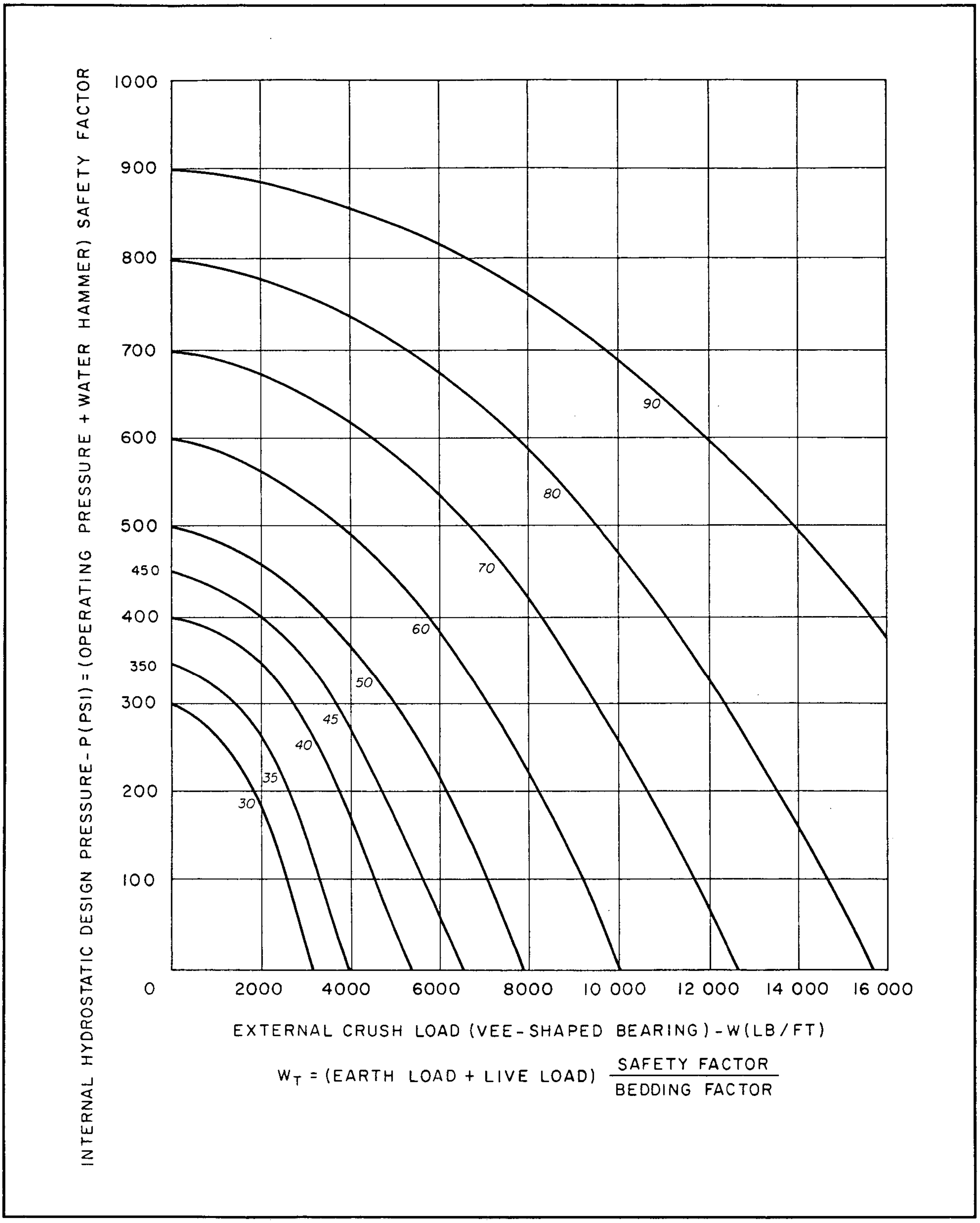


Figure 14B Combined loading curves for 20-in. transmission pipe.

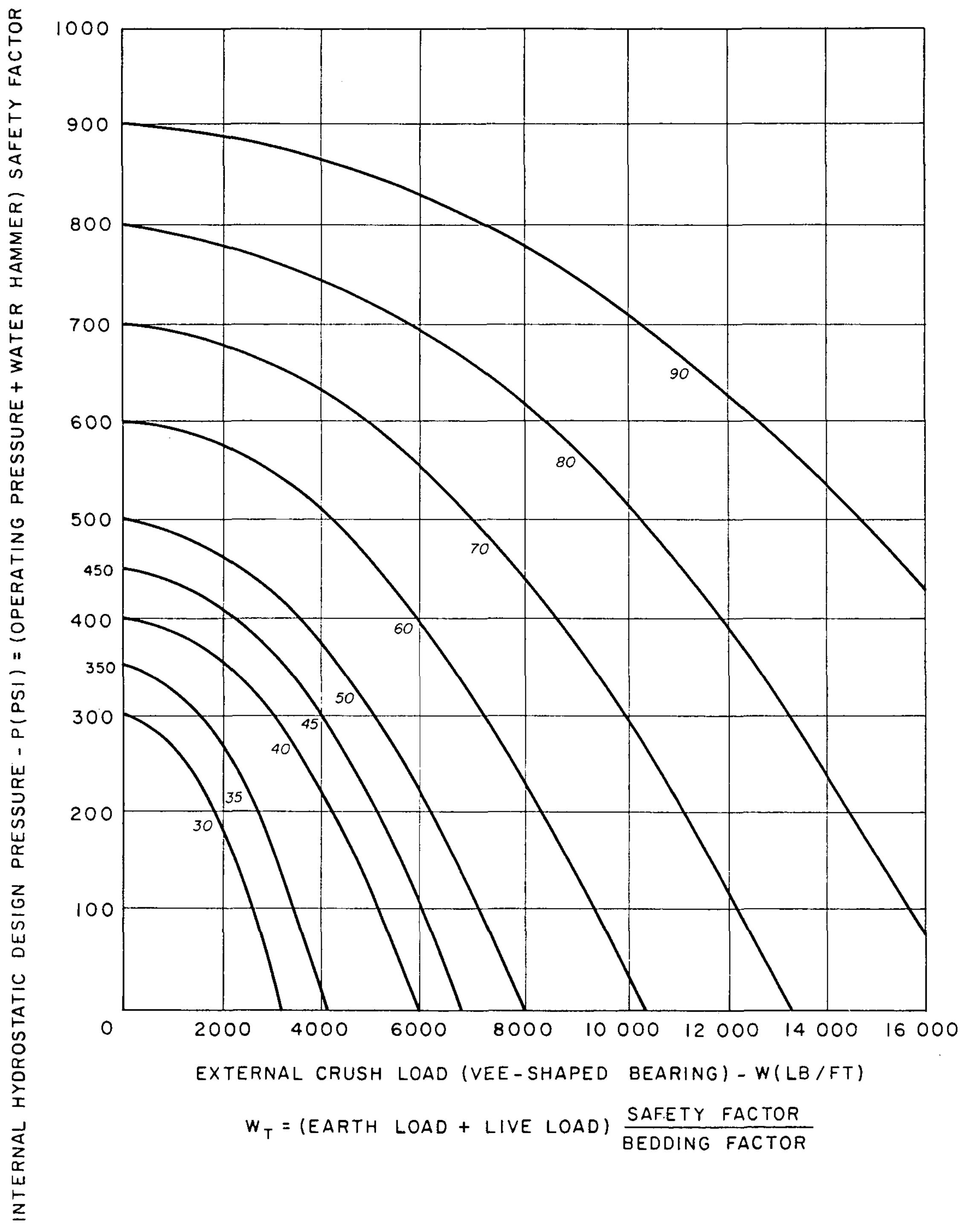


Figure 14c Combined loading curves for 21-in. transmission pipe.

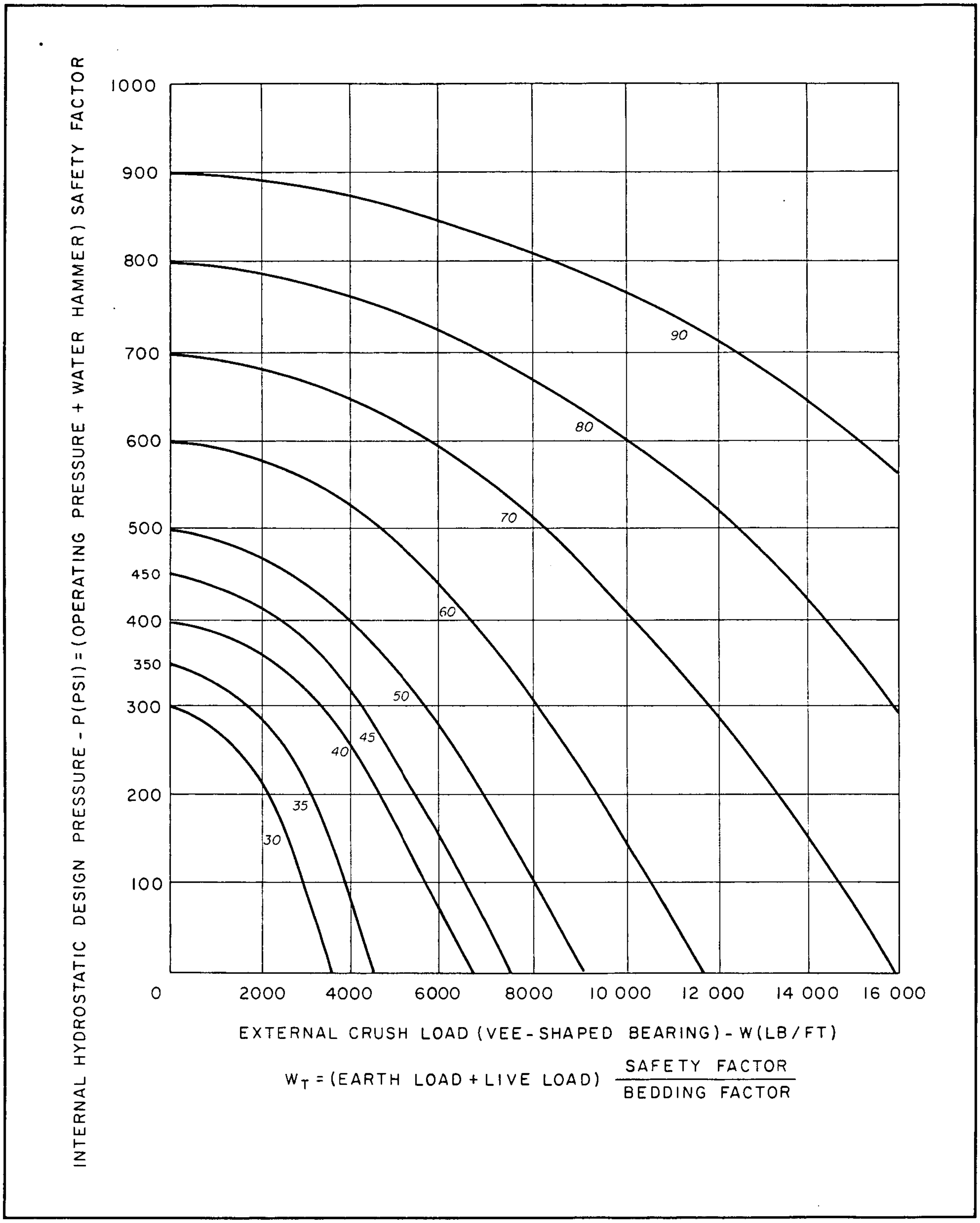


Figure 14D Combined loading curves for 24-in. transmission pipe.

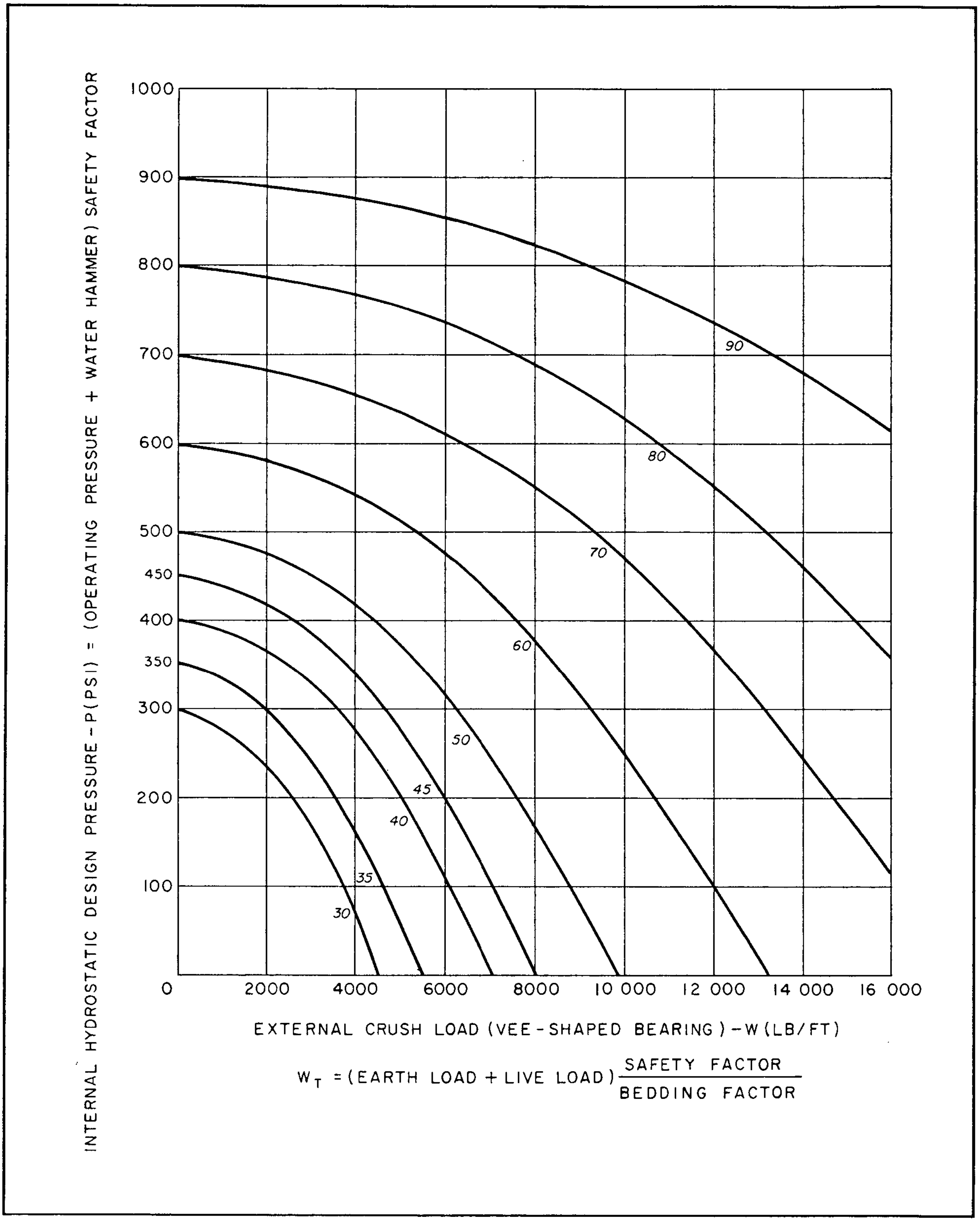


Figure 14E Combined loading curves for 27-in. transmission pipe.

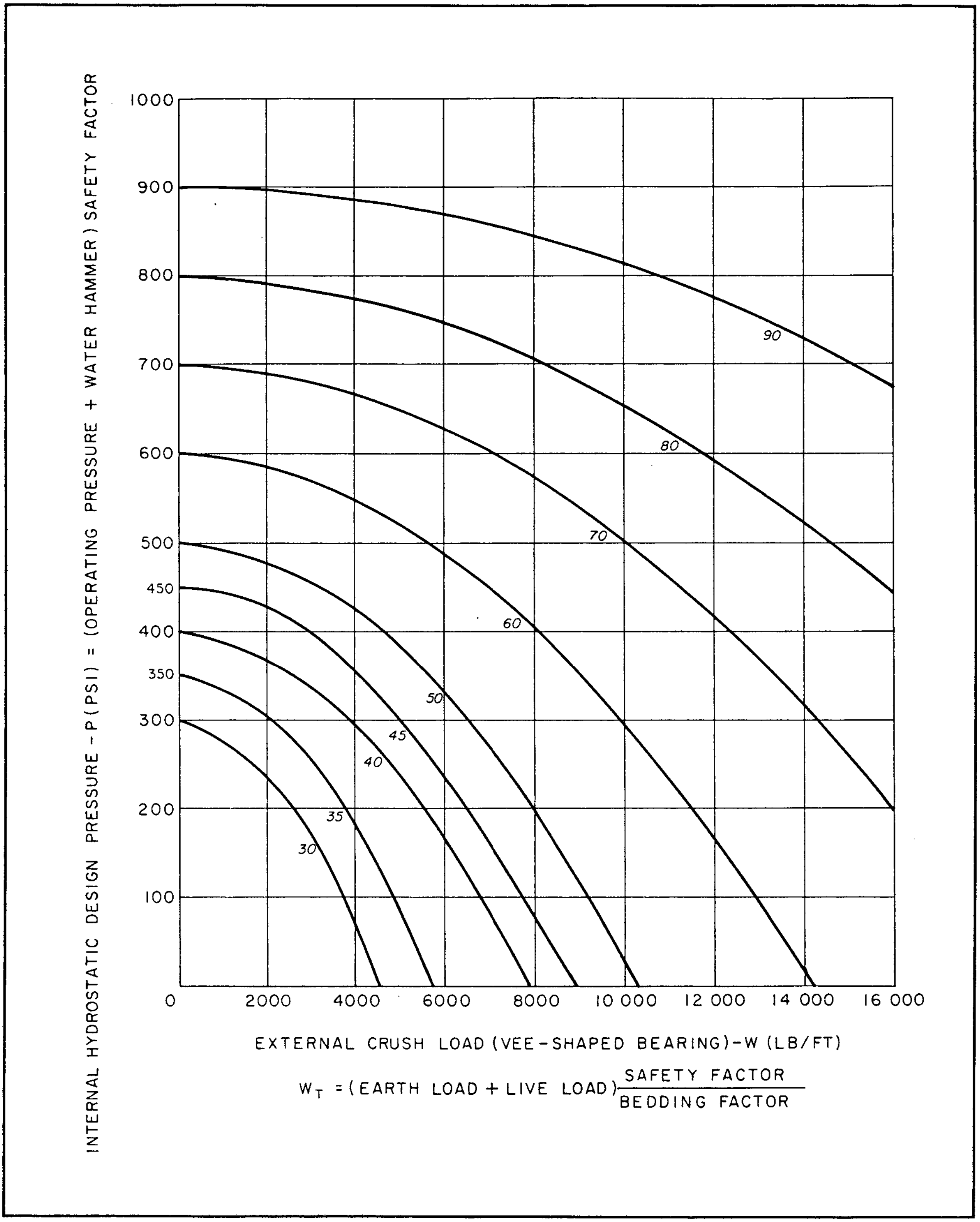


Figure 14F Combined loading curves for 30-in. transmission pipe.

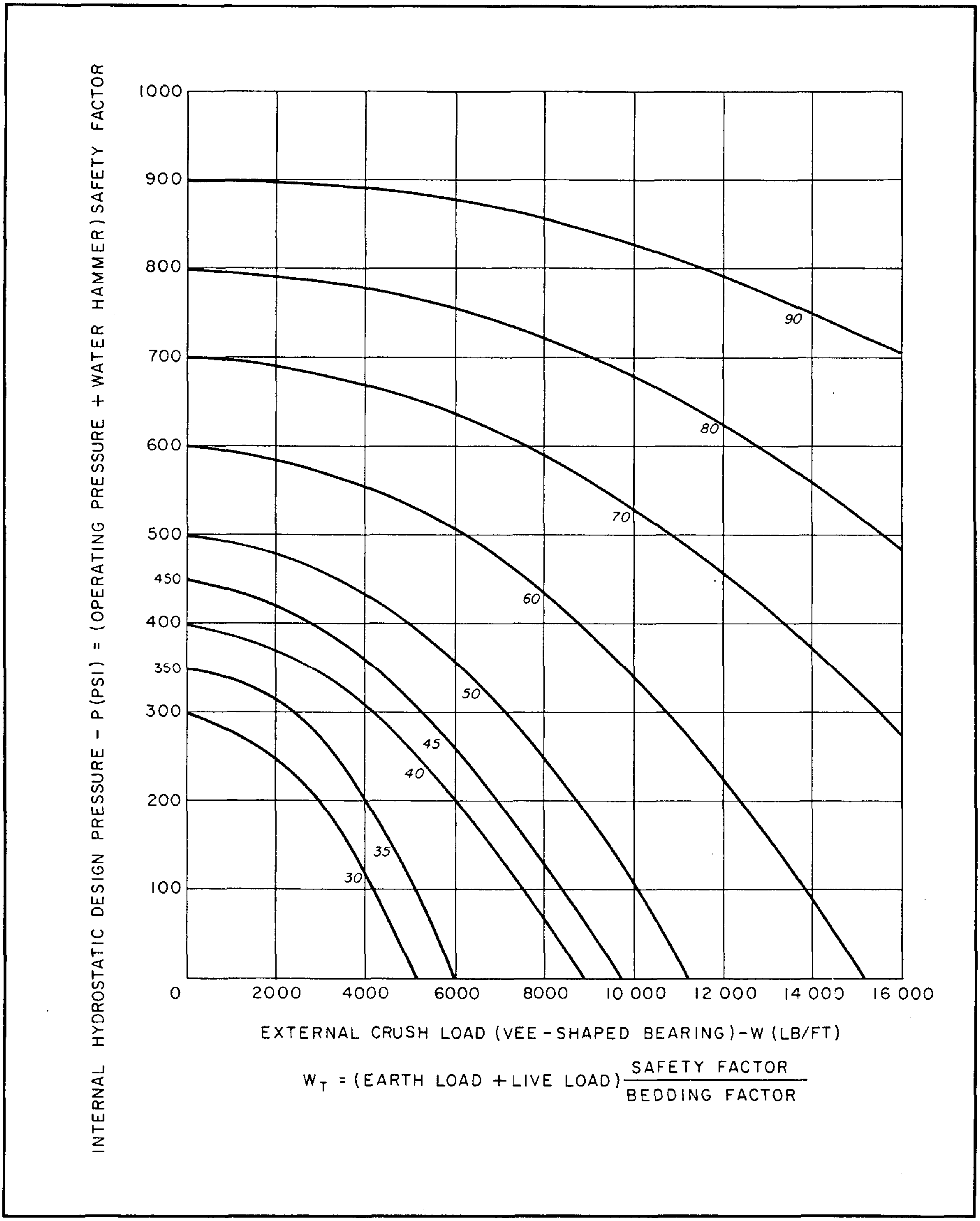


Figure 14G Combined loading curves for 33-in. transmission pipe.

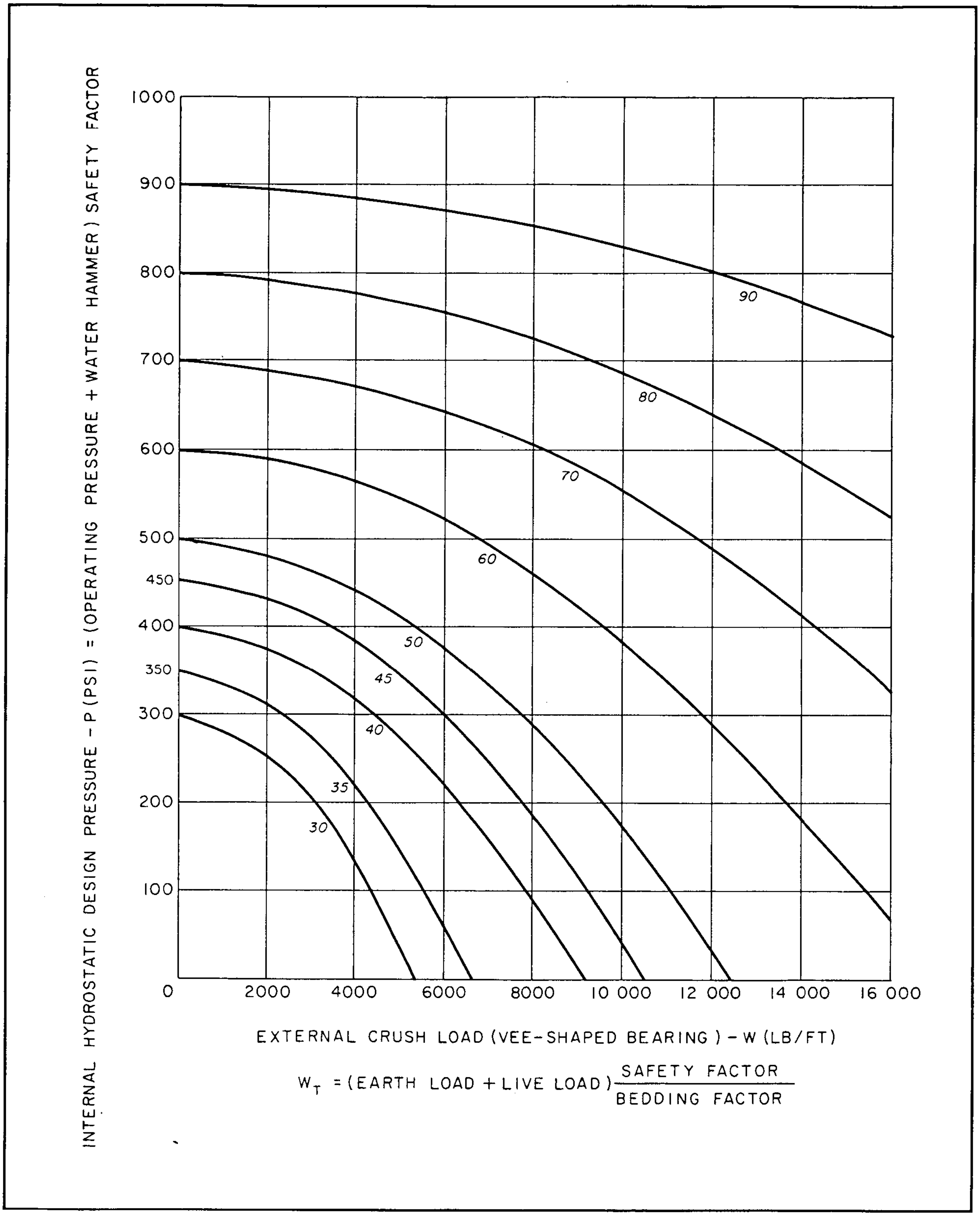


Figure 14H Combined loading curves for 36-in. transmission pipe.

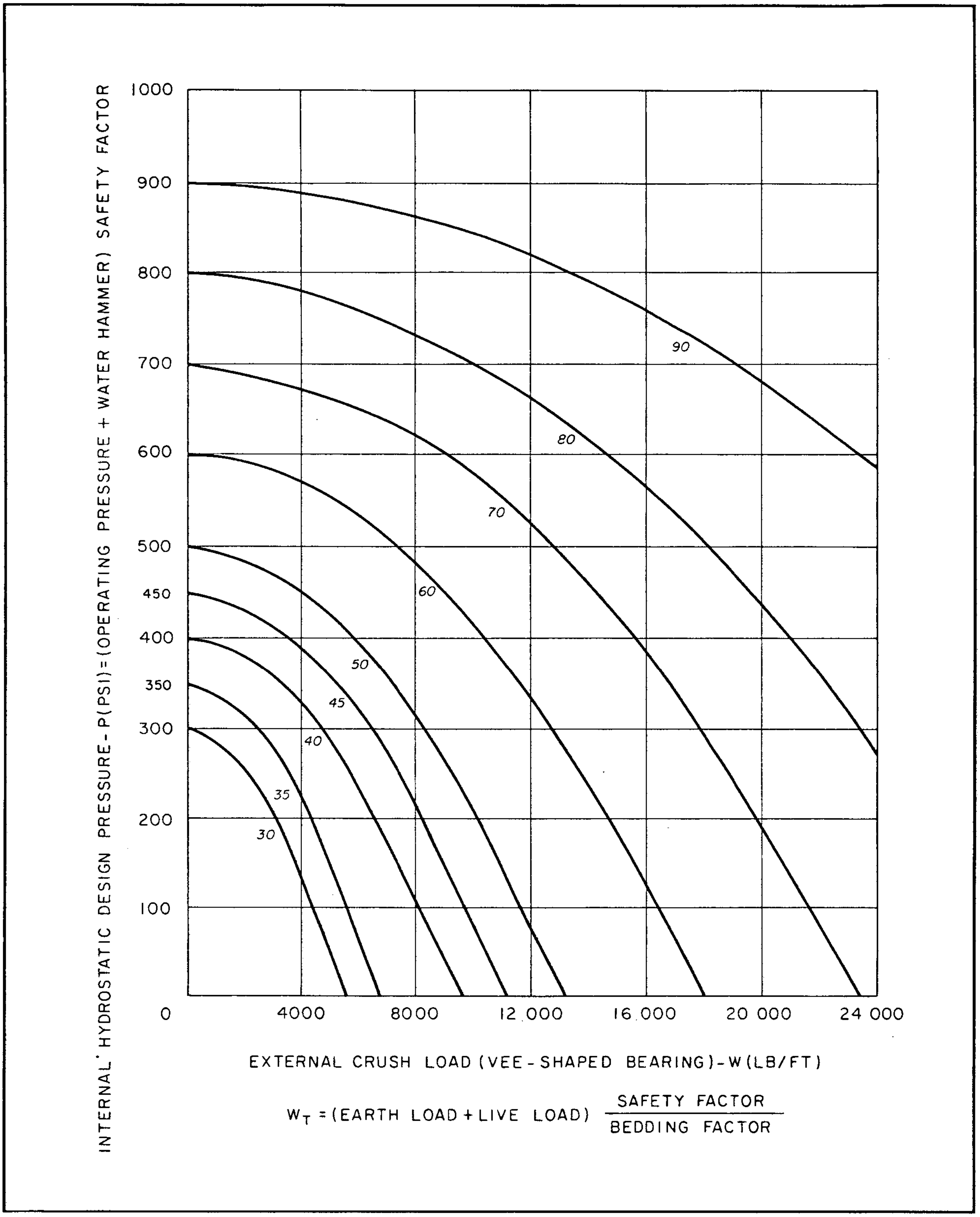


Figure 141 Combined loading curves for 39-in. transmission pipe.

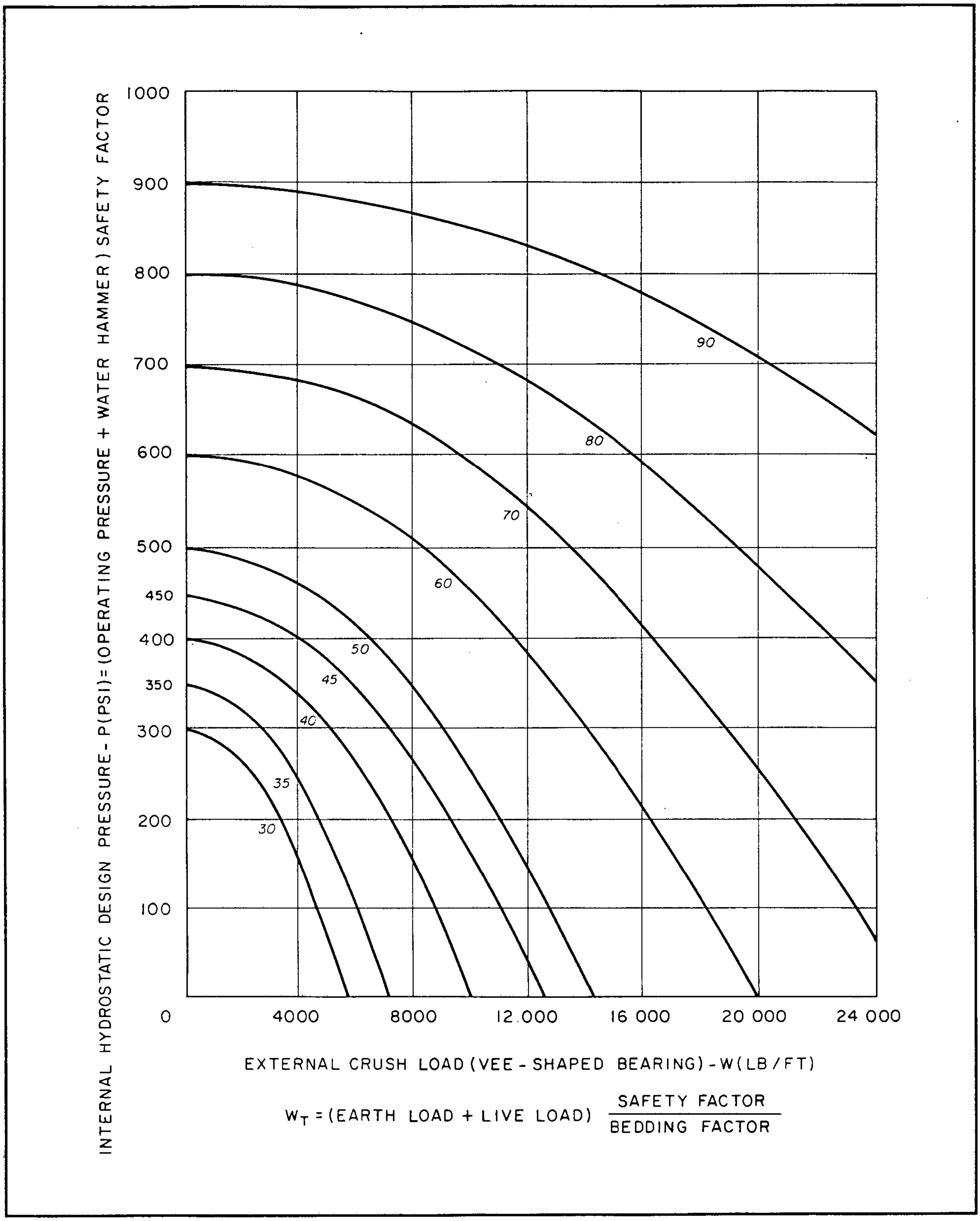


Figure 14J Combined loading curves for 42-in. transmission pipe.

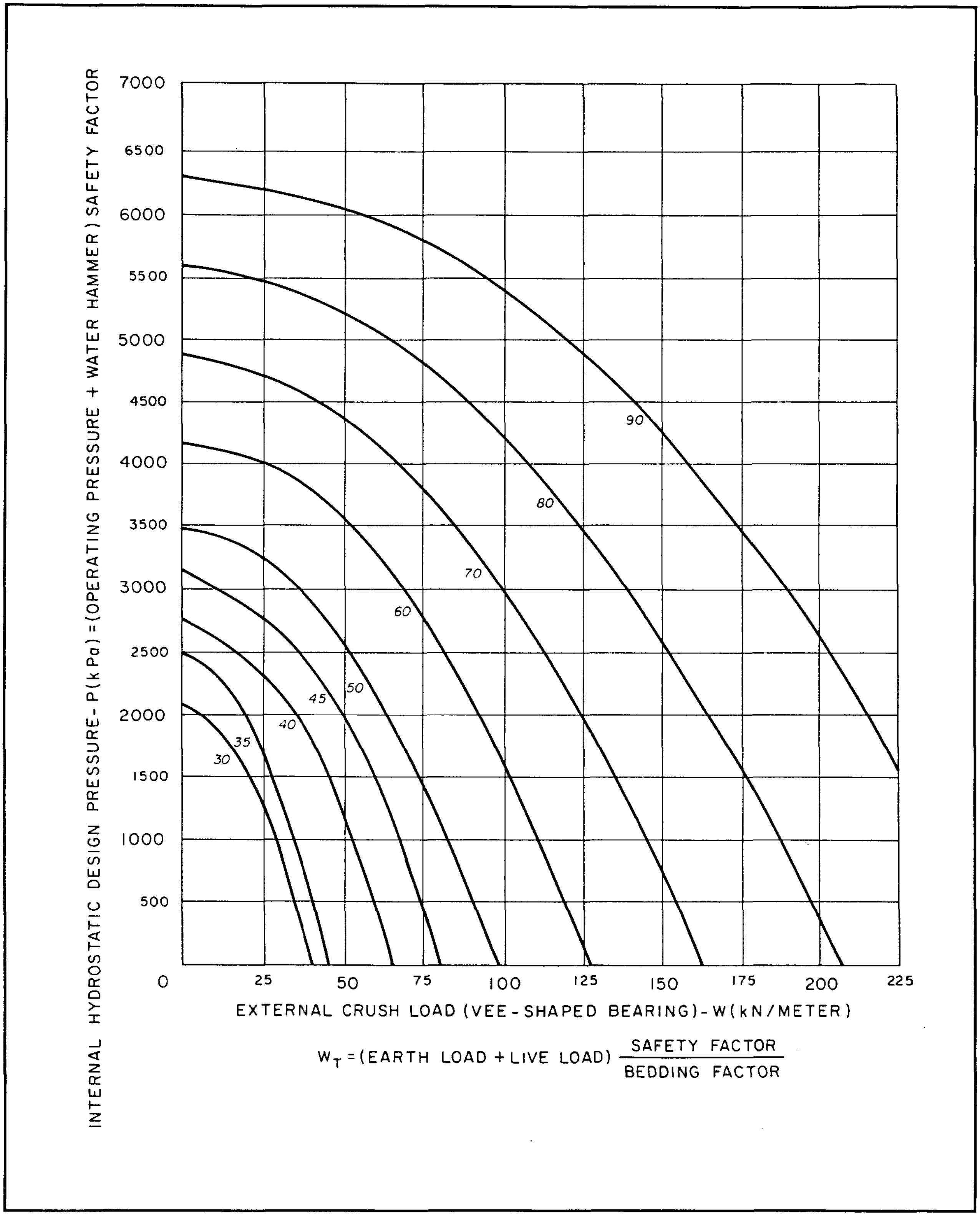


Figure 14A(m) Combined loading curves for 450-mm transmission pipe.

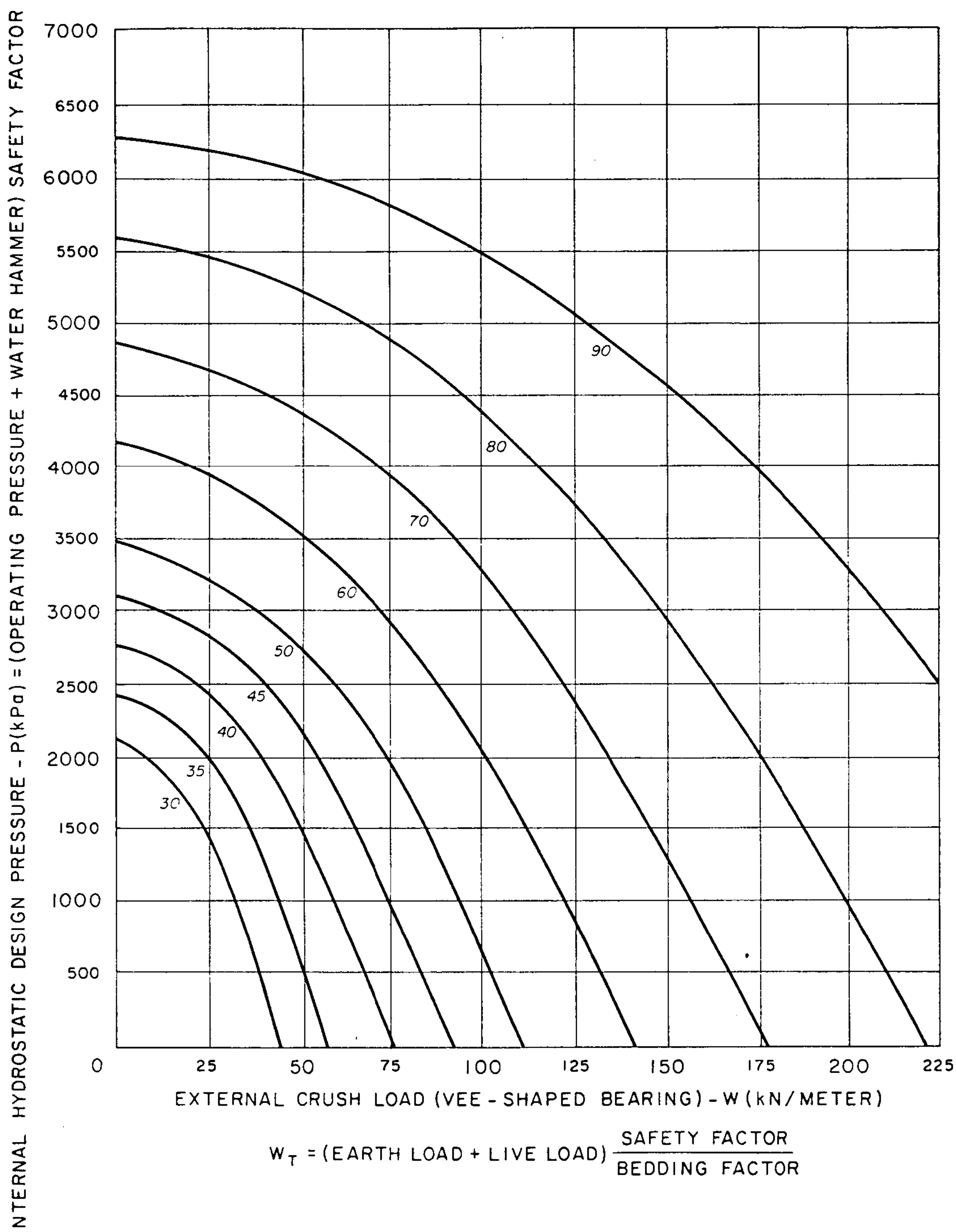


Figure 14B(m) Combined loading curves for 500-mm transmission pipe.

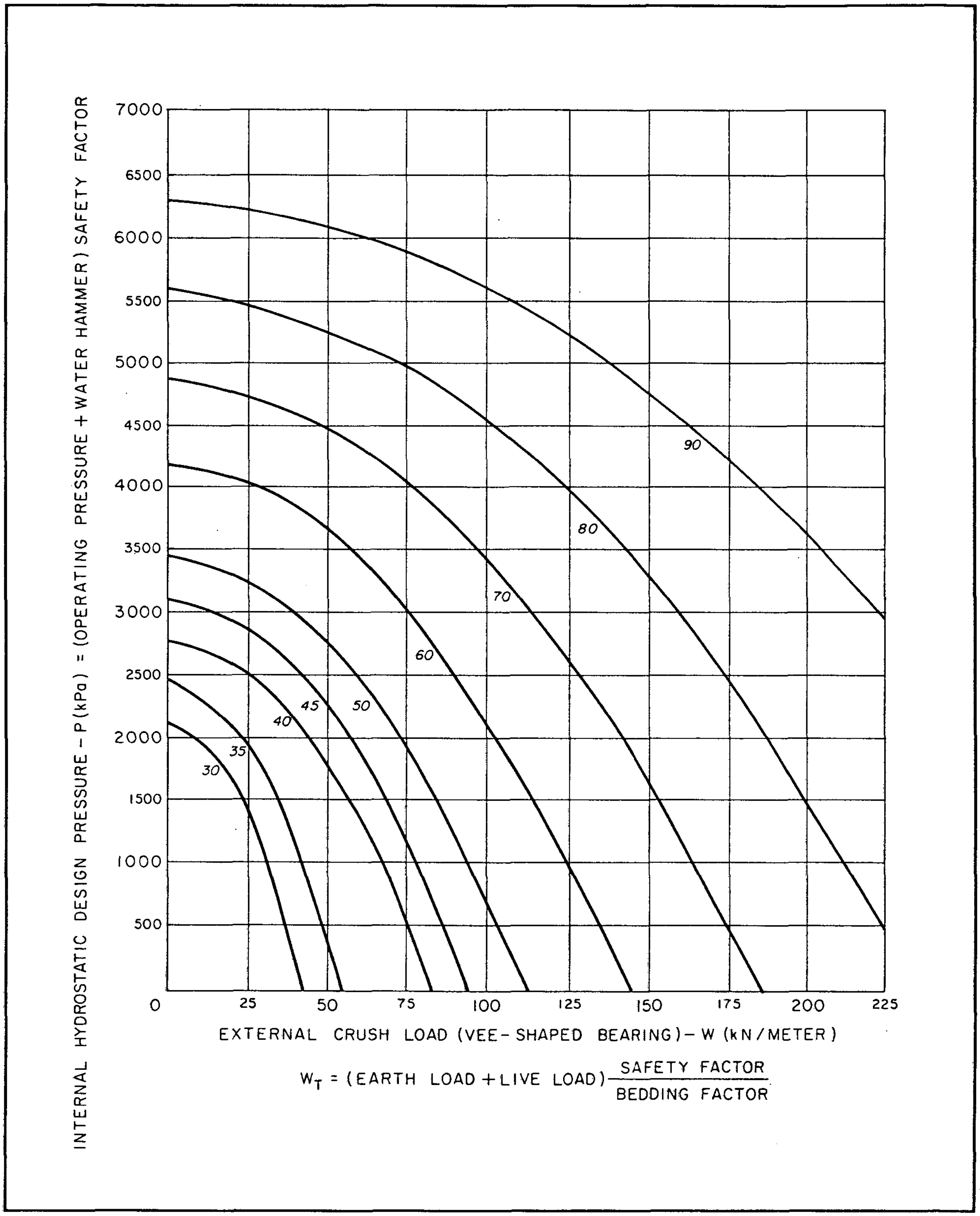


Figure 14c(m) Combined loading curves for 525-mm transmission pipe.

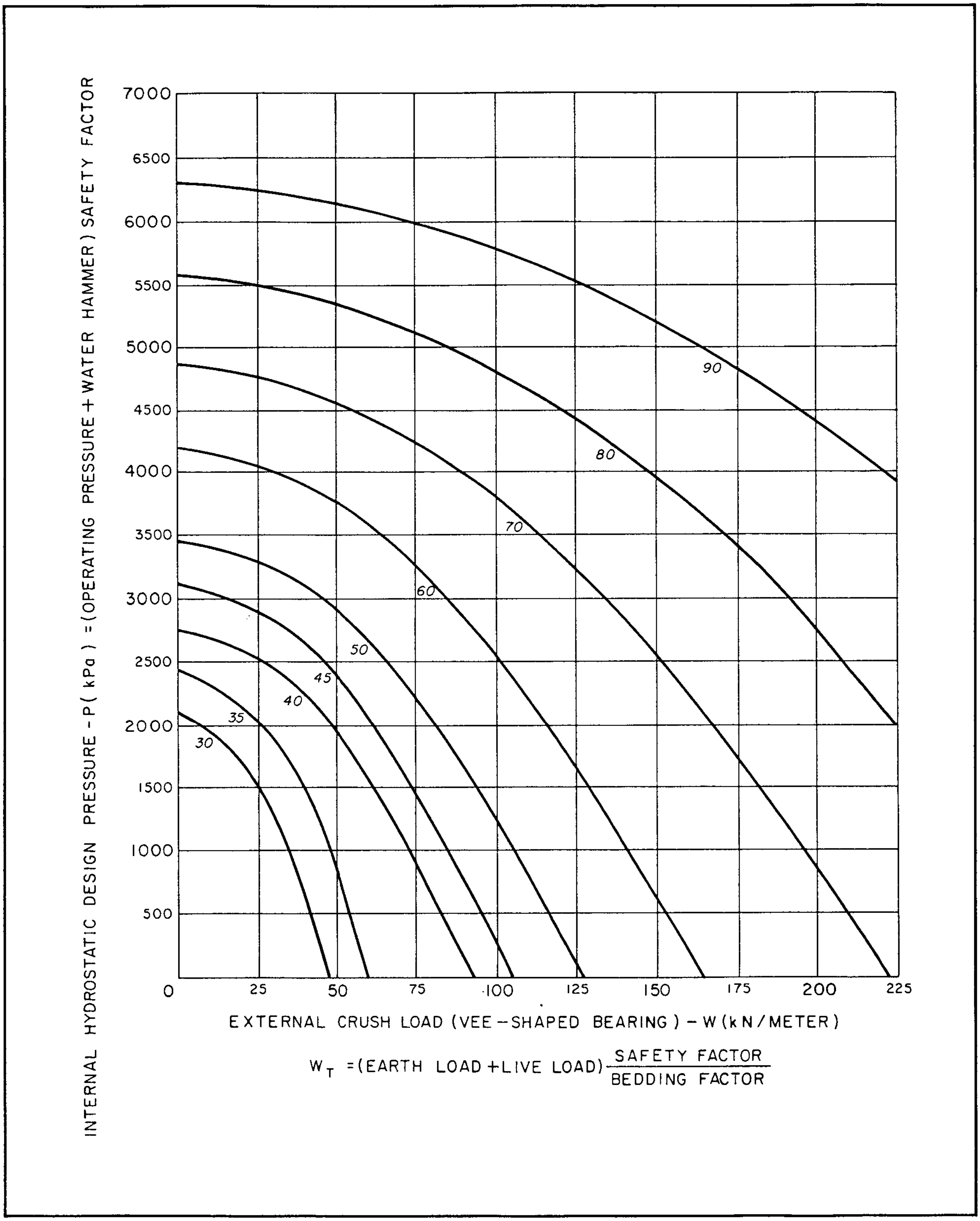


Figure 14D(m) Combined loading curves for 600-mm transmission pipe.

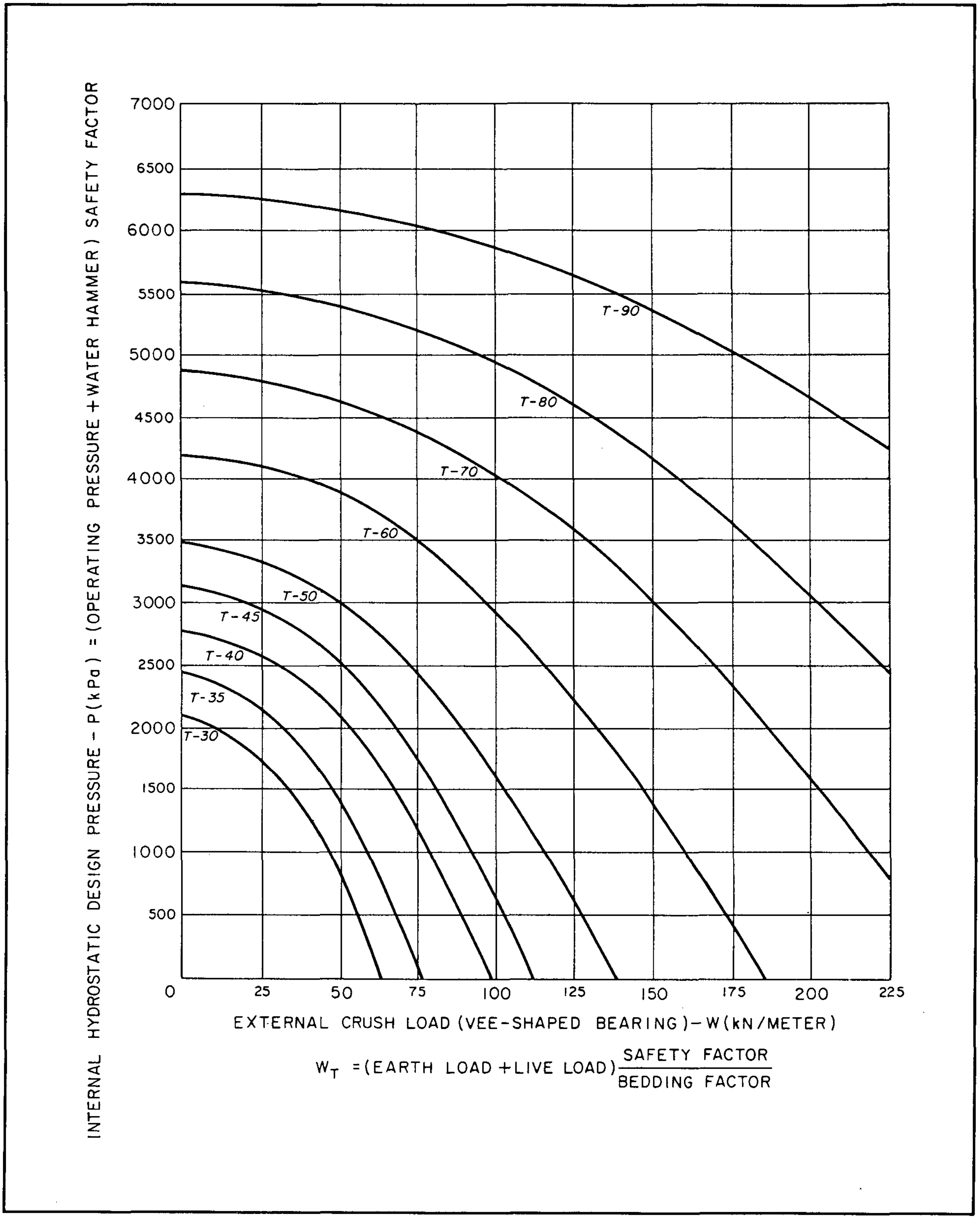


Figure 14E(m) Combined loading curves for 675-mm transmission pipe.

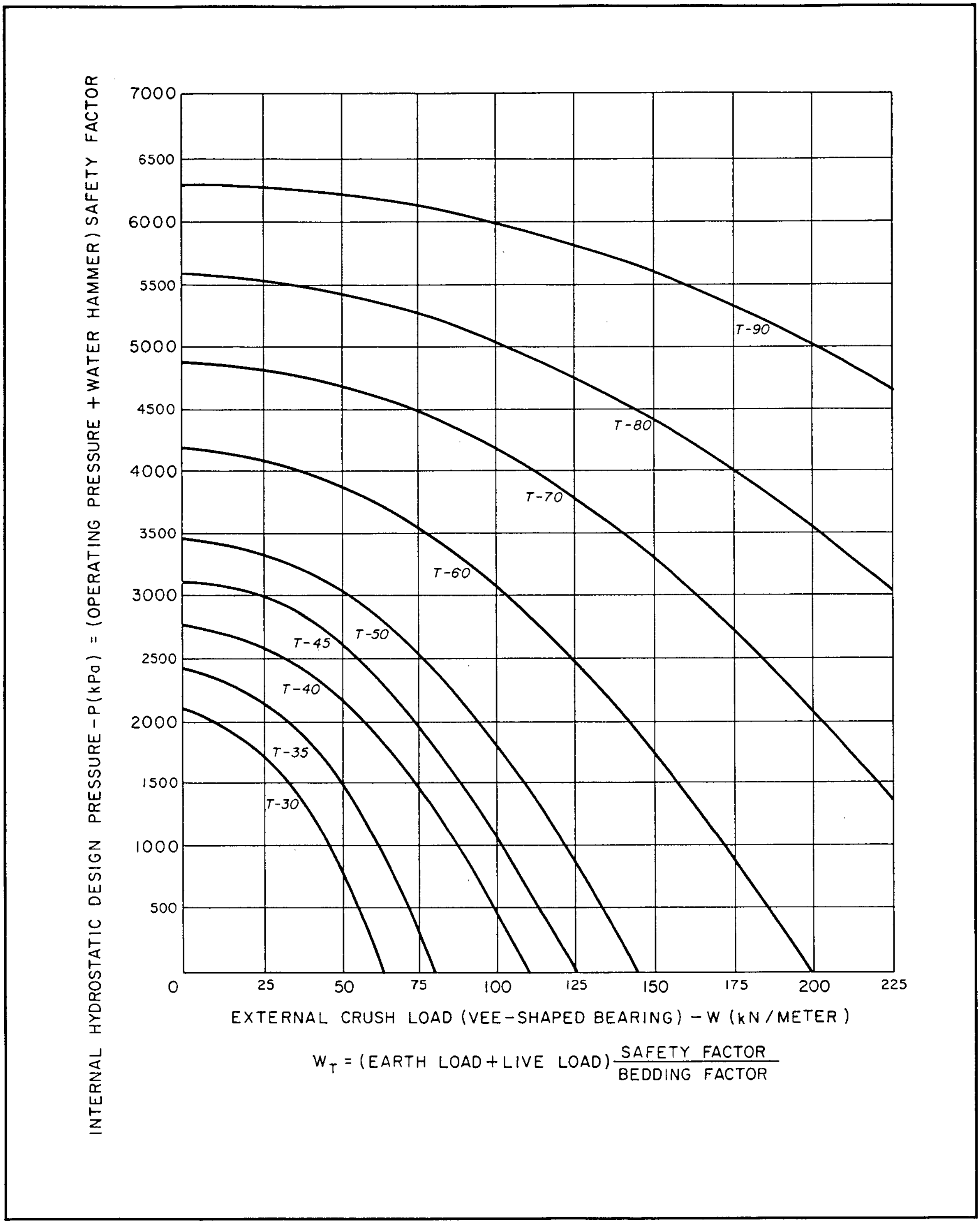


Figure 14F(m) Combined loading curves for 750-mm transmission pipe.

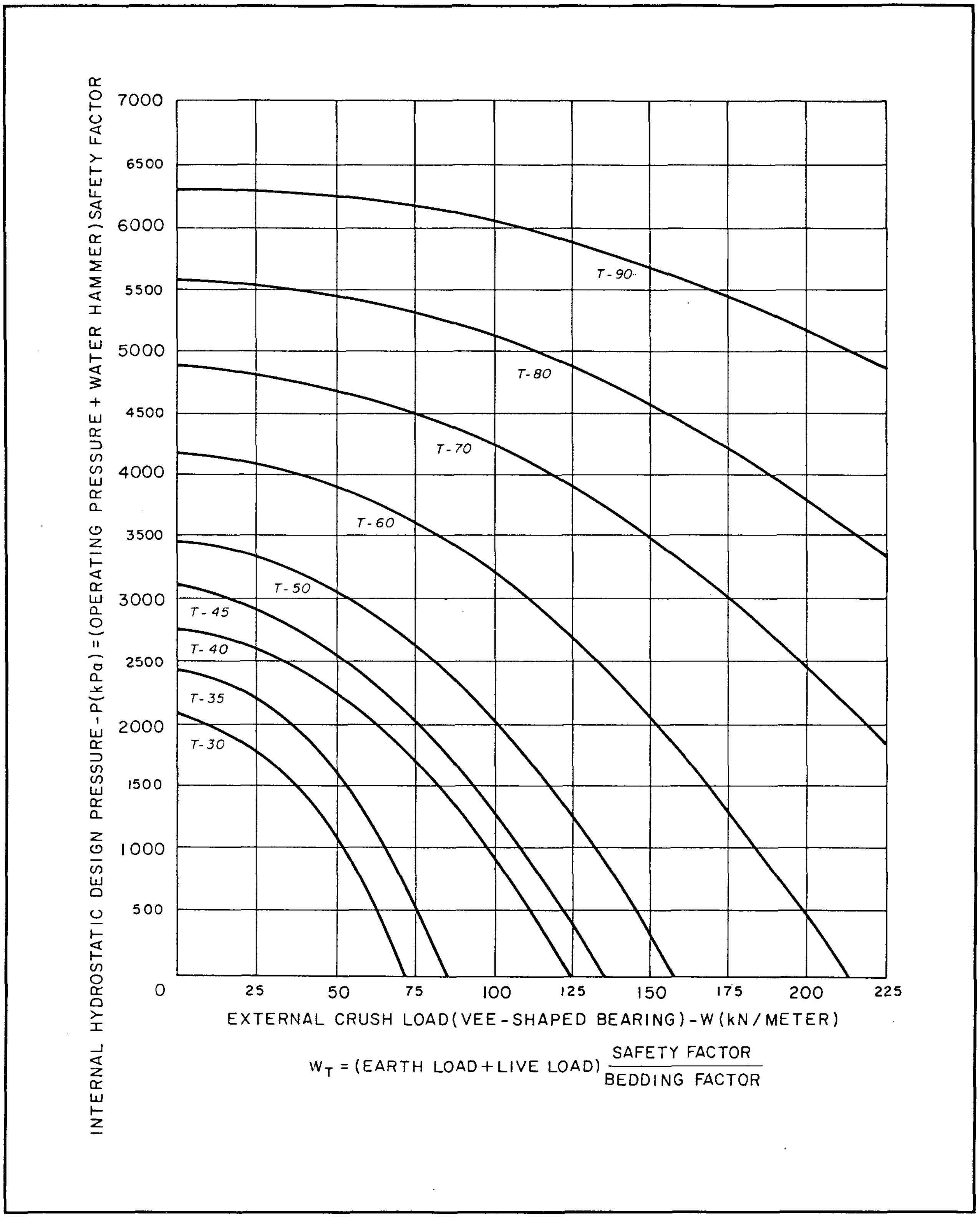


Figure 14G(m) Combined loading curves for 825-mm transmission pipe.

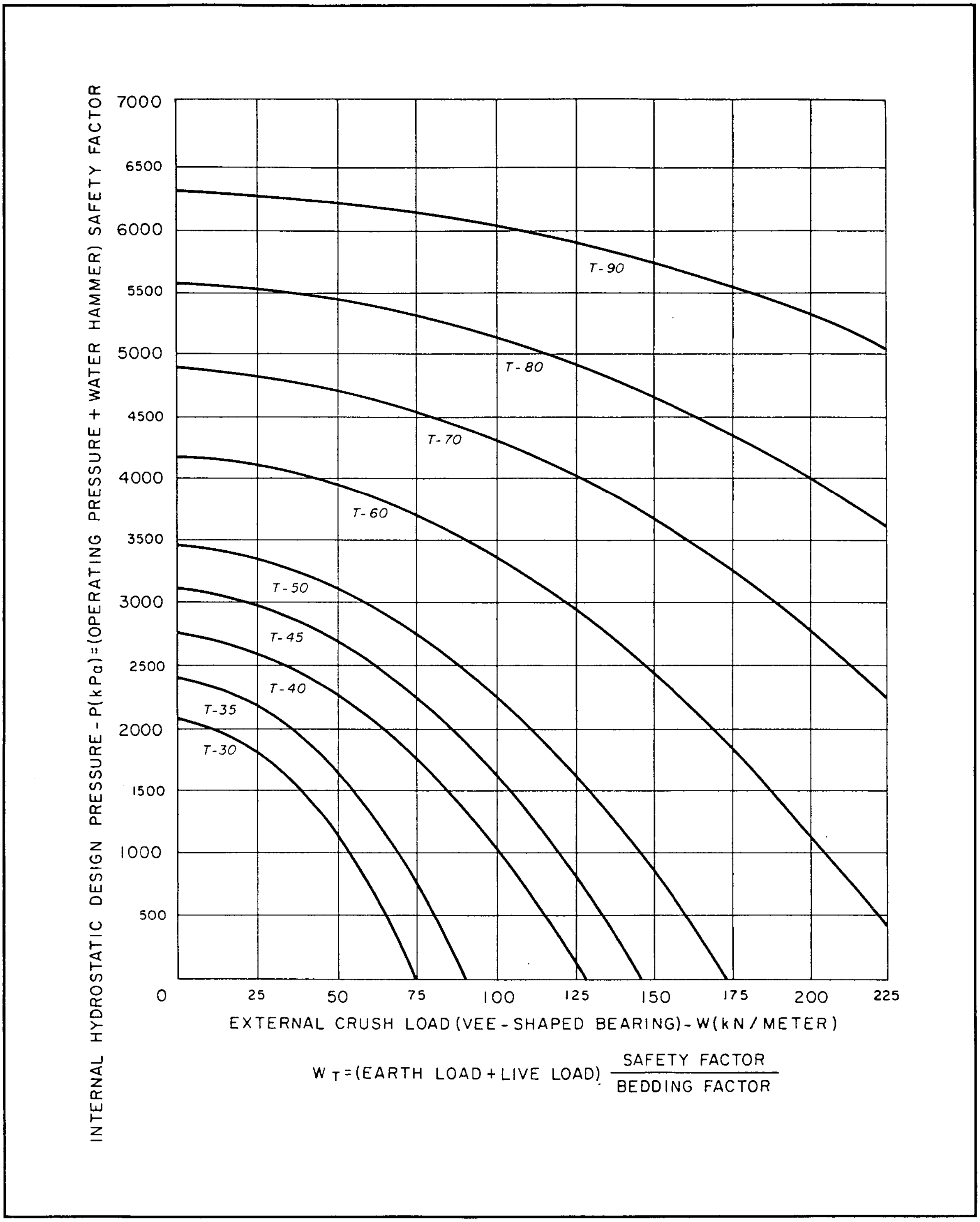


Figure 14H(m) Combined loading curves for 900-mm transmission pipe.

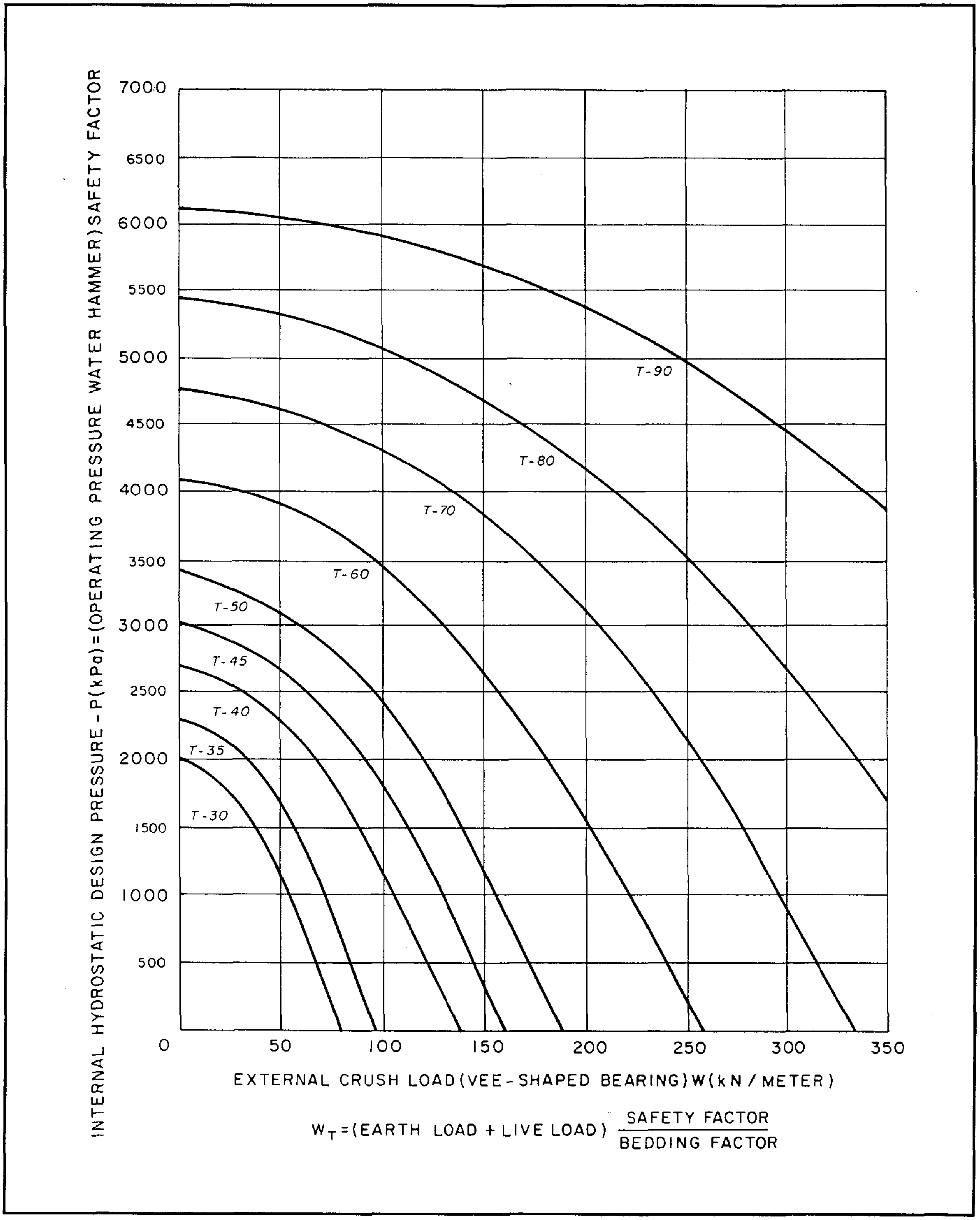


Figure 14I(m) Combined loading curves for 975-mm transmission pipe.

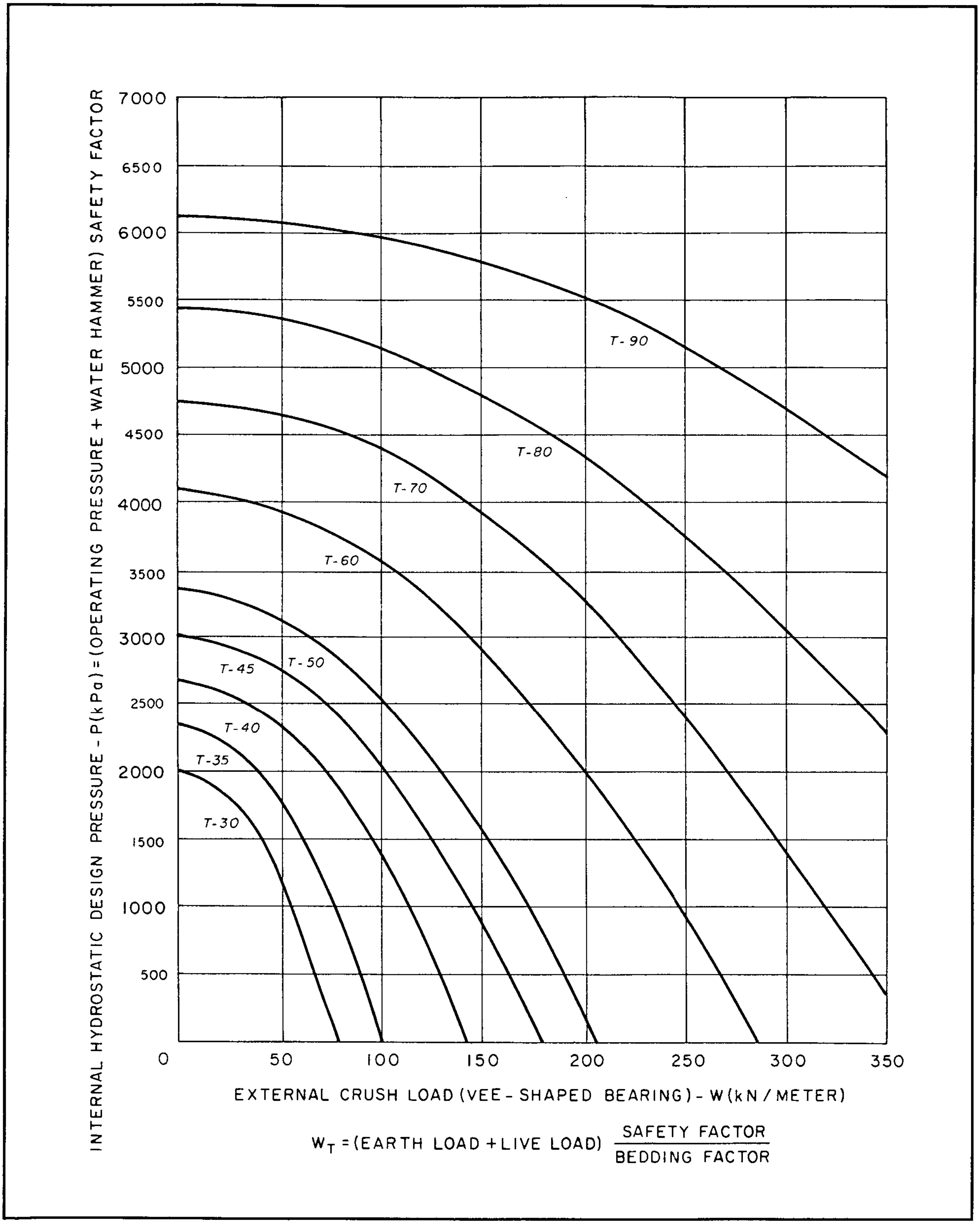
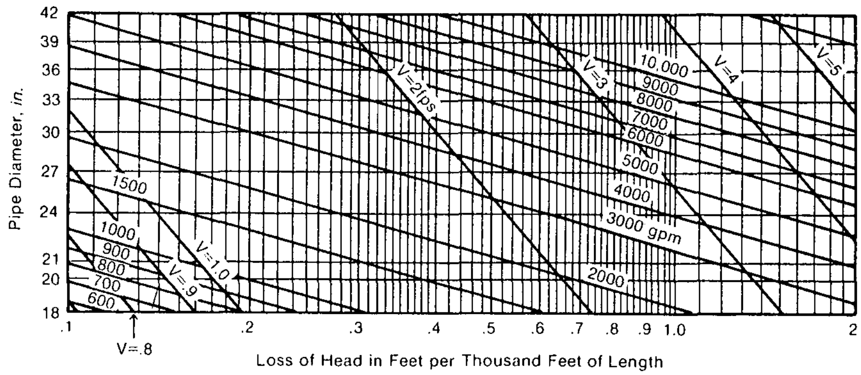


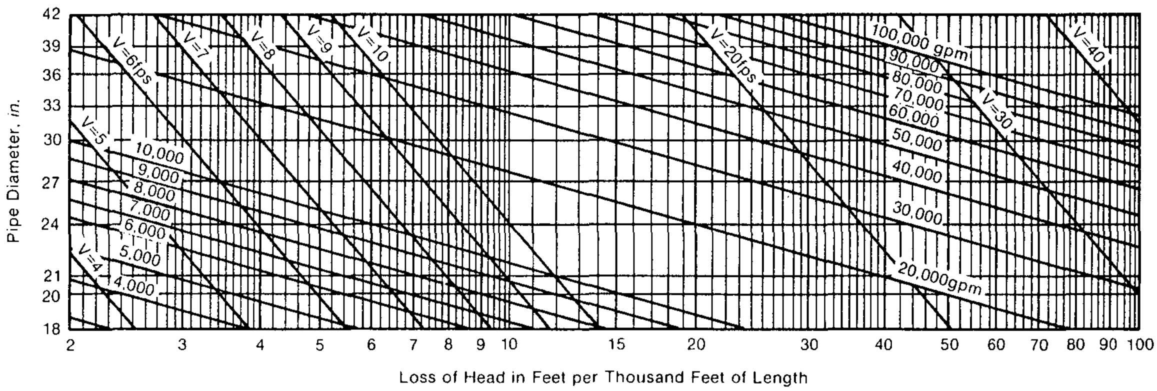
Figure 14j(m) Combined loading curves for 1050-mm transmission pipe.

APPENDIX A

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

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





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

Derived from the Hazen and Williams formula: $V = 1.318\ CR^{0.63}S^{0.54}$
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APPENDIX B
Surge Pressure Analysis

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

SECTION 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.

Sec. 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 the 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.

Sec. 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. Therefore, it is important to the pipe designer to know how to control the rate of velocity fluctuation, since by controlling this rate the magnitude of the pressure variations is controlled during the transitional periods. With such control, the pipe wall stresses during surge can be kept to a predetermined value that will allow an economical installation.

Sec. B.1.3 Wave Motion

Water, being liquid, will act in a fairly complex manner when undergoing acceleration or deceleration. Pressure waves are set up that move along the pipeline at a rate of 2500–4500 ft/s (760–1370 m/s), 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.

Sec. B.1.4 Causes

The three major causes of water hammer or surge are as follows:

1. The closing or opening, fully or partially, of a valve in a pipeline system (Sec. B.3).

2. The starting up or shutting down of a pump (switch or power failure) (Sec. B.4).

3. Entrapped air (Sec. B.7).

Sec. 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.

SECTION 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 that are accurate and that may be relied on for adequate analysis.

Sec. 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:

$$a = \frac{V_s}{\sqrt{1 + \frac{kd}{Ee}}} \qquad \text{(Eq B.1)}$$

Where:

a = pressure wave velocity, in feet per second (metres per second)
k = modulus of compression of water, 300,000 psi (2070 MPa)
d = internal diameter of pipe, in inches (millimetres)
E = modulus of elasticity of asbestos–cement pipe, 3,400,000 psi (23,400 MPa)
e = wall thickness, in inches (millimetres)
V_s = velocity of sound in water, 4660 ft/s (1420 m/s)

Sec. 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

$$h = \frac{aV}{g} \qquad \text{(Eq B.2)}$$

Where:

h	=	surge pressure, in feet of water (metres of water)
V	=	velocity of water in the pipeline during normal conditions, in feet per second (metres per second)
a	=	pressure wave velocity, in feet per second (metres per second)
g	=	acceleration due to gravity, 32.2 ft/s^2 (9.81 m/s^2)

Sec. 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:

$$U = \frac{2L}{a} \qquad \text{(Eq B.3)}$$

Where:

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 (metres)
a	=	pressure wave velocity, in feet per second (metres per second)

SECTION 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 Figure B.1, graph 1 presents a plot 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.

Sec. 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 Figure B.1 are drawn at the fastest rate of change (or steepest slope), the effective time of closure T_E is obtained. (See the curves in Figure B.1 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 B.3 and found to be x seconds, then the actual time for complete valve closure that will cause maximum pressure to occur will be approximately $2x$ seconds.

Sec. 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 pressure that the pipe will be required to carry in service. The design internal pressure is the operating pressure plus the water

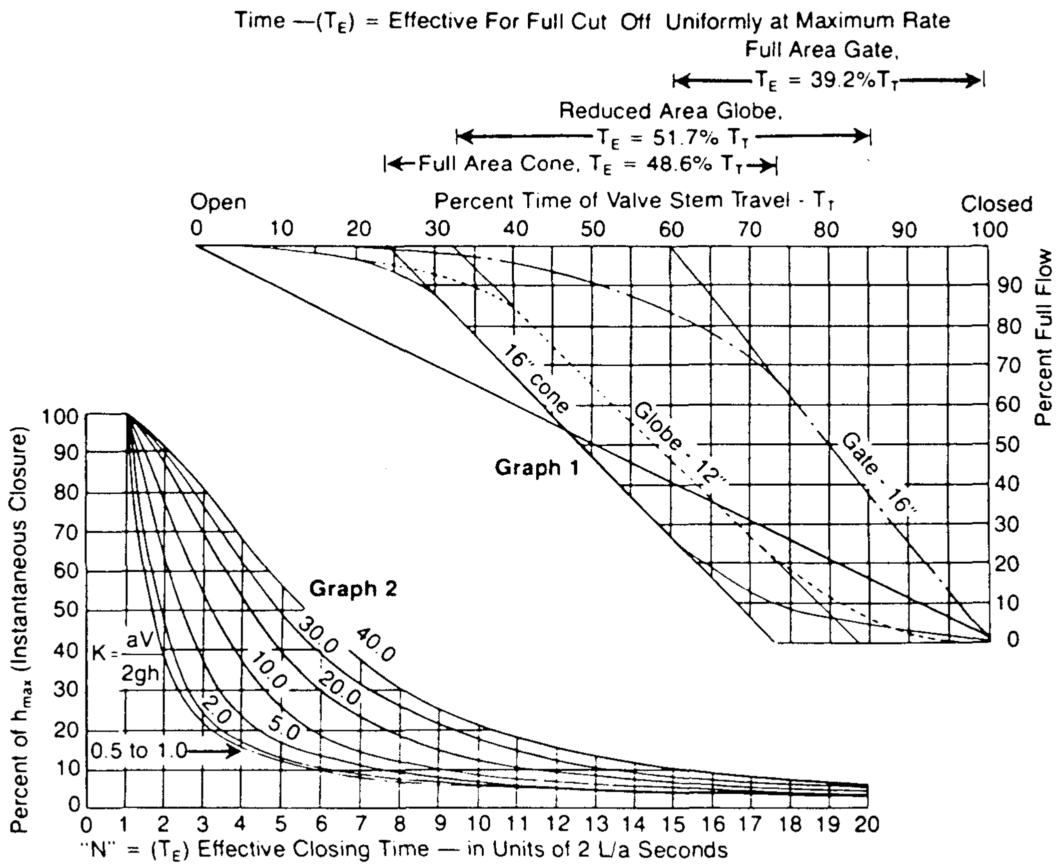

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Figure B.1 Time (T_E) = effective for full cut off uniformly at maximum rate.

hammer pressure. 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.

Sec. B.3.3 Determining Effective Time

Figure B.1 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:

$$K = \frac{aV}{2gh_o} \qquad \text{(Eq B.4)}$$

Where:

K = pipeline constant

a = pressure wave velocity, in feet per second (metres per second)

V = velocity of water in the flow line under normal conditions, in feet per second (metres per second)
g = acceleration due to gravity, 32.2 ft/s^2 (9.81 m/s^2)
h_o = operating pressure in the line under normal conditions, in feet of water (metres 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; 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 that 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.

SECTION B.4: PUMPED SYSTEMS

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

Sec. B.4.1 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 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.

Sec. 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.

Sec. B.4.3 Water Column Separation

Water column separation can be serious because of 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.

Sec. B.4.4 Entrapped Air

Water column separation can cause difficulties not only because of the beforementioned 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.

SECTION 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.

Sec. 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.

Sec. 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. Therefore, it is 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. Therefore, it is 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 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.

Sec. 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.

SECTION B.6: SURGE CALCULATION EXAMPLE

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

Problem. A 24-in. gravity transmission line is to operate at a pressure of 100 psi. Velocity in the line is to be 5 ft/s. 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

$$a = \frac{V_s}{\sqrt{1 + \dfrac{kd}{Ee}}}$$

$$= \frac{4660}{\sqrt{1 + \frac{3 \times 10^5 \times 24}{3.4 \times 10^6 \times 1.5}}}$$

$$= 3000 \text{ ft/s}$$

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

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

4. Determine constant K for use in graph 2 (Figure B.1)

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

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

$$\frac{50}{200} \times 100 = 25\%$$

6. Enter graph 2 (Figure B.1) 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 $2L/a$ s. The effective closing time in seconds would be $2L/a \times 2.6 = 3.33 \times 2.6 = 8.7$ s. The actual valve stem travel time would be twice this amount, or 17.4 s. Therefore, this calculated time (17.4 s) represents the fastest allowable time the valve can be closed to keep the surge pressure below the desired control level of 50 psi.

SECTION 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.

Sec. 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 because of temperature and pressure variation, or it may be caused by draining the line, or by draining parts of the line during normal shutdown. 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 to reduce operational difficulties. Suggested solutions for control are as follows:

1. *Intake.* Correct design procedures, provide low water-level pump cutoff.

2. *Release of air.* Air is entrained in the water at intake and its release cannot be prevented. However, the quantities are not large, and provisions for exhausting can be made by means of air valves. There are various types of air valves with different functions, and the selection of the proper type and location for installation is essential.

3. *Draining the line.* Air cannot be prevented from entering the line on draining, of course. Large orifice air valves should be provided for exhausting the air during refilling. Draining and then refilling does not occur often. Therefore, long filling times may be satisfactory.

4. *Drainage during shutdown.* This can be a serious problem. Open standpipes can be provided for air entry and exhaust. Sweeping air out by using high velocities is another 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 Sec. B.5.2 will normally be adequate.

Sec. 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 that may be on the order of 15 times the pipeline test pressure. Any pipeline material is seriously affected by this rapid magnitude of load increase. Hydrostatic failure because of 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 1 ft/s (0.3 m/s) or less.
5. Use

$$d/D = 1/10 \text{ to } 1/100$$

Where:

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.

*Colorado State University, Fort Collins, Colo.

APPENDIX C
Frictional Power Requirements

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

The chart shown in Figure C.1 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 kW·h, 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 C.1 (pages 60–65), 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 Figure C.1 are based on the following:

1. Cost per 1000 ft of pipe per year, in dollars.
2. Power cost = $0.01 per kW·h.
3. Motor-pump efficiency (combined) = 100 percent.
4. Friction coefficient C = 140.
5. Continuous operation.

NOTE: Yearly power cost values derived in Figure C.1 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 Figure C.1 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

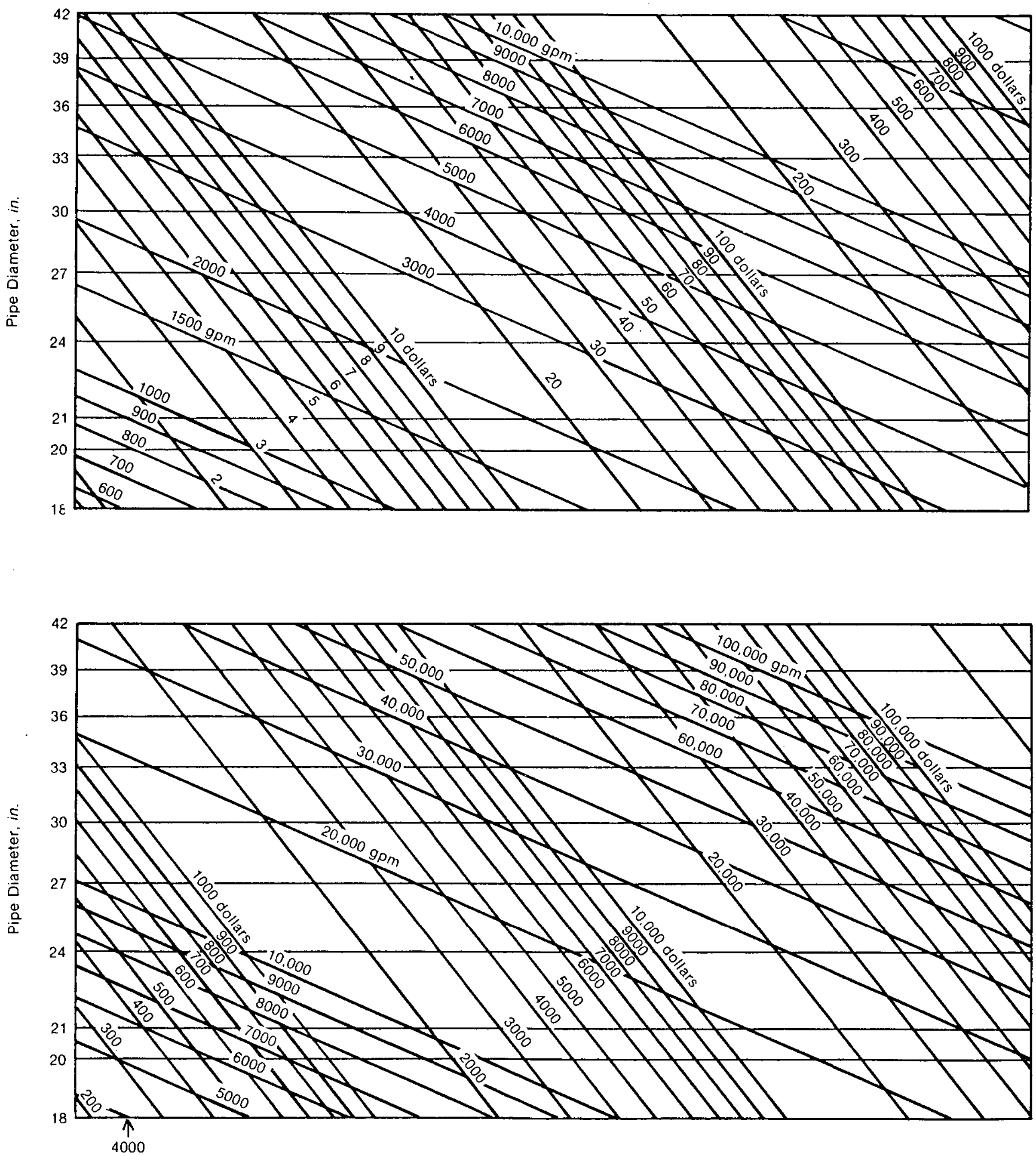

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Figure C.1 Yearly power cost to compensate for friction loss of head.

Apply the following formula to Table C.1:

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

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; and so forth.

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 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 C.1.

Table C.1 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

Table continued next page.

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Table C.1 (continued)

Years	.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	Years
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

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

Table continued next page

Table C.1 (continued)

Years	5.5%	6.0%	6.5%	7.0%	7.5%	8.0%	8.5%	9.0%	9.5%	10.0%	Years
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

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

Table continued next page

Table C.1 (continued)

Years	10.5%	11.0%	11.5%	12.0%	12.5%	13.0%	13.5%	14.0%	14.5%	15.0%	Years
21	8.345	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

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

Table continued next page

Table C.1 (continued)

Years	15.5%	16.0%	16.5%	17.0%	17.5%	18.0%	18.5%	19.0%	19.5%	20.0%	Years
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	5.896	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

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

Table continued next page

Table C.1 (continued)

Years	21%	22%	23%	24%	25%	26%	27%	28%	29%	30%	Years
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	3.751	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

21 March 1990 for
AWWA C403-89
1 November 1989

SUPERSEDING
AWWA C403-84
31 January 1985

Department of Defense Acceptance Notice

AWWA C403-89 was adopted on 21 March 1990 and is approved for use by the Department of Defense (DoD). AWWA has furnished the clearance required by existing regulations. Copies of this document are stocked by the DoD Single Stock Point, Military Specifications and Standards, Bldg. 40, 700 Robbins Ave., Philadelphia, PA 19111-5094, for issue to DoD activities only. All other requestors must obtain documents from AWWA, 6666 West Quincy Ave., Denver, CO 80235.

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