American Water Works Association
ANSI/AWWA C401-93
(Revision of ANSI/AWWA C401-83[R86])

AWWA STANDARD

FOR

THE SELECTION OF ASBESTOS-CEMENT PRESSURE PIPE, 4 IN. THROUGH 16 IN. (100 mm THROUGH 400 mm), FOR WATER DISTRIBUTION SYSTEMS

AMERICAN NATIONAL STANDARD

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AMERICAN WATER WORKS ASSOCIATION

6666 West Quincy Avenue, Denver, Colorado 80235

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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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*Liaison, nonvoting

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Contents

All AWWA standards follow the general format indicated subsequently. Some variations from this format may be found in a particular standard.

Tables

Foreword

This foreword is for information only and is not a part of AWWA C401.

I. Introduction

I.A. *Background.* In 1958 AWWA reactivated its Standards Committee on Asbestos–Cement Pipe, redesignating it as Committee 8340D on Asbestos–Cement Water Pipe. The committee was assigned the task of developing a new document to guide the user in the class selection and installation requirements for asbestos–cement pipe.

I.B. *History of Standard.* The standards committee developed AWWA Handbook H2, Standard Practice for the Selection of Asbestos–Cement Water Pipe, which was published in 1964. This handbook covered pipe sizes 4 in. (100 mm) through 36 in. (900 mm). Later in that same year, the standard was redesignated AWWA C401-64 and published under the same title. Subsequent editions of the standard included 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 C401-83, 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. The 1983 edition was reaffirmed without revision in 1986.

I.C. *Acceptance.* In May 1985, the US Environmental Protection Agency (USEPA) entered into a cooperative agreement with a consortium led by NSF International (NSF) to develop voluntary third-party consensus standards and a certification program for all direct and indirect drinking water additives. Other members of the consortium included the American Water Works Association Research Foundation (AWWARF), the Conference of State Health and Environmental Managers (COSHEM), the American Water Works Association (AWWA), and the Association of State Drinking Water Administrators (ASDWA). The consortium is responsible for the cooperative effort of manufacturers, regulators, product users, and other interested parties that develop and maintain the NSF standards.

In the United States, authority to regulate products for use in, or in contact with, drinking water rests with individual states.* Local agencies may choose to impose requirements more stringent than those required by the state. To evaluate the health effects of products and drinking water additives from such products, state and local agencies may use various references, including

1. An advisory program formerly administered by USEPA, Office of Drinking Water, discontinued on Apr. 7, 1990.
2. Specific policies of the state or local agency.
3. Two standards developed under the direction of NSF, ANSI†/NSF‡ 60, Drinking Water Treatment Chemicals—Health Effects, and ANSI/NSF 61, Drinking Water System Components—Health Effects.

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*Persons in Canada, Mexico, and non–North American countries should contact the appropriate authority having jurisdiction.

†American National Standards Institute, 11 W. 42nd St., New York, NY 10036.

‡NSF International, 3475 Plymouth Rd., Ann Arbor, MI 48106.

4. Other references, including AWWA standards, *Food Chemicals Codex*, *Water Chemicals Codex*,* and other standards considered appropriate by the state or local agency.

Various certification organizations may be involved in certifying products in accordance with ANSI/NSF 61. Individual states or local agencies have authority to accept or accredit certification organizations within their jurisdiction. Accreditation of certification organizations may vary from jurisdiction to jurisdiction.

Appendix A, "Toxicology Review and Evaluation Procedures," to ANSI/NSF 61 does not stipulate a maximum allowable level (MAL) of a contaminant for substances not regulated by a USEPA final maximum contaminant level (MCL). The MALs of an unspecified list of "unregulated contaminants" are based on toxicity testing guidelines (noncarcinogens) and risk characterization methodology (carcinogens). Use of Appendix A procedures may not always be identical, depending on the certifier.

AWWA C401-93 does not address additives requirements. Thus, users of this standard should consult the appropriate state or local agency having jurisdiction in order to

1. Determine additives requirements including applicable standards.
2. Determine the status of certifications by all parties offering to certify products for contact with, or treatment of, drinking water.
3. Determine current information on product certification.

II. Special Issues

II.A. *General.* The purpose of this standard is to provide guidance in the selection of asbestos–cement pressure pipe, manufactured in accordance with ANSI/AWWA C400 and installed in accordance with ANSI/AWWA C603. In addition to the physical strength parameters addressed in the standard, it is recommended that the user collect site-specific data on water chemistry both for the internal water to be carried by the pipe and external groundwater conditions, and the chemistry of the soil in which the pipe is to be installed. Criteria for various water and soil chemistry parameters that affect asbestos–cement pipe are discussed.

It is the responsibility of the user of an AWWA standard to determine that the products described in that standard are suitable for use in the particular application being considered.

II.B. *Type of pipe.* The following criteria are presented for determining the type of pipe to be used under various soil and water conditions. Each condition should be considered separately even though each may exist in combination with others. These criteria are based on exposures within the temperature range of 40–80°F (5–28°C). For exposure of pipe to temperatures beyond these limits, consult the manufacturer.

The following criteria are referenced as

1. Internal water (Table F.1).
2. External water (Table F.2).
3. Neutral soluble sulfates—internal and external (Table F.3).
4. Acidic soluble sulfates—internal and external.

*Both publications available from National Academy of Sciences, 2102 Constitution Ave. N.W., Washington, DC 20418.

III. Modification to Standard. Any modification of the provisions, definitions, or terminology in this standard must be provided in the purchaser's specifications.

IV. Major Revisions. Major revisions to AWWA C401-83(R86) included in this edition of the standard are as follows:

1. Sec. I.C, Acceptance, was added to the foreword.
2. Sec. II.C, Special Issues, was added to the foreword. This section now includes a discussion on criteria for selecting the type of asbestos–cement pipe. This section formerly appeared in the foreword to ANSI/AWWA C400-80 (R86).
3. Sec. III, Modification to Standard, was added to the foreword.
4. Sec. 1.4, Permeation, was added.
5. The discussion on water hammer and surge analysis (Sec. B.1 through Sec. B.6) was deleted from appendix B and the title of the appendix revised to "Entrapped Air."
6. Appendix C, Functional Power Requirements, was deleted in its entirety.

V. Comments. If you have any comments or questions about this standard, please call the AWWA Standards Department, (303) 794-7711, ext. 2201; FAX (303) 794-7310; or write to the department at 6666 W. Quincy Ave., Denver, CO 80235.

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SECTION 1: GENERAL

Sec. 1.1 Scope

This standard has been prepared so that the user may quickly determine the correct pressure classification of asbestos–cement pressure pipe to use under various combinations of internal pressure (working and surge) and external load (earth and superimposed live loads) in water distribution systems. Combined loading curves depicting the relationship between internal pressure and external load capabilities are included to expedite the selection of pipe class, which is defined in ANSI/AWWA C400.

NOTE: Appendix A contains a friction loss of head chart based on the Hazen–Williams formula. Appendix B is a discussion of entrapped air.

1.1.1 *Pressure classes.* Pipe pressure class designations of 100, 150, and 200 refer to the similarly numbered classes listed in ANSI/AWWA C400, Standard for Asbestos–Cement Pressure Pipe, 4 In. Through 16 In. (100 mm Through 400 mm), for Water Distribution Systems.

1.1.2 *Installation.* Detailed coverage of the installation of asbestos–cement pipe can be found in ANSI/AWWA C603.

Sec. 1.2 References

This standard references the following documents. In their latest editions, 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 Methods for Asbestos–Cement Pipe.

ANSI†/AWWA C400—Standard for Asbestos-Cement Pressure Pipe, 4 In. Through 16 In. (100 mm Through 400 mm), for Water Distribution Systems.

ANSI/AWWA C403—Standard for the Selection of Asbestos–Cement Transmission and Feeder Main Pipe, Sizes 18 In. Through 42 In. (450 mm Through 1050 mm).

Design and Construction of Sanitary and Storm Sewers. 1976. Manual of Engineering Practice No. 37. American Society Civil Engineers, New York.

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

Marston, A. 1930. *The Theory of External Loads on Closed Conduits in the Light of Latest Experiments.* Bull. 96. Iowa State College Engineering Experiment Station.

Schlick, W.J. 1940. *Supporting Strengths for Cast-Iron Pipe for Water and Gas Service.* Bull. 146. Iowa State College Engineering Experiment Station (June 1940).

Sec. 1.3 Symbols, Abbreviations, and Definitions

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

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

BF = bedding factor, which is a load factor correlating three-edge V-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 ditch 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.

†American National Standards Institute, 11 W. 42nd St., New York, NY 10036.

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 per square metre*).
P_o	=	static or working pressure, which is the maximum anticipated operating pressure in pounds per square inch (kilopascals).
P_s	=	surge pressure or water hammer pressure change due to a sudden velocity change, 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 V-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.)
p'	=	projection ratio for the negative projecting and imperfect ditch 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 ditch condition. (See Figure 10B and Figure 11.)
r_{sd}	=	settlement ratio for positive projection, negative projection, and imperfect ditch conditions.
SF	=	safety factor.
μ	=	the coefficient of internal friction of backfill material.
μ'	=	the 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 V-shaped bearing test that the pipe will withstand when no hydrostatic pressure exists.

*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 9.807 (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} = the 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 V-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.

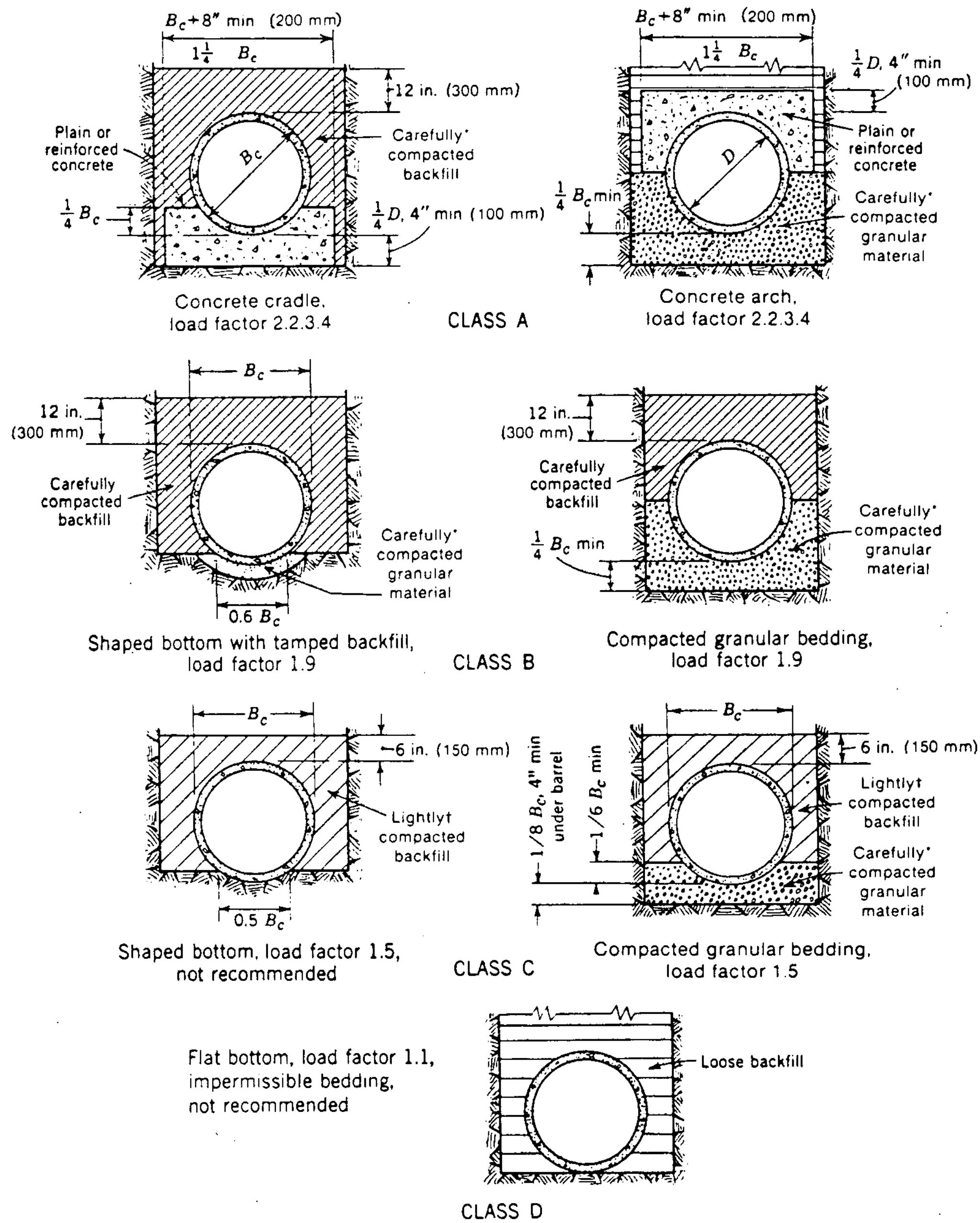
SECTION 2: GENERAL DESIGN

Sec. 2.1 Strength and Design Factors

The strength of asbestos–cement pressure pipe for water distribution systems must be sufficient to withstand the combined forces of all types of internal pressures (working and surge) and external loadings (earth, live, and impact). Adequate safety factors should be applied to strength requirements to ensure performance under other than ideal or calculated loading conditions. Safety factors are discussed under Sec. 5.

2.1.1 *Bedding conditions.* The bedding conditions shown in Figure 1 are representative of typical installations.

*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 9.807 (g, the acceleration of gravity) before the value is used in equations using SI units.



*Carefully compacted backfill: 95 percent proctor or 70 percent relative density.

†Lightly compacted backfill: 85–95 percent proctor or 40–70 percent relative density.

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

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Figure 1 Classes of bedding for conduits in trench

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 inside 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 extend 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 to 95 percent proctor or 40 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 area of steel to the area at the invert.

2.1.1.1.2 Concrete arch. The pipe shall be bedded in carefully compacted granular material having a minimum thickness of one fourth the outside pipe diameter (minimum of 4 in. [100 mm]) 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 inside 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; up to 3.4 for reinforced concrete with $p = 0.4$ percent; and up to 4.8 for reinforced concrete with $p = 1.0$ percent, in which p is the ratio of the area of steel to the 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 backfill to a minimum depth of 12 in. (300 mm) over the top of the pipe shall be filled with highly 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 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 backfill, to 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.

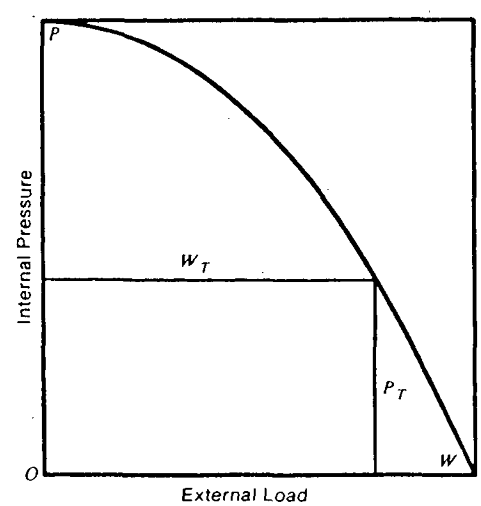
2.1.1.4 Class D—flat-bottom trench, impermissible bedding. In this class of bedding, the bottom of the trench is left flat, and no care is taken to secure compaction of backfill at the sides and immediately over the pipe. The load factor for class D bedding is 1.1.

2.1.1.4.1 Class D bedding is not recommended for pipeline construction. Under present construction conditions, class B or 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 V-shaped bearing (see Sec. 2.3) shows 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:

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



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

Figure 2 Load-pressure curve

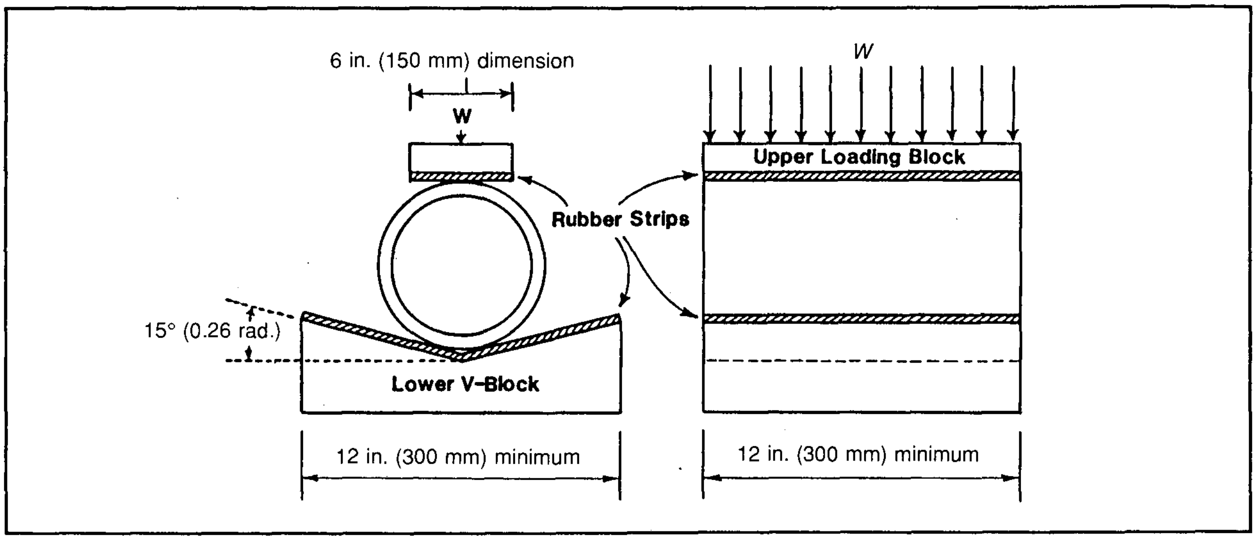


Figure 3 Assembly for three-edge V-shaped crushing strength test

Sec. 2.3 Three-Edge V-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 V-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 V-shaped bearing loads to correlate them to the actual field loads. Since the external load equals the bedding factor times the V-shaped bearing load, the bedding factor equals the external load divided by the three-edge V-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 pressure pipe for water distribution systems, external loads W_T are defined by the following equation:

$$W_T = \frac{W_E + W_s}{\text{BF}} \times (\text{SF}) \qquad \text{Eq 2}$$

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 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 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 distribution pipe design, earth loads are calculated by the general form of Marston's equation:

$$W_E = CW_eB_d^2 \qquad \text{Eq 3}$$

NOTE: In this equation and the following equations, density 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

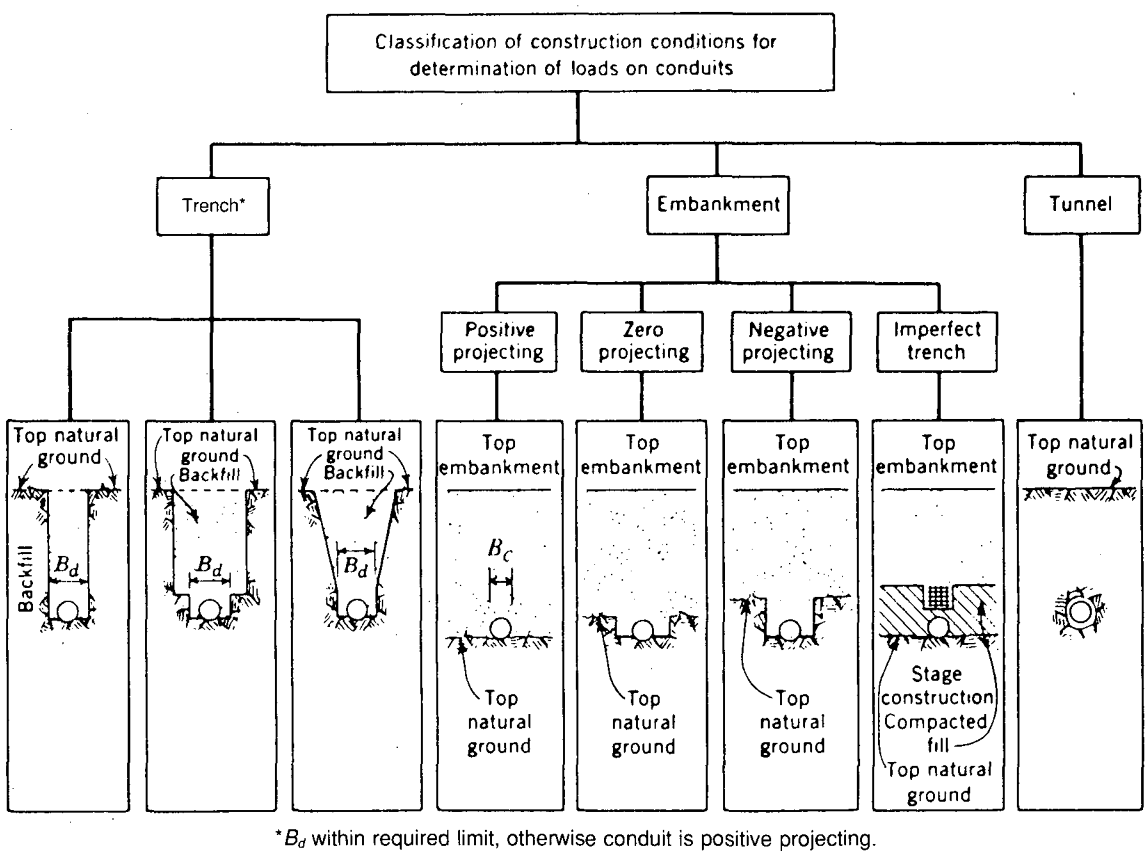


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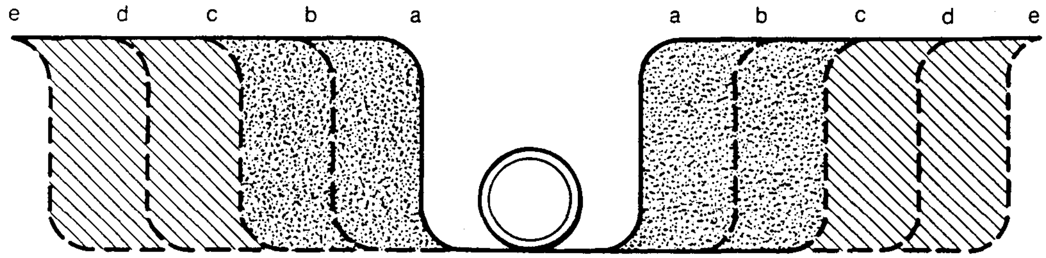
Figure 4 Classification of construction techniques



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

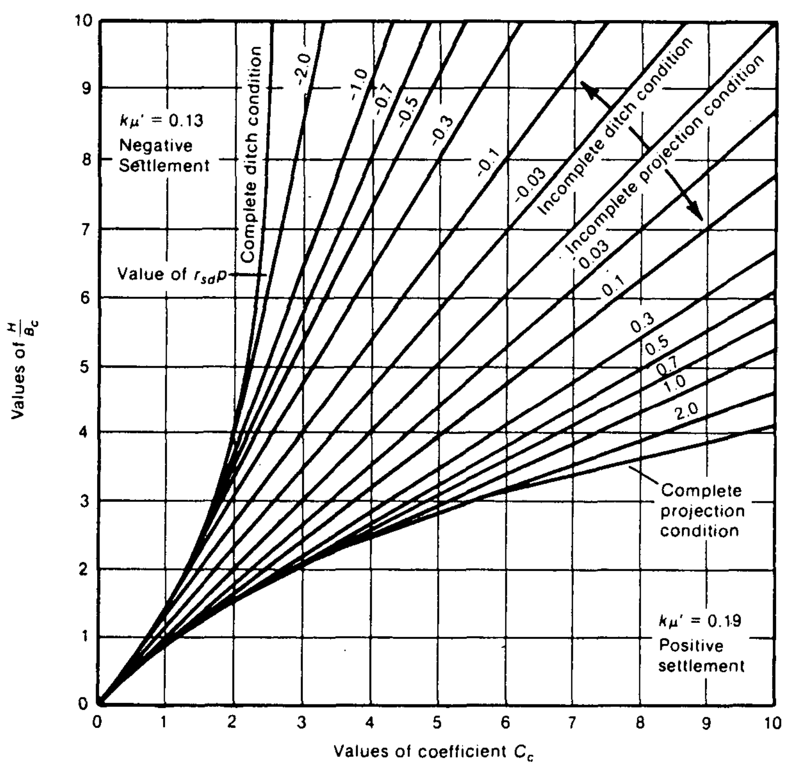


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Figure 7 Values of C_c for positive projecting pipe

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 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 and Figure 10B). 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. For asbestos–cement pipe design, the recommended value for the settlement ratio r_{sd} is zero. The projection ratio p can be determined from the relationships shown in Figure 10B.

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

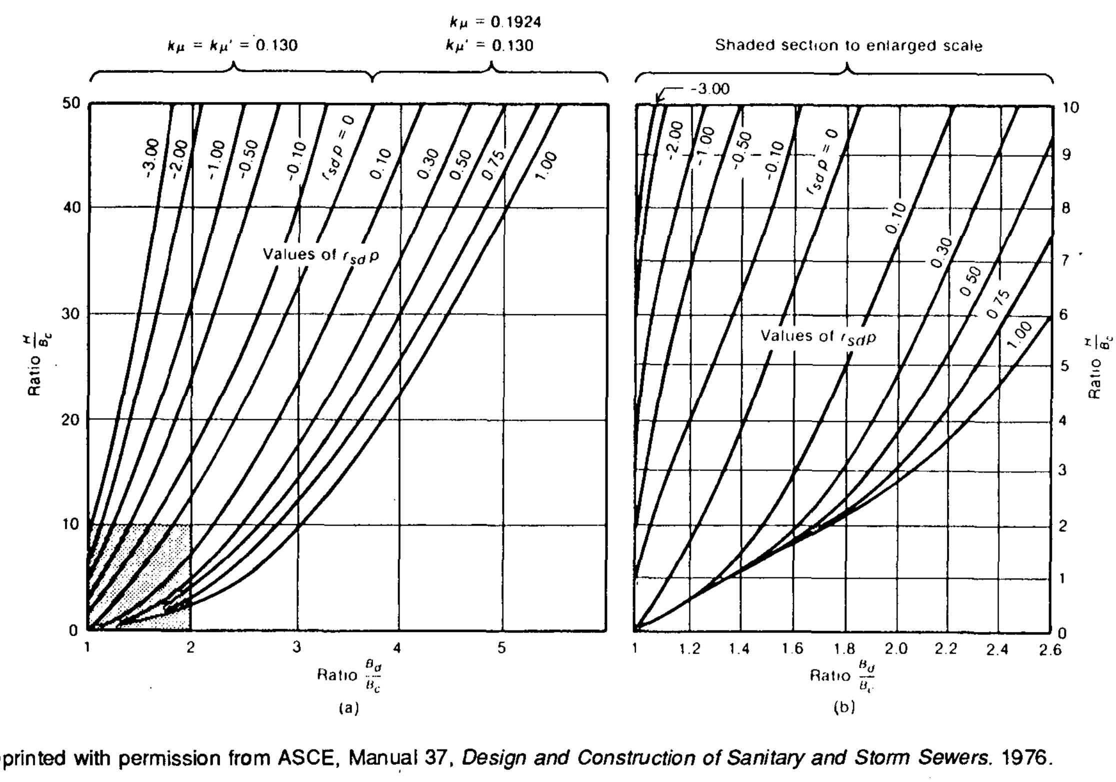

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Figure 8 Values of B_d/B_c at which the trench and positive projecting pipe equations give equal loads

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 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 infrequently and is included for general information only. 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

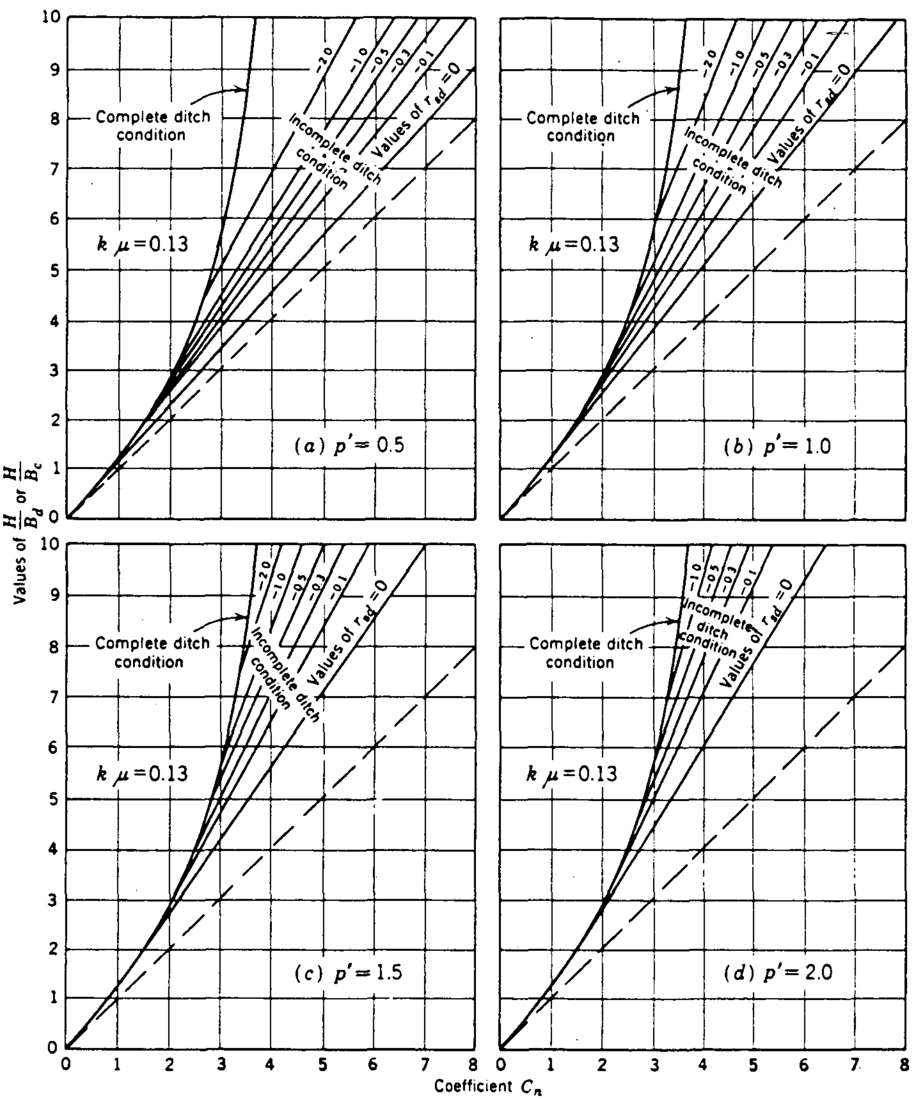

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Figure 9 Values of C_n for negative projecting pipe and imperfect ditch conditions

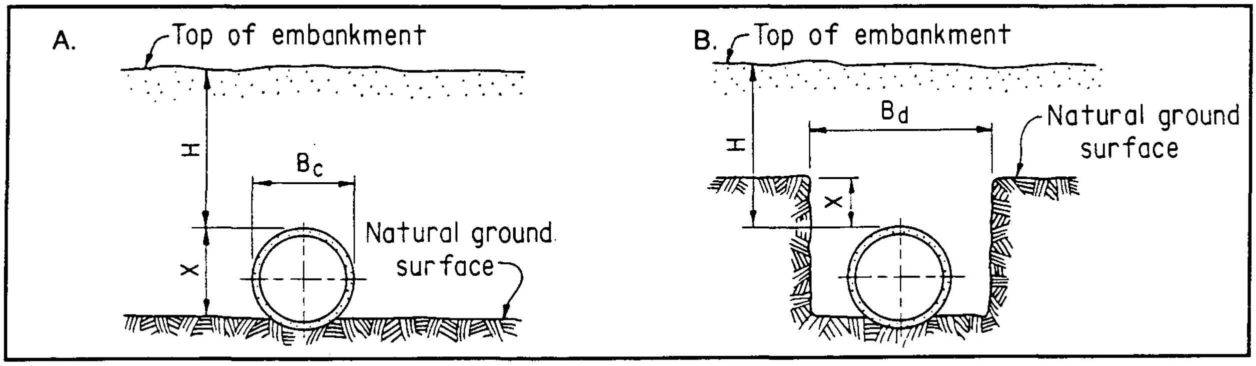

Figure 10A Positive projecting pipe projection ratio $p = \frac{x}{B_c}$

Figure 10B Negative projecting pipe projection ratio $p = \frac{x}{B_d}$

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). 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. For asbestos–cement pipe design, the recommended value for the settlement ratio r_{sd} is equal to –0.3. The projection ratio p can be determined from the relationship shown on Figure 11.

3.2.8 Tunnel conditions. There are two types of tunnel construction encountered in 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 carrier pipe is first jacked through an embankment. The carrier pipe is then placed into the sleeve without becoming an integral part of the tunnel construction. The sleeve supports the entire earth load and the carrier pipe 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 occurs when the carrier pipe itself must carry the external load. The area through which the pipeline must pass is bored and may be braced with supports. The carrier pipe is then placed in the tunnel, and the space between the pipe and tunnel braces backfilled with compacted earth, grout, or concrete. Once this operation is completed, the earth load automatically transfers from the tunnel supports to the carrier 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. If the value for the coefficient of cohesion is not available from laboratory tests, then the recommended safe design values in Table 1 are to be used.

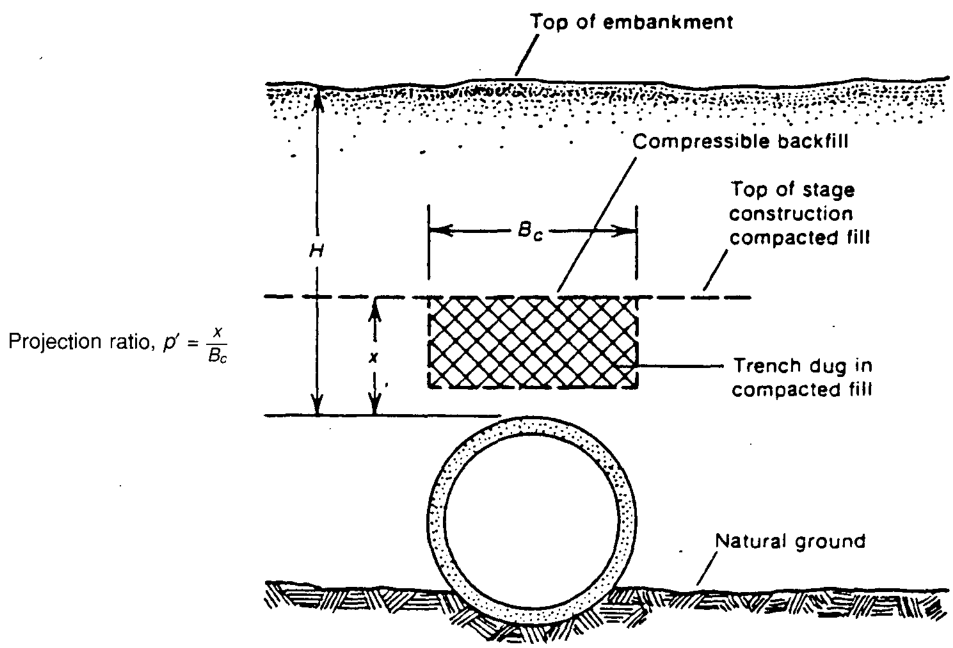

Figure 11 Projection ratio p' for the imperfect trench embankment condition

Table 1 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)

3.2.8.4 When the tunnel excavation becomes excessive, or when the space 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 using Eq 4 for trench conditions. It is difficult to determine that the tunnel excavation is excessive. Therefore, it is recommended that Eq 4 be used.

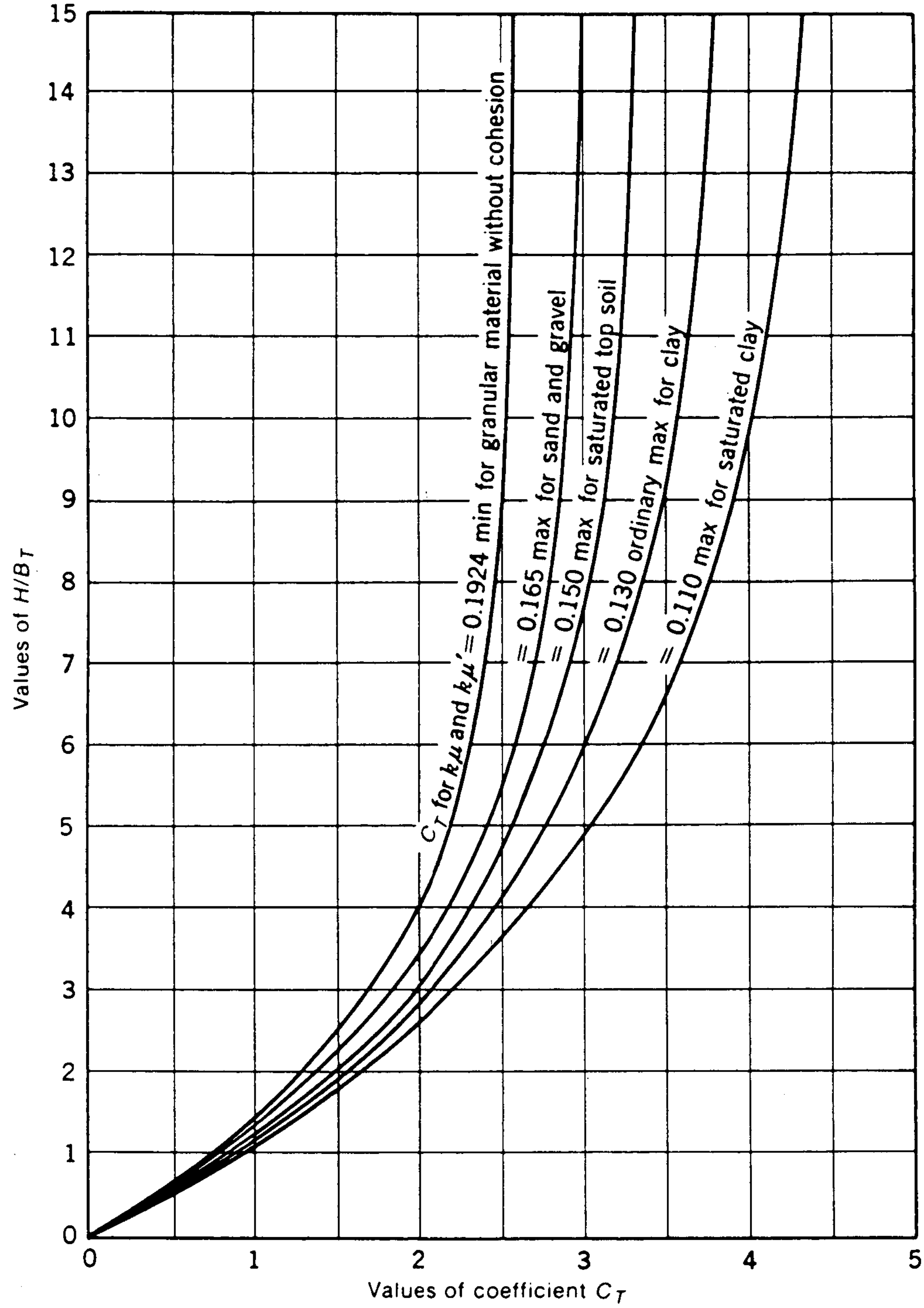

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Figure 12 Values of C_T for tunnel conditions

Sec. 3.3 Superimposed Loads

Superimposed or live 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: (1) concentrated W_{s1} and (2) distributed W_{s2}.

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

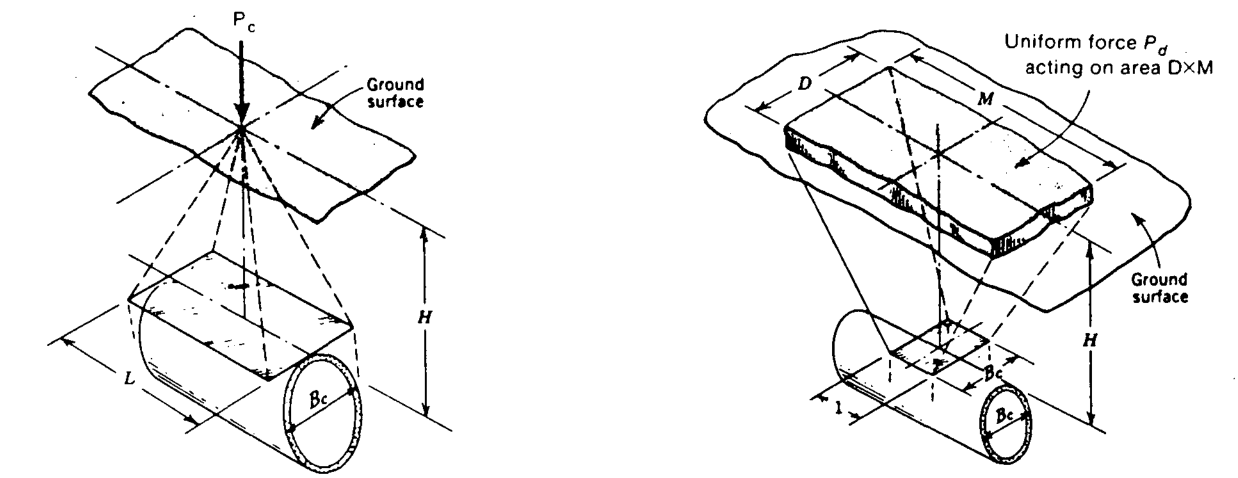
$$W_{sc} = \frac{C_s P_c F}{L} \qquad \text{Eq 10}$$

(see Tables 2 and 3)

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:

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

(see Table 4)



Unit load W_{s1} from superimposed concentrated live load

Unit load W_{s2} from uniformly distributed live load

Figure 13 Superimposed loads

Table 2 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 3 Values of load coefficients C_s for concentrated and distributed superimposed loads centered vertically over conduit

Pipe Size		Depth of cover—*ft (m)*										
in.	*(mm)*	2 (0.61)	2.5 (0.76)	3 (0.91)	4 (1.22)	5 (1.52)	6 (1.83)	8 (2.44)	10 (3.05)	12 (3.66)	16 (4.87)	20 (6.09)
4	(100)	0.105	0.076	0.055	0.033	0.022	0.016	0.009	0.006	0.004	0.002	0.0015
6	(150)	0.147	0.106	0.078	0.046	0.031	0.023	0.013	0.008	0.006	0.003	0.002
8	(200)	0.191	0.137	0.102	0.061	0.041	0.029	0.017	0.010	0.008	0.004	0.003
10	(250)	0.237	0.174	0.129	0.078	0.052	0.037	0.022	0.013	0.009	0.006	0.0035
12	(300)	0.279	0.202	0.153	0.092	0.062	0.044	0.025	0.016	0.011	0.007	0.004
14	(350)	0.317	0.232	0.175	0.106	0.071	0.050	0.030	0.018	0.013	0.008	0.005
16	(400)	0.354	0.259	0.197	0.121	0.081	0.057	0.034	0.021	0.015	0.009	0.0055

Table 4 Superimposed (wheel) load—single wheel = 16,000 lb (7250 kg)

Cover Over Top of Pipe		Pipe Diameter—*in. (mm)*					
		6 (150)*	8 (200)	10 (250)	12 (300)	14 (350)	16 (400)
ft	*(m)*	Wheel Load—*lb/ft (kN/m)*					
2	(0.61)	797 (11.6)	932 (13.6)	1272 (18.5)	1488 (21.7)	1691 (24.7)	1888 (27.5)
2.5	(0.76)	693 (10.1)	907 (13.2)	1076 (15.7)	1167 (17.0)	1237 (18.0)	1382 (20.2)
3	(0.91)	425 (6.20)	544 (7.93)	693 (10.1)	816 (11.9)	933 (13.6)	1048 (15.3)
4	(1.22)	256 (3.73)	331 (4.83)	421 (6.14)	490 (7.15)	565 (8.24)	645 (9.41)
5	(1.52)	176 (2.56)	218 (3.18)	277 (4.04)	330 (4.81)	378 (5.51)	432 (6.30)
6	(1.83)	149 (2.17)	197 (2.87)	245 (3.57)	235 (3.43)	267 (3.89)	304 (4.44)
8	(2.44)	69 (1.00)	91 (1.33)	112 (1.63)	139 (2.03)	160 (2.33)	181 (2.64)
10	(3.05)	43 (0.63)	59 (0.86)	74 (1.08)	85 (1.24)	96 (1.40)	112 (1.63)
12	(3.66)	37 (0.54)	48 (0.70)	53 (0.77)	59 (0.86)	69 (1.01)	80 (1.17)
16	(4.87)	21 (0.39)	27 (0.39)	32 (0.47)	37 (0.53)	43 (0.62)	48 (0.70)
20	(6.09)	5 (0.07)	11 (0.16)	16 (0.23)	21 (0.30)	26 (0.38)	29 (0.42)

*For 4-in. (100-mm) pipe, use same value as for 6-in. (150-mm) pipe.

SECTION 4: HYDROSTATIC PRESSURE

Sec. 4.1 Introduction

For the design of asbestos–cement pressure pipe for water distribution systems, the internal hydrostatic pressure P_T is defined by:

$$P_T = (P_o + P_s)\,\mathrm{SF} \qquad \text{Eq 12}$$

SF is the design safety factor. For asbestos–cement pressure pipe for water distribution systems, a safety factor of 4 is recommended when surge or water hammer is not calculated and added to operating pressure.

Sec. 4.2 Static or Working Pressure

The static or working 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–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 can be 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. Surge pressures in a distribution system can be of considerable magnitude, particularly when fire hydrants are rapidly opened or closed. The magnitude of this surge is difficult to determine and depends on the speed at which the fire hydrant is opened or closed. Design criteria for asbestos–cement pressure pipe for water distribution systems incorporate a safety factor of 4 in the operating or pressure class of the pipe to allow for an unknown amount of surge pressure that will occur in the system. Appendix B of ANSI/AWWA C403 presents a discussion of surge pressures and how they 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 analysis 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 pressure pipe for water distribution systems. (See Figures 14A through 14G and Figures 14A[m] through 14G[m].)

5.1.1 *Curve development.* The families of selection curves in this standard were developed using the Schlick formula that establishes a functional relationship between external load and internal pressure. The external and internal load intercepts are tabulated in Table 5 (page 36).

Sec. 5.2 Safety Factors

In distribution pipes, the effect of water hammer generated by the opening and closing of fire hydrants can be of significant magnitude because of the high velocities generated by open hydrant flow conditions on small-diameter lines in distribution systems. It is difficult to accurately evaluate the magnitude of surges, and if calculated, it would be impractical to attempt to control the surge by the use of surge tanks or other devices. Rather than employ a rule-of-thumb surge allowance based on an assumed velocity change, a safety factor of 4 is applied to the class pressure rating (see ANSI/AWWA C400 for defining parameters) of the pipe to account for undetermined surges.

5.2.1 *Design criteria.* The design criteria for asbestos–cement pressure pipe for water distribution systems is based on a design point on the combined loading parabolic curve where the following minimum conditions are met: (1) a safety factor of 4 times the pressure class of the pipe, and (2) a safety factor of 2.5 times the three-edge V-shaped bearing equivalent of an earth load calculated as 5 ft (1.52 m) depth of cover, a trench width equal to pipe inside diameter plus 2 ft (0.6 m) (or a positive projecting conduit condition if lesser), a soil density of 120 lb/cu ft (19 kN/m^3), and class C bedding condition.

Sec. 5.3 Use of Selection Charts

The scales are correlated to the three-edge V-shaped bearing equivalent of 2.5 times the earth load calculated using a soil density of 120 lb/cu ft (19 kN/m^3) and a trench width equal to the inside diameter (ID) of the pipe plus 2 ft (0.6 m) (or the positive projecting conduit condition if lesser).

5.3.1 *Design earth loads.* Table 6 gives the design earth load values, which are obtained by calculating the external earth load based on a trench width equal to the ID of the pipe plus 2 ft (0.6 m) (or the positive projecting conduit condition if lesser). The earth load is then divided by the appropriate bedding factor for the class of bedding and multiplied by a safety factor of 2.5. The design earth load values from Table 6 can then be used to enter the selection curve charts using the design external load values given at the top of the selection curve charts. When there is an external condition that warrants the consideration of all external loading factors and/or a change in the safety factor, the equivalent external load should be determined and the selection chart entered at the proper value of the design external load scale found at the top of the chart.

Sec. 5.4 Discussion

ANSI/AWWA C403 contains information similar to that contained herein but deals with larger diameter pipes. In ANSI/AWWA C403, the class selection is based on evaluation of all design conditions, including surge pressures. Adequate factors of safety are applied to the combination of loads to which the pipeline will be subjected.

The primary differences between AWWA C401 and ANSI/AWWA C403 are differing methods of designing pipelines to account for internal and external load conditions. In the smaller sizes covered by AWWA C401, surge pressures can be of great magnitude and are difficult to predict or control in design. In the larger sizes covered in ANSI/AWWA C403, the design is based on an evaluation of surge pressure, which 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

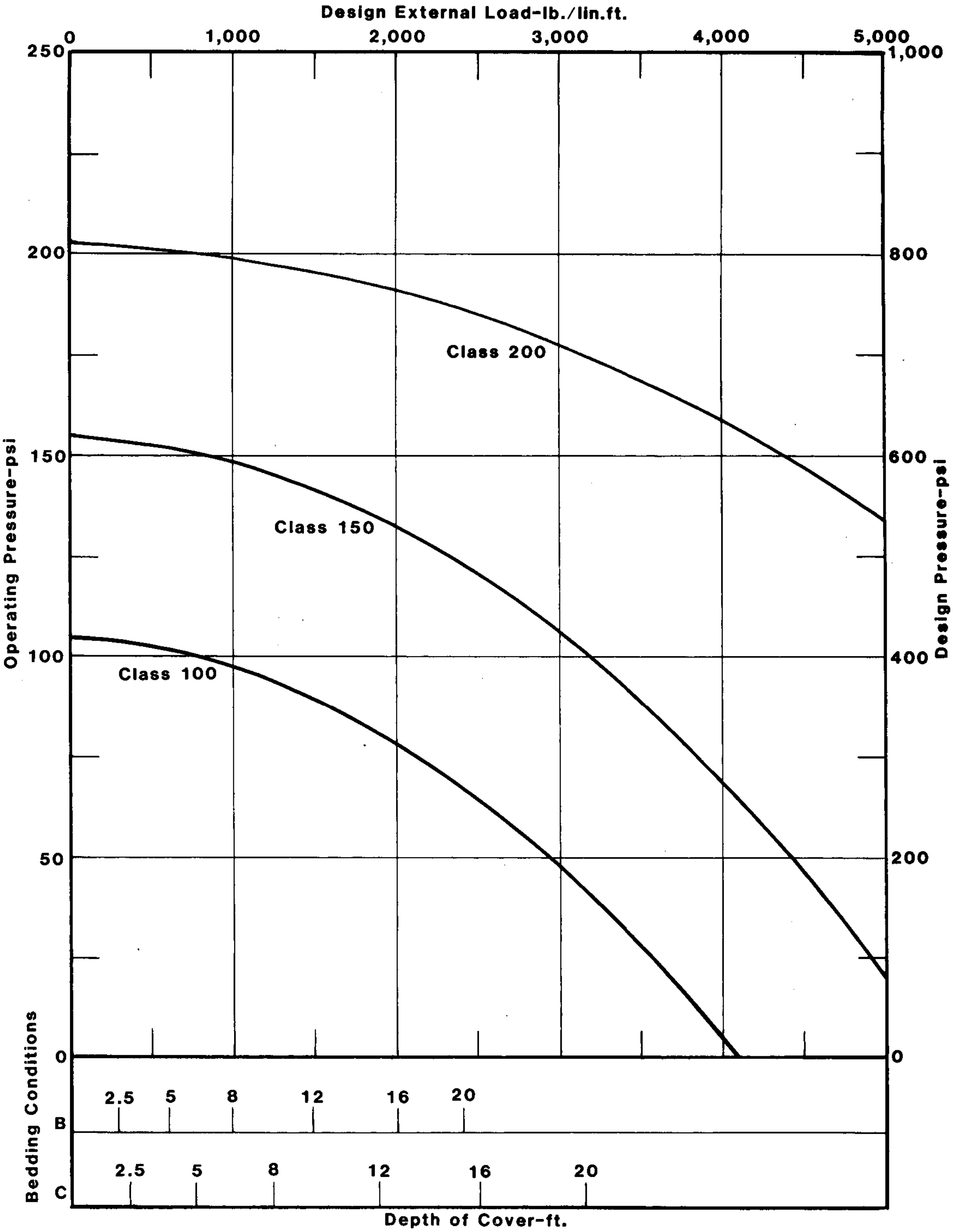


Figure 14A Selection curves for 4-in. asbestos-cement pipe

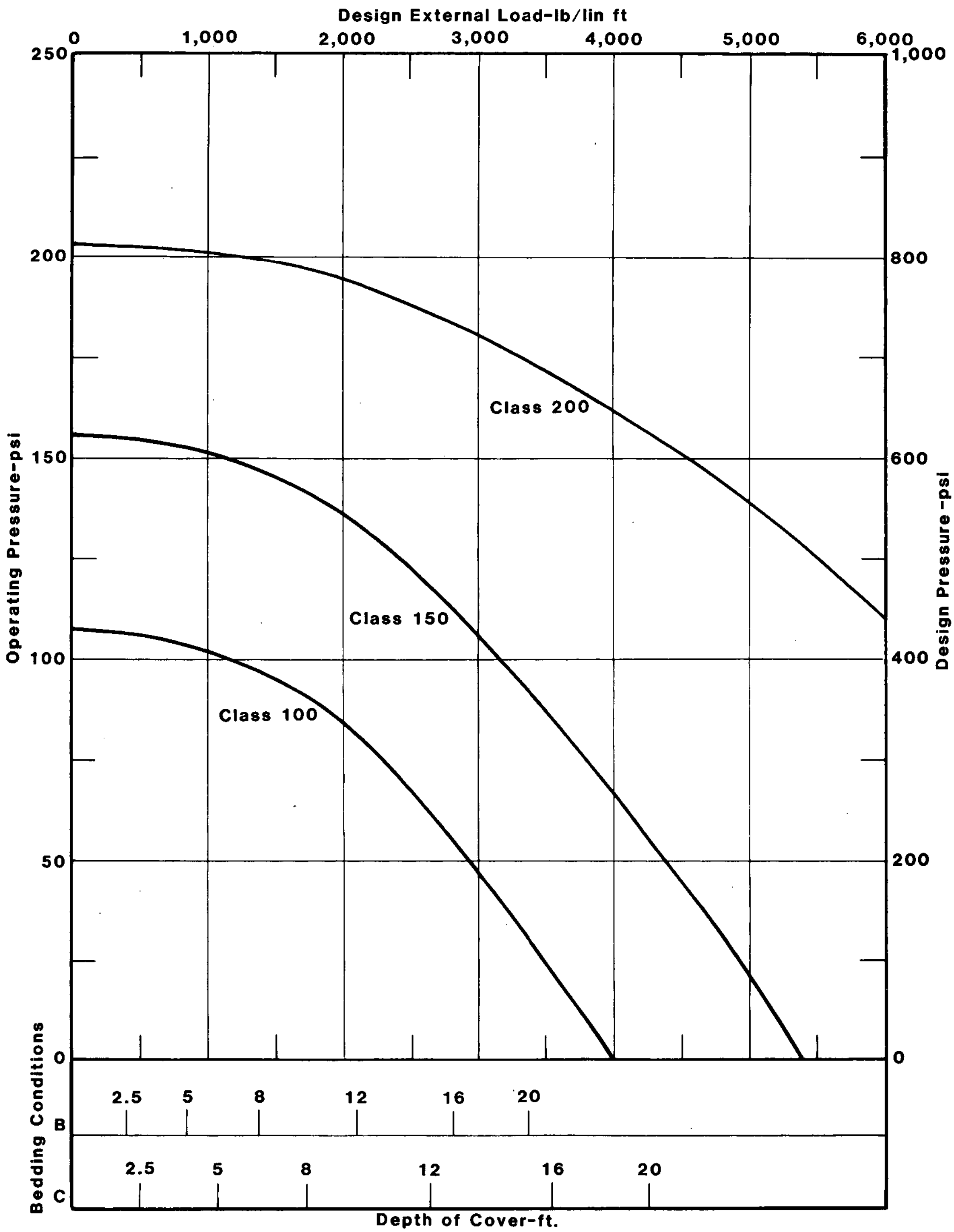


Figure 14B Selection curves for 6-in. asbestos-cement pipe

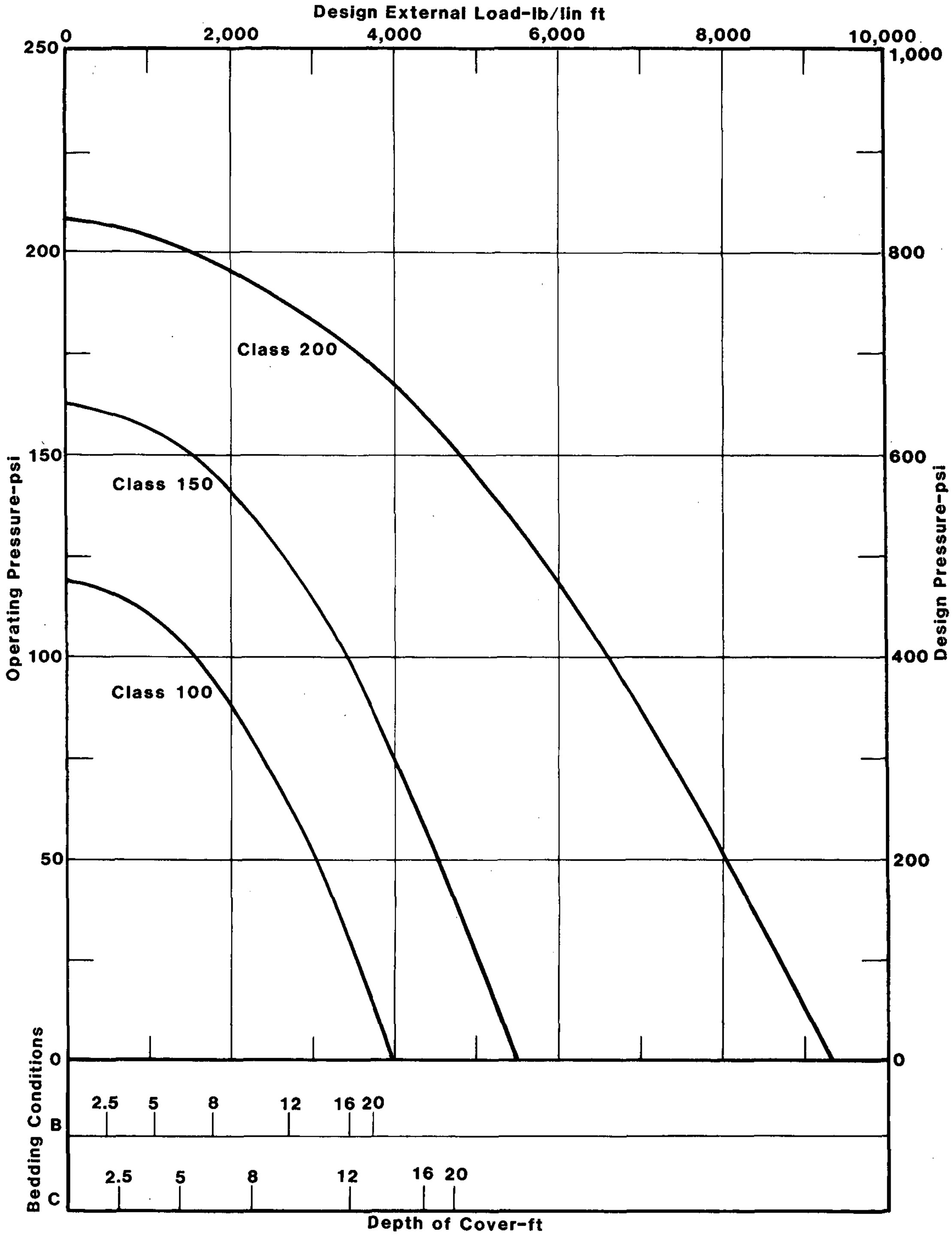


Figure 14C Selection curves for 8-in. asbestos-cement pipe

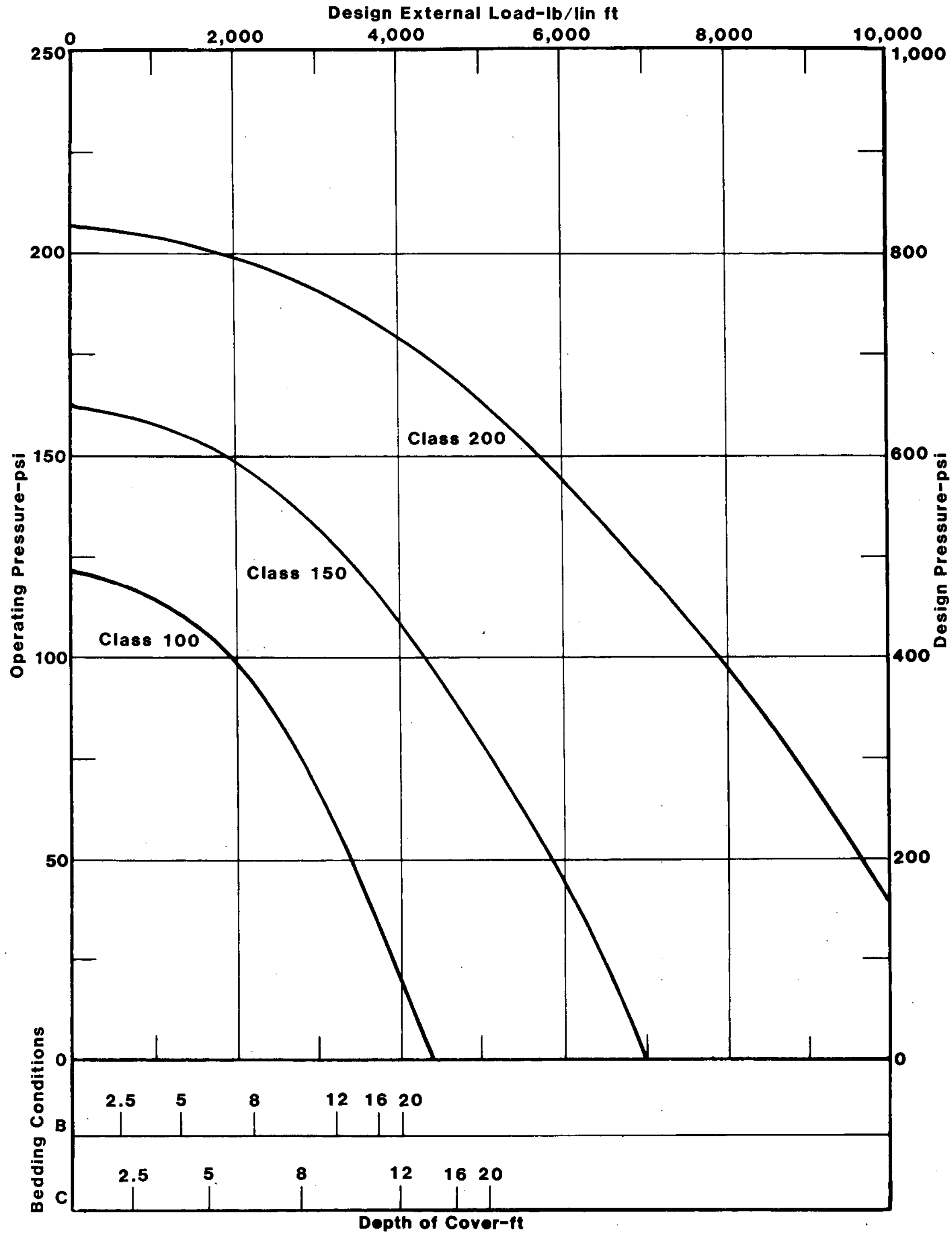


Figure 14D Selection curves for 10-in. asbestos-cement pipe

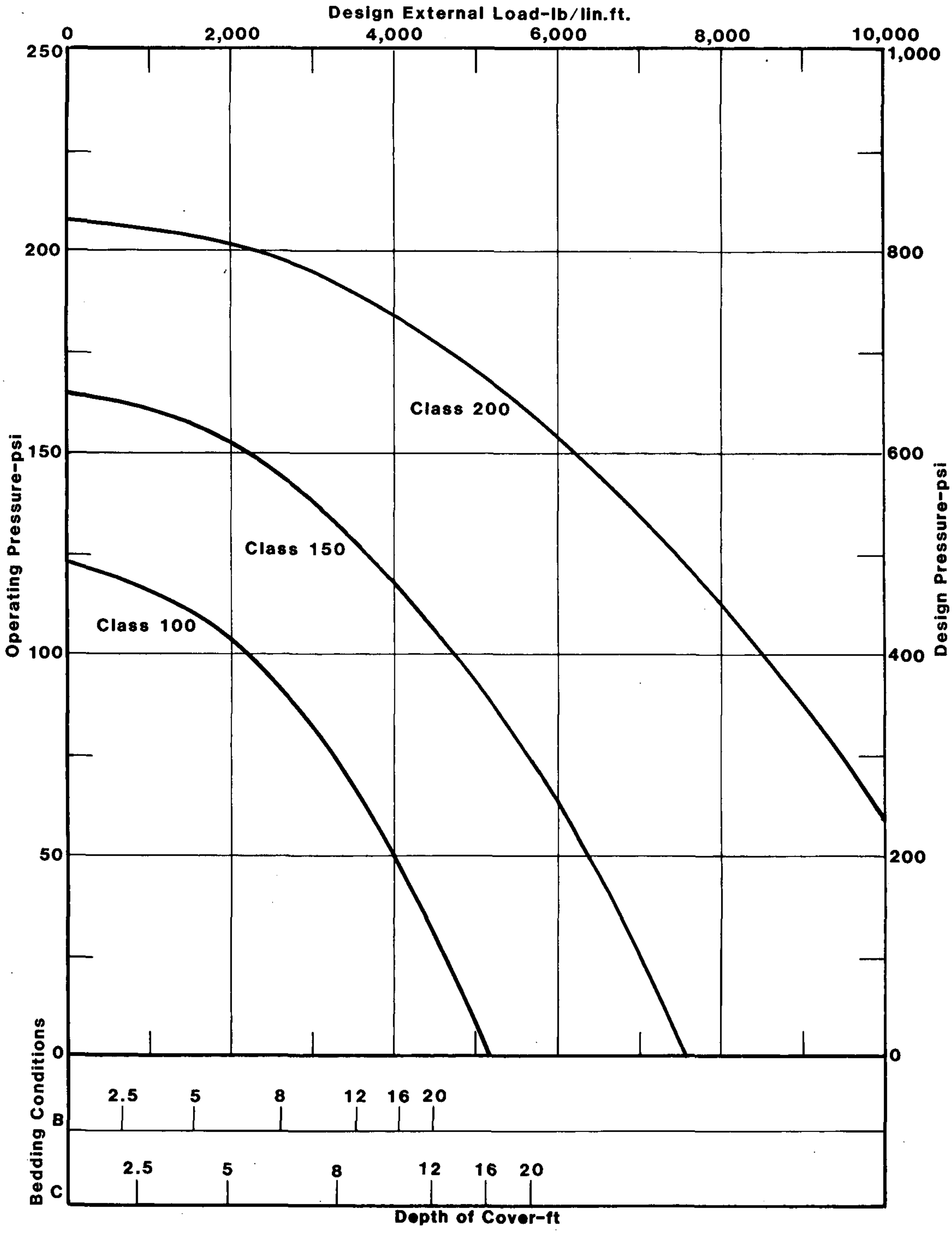


Figure 14E Selection curves for 12-in. asbestos-cement pipe

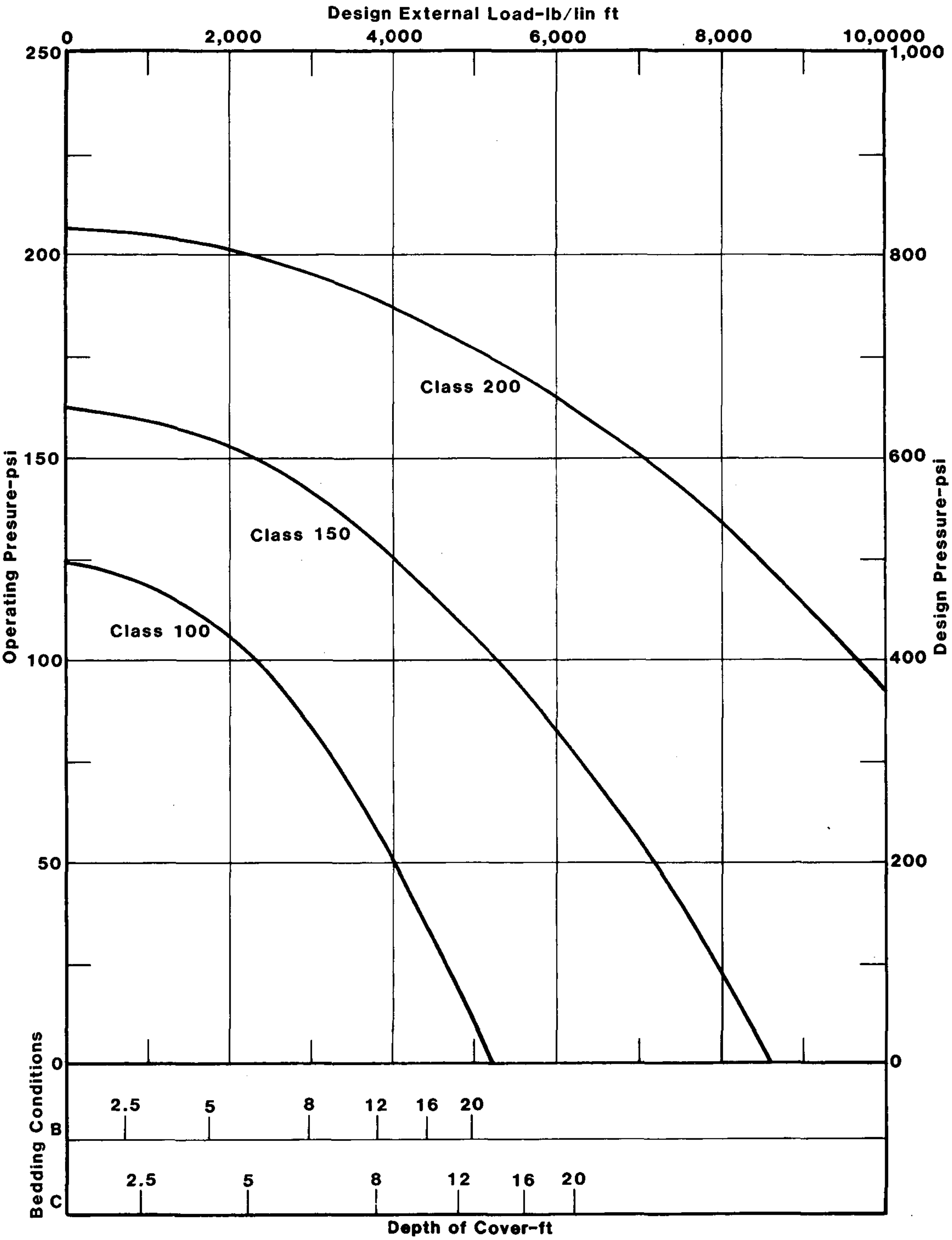


Figure 14F Selection curves for 14-in. asbestos-cement pipe

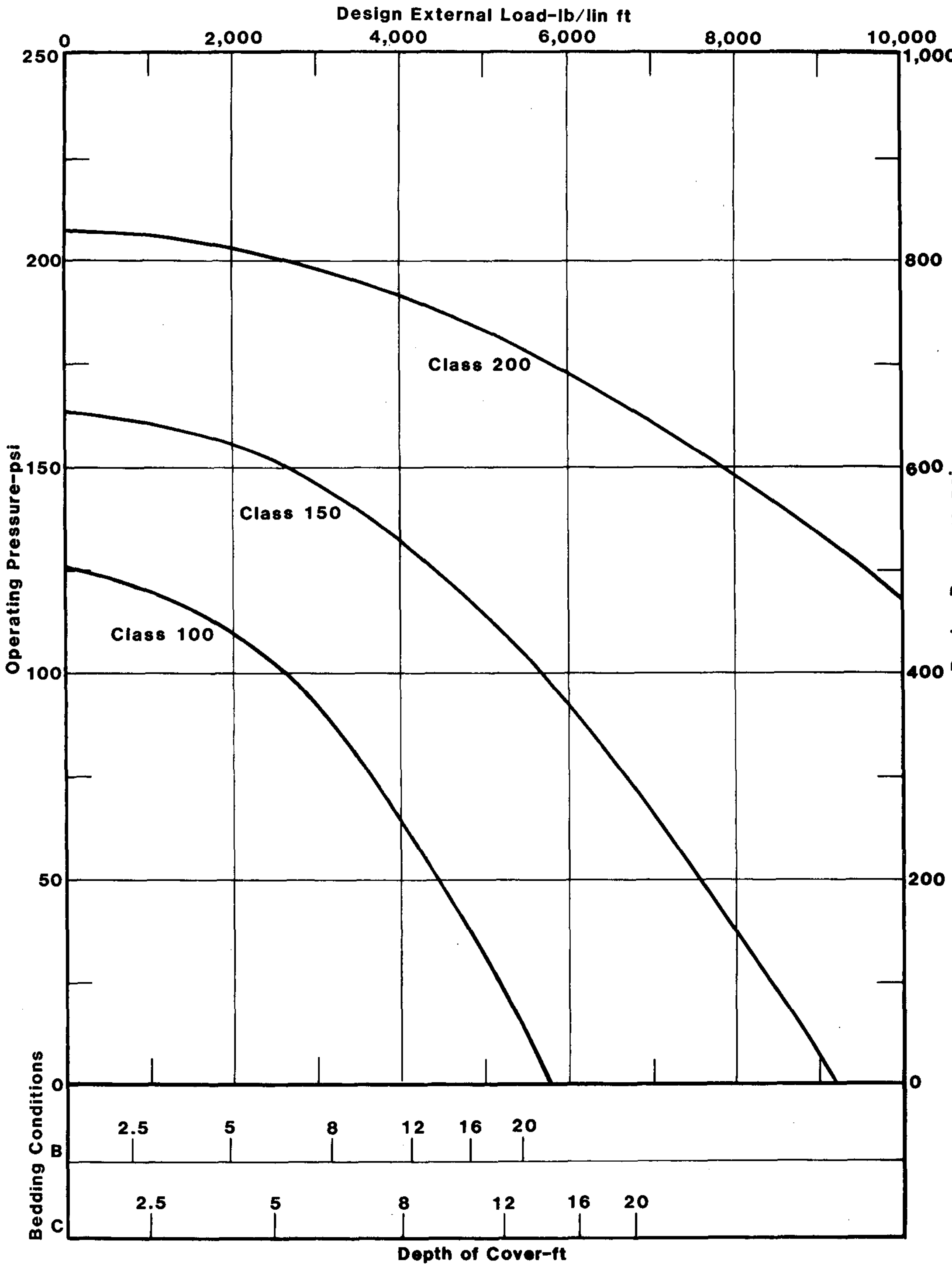


Figure 14G Selection curves for 16-in. asbestos-cement pipe

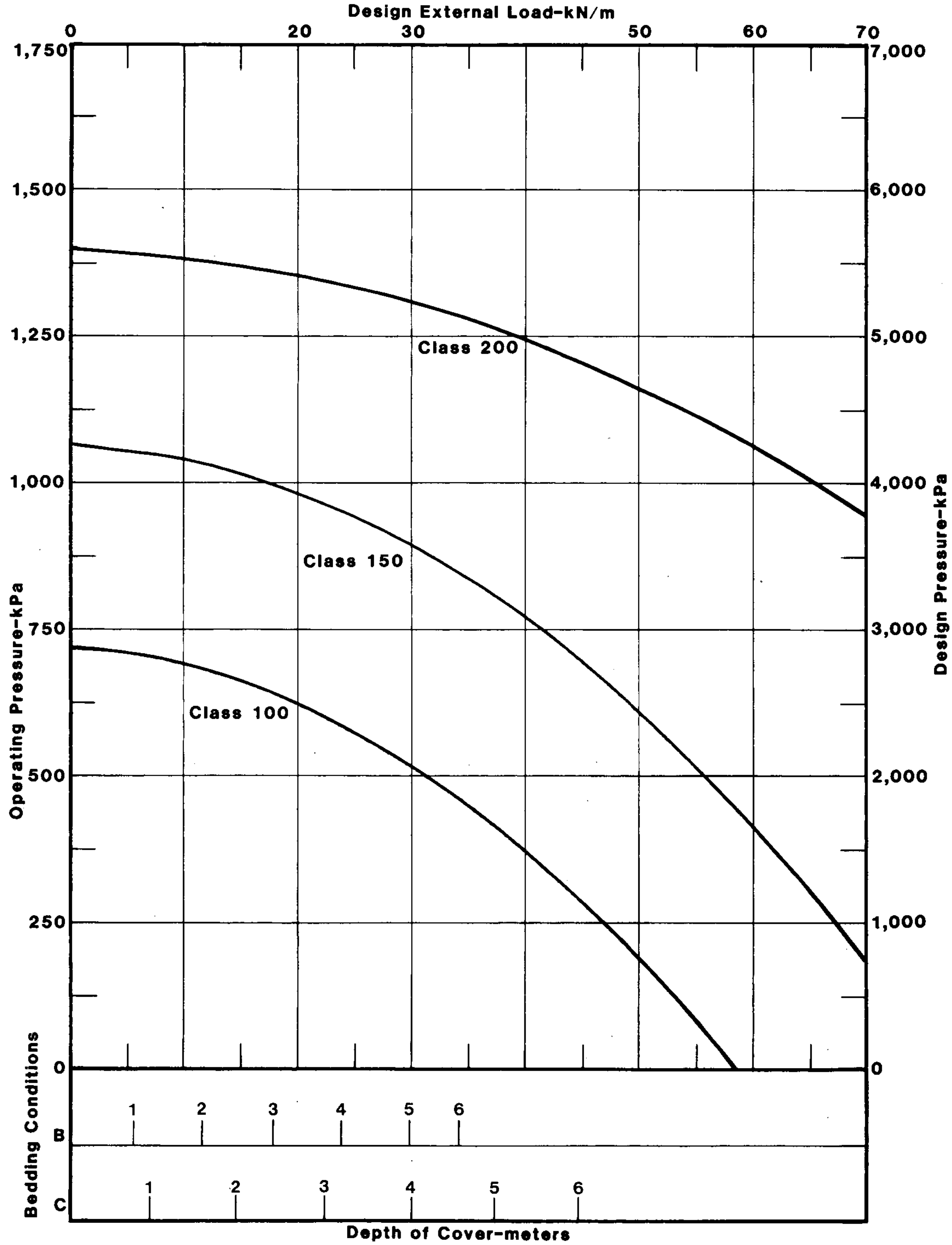


Figure 14A(m) Selection curves for 100-mm asbestos-cement pipe

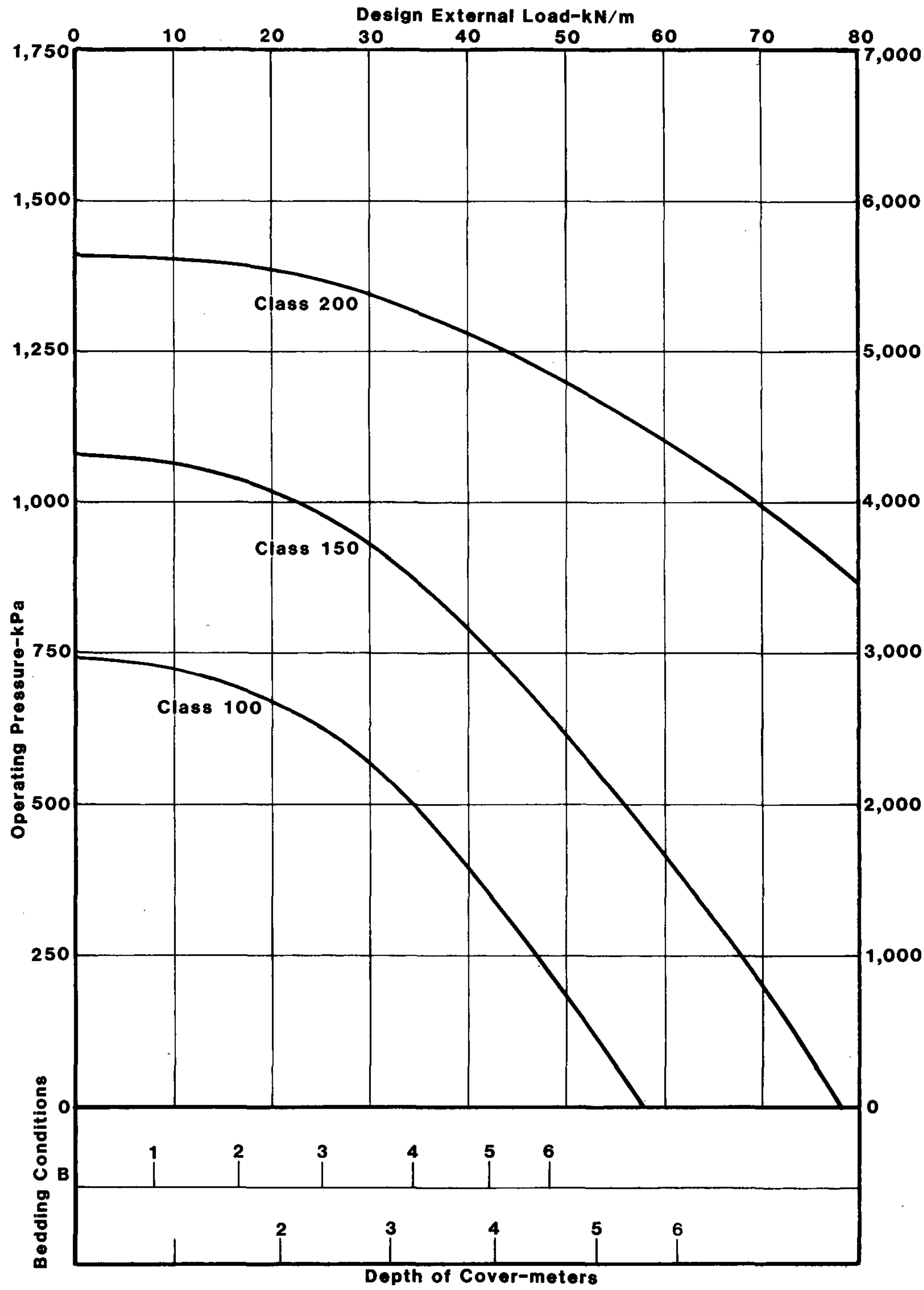


Figure 14B(m) Selection curves for 150-mm asbestos-cement pipe

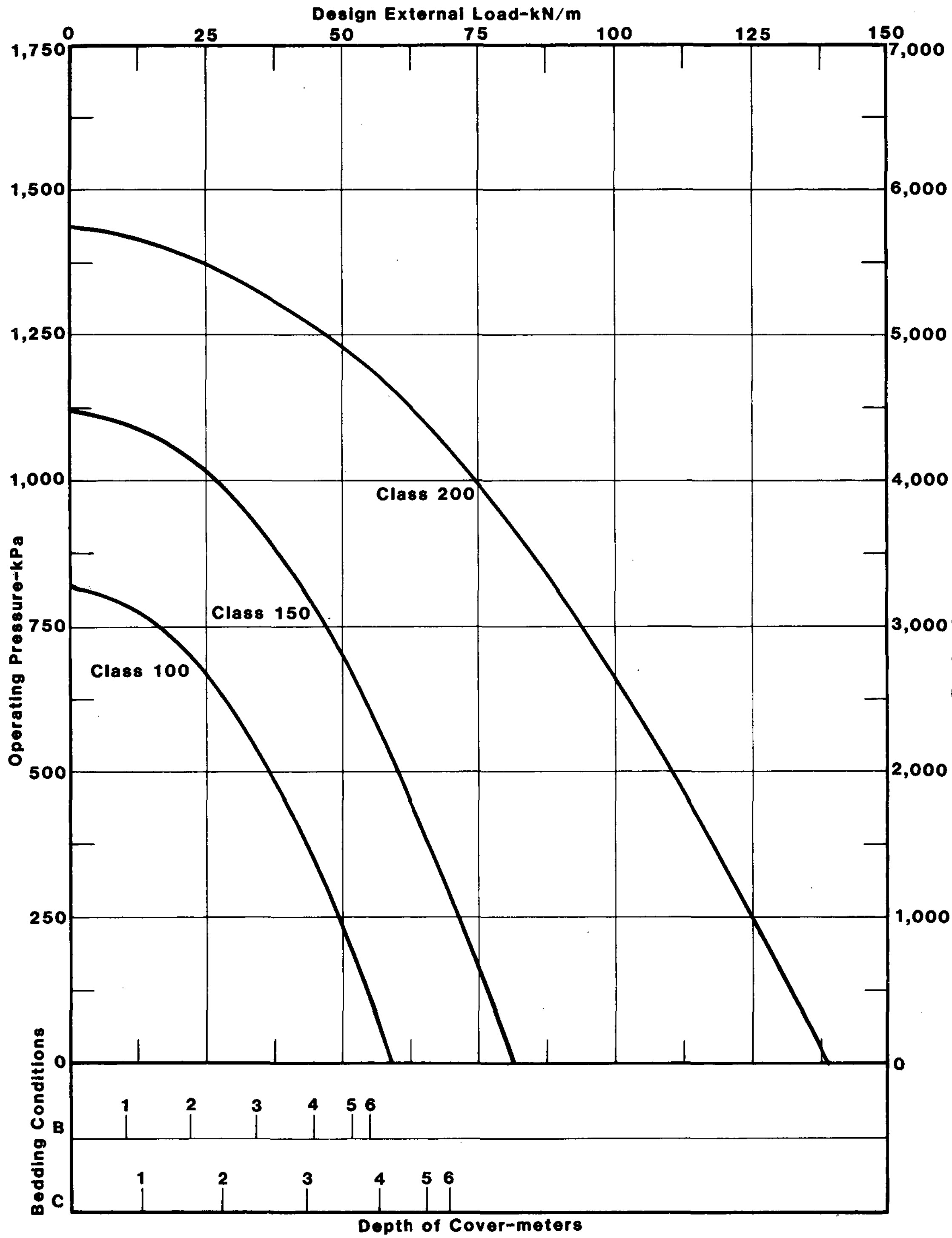


Figure 14C(m) Selection curves for 200-mm asbestos-cement pipe

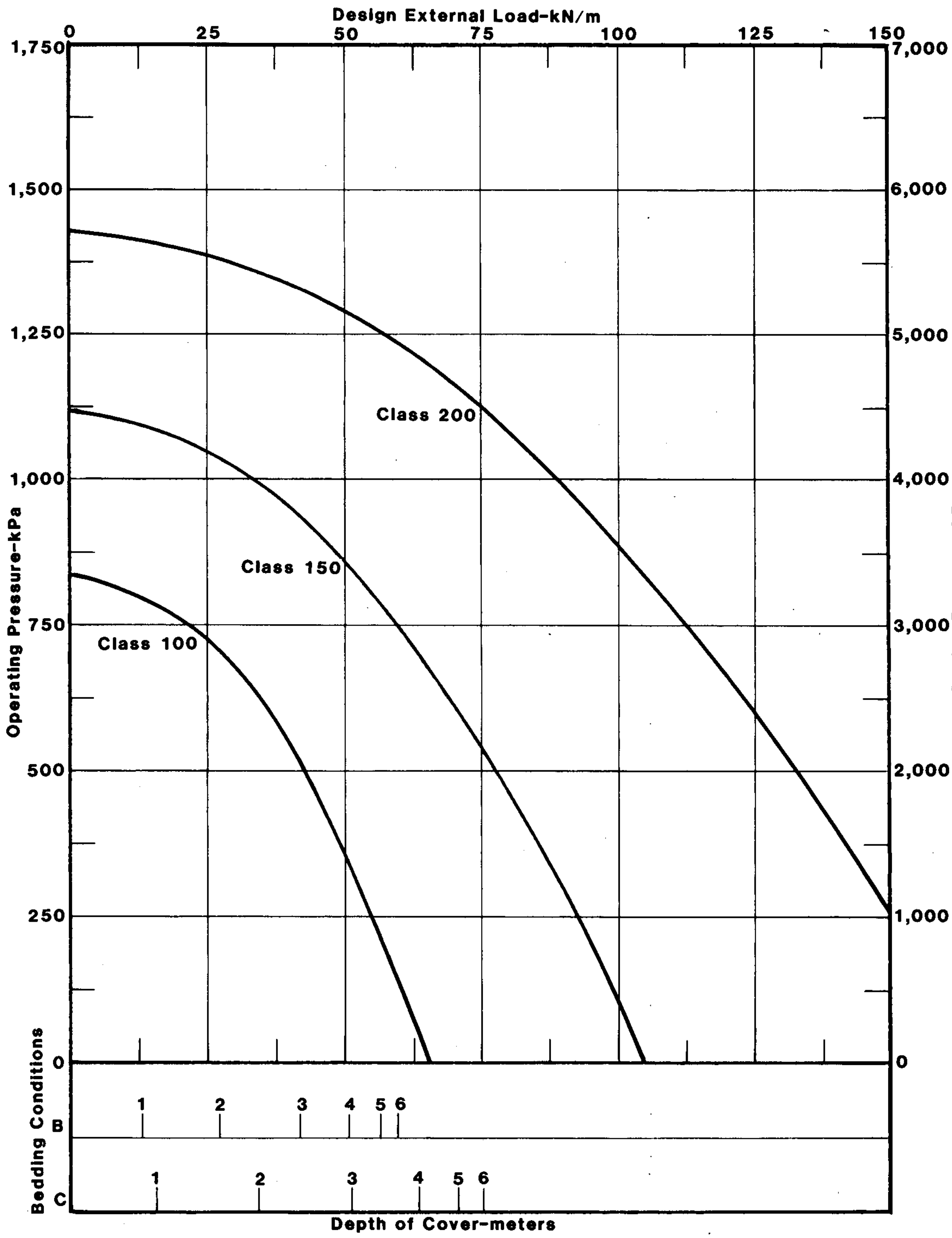


Figure 14D(m) Selection curves for 250-mm asbestos-cement pipe

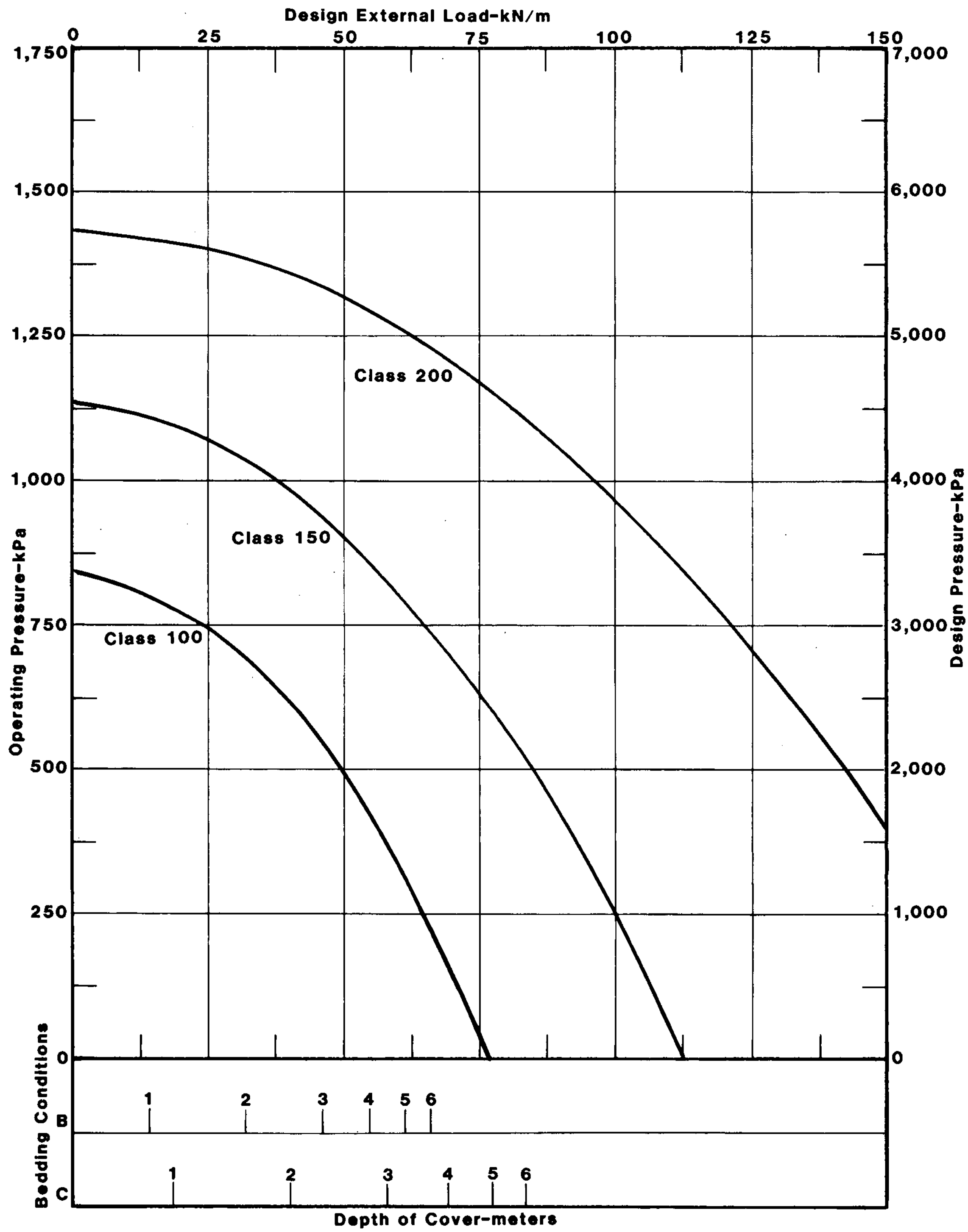


Figure 14E(m) Selection curves for 300-mm asbestos-cement pipe

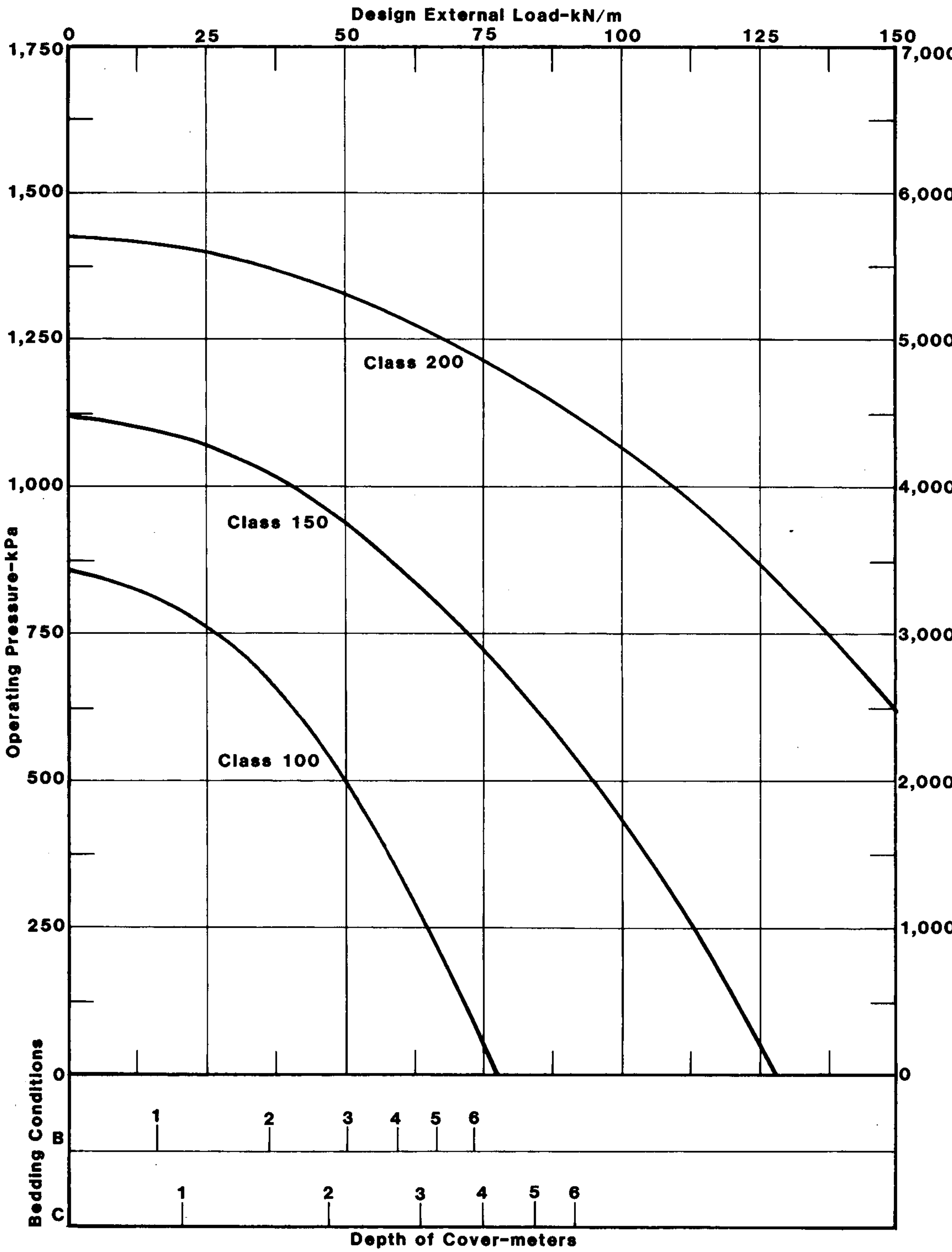


Figure 14F(m) Selection curves for 350-mm asbestos-cement pipe

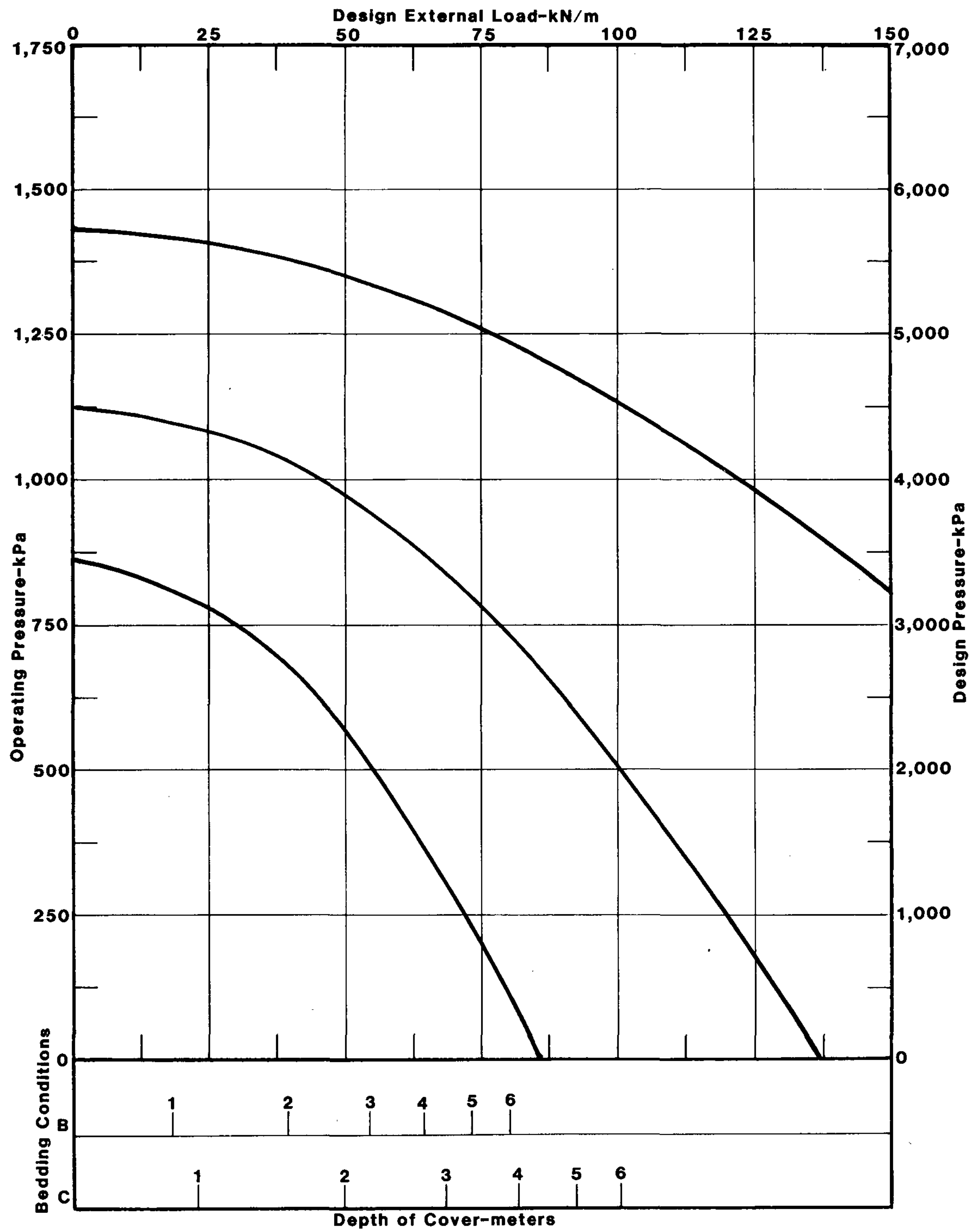


Figure 14G(m) Selection curves for 400-mm asbestos-cement pipe

Table 5 Design internal pressure and design external load*

Nominal Pipe Size		Class 100				Class 150				Class 200			
		Internal Pressure		External Load		Internal Pressure		External Load		Internal Pressure		External Load	
in.	*(mm)*	*psi*	*(kPa)*	*lb/lin. ft*	*(kN/m)*	*psi*	*(kPa)*	*lb/lin. ft*	*(kN/m)*	*psi*	*(kPa)*	*lb/lin. ft*	*(kN/m)*
4	(100)	417	(2900)	4100	(60)	616	(4200)	5400	(79)	809	(5600)	8700	(127)
6	(150)	441	(3000)	4000	(58)	632	(4400)	5400	(79)	815	(5600)	9000	(136)
8	(200)	472	(3300)	4000	(58)	653	(4500)	5500	(80)	824	(5700)	9300	(136)
10	(250)	490	(3400)	4400	(64)	650	(4500)	7000	(102)	826	(5700)	11,000	(161)
12	(300)	490	(3400)	5200	(76)	658	(4500)	7600	(111)	830	(5700)	11,800	(172)
14	(350)	500	(3400)	5200	(76)	650	(4500)	8600	(126)	826	(5700)	13,500	(197)
16	(400)	500	(3400)	5800	(85)	654	(4500)	9200	(134)	825	(5700)	15,400	(225)

*It is necessary to apply a load factor to the three-edge bearing loads obtained in the crushing tests in order to correlate them to the field loads.

Table 6 Design external earth load

Class B Bedding

Pipe Size		*H* 2.5 ft (0.76 m)		*H* 5.0 ft (1.52 m)		*H* 8.0 ft (2.44 m)		*H* 12 ft (3.66 m)		*H* 16 ft (4.88 m)		*H* 20 ft (6.10 m)	
in.	*(mm)*	*W—lb/ft (kN/m)*											
4	(100)	290	(4.23)	610	(8.90)	980	(14.30)	1490	(21.74)	1990	(29.04)	2500	(36.48)
6	(150)	390	(5.69)	840	(12.26)	1380	(20.14)	2090	(30.50)	2800	(40.86)	3360	(49.04)
8	(200)	490	(7.15)	1070	(15.62)	1770	(25.83)	2710	(39.55)	3380	(49.33)	3770	(55.02)
10	(250)	590	(8.61)	1330	(19.41)	2220	(32.40)	3230	(47.14)	3730	(54.44)	4170	(60.86)
12	(300)	670	(9.78)	1550	(22.62)	2610	(38.09)	3550	(51.81)	4120	(60.13)	4620	(67.42)
14	(350)	740	(10.80)	1760	(25.69)	2860	(41.74)	3810	(55.60)	4520	(65.96)	5000	(72.97)
16	(400)	800	(11.68)	1960	(28.60)	2980	(43.49)	4030	(58.81)	4990	(72.82)	5250	(76.62)

Class C Bedding

Pipe Size		*H* 2.5 ft (0.76 m)		*H* 5.0 ft (1.52 m)		*H* 8.0 ft (2.44 m)		*H* 12 ft (3.66 m)		*H* 16 ft (4.88 m)		*H* 20 ft (6.10 m)	
in.	*(mm)*	*W—lb/ft (kN/m)*											
4	(100)	370	(5.40)	770	(11.24)	1250	(18.24)	1890	(27.58)	2530	(36.92)	3170	(46.26)
6	(150)	500	(7.30)	1060	(15.47)	1740	(25.39)	2650	(38.67)	3550	(51.81)	4250	(62.02)
8	(200)	620	(9.05)	1360	(19.85)	2250	(32.84)	3430	(50.06)	4280	(62.46)	4780	(69.76)
10	(250)	750	(10.95)	1690	(24.66)	2820	(41.15)	4090	(59.69)	4730	(69.03)	5290	(77.20)
12	(300)	850	(12.40)	1970	(28.75)	3310	(48.31)	4500	(65.67)	5220	(76.18)	5850	(85.37)
14	(350)	940	(13.72)	2240	(32.69)	3620	(52.83)	4820	(70.34)	5730	(83.62)	6330	(92.38)
16	(400)	1010	(14.74)	2490	(36.34)	3770	(55.02)	5100	(74.43)	6320	(92.23)	6650	(97.05)

C401 considers only earth loads and a recommended safety factor of 2.5 is applied. In ANSI/AWWA C403, 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, ANSI/AWWA C403 design is based on a more detailed evaluation of the magnitude of surge pressure and live loadings, and factors of safety based on this more precise knowledge of actual operating conditions are applied.

Sec. 5.5 Illustrative Problem on Pipe Selection

The application of the curves to design is shown in the following problem:

Required: A 6-in. pipe to operate at a pressure of 120 psi at 8 ft depth of cover, bedding condition class C, soil weight 120 lb/cu ft.

Solution: Enter the selection curve for 6-in. pipe at bedding condition class C, 8-ft cover. The intersection of the 8-ft cover line with the 120-psi operating pressure line falls between pipe classes 100 and 150. Use 6-in., class 150. The intersection of the 8-ft cover line with the class 150 curve is at 140-psi operating pressure, or 560-psi design pressure. Therefore, the pressure safety factor equals 560/120 = 4.66, with a safety factor of 2.5 for external earth load.

APPENDIX A

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

This appendix is for information only and is not a part of AWWA C401.

Derived from the Hazen and Williams formula:

$$V = 1.318\ CR^{0.63}\ S^{0.54}$$

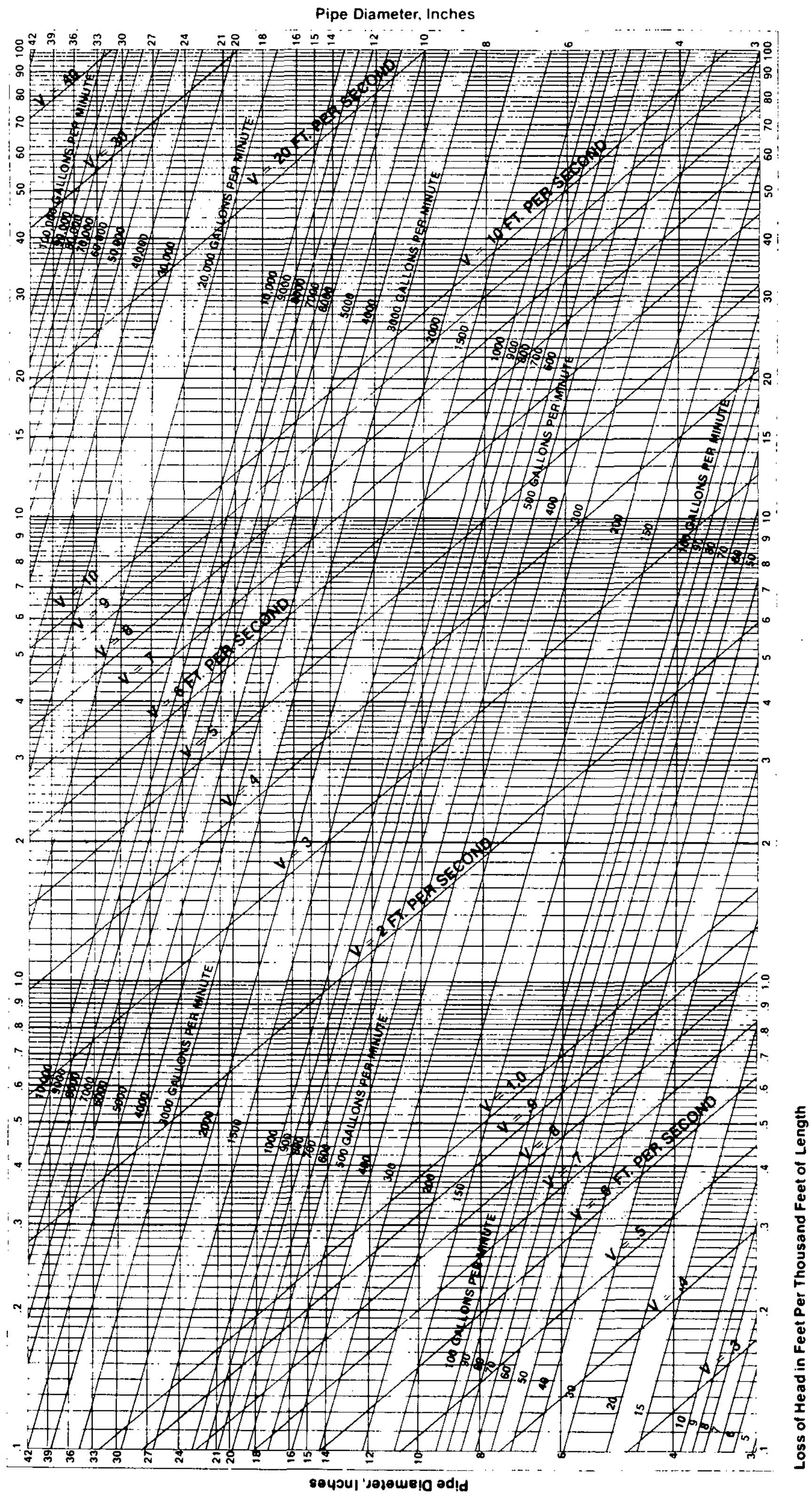
Asbestos–cement distribution and transmission pipe has a coefficient of C = 140. Because of asbestos–cement pipe's composition, this initial high flow capacity cannot be reduced by tuberculating water—the chief cause of loss of carrying capacity. This helps maintain the carrying capacity factor in minimizing pumping costs.

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

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	1.185 for C = 90
1.0.63 for C = 120	1.261 for C = 80
1.100 for C = 110	1.365 for C = 60
1.142 for C = 100	



APPENDIX B
Entrapped Air

This appendix is for information only and is not a part of AWWA C401.

SECTION B.1: GENERAL

Air entrapment 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.

SECTION B.2: ENTRANCE OF AIR

Air can enter a pipeline in many ways, not always through the intake. Entry may be caused by the release of air from water due to temperature and pressure variation, 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 to reduce operational difficulties. Suggested solutions for control are as follows:

1. Intake. Correct design procedures, including provision for low water-level pump cutoff.
2. Release of air. Air is entrained in the water at the intake and its release cannot be prevented. However, the quantities are usually not large and air valves can be used to remove the air. 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 pipeline. Air must be allowed to enter the pipeline when the pipe is drained. Large-orifice air valves should be provided for exhausting the air from the pipeline during refilling. Draining and then refilling does not often occur; 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.

SECTION B.3: RECOMMENDATIONS TO COMBAT AIR ENTRAPMENT

Colorado State University* has conducted studies to determine the effect of air entrapment in pipelines. The results 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 may 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 made to combat air entrapment are 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 slowly bled from pipeline.
4. Filling velocity in the pipeline should be limited to 1 ft/sec (0.3 m/s) or less.
5. Use d/D = 1/10 to 1/100.

Where:

d = diameter of air release valve
D = pipe diameter

*Colorado State University, Fort Collins, Colo.

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