CONCRETE PIPE

DESIGN MANUAL

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Technical programs of the American Concrete Pipe Association, since its founding in 1907, have been designed to compile engineering data on the hydraulics, loads and supporting strengths and design of concrete pipe. Information obtained is disseminated to producers and consumers of concrete pipe through technical literature and promotional handbooks. Other important activities of the Association include development of product specifications, government relations, participation in related trade and professional societies, advertising and promotion, an industry safety program and educational training. These services are made possible by the financial support of member companies located throughout the United States, Canada, and in almost 30 foreign countries.

FOREWORD

The principal objective in compiling the material for this **CONCRETE PIPE DESIGN MANUAL** was to present data and information on the design of concrete pipe systems in a readily usable form. The Design Manual is a companion volume to the **CONCRETE PIPE HANDBOOK** which provides an up-to-date compilation of the concepts and theories which form the basis for the design and installation of precast concrete pipe sewers and culverts and explanations for the charts, tables and design procedures summarized in the Design Manual.

Special recognition is acknowledged for the contribution of the staff of the American Concrete Pipe Association and the technical review and assistance of the engineers of the member companies of the Association in preparing this Design Manual. Also acknowledged is the development work of the American Association of State Highway and Transportation Officials, American Society of Civil Engineers, U. S. Army Corps of Engineers, U. S. Federal Highway Administration, Bureau of Reclamation, Iowa State University, Natural Resources Conservation Service, Water Environment Federation, and many others. Credit for much of the data in this Manual goes to the engineers of these organizations and agencies. Every effort has been made to assure accuracy, and technical data are considered reliable, but no guarantee is made or liability assumed.

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CHAPTER 1

INTRODUCTION

The design and construction of sewers and culverts are among the most important areas of public works engineering and, like all engineering projects, they involve various stages of development. The information presented in this manual does not cover all phases of the project, and the engineer may need to consult additional references for the data required to complete preliminary surveys.

This manual is a compilation of data on concrete pipe, and it was planned to provide all design information needed by the engineer when he begins to consider the type and shape of pipe to be used. All equations used in developing the figures and tables are shown along with limited supporting theory. A condensed bibliography of literature references is included to assist the engineer who wishes to further study the development of these equations.

Chapters have been arranged so the descriptive information can be easily followed into the tables and figures containing data which enable the engineer to select the required type and size concrete pipe without the lengthy computations previously required. All of these design aids are presently published in engineering textbooks or represent the computer analysis of involved equations. Supplemental data and information are included to assist in completing this important phase of the project, and illustrative example problems are presented in Chapters 2 through 4. A review of these examples will indicate the relative ease with which this manual can be used.

The revised Chapter 4 on Loads and Supporting Strengths incorporates the Standard Installations for concrete pipe bedding and design. The standard Installations are compatible with today's methods of installation and incorporate the latest research on concrete pipe. In 1996 the B, C, and D beddings, researched by Anson Marston and Merlin Spangler, were replaced in the AASHTO Bridge Specifications by the Standard Installations. A description of the B, C, and D beddings along with the appropriate design procedures are included in Appendix B of this manual to facilitate designs still using these beddings.

CHAPTER 2

HYDRAULICS OF SEWERS

The hydraulic design procedure for sewers requires:

1. Determination of Sewer System Type
2. Determination of Design Flow
3. Selection of Pipe Size
4. Determination of Flow Velocity

SANITARY SEWERS

DETERMINATION OF SEWER SYSTEM TYPE

Sanitary sewers are designed to carry domestic, commercial and industrial sewage with consideration given to possible infiltration of ground water. All types of flow are designed on the basis of having the flow characteristics of water.

DETERMINATION OF DESIGN FLOW

In designing sanitary sewers, average, peak and minimum flows are considered. Average flow is determined or selected, and a factor applied to arrive at the peak flow which is used for selecting pipe size. Minimum flows are used to determine if specified velocities can be maintained to prevent deposition of solids.

Average Flow. The average flow, usually expressed in gallons per day, is a hypothetical quantity which is derived from past data and experience. With adequate local historical records, the average rate of water consumption can be related to the average sewage flow from domestic, commercial and industrial sources. Without such records, information on probable average flows can be obtained from other sources such as state or national agencies. Requirements for minimum average flows are usually specified by local or state sanitary authorities or local, state and national public health agencies. Table 1 lists design criteria for domestic sewage flows for various municipalities. Commercial and industrial sewage flows are listed in Table 2. These tables were adapted from the “Design and Construction of Sanitary and Storm Sewers,” published by American Society of Civil Engineers and Water Pollution Control Federation. To apply flow criteria in the design of a sewer system, it is necessary to determine present and future zoning, population densities and types of business and industry.

Peak Flow. The actual flow in a sanitary sewer is variable, and many studies have been made of hourly, daily and seasonal variations. Typical results of one study are shown in Figure I adapted from “Design and Construction of Sanitary and Storm Sewers,” published by the American Society of Civil Engineers and Water Pollution Control Federation. Maximum and minimum daily flows are used in the design of treatment plants, but the sanitary sewer must carry the peak flow that will occur during its design life. This peak flow is defined as the mean rate of the maximum flow occurring during a 15-minute period for any 12-month period and is determined by multiplying average daily flow by an appropriate factor. Estimates of this factor range from 4.0 to 5.5 for design populations of one thousand, to a factor of 1.5 to 2.0 for design population of one million. Tables 1 and 2 list minimum peak loads used by some municipalities as a basis for design.

Minimum Flow. A minimum velocity of 2 feet per second, when the pipe is flowing full or half full, will prevent deposition of solids. The design should be checked using the minimum flow to determine if this self-cleaning velocity is maintained.

SELECTION OF PIPE SIZE

After the design flows have been calculated, pipe size is selected using Manning's formula. The formula can be solved by selecting a pipe roughness coefficient, and assuming a pipe size and slope. However, this trial and error method is not necessary since nomographs, tables, graphs and computer programs provide a direct solution.

Manning's Formula. Manning's formula for selecting pipe size is:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \tag{1}$$

A constant $C_1 = \frac{1.486}{n} AR^{2/3}$ which depends only on the geometry and characteristics of the pipe enables Manning's formula to be written as:

$$Q = C_1 S^{1/2} \tag{2}$$

Tables 3, 4, 5 and 6 list full flow values of C_1 for circular pipe, elliptical pipe, arch pipe, and box sections. Table A-1 in the Appendix lists values of $S^{1/2}$.

Manning's "*n*" Value. The difference between laboratory test values of Manning's "*n*" and accepted design values is significant. Numerous tests by public and other agencies have established Manning's "*n*" laboratory values. However, these laboratory results were obtained utilizing clean water and straight pipe sections without bends, manholes, debris, or other obstructions. The laboratory results indicated the only differences were between smooth wall and rough wall pipes. Rough wall, or corrugated pipe, have relatively high "*n*" values which are approximately 2.5 to 3 times those of smooth wall pipe.

All smooth wall pipes, such as concrete and plastic, were found to have "*n*" values ranging between 0.009 and 0.010, but, historically, engineers familiar with sewers have used 0.012 and 0.013. This "design factor" of 20-30 percent takes into account the difference between laboratory testing and actual installed conditions. The use of such design factors is good engineering practice, and, to be consistent for all pipe materials, the applicable Manning's " " laboratory value should be increased a similar amount in order to arrive at design values.

Full Flow Graphs. Graphical solutions of Manning's formula are presented for circular pipe in Figures 2 through 5 and for horizontal elliptical pipe, vertical elliptical pipe, arch pipe and box sections in Figures 6 through 19. When flow, slope and roughness coefficient are known, pipe size and the resulting velocity for full flow can be determined.

Partially Full Flow Graphs. Velocity, hydraulic radius and quantity and area of flow vary with the depth of flow. These values are proportionate to full flow values and for any depth of flow are plotted for circular pipe, horizontal elliptical pipe, vertical elliptical pipe, arch pipe, and box sections in Figures 20 through 24.

DETERMINATION OF FLOW VELOCITY

Minimum Velocity. Slopes required to maintain a velocity of 2 feet per second under full flow conditions with various "*n*" values are listed in Table 7 for circular pipe. The slopes required to maintain velocities other than 2 feet per second under full flow conditions can be obtained by multiplying the tabulated values by one-fourth of the velocity squared or by solving Manning's formula using Figures 2 through 19.

Maximum Velocity. Maximum design velocities for clear effluent in concrete pipe can be very high. Unless governed by topography or other restrictions, pipe slopes should be set as flat as possible to reduce excavation costs and consequently velocities are held close to the minimum.

STORM SEWERS

DETERMINATION OF SEWER SYSTEM TYPE

Storm sewers are designed to carry precipitation runoff, surface waters and, in some instances, ground water. Storm water flow is analyzed on the basis of having the flow characteristics of water.

DETERMINATION OF DESIGN FLOW

The Rational Method is widely used for determining design flows in urban and small watersheds. The method assumes that the maximum rate of runoff for a given intensity occurs when the duration of the storm is such that all parts of the watershed are contributing to the runoff at the interception point. The formula used is an empirical equation that relates the quantity of runoff from a given area to the total rainfall falling at a uniform rate on the same area and is expressed as:

$$Q = CiA \tag{3}$$

The runoff coefficient "C" and the drainage area "A" are both constant for a given area at a given time. Rainfall intensity " i ", however, is determined by using an appropriate storm frequency and duration which are selected on the basis of economics and engineering judgment. Storm sewers are designed on the basis that they will flow full during storms occurring at certain intervals. Storm frequency is selected through consideration of the size of drainage area, probable flooding, possible flood damage and projected development schedule for the area.

Runoff Coefficient. The runoff coefficient “C” is the ratio of the average rate of rainfall on an area to the maximum rate of runoff. Normally ranging between zero and unity, the runoff coefficient can exceed unity in those areas where rainfall occurs in conjunction with melting snow or ice. The soil characteristics, such as porosity, permeability and whether or not it is frozen are important considerations. Another factor to consider is ground cover, such as paved, grassy or wooded. In certain areas, the coefficient depends upon the slope of the terrain. Duration of rainfall and shape of area are also important factors in special instances. Average values for different areas are listed in Table 8.

Rainfall Intensity. Rainfall intensity “ i “ is the amount of rainfall measured in inches per hour that would be expected to occur during a storm of a certain duration. The storm frequency is the time in years in which a certain storm would be expected again and is determined statistically from available rainfall data.

Several sources, such as the U. S. Weather Bureau, have published tables and graphs for various areas of the country which show the relationship between rainfall intensity, storm duration and storm frequency. To illustrate these relationships, the subsequent figures and tables are presented as examples only, and specific design information is available for most areas. For a 2-year frequency storm of 30-minute duration, the expected rainfall intensities for the United States are plotted on the map in Figure 25. These intensities could be converted to storms of other durations and frequencies by using factors as listed in Tables 9 and 10 and an intensity-duration-frequency curve constructed as shown in Figure 26.

Time of Concentration. The time of concentration at any point in a sewer system is the time required for runoff from the most remote portion of the drainage area to reach that point. The most remote portion provides the longest time of concentration but is not necessarily the most distant point in the drainage area. Since a basic assumption of the Rational Method is that all portions of the area are contributing runoff, the time of concentration is used as the storm duration in calculating the intensity. The time of concentration consists of the time of flow from the most remote portion of the drainage area to the first inlet (called the inlet time) and the time of flow from the inlet through the system to the point under consideration (called the flow time). The inlet time is affected by the rainfall intensity, topography and ground conditions. Many designers use inlet times ranging from a minimum of 5 minutes for densely developed areas with closely spaced inlets to a maximum of 30 minutes for flat residential areas with widely spaced inlets. If the inlet time exceeds 30 minutes, then a detailed analysis is required because a very small inlet time will result in an overdesigned system while conversely for a very long inlet time the system will be underdesigned.

Runoff Area. The runoff area “A” is the drainage area in acres served by the storm sewer. This area can be accurately determined from topographic maps or field surveys.

SELECTION OF PIPE SIZE

Manning's Formula. Manning's formula for selecting pipe size is:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \qquad (1)$$

A constant $C_1 = \frac{1.486}{n} AR^{2/3}$ which depends only on the geometry and characteristics of the pipe enables Manning's formula to be written as:

$$Q = C_1 S^{1/2} \qquad (2)$$

Tables 3, 4, 5 and 6 for circular pipe, elliptical pipe, arch pipe, and box sections with full flow and Table A-1 in the Appendix for values of C_1 and $S^{1/2}$ respectively are used to solve formula (2). Graphical solutions of Manning's formula (1) are presented in Figures 2 through 5 for circular pipe, and Figures 6 through 19 for horizontal elliptical pipe, vertical elliptical pipe, arch pipe and box sections under full flow conditions.

Partial flow problems can be solved with the proportionate relationships plotted in Figure 20 through 24.

Manning's "*n*" Value. The difference between laboratory test values of Manning's "*n*" and accepted design values is significant. Numerous tests by public and other agencies have established Manning's "*n*" laboratory values. However, these laboratory results were obtained utilizing clean water and straight pipe sections without bends, manholes, debris, or other obstructions. The laboratory results indicated the only differences were between smooth wall and rough wall pipes. Rough wall, or corrugated pipe, have relatively high "*n*" values which are approximately 2.5 to 3 times those of smooth wall pipe.

All smooth wall pipes, such as concrete and plastic, were found to have "*n*" values ranging between 0.009 and 0.010, but, historically, engineers familiar with sewers have used 0.012 or 0.013. This "design factor" of 20-30 percent takes into account the difference between laboratory testing and actual installed conditions. The use of such design factors is good engineering practice, and, to be consistent for all pipe materials, the applicable Manning's "*n*" laboratory value should be increased a similar amount in order to arrive at design values.

DETERMINATION OF FLOW VELOCITY

Minimum Velocity. The debris entering a storm sewer system will generally have a higher specific gravity than sanitary sewage, therefore a minimum velocity of 3 feet per second is usually specified. The pipe slopes required to maintain this velocity can be calculated from Table 7 or by solving Manning's formula using Figures 2 through 19.

Maximum Velocity. Tests have indicated that concrete pipe can carry clear water of extremely high velocities without eroding. Actual performance records of storm sewers on grades up to 45 percent and carrying high percentages of solids indicate that erosion is seldom a problem with concrete pipe.

EXAMPLE PROBLEMS

EXAMPLE 2 - 1

STORM SEWER FLOW

Given: The inside diameter of a circular concrete pipe storm sewer is 48 inches, "*n*" = 0.012 and slope is 0.006 feet per foot.

Find: The full flow capacity, "Q".

Solution: The problem can be solved using Figure 4 or Table 3.

Figure 4 The slope for the sewer is 0.006 feet per foot or 0.60 feet per 100 feet. Find this slope on the horizontal axis. Proceed verticaly along the 0.60 line to the intersection of this line and the curve labelled 48 inches. Proceed horizontally to the vertical axis and read Q = 121 cubic feet per second.

Table 3 Enter Table 3 under the column *n* = 0.012 for a 48-inch diameter pipe and find C_1, = 1556. For S = 0.006, find $S^{1/2}$ = 0.07746 in Table A-1. Then Q = 1556 X 0.07746 or 121 cubic feet per second.

Answer: Q = 121 cubic feet per second.

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EXAMPLE 2 - 2

REQUIRED SANITARY SEWER SIZE

Given: A concrete pipe sanitary sewer with "*n*" = 0.013, slope of 0.6 percent and required full flow capacity of 110 cubic feet per second.

Find: Size of circular concrete pipe required.

Solution: This problem can be solved using Figure 5 or Table 3.

Figure 5 Find the intersection of a horizontal line through Q = 110 cubic feet per second and a slope of 0.60 feet per 100 feet. The minimum size sewer is 48 inches.

Table 3 For Q = 110 cubic feet per second and $S^{1/2}$ = 0.07746

$$C_1 = \frac{Q}{S^{1/2}} = \frac{110}{0.07746} = 1420$$

In the table, 1436 is the closest value of C_1, equal to or larger than 1420, so the minimum size sewer is 48 inches.

Answer: A 48-inch diameter circular pipe would have more than adequate capacity.

EXAMPLE 2 - 3
STORM SEWER MINIMUM SLOPE

Given: A 48-inch diameter circular concrete pipe storm sewer, "*n*" = 0.012 and flowing one-third full.

Find: Slope required to maintain a minimum velocity of 3 feet per second.

Solution: Enter Figure 20 on the vertical scale at Depth of Flow = 0.33 and project a horizontal line to the curved line representing velocity. On the horizontal scale directly beneath the point of intersection read a value of 0.81 which represents the proportional value to full flow.

$$\frac{V}{V_{full}} = 0.81$$

$$V_{full} = \frac{V}{0.81}$$

$$= \frac{3}{0.81}$$

$$= 3.7$$

Enter Figure 4 and at the intersection of the line representing 48-inch diameter and the interpolated velocity line of 3.7 read a slope of 0.088 percent on the horizontal scale.

Answer: The slope required to maintain a minimum velocity of 3 feet per second at one-third full is 0.088 percent.

EXAMPLE 2 - 4
SANITARY SEWER DESIGN

General: A multi-family housing project is being developed on 350 acres of rolling to flat ground. Zoning regulations establish a population density of 30 persons per acre. The state Department of Health specifies 100 gallons per capita per day as the average and 500 gallons per capita per day as the peak domestic sewage flow, and an infiltration allowance of 500 gallons per acre per day.

Circular concrete pipe will be used, "*n*"= 0.013, designed to flow full at peak load with a minimum velocity of 2 feet per second at one-third peak flow. Maximum spacing between manholes will be 400 feet.

Given: Population Density = 30 persons per acre
Average Flow = 100 gallons per capita per day
Peak Flow = 500 gallons per capita per day
Infiltration = 500 gallons per acre per day
Manning's Roughness = 0.0 13 *(See discussion of Manning's Coefficient "n" Value)*
Minimum Velocity = 2 feet per second @ 1/3 peak flow

Find: Design the final 400 feet of pipe between manhole Nos. 20 and 21, which serves 58 acres in addition to carrying the load from the previous pipe which serves the remaining 292 acres.

Solution: 1. Design Flow

Population-Manhole 1 to 20 = 30 X 292 = 8760
Population-Manhole 20 to 21 = 30 X 58 = 1740
Total population 10,500 persons
Peak flow-Manhole
1 to 20 = 500 X 8760 = 4,380,000 gallons per day
Infiltration-Manhole
1 to 20 - 500 X 292 = 146,000 gallons per day
Peak flow-Manhole
20 to 21 = 500 X 1740 = 870,000 gallons per day
Infiltration-Manhole
20 to 21 = 500 X 58 = 29,000 gallons per day

Total Peak flow = 5,425,000 gallons per day
use 5,425,000 gallons per day or 8.4 cubic feet per second

2. Selection of Pipe Size

In designing the sewer system, selection of pipe begins at the first manhole and proceeds downstream. The section of pipe preceding the final section is an 18-inch diameter, with slope = 0.0045 feet per foot. Therefore, for the final section the same pipe size will be checked and used unless it has inadequate capacity, excessive slope or inadequate velocity.

Enter Figure 5, from Q = 8.4 cubic feet per second on the vertical scale project a horizontal line to the 18-inch diameter pipe, read velocity = 4.7 feet per second.

From the intersection, project a vertical line to the horizontal scale, read slope = 0.63 feet per 100 feet.

3. Partial Flow

Enter Figure 20, from Proportion of Value for Full Flow = 0.33 on the horizontal scale project a line vertically to “flow” curve, from intersection project a line horizontally to “velocity” curve, from intersection project a line vertically to horizontal scale, read Proportion of Value for Full Flow - 0.83.

Velocity at minimum flow = 0.83 X 4.7 = 3.9 feet per second.

Answer: Use 18-inch diameter concrete pipe with slope of 0.0063 feet per foot.

The preceding computations are summarized in the following tabular forms, Illustrations 2.1 and 2.2.

Illustration 2.1 - Population and Flow

Manhole No.	DRAINAGE AREA			PEAK-FLOW - MGD					Cum. Flow cfs.
	Zoning	Acres	Ultimate Population	Domestic	Indus-trial	Infil-tration	Total	Cum. Total	
19	From Preceeding Computations							4.53	7.0
20	Multi-family	58	1740	.087	–	0.03	0.90	5.43	8.4
21	Trunk Sewer Interceptor Manhole								

Illustration 2.2 - Sanitary Sewer Design Data

Manhole		Flow cfs	SEWER					Manhole Flow-line Elevations	
No.	Sta.		Length ft.	Slope ft./ft.	Pipe Dia. in.	Velocity fps	Fall ft.	In	Out
19	46	7.0							389.51
20	50	8.4	400	0.0045	18	4.0	1.80	387.71	387.71
21	54		400	0.0063	18	4.7	2.52	385.19	

EXAMPLE 2 - 5
STORM SEWER DESIGN

General: A portion of the storm sewer system for the multi-family development is to serve a drainage area of about 30 acres. The state Department of Health specifies a 10-inch diameter minimum pipe size.

Circular concrete pipe will be used,”n” = 0.011, with a minimum velocity of 3 feet per second when flowing full. Minimum time of concentration is 10 minutes with a maximum spacing between manholes of 400 feet.

Given:

Drainage Area	A = 30 acres (total)
Runoff Coefficient	C = 0.40
Rainfall Intensity	i as shown in Figure 26
Roughness Coefficient	n = 0.0 11 (See discussion of Manning’s “n” Value)
Velocity	V = 3.0 feet per second (minimum at full flow)

Find: Design of the storm system as shown in Illustration 2.3, “Plan for Storm Sewer Example,” adapted from “Design and Construction of Concrete Sewers,” published by the Portland Cement Association.

Solution: The hydraulic properties of the storm sewer will be entered as they are determined on the example form Illustration 2.4, “Computation Sheet for Hydraulic Properties of Storm Sewer.” The design of the system begins at the upper manhole and proceeds downstream.

The areas contributing to each manhole are determined, entered incrementally in column 4, and as cumulative totals in column 5. The initial inlet time of 10 minutes minimum is entered in column 6, line 1, and from Figure 26 the intensity is found to be 4.2 inches per hour which is entered in column 8, line 1. Solving the Rational formula, Q = 1.68 cubic feet per second is entered in column 9, line 1. Enter Figure 3, for V = 3 feet per second and Q = 1.68 cubic feet per second, the 10-inch diameter pipe requires a slope = 0.39 feet per 100 feet. Columns 10, 12, 13, 14, 15 and 16, line 1, are now filled in. The flow time from manhole 7 to 6 is found by dividing the length (300 feet) between manholes by the velocity of flow (3 feet per second) and converting the answers to minutes (1.7 minutes) which is entered in column 7, line 1. This time increment is added to the 10-minute time of concentration for manhole 7 to arrive at 11.7 minutes time of concentration for manhole 6 which is entered in column 6, line 2.

From Figure 26, the intensity is found to be 4.0 inches per hour for a time of concentration of 11.7 minutes which is entered in column 8, line 2. The procedure outlined in the preceding paragraph is repeated for each section of sewer as shown in the table.

Answer: The design pipe sizes, slopes and other properties are as indicated in Illustration 2.4.

Illustration 2.3-Plan for Storm Sewer Example

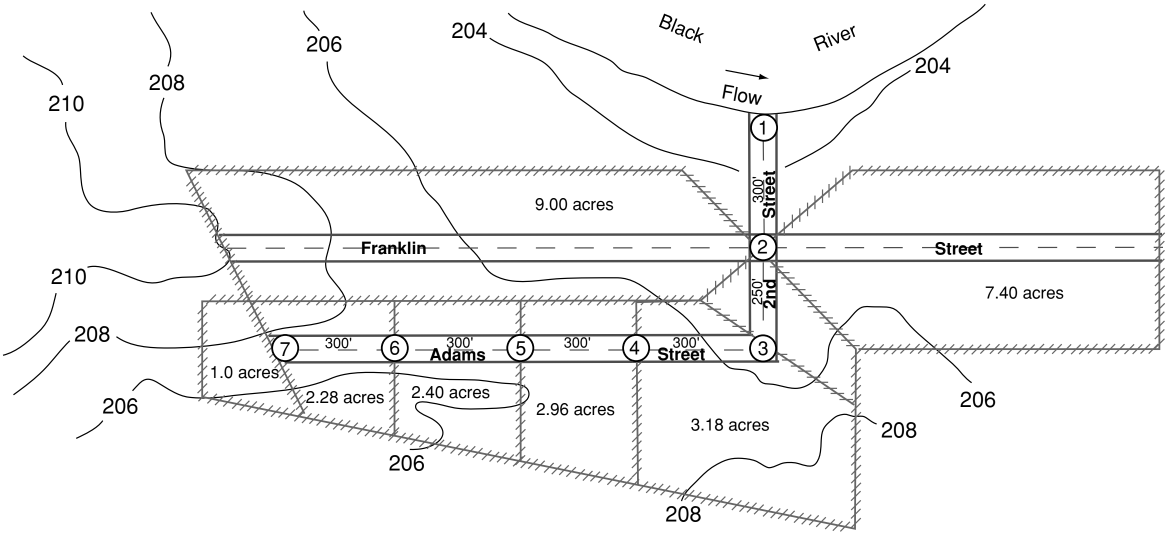


Illustration 2.4-Computation Sheet for Hydraulic Properties of Storm Sewer

	SEWER LOCATION			TRIBUTARY AREA		TIME OF FLOW (minutes)				SEWER DESIGN					PROFILE	
															Elevation of Invert	
Line Number	Street	From M. H.	To M. H.	Increments Acres	Total Acres A	To Upper End	In Section	Rate of Rainfall (in. per hour) *i*	Runoff (cfs.) Q	Slope (ft. per 100 ft.)	Diameter (in.)	Capacity (cfs.)	Velocity (fps.)	Length (ft.)	Upper End	Lower End
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Adams	7	6	1.00	1.00	10.0	1.7	4.2	1.68	0.39	10	1.7	3.0	300	200.00	198.83
2	Adams	6	5	2.28	3.28	11.7	1.7	4.0	5.25	0.18	18	5.3	3.0	300	198.16	197.62
3	Adams	5	4	2.40	5.68	13.4	1.3	3.8	8.63	0.23	21	8.65	3.8	300	197.37	196.68
4	Adams	4	3	2.96	8.64	14.7	1.2	3.7	12.0	0.23	24	13.0	4.1	300	196.43	195.74
5	2nd	3	2	3.18	11.82	15.9	0.9	3.6	17.0	0.23	27	17.0	4.5	250	195.49	194.91
6	2nd	2	1	17.84	29.66	16.8	-	3.5	41.6	0.30	36	42.0	6.1	300	194.41	193.51

EXAMPLE 2 - 6
SANITARY SEWER DESIGN

Given: A concrete box section sanitary sewer with "*n*" = 0.013, slope of 1.0% and required full flow capacity of 250 cubic feet per second.

Find: Size of concrete box section required for full flow.

Solution: This problem can be solved using Figure 19 or Table 6.

Figure 19 Find the intersection of a horizontal line through Q = 250 cubic feet per second and a slope of 1.0 feet per 100 feet. The minimum size box section is either a 6 foot span by 4 foot rise or a 5 foot span by 5 foot rise.

Table 6 For Q = 250 cubic feet per second and $S^{1/2} = 0.\ 100$

$$C_1 = \frac{Q}{S^{1/2}} = \frac{250}{0.100} = 2{,}500$$

In Table 6, under the column headed *n* = 0.013, 3,338 is the first value of C_1, equal to or larger than 2,500, therefore a box section with a 5 foot span X a 5 foot rise is adequate. Looking further in the same column, a box section with a 6 foot span and a 4 foot rise is found to have a C_1, value of 3,096, therefore a 6 X 4 box section is also adequate.

Answer: Either a 5 foot X 5 foot or a 6 foot X 4 foot box section would have a full flow capacity equal to or greater than Q = 250 cubic feet per second.

CHAPTER 3

HYDRAULICS OF CULVERTS

The hydraulic design procedure for culverts requires:

1. Determination of Design Flow
2. Selection of Culvert Size
3. Determination of Outlet Velocity

DETERMINATION OF DESIGN FLOW

The United States Geological Survey has developed a nationwide series of water-supply papers titled the “Magnitude and Frequency of Floods in the United States.” These reports contain tables of maximum known floods and charts for estimating the probable magnitude of floods of frequencies ranging from 1. 1 to 50 years. Table 11 indicates the Geological Survey regions, USGS district and principal field offices and the applicable water-supply paper numbers. Most states have adapted and consolidated those parts of the water-supply papers which pertain to specific hydrologic areas within the particular state. The hydrologic design procedures developed by the various states enable quick and accurate determination of design flow. It is recommended that the culvert design flow be determined by methods based on USGS data.

If USGS data are not available for a particular culvert location, flow quantities may be determined by the Rational Method or by statistical methods using records of flow and runoff. An example of the latter method is a nomograph developed by California and shown in Figure 27.

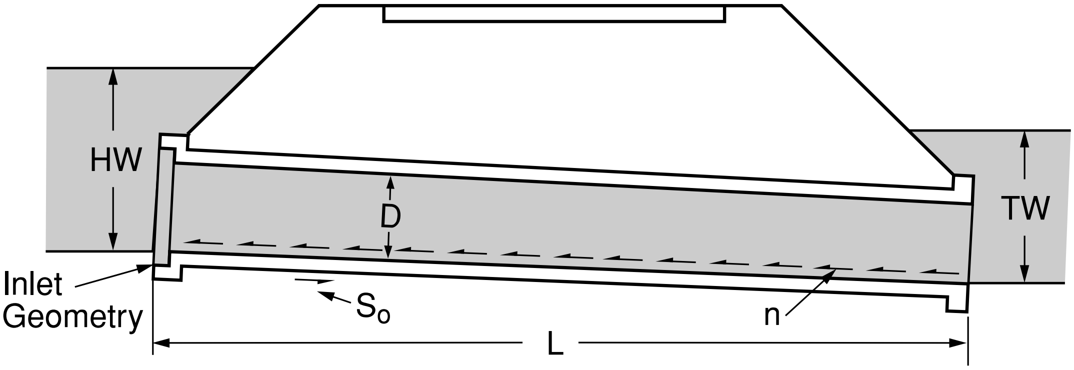
FACTORS AFFECTING CULVERT DISCHARGE

Factors affecting culvert discharge are depicted on the culvert cross section shown in Illustration 3.1 and are used in determining the type of discharge control.

Inlet Control. The control section is located at or near the culvert entrance, and, for any given shape and size of culvert, the discharge is dependent only on the inlet geometry and headwater depth. Inlet control will exist as long as water can flow through the barrel of the culvert at a greater rate than water can enter the inlet. Since the control section is at the inlet, the capacity is not affected by any hydraulic factors beyond the culvert entrance such as slope, length or surface roughness. Culverts operating under inlet control will always flow partially full.

Illustration 3.1 - Factors Affecting Culvert Discharge

D = Inside diameter for circular pipe
HW = Headwater depth at culvert entrance
L = Length of culvert
n = Surface roughness of the pipe wall, usually expressed in terms of Manning's n
S_o = Slope of the culvert pipe
TW = Tailwater depth at culvert outlet



Outlet Control. The control section is located at or near the culvert outlet and for any given shape and size of culvert, the discharge is dependent on all of the hydraulic factors upstream from the outlet such as shape, slope, length, surface roughness, tailwater depth, headwater depth and inlet geometry. Outlet control will exist as long as water can enter the culvert at a greater rate than water can flow through it. Culverts operating under outlet control can flow either full or partially full.

Critical Depth. Critical flow occurs when the sum of the kinetic energy (velocity head) plus the potential energy (static or depth head equal to the depth of the flow) for a given discharge is at a minimum. Conversely, the discharge through a pipe with a given total energy head will be maximum at critical flow. The depth of the flow at this point is defined as critical depth, and the slope required to produce the flow is defined as critical slope. Capacity of a culvert with an unsubmerged outlet will be established at the point where critical flow occurs. Since under inlet control, the discharge of the culvert is not reduced by as many hydraulic factors as under outlet control, for a given energy head, a culvert will have maximum possible discharge if it is operating at critical flow with inlet control. The energy head at the inlet control section is approximately equal to the head at the inlet minus entrance losses. Discharge is not limited by culvert roughness or outlet conditions but is dependent only on the shape and size of the culvert entrance. Although the discharge of a culvert operating with inlet control is not related to the pipe roughness, the roughness does determine the minimum slope (critical slope) at which inlet control will occur. Pipe with a smooth interior can be installed on a very flat slope and still have inlet control. Pipe with a rough interior must be installed on a much steeper slope to have inlet control. Charts of critical depth for various pipe and box section sizes and flows are shown in Figures 28 through 32.

SELECTION OF CULVERT SIZE

The many hydraulic design procedures available for determining the required size of a culvert vary from empirical formulas to a comprehensive mathematical analysis. Most empirical formulas, while easy to use, do not lend themselves to proper evaluation of all the factors that affect the flow of water through a culvert. The mathematical solution, while giving precise results, is time consuming. A systematic and simple design procedure for the proper selection of a culvert size is provided by Hydraulic Engineering Circular No. 5, "Hydraulic Charts for the Selection of Highway Culverts" and No. 10, "Capacity Charts for the Hydraulic Design of Highway Culverts," developed by the Bureau of Public Roads. The procedure when selecting a culvert is to determine the headwater depth from the charts for both assumed inlet and outlet controls. The solution which yields the higher headwater depth indicates the governing control. When this procedure is followed, Inlet Control Nomographs, Figures 33 through 37, and Outlet Control Nomographs, Figures 38 through 41, are used.

An alternative and simpler method is to use the Culvert Capacity Charts, Figures 42 through 145. These charts are based on the data given in Circular No. 5 and enable the hydraulic solution to be obtained directly without using the double solution for both inlet and outlet control required when the nomographs are used.

Culvert Capacity Chart Procedure. The Culvert Capacity Charts are a convenient tool for selection of pipe sizes when the culvert is installed with conditions as indicated on the charts. The nomographs must be used for other shapes, roughness coefficients, inlet conditions or submerged outlets.

List Design Data

A. Design discharge Q, in cubic feet per second, with average return period (i.e., Q_{25} or Q_{50}, etc.).
B. Approximate length L of culvert, in feet.
C. Slope of culvert.
D. Allowable headwater depth, in feet, which is the vertical distance from the culvert invert (flow line) at the entrance to the water surface elevation permissible in the headwater pool or approach channel upstream from the culvert.
E. Mean and maximum flood velocities in natural stream.
F. Type of culvert for first trial selection, including barrel cross sectional shape and entrance type.

Select Culvert Size

A. Select the appropriate capacity chart, Figures 42 to 145, for the culvert size approximately equal to the allowable headwater depth divided by 2.0.
B. Project a vertical line from the design discharge Q to the inlet control curve. From this intersection project a line horizontally and read the headwater depth on the vertical scale. If this headwater depth is more than the allowable, try the next larger size pipe. If the headwater depth is

less than the allowable, check the outlet control curves.

C. Extend the vertical line from the design discharge to the outlet control curve representing the length of the culvert. From this intersection project a line horizontally and read the headwater depth plus S_oL on the vertical scale. Subtract S_oL from the outlet control value to obtain the headwater depth. If the headwater depth is more than the allowable, try the next larger size pipe. If the headwater depth is less than the allowable, check the next smaller pipe size following the same procedure for both inlet control and outlet control.

D. Compare the headwater depths for inlet and outlet control. The higher headwater depth indicates the governing control.

Determine Outlet Velocity

A. If outlet control governs, the outlet velocity equals the flow quantity divided by the flow cross sectional area at the outlet. Depending upon the tailwater conditions, this flow area will be between that corresponding to critical depth and the full area of the pipe. If the outlet is not submerged, it is usually sufficiently accurate to calculate the flow area based on a depth of flow equal to the average of the critical depth and the vertical height of the pipe.

B. If inlet control governs, the outlet velocity may be approximated by Manning's formula using Figures 2 through 19 for full flow values and Figures 20 through 24 for partial flow values.

Record Selection

Record final selection of culvert with size, type, required headwater and outlet velocity.

Nomograph Procedure. The nomograph procedure is used for selection of culverts with entrance conditions other than projecting or for submerged outlets.

List Design Data

A. Design discharge Q, in cubic feet per second, with average return period (i.e., Q_{25} or $Q,_{50}$, etc.).

B. Approximate length *L* of culvert, in feet.

C. Slope of culvert.

D. Allowable headwater depth, in feet, which is the vertical distance from the culvert invert (flow line) at the entrance to the water surface elevation permissible in the headwater pool or approach channel upstream from the culvert.

E. Mean and maximum flood velocities in natural stream.

F. Type of culvert for first trial selection, including barrel cross sectional shape and entrance type.

Select Trial Culvert Size

Select a trial culvert with a rise or diameter equal to the allowable headwater divided by 2.0.

Find Headwater Depth for Trial Culvert

A. Inlet Control

(1) Given Q, size and type of culvert, use appropriate inlet control nomograph Figures 33 through 37 to find headwater depth:

(a) Connect with a straightedge the given culvert diameter or height (D) and the discharge Q; mark intersection of straightedge on HW/D scale marked (1).

(b) HW/D scale marked (1) represents entrance type used, read HW/D on scale (1). If another of the three entrance types listed on the nomograph is used, extend the point of intersection in (a) horizontally to scale (2) or (3) and read HW/D.

(c) Compute HW by multiplying HW/D by D.

(2) If HW is greater or less than allowable, try another trial size until HW is acceptable for inlet control.

B. Outlet Control

(1) Given Q, size and type of culvert and estimated depth of tailwater TW, in feet, above the invert at the outlet for the design flood condition in the outlet channel:

(a) Locate appropriate outlet control nomograph (Figures 38 through 41) for type of culvert selected. Find k_e, for entrance type from Table 12.

(b) Begin nomograph solution by locating starting point on length scale for proper k_e.

(c) Using a straightedge, connect point on length scale to size of culvert barrel and mark the point of crossing on the “turning line.”

(d) Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale.

(2) For tailwater TW elevation equal to or greater than the top of the culvert at the outlet set h_o equal to TW and find HW by the following equation:

$$HW = H + h_o - S_oL \qquad (3)$$

(3) For tailwater TW elevations less than the top of the culvert at the outlet, use $h_o = \frac{d_c + D}{2}$ or TW, whichever is the greater, where d_c, the critical depth in feet is determined from the appropriate critical depth chart (Figures 28 through 32).

C. Compare the headwaters found in paragraphs A *(Inlet Control)* and B *(Outlet Control)*. The higher headwater governs and indicates the flow control existing under the given conditions for the trial size selected.
D. If outlet control governs and the HW is higher than acceptable, select a larger trial size and find HW as instructed under paragraph B. Inlet control need not be checked, if the smaller size was satisfactory for this control as determined under paragraph A.

Try Another Culvert

Try a culvert of another size or shape and repeat the above procedure.

Determine Outlet Velocity

A. If outlet control governs, the outlet velocity equals the flow quantity divided by the flow cross sectional area at the outlet. Depending upon the tailwater conditions, this flow area will be between that corresponding to critical depth and the full area of the pipe. If the outlet is not submerged, it is sufficiently accurate to calculate flow area based on a depth of flow equal to the average of the critical depth and vertical height of the pipe.
B. If inlet control governs, the outlet velocity may be approximated by Manning's formula using Figures 2 through 19 for full flow values and Figures 20 through 24 for partial flow values.

Record Selection

Record final selection of culvert with size, type, required headwater and outlet velocity.

EXAMPLE PROBLEMS

EXAMPLE 3 - I

CULVERT CAPACITY CHART PROCEDURE

List Design Data

A. Q_{25} = 180 cubic feet per second
   Q_{50} = 225 cubic feet per second
B. L = 200 feet
C. S_o = 0.01 feet per foot
D. Allowable HW = 10 feet for 25 and 50-year storms
E. TW = 3.5 feet for 25-year storm
   TW = 4.0 feet for 50-year storm
F. Circular concrete culvert with a projecting entrance, *n* = 0.0 12

Select Culvert Size

A. Try $D = \frac{HW}{2.0} = \frac{10}{2.0}$ = 5 feet or 60 inch diameter as first trial size.
B. In Figure 54, project a vertical line from Q = 180 cubic feet per second

to the inlet control curve and read horizontally HW = 6.2. Since HW = 6.2 is considerably less than the allowable try a 54 inch diameter.
In Figure 53, project a vertical line from Q = 180 cubic feet per second to the inlet control curve and read horizontally HW = 7.2 feet.
In Figure 53, project a vertical line from Q = 225 cubic feet per second to the inlet control curve and read horizontally HW = 9.6 feet.

C. In Figure 53, extend the vertical line from Q = 180 cubic feet per second to the L = 200 feet outlet control curve and read horizontally HW + S_oL = 8.0 feet.
In Figure 53, extend the vertical line from Q = 225 cubic feet per second to the L = 200 feet outlet control curve and read horizontally HW + S_oL = 10.2 feet.
S_oL = 0.01 X 200 = 2.0 feet.
Therefore HW = 8.0 - 2.0 = 6.0 feet for 25-year storm
HW = 10.2 - 2.0 = 8.2 feet for 50-year storm

D. Since the calculated HW for inlet control exceeds the calculated HW for outlet control in both cases, inlet control governs for both the 25 and 50-year storm flows.

Determine Outlet Velocity

B. Enter Figure 4 on the horizontal scale at a pipe slope of 0.01 feet per foot (1.0 feet per 100 feet). Project a vertical line to the line representing 54-inch pipe diameter. Read a full flow value of 210 cubic feet per second on the vertical scale and a full flow velocity of 13.5 feet per second. Calculate $\frac{Q_{50}}{Q_{Full}} = \frac{225}{210} = 1.07$.
Enter Figure 20 at 1.07 on the horizontal scale and project a vertical line to the “flow” curve. At this intersection project a horizontal line to the “velocity” curve. Directly beneath this intersection read $\frac{V_{50}}{V_{Full}} = 1.12$ on the horizontal scale. Calculate $V_{50} = 1.12\ V_{Full} = 1.12$ X 13.5 = 15.1 feet per second.

Record Selection

Use a 54-inch diameter concrete pipe with allowable HW = 10.0 feet and actual HW = 7.2 and 9.6 feet respectively for the 25 and 50 year storm flows, and a maximum outlet velocity of 15.1 feet per second.

EXAMPLE 3 - 2

NOMOGRAPH PROCEDURE

List Design Data

A. Q_{25} = 180 cubic feet per second
   Q_{50} = 225 cubic feet per second

B. L = 200 feet

C. S_o = 0.01 feet per foot

D. Allowable HW = 10 feet for 25 and 50-year storms

E. TW = 3.5 feet for 25-year storm
   TW = 4.0 feet for 50-year storm

F. Circular concrete culvert with a projecting entrance, *n* = 0.012

Select Trial Culvert Size

$$D = \frac{HW}{2.0} = \frac{10}{2.0} = 5 \text{ feet}$$

Determine Trial Culvert Headwater Depth

A. Inlet Control

(1) For Q = 180 cubic feet per second and D = 60 inches, Figure 33 indicates HW/D = 1.25. Therefore HW = 1.25 X 5 =6.2 feet.

(2) Since HW = 6.2 feet is considerably less than allowable try a 54-inch pipe.
For Q = 180 cubic feet per second and D = 54 inches, Figure 33 indicates HW/D = 1.6. Therefore HW = 1.6 X 4.5 = 7.2 feet.
For Q = 225 cubic feet per second and D = 54 inches, Figure 33 indicates HW/D = 2.14. Therefore HW 2.14 X 4.5 = 9.6 feet.

B. *Outlet Control*

(I) TW = 3.5 and 4.0 feet is less than D = 4.5 feet.

(3) Table 12, k_e, = 0.2.
For D = 54 inches, Q = 180 cubic feet per second, Figure 28 indicates d_c, 3.9 feet which is less than D = 4.5 feet. Calculate

$$h_o = \frac{d_c + D}{2} = \frac{3.9 + 4.5}{2} = 4.2 \text{ feet.}$$

For D = 54 inches, Q = 180 cubic feet per second, k_e. = 0.2 and L = 200 feet.
Figure 38 indicates H = 3.8 feet.
Therefore HW = 3.8 + 4.2 - (0.01 X 200) = 6.0 feet (Equation 3).
For D = 54 inches, Q = 225 cubic feet per second, Figure 28 indicates d_c, = 4.2 feet which is less than D = 4.5 feet. Calculate

$$h_o = \frac{d_c + D}{2} = \frac{4.2 + 4.5}{2} = 4.3 \text{ feet.}$$

For D = 54 inches, Q = 225 cubic feet per second, k_e, = 0.2 and L = 200 feet.
Figure 38 indicates H = 5.9 feet.
Therefore HW = 5.9 + 4.3 - (0.01 X 200) = 8.2 feet (Equation 3).

C. Inlet control governs for both the 25 and 50-year design flows.

Try Another Culvert

A 48-inch culvert would be sufficient for the 25-year storm flow but for the 50-year storm flow the HW would be greater than the allowable.

Determine Outlet Velocity

B. Enter Figure 4 on the horizontal scale at a pipe slope of 0.01 feet per foot (1.0 feet per 100 feet). Project a vertical line to the line representing 54-inch pipe diameter. Read a full flow value of 210 cubic feet per second on the vertical scale and a full flow velocity of 13.5 feet per second. Calculate

$$\frac{Q_{50}}{Q_{Full}} = \frac{225}{210} = 1.07.$$

Enter Figure 20 at 1.07 on the horizontal scale and project a vertical line to the "flow" curve. At this intersection project a horizontal line to the "velocity" curve. Directly beneath this intersection read $\frac{V_{50}}{V_{Full}}$ = 1.12 on the horizontal scale. Calculate V_{50} = 1.12 V_{Full} = 1.12 X 13.5 = 15.1 feet per second.

Record Selection

Use a 54-inch diameter concrete pipe with allowable HW = 10.0 feet and actual HW = 7.2 and 9.6 feet respectively for the 25 and 50-year storm flows, and a maximum outlet velocity of 15.1 feet per second.

EXAMPLE 3 - 3

CULVERT DESIGN

General: A highway is to be constructed on embankment over a creek draining 400 acres. The embankment will be 41-feet high with 2:1 side slopes and a top width of 80 feet. Hydraulic design criteria requires a circular concrete pipe, *n* = 0.012, with the inlet projecting from the fill. To prevent flooding of upstream properties, the allowable headwater is 10.0 feet, and the design storm frequency is 25 years.

Given:	Drainage Area	A = 400 acres
	Roughness Coefficient	n = 0.012 *(See discussion of Manning's "n" Value)*
	Headwater	HW = 10 feet (allowable)

Find: The required culvert size.

Solution: 1. *Design Flow*

The design flow for 400 acres should be obtained using USGS data. Rather than present an analysis for a specific area, the design flow will be assumed as 250 cubic feet per second for a 25-year storm.

2. Selection of Culvert Size

The culvert will be set on the natural creek bed which has a one percent slope. A cross sectional sketch of the culvert and embankment indicates a culvert length of about 250 feet. No flooding of the outlet is expected.

Trial diameter HW/D = 2.0 feet $D = \frac{10}{2} = 5$ feet.

Enter Figure 54, from Q = 250 cubic feet per second project a line vertically to the inlet control curve, read HW = 8.8 feet on the vertical scale. Extend the vertical line to the outlet control curve for L = 250 feet, read $H + S_oL = 9.6$ on the vertical scale. $S_oL = 250 \times 0.01 = 2.5$ feet. Therefore, outlet control HW = 9.6 - 2.5 = 7.1 feet and inlet control governs.

Enter Figure 53, from Q = 250 cubic feet per second project a line vertically to the inlet control curve, read HW = 10.8 feet which is greater than the allowable.

3. *Determine Outlet Velocity*

For inlet control, the outlet velocity is determined from Manning's formula. Entering Figure 4, a 60-inch diameter pipe with S_o = 1.0 foot per 100 feet will have a velocity = 14.1 feet per second flowing full and a capacity of 280 cubic feet per second.

Enter Figure 20 with a Proportion of Value for Full Flow = $\frac{250}{280}$ or 0.9, read Depth of Flow = 0.74 and Velocity Proportion = 1.13. Therefore, outlet velocity = 1.13 X 14.1 = 15.9 feet per second.

Answer: A 60-inch diameter circular pipe would be required.

EXAMPLE 3 - 4

CULVERT DESIGN

General: An 800-foot long box culvert with an *n* = 0.012 is to be installed on a 0.5% slope. Because utility lines are to be installed in the embankment above the box culvert, the maximum rise is limited to 8 feet. The box section is required to carry a maximum flow of

1,000 cubic feet per second with an allowable headwater depth of 15 feet.

List Design Data

A. $Q = 1{,}000$ cubic feet per second
B. $L = 800$ feet
C. $S_o = 0.5\% = 0.005$ feet per foot
D. Allowable HW = 15 feet
E. Box culvert with projecting entrance and $n = 0.012$

Select Culvert Size

Inspecting the box section culvert capacity charts for boxes with rise equal to or less than 8 feet, it is found that a 8 X 8 foot and a 9 X 7 foot box section will all discharge 1,000 cubic feet per second with a headwater depth equal to or less than 15 feet under inlet control. Therefore, each of the two sizes will be investigated.

Determine Headwater Depth

8 X 8 foot Box Section

A. *Inlet Control*

Enter Figure 124, from Q = 1,000 project a vertical line to the inlet control curve. Project horizontally to the vertical scale and read a headwater depth of 14.8 feet for inlet control.

B. *Outlet Control*

Continue vertical projection from Q = 1,000 to the outlet control curve for L = 800 feet. Project horizontally to vertical scale and read a value for $(HW + S_oL) = 17.5$ feet. Then $HW = 17.5 - S_oL = 17.5 - (0.005 \text{ X } 800) = 13.5$ feet for outlet control.

Therefore inlet control governs.

9 X 7 - foot Box Section

Entering Figure 127, and proceeding in a similar manner, find a headwater depth of 14.7 for inlet control and 13.1 feet for outlet control with inlet control governing.

Determine Outlet Velocity

Entering Table 6, find area and C_1, value for each size box section and Table A-1 find value of $S^{1/2}$ for S_o, = 0.005, then $Q_{full} = C_1S^{1/2}$.

For 8 X 8 - foot Box Section

$Q_{full} = 12700 \text{ X } 0.07071 = 898$ cubic feet per second
$V_{full} = Q/A = 899 \div 63.11 = 14.2$ feet per second.

Then

$$\frac{Q_{partial}}{Q_{full}} = \frac{1000}{899} = 1.11.$$

Entering Figure 24.9 on the horizontal scale at 1.11, project a vertical line to intersect the flow curve. From this point, proceed horizontally to the right and intersect the velocity curve. From this point drop vertically to the horizontal scale and read a value of 1.18 for $V_{partial}/V_{full}$ ratio.

Then

$V_{partial} = 1.18 \text{ X } 14.2 = 16.8$ feet per second

Proceeding in a similar manner for the 9 X 7 foot box section, Figure 24.7, find a $V_{partial} = 16.9$ feet per second.

Record Selection

Use either a 8 X 8 foot box section with an actual HW of 14.8 feet and an outlet velocity of 16.8 feet per second or a 9 X 7 foot box section with an actual HW of 14.7 feet and an outlet velocity of 16.9 feet per second.

CHAPTER 4

LOADS AND SUPPORTING STRENGTHS

The design procedure for the selection of pipe strength requires:

I . Determination of Earth Load
2. Determination of Live Load
3. Selection of Bedding
4. Determination of Bedding Factor
5. Application of Factor of Safety
6. Selection of Pipe Strength

TYPES OF INSTALLATIONS

The earth load transmitted to a pipe is largely dependent on the type of installation. Three common types are Trench, Positive Projecting Embankment, and Negative Projecting Embankment. Pipelines are also installed by jacking or tunneling methods where deep installations are necessary or where conventional open excavation and backfill methods may not be feasible. The essential features of each of these installations are shown in Illustration 4.1.

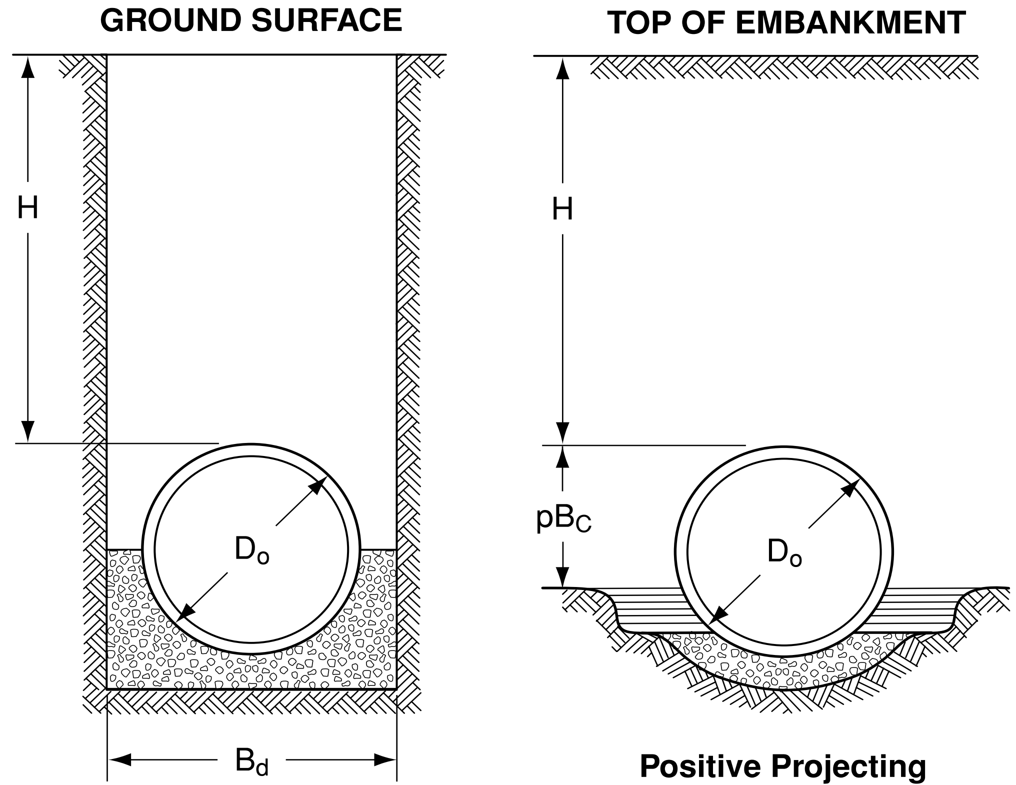
Trench. This type of installation is normally used in the construction of sewers, drains and water mains. The pipe is installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill extending to the ground surface.

Positive Projecting Embankment. This type of installation is normally used when the culvert is installed in a relatively flat stream bed or drainage path. The pipe is installed on the original ground or compacted fill and then covered by an earth fill or embankment.

Negative Projecting Embankment. This type of installation is normally used when the culvert is installed in a relatively narrow and deep stream bed or drainage path. The pipe is installed in a shallow trench of such depth that the top of the pipe is below the natural ground surface or compacted fill and then covered with an earth fill or embankment which extends above the original ground level.

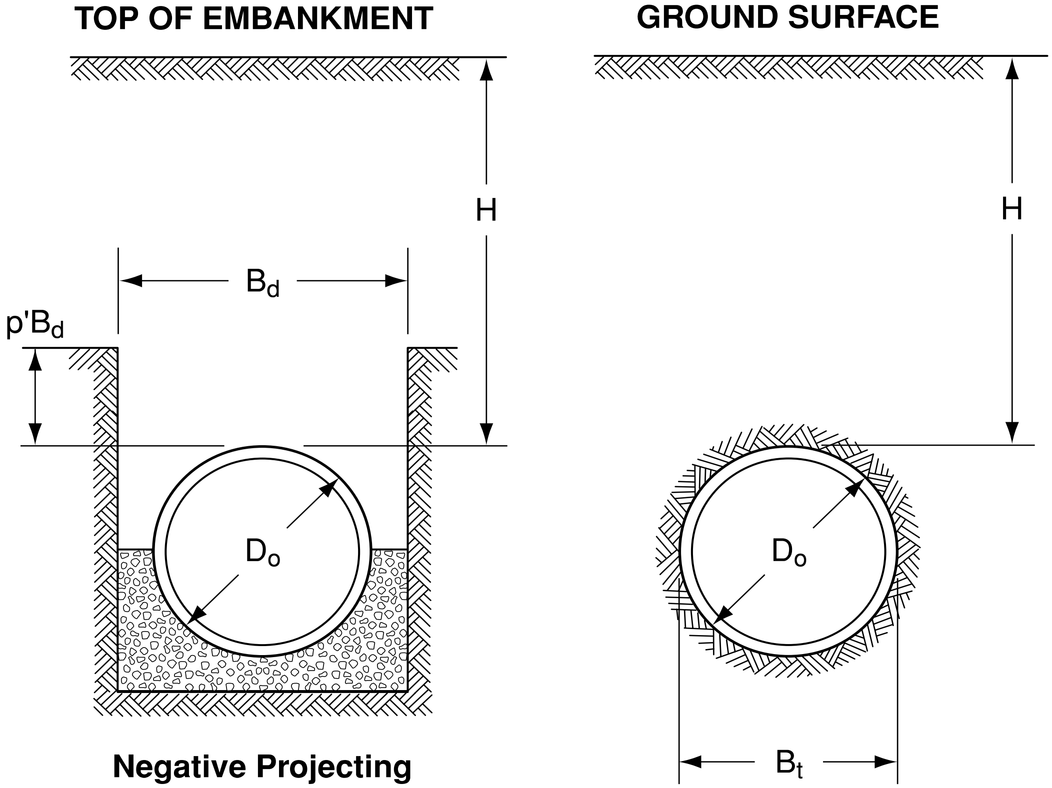
Jacked or Tunneled. This type of installation is used where surface conditions make it difficult to install the pipe by conventional open excavation and backfill methods, or where it is necessary to install the pipe under an existing embankment. A jacking pit is dug and the pipe is advanced horizontally underground.

Illustration 4.1 Essential Features of Types of Installations



Trench

Positive Projecting Embankment



Negative Projecting Embankment

Jacked or Tunneled

BACKGROUND

The classic theory of earth loads on buried concrete pipe, published in 1930 by A. Marston, was developed for trench and embankment conditions.

In later work published in 1933, M. G. Spangler presented three bedding configurations and the concept of a bedding factor to relate the supporting strength of buried pipe to the strength obtained in a three-edge bearing test.

Spangler's theory proposed that the bedding factor for a particular pipeline and, consequently, the supporting strength of the buried pipe, is dependent on two installation characteristics:

1. Width and quality of contact between the pipe and bedding.
2. Magnitude of lateral pressure and the portion of the vertical height of the pipe over which it acts.

For the embankment condition, Spangler developed a general equation for the bedding factor, which partially included the effects of lateral pressure. For the trench condition, Spangler established conservative fixed bedding factors, which neglected the effects of lateral pressure, for each of the three beddings. This separate development of bedding factors for trench and embankment conditions resulted in the belief that lateral pressure becomes effective only at trench widths equal to or greater than the transition width. Such an assumption is not compatible with current engineering concepts and construction methods. It is reasonable to expect some lateral pressure to be effective at trench widths less than transition widths. Although conservative designs based on the work of Marston and Spangler have been developed and installed successfully for years, the design concepts have their limitations when applied to real world installations.

The limitations include:

- Loads considered acting only at the top of the pipe.
- Axial thrust not considered.
- Bedding width of test installations less than width designated in his bedding configurations.
- Standard beddings developed to fit assumed theories for soil support rather than ease of and methods of construction.
- Bedding materials and compaction levels not adequately defined.

This section discusses the Standard Installations and the appropriate indirect design procedures to be used with them. The Standard Installations are the most recent beddings developed by ACPA to allow the engineer to take into consideration modern installation techniques when designing concrete pipe. For more information on design using the Marston/Spangler beddings, see Appendix B.

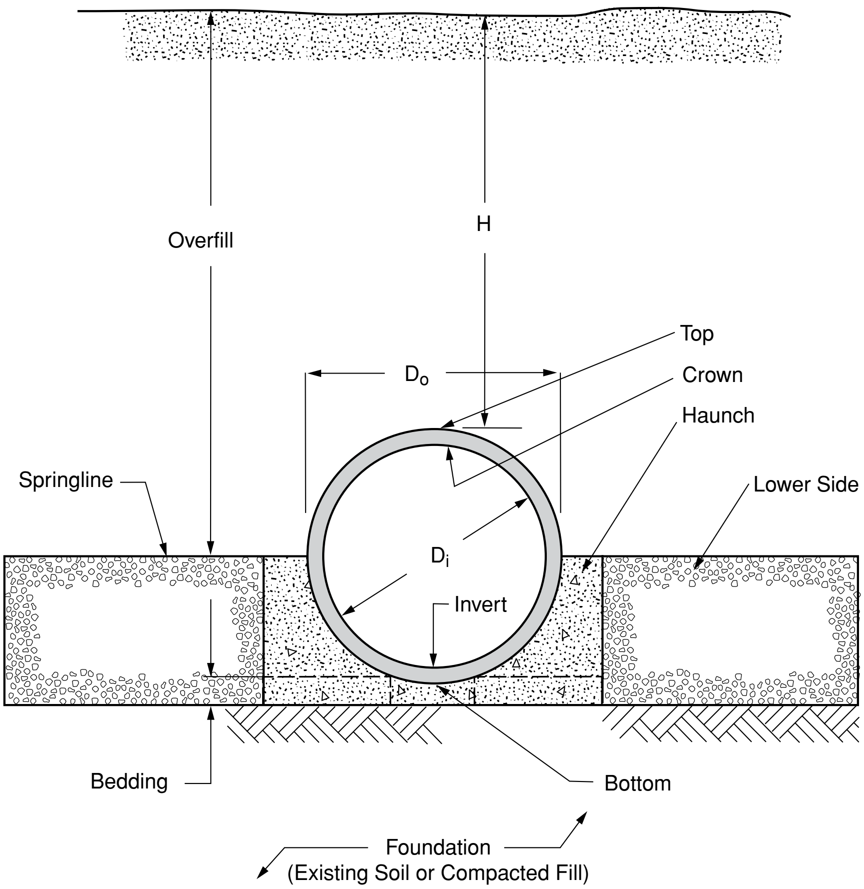
INTRODUCTION

In 1970, ACPA began a long-range research program on the interaction of buried concrete pipe and soil. The research resulted in the comprehensive finite element computer program SPIDA, Soil-Pipe Interaction Design and Analysis, for the direct design of buried concrete pipe.

Since the early 1980's, SPIDA has been used for a variety of studies, including the development of four new Standard Installations, and a simplified microcomputer design program, SIDD, Standard Installations Direct Design.

The procedure presented here replaces the historical A, B, C, and D beddings used in the indirect design method and found in the appendix of this manual, with the four new Standard Installations, and presents a state-of-the-art method for determination of bedding factors for the Standard Installations. Pipe and installation terminology as used in the Standard Installations, and this procedure, is defined in Illustration 4.2.

Illustration 4.2 Pipe/Installation Terminology



FOUR STANDARD INSTALLATIONS

Through consultations with engineers and contractors, and with the results of numerous SPIDA parameter studies, four new Standard Installations were developed and are presented in Illustration 4.4. The SPIDA studies were conducted for positive projection embankment conditions, which are the worst-case vertical load conditions for pipe, and which provide conservative results for other embankment and trench conditions.

The parameter studies confirmed ideas postulated from past experience and proved the following concepts:

- Loosely placed, uncompacted bedding directly under the invert of the pipe significantly reduces stresses in the pipe.
- Soil in those portions of the bedding and haunch areas directly under the pipe is difficult to compact.
- The soil in the haunch area from the foundation to the pipe springline provides significant support to the pipe and reduces pipe stresses.
- Compaction level of the soil directly above the haunch, from the pipe springline to the top of the pipe grade level, has negligible effect on pipe stresses. Compaction of the soil in this area is not necessary unless

required for pavement structures.

- Installation materials and compaction levels below the springline have a significant effect on pipe structural requirements.

The four Standard Installations provide an optimum range of soil-pipe interaction characteristics. For the relatively high quality materials and high compaction effort of a Type 1 Installation, a lower strength pipe is required. Conversely, a Type 4 Installation requires a higher strength pipe, because it was developed for conditions of little or no control over materials or compaction.

Generic soil types are designated in Illustration 4.5. The Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) soil classifications equivalent to the generic soil types in the Standard Installations are also presented in Illustration 4.5.

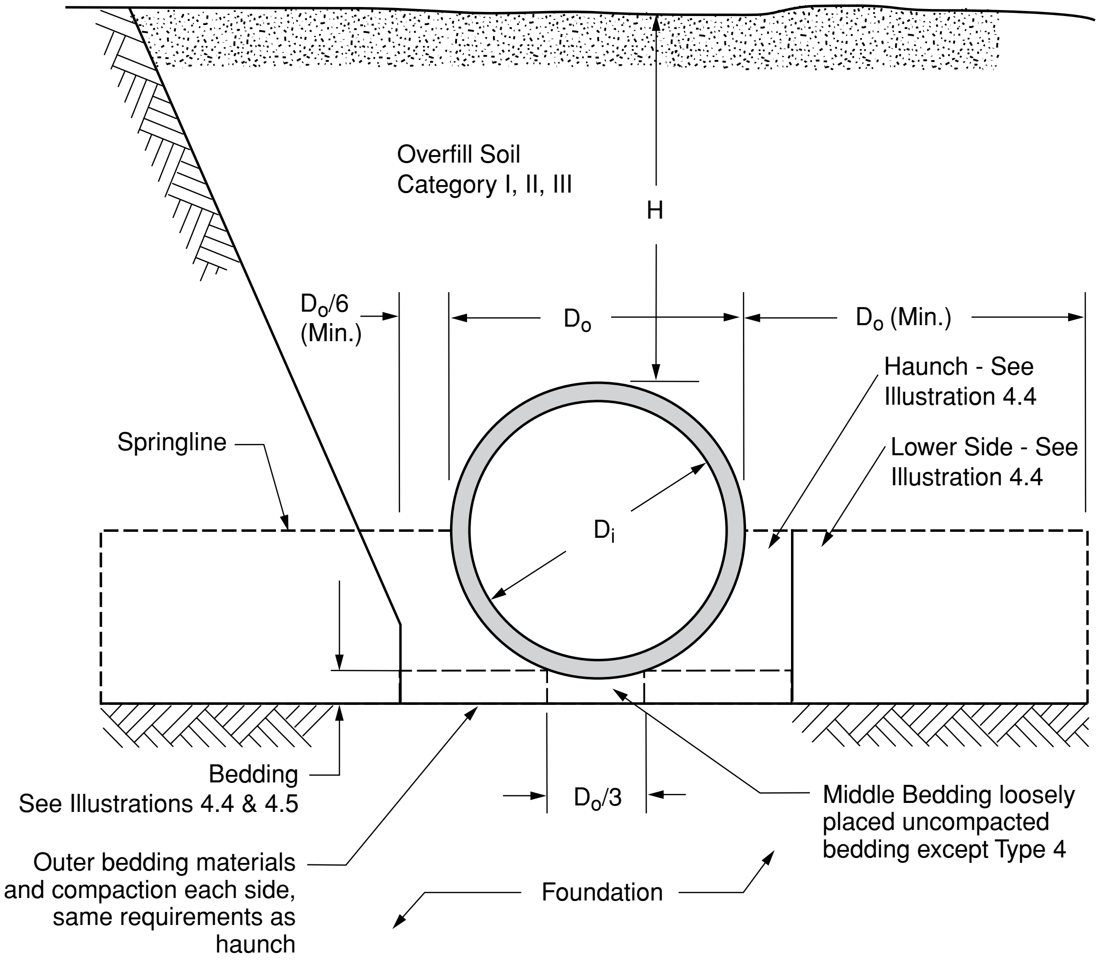


Illustration 4.3 Standard Trench/Embankment Installation

The SPIDA design runs with the Standard Installations were made with medium compaction of the bedding under the middle-third of the pipe, and with some compaction of the overfill above the springline of the pipe. This middle-third area under the pipe in the Standard Installations has been designated as loosely placed, uncompacted material. The intent is to maintain a slightly yielding bedding under the middle-third of the pipe so that the pipe may settle slightly into the bedding and achieve improved load distribution. Compactive efforts in the

Illustration 4.4 Standard Installations Soil and Minimum Compaction Requirements

Installation Type	Bedding Thickness	Haunch and Outer Bedding	Lower Side
Type 1	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6").	95% Category I	90% Category I, 95% Category II, or 100% Category III
Type 2	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6").	90% Category I or 95% Category II	85% Category I, 90% Category II, or 95% Category III
Type 3	Do/24 minimum, not less than 75 mm (3"). If rock foundation, use Do/12 minimum, not less than 150 mm (6") .	85% Category I, 90% Category II, or 95% Category III	85% Category I, 90% Category II, or 95% Category III
Type 4	No bedding required, except if rock foundation, use Do/12 minimum, not less than 150 mm (6").	No compaction required, except if Category III, use 85% Category III	No compaction required, except if Category III, use 85% Category III

Notes:

1. *Compaction and soil symbols - i.e. "95% Category I"- refers to Category I soil material with minimum standard Proctor compaction of 95%. See Illustration 4.5 for equivalent modified Proctor values.*
2. *Soil in the outer bedding, haunch, and lower side zones, except under the middle1/3 of the pipe, shall be compacted to at least the same compaction as the majority of soil in the overfill zone.*
3. *For trenches, top elevation shall be no lower than 0.1 H below finished grade or, for roadways, its top shall be no lower than an elevation of 1 foot below the bottom of the pavement base material.*
4. *For trenches, width shall be wider than shown if required for adequate space to attain the specified compaction in the haunch and bedding zones.*
5. *For trench walls that are within 10 degrees of vertical, the compaction or firmness of the soil in the trench walls and lower side zone need not be considered.*
6. *For trench walls with greater than 10 degree slopes that consist of embankment, the lower side shall be compacted to at least the same compaction as specified for the soil in the backfill zone.*
7. ***Subtrenches***
   - 7.1 *A subtrench is defined as a trench with its top below finished grade by more than 0.1 H or, for roadways, its top is at an elevation lower than 1ft. below the bottom of the pavement base material.*
   - 7.2 *The minimum width of a subtrench shall be 1.33 D_o or wider if required for adequate space to attain the specified compaction in the haunch and bedding zones.*
   - 7.3 *For subtrenches with walls of natural soil, any portion of the lower side zone in the subtrench wall shall be at least as firm as an equivalent soil placed to the compaction requirements specified for the lower side zone and as firm as the majority of soil in the overfill zone, or shall be removed and replaced with soil compacted to the specified level.*

middle-third of the bedding with mechanical compactors is undesirable, and could produce a hard flat surface, which would result in highly concentrated stresses in the pipe invert similar to those experienced in the three-edge bearing test. The most desirable construction sequence is to place the bedding to grade; install the pipe to grade; compact the bedding outside of the middle-third of the pipe; and then place and compact the haunch area up to the springline of the pipe. The bedding outside the middle-third of the pipe may be compacted prior to placing the pipe.

As indicated in Illustrations 4.3 and 4.4, when the design includes surface loads, the overfill and lower side areas should be compacted as required to support the surface load. With no surface loads or surface structure requirements, these areas need not be compacted.

Illustration 4.5 Equivalent USCS and AASHTO Soil Classifications for SIDD Soil Designations

	Representative Soil Types		Percent Compaction	
SIDD Soil	**USCS,**	**Standard AASHTO**	**Standard Proctor**	**Modified Proctor**
Gravelly Sand (Category 1)	SW, SP, GW, GP	A1,A3	100 95 90 85 80 61	95 90 85 80 75 59
Sandy Silt (Category II)	GM, SM, ML, Also GC, SC with less than 20% passing #200 sieve	A2, A4	100 95 90 85 80 49	95 90 85 80 75 46
Silty Clay (Category III)	CL, MH, GC, SC	A5, A6	100 95 90 85 80 45	90 85 80 75 70 40

SELECTION OF STANDARD INSTALLATION

The selection of a Standard Installation for a project should be based on an evaluation of the quality of construction and inspection anticipated. A Type 1 Standard Installation requires the highest construction quality and degree of inspection. Required construction quality is reduced for a Type 2 Standard Installation, and reduced further for a Type 3 Standard Installation. A Type 4 Standard Installation requires virtually no construction or quality inspection. Consequently, a Type 4 Standard Installation will require a higher strength pipe, and a Type I Standard Installation will require a lower strength pipe for the same depth of installation.

LOAD PRESSURES

SPIDA was programmed with the Standard Installations, and many design runs were made. An evaluation of the output of the designs by Dr. Frank J. Heger produced a load pressure diagram significantly different than proposed by previous theories. See Illustration 4.6. This difference is particularly significant under the pipe in the lower haunch area and is due in part to the assumption of the existence of partial voids adjacent to the pipe wall in this area. SIDD uses this pressure data to determine moments, thrusts, and shears in the pipe wall, and then uses the ACPA limit states design method to determine the required reinforcement areas to handle the pipe wall stresses. Using this method, each criteria that may limit or govern the design is considered separately in the evaluation of overall design requirements. SIDD, which is based on the four Standard Installations, is a stand-alone program developed by the American Concrete Pipe Association.

The Federal Highway Administration, FHWA, developed a microcomputer program, PIPECAR, for the direct design of concrete pipe prior to the development of SIDD. PIPECAR determines moment, thrust, and shear coefficients from either of two systems, a radial pressure system developed by Olander in 1950 and a uniform pressure system developed by Paris in the 1920's, and also uses the ACPA limit states design method to determine the required reinforcement areas to handle the pipe wall stresses. The SIDD system has been incorporated into PIPECAR as a state-of-the-art enhancement.

DETERMINATION OF EARTH LOAD

Positive Projecting Embankment Soil Load. Concrete pipe can be installed in either an embankment or trench condition as discussed previously. The type of installation has a significant effect on the loads carried by the rigid pipe. Although narrow trench installations are most typical, there are many cases where the pipe is installed in a positive projecting embankment condition, or a trench with a width significant enough that it should be considered a positive projecting embankment condition. In this condition the soil along side the pipe will settle more than the soil above the rigid pipe structure, thereby imposing additional load to the prism of soil directly above the pipe. With the Standard Installations, this additional load is accounted for by using a Vertical Arching Factor, VAF. This factor is multiplied by the prism load, PL, (weight of soil directly above the pipe) to give the total load of soil on the pipe.

$$W = VAF \times PL \tag{4.1}$$

Unlike the previous design method used for the Marston/Spangler beddings there is no need to assume a projection or settlement ratio. The Vertical Arching Factors for the Standard Installations are as shown in Illustration 4.7. The equation for soil prism load is shown below in Equation 4.2.

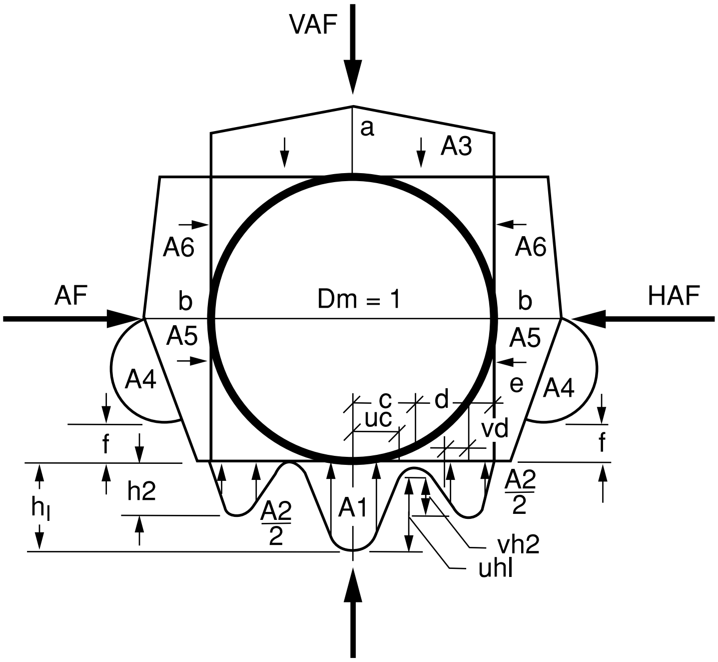
The prism load, PL, is further defined as:

$$PL = \gamma_S \left[H + \frac{D_o(4 - \pi)}{8} \right] D_o \tag{4.2}$$

where:

γ_s = soil unit weight, (lbs/ft^3)
H = height of fill, (ft)
D_o = outside diameter, (ft)

Illustration 4.6 Arching Coefficients and Heger Earth Pressure Distributions



Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6	a	b	c	e	f	u	v
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17	1.45	0.36	0.20	0.12	0.05	0.85	0.60
4	1.45	0.30	1.45	0.00	1.45	0.00	0.11	0.19	1.45	0.30	0.25	0.00	-	0.90	-

Notes:

1. *VAF and HAF are vertical and horizontal arching factors. These coefficients represent non-dimensional total vertical and horizontal loads on the pipe, respectively. The actual total vertical and horizontal loads are (VAF) X (PL) and (HAF) X (PL), respectively, where PL is the prism load.*
2. *Coefficients A1 through A6 represent the integration of non-dimensional vertical and horizontal components of soil pressure under the indicated portions of the component pressure diagrams (i.e. the area under the component pressure diagrams). The pressures are assumed to vary either parabolically or linearly, as shown, with the non-dimensional magnitudes at governing points represented by h1, h2, uh1, vh2, a and b. Non-dimensional horizontal and vertical dimensions of component pressure regions are defined by c, d, e, vc, vd, and f coefficients.*
3. *d is calculated as (0.5-c-e).*
   h1 is calculated as (1.5A1) / (c) (1+u).
   h2 is calculated as (1.5A2) / [(d) (1+v) + (2e)]

Illustration 4.7 Vertical Arching Factor (VAF)

Standard Installation	VAF
Type 1	1.35
Type 2	1.40
Type 3	1.40
Type 4	1.45

Note:

1. VAF are vertical arching factors. These coefficients represent nondimensional total vertical loads on the pipe. The actual total vertical loads are (VAF) X (PL), where PL is the prism load.

Trench Soil Load. In narrow or moderate trench width conditions, the resulting earth load is equal to the weight of the soil within the trench minus the shearing (frictional) forces on the sides of the trench. Since the new installed backfill material will settle more than the existing soil on the sides of the trench, the friction along the trench walls will relieve the pipe of some of its soil burden. The Vertical Arching Factors in this case will be less than those used for embankment design. The backfill load on pipe installed in a trench condition is computed by the equation:

$$W_d = C_d \gamma_s B_d^2 + \frac{D_o^2(4 - \pi)}{8} \gamma_s \tag{4.3}$$

The trench load coefficient, C_d, is further defined as:

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'} \tag{4.4}$$

where:

B_d = width of trench, (ft)
K = ratio of active lateral unit pressure to vertical unit pressure
μ' = tan ø', coefficient of friction between fill material and sides of trench

The value of C_d can be calculated using equation 4.4 above, or read from Figure 214 in the Appendix.

Typical values of $K\mu'$ are:

$K\mu'$ = .1924 Max. for granular materials without cohesion
$K\mu'$ = .165 Max for sand and gravel
$K\mu'$ = .150 Max. for saturated top soil
$K\mu'$ = .130 Max. for ordinary clay
$K\mu'$ = .110 Max for saturated clay

As trench width increases, the reduction in load from the frictional forces is offset by the increase in soil weight within the trench. As the trench width increases it starts to behave like an embankment, where the soil on the side of the pipe settles more than the soil above the pipe. Eventually, the embankment condition is reached when the trench walls are too far away from the pipe to help support the soil immediately adjacent to it. The transition width is the width of a trench at a particular depth where the trench load equals the embankment load. Once transition width is reached, there is no longer any benefit from frictional forces along the wall of the trench. Any pipe installed in a trench width equal to or greater than transition width should be designed for the embankment condition.

Tables 13 through 39 are based on equation (4.2) and list the transition widths for the four types of beddings with various heights of backfill.

Negative Projection Embankment Soil Load. The fill load on a pipe installed in a negative projecting embankment condition is computed by the equation:

$$W_n = C_n w B_d^{\,2} \qquad (4.5)$$

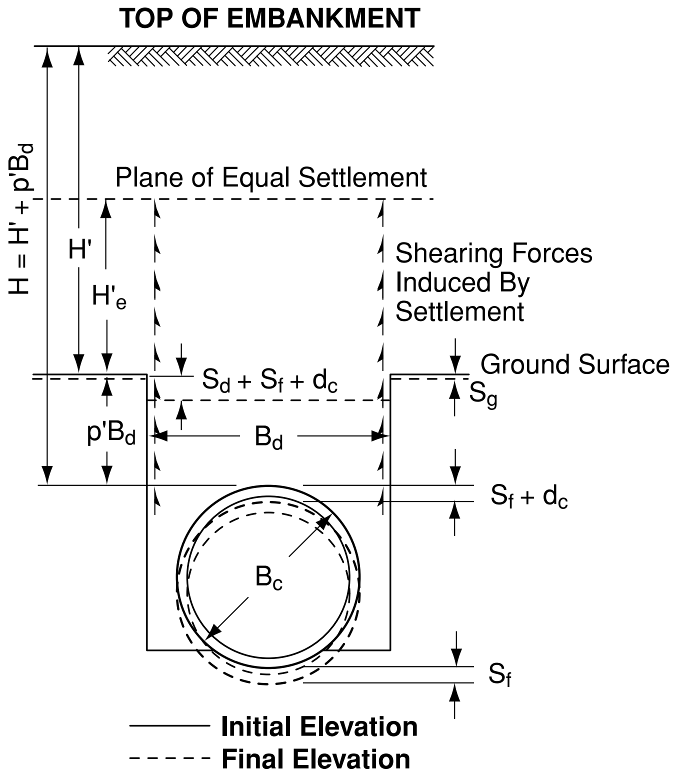
The embankment load coefficient C_n is further defined as:

$$C_n = \frac{1 - e^{-2K\mu'\frac{H}{B_d}}}{2K\mu'} \qquad \text{when } H \quad H_e \qquad (4.6)$$

$$C_n = \frac{1 - e^{-2K\mu'\frac{H_e}{B_d}}}{2K\mu'} + \left(\frac{H}{B_d} + \frac{H_e}{B_d}\right) e^{-2K\mu'\frac{H_e}{B_d}} \qquad \text{when } H > H_e \qquad (4.7)$$

The settlements which influence loads on negative projecting embankment installations are shown in Illustration 4.8.

Illustration 4.8 Settlements Which Influence Loads Negative Projection Embankment Installation



The settlement ratio is the numerical relationship between the pipe deflection and the relative settlement between the prism of fill directly above the pipe and adjacent soil. It is necessary to define the settlement ratio for negative projection embankment installations. Equating the deflection of the pipe and the total settlement of the prism of fill above the pipe to the settlement of the adjacent soil, the settlement ratio is:

$$r_{sd} = \frac{S_g - (S_d + S_f + d_c)}{S_d} \tag{4.8}$$

Recommended settlement ratio design values are listed in Table 40. The projection ratio (p') for this type of installation is the distance from the top of the pipe to the surface of the natural ground or compacted fill at the time of installation divided by the width of the trench. Where the ground surface is sloping, the average vertical distance from the top of the pipe to the original ground should be used in determining the projection ratio (p'). Figures 194 through 213 present fill loads in pounds per linear foot for circular pipe based on projection ratios of 0.5, 1.0, 1.5, 2.0 and settlement ratios of 0, -0.1, -0.3, -0.5 and -1.0. The dashed $H = p'B_d$ line represents the limiting condition where the height of fill is at the same elevation as the natural ground surface. The dashed $H = H_e$ line represents the condition where the height of the plane of equal settlement (H_e) is equal to the height of fill (H).

Jacked or Tunneled Soil Load. This type of installation is used where surface conditions make it difficult to install the pipe by conventional open excavation and backfill methods, or where it is necessary to install the pipe under an existing embankment. The earth load on a pipe installed by these methods is computed by the equation:

$$W_t = C_t w B_t^2 - 2cC_t B_t \tag{4.9}$$

where:

B_t = width of tunnel bore, (ft)

The jacked or tunneled load coefficient C_t is further defined as:

$$C_t = \frac{1 - e^{-2K\mu' \frac{H}{B_t}}}{2K\mu'} \tag{4.10}$$

In equation (4.9) the $C_t w B_t^2$ term is similar to the Negative Projection Embankment equation (4.5) for soil loads and the $2cC_tB_t$ term accounts for the cohesion of undisturbed soil. Conservative design values of the coefficient of cohesion for various soils are listed in Table 41. Figures 147, 149, 151 and 153 present values of the trench load term ($C_t w B_t^2$) in pounds per linear foot for a soil density of 120 pounds per cubic foot and Km' values of 0.165, 0.150, 0.130 and 0.110. Figures 148, 150, 152 and 154 present values of the cohesion term ($2cC_tB_t$) divided by the design value for the coefficient of cohesion (c). To obtain the total earth load for any given height of cover, width of bore or tunnel and type of soil, the value of the cohesion term must be multiplied by the appropriate coefficient of cohesion (c) and this product subtracted from the value of the trench load term.

FLUID LOAD

Fluid weight typically is about the same order of magnitude as pipe weight and generally represents a significant portion of the pipe design load only for large diameter pipe under relatively shallow fills. Fluid weight has been neglected in the traditional design procedures of the past, including the Marston Spangler design method utilizing the B and C beddings. There is no documentation of concrete pipe failures as a result of neglecting fluid load. However, some specifying agencies such as AASHTO and CHBDC, now require that the weight of the fluid inside the pipe always be considered when determining the D-load.

The Sixteenth Edition of the AASHTO Standard Specifications For Highway Bridges states: "The weight of fluid, W_F, in the pipe shall be considered in design based on a fluid weight, γ_w, of 62.4 lbs/cu.ft, unless otherwise specified."

DETERMINATION OF LIVE LOAD

To determine the required supporting strength of concrete pipe installed under asphalts, other flexible pavements, or relatively shallow earth cover, it is necessary to evaluate the effect of live loads, such as highway truck loads, in addition to dead loads imposed by soil and surcharge loads.

If a rigid pavement or a thick flexible pavement designed for heavy duty traffic is provided with a sufficient buffer between the pipe and pavement, then the live load transmitted through the pavement to the buried concrete pipe is usually negligible at any depth. If any culvert or sewer pipe is within the heavy duty traffic highway right-of-way, but not under the pavement structure, then such pipe should be analyzed for the effect of live load transmission from an unsurfaced roadway, because of the possibility of trucks leaving the pavement.

The AASHTO design loads commonly used in the past were the HS 20 with a 32,000 pound axle load in the Normal Truck Configuration, and a 24,000 pound axle load in the Alternate Load Configuration.

The AASHTO LRFD designates an HL 93 Live Load. This load consists of the greater of a HS 20 with 32,000 pound axle load in the Normal Truck Configuration, or a 25,000 pound axle load in the Alternate Load Configuration. In addition, a 640 pound per linear foot Lane Load is applied across a 10 foot wide lane at all depths of earth cover over the top of the pipe, up to a depth of 8 feet. This Lane Load converts to an additional live load of 64 pounds per square foot, applied to the top of the pipe for any depth of burial less than 8 feet. The average pressure intensity caused by a wheel load is calculated by Equation 4.12. The Lane Load intensity is added to the wheel load pressure intensity in Equation 4.13.

The HS 20, 32,000 pound and the Alternate Truck 25,000 pound design axle are carried on dual wheels. The contact area of the dual wheels with the ground is assumed to be rectangle, with dimensions presented in Illustration 4.9.

Illustration 4.9 AASHTO Wheel Load Surface Contact Area (Foot Print)

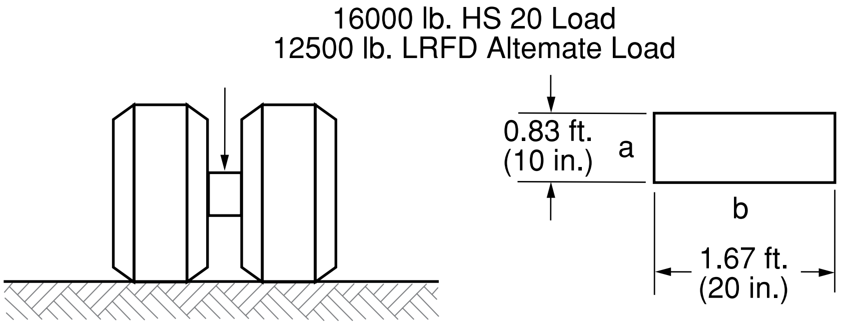
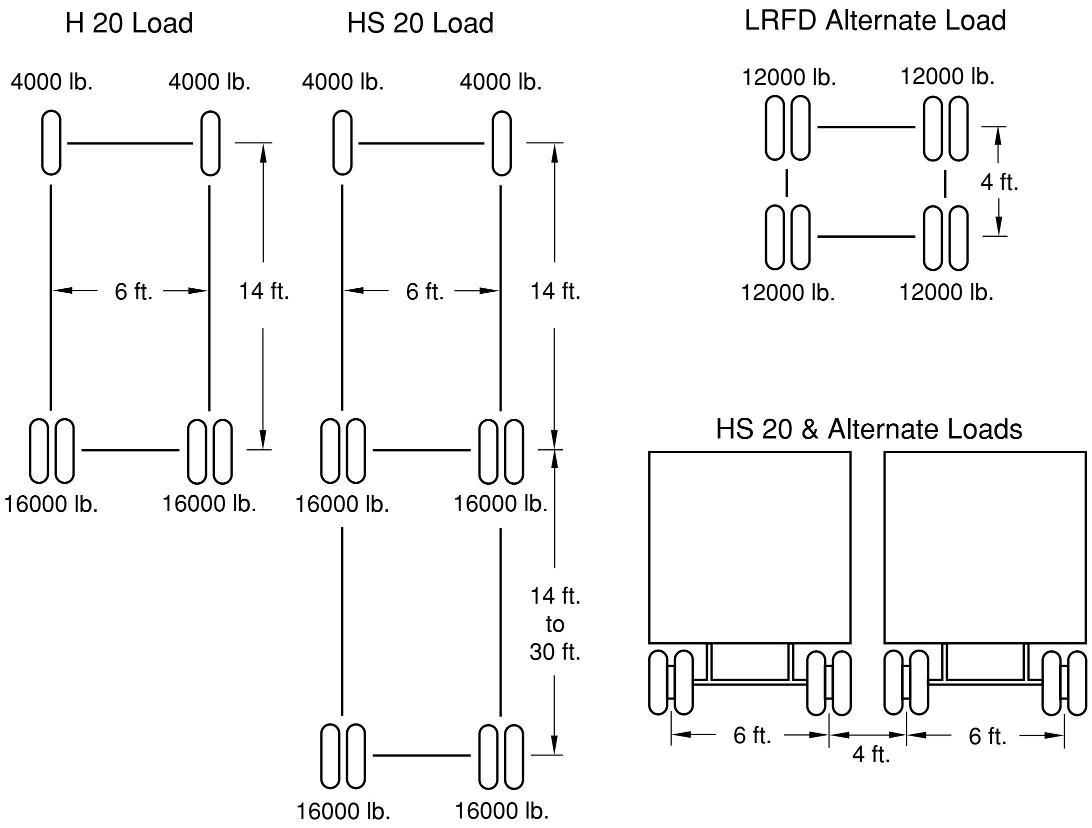


Illustration 4.10 AASHTO Wheel Loads and Wheel Spacings



Impact Factors. The AASHTO LRFD Standard applies a dynamic load allowance, sometimes called Impact Factor, to account for the truck load being non-static. The dynamic load allowance, IM, is determined by Equation 4.11:

$$IM = \frac{33(1.0 - 0.125H)}{100} \qquad (4.11)$$

where:

H = height of earth cover over the top of the pipe, ft.

Load Distribution. The surface load is assumed to be uniformly spread on any horizontal subsoil plane. The spread load area is developed by increasing the length and width of the wheel contact area for a load configuration as shown in Illustration 4.13 for a dual wheel. On a horizontal soil plane, the dimensional increases to the wheel contact area are based on height of earth cover over the top of the pipe as presented in Illustration 4.11 for two types of soil.

Illustration 4.11 Dimensional Increase Factor, AASHTO LRFD

Soil Type	Dimensional Increase Factor
LRFD select granular	1.15H
LRFD any other soil	1.00H

As indicated by Illustrations 4.14 and 4.15, the spread load areas from adjacent wheels will overlap as height of earth cover over the top of the pipe increases. At shallow depths, the maximum pressure will be developed by an HS 20 dual wheel, since at 16,000 pounds it applies a greater load than the 12,500 pound Alternate Load. At intermediate depths, the maximum pressure will be developed by the wheels of two HS 20 trucks in the passing mode, since at 16,000 pounds each, the two wheels apply a greater load than the 12,500 pounds of an Alternate Load wheel. At greater depths, the maximum pressure will be developed by wheels of two Alternate Load configuration trucks in the passing mode, since at 12,500 pounds each, the four wheels apply the greatest load(50,000 pounds). Intermediate depths begin when the spread area of dual wheels of two HS 20 trucks in the passing mode meet and begin to overlap. Greater depths begin when the spread area b of two single dual wheels of two Alternate Load configurations in the passing mode meet and begin to overlap.

Since the exact geometric relationship of individual or combinations of surface wheel loads cannot be anticipated, the most critical loading configurations along with axle loads and rectangular spread load area are presented in Illustration 4.12 for the two AASHTO LRFD soil types.

Illustration 4.12 LRFD Critical Wheel Loads and Spread Dimensions at the Top of the Pipe

Vehicle Traveling Perpendicular to Pipe					
	H, ft	**P, lbs**	**Spread a, ft**	**Spread b, ft**	**Figure**
Live Load Distribution of 1.15 x H for Select Granular Fill	$H + 1.15D_O < 2.05$	16,000	a + 1.15H	b + 1.15H	3
	$2.05 - 1.15D_O < H < 5.5$	32,000	a + 4 + 1.15H	b + 1.15H	4
	5.5 < H	50,000	a + 4 + 1.15H	b + 4 + 1.15H	5
Live Load Distribution of 1.0 x H for Other Soils	$H + 1.30D_O < 2.30$	16,000	a + 1.00H	b + 1.00H	3
	$2.30 - 1.30\ D_O < H < 6.3$	32,000	a + 4 + 1.00H	b + 1.00H	4
	6.3 < H	50,000	a + 4 + 1.00H	b + 4 + 1.00H	5
Vehicle Traveling Parallel to Pipe					
Live Load Distribution of 1.15 x H for Select Granular Fill	H < 2.03	16,000	a + 1.15H	b + 1.15H	3
	2.03 < H < 5.5	32,000	a + 4 + 1.15H	b + 1.15H	4
	5.5 <H	50,000	a + 4 + 1.15H	b + 4 + 1.15H	5
Live Load Distribution of 1.0 x H for Other Soils	H < 2.33	16,000	a + 1.00H	b + 1.00H	3
	2.33 < H < 6.3	32,000	a + 4 + 1.00H	b + 1.00H	4
	6.3 < H	50,000	a + 4 + 1.00H	b + 4 + 1.00H	5

Illustration 4.13 Spread Load Area - Single Dual Wheel

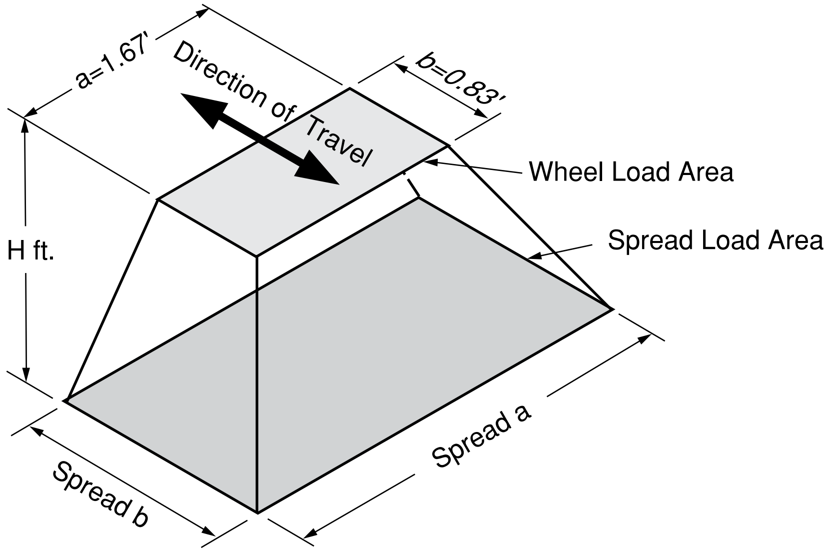


Illustration 4.14 Spread Load Area - Two Single Dual Wheels of Trucks in Passing Mode

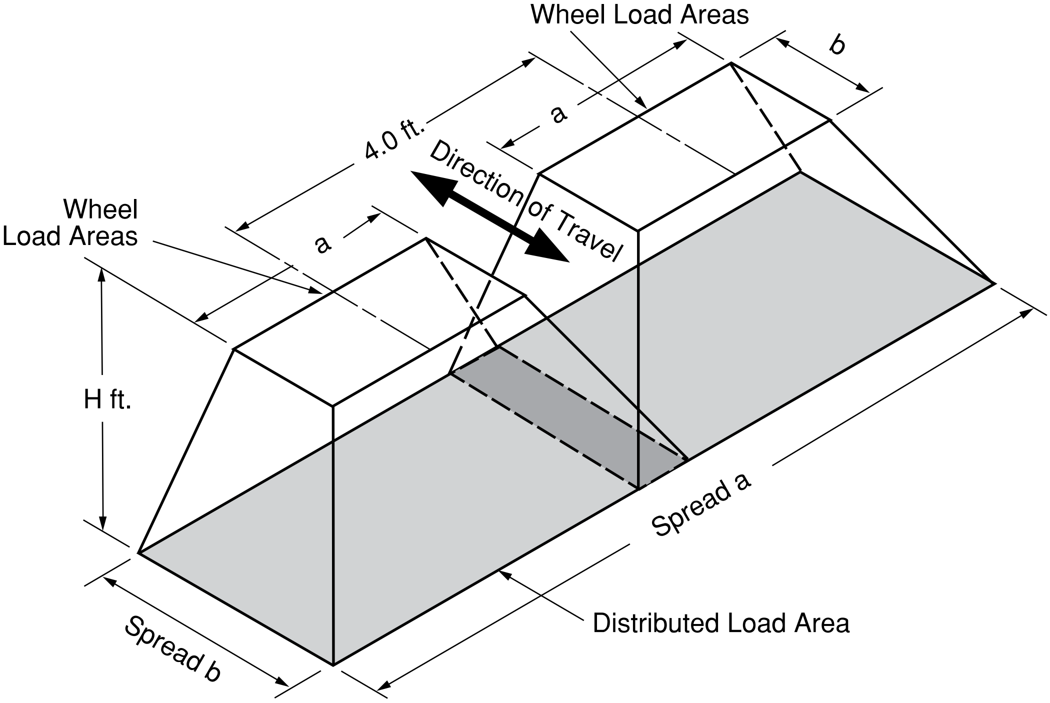
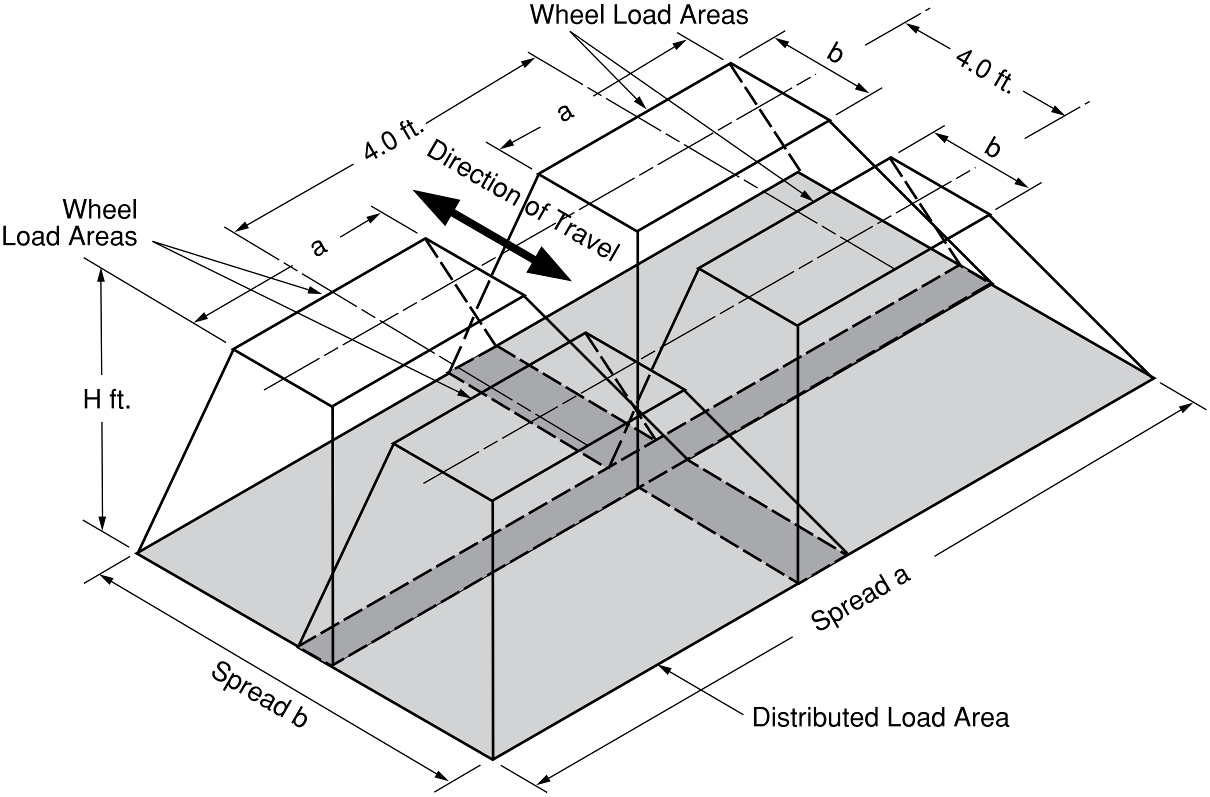


Illustration 4.15 Spread Load Area - Two Single Dual Wheels of Two Alternate Loads in Passing Mode



Average Pressure Intensity. The wheel load average pressure intensity on the subsoil plane at the outside top of the concrete pipe is:

$$w = \frac{P(1 + IM)}{A} \qquad (4.12)$$

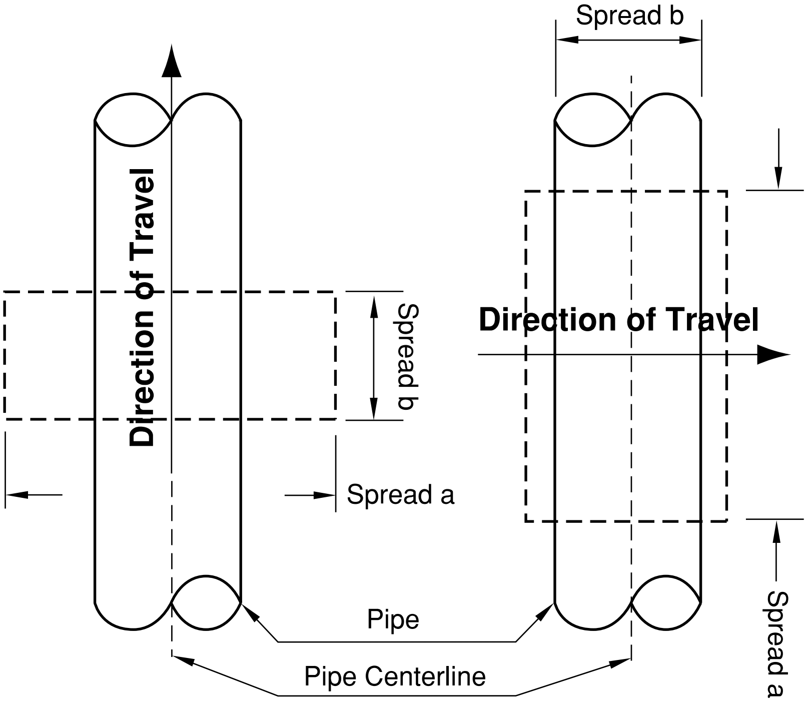
where:

w = wheel load average pressure intensity, pounds per square foot
P = total live wheel load applied at the surface, pounds
A = spread wheel load area at the outside top of the pipe, square feet
IM = dynamic load allowance

From the appropriate Table in Illustration 4.12, select the critical wheel load and spread dimensions for the height of earth cover over the outside top of the pipe, H. The spread live load area is equal to Spread a times Spread b. Select the appropriate dynamic load allowance, using Equation 4.11.

Total Live Load. A designer is concerned with the maximum possible loads, which occur when the distributed load area is centered over the buried pipe. Depending on the pipe size and height of cover, the most critical loading orientation can occur either when the truck travels transverse or parallel to the centerline of the pipe. Illustration 4.16 shows the dimensions of the spread load area, A, as related to whether the truck travel is transverse or parallel to the centerline of the pipe.

Illustration 4.16 Spread Load Area Dimensions vs Direction of Truck



Unless you are certain of the pipeline orientation, the total live load in pounds, W_T, must be calculated for each travel orientation, and the maximum calculated value must be used in Equation 4.14 to calculate the live load on the pipe in pounds per linear foot.

The LRFD requires a Lane Load, L_L, of 64 pounds per square foot on the top of the pipe at any depth less than 8 feet.

The total live load acting on the pipe is:

$$W_T = (w + L_L)\ L\ S_L \tag{4.13}$$

where:

W_T = total live load, pounds

w = wheel load average pressure intensity, pounds per square foot (at the top of the pipe)

L_L = lane loading if AASHTO LRFD is used, pounds per square foot

$0 \leq H < 8,\ L_L$ = 64, pounds per square foot

$H \geq 8,\ L_L$ = 0

L = dimension of load area parallel to the longitudinal axis of pipe, feet

S_L = outside horizontal span of pipe, B_c, or dimension of load area transverse to the longitudinal axis of pipe, whichever is less, feet

Total Live Load in Pounds per Linear Foot. The total live load in pounds per linear foot, W_L, is calculated by dividing the Total Live Load, W_T, by the Effective Supporting Length, L_e (See Illustration 4.17), of the pipe:

$$W_L = \frac{W_T}{L_e} \tag{4.14}$$

where:

W_L = live load on top of pipe, pounds per linear foot

L_e = effective supporting length of pipe, feet

The effective supporting length of pipe is:

$$L_e = L + 1.75(3/4R_O)$$

where:

R_O = outside vertical Rise of pipe, feet

Illustration 4.17 Effective Supporting Length of Pipe

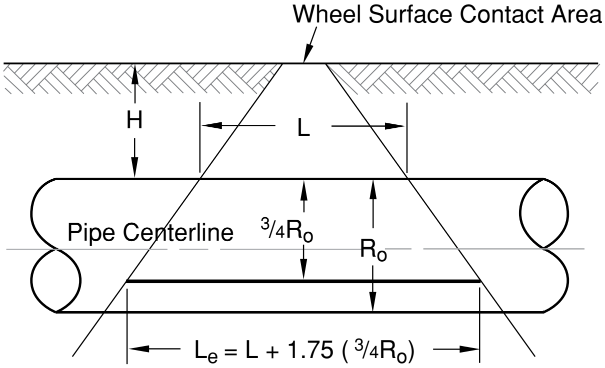
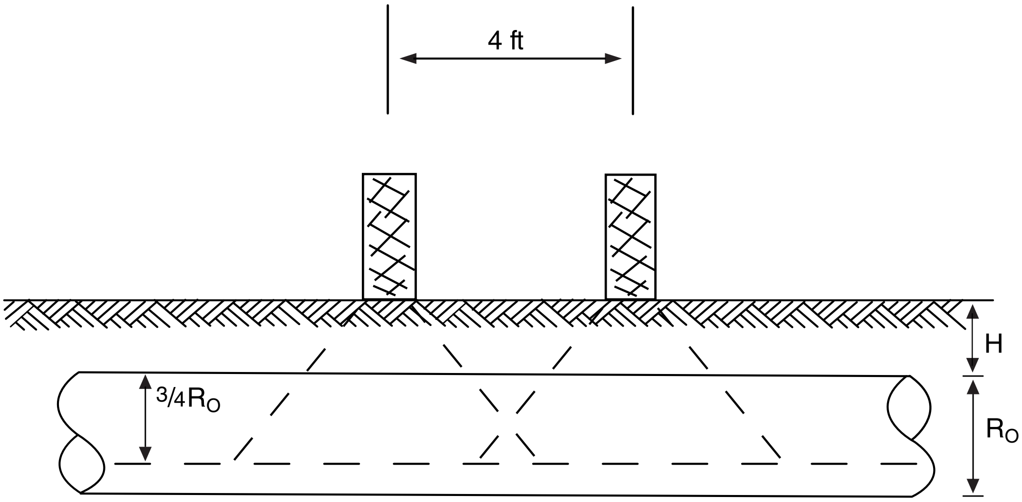


Illustration 4.18 Load Spread through Soil and Pipe



Airports. The distribution of aircraft wheel loads on any horizontal plane in the soil mass is dependent on the magnitude and characteristics of the aircraft loads, the aircraft's landing gear configuration, the type of pavement structure and the subsoil conditions. Heavier gross aircraft weights have resulted in multiple wheel undercarriages consisting of dual wheel assemblies and/or dual tandem assemblies. The distribution of wheel loads through rigid pavement are shown in Illustration 4.18.

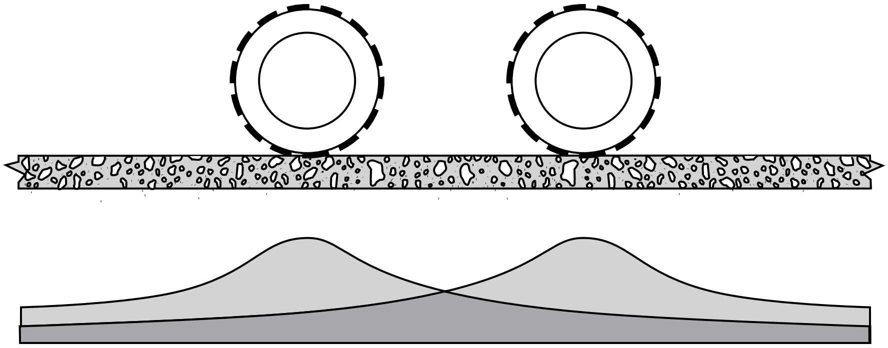
If a rigid pavement is provided, an aircraft wheel load concentration is distributed over an appreciable area and is substantially reduced in intensity at the subgrade. For multi-wheeled landing gear assemblies, the total pressure intensity is dependent on the interacting pressures produced by each individual wheel. The maximum load transmitted to a pipe varies with the pipe size under consideration, the pipe's relative location with respect to the particular landing gear configuration and the height of fill between the top of the pipe and the subgrade surface.

For a flexible pavement, the area of the load distribution at any plane in the soil mass is considerably less than for a rigid pavement. The interaction of pressure intensities due to individual wheels of a multi-wheeled landing gear assembly is also less pronounced at any given depth of cover.

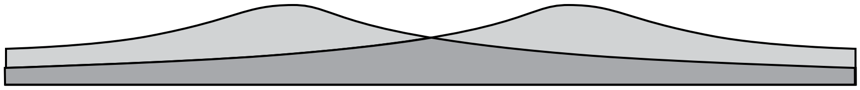
In present airport design practices, the aircraft's maximum takeoff weight is used since the maximum landing weight is usually considered to be about three fourths the takeoff weight. Impact is not considered, as criteria are not yet available to include dynamic effects in the design process.

Rigid Pavement.

Illustration 4.19 Aircraft Pressure Distribution, Rigid Pavement



Fill Height H = 2 Feet



Fill Height H = 6 Feet

The pressure intensity is computed by the equation:

$$p(H,X) = \frac{CP}{R_s{}^2} \tag{4.15}$$

where:

P = Load at the surface, pounds

C = Load coefficient, dependent on the horizontal distance (X), the vertical distance (H), and R_s

R_s = Radius of Stiffness of the pavement, feet

R_s is further defined as:

$$R_s = \sqrt[4]{\frac{(Eh)^3}{12\,(1 - \mu^2)\,k}} \tag{4.16}$$

where:

E = modulus of elasticity of the pavement, pounds per square inch

h = pavement thickness, inches

μ = Poisson’s ratio (generally assumed 0.15 for concrete pavement)

k = modulus of subgrade reaction, pounds per cubic inch

Tables 46 through 50 present pressure coefficients in terms of the radius of stiffness as developed by the Portland Cement Association and published in the report “Vertical Pressure on Culverts Under Wheel Loads on Concrete Pavement Slabs.” 3

Values of radius of stiffness are listed in Table 52 for pavement thickness and modulus of subgrade reaction.

Tables 53 through 55 present aircraft loads in pounds per linear foot for circular, horizontal elliptical and arch pipe. The Tables are based on equations

4.15 and 4.16 using a 180,000 pound dual tandem wheel assembly, 190 pounds per square inch tire pressure, 26-inch spacing between dual tires, 66-inch spacing between tandem axles, k value of 300 pounds per cubic inch, 12-inch, thick concrete pavement and an R_s, value of 37.44 inches. Subgrade and subbase support for a rigid pavement is evaluated in terms of k, the modulus of subgrade reaction. A k value of 300 pounds per cubic inch was used, since this value represents a desirable subgrade or subbase material. In addition, because of the interaction between the pavement and subgrade, a lower value of k (representing reduced subgrade support) results in less load on the pipe.

Although Tables 53 through 55 are for specific values of aircraft weights and landing gear configuration, the tables can be used with sufficient accuracy for all heavy commercial aircraft currently in operation. Investigation of the design loads of future jets indicates that although the total loads will greatly exceed present aircraft loads, the distribution of such loads over a greater number of landing gears and wheels will not impose loads on underground conduits greater than by commercial aircraft currently in operation. For lighter aircrafts and/or different rigid pavement thicknesses, it is necessary to calculate loads as illustrated in Example 4.10.

Flexible Pavement. AASHTO considers flexible pavement as an unpaved surface and therefore live load distributions may be calculated as if the load were bearing on soil. Cover depths are measured from the top of the flexible pavement.

Railroads. In determining the live load transmitted to a pipe installed under railroad tracks, the weight on the locomotive driver axles plus the weight of the track structure, including ballast, is considered to be uniformly distributed over an area equal to the length occupied by the drivers multiplied by the length of ties.

The American Railway Engineering and Maintenance of Way Association (AREMA) recommends a Cooper E80 loading with axle loads and axle spacing as shown in Illustration 4.19. Based on a uniform load distribution at the bottom of the ties and through the soil mass, the live load transmitted to a pipe underground is computed by the equation:

$$W_L = Cp_oB_cI_f \tag{4.17}$$

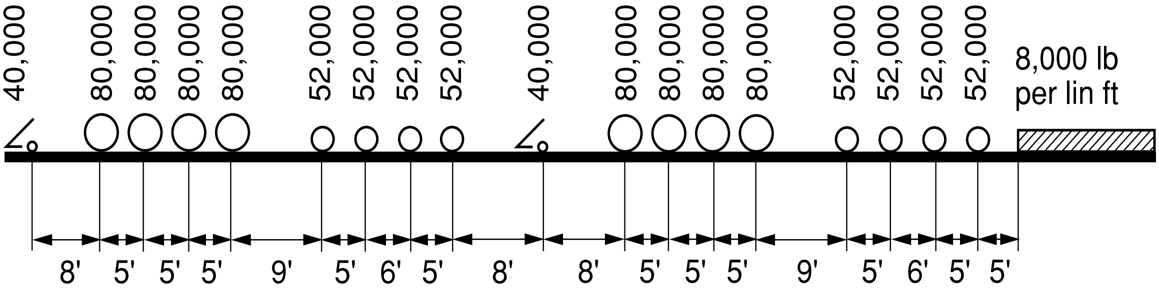
where:

C = load coefficient
p_o = tire pressure, pounds per square foot
B_c = outside span of the pipe, feet
I_f = impact factor

Tables 56 through 58 present live loads in pounds per linear foot based on equation (4.17) with a Cooper E80 design loading, track structure weighing 200 pounds per linear foot and the locomotive load uniformly distributed over an area 8 feet X 20 feet yielding a uniform live load of 2025 pounds per square foot. In accordance with the AREMA “Manual of Recommended Practice” an impact factor of 1.4 at zero cover decreasing to 1.0 at ten feet of cover is included in the Tables.

Illustration 4.20 Cooper E 80 Wheel Loads and Axel Spacing

Based on a uniform load distribution at the bottom of the ties and through the



soil mass, the design track unit load, W_L, in pounds per square foot, is determined from the AREMA graph presented in Figure 215. To obtain the live load transmitted to the pipe in pounds per linear foot, it is necessary to multiply the unit load, W_L, from Figure 215, by the outside span, B_c, of the pipe in feet.

Loadings on a pipe within a casing pipe shall be taken as the full dead load, plus live load, plus impact load without consideration of the presence of the casing pipe, unless the casing pipe is fully protected from corrosion.

Culvert or sewer pipe within the railway right-of-way, but not under the track structure, should be analyzed for the effect of live loads because of the possibility of train derailment.

Construction Loads. During grading operations it may be necessary for heavy construction equipment to travel over an installed pipe. Unless adequate protection is provided, the pipe may be subjected to load concentrations in excess of the design loads. Before heavy construction equipment is permitted to cross over a pipe, a temporary earth fill should be constructed to an elevation at least 3 feet over the top of the pipe. The fill should be of sufficient width to prevent possible lateral displacement of the pipe.

SELECTION OF BEDDING

A bedding is provided to distribute the vertical reaction around the lower exterior surface of the pipe and reduce stress concentrations within the pipe wall. The load that a concrete pipe will support depends on the width of the bedding contact area and the quality of the contact between the pipe and bedding. An important consideration in selecting a material for bedding is to be sure that positive contact can be obtained between the bed and the pipe. Since most granular materials will shift to attain positive contact as the pipe settles, an ideal load distribution can be attained through the use of clean coarse sand, well-rounded pea gravel or well-graded crushed rock.

BEDDING FACTORS

Under installed conditions the vertical load on a pipe is distributed over its width and the reaction is distributed in accordance with the type of bedding. When the pipe strength used in design has been determined by plant testing, bedding

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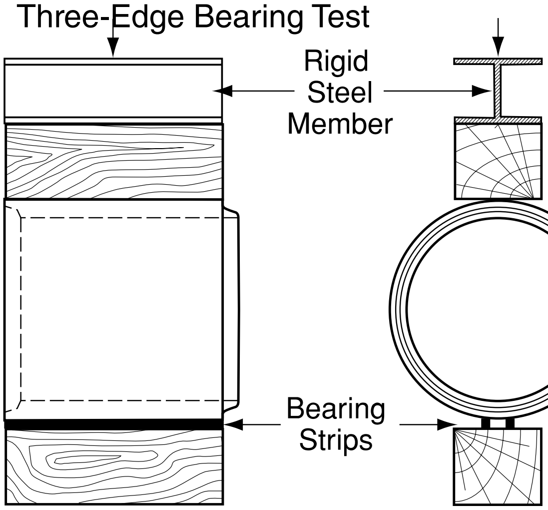
[3] Op. cit., p. 28

[4] Equation (21) is recommended by WPCF-ASCE Manual, The Design and Construction of Sanitary Storm Sewers.

factors must be developed to relate the in-place supporting strength to the more severe plant test strength. The bedding factor is the ratio of the strength of the pipe under the installed condition of loading and bedding to the strength of the pipe in the plant test. This same ratio was defined originally by Spangler as the load factor. This latter term, however, was subsequently defined in the ultimate strength method of reinforced concrete design with an entirely different meaning. To avoid confusion, therefore, Spangler's term was renamed the bedding factor. The three-edge bearing test as shown in Illustration 4.20 is the normally accepted plant test so that all bedding factors described in the following pages relate the in-place supporting strength to the three-edge bearing strength.

Illustration 4.21 Three-Edge Bearing Test



Although developed for the direct design method, the Standard Installations are readily applicable to and simplify the indirect design method. The Standard Installations are easier to construct and provide more realistic designs than the historical A, B, C, and D beddings. Development of bedding factors for the Standard Installations, as presented in the following paragraphs, follows the concepts of reinforced concrete design theories. The basic definition of bedding factor is that it is the ratio of maximum moment in the three-edge bearing test to the maximum moment in the buried condition, when the vertical loads under each condition are equal:

$$B_f = \frac{M_{TEST}}{M_{FIELD}} \qquad (4.18)$$

where:

B_f = bedding factor

M_{TEST} = maximum moment in pipe wall under three-edge bearing test load, inch-pounds

M_{FIELD} = maximum moment in pipe wall under field loads, inch-pounds

Consequently, to evaluate the proper bedding factor relationship, the vertical load on the pipe for each condition must be equal, which occurs when the springline axial thrusts for both conditions are equal. In accordance with the laws of statics and equilibrium, M_{TEST} and M_{FIELD} are:

$$M_{TEST} = [0.318N_{FS}] \times [D + t] \tag{4.19}$$

$$M_{FIELD} = [M_{FI}] - [0.38tN_{FI}] - [0.125N_{FI} \times c] \tag{4.20}$$

where:

N_{FS} = axial thrust at the springline under a three-edge bearing test load, pounds per foot

D = inside pipe diameter, inches

t = pipe wall thickness, inches

M_{FI} = moment at the invert under field loading, inch-pounds/ft

N_{FI} = axial thrust at the invert under field loads, pounds per foot

c = thickness of concrete cover over the inner reinforcement, inches

Substituting equations 4.19 and 4.20 into equation 4.18.

$$B_f = \frac{[0.318N_{FS}] \times [D + t]}{[M_{FI}] - [0.38tN_{FI}] - [0.125N_{FI} \times C]} \tag{4.21}$$

Using this equation, bedding factors were determined for a range of pipe diameters and depths of burial. These calculations were based on one inch cover over the reinforcement, a moment arm of 0.875d between the resultant tensile and compressive forces, and a reinforcement diameter of 0.075t. Evaluations indicated that for A, B and C pipe wall thicknesses, there was negligible variation in the bedding factor due to pipe wall thickness or the concrete cover, c, over the reinforcement. The resulting bedding factors are presented in Illustration 4.21.

Illustration 4.22 Bedding Factors, Embankment Conditions, B_{fe}

Pipe Diameter	**Standard Installation** **Type 1**	**Type 2**	**Type 3**	**Type 4**
12 in.	4.4	3.2	2.5	1.7
24 in.	4.2	3.0	2.4	1.7
36 in.	4.0	2.9	2.3	1.7
72 in.	3.8	2.8	2.2	1.7
144 in.	3.6	2.8	2.2	1.7

Notes:

1. *For pipe diameters other than listed in Illustration 4.21, embankment condition factors, B_{fe} can be obtained by interpolation.*
2. *Bedding factors are based on the soils being placed with the minimum compaction specified in Illustration 4.4 for each standard installation.*

Determination of Bedding Factor. For trench installations as discussed previously, experience indicates that active lateral pressure increases as trench width increases to the transition width, provided the sidefill is compacted. A SIDD parameter study of the Standard Installations indicates the bedding factors are constant for all pipe diameters under conditions of zero lateral pressure on the pipe. These bedding factors exist at the interface of the pipewall and the soil and are called minimum bedding factors, B_{fo}, to differentiate them from the fixed bedding factors developed by Spangler. Illustration 4.22 presents the minimum bedding factors.

Illustration 4.23 Trench Minimum Bedding Factors, B_{fo}

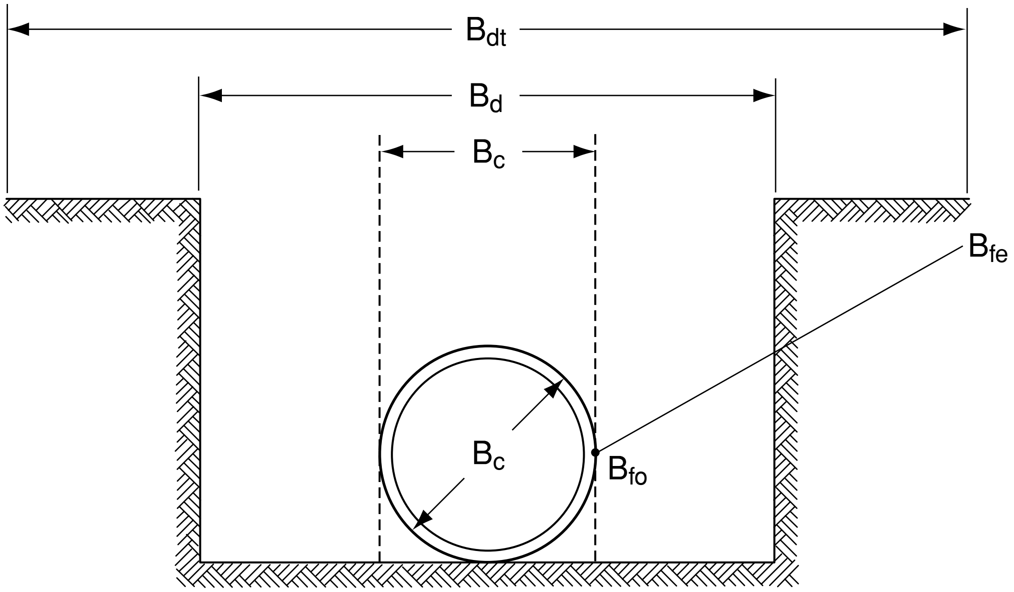
Standard Installation	Minimum Bedding Factor, B_{fo}
Type 1	2.3
Type 2	1.9
Type 3	1.7
Type 4	1.5

Note:

1. *Bedding factors are based on the soils being placed with the minimum compaction specified in Illustration 4.4 for each Standard Installation.*
2. *For pipe installed in trenches dug in previously constructed embankment, the load and the bedding factor should be determined as an embankment condition unless the backfill placed over the pipe is of lesser compaction than the embankment.*

A conservative linear variation is assumed between the minimum bedding factor and the bedding factor for the embankment condition, which begins at transition width.

Illustration 4.24 Variable Bedding Factor



The equation for the variable trench bedding factor, is:

$$B_{fv} = \frac{[B_{fe} - B_{fo}][B_d - B_c]}{[B_{dt} - B_c]} + B_{fo} \qquad (4.22)$$

where:

B_c = outside horizontal span of pipe, feet
B_d = trench width at top of pipe, feet

B_{dt} = transition width at top of pipe, feet
B_{fe} = bedding factor, embankment
B_{fo} = minimum bedding factor, trench
B_{fv} = variable bedding factor, trench

Transition width values, B_{dt} are provided in Tables 13 through 39.

For pipe installed with 6.5 ft or less of overfill and subjected to truck loads, the controlling maximum moment may be at the crown rather than the invert. Consequently, the use of an earth load bedding factor may produce unconservative designs. Crown and invert moments of pipe for a range of diameters and burial depths subjected to HS20 truck live loadings were evaluated. Also evaluated, was the effect of bedding angle and live load angle (width of loading on the pipe). When HS20 or other live loadings are encountered to a significant value, the live load bedding factors, B_{fLL}, presented in Illustration 4.24 are satisfactory for a Type 4 Standard Installation and become increasingly conservative for Types 3, 2, and 1. Limitations on B_{fLL} are discussed in the section on Selection of Pipe Strength.

Illustration 4.25 Bedding Factors, B_{fLL}, for HS20 Live Loadings

Fill Height, Ft.	Pipe Diameter, Inches 12	24	36	48	60	72	84	96	108	120	144
0.5	2.2	1.7	1.4	1.3	1.3	1.1	1.1	1.1	1.1	1.1	1.1
1.0	2.2	2.2	1.7	1.5	1.4	1.3	1.3	1.3	1.1	1.1	1.1
1.5	2.2	2.2	2.1	1.8	1.5	1.4	1.4	1.3	1.3	1.3	1.1
2.0	2.2	2.2	2.2	2.0	1.8	1.5	1.5	1.4	1.4	1.3	1.3
2.5	2.2	2.2	2.2	2.2	2.0	1.8	1.7	1.5	1.4	1.4	1.3
3.0	2.2	2.2	2.2	2.2	2.2	2.2	1.8	1.7	1.5	1.5	1.4
3.5	2.2	2.2	2.2	2.2	2.2	2.2	1.9	1.8	1.7	1.5	1.4
4.0	2.2	2.2	2.2	2.2	2.2	2.2	2.1	1.9	1.8	1.7	1.5
4.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8	1.7
5.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8

Application of Factor of Safety. The indirect design method for concrete pipe is similar to the common working stress method of steel design, which employs a factor of safety between yield stress and the desired working stress. In the indirect method, the factor of safety is defined as the relationship between the ultimate strength D-load and the 0.01inch crack D-load. This relationship is specified in the ASTM Standards C 76 and C 655 on concrete pipe. The relationship between ultimate D-load and 0.01-inch crack D-load is 1.5 for 0.01 inch crack D-loads of 2,000 or less; 1.25 for 0.01 inch crack D loads of 3,000 or more; and a linear reduction from 1.5 to 1.25 for 0.01 inch crack D-loads between more than 2,000 and less than 3,000. Therefore, a factor of safety of 1.0 should be applied if the 0.01 inch crack strength is used as the design criterion rather than the ultimate strength. The 0.01 inch crack width is an arbitrarily chosen test criterion and not a criteri for field performance or service limit.

SELECTION OF PIPE STRENGTH

The American Society for Testing and Materials has developed standard specifications for precast concrete pipe. Each specification contains design, manufacturing and testing criteria.

ASTM Standard C 14 covers three strength classes for nonreinforced concrete pipe. These classes are specified to meet minimum ultimate loads, expressed in terms of three-edge bearing strength in pounds per linear foot.

ASTM Standard C 76 for reinforced concrete culvert, storm drain and sewer pipe specifies strength classes based on D-load at 0.01-inch crack and/or ultimate load. The 0.01-inch crack D-load ($D_{0.01}$) is the maximum three-edge-bearing test load supported by a concrete pipe before a crack occurs having a width of 0.01 inch measured at close intervals, throughout a length of at least 1 foot. The ultimate D-load (D_{ult}) is the maximum three-edge-bearing test load supported by a pipe divided by the pipe's inside diameter. D-loads are expressed in pounds per linear foot per foot of inside diameter.

ASTM Standard C 506 for reinforced concrete arch culvert, storm drain, and sewer pipe specifies strengths based on D-load at 0.01-inch crack and/or ultimate load in pounds per linear foot per foot of inside span.

ASTM Standard C 507 for reinforced concrete elliptical culvert, storm drain and sewer pipe specifies strength classes for both horizontal elliptical and vertical elliptical pipe based on D-load at 0.01-inch crack and/or ultimate load in pounds per linear foot per foot of inside span.

ASTM Standard C 655 for reinforced concrete D-load culvert, storm drain and sewer pipe covers acceptance of pipe designed to meet specific D-load requirements.

ASTM Standard C 985 for nonreinforced concrete specified strength culvert, storm drain, and sewer pipe covers acceptance of pipe designed for specified strength requirements.

Since numerous reinforced concrete pipe sizes are available, three-edge bearing test strengths are classified by D-loads. The D-load concept provides strength classification of pipe independent of pipe diameter. For reinforced circular pipe the three-edge-bearing test load in pounds per linear foot equals D-load times inside diameter in feet. For arch, horizontal elliptical and vertical elliptical pipe the three-edge bearing test load in pounds per linear foot equals D-load times nominal inside span in feet.

The required three-edge-bearing strength of non-reinforced concrete pipe is expressed in pounds per linear foot, not as a D-load, and is computed by the equation:

$$\text{T.E.B} = \left[\left(\frac{W_E + W_F}{B_f}\right) + \frac{W_L}{B_{fLL}}\right] \text{x F.S.} \tag{4.23}$$

The required three-edge bearing strength of circular reinforced concrete pipe is expressed as *D*-load and is computed by the equation:

$$\text{D-load} = \left[\left(\frac{W_E + W_F}{B_f}\right) + \frac{W_L}{B_{fLL}}\right] \text{x} \frac{\text{F.S.}}{D} \tag{4.24}$$

The determination of required strength of elliptical and arch concrete pipe is computed by the equation:

$$\text{D-load} = \left[\left(\frac{W_E + W_F}{B_f}\right) + \frac{W_L}{B_{fLL}}\right] x \frac{F.S.}{S} \tag{4.25}$$

where:

S = inside horizontal span of pipe, ft.

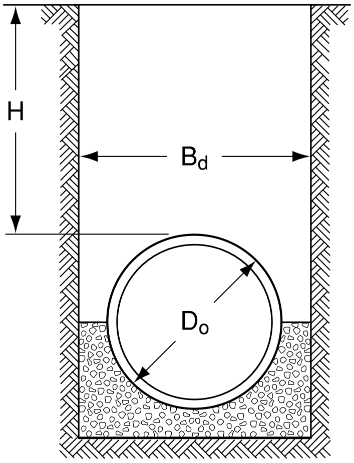
When an HS20 truck live loading is applied to the pipe, use the live load bedding factor, B_{fLL}, as indicated in Equations 4.23 – 4.25, unless the earth load bedding factor, B_f, is of lesser value in which case, use the lower B_f value in place of B_{fLL}. For example, with a Type 4 Standard Installation of a 48 inch diameter pipe under 1.0 feet of fill, the factors used would be $B_f = 1.7$ and $B_{fLL} = 1.5$; but under 2.5 feet or greater fill, the factors used would be B_f= 1.7 and B_{fLL}, = 1.7 rather than 2.2. For trench installations with trench widths less than transition width, B_{fLL} would be compared to the variable trench bedding factor, B_{fv}. Although their loads are generally less concentrated, the live load bedding factor may be conservatively used for aircraft and railroad loadings.

The use of the six-step indirect design method is illustrated by examples on the following pages.

EXAMPLE PROBLEMS

EXAMPLE PROBLEMS

EXAMPLE 4-1
Trench Installation



Given: A 48 inch circular pipe is to be installed in a 7 foot wide trench with 10 feet of cover over the top of the pipe. The pipe will be backfilled with sand and gravel weighing 110 pounds per cubic foot. Assume a Type 4 Installation.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
   To determine the earth load, we must first determine if the installation is behaving as a trench installation or an embankment installation. Since we are not told what the existing in-situ material is, conservatively assume a Kμ' value between the existing soil and backfill of 0.150.

   From Table 23, The transition width for a 48 inch diameter pipe with a Kμ' value of 0.150 under 10 feet of fill is:

   B_{dt} = 8.5 feet

   Transition width is greater than the actual trench width, therefore the installation will act as a trench. Use Equations 4.3 and 4.4 to determine the soil load.

   w = 110 pounds per cubic foot
   H = 10 feet
   B_d = 7 feet
   $K\mu'$ = 0.150

   $$D_o = \frac{48 + 2\,(5)}{12}$$

   Note: Wall thickness for a 48 inch inside diameter pipe with a B wall is 5-inches per ASTM C 76.

   D_o = 4.83 feet

The value of Cd can be obtained from Figure 214, or calculated using Equation 4.4.

$$C_d = \frac{1 - e^{-2\,(0.150)\left(\frac{10}{7}\right)}}{(2)\,(0.150)} \qquad \text{Equation 4.4}$$

$C_d = 1.16$

$$W_d = (1.16)(110)(7)^2 + \frac{(4.83)^2\,(4 - \pi)}{8}\,(110) \qquad \text{Equation 4.3}$$

W_d = 6,538 pounds per linear foot

$W_e = W_d$ W_E = 6,538 earth load in pounds per linear foot

Weight of Fluid, W_F, for a 48' pipe

$W_F = \gamma_w \text{ x } A$

$$W_F = 62.4 \text{ x } \frac{\pi\,(D_1)^2}{4} = 62.4 \text{ x } \frac{\pi\,(4)^2}{4}$$

W_F = 784.1 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at a depth of 10 feet.

3. Selection of Bedding
   Because of the narrow trench, good compaction of the soil on the sides of the pipe would be difficult, although not impossible. Therefore a Type 4 Installation was assumed.

4. Determination of Bedding Factor, (B_{fv})
   The pipe is installed in a trench that is less than transition width. Therefore, Equation 4.24 must be used to determine the variable bedding factor.

$B_c = D_o$ B_c = 4.83 outside diameter of pipe in feet

B_d = 7 width of trench in feet

B_{dt} = 8.5 transition width in feet

B_{fe} = 1.7 embankment bedding factor

B_{fo} = 1.5 minimum bedding factor

$$B_{fv} = \frac{(1.7 - 1.5)\,(7 - 4.83)}{8.5 - 4.83} + 1.5 \qquad \text{Equation 4.24}$$

$B_{fv} = 1.62$

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.26

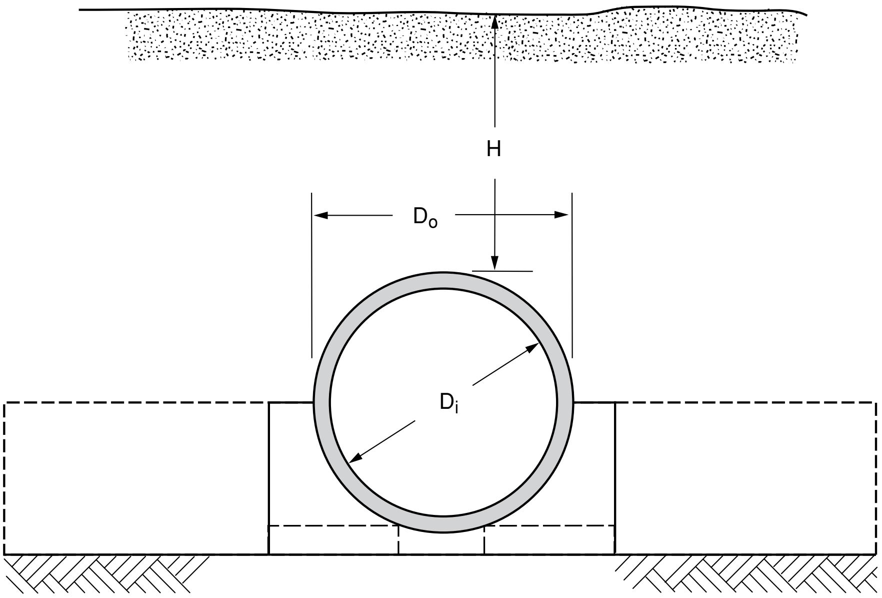
W_E = 6,538 earth load in pounds per linear foot
W_F = 784 fluid load in pounds per linear foot
W_L = 0 live load is negligible
B_f = B_{fv} $B_f = 1.62$ earth load bedding factor
B_{fLL} = N/A live load bedding factor is not applicable
D = 4 inside diameter of pipe in feet

$$D_{0.01} = \left(\frac{6{,}538 + 784.1}{1.62}\right)\left(\frac{1}{4}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 1,130 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 1,130 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-2
Positive Projection Embankment Installation



Given: A 48 inch circular pipe is to be installed in a positive projecting embankment condition using a Type 1 installation. The pipe will be covered with 35 feet of 120 pounds per cubic foot overfill.

Find: The required pipe strength in terms of 0.01 inch D-load

1. Determination of Earth Load (W_E)
   Per the given information, the installation behaves as a positive projecting embankment. Therefore, use Equation 4.2 to determine the soil prism load and multiply it by the appropriate vertical arching factor.

$$D_o = \frac{48 + 2\,(5)}{12}$$

Note: The wall thickness for a 48-inch pipe with a B wall is 5-inches per ASTM C76.

D_o = 4.83 outside diameter of pipe in feet

w = 120 unit weight of soil in pounds per cubic foot

H = 35 height of cover in feet

$$PL = 120 \left[35 + \frac{4.83\,(4 - \pi)}{8} \right] 4.83 \qquad \text{Equation 4.2}$$

PL = 20,586 pounds per linear foot

Immediately listed below Equation 4.2 are the vertical arching factors (VAFs) for the four types of Standard Installations. Using a VAF of 1.35 for a Type 1 Installation, the earth load is:

$W_E = 1.35 \text{ x } 20{,}586$

$W_E = 27{,}791$ pounds per linear foot Equation 4.1

Weight of Fluid, W_F, for a 48" pipe

$W_F = \gamma_w \text{ x } A$

$$W_F = 62.4 \text{ x } \frac{\pi\,(D_1)^2}{4} = 62.4 \text{ x } \frac{\pi\,(4)^2}{4}$$

$W_F = 784.1$ pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at a depth of 35 feet.

3. Selection of Bedding
   A Type 1 Installation will be used for this example

4. Determination of Bedding Factor, (B_{fe})
   The embankment bedding factor for a Type 1 Installation may be interpolated from Illustration 4.21

   B_{fe36} = 4.0

   B_{fe72} = 3.8

   $$B_{fe48} = \left(\frac{72 - 48}{72 - 36} \right) (4.0 - 3.8) + 3.8$$

   B_{fe48} = 3.93

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.26

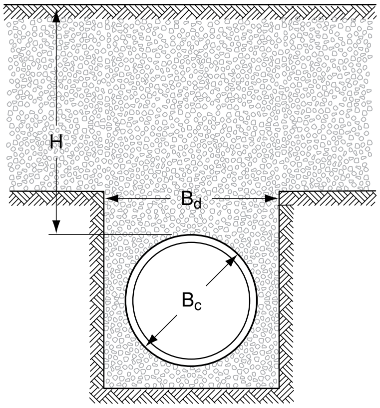
W_E = 27,791 earth load in pounds per linear foot
W_F = 784 fluid load in pounds per linear foot
W_L = 0 live load is negligible
B_f = B_{fe} B_f = 3.93 earth load bedding factor
B_{fLL} = N/A live load bedding factor is not applicable
D = 4 inside diameter of pipe in feet

$$D_{0.01} = \left(\frac{27{,}791 + 784.1}{3.93}\right)\left(\frac{1.0}{4}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 1,818 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test for the 0.01 inch crack of 1,818 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-3
Negative Projection Embankment Installation



Given: A 72 inch circular pipe is to be installed in a negative projecting embankment condition in ordinary soil. The pipe will be covered with 35 feet of 120 pounds per cubic foot overfill. A 10 foot trench width will be constructed with a 5 foot depth from the top of the pipe to the natural ground surface.

Find: The required pipe strength in terms of 0.01 inch D-load

1. Determination of Earth Load (W_E)
   A settlement ratio must first be assumed. The negative projection ratio of this installation is the height of soil from the top of the pipe to the top of the natural ground (5 ft) divided by the trench width (10 ft). Therefore the negative projection ratio of this installation is p' = 0.5. From Table 40, for a negative projection ratio of p' = 0.5, the design value of the settlement ratio is -0.1.

   Enter Figure 195 on the horizontal scale at H = 35 feet. Proceed vertically until the line representing B_d = 10 feet is intersected. At this point the vertical scale shows the fill load to be 27,500 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 20 percent for 120 pound material since Figure 195 shows values for 100 pound material.

W_n = 1.20 x 27,500
W_n = 33,000 pounds per linear foot
$W_E = W_n$ W_E = 33,000 earth load in pounds per linear foot

Weight of Fluid, W_F, for a 72" pipe
$W_F = \gamma_w \times A$

$$W_F = 62.4 \text{ x } \frac{\pi (D_1)^2}{4} = 62.4 \text{ x } \frac{\pi (6)^2}{4}$$

W_F = 1764 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at a depth of 35 feet.

3. Selection of Bedding
   No specific bedding was given. Assuming the contractor will put minimal effort into compacting the soil, a Type 3 Installation is chosen.

4. Determination of Bedding Factor, (B_{fv})
   The variable bedding factor will be determined using Equation 4.24 in the same fashion as if the pipe were installed in a trench.

$$B_c = \frac{72 + 2\,(7)}{12}$$

Note: The wall thickness for a 72-inch pipe with a B wall is 7-inches per ASTM C 76.

B_c = 7.17 outside diameter of pipe in feet

B_d = 10 trench width in feet

B_{dt} = 14.1 transition width for a Type 3 Installation with $K\mu'$=0.150

B_{fe} = 2.2 embankment bedding factor (taken from Illustration 4.21)

B_{fo} = 1.7 minimum bedding factor (taken from Illustration 4.22)

$$B_{fv} = \frac{(2.2 - 1.7)\,(10 - 7.17)}{14.1 - 7.17} + 1.7 \qquad \text{Equation 4.24}$$

B_{fv} = 1.9

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.26

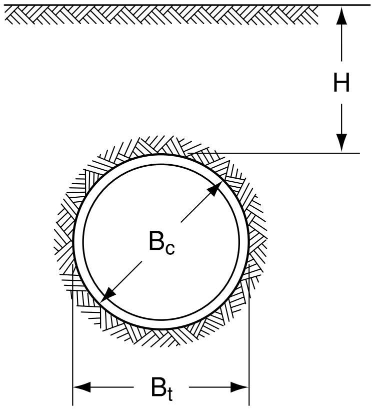
W_E = 33,000 earth load in pounds per linear foot
W_F = 1,764 fluid load in pounds per linear foot
W_L = 0 live load is negligible
B_f = B_{fv} B_f = 1.9 earth load bedding factor
B_{fLL} = N/A live load bedding factor is not applicable
D = 6 inside diameter of pipe in feet

$$D_{0.01} = \left(\frac{33{,}000 + 1{,}764}{1.9}\right)\left(\frac{1.0}{6}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 3,050 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 3,050 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-4
Jacked or Tunneled Installation



Given: A 48 inch circular pipe is to be installed by the jacking method of construction with a height of cover over the top of the pipe of 40 feet. The pipe will be jacked through ordinary clay material weighing 110 pounds per cubic foot throughout its entire length. The limit of excavation will be 5 feet.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
A coefficient of cohesion value must first be assumed. In Table 41, values of the coefficient of cohesion from 40 to 1,000 are given for clay. A conservative value of 100 pounds per square foot will be used.

Enter Figure 151, Ordinary Clay, and project a horizontal line from H = 40 feet on the vertical scale and a vertical line from B_t = 5 feet on the horizontal scale. At the intersection of these two lines interpolate between the curved lines for a value of 9,500 pounds per linear foot, which accounts for earth load without cohesion. Decrease the load in proportion to 110/120 for 110 pound material since Figure 151 shows values for 120 pound material.

$$W_t = \frac{110}{120} \text{ x } 9{,}500$$

W_t = 8,708 pounds per linear foot

Enter Figure 152, Ordinary Clay, and project a horizontal line from H = 40 feet on the vertical scale and a vertical line from B_t = 5 feet on the horizontal scale. At the intersection of these two lines interpolate between the curved lines for a value of 33, which accounts for the cohesion of the soil. Multiply this value by the coefficient of cohesion, c = 100, and subtract the product from the 8,708 value obtained from figure 151.

W_t = 8,708 –100 (33)
W_t = 5,408 pounds per linear foot
W_E = W_t W_E = 5,408 earth load in pounds per linear foot

Note: If the soil properties are not consistent, or sufficient information on the soil is not available, cohesion may be neglected and a conservative value of 8,708 lbs/ft used.

Weight of Fluid, W_F, for a 48" pipe
$W_F = \gamma_w \text{ x } A$

$$W_F = 62.4 \text{ x } \frac{\pi (D_1)^2}{4} = 62.4 \text{ x } \frac{\pi (4)^2}{4}$$

W_F = 784.1 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at 40 feet.

3. Selection of Bedding
   The annular space between the pipe and limit of excavation will be filled with grout.

4. Determination of Bedding Factor (B_{fv})
   Since the space between the pipe and the bore will be filled with grout, there will be positive contact of bedding around the periphery of the pipe. Because of this beneficial bedding condition, little flexural stress should be induced in the pipe wall. A conservative variable bedding factor of 3.0 will be used.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.
6. Selection of Pipe Strength
   The D-load is given by Equation 4.26.

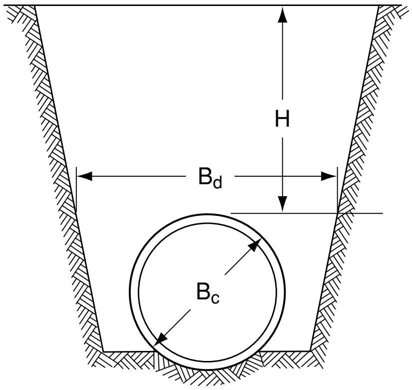
W_E = 5,408 earth load in pounds per linear foot
W_F = 784 fluid load in pounds per linear foot
W_L = 0 live load is negligible
B_f = B_{fv} $B_f = 3.0$ earth load bedding factor
B_{fLL} = N/A live load bedding factor is not applicable
D = 4 inside diameter of pipe in feet

$$D_{0.01} = \left(\frac{5{,}408 + 784.1}{3.0}\right)\left(\frac{1.0}{4}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 516 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 516 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-5
Wide Trench Installation



Given: A 24 inch circular non reinforced concrete pipe is to be installed in a 5 foot wide trench with 10 feet of cover over the top of the pipe. The pipe will be backfilled with ordinary clay weighing 120 pounds per cubic foot.

Find: The required three-edge bearing test strength for nonreinforced pipe and the ultimate D-load for reinforced pipe.

1. Determination of Earth Load (W_E)
To determine the earth load, we must first determine if the installation is behaving as a trench installation or an embankment installation. Assume that since the pipe is being backfilled with clay that they are using in-situ soil for backfill. Assume a Kμ' value between the existing soil and backfill of 0.130. We will assume a Type 4 Installation for this example.

From Table 17, the transition width for a 24 inch diameter pipe with a Kμ' value of 0.130 under 10 feet of fill is:
$B_{dt} = 4.8$
Since the transition width is less than the trench width, this installation will act as an embankment. Therefore calculate the prism load per

Equation 4.2 and multiply it by the appropriate vertical arching factor (VAF).

$$D_o = \frac{24 + 2\,(3)}{12}$$

Note: The wall thickness for a 24-inch pipe with a B wall is 3-inches per ASTM C76.

D_o = 2.5 outside diameter of pipe in feet

w = 120 unit weight of soil in pounds per cubic foot

H = 10 height of cover in feet

$$PL = 120\left[10 + \frac{2.5\,(4 - \pi)}{8}\right]2.5 \qquad \text{Equation 4.2}$$

PL = 3,080 pounds per linear foot

Immediately listed below Equation 4.2 are the vertical arching factors (VAF) for the four types of Standard Installations. Using a VAF of 1.45 for a Type 4 Installation, the earth load is:

$W_E = 1.45 \times 3{,}080$

$W_E = 4{,}466$ pounds per linear foot Equation 4.1

Weight of Fluid, W_F, for a 24" pipe

$W_F = \gamma_w \times A$

$$W_F = 62.4 \times \frac{\pi\,(D_1)^2}{4} = 62.4 \times \frac{\pi\,(2)^2}{4}$$

$W_F = 196$ pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at a depth of 10 feet.

3. Selection of Bedding
   A Type 4 Installation has been chosen for this example

4. Determination of Bedding Factor, (B_{fe})
   Since this installation behaves as an embankment, an embankment bedding factor will be chosen. From Illustration 4.21, the embankment bedding factor for a 24 inch pipe installed in a Type 4 Installation is:

   $B_{fe} = 1.7$

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.26.

W_E = 4,466 earth load in pounds per linear foot
W_F = 196 fluid load in pounds per linear foot
W_L = 0 live load is negligible
B_f = B_{fe} $B_f = 1.7$ earth load bedding factor
B_{fLL} = N/A live load bedding factor is not applicable
D = 2 inside diameter of pipe in feet

The ultimate three-edge bearing strength for nonreinforced concrete pipe is given by Equation 4.25

$$\text{TEB} = \left(\frac{4{,}466 + 196}{1.7}\right) 1.5 \qquad \text{Equation 4.25}$$

TEB = 4,114 pounds per linear foot

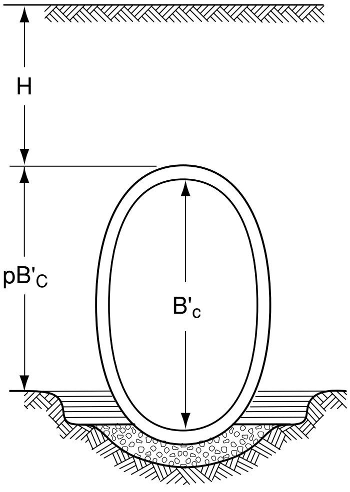
The D-load for reinforced concrete pipe is given by Equation 4.26.

$$D_{0.01} = \left(\frac{4{,}466 + 196}{1.7}\right)\left(\frac{1.0}{2}\right) \qquad \text{Equation 4.26}$$

$D_{0.01} = 1{,}371$ pounds per linear foot per foot of diameter

Answer: A nonreinforced pipe which would withstand a minimum three-edge bearing test load of 4,114 pounds per linear foot would be required.

EXAMPLE 4-6
Positive Projection Embankment Installation Vertical Elliptical Pipe



Given: A 76 inch x 48 inch vertical elliptical pipe is to be installed in a positive projection embankment condition in ordinary soil. The pipe will be covered with 50 feet of 120 pounds per cubic foot overfill.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)

Note: The Standard Installations were initially developed for circular pipe, and their benefit has not yet been established for elliptical and arch pipe. Therefore, the traditional Marston/Spangler design method using B and C beddings is still conservatively applied for these shapes.

A settlement ratio must first be assumed. In Table 40, values of settlement ratio from +0.5 to +0.8 are given for positive projecting installation on a foundation of ordinary soil. A value of 0.7 will be used. The product of the settlement ratio and the projection ratio will be 0.49 ($r_{sd}p$ approximately 0.5).

Enter Figure 182 on the horizontal scale at H = 50 feet. Proceed vertically until the line representing R x S = 76" x 48" is intersected. At this point the vertical scale shows the fill load to be 41,000 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 20 percent for 120 pound material.

W_c = 1.20 x 41,000

W_c = 49,200 per linear foot

$W_E = W_c$ W_E = 49,200 earth load in pounds per linear foot

Weight of Fluid, W_F, for a 76" x 48" pipe

$W_F = \gamma_w \times A$

$$W_F = 62.4 \times \frac{\pi 6.33 \times 4}{4}$$

W_F = 1241 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 44, live load is negligible at a depth of 50 feet.

3. Selection of Bedding
   Due to the high fill height you will more than likely want good support around the pipe, a Class B bedding will be assumed for this example.

4. Determination of Bedding Factor (B_{fe})
   First determine the H/B_c ratio.

$H = 50$

$$B_c = \frac{48 + 2\,(6.5)}{12}$$

Note: the wall thickness for a 72" x 48" elliptical pipe is 6.5" per ASTM C507.

B_c = 5.08 outside diameter of pipe in feet

H/B_c = 9.84

From Table 59, for an H/Bc ratio of 9.84, r_{sdp} value of 0.5, p value of 0.7, and a Class B bedding, an embankment bedding factor of 2.71 is obtained.

$B_{fe} = 2.71$

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.27

   W_E = 49,200 earth load in pounds per linear foot
   W_F = 1,242 fluid load in pounds per linear foot
   W_L = 0 live load is negligible
   B_f = B_{fe} $B_f = 2.71$ earth load bedding factor
   B_{fLL} = N/A live load bedding factor is not applicable
   S = 4 inside diameter of pipe in feet

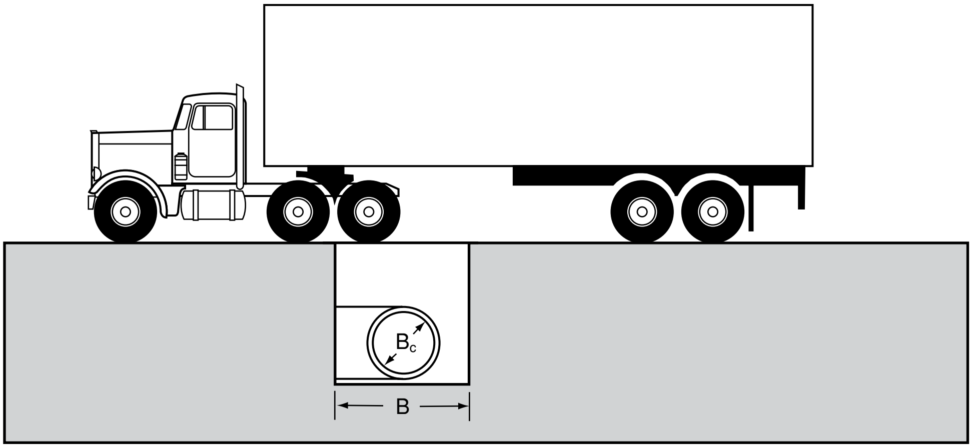
$$D_{0.01} = \left(\frac{49{,}200 + 1{,}241}{2.71}\right)\left(\frac{1.0}{4}\right) \qquad \text{Equation 4.27}$$

   $D_{0.01}$ = 4,653 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 4,654 pounds per linear foot per foot of inside horizontal span would be required.

EXAMPLE 4-7

Highway Live Load



Given: A 24 inch circular pipe is to be installed in a positive projection embankment under an unsurfaced roadway and covered with 2.0 feet of 120 pounds per cubic foot backfill material.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
   Per the given information, the installation behaves as a positive projecting embankment. Therefore, use Equation 4.2 to determine the soil prism load and multiply it by the appropriate vertical arching factor.

$$D_o = \frac{24 + 2\ (3)}{12}$$

Note: The wall thickness for a 24-inch pipe with a B wall is 3-inches per ASTM C76.

D_o = 2.5 outside diameter of pipe in feet

w = 120 unit weight of soil in pounds per cubic foot

H = 2 height of cover in feet

$$PL = 120 \left[2 + \frac{2.5\ \ (4 - \pi)}{8}\right] 2.5$$ Equation 4.2

PL = 680 pounds per linear foot

Assume a Type 2 Standard Installation and use the appropriate vertical arching factor listed below Equation 4.2.

VAF = 1.4

W_E = 1.40 x 680

W_E = 952 pounds per linear foot Equation 4.1

Weight of Fluid, W_F, for a 24" pipe

$W_F = \gamma_w$ x A

$$W_F = 62.4 \text{ x } \frac{\pi\,(2)^2}{4}$$

W_F = 196 pounds per linear foot

2. Determination of Live Load (W_L)
   Since the pipe is being installed under an unsurfaced roadway with shallow cover, a truck loading based on AASHTO will be evaluated. From Table 42, for D = 24 inches and H = 2.0 feet, a live load of 1,780 pounds per linear foot is obtained. This live load value includes impact.
   W_L = 1,780 pounds per linear foot

3. Selection of Bedding
   A Type 2 Standard Installation will be used for this example.

4. Determination of Bedding Factor, (B_{fe})
   a.) Determination of Embankment Bedding Factor
   From Illustration 4.21, the earth load bedding factor for a 24 inch pipe installed in a Type 2 positive projecting embankment condition is 3.0.

   B_{fe} = 3.0

   b.) Determination of Live Load Bedding Factor, (B_{fLL})
   From Illustration 4.24, the live load bedding factor for a 24 inch pipe under 2 feet of cover is 2.2.

   B_{fLL} = 2.2

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by equation 4.26

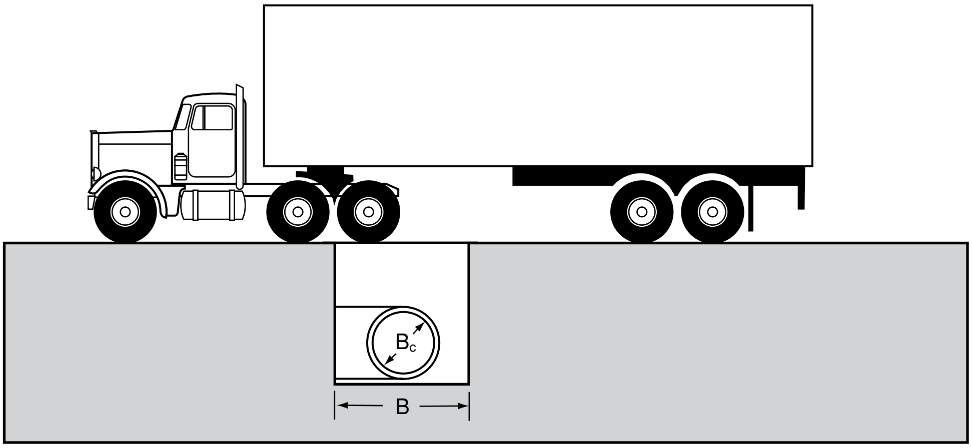
   W_E = 952 earth load in pounds per linear foot
   W_F = 196 fluid load in pounds per linear foot
   W_L = 1,780 live load in pounds per linear foot
   B_f = B_{fe} $B_f = 3$ earth load bedding factor
   B_{fLL} = 2.2 live load bedding factor is not applicable
   D = 2 inside diameter of pipe in feet

$$D_{0.01} = \left[\frac{952 + 196}{3.0} + \frac{1{,}780}{2.2}\right]\left(\frac{1.0}{2}\right) \qquad \text{Equation 4.26}$$

   $D_{0.01}$ = 596 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test for the 0.01 inch crack of 596 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-8
Highway Live Load per AASHTO LRFD



Given: A 30-inch diameter, B wall, concrete pipe is to be installed as a storm drain under a flexible pavement and subjected to AASHTO highway loadings. The pipe will be installed in a 6 ft wide trench with a minimum of 2 feet of cover over the top of the pipe. The AASHTO LRFD Criteria will be used with Select Granular Soil and a Type 3 Installation.

Find: The maximum 0.01” D_{load} required of the pipe.

1. Determination of Earth Load (W_E)
   Per review of Table 19, the 6 ft. trench is wider than transition width.

Therefore, the earth load is equal to the soil prism load multiplied by the appropriate vertical arching factor.

$$D_o = \frac{30 + 2\,(3.5)}{12}$$

Note: The wall thickness for a 30-inch pipe with a B wall is 3.5-inches per ASTM C76.

D_o = 3.08 outside diameter of pipe in feet

w = 120 unit weight of soil in pounds per cubic foot

H = 2 height of cover in feet

$$PL = 120\left[2 + \frac{3.08\,(4 - \pi)}{8}\right]3.08$$

PL = 861 pounds per linear foot

Illustration 4.7 lists the vertical arching factors (VAFs) for the four types of Standard Installations. Using a VAF of 1.40 for a Type 3 Installation, the earth load is:

W_E = 1.40 x 861 Equation 4.1

W_E = 1,205 pounds per linear foot

The weight of concrete pavement must be included also. Assuming 150 pounds per cubic foot unit weight of concrete, the total weight of soil and concrete is:

W_E = 1,205 + 150 x 1.0 x 3.08

W_E = 1,655 pounds per linear foot

Weight of Fluid, W_F, for a 30" pipe

$W_F = \gamma_w \times A$

$$W_F = 62.4 \times \frac{\pi\,(2.5)^2}{4}$$

W_F = 306 pounds per linear foot

2. Review project data.
   A 30-inch diameter, B wall, circular concrete pipe has a wall thickness of 3.5 inches, per ASTM C76 therefore

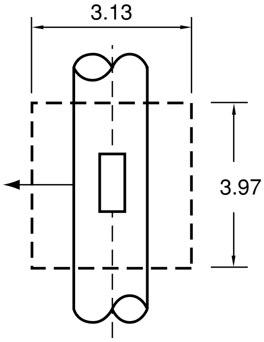
   $$B_c = \frac{30 + 2\,(3.5)}{12}$$

   B_c = 3.08

   And R_o, the outside height of the pipe, is 3.08 feet. Height of earth cover is 2 feet. Use AASHTO LRFD Criteria with Select Granular Soil Fill.
3. Calculate average pressure intensity of the live load on the plane at the outside top of the pipe.
   From Illustration 4.12, the critical load, P, is 16,000 pounds from an HS 20 single dual wheel, and the Spread Area is:

A = (Spread a)(Spread b)
A = (1.67 + 1.15x2)(0.83 + 1.15x2)
A = (3.97)(3.13)
A = 12.4 square feet

I.M. = 33(1.0-0.125H)/100
I.M. = 0.2475 (24.75%)
w = P(1+IM)/A
w = 16,000(1+0.2475)/12.4
w = 1,610 lb/ft^2

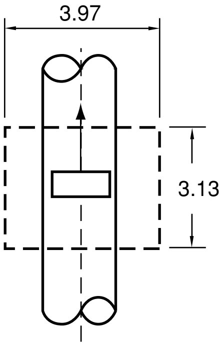


4. Calculate total live load acting on the pipe.

$W_T = (w + L_L)LS_L$

Assuming truck travel transverse to pipe centerline.

L_L = 64
L = Spread a = 3.97 feet
Spread b = 3.13 feet
B_c = 3.08 feet, which is less than Spread b, therefore
S_L = 3.08 feet
W_T = (1,610 + 64) 3.97 x 3.08 = 20,500 pounds



Assuming truck travel parallel to pipe centerline.
L_L = 64
Spread a = 3.97 feet
L = Spread b = 3.13 feet
B_c = 3.08 feet, which is less than Spread a, therefore
S_L = 3.08 feet
W_T = (1,610 + 64) 3.08 x 3.13 = 16,100 pounds

W_T Maximum = 20,500 pounds; and truck travel is transverse to pipe centerline

5. Calculate live load on pipe in pounds per linear foot, (W_L)

R_o = 3.08 feet
L_e = L + 1.75 (3/4Ro)
L_e = 3.97 + 1.75(.75 x 3.08) = 8.01 feet
W_L = W_T/L_e
W_L = 20,500/8.01 = 2,559 pounds per linear foot

The pipe should withstand a maximum live load of 2,559 pounds per linear foot.

6. Determination of Bedding Factor, (B_{fe})

a) Determination of Embankment Bedding Factor
The embankment bedding factor for a Type 3 Installation may be interpolated from Illustration 4.21

$B_{fe24} = 2.4$
$B_{fe36} = 2.3$
$$B_{fe30} = \frac{36 - 30}{34 - 24}(2.4 - 2.3) + 2.3$$
$B_{fe30} = 2.3$

b) Determination of Live Load Bedding Factor

From Illustration 4.24, the live load bedding factor for a 30 inch pipe under 3 feet of cover (one foot of pavement and two feet of soil) can be interpolated

$B_{fLL24} = 2.4$
$B_{fLL36} = 2.2$
Therefore $B_{fLL30} = 2.3$

7. Application of Factor of Safety (F.S.)
A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

8 Selection of Pipe Strength

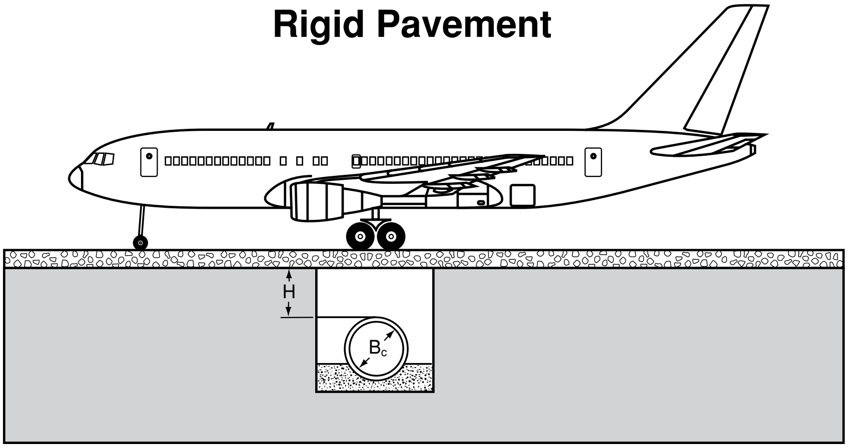
W_E = 1,655 earth load in pounds per linear foot
W_F = 307 fluid load in pounds per linear foot
W_L = 2,559 live load in pounds per linear foot
$B_f = B_{fe}$ $B_f = 2.35$ earth load bedding factor
B_{fLL} = 2.3 live load bedding factor is not applicable
D = 2.5 inside diameter of pipe in feet

$$D_{0.01} = \left[\frac{1,655 + 306}{2.35} + \frac{2,559}{2.3}\right]\left(\frac{1.0}{2.5}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 779 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test for the 0.01 inch crack of 779 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-9
Aircraft Live Load
Rigid Pavement



Given: A 12 inch circular pipe is to be installed in a narrow trench, B_d = 3ft under a 12 inch thick concrete airfield pavement and subject to heavy commercial aircraft loading. The pipe will be covered with 1.0 foot (measured from top of pipe to bottom of pavement slab) of sand and gravel material weighing 120 pounds per cubic foot.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
   Per review of Table 13, the 3 ft. trench is wider than transition width. Therefore, the earth load is equal to the soil prism load multiplied by the appropriate vertical arching factor.

$$D_o = \frac{12 + 2\ (2)}{12}$$

Note: The wall thickness for a 12-inch pipe with a B wall is 2-inches per ASTM C76.

D_o = 1.33 outside diameter of pipe in feet

w = 120 unit weight of soil in pounds per cubic foot

H = 1 height of cover in feet

$$PL = 120 \left[1 + \frac{1.33\ (4 - \pi)}{8} \right] 1.33 \qquad \text{Equation 4.2}$$

PL = 182 pounds per linear foot

Immediately listed below Equation 4.2 are the vertical arching factors (VAFs) for the four types of Standard Installations. Using a VAF of 1.40 for a Type 2 Installation, the earth load is:

W_E = 1.40 x 182 Equation 4.1

W_E = 255 pounds per linear foot

The weight of concrete pavement must be included also. Assuming 150 pounds per cubic foot unit weight of concrete, the total weight of soil and concrete is:

W_E = 255 + 150 x 1.0 x 1.33

W_E = 455 pounds per linear foot

Weight of Fluid, W_F, for a 12" pipe

$W_F = \gamma_w$ x A

$$W_F = 62.4 \text{ x } \frac{\pi (1)^2}{4}$$

W_F = 49 pounds per linear foot

2. Determination of Live Load (W_L)
   It would first be necessary to determine the bearing value of the backfill and/or subgrade. A modulus of subgrade reaction, k = 300 pounds per cubic inch will be assumed for this example. This value is used in Table 53A and represents a moderately compacted granular material, which is in line with the Type 2 Installation we are using.

   Based on the number of undercarriages, landing gear configurations and gross weights of existing and proposed future aircrafts, the Concorde is a reasonable commercial aircraft design loading for pipe placed under airfields. From Table 53A, for D = 12 inches and H = 1.0 foot, a live load of 1,892 pounds per linear foot is obtained.
   W_L = 1892 pounds per linear foot

3. Selection of Bedding
   Since this installation is under an airfield, a relatively good installation is required, therefore use a Type 2 Installation.

4. Determination of Bedding Factor, (B_{fe})
   a.) Determination of Embankment Bedding Factor

   From Illustration 4.21, the embankment bedding factor for a 12 inch pipe installed in a positive projecting embankment condition is 3.2.

   B_{fe} = 3.2

   b.) Determination of Live Load Bedding Factor

   From Illustration 4.24, the live load bedding factor for a 12 inch pipe under 2 feet of cover (one foot of pavement and one foot of soil) is 2.2.

   B_{fLL} = 2.2

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

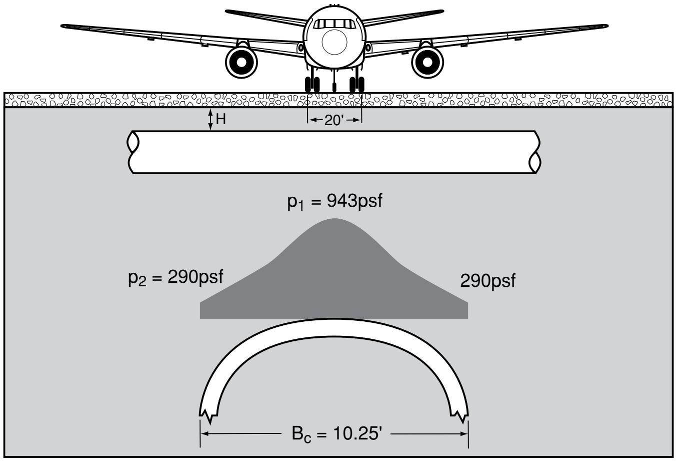
6. Selection of Pipe Strength
   The D-load is given by Equation 4.26

W_E = 455 earth load in pounds per linear foot
W_F = 49 fluid load in pounds per linear foot
W_L = 1,892 live load in pounds per linear foot
B_f = B_{fe} B_f = 3.2 earth load bedding factor
B_{fLL} = 2.2 live load bedding factor is not applicable
D = 1 inside diameter of pipe in feet

$$D_{0.01} = \left[\frac{455 + 49}{3.2} + \frac{1,892}{2.2}\right]\left(\frac{1.0}{1.0}\right) \qquad \text{Equation 4.26}$$

Answer: A pipe which would withstand a minimum three-edge bearing test for the 0.01 inch crack of 1,018 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE 4-10
Aircraft Live Load Rigid Pavement



Given: A 68 inch x 106 inch horizontal elliptical pipe is to be installed in a positive projecting embankment condition under a 7 inch thick concrete airfield pavement and subject to two 60,000 pound wheel loads spaced 20 feet, center to center. The pipe will be covered with 3-feet (measured from top of pipe to bottom of pavement slab) of sand and gravel material weighing 120 pounds per cubic foot.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
   Note: The Standard Installations were initially developed for circular

pipe, and their benefit has not yet been established for elliptical and arch pipe. Therefore, the traditional Marston/Spangler design method using B and C beddings is still conservatively applied for these shapes.

A settlement ratio must first be assumed. In Table 40, values of settlement ratio from +0.5 to +0.8 are given for positive projecting installations on a foundation of ordinary soil. A value of 0.7 will be used. The product of the settlement ratio and the projection ratio will be 0.49 ($r_{sd}p$ approximately 0.5).

Enter Figure 187 on the horizontal scale at H = 3 ft. Proceed vertically until the line representing R x S = 68" x 106" is intersected. At this point the vertical scale shows the fill load to be 3,400 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 20 percent for 120 pound material.

W_d = 3,400 x 1.2

W_d = 4,080 pounds per linear foot

outside span of pipe is:

$$B_c = \frac{106 + 2\,(8.5)}{12}$$

Note: The wall thickness for a 68"x106" ellipitical pipe is 8.5-inches per ASTM C76.

B_c = 10.25 feet

Assuming 150 pounds per cubic foot concrete, the weight of the pavement is:

W_p = 150 x 7/12 x 10.25

W_p = 897 pounds per linear foot

$W_E = W_d + W_p$

W_E = 4,977 pounds per linear foot

Weight of Fluid, W_F, for a 68" x 106" pipe

$W_F = \gamma \times A$

$$W_F = 62.4 \times \frac{\pi\,(5.67 \text{ X } 8.83)}{4}$$

W_F = 2454 pounds per linear foot

2. Determination of Live Load (W_L)

Assuming a modulus of subgrade reaction of k = 300 pounds per cubic inch and a pavement thickness of h = 7 inches, a radius of stiffness of 24.99 inches (2.08 feet) is obtained from Table 52. The wheel spacing in terms of the radius of stiffness is 20/2.08 = 9.6 R_s, therefore the maximum live load on the pipe will occur when one wheel is directly over the centerline of the pipe and the second wheel disregarded. The pressure intensity on the pipe is given by Equation 4.15:

$$P_{(X,H)} = \frac{C \times P}{R_s^2}$$

The pressure coefficient (C) is obtained from Table 46 at x = 0 and H = 3 feet.

For $x/R_s = 0$ and $H/R_s = 3/2.08 = 1.44$, C = 0.068 by interpolation between $H/R_s = 1.2$ and $H/R_s = 1.6$ in Table 46.

$$p_1 = \frac{(0.068)(60{,}000)}{(2.08)^2} \qquad \text{Equation 4.15}$$

p_1 = 943 pounds per square foot

In a similar manner pressure intensities are calculated at convenient increments across the width of the pipe. The pressure coefficients and corresponding pressures in pounds per square foot are listed in the accompanying table.

	x/R_s							
Point	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8
Pressure								
Coefficient C	0.068	0.064	0.058	0.050	0.041	0.031	0.022	0.015
Pressure psf	943	887	804	693	568	430	305	208

For convenience of computing the load in pounds per linear foot, the pressure distribution can be broken down into two components; a uniform load and a parabolic load.

The uniform load occurs where the minimum load is applied to the pipe at:

$$\frac{x}{R_s} = \frac{\frac{1}{2}B_c}{R_s} = \frac{5.13}{2.08}$$

$$\frac{x}{R_s} = 2.5$$

The pressure, p_2, is then interpolated between the points 2.4 and 2.8 from the chart x/R_s above, and equal to 290 pounds per square foot.

The parabolic load (area of a parabola = 2/3ab, or in this case $2/3\ (p_1\text{-}p_2)B_c$ has a maximum pressure of 653 pounds per foot.

Therefore the total live load, (W_L) is equal to:

$W_L = p_2 \times B_c + 2/3\ (p_1\text{-}p_2)B_c$
$W_L = 290 \times 10.25 + 2/3(943\text{-}290)10.25$
W_L = 7,435 pounds per linear foot

3. Selection of Bedding
   A Class B bedding will be assumed for this example.
4. Determination of Bedding Factor, (B_{fe})
   a.) Determination of Embankment Bedding Factor

From Table 60, a Class B bedding with p = 0.7, H/B_c = 3 ft/10.25 ft. = 0.3, and $r_{sd}p$ = 0.5, an embankment bedding factor of 2.42 is obtained.

$B_{fe} = 2.42$

b.) Determination of Live Load Bedding Factor
Live Load Bedding Factors are given in Illustration 4.24 for circular pipe. These factors can be applied to elliptical pipe by using the span of the pipe in place of diameter. The 106" span for the elliptical pipe in this example is very close to the 108" pipe diameter value in the table. Therefore, from Illustration 4.24, the live load bedding factor for a pipe with a span of 108 inches, buried under 3.5 feet of fill (3 feet of cover plus 7 inches of pavement is approx. 3.5 feet) is 1.7.

$B_{fLL} = 1.7$

5. Application of Factor of Safety (F.S.)
A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of pipe strength
The D-load given is given by Equation 4.27

W_E = 49,277 earth load in pounds per linear foot

W_F = 2,453 fluid load in pounds per linear foot

W_L = 7,435 live load in pounds per linear foot

$B_f = B_{fe}$ B_f = 2.42 earth load bedding factor

B_{fLL} = 1.7 live load bedding factor

S = 106/12

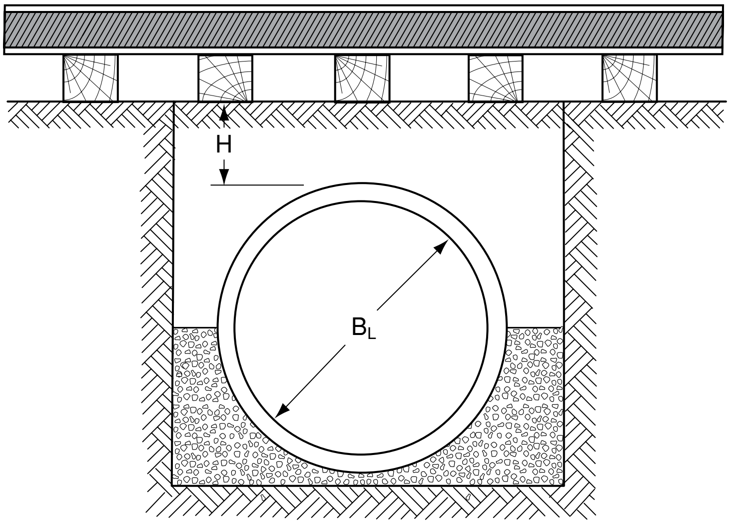
S = 8.83 inside span of pipe in feet

$$D_{0.01} = \left[\frac{4{,}977 + 2{,}454}{2.42} + \frac{7{,}435}{1.7}\right]\left(\frac{1.0}{8.83}\right) \qquad \text{Equation 4.27}$$

$D_{0.01}$ = 843 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 843 pounds per linear foot per foot of inside horizontal span would be required.

EXAMPLE 4-11
Railroad Live Load



Given: A 48 inch circular pipe is to be installed under a railroad in a 9 foot wide trench. The pipe will be covered with 1.0 foot of 120 pounds per cubic foot overfill (measured from top of pipe to bottom of ties).

Find: The required pipe strength in terms of 0.01 inch crack D-load.

1. Determination of Earth Load (W_E)
   The transition width tables do not have fill heights less than 5 ft. With only one foot of cover, assume an embankment condition. An installation directly below the tracks such as this would probably require good granular soil well compacted around it to avoid settlement of the tracks. Therefore assume a Type 1 Installation and multiply the soil prism load by a vertical arching factor of 1.35.

$$D_o = \frac{48 + 2\,(5)}{12}$$

Note: The wall thickness for a 48-inch pipe with a B wall is 5-inches per ASTM C76.

D_o = 4.83 outside diameter of pipe in feet
w = 120 unit weight of soil in pounds per cubic foot
H = 1 height of cover in feet

$$PL = 120 \left[1 + \frac{4.83\,(4 - \pi)}{8} \right] 4.83 \qquad \text{Equation 4.2}$$

PL = 880 pounds per linear foot

PL = 880 pounds per linear foot
Immediately listed below Equation 4.2 are the vertical arching factors (VAFs) for the four types of Standard Installations. Using a VAF of 1.35 for a Type 1 Installation, the earth load is:

W_E = 1.35 x 880
W_E = 1,188 pounds per linear foot Equation 4.1

Weight of Fluid, W_F, for a 48" pipe
$W_F = \gamma_w \text{ x } A$

$$W_F = 62.4 \text{ x } \frac{\pi (4)^2}{4}$$

W_F = 784.1 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 56, for a 48 inch diameter concrete pipe, H = 1.0 foot, and a Cooper E80 design load, a live load of 13,200 pounds per linear foot is obtained. This live load value includes impact.
   W_L = 13,200 pounds per linear foot

3. Selection of Bedding
   Since the pipe is in shallow cover directly under the tracks, a Type 1 Installation will be used.

4. Determination of Bedding Factor, (B_{fe})
   a.) Determination of Embankment Bedding Factor

   The embankment bedding factor for 48 inch diameter pipe in a Type 1 Installation may be interpolated from Illustration 4.21.

   $B_{fe36} = 4.0$
   $B_{fe72} = 3.8$

   $$B_{fe} = \frac{72 - 48\ (4.0 - 3.8)}{72 - 36} + 3.8$$

   $B_{fe} = 3.93$

   b.) Determination of Live Load Bedding Factor

   From Illustration 4.24, the live load bedding factor for a 48 inch pipe installed under 1 foot of cover is:
   $B_{fLL} = 1.5$

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation 4.26

W_E = 1,188 earth load in pounds per linear foot
W_F = 784 fluid load in pounds per linear foot
W_L = 13,200 live load in pounds per linear foot
B_f = B_{fe} B_f = 3.93 earth load bedding factor
B_{fLL} = 1.5 live load bedding factor is applicable
D = 4

$$D_{0.01} = \left[\frac{1{,}188 + 784.1}{3.93} + \frac{13{,}200}{1.5}\right]\left(\frac{1.0}{4}\right) \qquad \text{Equation 4.26}$$

$D_{0.01}$ = 2,325 pounds per linear foot per foot of diameter

Answer: A pipe which would withstand a minimum three-edge bearing test for the 0.01 inch crack of 2,326 pounds per linear foot per foot of inside diameter would be required.

CHAPTER 5

SUPPLEMENTAL DATA

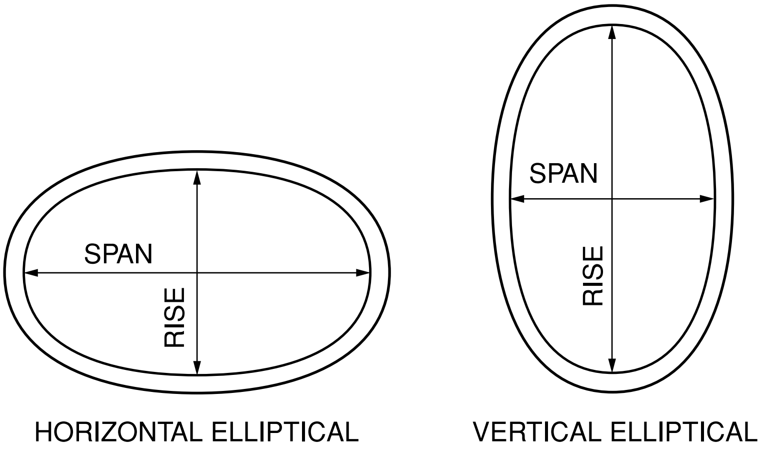
CIRCULAR CONCRETE PIPE

Illustration 5.2 includes tables of dimensions and approximate weights of most frequently used types of circular concrete pipe. Weights are based on concrete weighing 150 pounds per cubic foot. Concrete pipe may be produced which conforms to the requirements of the respective specifications but with increased wall thickness and different concrete density.

ELLIPTICAL CONCRETE PIPE

Elliptical pipe, shown in Illustration 5.1, installed with the major axis horizontal or vertical, represents two different products from the stand-point of structural strength, hydraulic characteristics and type of application. Illustration 5.3 includes the dimensions and approximate weights of elliptical concrete pipe.

Illustration 5.1 Typical Cross Sections of Horizontal Elliptical and Vertical Elliptical Pipe



Horizontal Elliptical (HE) Pipe. Horizontal elliptical concrete pipe is installed with the major axis horizontal and is extensively used for minimum cover conditions or where vertical clearance is limited by existing structures. It offers the hydraulic advantage of greater capacity for the same depth of flow than most other structures of equivalent water-way area. Under most embankment conditions, its wide span results in greater earth loadings for the same height of cover than for the equivalent size circular pipe and, at the same time, there is a reduction in effective lateral support due to the smaller vertical dimension of the section. Earth loadings are normally greater than for the equivalent circular pipe in

Illustration 5.2 Dimensions and Approximate Weights of Concrete Pipe

ASTM C 14 - Nonreinforced Sewer and Culvert Pipe, Bell and Spigot Joint.

CLASS 1			CLASS 2		CLASS 3	
Internal Diameter, inches	**Minimum Wall Thickness, inches**	**Approx. Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approx. Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approx. Weight, pounds per foot**
4	5/8	9.5	3/4	13	7/8	15
6	5/8	17	3/4	20	1	24
8	3/4	27	7/8	31	1 1/8	36
10	7/8	37	1	42	1 1/4	50
12	1	50	1 3/8	68	1 3/4	90
15	1 1/4	80	1 5/8	100	1 7/8	120
18	1 1/2	110	2	160	2 1/4	170
21	1 3/4	160	2 1/4	210	2 3/4	260
24	2 1/8	200	3	320	3 3/8	350
27	3 1/4	390	3 3/4	450	3 3/4	450
30	3 1/2	450	4 1/4	540	4 1/4	540
33	3 3/4	520	4 1/2	620	4 1/2	620
36	4	580	4 3/4	700	4 3/4	700

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Bell and Spigot Joint.

WALL A			WALL B	
Internal Diameter, inches	**Minimum Wall Thickness inches**	**Approximate Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approximate Weight,pounds per foot**
12	1 3/4	90	2	110
15	1 7/8	120	2 1/4	150
18	2	160	2 1/2	200
21	2 1/4	210	2 3/4	260
24	2 1/2	270	3	330
27	2 5/8	310	3 1/4	390
30	2 3/4	360	3 1/2	450

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

Illustration 5.2 (Continued) Dimensions and Approximate Weights of Concrete Pipe

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Tongue and Groove Joints

	WALL A		WALL B		WALL C	
Internal Diameter inches	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot
12	1 3/4	79	2	93	—	—
15	1 7/8	103	2 1/4	127	—	—
18	2	131	2 1/2	168	—	—
21	2 1/4	171	2 3/4	214	—	—
24	2 1/2	217	3	264	3 3/4	366
27	2 5/8	255	3 1/4	322	4	420
30	2 3/4	295	3 1/2	384	4 1/4	476
33	2 7/8	336	3 3/4	451	4 1/2	552
36	3	383	4	524	4 3/4	654
42	3 1/2	520	4 1/2	686	5 1/4	811
48	4	683	5	867	5 3/4	1011
54	4 1/2	864	5 1/2	1068	6 1/4	1208
60	5	1064	6	1295	6 3/4	1473
66	5 1/2	1287	6 1/2	1542	7 1/4	1735
72	6	1532	7	1811	7 3/4	2015
78	6 1/2	1797	7 1/2	2100	8 1/4	2410
84	7	2085	8	2409	8 3/4	2660
90	7 1/2	2395	8 1/2	2740	9 1/4	3020
96	8	2710	9	3090	9 3/4	3355
102	8 1/2	3078	9 1/2	3480	10 1/4	3760
108	9	3446	10	3865	10 3/4	4160

Illustration 5.2 (Continued) Dimensions and Approximate Weights of Concrete Pipe

Large Sizes of Pipe Tongue and Groove Joint			
Internal Diameter Inches	**Internal Diameter Feet**	**Wall Thickness Inches**	**Approximate Weight, pounds per foot**
114	9 1/2	9 1/2	3840
120	10	10	4263
126	10 1/2	10 1/2	4690
132	11	11	5148
138	11 1/2	11 1/2	5627
144	12	12	6126
150	12 1/2	12 1/2	6647
156	13	13	7190
162	13 1/2	13 1/2	7754
168	14	14	8339
174	14 1/2	14 1/2	8945
180	15	15	9572

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

the trench condition, since a greater trench width is usually required for HE pipe. For shallow cover, where live load requirements control the design, loading is almost identical to that for an equivalent size circular pipe with the same invert elevation.

Vertical Elliptical (VE) Pipe. Vertical elliptical concrete pipe is installed with the major axis vertical and is useful where minimum horizontal clearances are encountered or where unusual strength characteristics are desired. Hydraulically, it provides higher flushing velocities under minimum flow conditions and carries equal flow at a greater depth than equivalent HE or circular pipe. For trench conditions the smaller span requires less excavation than an equivalent size circular pipe and the pipe is subjected to less vertical earth load due to the narrower trench. The structural advantages of VE pipe are particularly applicable in the embankment condition where the greater height of the section increases the effective lateral support while the vertical load is reduced due to the smaller span.

CONCRETE ARCH PIPE

Arch pipe, as shown in Illustration 5.4, is useful in minimum cover situations or other conditions where vertical clearance problems are encountered. It offers the hydraulic advantage of greater capacity for the same depth of flow than most other structures of equivalent water-way area. Structural characteristics are

Illustration 5.3 Dimensions and Approximate Weights of Elliptical Concrete Pipe

ASTM C 507-Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe

Equivalent Round Size, inches	Minor Axis, inches	Major Axis, inches	Minimum Wall Thickness, inches	Water-Way Area, square feet	Approximate Weight, pounds per foot
18	14	23	2 3/4	1.8	195
24	19	30	3 1/4	3.3	300
27	22	34	3 1/2	4.1	365
30	24	38	3 3/4	5.1	430
33	27	42	3 3/4	6.3	475
36	29	45	4 1/2	7.4	625
39	32	49	4 3/4	8.8	720
42	34	53	5	10.2	815
48	38	60	5 1/2	12.9	1000
54	43	68	6	16.6	1235
60	48	76	6 1/2	20.5	1475
66	53	83	7	24.8	1745
72	58	91	7 1/2	29.5	2040
78	63	98	8	34.6	2350
84	68	106	8 1/2	40.1	2680
90	72	113	9	46.1	3050
96	77	121	9 1/2	52.4	3420
102	82	128	9 3/4	59.2	3725
108	87	136	10	66.4	4050
114	92	143	10 1/2	74.0	4470
120	97	151	11	82.0	4930
132	106	166	12	99.2	5900
144	116	180	13	118.6	7000

similar to those of horizontal elliptical pipe in that under similar cover conditions it is subject to the same field load as a round pipe with the same span. For minimum cover conditions where live load requirements control the design, the loading to which arch pipe is subjected is almost identical to that for an equivalent size circular pipe with the same invert elevation. Illustration 5.5 includes the dimensions and approximate weights of concrete arch pipe.

Illustration 5.4 Typical Cross Section of Arch Pipe

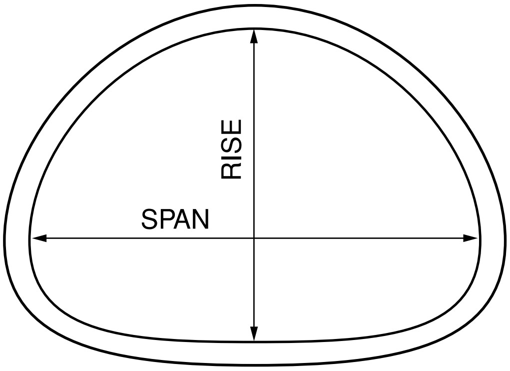
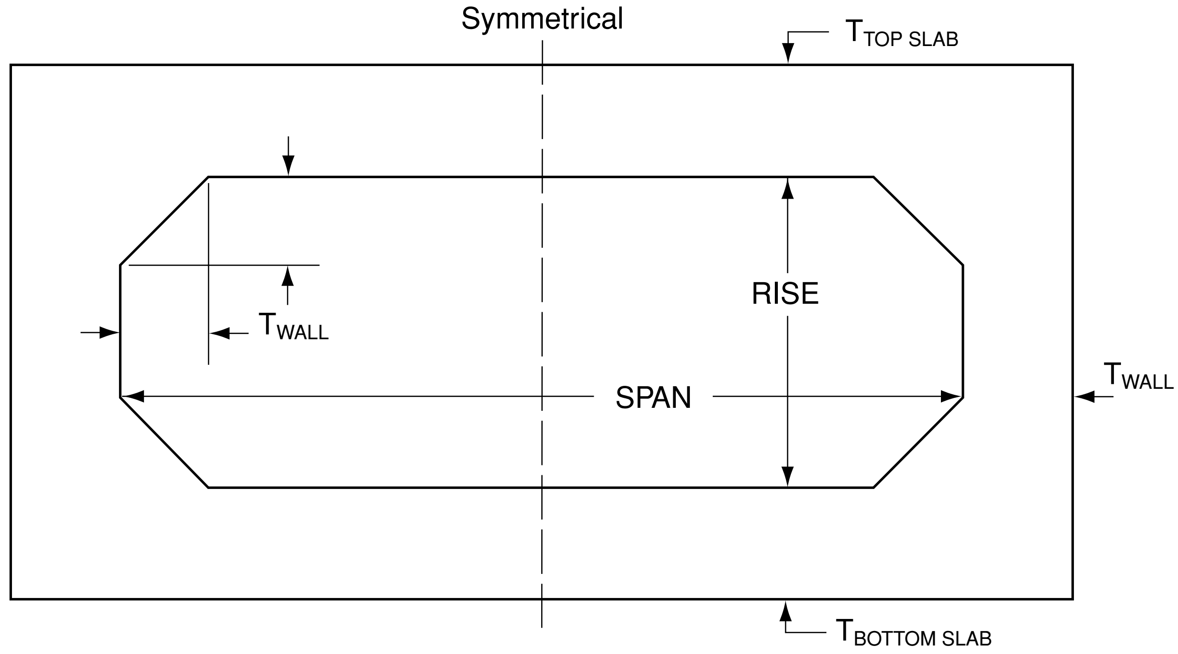


Illustration 5.5 Dimensions and Approximate Weights of Concrete Arch Pipe

ASTM C 506 - Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe

Equivalent Round Size, inches	Minimum Rise, inches	Minimum Span, inches	Minimum Wall Thickness, inches	Water-Way Area, square feet	Approximate Weight, pounds per foot
15	11	18	2 1/4	1.1	—
18	13 1/2	22	2 1/2	1.65	170
21	15 1/2	26	2 3/4	2.2	225
24	18	28 1/2	3	2.8	320
30	22 1/2	36 1/4	3 1/2	4.4	450
36	26 5/8	43 3/4	4	6.4	595
42	31 5/16	51 1/8	4 1/2	8.8	740
48	36	58 1/2	5	11.4	880
54	40	65	5 1/2	14.3	1090
60	45	73	6	17.7	1320
72	54	88	7	25.6	1840
84	62	102	8	34.6	2520
90	72	115	8 1/2	44.5	2750
96	77 1/4	122	9	51.7	3110
108	87 1/8	138	10	66.0	3850
120	96 7/8	154	11	81.8	5040
132	106 1/2	168 3/4	10	99.1	5220

Illustration 5.6 Typical Cross Section of Precast Concrete Box Sections



CONCRETE BOX SECTIONS

Precast concrete box sections, as shown in Illustration 5.6, are useful in minimum cover and width situations or other conditions where clearance problems are encountered, for special waterway requirements, or designer preference. Illustration 5.7 includes the dimensions and approximate weights of standard precast concrete box sections. Special design precast concrete box sections may be produced which conform to the requirements of the respective specifications but in different size and cover conditions.

Illustration 5.7 Dimensions and Approximate Weights of Concrete Box Sections

ASTM C1433 - PRECAST REINFORCED CONCRETE BOX SECTIONS

Span (Ft.)	Rise (Ft.)	Thickness (in.)			Waterway Area (Sq. Feet)	Approx. Weight† (lbs/ft)
		Top Slab	Bot. Slab	Wall		
3	2	7	6	4	5.8	830
3	3	7	6	4	8.8	930
4	2	7 1/2	6	5	7.7	1120
4	3	7 1/2	6	5	11.7	1240
4	4	7 1/2	6	5	15.7	1370
5	3	8	7	6	14.5	1650
5	4	8	7	6	19.5	1800
5	5	8	7	6	24.5	1950
6	3	8	7	7	17.3	1970
6	4	8	7	7	23.3	2150
6	5	8	7	7	29.3	2320
6	6	8	7	7	35.3	2500
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

SPECIAL SECTIONS

Precast Concrete Manhole Sections. Precast manholes offer significant savings in installed cost over cast-in-place concrete, masonry or brick manholes and are universally accepted for use in sanitary or storm sewers. Precast, reinforced concrete manhole sections are available throughout the United States and Canada, and are generally manufactured in accordance with the provisions of American Society for Testing and Materials Standard C 478.

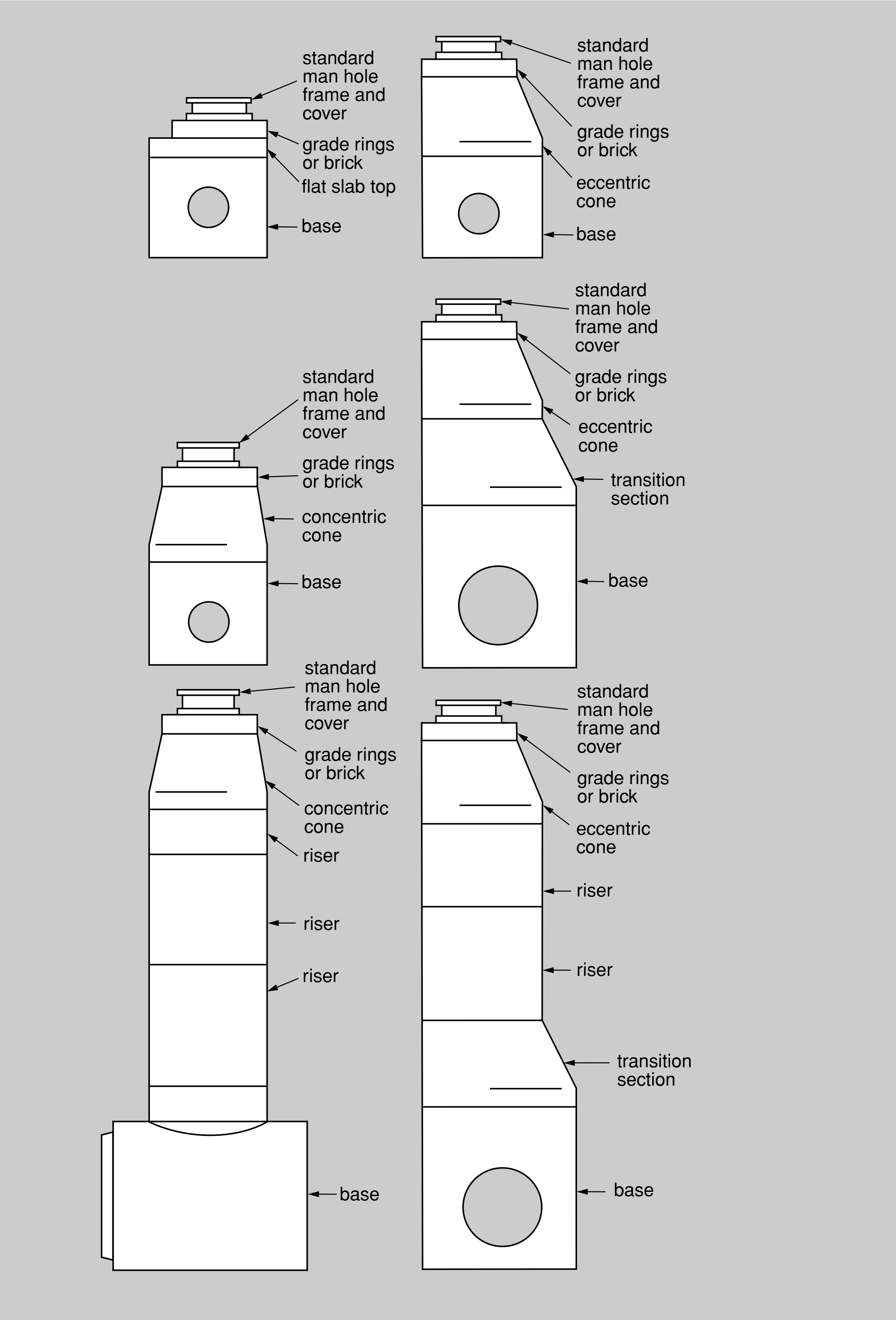
The typical precast concrete manhole as shown in Illustration 5.8 consists of riser sections, a top section and grade rings and, in many cases, precast base sections or tee sections. The riser sections are usually 48 inches in diameter, but are available from 36 inches up to 72 inches and larger. They are of circular cross section, and a number of sections may be joined vertically on top of the base or junction chamber. Most precast manholes employ an eccentric or a concentric cone section instead of a slab top. These reinforced cone sections affect the transition from the inside diameter of the riser sections to the specified size of the top opening. Flat slab tops are normally used for very shallow manholes and consist of a reinforced circular slab at least 6-inches thick for risers up to 48 inches in diameter and 8-inches thick for larger riser sizes. The slab which rests on top of the riser sections is cast with an access opening.

Precast grade rings, which are placed on top of either the cone or flat slab top section, are used for close adjustment of top elevation. Cast iron manhole cover assemblies are normally placed on top of the grade rings.

The manhole assembly may be furnished with or without steps inserted into the walls of the sections. Reinforcement required by ASTM Standard C 478 is primarily designed to resist handling stresses incurred before and during installation, and is more than adequate for that purpose. Such stresses are more severe than those encountered in the vertically installed manhole. In normal installations, the intensity of the earth loads transmitted to the manhole risers is only a fraction of the intensity of the vertical pressure.

The maximum allowable depth of a typical precast concrete manhole with regard to lateral earth pressures is in excess of 300 feet or, for all practical purposes, unlimited, Because of this, the critical or limiting factor for manhole depth is the supporting strength of the base structure or the resistance to crushing of the ends of the riser section. This phenomena, being largely dependent on the relative settlement of the adjacent soil mass, does not lend itself to precise analysis. Even with extremely conservative values for soil weights, lateral pressure and friction coefficients, it may be concluded several hundred feet can be safely supported by the riser sections without end crushing, based on the assumption that provision is made for uniform bearing at the ends of the riser sections and the elimination of localized stress concentrations.

Illustration 5.8 Typical Configuration of Precast Manhole Sections



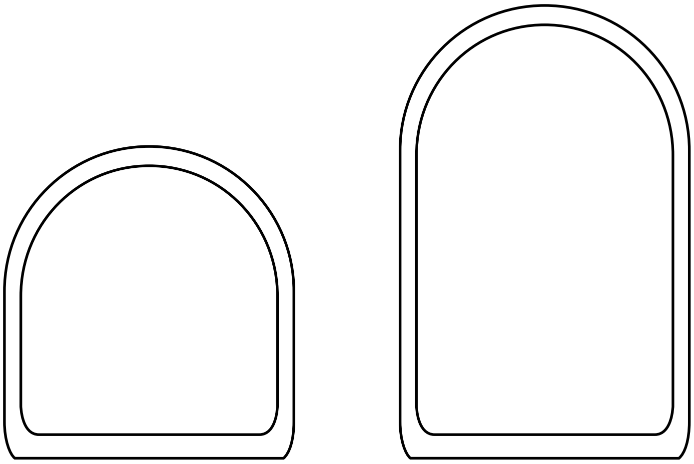
When confronted with manhole depths greater than those commonly encountered, there may be a tendency to specify additional circumferential reinforcement in the manhole riser sections. Such requirements are completely unnecessary and only result in increasing the cost of the manhole structure.

A number of joint types may be used for manhole risers and tops, including mortar, mastic, rubber gaskets or combinations of these three basic types for sealing purposes. Consideration should be given to manhole depth, the presence of groundwater and the minimum allowable leakage rates in the selection of specific joint requirements.

Flat Base Pipe. Flat base pipe as shown in Illustration 5.9 has been used as cattle passes, pedestrian underpasses and utility tunnels. It is normally furnished with joints designed for use with mortar or mastic fillers and may be installed by the conventional open trenching method or by jacking.

Although not covered by any existing national specification, standard designs have been developed by various manufacturers which are appropriate for a wide range of loading conditions.

Illustration 5.9 Typical Cross Sections of Flat Base Pipe



STANDARD SPECIFICATIONS FOR CONCRETE PIPE

Nationally accepted specifications covering concrete pipe along with the applicable size ranges and scopes of the individual specifications are included in the following list.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 14 Concrete Sewer, Storm Drain and Culvert Pipe: Covers nonreinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, storm water, and for the construction of culverts in sizes from 4 inches through 36 inches in diameter.

ASTM C 76	Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe: Covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm waters, and for the construction of culverts. Class I - 60 inches through 144 inches in diameter; Class II, III, IV and V - 12 inches through 144 inches in diameter. Larger sizes and higher classes are available as special designs.
ASTM C 118	Concrete Pipe for Irrigation or Drainage: Covers concrete pipe intended to be used for the conveyance of irrigation water under low hydrostatic heads, generally not exceeding 25 feet, and for use in drainage in sizes from 4 inches through 24 inches in diameter.
ASTM C 361	Reinforced Concrete Low-Head Pressure Pipe: Covers reinforced concrete pipe intended to be used for the construction of pressure conduits with low internal hydrostatic heads generally not exceeding 125 feet in sizes from 12 inches through 108 inches in diameter.
ASTM C 412	Concrete Drain Tile: Covers nonreinforced concrete drain tile with internal diameters from 4 inches to 24 inches for Standard Quality, and 4 inches to 36 inches for Extra-Quality, Heavy-Duty Extra-Quality and Special Quality Concrete Drain Tile.
ASTM C 443	Joints for Circular Concrete Sewer and Culvert Pipe, with Rubber Gaskets: Covers joints where infiltration or exfiltration is a factor in the design, including the design of joints and the requirements for rubber gaskets to be used therewith for pipe conforming in all other respects to ASTM C 14 or ASTM C 76.
ASTM C 444	Perforated Concrete Pipe: Covers perforated concrete pipe intended to be used for underdrainage in sizes 4 inches and larger.
ASTM C 478	Precast Reinforced Concrete Manhole Sections: Covers precast reinforced concrete manhole risers, grade rings and tops to be used to construct manholes for storm and sanitary sewers.
ASTM C 497	Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile: Covers procedures for testing concrete pipe and tile.
ASTM C 505	Nonreinforced Concrete Irrigation Pipe With Rubber Gasket Joints: Covers pipe to be used for the conveyance of irrigation water with working pressures, including hydraulic transients, of up to 30 feet of head. Higher pressures may be used up to a maximum of 50 feet for 6 inch through 12 inch diameters, and 40 feet for 15 inch through 18 inch diameters by increasing the strength of the pipe.

ASTM C 506	Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe: Covers pipe to be used for the conveyance of sewage, industrial waste, and storm water and for the construction of culverts in sizes from 15 inch through 132 inch equivalent circular diameter. Larger sizes are available as special designs.
ASTM C 507	Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe: Covers reinforced elliptically shaped concrete pipe to be used for the conveyance of sewage, industrial waste and storm water, and for the construction of culverts. Five standard classes of horizontal elliptical, 18 inches through 144 inches in equivalent circular diameter and five standard classes of vertical elliptical, 36 inches through 144 inches in equivalent circular diameter are included. Larger sizes are available as special designs.
ASTM C 655	Reinforced Concrete D-load Culvert, Storm Drain and Sewer Pipe: Covers acceptance of pipe design and production pipe based upon the D-load concept and statistical sampling techniques for concrete pipe to be used for the conveyance of sewage, industrial waste and storm water and construction of culverts.
ASTM C 822	Standard Definitions and Terms Relating to Concrete Pipe and Related Products: Covers words and terms used in concrete pipe standards.
ASTM C 877	External Sealing Bands for NonCircular Concrete Sewer, Storm Drain and Culvert Pipe: Covers external sealing bands to be used for noncircular pipe conforming to ASTM C 506, C 507, C 789 and C 850.
ASTM C 923	Resilient Connectors Between Reinforced Concrete Manhole Structures and Pipes: Covers the minimum performance and material requirements for resilient connections between pipe and reinforced concrete manholes conforming to ASTM C 478.
ASTM C 924	Testing Concrete Pipe Sewer Lines by Low-Pressure Air Test Method: Covers procedures for testing concrete pipe sewer lines when using the low-pressure air test method to demonstrate the integrity of the installed material and construction procedures.
ASTM C 969	Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines: Covers procedures for testing installed precast concrete pipe sewer lines using either water infiltration or exfiltration acceptance limits to demonstrate the integrity of the installed materials and construction procedure.

ASTM C 985	Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe: Covers nonreinforced concrete pipe designed for specified strengths and intended to be used for the conveyance of sewage, industrial wastes, storm water, and for the construction of culverts.
ASTM C 990	Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Sealants: Covers joints for precast concrete pipe, box, and other sections using preformed flexible joint sealants for use in storm sewers and culverts which are not intended to operate under internal pressure, or are not subject to infiltration or exfiltration limits.
ASTM C 1103	Joint Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines: Covers procedures for testing the joints of installed precast concrete pipe sewer lines, when using either air or water under low pressure to demonstrate the integrity of the joint and construction procedure.
ASTM C 1131	Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems: Covers procedures for least cost (life cycle) analysis (LCA) of materials, systems, or structures proposed for use in the construction of concrete culvert, storm sewer and sanitary sewer systems.
ASTM C 1214	Test Method for Concrete Pipe Sewerlines by Negative Air Pressure (Vacuum) Test Method: Covers procedures for testing concrete pipe sewerlines, when using the negative air pressure (vacuum) test method to demonstrate the integrity of the installed material and the construction procedures.
ASTM C 1244	Test Method for Concrete Sewer Manholes by the Negative Air Pressure (Vacuum) Test: Covers procedures for testing precast concrete manhole sections when using the vacuum test method to demonstrate the integrity of the installed materials and the construction procedures.
ASTM C 1417	Manufacture of Reinforced Concrete Sewer, Storm Drain, and Culvert Pipe for Direct Design: Covers the manufacture and acceptance of precast concrete pipe designed to conform to the owner’s design requirements and to ASCE 15-93 (Direct Design Standard) or an equivalent design specification.
ASTM C 1433	Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers: Covers single-cell precast reinforced concrete box sections intended to be used for the construction of culverts

for the conveyance of storm water and industrial wastes and sewage.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO M 86	Concrete Sewer, Storm Drain, and Culvert Pipe: Similar to ASTM C 14.
AASHTO M 170	Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe: Similar to ASTM C 76.
AASHTO M 175	Perforated Concrete Pipe: Similar to ASTM C 444.
AASHTO M 178	Concrete Drain Tile: Similar to ASTM C 412.
AASHTO M 198	Joints for Circular Concrete Sewer and Culvert Pipe, Using Flexible Watertight Gaskets: Similar to ASTM C 990.
AASHTO M 199	Precast Reinforced Concrete Manhole Sections: Similar to ASTM C 478.
AASHTO M 206	Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe: Similar to ASTM C 506.
AASHTO M 207	Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe: Similar to ASTM C 507.
AASHTO M 242	Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe: Similar to ASTM C 655.
AASHTO M 259	Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers: Similar to ASTM C 789.
AASHTO M 262	Concrete Pipe and Related Products: Similar to ASTM C 882.
AASHTO M 273	Precast Reinforced Box Section for Culverts, Storm Drains, and Sewers with less than 2 feet of Cover Subject to Highway Loadings: Similar to ASTM C 850.
AASHTO T 280	Methods of Testing Concrete Pipe, Sections, or Tile: Similar to ASTM C 497.
AASHTO M 315	Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets: Similar to ASTM C 443.

PIPE JOINTS

Pipe joints perform a variety of functions depending upon the type of pipe and its application. To select a proper joint, determine which of the following characteristics are pertinent and what degree of performance is acceptable.

Joints are designed to provide:

1. Resistance to infiltration of ground water and/or backfill material.
2. Resistance to exfiltration of sewage or storm water.
3. Control of leakage from internal or external heads.
4. Flexibility to accommodate lateral deflection or longitudinal movement without creating leakage problems.
5. Resistance to shear stresses between adjacent pipe sections without creating leakage problems.
6. Hydraulic continuity and a smooth flow line.
7. Controlled infiltration of ground water for subsurface drainage.
8. Ease of installation.

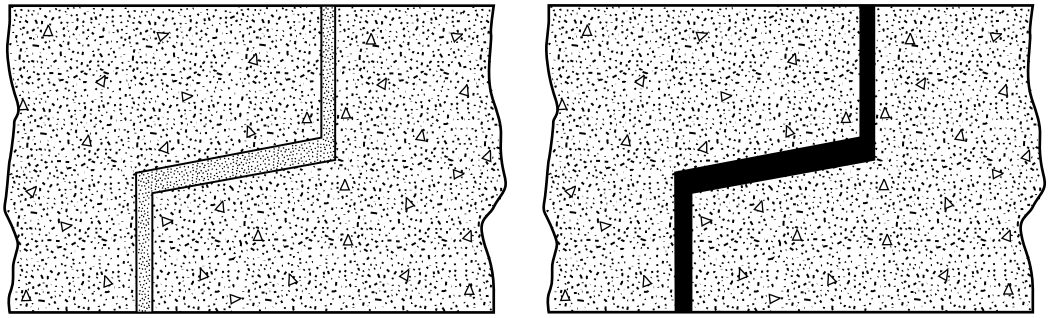
The actual field performance of any pipe joint depends primarily upon the inherent performance characteristics of the joint itself, the severity of the conditions of service, and the care with which it is installed.

Since economy is important, it is usually necessary to compare the installed cost of several types of joints against pumping and treatment costs resulting from increased or decreased amounts of infiltration.

The concrete pipe industry utilizes a number of different joints, listed below, to satisfy a broad range of performance requirements. These joints vary in cost, as well as in inherent performance characteristics. The field performance of all is dependent upon proper installation procedures.

- Concrete surfaces, either bell and spigot or tongue and groove, with some packing such as cement mortar, a preformed mastic compound, or a trowel applied mastic compound, as shown in Illustration 5.10. These joints have no inherent watertightness but depend exclusively upon the workmanship of the contractor. Field poured concrete diapers or collars are sometimes used with these joints to improve performance. Joints employing mortar joint fillers are rigid, and any deflection or movement after installation will cause cracks permitting leakage. If properly applied, mastic joint fillers provide a degree of flexibility without impairing watertightness. These joints are not generally recommended for any internal or external head conditions if leakage is an important consideration. Another jointing system used with this type joint is the external sealing band type rubber gasket conforming to ASTM C 877. Generally limited to straight wall and modified tongue and groove configurations, this jointing system has given good results in resisting external heads of the magnitude normally encountered in sewer construction.

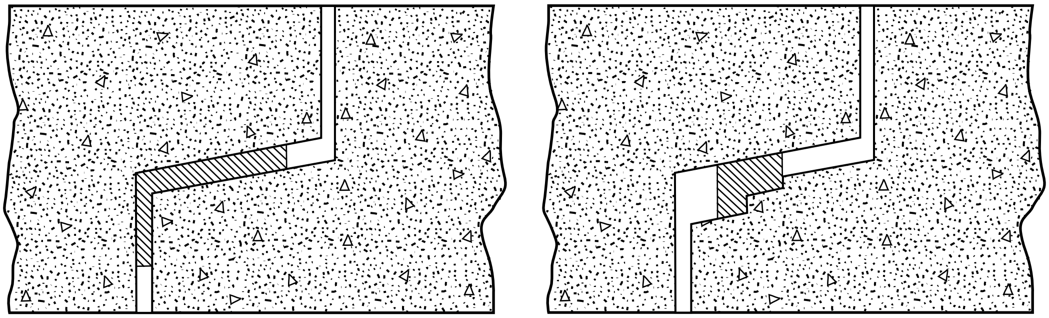
Illustration 5.10 Typical Cross Sections of Joints With Mortar or Mastic Packing



MORTOR PACKING MASTIC PACKING

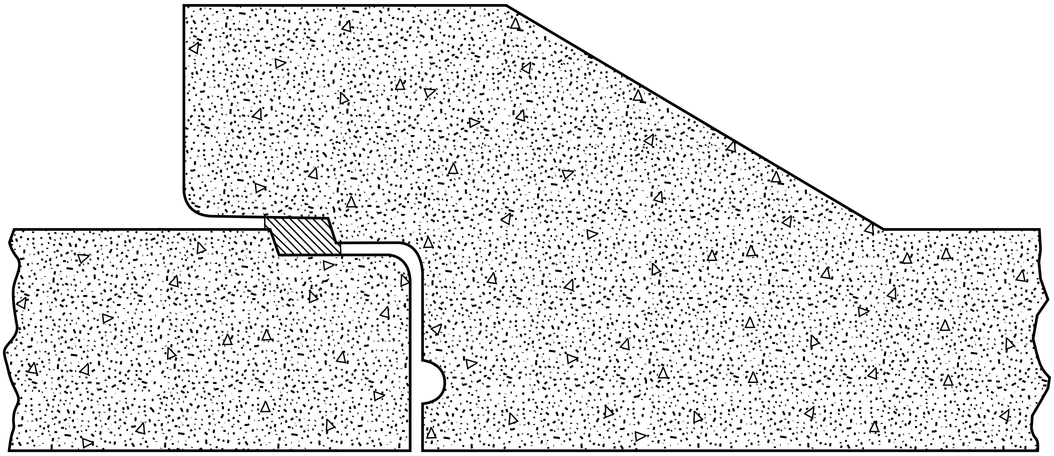
- Concrete surfaces, with or without shoulders on the tongue or the groove, with a compression type rubber gasket as shown in Illustration 5.11. Although there is wide variation in joint dimensions and gasket cross section for this type joint, most are manufactured in conformity with ASTM C 443. This type joint is primarily intended for use with pipe manufactured to meet the requirements of ASTM C 14 or ASTM C 76 and may be used with either bell and spigot or tongue and groove pipe.

Illustration 5.11 Typical Cross Sections of Basic Compression Type Rubber Gasket Joints



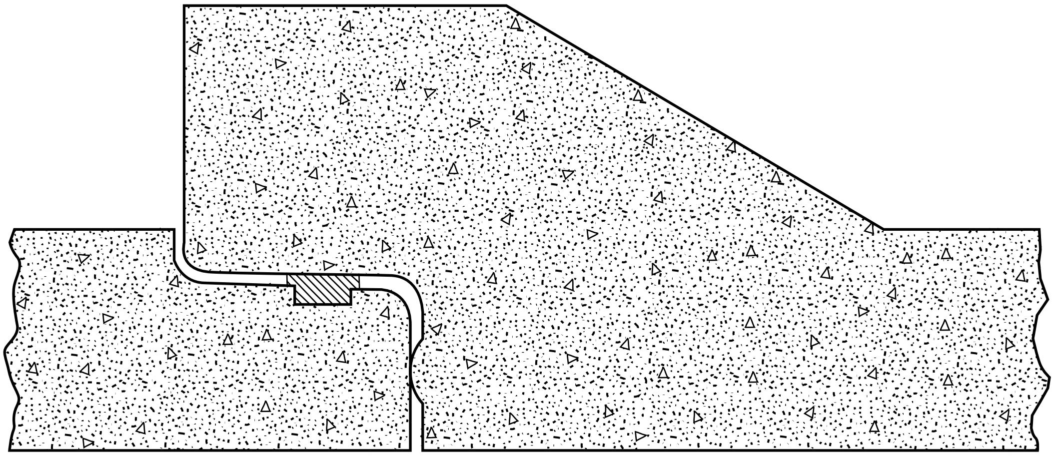
- Concrete surfaces with opposing shoulders on both the bell and spigot for use with an 0-ring, or circular cross section, rubber gasket as shown in Illustration 5.12. Basically designed for low pressure capability, these joints are frequently used for irrigation lines, waterlines, sewer force mains, and gravity or low head sewer lines where infiltration or exfiltration is a factor in the design. Meeting all of the requirements of ASTM C 443, these type joints are also employed with pipe meeting the requirements of ASTM C 361. They provide good inherent watertightness in both the straight and deflected positions, which can be demonstrated by plant tests.

Illustration 5.12 Typical Cross Sections of Opposing Shoulder Type Joint With 0-ring Gasket



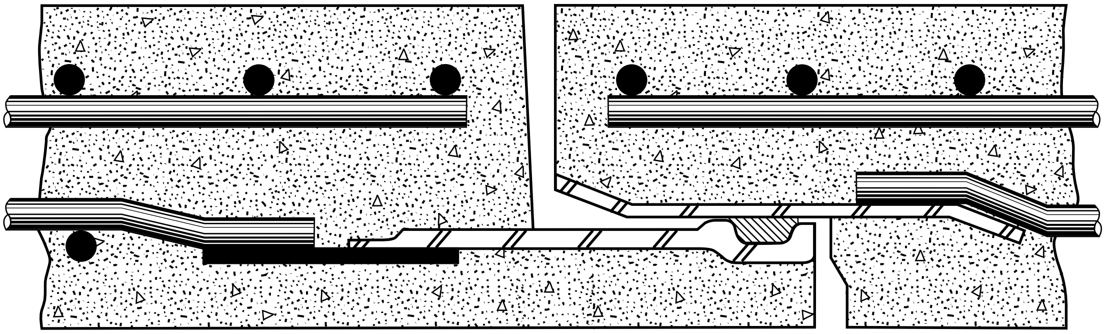
- Concrete surfaces with a groove on the spigot for an 0-ring rubber gasket, as shown in Illustration 5.13. Also referred to as a confined 0-ring type joint, these are designed for low pressure capabilities and are used for irrigation lines, water lines, sewer force mains, and sewers where infiltration or exfiltration is a factor in the design. This type joint, which provides excellent inherent watertightness in both the straight and deflected positions, may be employed to meet the joint requirements of ASTM C 443 and ASTM C 361.

Illustration 5.13 Typical Cross Section of Spigot Groove Type Joint With 0-ring Gasket



- Steel bell and spigot rings with a groove on the spigot for an 0-ring rubber gasket, as shown in Illustration 5.14. Basically a high pressure joint designed for use in water transmission and distribution lines, these are also used for irrigation lines, sewer force mains, and sewers where infiltration or exfiltration is a factor in the design. This type of joint will meet the joint requirements of ASTM C 443 and ASTM C 361. Combining great shear strength and excellent inherent watertightness and flexibility, this type joint is the least subject to damage during installation.

Illustration 5.14 Typical Cross Section of Steel End Ring Joint With Spigot Groove and 0-ring Gasket



Since both field construction practices and conditions of service are subject to variation, it is impossible to precisely define the field performance characteristics of each of the joint types. Consultation with local concrete pipe manufacturers will provide information on the availability and cost of the various joints. Based on this information and an evaluation of groundwater conditions, the specifications should define allowable infiltration or exfiltration rates and/or the joint types which are acceptable.

JACKING CONCRETE PIPE

Concrete pipelines were first jacked in place by the Northern Pacific Railroad between 1896 and 1900. In more recent years, this technique has been applied to sewer construction where intermediate shafts along the line of the sewer are used as jacking stations.

Reinforced concrete pipe as small as 18-inch inside diameter and as large as 132-inch inside diameter have been installed by jacking.

Required Characteristics of Concrete Jacking Pipe. Two types of loading conditions are imposed on concrete pipe installed by the jacking method; the axial load due to the jacking pressures applied during installation, and the earth loading due to the overburden, with some possible influence from live loadings, which will generally become effective only after installation is completed.

It is necessary to provide for relatively uniform distribution of the axial load around the periphery of the pipe to prevent localized stress concentrations. This is accomplished by keeping the pipe ends parallel within the tolerances prescribed by ASTM C 76, by using a cushion material, such as plywood or hardboard, between the pipe sections, and by care on the part of the contractor to insure that the jacking force is properly distributed through the jacking frame to the pipe and parallel with the axis of the pipe. The cross sectional area of the concrete pipe wall is more than adequate to resist pressures encountered in any normal jacking operation. For projects where extreme jacking pressures are anticipated due to long jacking distances or excessive unit frictional forces, higher concrete compressive strength may be required, along with greater care to avoid bearing stress concentrations. Little or no gain in axial crushing resistance is provided by specifying a higher class of pipe.

For a comprehensive treatment of earth loads on jacked pipe see Chapter 4. The earth loads on jacked pipe are similar to loads on a pipe installed in a trench with the same width as the bore with one significant difference. In a jacked pipe installation the cohesive forces within the soil mass in most instances are appreciable and tend to reduce the total vertical load on the pipe. Thus the vertical load on a jacked pipe will always be less than on a pipe in a trench installation with the same cover and, unless noncohesive materials are encountered, can be substantially less.

With the proper analysis of loadings and selection of the appropriate strength class of pipe, few additional characteristics of standard concrete pipe need be considered. Pipe with a straight wall, without any increase in outside diameter at the bell or groove, obviously offers fewer problems and minimizes the required excavation. Considerable quantities of modified tongue and groove pipe have been jacked, however, and presented no unusual problems.

The Jacking Method. The usual procedure in jacking concrete pipe is to equip the leading edge with a cutter, or shoe, to protect the pipe. As succeeding lengths of pipe are added between the lead pipe and the jacks, and the pipe jacked forward, soil is excavated and removed through the pipe. Material is trimmed with care and excavation does not precede the jacking operation more than necessary. Such a procedure usually results in minimum disturbance of the natural soils adjacent to the pipe.

Contractors occasionally find it desirable to coat the outside of the pipe with a lubricant, such as bentonite, to reduce the frictional resistance. In some instances, this lubricant has been pumped through special fittings installed in the wall of the pipe.

Because of the tendency of jacked pipe to “set” when forward movement is interrupted for as long as a few hours, resulting in significantly increased frictional resistance, it is desirable to continue jacking operations until completed.

In all jacking operations it is important that the direction of jacking be carefully established prior to beginning the operation. This requires the erection of guide rails in the bottom of the jacking pit or shaft. In the case of large pipe, it is desirable to have such rails carefully set in a concrete slab. The number and capacity of the jacks required depend primarily upon the size and length of the pipe to be jacked and the type of soil encountered.

Illustration 5.15 Steps in Jacking Concrete Pipe

1. Pits are excavated on each side. The jacks will bear against the back of the left pit so a steel or wood abutment is added for reinforcement. A simple track is added to guide the concrete pipe section. The jack(s) are positioned in place on supports.

2. A section of concrete pipe is lowered into the pit.

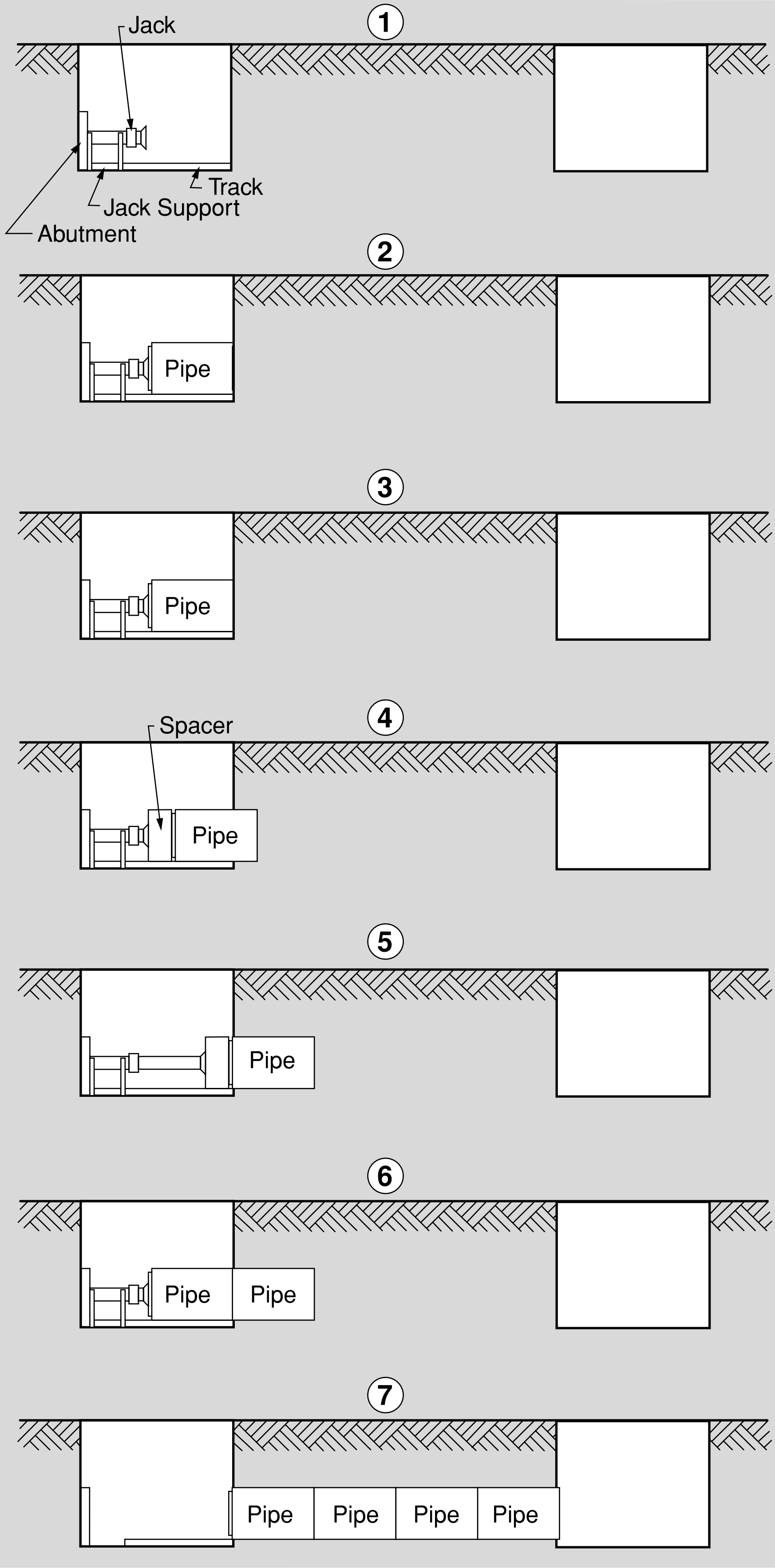
3. The jack(s) are operated pushing the pipe section forward.

4. The jack ram(s) are retracted and a "spacer" is added between the jack(s) and pipe.

5. The jack(s) are operated and the pipe is pushed forward again.

6. It may become necessary to repeat the above steps 4 and 5 several times until the pipe is pushed forward enough to allow room for the next section of pipe. It is extremely important, therefore, that the strokes of the jacks be as long as possible to reduce the number of spacers required and thereby reduce the amount of time and cost. The ideal situation would be to have the jack stroke longer than the pipe to completely eliminate the need for spacers.

7. The next section of pipe is lowered into the pit and the above steps repeated. The entire process above is repeated until the operation is complete.



Backstops for the jacks must be strong enough and large enough to distribute the maximum capacity of the jacks against the soil behind the backstops. A typical installation for jacking concrete pipe is shown in Illustration 5.15.

BENDS AND CURVES

Changes in direction of concrete pipe sewers are most commonly effected at manhole structures. This is accomplished by proper location of the inlet and outlet openings and finishing of the invert in the structure to reflect the desired angular change of direction.

In engineering both grade and alignment changes in concrete pipelines it is not always practical or feasible to restrict such changes to manhole structures. Fortunately there are a number of economical alternatives.

Deflected Straight Pipe. With concrete pipe installed in straight alignment and the joints in a home (or normal) position, the joint space, or distance between the ends of adjacent pipe sections, will be essentially uniform around the periphery of the pipe. Starting from this home position any joint may be opened up to a maximum permissible joint opening on one side while the other side remains in the home position. The difference between the home and opened joint space is generally designated as the pull. This maximum permissible opening retains some margin between it and the limit for satisfactory function of the joint. It varies for different joint configurations and is best obtained from the pipe manufacturer.

Opening a joint in this manner effects an angular deflection of the axis of the pipe, which, for any given pull is a function of the pipe diameter. Thus, given the values of any two of the three factors; pull, pipe diameter, and deflection angle, the remaining factor may be readily calculated.

The radius of curvature which may be obtained by this method is a function of the deflection angle per joint and the length of the pipe sections. Thus, longer lengths of pipe will provide a longer radius for the same pull than would be obtained with shorter lengths.The radius of curvature is computed by the equation:

$$R = \frac{L}{2(\tan 1/2 \times \frac{\Delta}{N})}$$

where:

R = Radius of curvature, feet

L = Average laid length of pipe sections measured along the centerline, feet

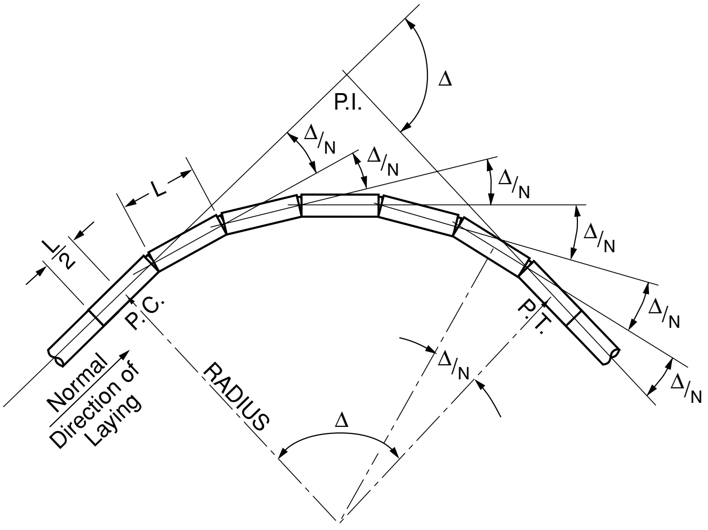
Δ = Total deflection angle of curve, degrees

N = Number of pipe with pulled joints

$\frac{\Delta}{N}$ = Total deflection of each pipe, degrees

Using the deflected straight pipe method, Illustration 5.16 shows that the P.C. (point of curve) will occur at the midpoint of the last undeflected pipe and the P.T. (point of tangent) will occur at the midpoint of the last pulled pipe.

Illustration 5.16 Curved Alignment Using Deflected Straight Pipe



Radius Pipe. Sharper curvature with correspondingly shorter radii can be accommodated with radius pipe than with deflected straight pipe. This is due to the greater deflection angle per joint which may be used. In this case the pipe is manufactured longer on one side than the other and the deflection angle is built in at the joint. Also referred to as bevelled or mitered pipe, it is similar in several respects to deflected straight pipe. Thus, shorter radii may be obtained with shorter pipe lengths; the maximum angular deflection which can be obtained at each joint is a function of both the pipe diameter and a combination of the geometric configuration of the joint and the method of manufacture.

These last two factors relate to how much shortening or drop can be applied to one side of the pipe. The maximum drop for any given pipe is best obtained from the manufacturer of the pipe since it is based on manufacturing feasibility.

The typical alignment problem is one in which the total Δ angle of the curve and the required radius of curvature have been determined. The diameter and direction of laying of the pipe are known. To be determined is whether the curve can be negotiated with radius pipe and, if so, what combination of pipe lengths and drop are required. Information required from the pipe manufacturer is the maximum permissible drop, the wall thicknesses of the pipe and the standard lengths in which the pipe is available. Any drop up to the maximum may be used as required to fit the curve.

Values obtained by the following method are approximate, but are within a range of accuracy that will permit the pipe to be readily installed to fit the required alignment.

The tangent of the deflection angle, $\frac{\Delta}{N}$ required at each joint is computed by the equation:

$$\tan \frac{\Delta}{N} = \frac{L}{R + D/2 + t}$$

where:

Δ = Total deflection angle of curve, degrees
N = Number of radius pipe
L = The standard pipe length being used, feet
R = Radius of curvature, feet
D = Inside diameter of the pipe, feet
t = Wall thickness of the pipe, feet

The required drop in inches to provide the deflection angle, $\frac{\Delta}{N}$ computed by the equation:

$$\text{Drop} = 12(D + 2t) \tan \frac{\Delta}{N}$$

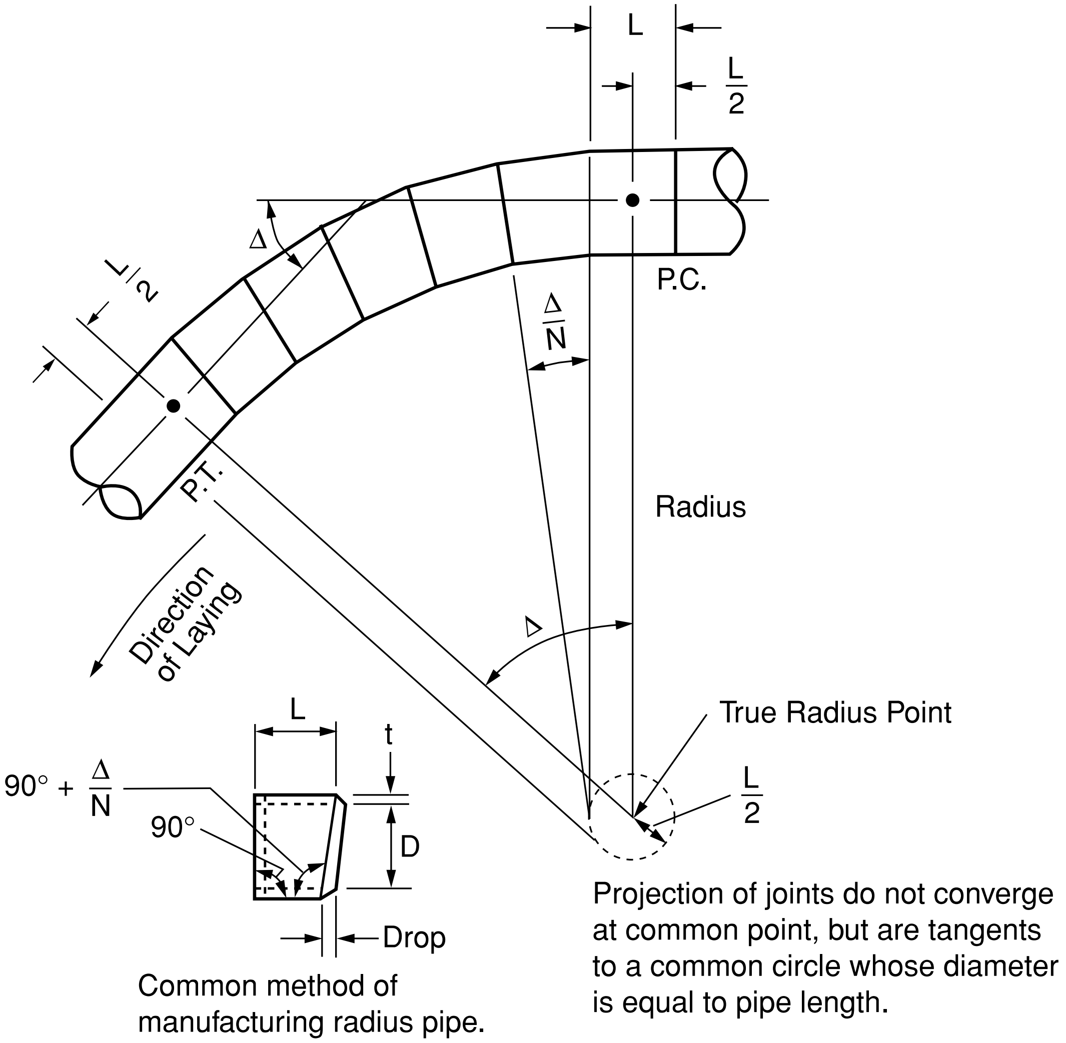
The number of pieces of radius pipe required is equal to the length of the circular curve in feet divided by the centerline length of the radius pipe (L - 1/2 Drop). Minor modifications in the radius are normally made so this quotient will be a whole number.

If the calculated drop exceeds the maximum permissible drop, it will be necessary to either increase the radius of curvature or to use shorter pipe lengths. Otherwise special fittings must be used as covered in the next section.

It is essential that radius pipe be oriented such that the plane of the dropped joint is at right angles to the theoretical circular curve. For this reason lifting holes in the pipe must be accurately located, or, if lifting holes are not provided, the top of the pipe should be clearly and accurately marked by the manufacturer so that the deflection angle is properly oriented.

It should also be noted that a reasonable amount of field adjustment is possible by pulling the radius pipe joints in the same manner as with deflected straight pipe.

Illustration 5.17 Curved Alignment Using Radius Pipe



Common method of manufacturing radius pipe.

Projection of joints do not converge at common point, but are tangents to a common circle whose diameter is equal to pipe length.

As indicated in Illustration 5.17, the P.C. (point of curve) falls at the midpoint of the last straight pipe and the P.T. (point of tangent) falls one half of the standard pipe length back from the straight end of the last radius pipe. To assure that the P.C. will fall at the proper station it is generally necessary that a special short length of pipe be installed in the line, ahead of the P.C.

Bends and Special Sections. Extremely short radius curves cannot be negotiated with either deflected straight pipe or with conventional radius pipe. Several alternatives are available through the use of special precast sections to solve such alignment problems.

Sharper curves can be handled by using special short lengths of radius pipe rather than standard lengths. These may be computed in accordance with the methods discussed for radius pipe.

Certain types of manufacturing processes permit the use of a dropped joint on both ends of the pipe, which effectively doubles the deflection. Special bends, or elbows can be manufactured to meet any required deflection angle and some manufacturers produce standard bends which provide given angular deflection per section.

One or more of these methods may be employed to meet the most severe alignment problems. Since manufacturing processes and local standards vary, local concrete pipe manufacturers should be consulted to determine the availability and geometric configuration of special sections.

SIGNIFICANCE OF CRACKING

The occurrence, function and significance of cracks have probably been the subject of more misunderstanding and unnecessary concern by engineers than any other phenomena related to reinforced concrete pipe.

Reinforced concrete pipe, like reinforced concrete structures in general, are made of concrete reinforced with steel in such a manner that the high compressive strength of the concrete is balanced by the high tensile strength of the steel. In reinforced concrete pipe design, no value is given to the tensile strength of the concrete. The tensile strength of the concrete, however, is important since all parts of the pipe are subject to tensile forces at some time subsequent to manufacture. When concrete is subjected to tensile forces in excess of its tensile strength, it cracks.

Unlike most reinforced concrete structures, reinforced concrete sewer and culvert pipe is designed to meet a specified cracking load rather than a specified stress level in the reinforcing steel. This is both reasonable and conservative since reinforced concrete pipe may be pretested in accordance with detailed national specifications.

In the early days of the concrete pipe industry, the first visible crack observed in a three-edge bearing test was the accepted criterion for pipe performance. However, the observation of such cracks was subject to variations depending upon the zeal and eyesight of the observer. The need soon became obvious for a criterion based on a measurable crack of a specified width. Eventually the 0.01-inch crack, as measured by a feeler gage of a specified shape, became the accepted criterion for pipe performance.

The most valid basis for selection of a maximum allowable crack width is the consideration of exposure and potential corrosion of the reinforcing steel. If a crack is sufficiently wide to provide access to the steel by both moisture and oxygen, corrosion will be initiated. Oxygen is consumed by the oxidation process and in order for corrosion to be progressive there must be a constant replenishment.

Bending cracks are widest at the surface and get rapidly smaller as they approach the reinforcing steel. Unless the crack is wide enough to allow circulation of the moisture and replenishment of oxygen, corrosion is unlikely. Corrosion is even further inhibited by the alkaline environment resulting from the cement.

While cracks considerably in excess of 0.01-inch have been observed after a period of years with absolutely no evidence of corrosion, 0.01-inch is a conservative and universally accepted maximum crack width for design of reinforced concrete pipe.

- Reinforced concrete pipe is designed to crack. Cracking under load indicates that the tensile stresses have been transferred to the reinforcing steel.
- A crack 0.01-inch wide does not indicate structural distress and is not harmful.
- Cracks much wider than 0.01-inch should probably be sealed to insure protection of the reinforcing steel.
- An exception to the above occurs with pipe manufactured with greater than 1 inch cover over the reinforcing steel. In these cases acceptable crack width should be increased in proportion to the additional concrete cover.

Tables

Table 1

SEWAGE FLOWS USED FOR DESIGN

City	Year of Data	Average rate of water consumption, in gpcd[1]	Population served, in thousands	Per capita sewage flow average[2], in gpcd[1]	Sewer design basis in gpcd[1]	Remarks
Baltimore, Md.	–	160	1,300	100	135 x factor	Factor 4 to 2
Berkeley, Calif.	–	76	113	60	92	–
Boston, Mass.	–	145	801	140	150	Flowing half full
Cleveland, Ohio [3]	1946	–	–	100	–	–
Cranston, R.I.[3]	1943	–	–	119	167	–
Des Moines, Iowa [3]	1949	–	–	100	200	–
Grand Rapids, Mich.	–	178	200	189.5	200	–
Great Peoria, Illinois	1960	90	150	75	800 8,500	Based on 12 persons per acre for lateral and trunk sewers respectively
Greenville County, South Carolina	1959	110	200	150	300	Service area includes city of Greenville.[1] Sewers 24" and less designed to flow 1/2 full at 300 gpcd,[1] sewers larger than 24" designed to have 1' freeboard
Hagerstown, Md.	–	100	38	100	250	–
Jefferson County, Ala.	–	102	500	100	300	–
Johnson County, Kans.	1958					
Indian Creek Main Sewer Dist.	–	70	30	60	675	Most houses have basements with interior foundation drains
Mission Township Main Sewer Dist.	–	70	70	60	1,350	Most houses have basements with exterior foundation drains
Kansas City, Mo.	1958	–	500	60	675	For trunks and interceptors
					1,350	For laterals and submains. Many houses have basements and exterior foundation drains
Lancaster County, Neb.	1962	167	148	92	400	Serves City of Lincoln
Las Vegas, Nev.	–	410	45	209	250	–
Lincoln, Neb. (Lateral Dists.)	1964			60	See remarks	For lateral sewers max. flow by formula: peak flow= 5 x avg. flow÷(Pop in 1000's)$^{0.2}$
Little Rock, Ark.	–	50	100	50	100	–
Los Angeles, Calif.	1965	185	2,710	85	*	*85 gpcd[1] residential multiplied by peak factor.
Los Angeles County Sanitation District	1964	200	3,500	70*	–	*Domestic flow only, ranges from 50 to 90 gpcd[1] depending on cost of water, type of residence, etc. Domestic plus industrial averages 90 gpcd[1]
Madison, Wisc.[3]	1937	–	–	–	300	Maximum hourly rate
Memphis, Tenn.	–	125	450	100	100	–
Milwaukee, Wisc.[3]	1945	–	–	125	–	All in 12 hr-250-gpcd[1] rate
Orlando, Fla.	–	150	75	70	190	–
Painesville, Ohio [3]	1947	–	–	125	600	Includes infiltration and roof water
Rapid City, S. Dak.	–	122	40	121	125	–
Rochester, N.Y.[3]	1946	–	–	–	250	New York State Board of Health standard
Santa Monica, Calif.	–	137	75	92	92	–
Shreveport, La.	1961	125	165	–	–	Sewer design is 150 gpcd[1] plus 600 gp acre per day infiltration. Sewers 24" in diameter and less designed to flow 1/2 full, sewers larger than 24" designed to have 1' freeboard
Springfield, Mass.[3]	1949	–	–	–	200	150 gpcd[1] was used on a special project
St. Joseph, Mo.	1960	–	85	125	450	Main Sewers
					350	Interceptors
Toledo, Ohio [3]	1946	–	–	–	160	–
Washington, D. C., Suburban Sanitary District[3]	1946			100	2 to 3.3 x average	–
Wyoming, Mich.	1960	150	50	82*	400	*Calculated actual domestic sewage flow, not including infiltration or industrial flow

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[1] *Gallons per capita per day. To convert to liters per capita per day multiply by 3.8.*

[2] *Measure or estimated domestic sewage.*

[3] *"Sewer Capacity Design Practice" by William E. Stanley and Warren J. Kaufman, Journal, Boston Soc. of Civil Engrs., October, 1953, p. 317, Table 2.*

Table 2

SEWER CAPACITY ALLOWANCES FOR COMMERCIAL AND INDUSTRIAL AREAS

City	Year data	Commercial	Industrial
Baltimore, Md.[1]	1949	135 gpcd[2] (range 6,750 to 13,500 gpd per acre), resident population	7,500 gpd per acre minimum
Berkeley, Calif	–	–	50,000 gpd per acre
Buffalo, N.Y.[3]	–	60,000 gpd per acre	–
Cincinnati, Ohio[3]	–	40,000 gpd per acre	–
Columbus, Ohio[1]	1946	40,000 gpd per acre; excess added to residential amount	–
Cranston, R.I.[1]	1943	25,000 gpd per acre	–
Dallas, Texas	1960	30,000 gpd per acre added to domestic rate for down town: 60,000 gpd per acre for tunnel relief sewers	–
Detroit, Mich.	–	50,000 gpd per acre	–
Grand Rapids, Mich.	–	40-50 gpcd,[2] office buildings 400-500 gpd per room, hotels 200 gpd per bed, hospitals 200-300 gpd per room, schools	250,000 gpd per acre
Hagerstown, Md.	–	180-250 gpd per room, hotels 150, gpd per bed, hospitals 120-150 gpd per room, schools	–
Houston, Texas	1960	Office Bldgs. – 0.36 gal per sq ft per day (peak) Retail Space – 0.20 gp sq ft pd (peak) Hotels – 0.93 gp sq ft pd (peak)	–
Las Vegas, Nev.	–	310-525 gpd per room, resort hotels 15 gpcd,[2] schools	–
Lincoln, Neb.	1962	7,000 gpd per acre	–
Los Angeles, Calif.	1965	Commercial, 11,700 gpd per acre Industrial, 0.024 cfs per acre Hospital, 0.75 mgd per hospital School, 0.12 mgd per school University, 0.73 mgd per university	
Los Angeles County Sanitation District	1964	10,000 gpd per acre, avg. 25,000 gpd per acre, peak	–
Kansas City, Mo.	1958	5,000 gpd per acre	10,000 gpd per acre
Memphis, Tenn.	–	2.000 gpd per acre	2,000 gpd per acre
Milwaukee, Wis.[1]	1945	60,500 gpd per acre	–
Santa Monica, Calif.	–	9,700 gpd per acre, commercial 7,750 gpd per acre, hotels	13,600 gpd per acre
Shreveport, La.	–	3,000 gpd per acre	–
St. Joseph, Mo.	1962	6,000 gpd per acre	–
St. Louis, Mo.	1960	90,000 gpd per acre avg. 165,000 gpd per acre peak	–
Toledo, Ohio[1]	1946	15,000 to 30,000 gpd per acre, average to peak allowances	–
Toronto	1960	63,500 gpd per acre downtown sewers	–

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[1] *"Sewer Capacity Design Practice," by William E. Stanley and Warren J. Kaufman, Journal, Boston Soc. of Civ., Engrs., October, 1953. p. 320, Table 3.*

[2] *Gallons per capita per day.*

[3] *Sludge & Sewage Treatment, Harold Bobbitt, 6-Edition, John Wiley & Sons.*

Table 3

FULL FLOW COEFFICIENT VALUES CIRCULAR CONCRETE PIPE

D Pipe Diameter (inches)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Value of $C_1 = \frac{1.486}{n} \times A \times R^{2/3}$			
			n=0.010	n=0.011	n=0.012	n=0.013
8	0.349	0.167	15.8	14.3	13.1	12.1
10	0.545	0.208	28.4	25.8	23.6	21.8
12	0.785	0.250	46.4	42.1	38.6	35.7
15	1.227	0.312	84.1	76.5	70.1	64.7
18	1.767	0.375	137	124	114	105
21	2.405	0.437	206	187	172	158
24	3.142	0.500	294	267	245	226
27	3.976	0.562	402	366	335	310
30	4.909	0.625	533	485	444	410
33	5.940	0.688	686	624	574	530
36	7.069	0.750	867	788	722	666
42	9.621	0.875	1308	1189	1090	1006
48	12.566	1.000	1867	1698	1556	1436
54	15.904	1.125	2557	2325	2131	1967
60	19.635	1.250	3385	3077	2821	2604
66	23.758	1.375	4364	3967	3636	3357
72	28.274	1.500	5504	5004	4587	4234
78	33.183	1.625	6815	6195	5679	5242
84	38.485	1.750	8304	7549	6920	6388
90	44.170	1.875	9985	9078	8321	7681
96	50.266	2.000	11850	10780	9878	9119
102	56.745	2.125	13940	12670	11620	10720
108	63.617	2.250	16230	14760	13530	12490
114	70.882	2.375	18750	17040	15620	14420
120	78.540	2.500	21500	19540	17920	16540
126	86.590	2.625	24480	22260	20400	18830
132	95.033	2.750	27720	25200	23100	21330
138	103.870	2.875	31210	28370	26010	24010
144	113.100	3.000	34960	31780	29130	26890

Table 4

FULL FLOW COEFFICIENT VALUES ELLIPTICAL CONCRETE PIPE

Pipe Size R x S (HE) S x R (VE) (Inches)	Approximate Equivalent Circular Diameter (Inches)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Value of $C_1 = \frac{1.486}{n} \times A \times R^{2/3}$			
				n = 0.010	n = 0.011	n = 0.012	n = 0.013
14 x 23	18	1.8	0.367	138	125	116	108
19 x 30	24	3.3	0.490	301	274	252	232
22 x 34	27	4.1	0.546	405	368	339	313
24 x 38	30	5.1	0.613	547	497	456	421
27 x 42	33	6.3	0.686	728	662	607	560
29 x 45	36	7.4	0.736	891	810	746	686
32 x 49	39	8.8	0.812	1140	1036	948	875
34 x 53	42	10.2	0.875	1386	1260	1156	1067
38 x 60	48	12.9	0.969	1878	1707	1565	1445
43 x 68	54	16.6	1.106	2635	2395	2196	2027
48 x 76	60	20.5	1.229	3491	3174	2910	2686
53 x 83	66	24.8	1.352	4503	4094	3753	3464
58 x 91	72	29.5	1.475	5680	5164	4734	4370
63 x 98	78	34.6	1.598	7027	6388	5856	5406
68 x 106	84	40.1	1.721	8560	7790	7140	6590
72 x 113	90	46.1	1.845	10300	9365	8584	7925
77 x 121	96	52.4	1.967	12220	11110	10190	9403
82 x 128	102	59.2	2.091	14380	13070	11980	11060
87 x 136	108	66.4	2.215	16770	15240	13970	12900
92 x 143	114	74.0	2.340	19380	17620	16150	14910
97 x 151	120	82.0	2.461	22190	20180	18490	17070
106 x 166	132	99.2	2.707	28630	26020	23860	22020
116 x 180	144	118.6	2.968	36400	33100	30340	28000

Table 5

FULL FLOW COEFFICIENT VALUES CONCRETE ARCH PIPE

Pipe Size R x S (Inches)	Approximate Equivalent Circular Diameter (Inches)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Value of $C_1 = \frac{1.486}{n} \times A \times R^{2/3}$			
				n = 0.010	n = 0.011	n = 0.012	n = 0.013
11 x 18	15	1.1	0.25	65	59	54	50
13½ x 22	18	1.6	0.30	110	100	91	84
15½ x 26	21	2.2	0.36	165	150	137	127
18 x 28½	24	2.8	0.45	243	221	203	187
22½ x 36¼	30	4.4	0.56	441	401	368	339
26⅝ x 43¾	36	6.4	0.68	736	669	613	566
31⁵⁄₁₆ x 51⅛	42	8.8	0.80	1125	1023	938	866
36 x 58½	48	11.4	0.90	1579	1435	1315	1214
40 x 65	54	14.3	1.01	2140	1945	1783	1646
45 x 73	60	17.7	1.13	2851	2592	2376	2193
54 x 88	72	25.6	1.35	4641	4219	3867	3569
62 x 102	84	34.6	1.57	6941	6310	5784	5339
72 x 115	90	44.5	1.77	9668	8789	8056	7436
77¼ x 122	96	51.7	1.92	11850	10770	9872	9112
87⅛ x 138	108	66.0	2.17	16430	14940	13690	12640
96⅞ x 154	120	81.8	2.42	21975	19977	18312	16904
106½ x 168¾	132	99.1	2.65	28292	25720	23577	21763

Table 6

FULL FLOW COEFFICIENT VALUES
PRECAST CONCRETE BOX SECTIONS

Box Size Span x Rise (Feet)	A Area (Square Feet)	R Hydraulic Radius (Feet)	$C = 1.486/n(A \times R^{2/3})$		Box Size Span x Rise (Feet)	A Area (Square Feet)	R Hydraulic Radius (Feet)	$C = 1.486/n(A \times R^{2/3})$	
			n = 0.012	n = 0.013				n = 0.012	n = 0.013
3 X 2	5.78	0.63	524	484	9 X 5	43.88	1.67	7060	7070
3 X 3	8.78	0.78	923	852	9 X 6	52.88	1.87	9950	9180
4 X 2	7.65	0.69	743	686	9 X 7	61.88	2.05	12400	11400
4 X 3	11.65	0.90	1340	1240	9 X 8	70.88	2.20	14800	13700
4 X 4	15.65	1.04	1990	1840	9 X 9	79.88	2.33	17400	16100
5 X 3	14.50	0.98	1770	1630	10 X 5	48.61	1.73	8690	8020
5 X 4	19.50	1.16	2660	2460	10 X 6	58.61	1.95	11300	10462
5 X 5	24.50	1.30	3620	3340	10 X 7	68.61	2.14	14100	13000
6 X 3	17.32	1.04	2200	2030	10 X 8	78.61	2.31	17000	15700
6 X 4	23.32	1.25	3350	3100	10 X 9	88.61	2.46	20000	18500
6 X 5	29.32	1.42	4590	4240	10 X 10	98.61	2.59	23000	21300
6 X 6	35.32	1.56	5880	5430	11 X 4	42.32	1.52	6930	6390
7 X 4	27.11	1.33	4050	3740	11 X 6	64.32	2.02	12730	11700
7 X 5	34.11	1.52	5590	5160	11 X 8	86.32	2.41	19200	17700
7 X 6	41.11	1.68	7200	6650	11 X 10	108.32	2.72	26100	24100
7 X 7	48.11	1.82	8880	8200	11 X 11	119.32	2.85	29700	27400
8 X 4	31.11	1.39	4790	4420	12 X 4	46.00	1.55	7630	7050
8 X 5	39.11	1.60	6630	6120	12 X 6	70.00	2.08	14100	13000
8 X 6	47.11	1.78	8760	7920	12 X 8	94.00	2.50	21400	19800
8 X 7	55.11	1.94	10600	9790	12 X 10	118.00	2.83	29300	27000
8 X 8	63.11	2.07	12700	11700	12 X 12	142.00	3.11	37500	34600

Table 7

SLOPES REQUIRED FOR V = 2fps AT FULL AND HALF FULL FLOW

Pipe Diameter (Inches)	Slope in %			
	n = 0.010	n = 0.011	n = 0.012	n = 0.013
8	0.197	0.238	0.284	0.332
10	0.147	0.178	0.213	0.248
12	0.115	0.139	0.166	0.194
15	0.086	0.104	0.123	0.145
18	0.067	0.081	0.097	0.114
21	0.055	0.066	0.079	0.092
24	0.046	0.055	0.066	0.077
27	0.039	0.047	0.056	0.065
30	0.034	0.041	0.049	0.057
33	0.030	0.036	0.043	0.051
36	0.027	0.032	0.038	0.045
42	0.022	0.026	0.031	0.036
48	0.018	0.022	0.026	0.031
54	0.015	0.019	0.022	0.027
60	0.013	0.016	0.019	0.023
66	0.012	0.014	0.017	0.020
72	0.011	0.013	0.015	0.018
78	0.010	0.011	0.014	0.016
84	0.009	0.010	0.012	0.015
90	0.008	0.010	0.011	0.013
96	0.007	0.009	0.010	0.012
102	0.007	0.008	0.010	0.011
108	0.006	0.007	0.009	0.010
114	0.006	0.007	0.008	0.010
120	0.005	0.006	0.008	0.009
126	0.005	0.006	0.007	0.008
132	0.004	0.006	0.007	0.008
138	0.004	0.005	0.006	0.007
144	0.004	0.005	0.006	0.007

Note: For a velocity V other than 2fps, multiple the above by $\frac{V^2}{4}$.

Table 8

RUNOFF COEFFICIENTS FOR VARIOUS AREAS

DESCRIPTION OF AREA	RUNOFF COEFFICIENTS
Business:	
Downtown areas	0.70 to 0.95
Neighborhood areas	0.50 to 0.70
Residential:	
Single-family areas	0.30 to 0.50
Multi units, detached	0.40 to 0.60
Multi units, attached	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment dwelling areas	0.50 to 0.70
Industrial:	
Light areas	0.50 to 0.80
Heavy areas	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Railroad yard areas	0.20 to 0.40
Unimproved areas	0.10 to 0.30

Table 9

RAINFALL INTENSITY CONVERSION FACTORS

Duration in Minutes	Factor	Duration in Minutes	Factor
5	2.22	40	0.8
10	1.71	50	0.7
15	1.44	60	0.6
20	1.25	90	0.5
30	1.00	120	0.4

Table 10

RECURRENCE INTERVAL FACTORS

Recurrence Interval in Years	Factor
2	1.0
5	1.3
10	1.6
25	1.9
50	2.2

Table 11

NATIONWIDE FLOOD-FREQUENCY PROJECTS

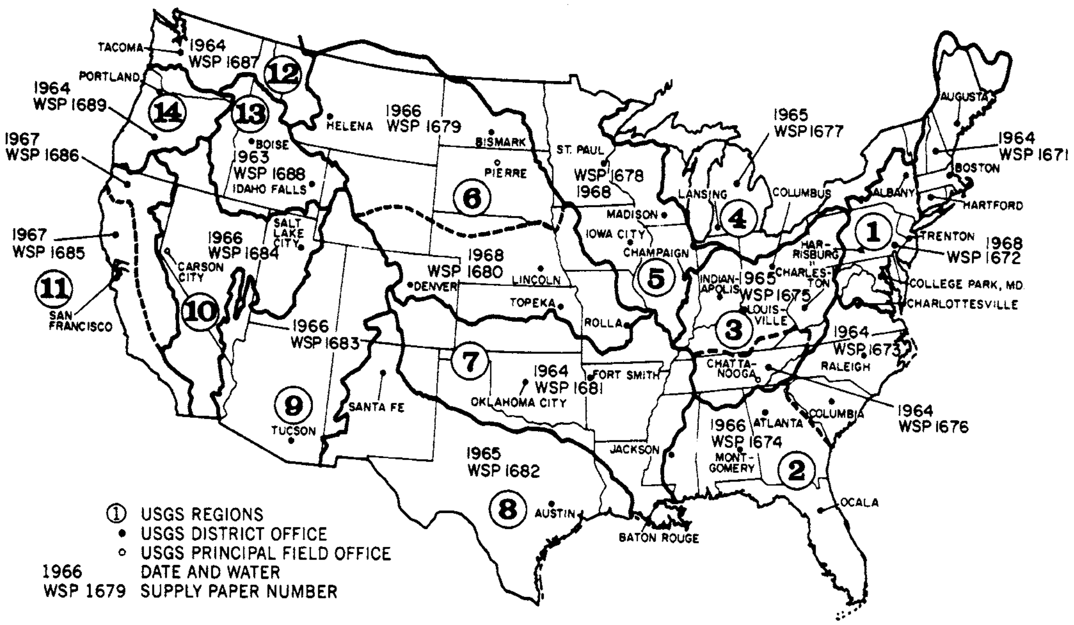


Table 12

ENTRANCE LOSS COEFFICIENTS

Coefficient k_e to apply to velocity head $\frac{V^2}{2g}$ for determination of head loss at entrance to a structure, such as a culvert or conduit, operating full or partly full with *control at the outlet.*

$$\text{Entrance head loss } H_e = k_e \frac{V^2}{2g}$$

TYPE OF ENTRANCE	COEFFICIENT k_e
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
End-Section conforming to fill slope	0.5

Note: "End Section conforming to fill slope" are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance.

TYPE OF STRUCTURE AND DESIGN OF ENTRANCE BOX, REINFORCED CONCRETE	COEFFICIENT k_e
Headwall parallel to embankment (no wing walls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension	0.2
Wing walls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension	0.2
Wing walls at 10° to 25° to barrel	
Square-edged at crown	0.5
Wing walls parallel (extension of sides)	
Square-edged at crown	0.7

BUREAU OF PUBLIC ROADS - JAN. 1963

Table 13

Pipe Size = 12"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku’ = 0.165				Ku’ = 0.150				Ku’ = 0.130				Ku’ = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.4	2.4	2.4	2.5	2.3	2.4	2.4	2.4
6	2.6	2.7	2.7	2.8	2.5	2.6	2.6	2.7	2.5	2.5	2.5	2.6	2.4	2.5	2.5	2.5
7	2.7	2.8	2.8	2.9	2.6	2.7	2.7	2.8	2.6	2.6	2.6	2.7	2.5	2.5	2.5	2.6
8	2.8	2.9	2.9	3.0	2.7	2.8	2.8	2.9	2.6	2.7	2.7	2.8	2.5	2.6	2.6	2.7
9	2.9	3.0	3.0	3.1	2.8	2.9	2.9	3.0	2.7	2.8	2.8	2.9	2.6	2.7	2.7	2.7
10	3.0	3.1	3.1	3.2	2.9	3.0	3.0	3.1	2.8	2.9	2.9	2.9	2.7	2.7	2.7	2.8
11	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	2.9	2.9	2.9	3.0	2.7	2.8	2.8	2.9
12	3.2	3.3	3.3	3.3	3.1	3.2	3.2	3.2	2.9	3.0	3.0	3.1	2.8	2.9	2.9	3.0
13	3.3	3.3	3.3	3.4	3.2	3.2	3.2	3.3	3.0	3.1	3.1	3.2	2.9	2.9	2.9	3.0
14	3.4	3.4	3.4	3.5	3.2	3.3	3.3	3.4	3.1	3.2	3.2	3.2	2.9	3.0	3.0	3.1
15	3.4	3.5	3.5	3.6	3.3	3.4	3.4	3.5	3.2	3.2	3.2	3.3	3.0	3.1	3.1	3.2
16	3.5	3.6	3.6	3.7	3.4	3.5	3.5	3.6	3.2	3.3	3.3	3.4	3.1	3.1	3.1	3.2
17	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.6	3.3	3.4	3.4	3.5	3.1	3.2	3.2	3.3
18	3.7	3.8	3.8	3.8	3.5	3.6	3.6	3.7	3.4	3.4	3.4	3.5	3.2	3.3	3.3	3.3
19	3.7	3.8	3.8	3.9	3.6	3.7	3.7	3.8	3.4	3.5	3.5	3.6	3.2	3.3	3.3	3.4
20	3.8	3.9	3.9	4.0	3.7	3.8	3.8	3.9	3.5	3.6	3.6	3.7	3.3	3.4	3.4	3.5
21	3.9	4.0	4.0	4.1	3.8	3.8	3.8	3.9	3.6	3.6	3.6	3.7	3.3	3.4	3.4	3.5
22	4.0	4.0	4.0	4.1	3.8	3.9	3.9	4.0	3.6	3.7	3.7	3.8	3.4	3.5	3.5	3.6
23	4.0	4.1	4.0	4.2	3.9	4.0	4.0	4.1	3.7	3.8	3.8	3.8	3.5	3.5	3.5	3.6
24	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1	3.7	3.8	3.8	3.9	3.5	3.6	3.6	3.7
25	4.2	4.3	4.3	4.3	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.0	3.6	3.6	3.6	3.7
26	4.2	4.3	4.3	4.4	4.1	4.2	4.2	4.3	3.9	3.9	3.9	4.0	3.6	3.7	3.7	3.8
27	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1	3.7	3.8	3.8	3.8
28	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.1	3.7	3.8	3.8	3.9
29	4.4	4.5	4.5	4.6	4.3	4.4	4.4	4.4	4.0	4.1	4.1	4.2	3.8	3.9	3.9	3.9
30	4.4	4.5	4.5	4.6	4.3	4.4	4.4	4.4	4.0	4.1	4.1	4.2	3.8	3.9	3.9	3.9

Table 14

Pipe Size = 15"

Height of Backfill H Above Top of Pipe, Feet

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	2.9	3.0	3.0	3.1	2.9	3.0	3.0	3.0	2.8	2.9	2.9	3.0	2.7	2.8	2.8	2.9
6	3.0	3.1	3.1	3.2	3.0	3.1	3.1	3.2	2.9	3.0	3.0	3.1	2.8	2.9	2.9	3.0
7	3.1	3.2	3.2	3.3	3.1	3.2	3.2	3.3	3.0	3.1	3.1	3.2	2.9	3.0	3.0	3.1
8	3.3	3.3	3.3	3.4	3.2	3.3	3.3	3.4	3.1	3.2	3.2	3.2	3.0	3.0	3.0	3.1
9	3.4	3.4	3.4	3.5	3.3	3.4	3.4	3.5	3.2	3.2	3.2	3.3	3.0	3.1	3.1	3.2
10	3.5	3.5	3.5	3.6	3.4	3.5	3.5	3.5	3.2	3.3	3.3	3.4	3.1	3.2	3.2	3.3
11	3.6	3.6	3.6	3.7	3.5	3.5	3.5	3.6	3.3	3.4	3.4	3.5	3.2	3.3	3.3	3.4
12	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.7	3.4	3.5	3.5	3.6	3.2	3.3	3.3	3.4
13	3.7	3.8	3.8	3.9	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.7	3.3	3.4	3.4	3.5
14	3.8	3.9	3.9	4.0	3.7	3.8	3.8	3.9	3.6	3.6	3.6	3.7	3.4	3.5	3.5	3.6
15	3.9	4.0	4.0	4.1	3.8	3.9	3.9	4.0	3.6	3.7	3.7	3.8	3.5	3.5	3.5	3.6
16	4.0	4.1	4.1	4.2	3.9	4.0	4.0	4.1	3.7	3.8	3.8	3.9	3.5	3.6	3.6	3.7
17	4.1	4.2	4.2	4.3	4.0	4.0	4.0	4.1	3.8	3.9	3.9	4.0	3.6	3.7	3.7	3.8
18	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.0	3.6	3.7	3.7	3.8
19	4.2	4.3	4.3	4.4	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1	3.7	3.8	3.8	3.9
20	4.3	4.4	4.4	4.5	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.0
21	4.4	4.5	4.5	4.6	4.3	4.4	4.4	4.5	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.0
22	4.5	4.6	4.6	4.7	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1
23	4.6	4.7	4.7	4.8	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4	3.9	4.0	4.0	4.1
24	4.6	4.7	4.7	4.8	4.5	4.6	4.6	4.7	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2
25	4.7	4.8	4.8	4.9	4.5	4.6	4.6	4.7	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.2
26	4.8	4.9	4.9	5.0	4.6	4.7	4.7	4.8	4.4	4.5	4.5	4.6	4.1	4.2	4.2	4.3
27	4.8	5.0	5.0	5.1	4.7	4.8	4.8	4.9	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4
28	4.9	5.0	5.0	5.1	4.7	4.8	4.8	4.9	4.5	4.6	4.6	4.7	4.2	4.3	4.3	4.4
29	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.0	4.5	4.6	4.6	4.8	4.3	4.4	4.4	4.5
30	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.0	4.5	4.6	4.6	4.8	4.3	4.4	4.4	4.5

Table 15

Pipe Size = 18"

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	3.4	3.5	3.5	3.6	3.3	3.4	3.4	3.5	3.2	3.3	3.3	3.4	3.1	3.2	3.2	3.3
6	3.5	3.6	3.6	3.7	3.4	3.5	3.5	3.6	3.3	3.4	3.4	3.5	3.2	3.3	3.3	3.4
7	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.7	3.4	3.5	3.5	3.6	3.3	3.4	3.4	3.5
8	3.7	3.8	3.8	3.9	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.7	3.4	3.5	3.5	3.6
9	3.8	3.9	3.9	4.0	3.7	3.8	3.8	3.9	3.6	3.7	3.7	3.8	3.5	3.6	3.6	3.7
10	3.9	4.0	4.0	4.1	3.8	3.9	3.9	4.0	3.7	3.8	3.8	3.9	3.5	3.6	3.6	3.7
11	4.0	4.1	4.1	4.2	3.9	4.0	4.0	4.1	3.8	3.9	3.9	4.0	3.6	3.7	3.7	3.8
12	4.1	4.2	4.2	4.3	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.1	3.7	3.8	3.8	3.9
13	4.2	4.3	4.3	4.4	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1	3.8	3.9	3.9	4.0
14	4.3	4.4	4.4	4.5	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2	3.8	3.9	3.9	4.0
15	4.4	4.5	4.5	4.6	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.3	3.9	4.0	4.0	4.1
16	4.5	4.6	4.6	4.7	4.3	4.4	4.4	4.6	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2
17	4.6	4.7	4.7	4.8	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4	4.0	4.1	4.1	4.2
18	4.6	4.8	4.8	4.9	4.5	4.6	4.6	4.7	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.3
19	4.7	4.8	4.8	5.0	4.6	4.7	4.7	4.8	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4
20	4.8	4.9	4.9	5.0	4.7	4.8	4.8	4.9	4.4	4.6	4.6	4.7	4.2	4.3	4.3	4.4
21	4.9	5.0	5.0	5.1	4.7	4.9	4.9	5.0	4.5	4.6	4.6	4.7	4.3	4.4	4.4	4.5
22	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.0	4.6	4.7	4.7	4.8	4.3	4.5	4.5	4.6
23	5.1	5.2	5.2	5.3	4.9	5.0	5.0	5.1	4.7	4.8	4.8	4.9	4.4	4.5	4.5	4.6
24	5.1	5.3	5.3	5.4	5.0	5.1	5.1	5.2	4.7	4.8	4.8	5.0	4.5	4.6	4.6	4.7
25	5.2	5.3	5.3	5.5	5.0	5.2	5.2	5.3	4.8	4.9	4.9	5.0	4.5	4.6	4.6	4.8
26	5.3	5.4	5.4	5.5	5.1	5.2	5.2	5.3	4.9	5.0	5.0	5.1	4.6	4.7	4.7	4.8
27	5.4	5.5	5.5	5.6	5.2	5.3	5.3	5.4	4.9	5.0	5.0	5.2	4.6	4.8	4.8	4.9
28	5.4	5.6	5.6	5.7	5.3	5.4	5.4	5.5	5.0	5.1	5.1	5.2	4.7	4.8	4.8	4.9
29	5.5	5.6	5.6	5.8	5.3	5.4	5.4	5.6	5.0	5.2	5.2	5.3	4.8	4.9	4.9	5.0
30	5.5	5.6	5.6	5.8	5.3	5.4	5.4	5.6	5.0	5.2	5.2	5.3	4.8	4.9	4.9	5.0

Height of Backfill H Above Top of Pipe, Feet

Table 16

Pipe Size = 21"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	3.8	3.9	3.9	4.0	3.7	3.8	3.8	4.0	3.6	3.8	3.8	3.9	3.6	3.7	3.7	3.8
6	3.9	4.0	4.0	4.1	3.8	3.9	3.9	4.1	3.7	3.9	3.9	4.0	3.6	3.8	3.8	3.9
7	4.0	4.1	4.1	4.2	3.9	4.1	4.1	4.2	3.8	3.9	3.9	4.1	3.7	3.8	3.8	4.0
8	4.1	4.2	4.2	4.4	4.0	4.2	4.2	4.3	3.9	4.0	4.0	4.2	3.8	3.9	3.9	4.0
9	4.2	4.4	4.4	4.5	4.1	4.3	4.3	4.4	4.0	4.1	4.1	4.3	3.9	4.0	4.0	4.1
10	4.3	4.5	4.5	4.6	4.2	4.4	4.4	4.5	4.1	4.2	4.2	4.3	4.0	4.1	4.1	4.2
11	4.4	4.6	4.6	4.7	4.3	4.5	4.5	4.6	4.2	4.3	4.3	4.4	4.0	4.2	4.2	4.3
12	4.5	4.7	4.7	4.8	4.4	4.6	4.6	4.7	4.3	4.4	4.4	4.5	4.1	4.2	4.2	4.4
13	4.6	4.8	4.8	4.9	4.5	4.6	4.6	4.8	4.4	4.5	4.5	4.6	4.2	4.3	4.3	4.4
14	4.7	4.9	4.9	5.0	4.6	4.7	4.7	4.9	4.4	4.6	.46	4.7	4.3	4.4	4.4	4.5
15	4.8	5.0	5.0	5.1	4.7	4.8	4.8	5.0	4.5	4.6	4.6	4.8	4.3	4.5	4.5	4.6
16	4.9	5.1	5.1	5.2	4.8	4.9	4.9	5.0	4.6	4.7	4.7	4.8	4.4	4.5	4.5	4.6
17	5.0	5.2	5.2	5.3	4.9	5.0	5.0	5.1	4.7	4.8	4.8	4.9	4.5	4.6	4.6	4.7
18	5.1	5.2	5.2	5.4	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.0	4.5	4.7	4.7	4.8
19	5.2	5.3	5.3	5.5	5.1	5.2	5.2	5.3	4.8	5.0	5.0	5.1	4.6	4.7	4.7	4.9
20	5.3	5.4	5.4	5.6	5.1	5.3	5.3	5.4	4.9	5.0	5.0	5.2	4.7	4.8	4.8	4.9
21	5.4	5.5	5.5	5.6	5.2	5.3	5.3	5.5	5.0	5.1	5.1	5.2	4.7	4.9	4.9	5.0
22	5.5	5.6	5.6	5.7	5.3	5.4	5.4	5.6	5.1	5.2	5.2	5.3	4.8	4.9	4.9	5.1
23	5.5	5.7	5.7	5.8	5.4	5.5	5.5	5.6	5.1	5.3	5.3	5.4	4.9	5.0	5.0	5.1
24	5.6	5.8	5.8	5.9	5.4	5.6	5.6	5.7	5.2	5.3	5.3	5.5	4.9	5.1	5.1	5.2
25	5.7	5.8	5.8	6.0	5.5	5.7	5.7	5.8	5.3	5.4	5.4	5.5	5.0	5.1	5.1	5.2
26	5.8	5.9	5.9	6.1	5.6	5.7	5.7	5.9	5.3	5.5	5.5	5.6	5.1	5.2	5.2	5.3
27	5.9	6.0	6.0	6.1	5.7	5.8	5.8	5.9	5.4	5.5	5.5	5.7	5.1	5.2	5.2	5.4
28	6.0	6.1	6.1	6.2	5.7	5.9	5.9	6.0	5.5	5.6	5.6	5.7	5.2	5.3	5.3	5.4
29	6.0	6.2	6.2	6.3	5.8	6.0	6.0	6.1	5.5	5.7	5.7	5.8	5.2	5.4	5.4	5.5
30	6.0	6.2	6.2	6.3	5.8	6.0	6.0	6.1	5.5	5.7	5.7	5.8	5.2	5.4	5.4	5.5

Table 17

Pipe Size = 24"

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	4.2	4.3	4.3	4.5	4.1	4.3	4.3	4.4	4.1	4.2	4.2	4.3	4.0	4.1	4.1	4.2
6	4.3	4.5	4.5	4.6	4.2	4.4	4.4	4.5	4.2	4.3	4.3	4.4	4.1	4.2	4.2	4.3
7	4.4	4.6	4.6	4.7	4.4	4.5	4.5	4.6	4.3	4.4	4.4	4.5	4.1	4.3	4.3	4.4
8	4.6	4.7	4.7	4.8	4.5	4.6	4.6	4.7	4.3	4.5	4.5	4.6	4.2	4.4	4.4	4.5
9	4.7	4.8	4.8	4.9	4.6	4.7	4.7	4.8	4.4	4.6	4.6	4.7	4.3	4.4	4.4	4.6
10	4.8	4.9	4.9	5.0	4.7	4.8	4.8	4.9	4.5	4.7	4.7	4.8	4.4	4.5	4.5	4.6
11	4.9	5.0	5.0	5.2	4.8	4.9	4.9	5.0	4.6	4.8	4.8	4.9	4.5	4.6	4.6	4.7
12	5.0	5.1	5.1	5.3	4.9	5.0	5.0	5.1	4.7	4.8	4.8	5.0	4.5	4.7	4.7	4.8
13	5.1	5.2	5.2	5.4	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.1	4.6	4.7	4.7	4.9
14	5.2	5.3	5.3	5.5	5.1	5.2	5.2	5.3	4.9	5.0	5.0	5.2	4.7	4.8	4.8	5.0
15	5.3	5.4	5.4	5.6	5.2	5.3	5.3	5.4	5.0	5.1	5.1	5.2	4.8	4.9	4.9	5.0
16	5.4	5.5	5.5	5.7	5.2	5.4	5.4	5.5	5.0	5.2	5.2	5.3	4.8	5.0	5.0	5.1
17	5.5	5.6	5.6	5.8	5.3	5.5	5.5	5.6	5.1	5.3	5.3	5.4	4.9	5.0	5.0	5.2
18	5.6	5.7	5.7	5.9	5.4	5.6	5.6	5.7	5.2	5.3	5.3	5.5	5.0	5.1	5.1	5.3
19	5.7	5.8	5.8	6.0	5.5	5.7	5.7	5.8	5.3	5.4	5.4	5.6	5.0	5.2	5.2	5.3
20	5.8	5.9	5.9	6.1	5.6	5.7	5.7	5.9	5.4	5.5	5.5	5.6	5.1	5.3	5.3	5.4
21	5.9	6.0	6.0	6.1	5.7	5.8	5.8	6.0	5.4	5.6	5.6	5.7	5.2	5.3	5.3	5.5
22	5.9	6.1	6.1	6.2	5.8	5.9	5.9	6.0	5.5	5.7	5.7	5.8	5.3	5.4	5.4	5.5
23	6.0	6.2	6.2	6.3	5.8	6.0	6.0	6.1	5.6	5.7	5.7	5.9	5.3	5.5	5.5	5.6
24	6.1	6.3	6.3	6.4	5.9	6.1	6.1	6.2	5.7	5.8	5.8	5.9	5.4	5.5	5.5	5.7
25	6.2	6.3	6.3	6.5	6.0	6.2	6.2	6.3	5.7	5.9	5.9	6.0	5.4	5.6	5.6	5.7
26	6.3	6.4	6.4	6.6	6.1	6.2	6.2	6.4	5.8	5.9	5.9	6.1	5.5	5.7	5.7	5.8
27	6.4	6.5	6.5	6.7	6.2	6.3	6.3	6.5	5.9	6.0	6.0	6.2	5.6	5.7	5.7	5.9
28	6.4	6.6	6.6	6.8	6.2	6.4	6.4	6.5	5.9	6.1	6.1	6.2	5.6	5.8	5.8	5.9
29	6.5	6.7	6.7	6.8	6.3	6.5	6.5	6.6	6.0	6.2	6.2	6.3	5.7	5.8	5.8	6.0
30	6.5	6.7	6.7	6.8	6.3	6.5	6.5	6.6	6.0	6.2	6.2	6.3	5.7	5.8	5.8	6.0

Height of Backfill H Above Top of Pipe, Feet

Table 18

Pipe Size = 27"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	4.6	4.8	4.8	4.9	4.6	4.7	4.7	4.9	4.5	4.6	4.6	4.8	4.4	4.5	4.5	4.7
6	4.7	4.9	4.9	5.0	4.7	4.8	4.8	5.0	4.6	4.7	4.7	4.9	4.5	4.6	4.6	4.8
7	4.9	5.0	5.0	5.2	4.8	4.9	4.9	5.1	4.7	4.8	4.8	5.0	4.6	4.7	4.7	4.9
8	5.0	5.1	5.1	5.3	4.9	5.0	5.0	5.2	4.8	4.9	4.9	5.1	4.6	4.8	4.8	4.9
9	5.1	5.2	5.2	5.4	5.0	5.1	5.1	5.3	4.9	5.0	5.0	5.2	4.7	4.9	4.9	5.0
10	5.2	5.4	5.4	5.5	5.1	5.2	5.2	5.4	5.0	5.1	5.1	5.3	4.8	5.0	5.0	5.1
11	5.3	5.5	5.5	5.6	5.2	5.4	5.4	5.5	5.0	5.2	5.2	5.3	4.9	5.0	5.0	5.2
12	5.4	5.6	5.6	5.7	5.3	5.5	5.5	5.6	5.1	5.3	5.3	5.4	5.0	5.1	5.1	5.3
13	5.5	5.7	5.7	5.8	5.4	5.6	5.6	5.7	5.2	5.4	5.4	5.5	5.0	5.2	5.2	5.3
14	5.6	5.8	5.8	5.9	5.5	5.7	5.7	5.8	5.3	5.5	5.5	5.6	5.1	5.3	5.3	5.4
15	5.7	5.9	5.9	6.0	5.6	5.7	5.7	5.9	5.4	5.5	5.5	5.7	5.2	5.3	5.3	5.5
16	5.8	6.0	6.0	6.1	5.7	5.8	5.8	6.0	5.5	5.6	5.6	5.8	5.3	5.4	5.4	5.6
17	5.9	6.1	6.1	6.2	5.8	5.9	5.9	6.1	5.6	5.7	5.7	5.9	5.3	5.5	5.5	5.6
18	6.0	6.2	6.2	6.3	5.9	6.0	6.0	6.2	5.6	5.8	5.8	6.0	5.4	5.6	5.6	5.7
19	6.1	6.3	6.3	6.4	6.0	6.1	6.1	6.3	5.7	5.9	5.9	6.0	5.5	5.6	5.6	5.8
20	6.2	6.4	6.4	6.5	6.0	6.2	6.2	6.4	5.8	6.0	6.0	6.1	5.6	5.7	5.7	5.9
21	6.3	6.5	6.5	6.6	6.1	6.3	6.3	6.5	5.9	6.0	6.0	6.2	5.6	5.8	5.8	5.9
22	6.4	6.6	6.6	6.7	6.2	6.4	6.4	6.5	6.0	6.1	6.1	6.3	5.7	5.8	5.8	6.0
23	6.5	6.7	6.7	6.8	6.3	6.5	6.5	6.6	6.0	6.2	6.2	6.4	5.8	5.9	5.9	6.1
24	6.6	6.7	6.7	6.9	6.4	6.5	6.5	6.7	6.1	6.3	6.3	6.4	5.8	6.0	6.0	6.1
25	6.7	6.8	6.8	7.0	6.5	6.6	6.6	6.8	6.2	6.3	6.3	6.5	5.9	6.1	6.1	6.2
26	6.8	6.9	6.9	7.1	6.6	6.7	6.7	6.9	6.3	6.4	6.4	6.6	6.0	6.1	6.1	6.3
27	6.8	7.0	7.0	7.2	6.6	6.8	6.8	7.0	6.3	6.5	6.5	6.7	6.0	6.2	6.2	6.3
28	6.9	7.1	7.1	7.3	6.7	6.9	6.9	7.0	6.4	6.6	6.6	6.7	6.1	6.2	6.2	6.4
29	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.1	6.5	6.6	6.6	6.8	6.2	6.3	6.3	6.5
30	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.1	6.5	6.6	6.6	6.8	6.2	6.3	6.3	6.5

Table 19

Pipe Size = 30"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	5.0	5.2	5.2	5.4	5.0	5.1	5.1	5.3	4.9	5.1	5.1	5.2	4.8	5.0	5.0	5.1
6	5.2	5.3	5.3	5.5	5.1	5.3	5.3	5.4	5.0	5.2	5.2	5.3	4.9	5.1	5.1	5.2
7	5.3	5.4	5.4	5.6	5.2	5.4	5.4	5.5	5.1	5.3	5.3	5.4	5.0	5.1	5.1	5.3
8	5.4	5.6	5.6	5.7	5.3	5.5	5.5	5.6	5.2	5.4	5.4	5.5	5.1	5.2	5.2	5.4
9	5.5	5.7	5.7	5.8	5.4	5.6	5.6	5.7	5.3	5.4	5.4	5.6	5.1	5.3	5.3	5.5
10	5.6	5.8	5.8	6.0	5.5	5.7	5.7	5.9	5.4	5.5	5.5	5.7	5.2	5.4	5.4	5.5
11	5.7	5.9	5.9	6.1	5.6	5.8	5.8	6.0	5.5	5.6	5.6	5.8	5.3	5.5	5.5	5.6
12	5.9	6.0	6.0	6.2	5.7	5.9	5.9	6.1	5.6	5.7	5.7	5.9	5.4	5.5	5.5	5.7
13	6.0	6.1	6.1	6.3	5.8	6.0	6.0	6.2	5.7	5.8	5.8	6.0	5.5	5.6	5.6	5.8
14	6.1	6.2	6.2	6.4	5.9	6.1	6.1	6.3	5.7	5.9	5.9	6.1	5.5	5.7	5.7	5.9
15	6.2	6.3	6.3	6.5	6.0	6.2	6.2	6.4	5.8	6.0	6.0	6.2	5.6	5.8	5.8	5.9
16	6.3	6.4	6.4	6.6	6.1	6.3	6.3	6.5	5.9	6.1	6.1	6.2	5.7	5.9	5.9	6.0
17	6.4	6.6	6.6	6.7	6.2	6.4	6.4	6.6	6.0	6.2	6.2	6.3	5.8	5.9	5.9	6.1
18	6.5	6.7	6.7	6.8	6.3	6.5	6.5	6.7	6.1	6.3	6.3	6.4	5.8	6.0	6.0	6.2
19	6.6	6.8	6.8	6.9	6.4	6.6	6.6	6.7	6.2	6.3	6.3	6.5	5.9	6.1	6.1	6.3
20	6.7	6.9	6.9	7.0	6.5	6.7	6.7	6.8	6.2	6.4	6.4	6.6	6.0	6.2	6.2	6.3
21	6.8	6.9	6.9	7.1	6.6	6.8	6.8	6.9	6.3	6.5	6.5	6.7	6.1	6.2	6.2	6.4
22	6.9	7.0	7.0	7.2	6.7	6.8	6.8	7.0	6.4	6.6	6.6	6.8	6.1	6.3	6.3	6.5
23	7.0	7.1	7.1	7.3	6.8	6.9	6.9	7.1	6.5	6.7	6.7	6.8	6.2	6.4	6.4	6.5
24	7.1	7.2	7.2	7.4	6.8	7.0	7.0	7.2	6.6	6.7	6.7	6.9	6.3	6.4	6.4	6.6
25	7.1	7.3	7.3	7.5	6.9	7.1	7.1	7.3	6.6	6.8	6.8	7.0	6.3	6.5	6.5	6.7
26	7.2	7.4	7.4	7.6	7.0	7.2	7.2	7.4	6.7	6.9	6.9	7.1	6.4	6.6	6.6	6.7
27	7.3	7.5	7.5	7.7	7.1	7.3	7.3	7.5	6.8	7.0	7.0	7.1	6.5	6.6	6.6	6.8
28	7.4	7.6	7.6	7.8	7.2	7.4	7.4	7.5	6.9	7.0	7.0	7.2	6.5	6.7	6.7	6.9
29	7.5	7.7	7.7	7.9	7.3	7.4	7.4	7.6	6.9	7.1	7.1	7.3	6.6	6.8	6.8	6.9
30	7.5	7.7	7.7	7.9	7.3	7.4	7.4	7.6	6.9	7.1	7.1	7.3	6.6	6.8	6.8	6.9

Table 20

Pipe Size = 33"

Height of Backfill H Above Top of Pipe, Feet	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	5.5	5.6	5.6	5.8	5.4	5.6	5.6	5.8	5.3	5.5	5.5	5.7	5.2	5.4	5.4	5.6
6	5.6	5.8	5.8	5.9	5.5	5.7	5.7	5.9	5.4	5.6	5.6	5.8	5.3	5.5	5.5	5.7
7	5.7	5.9	5.9	6.1	5.6	5.8	5.8	6.0	5.5	5.7	5.7	5.9	5.4	5.6	5.6	5.8
8	5.8	6.0	6.0	6.2	5.7	5.9	5.9	6.1	5.6	5.8	5.8	6.0	5.5	5.7	5.7	5.8
9	5.9	6.1	6.1	6.3	5.8	6.0	6.0	6.2	5.7	5.9	5.9	6.1	5.6	5.7	5.7	5.9
10	6.1	6.2	6.2	6.4	5.9	6.1	6.1	6.3	5.8	6.0	6.0	6.2	5.6	5.8	5.8	6.0
11	6.2	6.4	6.4	6.5	6.1	6.2	6.2	6.4	5.9	6.1	6.1	6.3	5.7	5.9	5.9	6.1
12	6.3	6.5	6.5	6.7	6.2	6.3	6.3	6.5	6.0	6.2	6.2	6.3	5.8	6.0	6.0	6.2
13	6.4	6.6	6.6	6.8	6.3	6.4	6.4	6.6	6.1	6.3	6.3	6.4	5.9	6.1	6.1	6.2
14	6.5	6.7	6.7	6.9	6.4	6.5	6.5	6.7	6.2	6.3	6.3	6.5	6.0	6.1	6.1	6.3
15	6.6	6.8	6.8	7.0	6.5	6.6	6.6	6.8	6.3	6.4	6.4	6.6	6.0	6.2	6.2	6.4
16	6.7	6.9	6.9	7.1	6.6	6.7	6.7	6.9	6.3	6.5	6.5	6.7	6.1	6.3	6.3	6.5
17	6.8	7.0	7.0	7.2	6.7	6.8	6.8	7.0	6.4	6.6	6.6	6.8	6.2	6.4	6.4	6.6
18	6.9	7.1	7.1	7.3	6.8	6.9	6.9	7.1	6.5	6.7	6.7	6.9	6.3	6.5	6.5	6.6
19	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.2	6.6	6.8	6.8	7.0	6.3	6.5	6.5	6.7
20	7.1	7.3	7.3	7.5	6.9	7.1	7.1	7.3	6.7	6.9	6.9	7.1	6.4	6.6	6.6	6.8
21	7.2	7.4	7.4	7.6	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.1	6.5	6.7	6.7	6.9
22	7.3	7.5	7.5	7.7	7.1	7.3	7.3	7.5	6.9	7.0	7.0	7.2	6.6	6.7	6.7	6.9
23	7.4	7.6	7.6	7.8	7.2	7.4	7.4	7.6	6.9	7.1	7.1	7.3	6.6	6.8	6.8	7.0
24	7.5	7.7	7.7	7.9	7.3	7.5	7.5	7.7	7.0	7.2	7.2	7.4	6.7	6.9	6.9	7.1
25	7.6	7.8	7.8	8.0	7.4	7.6	7.6	7.8	7.1	7.3	7.3	7.5	6.8	7.0	7.0	7.1
26	7.7	7.9	7.9	8.1	7.5	7.7	7.7	7.9	7.2	7.4	7.4	7.5	6.8	7.0	7.0	7.2
27	7.8	8.0	8.0	8.2	7.6	7.8	7.8	7.9	7.2	7.4	7.4	7.6	6.9	7.1	7.1	7.3
28	7.9	8.1	8.1	8.3	7.6	7.8	7.8	8.0	7.3	7.5	7.5	7.7	7.0	7.1	7.2	7.4
29	8.0	8.2	8.2	8.4	7.7	7.9	7.9	8.1	7.4	7.6	7.6	7.8	7.1	7.2	7.2	7.4
30	8.0	8.2	8.2	8.4	7.7	7.9	7.9	8.1	7.4	7.6	7.6	7.8	7.1	7.2	7.2	7.4

Table 21

Pipe Size = 36"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	5.9	6.1	6.1	6.3	5.8	6.0	6.0	6.2	5.7	5.9	5.9	6.1	5.6	5.8	5.8	6.0
6	6.0	6.2	6.2	6.4	5.9	6.1	6.1	6.3	5.8	6.0	6.0	6.2	5.7	5.9	5.9	6.1
7	6.1	6.3	6.3	6.5	6.0	6.2	6.2	6.4	5.9	6.1	6.1	6.3	5.8	6.0	6.0	6.2
8	6.2	6.4	6.4	6.6	6.2	6.3	6.3	6.5	6.0	6.2	6.2	6.4	5.9	6.1	6.1	6.3
9	6.4	6.6	6.6	6.8	6.3	6.5	6.5	6.7	6.1	6.3	6.3	6.5	6.0	6.2	6.2	6.4
10	6.5	6.7	6.7	6.9	6.4	6.6	6.6	6.8	6.2	6.4	6.4	6.6	6.1	6.3	6.3	6.4
11	6.6	6.8	6.8	7.0	6.5	6.7	6.7	6.9	6.3	6.5	6.5	6.7	6.1	6.3	6.3	6.5
12	6.7	6.9	6.9	7.1	6.6	6.8	6.8	7.0	6.4	6.6	6.6	6.8	6.2	6.4	6.4	6.6
13	6.8	7.0	7.0	7.2	6.7	6.9	6.9	7.1	6.5	6.7	6.7	6.9	6.3	6.5	6.5	6.7
14	6.9	7.1	7.1	7.3	6.8	7.0	7.0	7.2	6.6	6.8	6.8	7.0	6.4	6.6	6.6	6.8
15	7.0	7.2	7.2	7.4	6.9	7.1	7.1	7.3	6.7	6.9	6.9	7.1	6.5	6.7	6.7	6.9
16	7.2	7.4	7.4	7.6	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.2	6.5	6.7	6.7	6.9
17	7.3	7.5	7.5	7.7	7.1	7.3	7.3	7.5	6.9	7.1	7.1	7.3	6.6	6.8	6.8	7.0
18	7.4	7.6	7.6	7.8	7.2	7.4	7.4	7.6	6.9	7.1	7.1	7.3	6.7	6.9	6.9	7.1
19	7.5	7.7	7.7	7.9	7.3	7.5	7.5	7.7	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.2
20	7.6	7.8	7.8	8.0	7.4	7.6	7.6	7.8	7.1	7.3	7.3	7.5	6.9	7.0	7.0	7.2
21	7.7	7.9	7.9	8.1	7.5	7.7	7.7	7.9	7.2	7.4	7.4	7.6	6.9	7.1	7.1	7.3
22	7.8	8.0	8.0	8.2	7.6	7.8	7.8	8.0	7.3	7.5	7.5	7.7	7.0	7.2	7.2	7.4
23	7.9	8.1	8.1	8.3	7.7	7.9	7.9	8.1	7.4	7.6	7.6	7.8	7.1	7.3	7.3	7.5
24	8.0	8.2	8.2	8.4	7.7	8.0	8.0	8.2	7.5	7.7	7.7	7.9	7.1	7.3	7.3	7.5
25	8.1	8.3	8.3	8.5	7.8	8.0	8.0	8.2	7.5	7.7	7.7	7.9	7.2	7.4	7.4	7.6
26	8.2	8.4	8.4	8.6	7.9	8.1	8.1	8.3	7.6	7.8	7.8	8.0	7.3	7.5	7.5	7.7
27	8.2	8.5	8.5	8.7	8.0	8.2	8.2	8.4	7.7	7.9	7.9	8.1	7.4	7.6	7.6	7.8
28	8.3	8.6	8.6	8.8	8.1	8.3	8.3	8.5	7.8	8.0	8.0	8.2	7.4	7.6	7.6	7.8
29	8.4	8.6	8.6	8.9	8.2	8.4	8.4	8.6	7.8	8.1	8.1	8.3	7.5	7.7	7.7	7.9
30	8.4	8.6	8.6	8.9	8.2	8.4	8.4	8.6	7.8	8.1	8.1	8.3	7.5	7.7	7.7	7.9

Table 22

Pipe Size = 42"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	6.7	7.0	7.0	7.2	6.7	6.9	6.9	7.1	6.6	6.8	6.8	7.0	6.5	6.7	6.7	7.0
6	6.9	7.1	7.1	7.3	6.8	7.0	7.0	7.2	6.7	6.9	6.9	7.1	6.6	6.8	6.8	7.0
7	7.0	7.2	7.2	7.4	6.9	7.1	7.1	7.3	6.8	7.0	7.0	7.2	6.6	6.9	6.9	7.1
8	7.1	7.3	7.3	7.5	7.0	7.2	7.2	7.5	6.9	7.1	7.1	7.3	6.7	7.0	7.0	7.2
9	7.2	7.4	7.4	7.7	7.1	7.3	7.3	7.6	7.0	7.2	7.2	7.4	6.8	7.0	7.0	7.3
10	7.3	7.6	7.6	7.8	7.2	7.4	7.4	7.7	7.1	7.3	7.3	7.5	6.9	7.1	7.1	7.3
11	7.4	7.7	7.7	7.9	7.3	7.6	7.6	7.8	7.2	7.4	7.4	7.6	7.0	7.2	7.2	7.4
12	7.6	7.8	7.8	8.0	7.4	7.7	7.7	7.9	7.2	7.5	7.5	7.7	7.1	7.3	7.3	7.5
13	7.7	7.9	7.9	8.1	7.5	7.8	7.8	8.0	7.3	7.6	7.6	7.8	7.1	7.4	7.4	7.6
14	7.8	8.0	8.0	8.3	7.6	7.9	7.9	8.1	7.4	7.7	7.7	7.9	7.2	7.5	7.5	7.7
15	7.9	8.1	8.1	8.4	7.7	8.0	8.0	8.2	7.5	7.8	7.8	8.0	7.3	7.5	7.5	7.8
16	8.0	8.2	8.2	8.5	7.9	8.1	8.1	8.3	7.6	7.9	7.9	8.1	7.4	7.6	7.6	7.8
17	8.1	8.4	8.4	8.6	8.0	8.2	8.2	8.4	7.7	7.9	7.9	8.2	7.5	7.7	7.7	7.9
18	8.2	8.5	8.5	8.7	8.1	8.3	8.3	8.5	7.8	8.0	8.0	8.3	7.5	7.8	7.8	8.0
19	8.3	8.6	8.6	8.8	8.2	8.4	8.4	8.6	7.9	8.1	8.1	8.4	7.6	7.9	7.9	8.1
20	8.4	8.7	8.7	8.9	8.3	8.5	8.5	8.7	8.0	8.2	8.2	8.4	7.7	7.9	7.9	8.2
21	8.6	8.8	8.8	9.0	8.4	8.6	8.6	8.8	8.1	8.3	8.3	8.5	7.8	8.0	8.0	8.2
22	8.7	8.9	8.9	9.1	8.4	8.7	8.7	8.9	8.2	8.4	8.4	8.6	7.9	8.1	8.1	8.3
23	8.8	9.0	9.0	9.2	8.5	8.8	8.8	9.0	8.2	8.5	8.5	8.7	7.9	8.2	8.2	8.4
24	8.9	9.1	9.1	9.3	8.6	8.9	8.9	9.1	8.3	8.6	8.6	8.8	8.0	8.2	8.2	8.5
25	9.0	9.2	9.2	9.4	8.7	9.0	9.0	9.2	8.4	8.6	8.6	8.9	8.1	8.3	8.3	8.5
26	9.1	9.3	9.3	9.5	8.8	9.1	9.1	9.3	8.5	8.7	8.7	9.0	8.2	8.4	8.4	8.6
27	9.2	9.4	9.4	9.6	8.9	9.1	9.1	9.4	8.6	8.8	8.8	9.0	8.2	8.5	8.5	8.7
28	9.3	9.5	9.5	9.7	9.0	9.2	9.2	9.5	8.7	8.9	8.9	9.1	8.3	8.5	8.5	8.8
29	9.3	9.6	9.6	9.8	9.1	9.3	9.3	9.6	8.7	9.0	9.0	9.2	8.4	8.6	8.6	8.8
30	9.3	9.6	9.6	9.8	9.1	9.3	9.3	9.6	8.7	9.0	9.0	9.2	8.4	8.6	8.6	8.8

Table 23

Pipe Size = 48"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	7.5	7.8	7.8	8.0	7.4	7.7	7.7	8.0	7.3	7.6	7.6	7.9	7.2	7.5	7.5	7.8
6	7.6	7.9	7.9	8.1	7.5	7.8	7.8	8.0	7.4	7.7	7.7	7.9	7.3	7.6	7.6	7.8
7	7.7	8.0	8.0	8.2	7.6	7.9	7.9	8.2	7.5	7.8	7.8	8.0	7.4	7.6	7.6	7.9
8	7.8	8.1	8.1	8.4	7.7	8.0	8.0	8.3	7.6	7.9	7.9	8.1	7.5	7.7	7.7	8.0
9	8.0	8.2	8.2	8.5	7.8	8.1	8.1	8.4	7.7	8.0	8.0	8.2	7.5	7.8	7.8	8.1
10	8.1	8.3	8.3	8.6	8.0	8.2	8.2	8.5	7.8	8.1	8.1	8.3	7.6	7.9	7.9	8.1
11	8.2	8.5	8.5	8.7	8.1	8.3	8.3	8.6	7.9	8.2	8.2	8.4	7.7	8.0	8.0	8.2
12	8.3	8.6	8.6	8.8	8.2	8.4	8.4	8.7	8.0	8.2	8.2	8.5	7.8	8.1	8.1	8.3
13	8.4	8.7	8.7	9.0	8.3	8.5	8.5	8.8	8.1	8.3	8.3	8.6	7.9	8.1	8.1	8.4
14	8.5	8.8	8.8	9.1	8.4	8.7	8.7	8.9	8.2	8.4	8.4	8.7	8.0	8.2	8.2	8.5
15	8.7	8.9	8.9	9.2	8.5	8.8	8.8	9.0	8.3	8.5	8.5	8.8	8.0	8.3	8.3	8.6
16	8.8	9.0	9.0	9.3	8.6	8.9	8.9	9.1	8.4	8.6	8.6	8.9	8.1	8.4	8.4	8.6
17	8.9	9.2	9.2	9.4	8.7	9.0	9.0	9.2	8.5	8.7	8.7	9.0	8.2	8.5	8.5	8.7
18	9.0	9.3	9.3	9.5	8.8	9.1	9.1	9.3	8.6	8.8	8.8	9.1	8.3	8.5	8.5	8.8
19	9.1	9.4	9.4	9.6	8.9	9.2	9.2	9.4	8.6	8.9	8.9	9.2	8.4	8.6	8.6	8.9
20	9.2	9.5	9.5	9.7	9.0	9.3	9.3	9.5	8.7	9.0	9.0	9.3	8.4	8.7	8.7	9.0
21	9.3	9.6	9.6	9.9	9.1	9.4	9.4	9.6	8.8	9.1	9.1	9.3	8.5	8.8	8.8	9.0
22	9.4	9.7	9.7	10.0	9.2	9.5	9.5	9.7	8.9	9.2	9.2	9.4	8.6	8.9	8.9	9.1
23	9.5	9.8	9.8	10.1	9.3	9.6	9.6	9.8	9.0	9.3	9.3	9.5	8.7	8.9	8.9	9.2
24	9.6	9.9	9.9	10.2	9.4	9.7	9.7	9.9	9.1	9.4	9.4	9.6	8.8	9.0	9.0	9.3
25	9.7	10.0	10.0	10.3	9.5	9.8	9.8	10.0	9.2	9.4	9.4	9.7	8.8	9.1	9.1	9.4
26	9.8	10.1	10.1	10.4	9.6	9.9	9.9	10.1	9.3	9.5	9.5	9.8	8.9	9.2	9.2	9.4
27	9.9	10.2	10.2	10.5	9.7	10.0	10.0	10.2	9.3	9.6	9.6	9.9	9.0	9.2	9.2	9.5
28	10.0	10.3	10.3	10.6	9.8	10.1	10.1	10.3	9.4	9.7	9.7	10.0	9.1	9.3	9.3	9.6
29	10.1	10.4	10.4	10.7	9.9	10.2	10.2	10.4	9.5	9.8	9.8	10.0	9.1	9.4	9.4	9.7
30	10.1	10.4	10.4	10.7	9.9	10.2	10.2	10.4	9.5	9.8	9.8	10.0	9.1	9.4	9.4	9.7

Table 24

Pipe Size = 54"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	8.3	8.6	8.6	8.9	8.3	8.6	8.6	8.9	8.2	8.5	8.5	8.8	8.1	8.4	8.4	8.7
6	8.4	8.7	8.7	9.0	8.4	8.7	8.7	9.0	8.3	8.6	8.6	8.9	8.2	8.5	8.5	8.8
7	8.6	8.9	8.9	9.2	8.5	8.8	8.8	9.1	8.4	8.6	8.6	8.9	8.2	8.5	8.5	8.8
8	8.7	9.0	9.0	9.3	8.6	8.9	8.9	9.2	8.4	8.7	8.7	9.0	8.3	8.6	8.6	8.9
9	8.8	9.1	9.1	9.4	8.7	9.0	9.0	9.3	8.5	8.8	8.8	9.1	8.4	8.7	8.7	9.0
10	8.9	9.2	9.2	9.5	8.8	9.1	9.1	9.4	8.6	8.9	8.9	9.2	8.5	8.8	8.8	9.0
11	9.0	9.3	9.3	9.6	8.9	9.2	9.2	9.5	8.7	9.0	9.0	9.3	8.5	8.8	8.8	9.1
12	9.2	9.5	9.5	9.7	9.0	9.3	9.3	9.6	8.8	9.1	9.1	9.4	8.6	8.9	8.9	9.2
13	9.3	9.6	9.6	9.9	9.1	9.4	9.4	9.7	8.9	9.2	9.2	9.5	8.7	9.0	9.0	9.3
14	9.4	9.7	9.7	10.0	9.2	9.5	9.5	9.8	9.0	9.3	9.3	9.6	8.8	9.1	9.1	9.4
15	9.5	9.8	9.8	10.1	9.3	9.6	9.6	9.9	9.1	9.4	9.4	9.7	8.9	9.2	9.2	9.5
16	9.6	9.9	9.9	10.2	9.5	9.7	9.7	10.0	9.2	9.5	9.5	9.8	9.0	9.3	9.3	9.5
17	9.7	10.0	10.0	10.3	9.6	9.9	9.9	10.1	9.3	9.6	9.6	9.9	9.0	9.3	9.3	9.6
18	9.9	10.2	10.2	10.4	9.7	10.0	10.0	10.2	9.4	9.7	9.7	10.0	9.1	9.4	9.4	9.7
19	10.0	10.3	10.3	10.6	9.8	10.1	10.1	10.4	9.5	9.8	9.8	10.1	9.2	9.5	9.5	9.8
20	10.1	10.4	10.4	10.7	9.9	10.2	10.2	10.5	9.6	9.9	9.9	10.2	9.3	9.6	9.6	9.9
21	10.2	10.5	10.5	10.8	10.0	10.3	10.3	10.6	9.7	10.0	10.0	10.3	9.4	9.7	9.7	9.9
22	10.3	10.6	10.6	10.9	10.1	10.4	10.4	10.7	9.8	10.1	10.1	10.3	9.4	9.7	9.7	10.0
23	10.4	10.7	10.7	11.0	10.2	10.5	10.5	10.8	9.9	10.1	10.1	10.4	9.5	9.8	9.8	10.1
24	10.5	10.8	10.8	11.1	10.3	10.6	10.6	10.9	9.9	10.2	10.2	10.5	9.6	9.9	9.9	10.2
25	10.6	10.9	10.9	11.2	10.4	10.7	10.7	11.0	10.0	10.3	10.3	10.6	9.7	10.0	10.0	10.3
26	10.7	11.0	11.0	11.3	10.5	10.8	10.8	11.1	10.1	10.4	10.4	10.7	9.8	10.1	10.1	10.3
27	10.8	11.1	11.1	11.4	10.6	10.9	10.9	11.2	10.2	10.5	10.5	10.8	9.8	10.1	10.1	10.4
28	10.9	11.2	11.2	11.5	10.7	11.0	11.0	11.3	10.3	10.6	10.6	10.9	9.9	10.2	10.2	10.5
29	11.0	11.3	11.3	11.6	10.8	11.1	11.1	11.4	10.4	10.7	10.7	11.0	10.0	10.3	10.3	10.6
30	11.0	11.3	11.3	11.6	10.8	11.1	11.1	11.4	10.4	10.7	10.7	11.0	10.0	10.3	10.3	10.6

Table 25

Pipe Size = 60"

Transition Widths (FT)

Height of Backfill H Above Top of Pipe, Feet

	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	9.2	9.5	9.5	9.9	9.1	9.5	9.5	9.8	9.0	9.4	9.4	9.7	8.9	9.3	9.3	9.6
6	9.3	9.6	9.6	10.0	9.2	9.6	9.6	9.9	9.1	9.4	9.4	9.8	9.0	9.3	9.3	9.7
7	9.4	9.7	9.7	10.1	9.3	9.6	9.6	10.0	9.2	9.5	9.5	9.9	9.1	9.4	9.4	9.7
8	9.5	9.9	9.9	10.2	9.4	9.8	9.8	10.1	9.3	9.6	9.6	9.9	9.1	9.5	9.5	9.8
9	9.6	10.0	10.0	10.3	9.5	9.9	9.9	10.2	9.4	9.7	9.7	10.0	9.2	9.5	9.5	9.9
10	9.8	10.1	10.1	10.4	9.6	10.0	10.0	10.3	9.5	9.8	9.8	10.1	9.3	9.6	9.6	9.9
11	9.9	10.2	10.2	10.5	9.8	10.1	10.1	10.4	9.6	9.9	9.9	10.2	9.4	9.7	9.7	10.0
12	10.0	10.3	10.3	10.6	9.9	10.2	10.2	10.5	9.7	10.0	10.0	10.3	9.5	9.8	9.8	10.1
13	10.1	10.4	10.4	10.8	10.0	10.3	10.3	10.6	9.8	10.1	10.1	10.4	9.6	9.9	9.9	10.2
14	10.2	10.6	10.6	10.9	10.1	10.4	10.4	10.7	9.9	10.2	10.2	10.5	9.6	10.0	10.0	10.3
15	10.4	10.7	10.7	11.0	10.2	10.5	10.5	10.8	10.0	10.3	10.3	10.6	9.7	10.0	10.0	10.4
16	10.5	10.8	10.8	11.1	10.3	10.6	10.6	10.9	10.1	10.4	10.4	10.7	9.8	10.1	10.1	10.4
17	10.6	10.9	10.9	11.2	10.4	10.7	10.7	11.0	10.1	10.5	10.5	10.8	9.9	10.2	10.2	10.5
18	10.7	11.0	11.0	11.4	10.5	10.8	10.8	11.2	10.2	10.6	10.6	10.9	10.0	10.3	10.3	10.6
19	10.8	11.2	11.2	11.5	10.6	10.9	10.9	11.3	10.3	10.7	10.7	11.0	10.0	10.4	10.4	10.7
20	10.9	11.3	11.3	11.6	10.7	11.0	11.0	11.4	10.4	10.8	10.8	11.1	10.1	10.4	10.4	10.8
21	11.1	11.4	11.4	11.7	10.8	11.2	11.2	11.5	10.5	10.8	10.8	11.2	10.2	10.5	10.5	10.8
22	11.2	11.5	11.5	11.8	10.9	11.3	11.3	11.6	10.6	10.9	10.9	11.3	10.3	10.6	10.6	10.9
23	11.3	11.6	11.6	11.9	11.0	11.4	11.4	11.7	10.7	11.0	11.0	11.4	10.4	10.7	10.7	11.0
24	11.4	11.7	11.7	12.0	11.1	11.5	11.5	11.8	10.8	11.1	11.1	11.4	10.5	10.8	10.8	11.1
25	11.5	11.8	11.8	12.1	11.2	11.6	11.6	11.9	10.9	11.2	11.2	11.5	10.5	10.8	10.8	11.2
26	11.6	11.9	11.9	12.3	11.3	11.7	11.7	12.0	11.0	11.3	11.3	11.6	10.6	10.9	10.9	11.2
27	11.7	12.0	12.0	12.4	11.4	11.8	11.8	12.1	11.1	11.4	11.4	11.7	10.7	11.0	11.0	11.3
28	11.8	12.1	12.1	12.5	11.5	11.9	11.9	12.2	11.2	11.5	11.5	11.8	10.8	11.1	11.1	11.4
29	11.9	12.2	12.2	12.6	11.6	12.0	12.0	12.3	11.2	11.6	11.6	11.9	10.8	11.2	11.2	11.5
30	11.9	12.2	12.2	12.6	11.6	12.0	12.0	12.3	11.2	11.6	11.6	11.9	10.8	11.2	11.2	11.5

Table 26

Pipe Size = 66"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	10.1	10.4	10.4	10.8	10.0	10.4	10.4	10.7	9.9	10.3	10.3	10.7	9.8	10.2	10.2	10.6
6	10.2	10.5	10.5	10.9	10.1	10.4	10.4	10.8	10.0	10.3	10.3	10.7	9.9	10.2	10.2	10.6
7	10.3	10.6	10.6	11.0	10.2	10.5	10.5	10.9	10.0	10.4	10.4	10.8	9.9	10.3	10.3	10.6
8	10.4	10.7	10.7	11.1	10.3	10.6	10.6	11.0	10.1	10.5	10.5	10.9	10.0	10.3	10.3	10.7
9	10.5	10.8	10.8	11.2	10.4	10.7	10.7	11.1	10.2	10.6	10.6	10.9	10.1	10.4	10.4	10.8
10	10.6	11.0	11.0	11.3	10.5	10.8	10.8	11.2	10.3	10.7	10.7	11.0	10.1	10.5	10.5	10.9
11	10.7	11.1	11.1	11.4	10.6	10.9	10.9	11.3	10.4	10.8	10.8	11.1	10.2	10.6	10.6	10.9
12	10.8	11.2	11.2	11.6	10.7	11.1	11.1	11.4	10.5	10.9	10.9	11.2	10.3	10.7	10.7	11.0
13	11.0	11.3	11.3	11.7	10.8	11.2	11.2	11.5	10.6	11.0	11.0	11.3	10.4	10.7	10.7	11.1
14	11.1	11.4	11.4	11.8	10.9	11.3	11.3	11.6	10.7	11.1	11.1	11.4	10.5	10.8	10.8	11.2
15	11.2	11.6	11.6	11.9	11.0	11.4	11.4	11.7	10.8	11.1	11.1	11.5	10.6	10.9	10.9	11.3
16	11.3	11.7	11.7	12.0	11.1	11.5	11.5	11.8	10.9	11.2	11.2	11.6	10.6	11.0	11.0	11.3
17	11.4	11.8	11.8	12.2	11.3	11.6	11.6	12.0	11.0	11.3	11.3	11.7	10.7	11.1	11.1	11.4
18	11.6	11.9	11.9	12.3	11.4	11.7	11.7	12.1	11.1	11.4	11.4	11.8	10.8	11.2	11.2	11.5
19	11.7	12.0	12.0	12.4	11.5	11.8	11.8	12.2	11.2	11.5	11.5	11.9	10.9	11.2	11.2	11.6
20	11.8	12.1	12.1	12.5	11.6	11.9	11.9	12.3	11.3	11.6	11.6	12.0	11.0	11.3	11.3	11.7
21	11.9	12.3	12.3	12.6	11.7	12.0	12.0	12.4	11.4	11.7	11.7	12.1	11.0	11.4	11.4	11.7
22	12.0	12.4	12.4	12.7	11.8	12.1	12.1	12.5	11.5	11.8	11.8	12.2	11.1	11.5	11.5	11.8
23	12.1	12.5	12.5	12.8	11.9	12.2	12.2	12.6	11.6	11.9	11.9	12.3	11.2	11.6	11.6	11.9
24	12.2	12.6	12.6	13.0	12.0	12.3	12.3	12.7	11.6	12.0	12.0	12.4	11.3	11.6	11.6	12.0
25	12.4	12.7	12.7	13.1	12.1	12.5	12.5	12.8	11.7	12.1	12.1	12.4	11.4	11.7	11.7	12.1
26	12.5	12.8	12.8	13.2	12.2	12.6	12.6	12.9	11.8	12.2	12.2	12.5	11.5	11.8	11.8	12.2
27	12.6	12.9	12.9	13.3	12.3	12.7	12.7	13.0	11.9	12.3	12.3	12.6	11.5	11.9	11.9	12.2
28	12.7	13.0	13.0	13.4	12.4	12.8	12.8	13.1	12.0	12.4	12.4	12.7	11.6	12.0	12.0	12.3
29	12.8	13.2	13.2	13.5	12.5	12.9	12.9	13.2	12.1	12.5	12.5	12.8	11.7	12.0	12.0	12.4
30	12.8	13.2	13.2	13.5	12.5	12.9	12.9	13.2	12.1	12.5	12.5	12.8	11.7	12.0	12.0	12.4

Table 27

Pipe Size = 72"

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	10.9	11.3	11.3	11.8	10.9	11.3	11.3	11.7	10.8	11.2	11.2	11.6	10.7	11.1	11.1	11.5
6	11.0	11.4	11.4	11.8	10.9	11.3	11.3	11.7	10.8	11.2	11.2	11.6	10.7	11.1	11.1	11.5
7	11.1	11.5	11.5	11.9	11.0	11.4	11.4	11.8	10.9	11.3	11.3	11.7	10.8	11.2	11.2	11.6
8	11.2	11.6	11.6	12.0	11.1	11.5	11.5	11.9	11.0	11.4	11.4	11.8	10.8	11.2	11.2	11.6
9	11.3	11.7	11.7	12.1	11.2	11.6	11.6	12.0	11.1	11.5	11.5	11.8	10.9	11.3	11.3	11.7
10	11.5	11.8	11.8	12.2	11.3	11.7	11.7	12.1	11.2	11.5	11.5	11.9	11.0	11.4	11.4	11.8
11	11.6	12.0	12.0	12.3	11.4	11.8	11.8	12.2	11.2	11.6	11.6	12.0	11.1	11.4	11.4	11.8
12	11.7	12.1	12.1	12.5	11.5	11.9	11.9	12.3	11.3	11.7	11.7	12.1	11.1	11.5	11.5	11.9
13	11.8	12.2	12.2	12.6	11.7	12.0	12.0	12.4	11.4	11.8	11.8	12.2	11.2	11.6	11.6	12.0
14	11.9	12.3	12.3	12.7	11.8	12.2	12.2	12.5	11.5	11.9	11.9	12.3	11.3	11.7	11.7	12.1
15	12.1	12.4	12.4	12.8	11.9	12.3	12.3	12.6	11.6	12.0	12.0	12.4	11.4	11.8	11.8	12.1
16	12.2	12.6	12.6	12.9	12.0	12.4	12.4	12.8	11.7	12.1	12.1	12.5	11.5	11.9	11.9	12.2
17	12.3	12.7	12.7	13.1	12.1	12.5	12.5	12.9	11.8	12.2	12.2	12.6	11.6	11.9	11.9	12.3
18	12.4	12.8	12.8	13.2	12.2	12.6	12.6	13.0	11.9	12.3	12.3	12.7	11.6	12.0	12.0	12.4
19	12.5	12.9	12.9	13.3	12.3	12.7	12.7	13.1	12.0	12.4	12.4	12.8	11.7	12.1	12.1	12.5
20	12.6	13.0	13.0	13.4	12.4	12.8	12.8	13.2	12.1	12.5	12.5	12.9	11.8	12.2	12.2	12.6
21	12.8	13.1	13.1	13.5	12.5	12.9	12.9	13.3	12.2	12.6	12.6	13.0	11.9	12.3	12.3	12.6
22	12.9	13.3	13.3	13.6	12.6	13.0	13.0	13.4	12.3	12.7	12.7	13.1	12.0	12.3	12.3	12.7
23	13.0	13.4	13.4	13.8	12.7	13.1	13.1	13.5	12.4	12.8	12.8	13.2	12.1	12.4	12.4	12.8
24	13.1	13.5	13.5	13.9	12.8	13.2	13.2	13.6	12.5	12.9	12.9	13.3	12.1	12.5	12.5	12.9
25	13.2	13.6	13.6	14.0	13.0	13.3	13.3	13.7	12.6	13.0	13.0	13.4	12.2	12.6	12.6	13.0
26	13.3	13.7	13.7	14.1	13.1	13.4	13.4	13.8	12.7	13.1	13.1	13.4	12.3	12.7	12.7	13.1
27	13.4	13.8	13.8	14.2	13.2	13.5	13.5	13.9	12.8	13.2	13.2	13.5	12.4	12.8	12.8	13.1
28	13.5	13.9	13.9	14.3	13.3	13.6	13.6	14.0	12.9	13.2	13.2	13.6	12.5	12.8	12.8	13.2
29	13.7	14.0	14.0	14.4	13.4	13.7	13.7	14.1	13.0	13.3	13.3	13.7	12.5	12.9	12.9	13.3
30	13.7	14.0	14.0	14.4	13.4	13.7	13.7	14.1	13.0	13.3	13.3	13.7	12.5	12.9	12.9	13.3

Height of Backfill H Above Top of Pipe, Feet

Table 28

Pipe Size = 78"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	11.8	12.3	12.3	12.7	11.7	12.2	12.2	12.6	11.6	12.1	12.1	12.5	11.5	12.0	12.0	12.5
6	11.9	12.3	12.3	12.8	11.8	12.2	12.2	12.7	11.7	12.1	12.1	12.6	11.6	12.0	12.0	12.5
7	12.0	12.4	12.4	12.8	11.9	12.3	12.3	12.7	11.7	12.2	12.2	12.6	11.6	12.1	12.1	12.5
8	12.1	12.5	12.5	12.9	12.0	12.4	12.4	12.8	11.8	12.3	12.3	12.7	11.7	12.1	12.1	12.5
9	12.2	12.6	12.6	13.0	12.1	12.5	12.5	12.9	11.9	12.3	12.3	12.8	11.7	12.2	12.2	12.6
10	12.3	12.7	12.7	13.1	12.2	12.6	12.6	13.0	12.0	12.4	12.4	12.8	11.8	12.2	12.2	12.7
11	12.4	12.8	12.8	13.3	12.3	12.7	12.7	13.1	12.1	12.5	12.5	12.9	11.9	12.3	12.3	12.7
12	12.5	13.0	13.0	13.4	12.4	12.8	12.8	13.2	12.2	12.6	12.6	13.0	12.0	12.4	12.4	12.8
13	12.7	13.1	13.1	13.5	12.5	12.9	12.9	13.3	12.3	12.7	12.7	13.1	12.1	12.5	12.5	12.9
14	12.8	13.2	13.2	13.6	12.6	13.0	13.0	13.4	12.4	12.8	12.8	13.2	12.1	12.6	12.6	13.0
15	12.9	13.3	13.3	13.7	12.7	13.1	13.1	13.5	12.5	12.9	12.9	13.3	12.2	12.6	12.6	13.0
16	13.0	13.4	13.4	13.9	12.8	13.2	13.2	13.7	12.6	13.0	13.0	13.4	12.3	12.7	12.7	13.1
17	13.1	13.6	13.6	14.0	12.9	13.4	13.4	13.8	12.7	13.1	13.1	13.5	12.4	12.8	12.8	13.2
18	13.3	13.7	13.7	14.1	13.0	13.5	13.5	13.9	12.8	13.2	13.2	13.6	12.5	12.9	12.9	13.3
19	13.4	13.8	13.8	14.2	13.2	13.6	13.6	14.0	12.9	13.3	13.3	13.7	12.6	13.0	13.0	13.4
20	13.5	13.9	13.9	14.3	13.3	13.7	13.7	14.1	13.0	13.4	13.4	13.8	12.6	13.0	13.0	13.5
21	13.6	14.0	14.0	14.4	13.4	13.8	13.8	14.2	13.1	13.5	13.5	13.9	12.7	13.1	13.1	13.5
22	13.7	14.1	14.1	14.6	13.5	13.9	13.9	14.3	13.1	13.6	13.6	14.0	12.8	13.2	13.2	13.6
23	13.8	14.3	14.3	14.7	13.6	14.0	14.0	14.4	13.2	13.7	13.7	14.1	12.9	13.3	13.3	13.7
24	14.0	14.4	14.4	14.8	13.7	14.1	14.1	14.5	13.3	13.8	13.8	14.2	13.0	13.4	13.4	13.8
25	14.1	14.5	14.5	14.9	13.8	14.2	14.2	14.6	13.4	13.8	13.8	14.3	13.1	13.5	13.5	13.9
26	14.2	14.6	14.6	15.0	13.9	14.3	14.3	14.7	13.5	13.9	13.9	14.4	13.1	13.5	13.5	14.0
27	14.3	14.7	14.7	15.1	14.0	14.4	14.4	14.8	13.6	14.0	14.0	14.4	13.2	13.6	13.6	14.0
28	14.4	14.8	14.8	15.2	14.1	14.5	14.5	14.9	13.7	14.1	14.1	14.5	13.3	13.7	13.7	14.1
29	14.5	14.9	14.9	15.4	14.2	14.6	14.6	15.1	13.8	14.2	14.2	14.6	13.4	13.8	13.8	14.2
30	14.5	14.9	14.9	15.4	14.2	14.6	14.6	15.1	13.8	14.2	14.2	14.6	13.4	13.8	13.8	14.2

Table 29

Pipe Size = 84"

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	12.6	13.1	13.1	13.6	12.5	13.0	13.0	13.5	12.4	12.9	12.9	13.4	12.3	12.8	12.8	13.3
6	12.6	13.1	13.1	13.6	12.6	13.0	13.0	13.5	12.4	12.9	12.9	13.4	12.3	12.8	12.8	13.3
7	12.7	13.2	13.2	13.7	12.6	13.1	13.1	13.6	12.5	13.0	13.0	13.4	12.4	12.8	12.8	13.3
8	12.8	13.3	13.3	13.8	12.7	13.2	13.2	13.7	12.6	13.0	13.0	13.5	12.4	12.9	12.9	13.4
9	12.9	13.4	13.4	13.9	12.8	13.3	13.3	13.7	12.7	13.1	13.1	13.6	12.5	13.0	13.0	13.4
10	13.0	13.5	13.5	14.0	12.9	13.4	13.4	13.8	12.7	13.2	13.2	13.7	12.6	13.0	13.0	13.5
11	13.2	13.6	13.6	14.1	13.0	13.5	13.5	13.9	12.8	13.3	13.3	13.7	12.6	13.1	13.1	13.5
12	13.3	13.7	13.7	14.2	13.1	13.6	13.6	14.0	12.9	13.4	13.4	13.8	12.7	13.2	13.2	13.6
13	13.4	13.9	13.9	14.3	13.2	13.7	13.7	14.1	13.0	13.5	13.5	13.9	12.8	13.2	13.2	13.7
14	13.5	14.0	14.0	14.4	13.3	13.8	13.8	14.2	13.1	13.6	13.6	14.0	12.9	13.3	13.3	13.8
15	13.6	14.1	14.1	14.5	13.5	13.9	13.9	14.4	13.2	13.7	13.7	14.1	13.0	13.4	13.4	13.8
16	13.8	14.2	14.2	14.7	13.6	14.0	14.0	14.5	13.3	13.8	13.8	14.2	13.0	13.5	13.5	13.9
17	13.9	14.3	14.3	14.8	13.7	14.1	14.1	14.6	13.4	13.9	13.9	14.3	13.1	13.6	13.6	14.0
18	14.0	14.5	14.5	14.9	13.8	14.2	14.2	14.7	13.5	13.9	13.9	14.4	13.2	13.7	13.7	14.1
19	14.1	14.6	14.6	15.0	13.9	14.3	14.3	14.8	13.6	14.0	14.0	14.5	13.3	13.7	13.7	14.2
20	14.2	14.7	14.7	15.1	14.0	14.5	14.5	14.9	13.7	14.1	14.1	14.6	13.4	13.8	13.8	14.3
21	14.4	14.8	14.8	15.3	14.1	14.6	14.6	15.0	13.8	14.2	14.2	14.7	13.5	13.9	13.9	14.3
22	14.5	14.9	14.9	15.4	14.2	14.7	14.7	15.1	13.9	14.3	14.3	14.8	13.5	14.0	14.0	14.4
23	14.6	15.0	15.0	15.5	14.3	14.8	14.8	15.2	14.0	14.4	14.4	14.9	13.6	14.1	14.1	14.5
24	14.7	15.2	15.2	15.6	14.4	14.9	14.9	15.3	14.1	14.5	14.5	15.0	13.7	14.1	14.1	14.6
25	14.8	15.3	15.3	15.7	14.6	15.0	15.0	15.4	14.2	14.6	14.6	15.1	13.8	14.2	14.2	14.7
26	14.9	15.4	15.4	15.8	14.7	15.1	15.1	15.6	14.3	14.7	14.7	15.2	13.9	14.3	14.3	14.8
27	15.1	15.5	15.5	16.0	14.8	15.2	15.2	15.7	14.4	14.8	14.8	15.3	14.0	14.4	14.4	14.8
28	15.2	15.6	15.6	16.1	14.9	15.3	15.3	15.8	14.5	14.9	14.9	15.3	14.0	14.5	14.5	14.9
29	15.3	15.7	15.7	16.2	15.0	15.4	15.4	15.9	14.6	15.0	15.0	15.4	14.1	14.6	14.6	15.0
30	15.3	15.7	15.7	16.2	15.0	15.4	15.4	15.9	14.6	15.0	15.0	15.4	14.1	14.6	14.6	15.0

Height of Backfill H Above Top of Pipe, Feet

Table 30

Pipe Size = 90"

Height of Backfill H Above Top of Pipe, Feet	Transition Widths (FT)															
	Ku’ = 0.165				Ku’ = 0.150				Ku’ = 0.130				Ku’ = 0.110			
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
5	13.5	14.0	14.0	14.5	13.4	13.9	13.9	14.5	13.3	13.8	13.8	14.4	13.2	13.7	13.7	14.3
6	13.5	14.0	14.0	14.5	13.4	13.9	13.9	14.5	13.3	13.8	13.8	14.4	13.2	13.7	13.7	14.3
7	13.6	14.1	14.1	14.6	13.5	14.0	14.0	14.5	13.4	13.9	13.9	14.4	13.2	13.7	13.7	14.3
8	13.7	14.2	14.2	14.7	13.6	14.1	14.1	14.6	13.4	13.9	13.9	14.4	13.3	13.8	13.8	14.3
9	13.8	14.3	14.3	14.8	13.7	14.2	14.2	14.7	13.5	14.0	14.0	14.5	13.3	13.8	13.8	14.3
10	13.9	14.4	14.4	14.9	13.8	14.3	14.3	14.7	13.6	14.1	14.1	14.6	13.4	13.9	13.9	14.4
11	14.0	14.5	14.5	15.0	13.9	14.4	14.4	14.8	13.7	14.2	14.2	14.7	13.5	14.0	14.0	14.5
12	14.1	14.6	14.6	15.1	14.0	14.5	14.5	14.9	13.8	14.3	14.3	14.7	13.6	14.0	14.0	14.5
13	14.2	14.7	14.7	15.2	14.1	14.6	14.6	15.0	13.9	14.3	14.3	14.8	13.6	14.1	14.1	14.6
14	14.4	14.8	14.8	15.3	14.2	14.7	14.7	15.2	14.0	14.4	14.4	14.9	13.7	14.2	14.2	14.7
15	14.5	15.0	15.0	15.4	14.3	14.8	14.8	15.3	14.1	14.5	14.5	15.0	13.8	14.3	14.3	14.8
16	14.6	15.1	15.1	15.6	14.4	14.9	14.9	15.4	14.1	14.6	14.6	15.1	13.9	14.4	14.4	14.8
17	14.7	15.2	15.2	15.7	14.5	15.0	15.0	15.5	14.2	14.7	14.7	15.2	14.0	14.4	14.4	14.9
18	14.8	15.3	15.3	15.8	14.6	15.1	15.1	15.6	14.3	14.8	14.8	15.3	14.0	14.5	14.5	15.0
19	15.0	15.4	15.4	15.9	14.7	15.2	15.2	15.7	14.4	14.9	14.9	15.4	14.1	14.6	14.6	15.1
20	15.1	15.6	15.6	16.0	14.9	15.3	15.3	15.8	14.5	15.0	15.0	15.5	14.2	14.7	14.7	15.2
21	15.2	15.7	15.7	16.2	15.0	15.4	15.4	15.9	14.6	15.1	15.1	15.6	14.3	14.8	14.8	15.2
22	15.3	15.8	15.8	16.3	15.1	15.5	15.5	16.0	14.7	15.2	15.2	15.7	14.4	14.8	14.8	15.3
23	15.4	15.9	15.9	16.4	15.2	15.7	15.7	16.1	14.8	15.3	15.3	15.8	14.5	14.9	14.9	15.4
24	15.6	16.0	16.0	16.5	15.3	15.8	15.8	16.2	14.9	15.4	15.4	15.9	14.5	15.0	15.0	15.5
25	15.7	16.2	16.2	16.6	15.4	15.9	15.9	16.4	15.0	15.5	15.5	16.0	14.6	15.1	15.1	15.6
26	15.8	16.3	16.3	16.8	15.5	16.0	16.0	16.5	15.1	15.6	15.6	16.1	14.7	15.2	15.2	15.7
27	15.9	16.4	16.4	16.9	15.6	16.1	16.1	16.6	15.2	15.7	15.7	16.2	14.8	15.3	15.3	15.7
28	16.0	16.5	16.5	17.0	15.7	16.2	16.2	16.7	15.3	15.8	15.8	16.3	14.9	15.3	15.3	15.8
29	16.1	16.6	16.6	17.1	15.8	16.3	16.3	16.8	15.4	15.9	15.9	16.3	15.0	15.4	15.4	15.9
30	16.1	16.6	16.6	17.1	15.8	16.3	16.3	16.8	15.4	15.9	15.9	16.3	15.0	15.4	15.4	15.9

Table 31

Pipe Size = 96"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	14.3	14.9	14.9	15.5	14.3	14.9	14.9	15.4	14.2	14.8	14.8	15.3	14.1	14.7	14.7	15.2
6	14.4	14.9	14.9	15.5	14.3	14.9	14.9	15.4	14.2	14.8	14.8	15.3	14.1	14.7	14.7	15.2
7	14.5	15.0	15.0	15.5	14.4	14.9	14.9	15.5	14.2	14.8	14.8	15.3	14.1	14.7	14.7	15.2
8	14.5	15.1	15.1	15.6	14.4	15.0	15.0	15.5	14.3	14.8	14.8	15.4	14.1	14.7	14.7	15.2
9	14.6	15.2	15.2	15.7	14.5	15.1	15.1	15.6	14.4	14.9	14.9	15.4	14.2	14.7	14.7	15.3
10	14.7	15.3	15.3	15.8	14.6	15.1	15.1	15.7	14.4	15.0	15.0	15.5	14.3	14.8	14.8	15.3
11	14.9	15.4	15.4	15.9	14.7	15.2	15.2	15.8	14.5	15.0	15.0	15.6	14.3	14.8	14.8	15.4
12	15.0	15.5	15.5	16.0	14.8	15.3	15.3	15.9	14.6	15.1	15.1	15.6	14.4	14.9	14.9	15.4
13	15.1	15.6	15.6	16.1	14.9	15.4	15.4	16.0	14.7	15.2	15.2	15.7	14.5	15.0	15.0	15.5
14	15.2	15.7	15.7	16.2	15.0	15.5	15.5	16.1	14.8	15.3	15.3	15.8	14.6	15.1	15.1	15.6
15	15.3	15.8	15.8	16.4	15.1	15.7	15.7	16.2	14.9	15.4	15.4	15.9	14.6	15.1	15.1	15.7
16	15.4	16.0	16.0	16.5	15.3	15.8	15.8	16.3	15.0	15.5	15.5	16.0	14.7	15.2	15.2	15.7
17	15.6	16.1	16.1	16.6	15.4	15.9	15.9	16.4	15.1	15.6	15.6	16.1	14.8	15.3	15.3	15.8
18	15.7	16.2	16.2	16.7	15.5	16.0	16.0	16.5	15.2	15.7	15.7	16.2	14.9	15.4	15.4	15.9
19	15.8	16.3	16.3	16.8	15.6	16.1	16.1	16.6	15.3	15.8	15.8	16.3	15.0	15.5	15.5	16.0
20	15.9	16.4	16.4	17.0	15.7	16.2	16.2	16.7	15.4	15.9	15.9	16.4	15.0	15.5	15.5	16.1
21	16.1	16.6	16.6	17.1	15.8	16.3	16.3	16.8	15.5	16.0	16.0	16.5	15.1	15.6	15.6	16.1
22	16.2	16.7	16.7	17.2	15.9	16.4	16.4	16.9	15.6	16.1	16.1	16.6	15.2	15.7	15.7	16.2
23	16.3	16.8	16.8	17.3	16.0	16.5	16.5	17.0	15.7	16.2	16.2	16.7	15.3	15.8	15.8	16.3
24	16.4	16.9	16.9	17.4	16.1	16.6	16.6	17.2	15.8	16.3	16.3	16.8	15.4	15.9	15.9	16.4
25	16.5	17.0	17.0	17.5	16.2	16.8	16.8	17.3	15.9	16.4	16.4	16.9	15.5	16.0	16.0	16.5
26	16.6	17.2	17.2	17.7	16.4	16.9	16.9	17.4	16.0	16.5	16.5	17.0	15.5	16.0	16.0	16.5
27	16.8	17.3	17.3	17.8	16.5	17.0	17.0	17.5	16.0	16.6	16.6	17.1	15.6	16.1	16.1	16.6
28	16.9	17.4	17.4	17.9	16.6	17.1	17.1	17.6	16.1	16.6	16.6	17.2	15.7	16.2	16.2	16.7
29	17.0	17.5	17.5	18.0	16.7	17.2	17.2	17.7	16.2	16.7	16.7	17.2	15.8	16.3	16.3	16.8
30	17.0	17.5	17.5	18.0	16.7	17.2	17.2	17.7	16.2	16.7	16.7	17.2	15.8	16.3	16.3	16.8

Table 32

Pipe Size = 102"

Height of Backfill H Above Top of Pipe, Feet

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	15.2	15.9	15.9	16.5	15.2	15.8	15.8	16.4	15.1	15.7	15.7	16.3	15.0	15.6	15.6	16.2
6	15.3	15.9	15.9	16.5	15.2	15.8	15.8	16.4	15.1	15.7	15.7	16.3	15.0	15.6	15.6	16.2
7	15.3	15.9	15.9	16.5	15.2	15.8	15.8	16.4	15.1	15.7	15.7	16.3	15.0	15.6	15.6	16.2
8	15.4	16.0	16.0	16.6	15.3	15.9	15.9	16.4	15.2	15.7	15.7	16.3	15.0	15.6	15.6	16.2
9	15.5	16.1	16.1	16.6	15.4	15.9	15.9	16.5	15.2	15.8	15.8	16.3	15.1	15.6	15.6	16.2
10	15.6	16.2	16.2	16.7	15.5	16.0	16.0	16.6	15.3	15.9	15.9	16.4	15.1	15.7	15.7	16.2
11	15.7	16.3	16.3	16.8	15.6	16.1	16.1	16.7	15.4	15.9	15.9	16.5	15.2	15.7	15.7	16.3
12	15.8	16.4	16.4	16.9	15.7	16.2	16.2	16.8	15.5	16.0	16.0	16.6	15.2	15.8	15.8	16.3
13	15.9	16.5	16.5	17.0	15.8	16.3	16.3	16.9	15.5	16.1	16.1	16.6	15.3	15.9	15.9	16.4
14	16.1	16.6	16.6	17.2	15.9	16.4	16.4	17.0	15.6	16.2	16.2	16.7	15.4	15.9	15.9	16.5
15	16.2	16.7	16.7	17.3	16.0	16.5	16.5	17.1	15.7	16.3	16.3	16.8	15.5	16.0	16.0	16.6
16	16.3	16.8	16.8	17.4	16.1	16.6	16.6	17.2	15.8	16.4	16.4	16.9	15.6	16.1	16.1	16.6
17	16.4	17.0	17.0	17.5	16.2	16.7	16.7	17.3	15.9	16.5	16.5	17.0	15.6	16.2	16.2	16.7
18	16.5	17.1	17.1	17.6	16.3	16.9	16.9	17.4	16.0	16.6	16.6	17.1	15.7	16.3	16.3	16.8
19	16.7	17.2	17.2	17.7	16.4	17.0	17.0	17.5	16.1	16.7	16.7	17.2	15.8	16.3	16.3	16.9
20	16.8	17.3	17.3	17.9	16.5	17.1	17.1	17.6	16.2	16.8	16.8	17.3	15.9	16.4	16.4	17.0
21	16.9	17.4	17.4	18.0	16.6	17.2	17.2	17.7	16.3	16.8	16.8	17.4	16.0	16.5	16.5	17.0
22	17.0	17.6	17.6	18.1	16.8	17.3	17.3	17.8	16.4	16.9	16.9	17.5	16.0	16.6	16.6	17.1
23	17.1	17.7	17.7	18.2	16.9	17.4	17.4	17.9	16.5	17.0	17.0	17.6	16.1	16.7	16.7	17.2
24	17.3	17.8	17.8	18.3	17.0	17.5	17.5	18.1	16.6	17.1	17.1	17.7	16.2	16.7	16.7	17.3
25	17.4	17.9	17.9	18.5	17.1	17.6	17.6	18.2	16.7	17.2	17.2	17.8	16.3	16.8	16.8	17.4
26	17.5	18.0	18.0	18.6	17.2	17.7	17.7	18.3	16.8	17.3	17.3	17.9	16.4	16.9	16.9	17.4
27	17.6	18.2	18.2	18.7	17.3	17.8	17.8	18.4	16.9	17.4	17.4	18.0	16.5	17.0	17.0	17.5
28	17.7	18.3	18.3	18.8	17.4	18.0	18.0	18.5	17.0	17.5	17.5	18.1	16.5	17.1	17.1	17.6
29	17.8	18.4	18.4	18.9	17.5	18.1	18.1	18.6	17.1	17.6	17.6	18.2	16.6	17.2	17.2	17.7
30	17.8	18.4	18.4	18.9	17.5	18.1	18.1	18.6	17.1	17.6	17.6	18.2	16.6	17.2	17.2	17.7

Table 33

Pipe Size = 108"

Transition Widths (FT)

	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	16.1	16.8	16.8	17.4	16.1	16.7	16.7	17.4	16.0	16.6	16.6	17.3	15.9	16.5	16.5	17.2
6	16.1	16.8	16.8	17.4	16.1	16.7	16.7	17.4	16.0	16.6	16.6	17.3	15.9	16.5	16.5	17.2
7	16.2	16.8	16.8	17.4	16.1	16.7	16.7	17.4	16.0	16.6	16.6	17.3	15.9	16.5	16.5	17.2
8	16.3	16.9	16.9	17.5	16.2	16.8	16.8	17.4	16.0	16.6	16.6	17.3	15.9	16.5	16.5	17.2
9	16.4	17.0	17.0	17.6	16.2	16.8	16.8	17.4	16.1	16.7	16.7	17.3	15.9	16.5	16.5	17.2
10	16.5	17.1	17.1	17.7	16.3	16.9	16.9	17.5	16.1	16.7	16.7	17.3	16.0	16.6	16.6	17.2
11	16.6	17.2	17.2	17.7	16.4	17.0	17.0	17.6	16.2	16.8	16.8	17.4	16.0	16.6	16.6	17.2
12	16.7	17.3	17.3	17.8	16.5	17.1	17.1	17.7	16.3	16.9	16.9	17.5	16.1	16.7	16.7	17.3
13	16.8	17.4	17.4	18.0	16.6	17.2	17.2	17.8	16.4	17.0	17.0	17.6	16.2	16.7	16.7	17.3
14	16.9	17.5	17.5	18.1	16.7	17.3	17.3	17.9	16.5	17.1	17.1	17.6	16.2	16.8	16.8	17.4
15	17.0	17.6	17.6	18.2	16.8	17.4	17.4	18.0	16.6	17.2	17.2	17.7	16.3	16.9	16.9	17.5
16	17.1	17.7	17.7	18.3	16.9	17.5	17.5	18.1	16.7	17.2	17.2	17.8	16.4	17.0	17.0	17.5
17	17.3	17.8	17.8	18.4	17.0	17.6	17.6	18.2	16.8	17.3	17.3	17.9	16.5	17.0	17.0	17.6
18	17.4	18.0	18.0	18.5	17.2	17.7	17.7	18.3	16.9	17.4	17.4	18.0	16.6	17.1	17.1	17.7
19	17.5	18.1	18.1	18.6	17.3	17.8	17.8	18.4	17.0	17.5	17.5	18.1	16.6	17.2	17.2	17.8
20	17.6	18.2	18.2	18.8	17.4	18.0	18.0	18.5	17.1	17.6	17.6	18.2	16.7	17.3	17.3	17.9
21	17.7	18.3	18.3	18.9	17.5	18.1	18.1	18.6	17.1	17.7	17.7	18.3	16.8	17.4	17.4	17.9
22	17.9	18.4	18.4	19.0	17.6	18.2	18.2	18.7	17.2	17.8	17.8	18.4	16.9	17.4	17.4	18.0
23	18.0	18.6	18.6	19.1	17.7	18.3	18.3	18.9	17.3	17.9	17.9	18.5	17.0	17.5	17.5	18.1
24	18.1	18.7	18.7	19.2	17.8	18.4	18.4	19.0	17.4	18.0	18.0	18.6	17.0	17.6	17.6	18.2
25	18.2	18.8	18.8	19.4	17.9	18.5	18.5	19.1	17.5	18.1	18.1	18.7	17.1	17.7	17.7	18.3
26	18.3	18.9	18.9	19.5	18.0	18.6	18.6	19.2	17.6	18.2	18.2	18.8	17.2	17.8	17.8	18.3
27	18.5	19.0	19.0	19.6	18.1	18.7	18.7	19.3	17.7	18.3	18.3	18.9	17.3	17.9	17.9	18.4
28	18.6	19.1	19.1	19.7	18.3	18.8	18.8	19.4	17.8	18.4	18.4	19.0	17.4	17.9	17.9	18.5
29	18.7	19.3	19.3	19.8	18.4	18.9	18.9	19.5	17.9	18.5	18.5	19.1	17.5	18.0	18.0	18.6
30	18.7	19.3	19.3	19.8	18.4	18.9	18.9	19.5	17.9	18.5	18.5	19.1	17.5	18.0	18.0	18.6

Height of Backfill H Above Top of Pipe, Feet

Table 34

Pipe Size = 114"

Height of Backfill H Above Top of Pipe, Feet

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	17.0	17.7	17.7	18.4	17.0	17.7	17.7	18.4	16.9	17.6	17.6	18.3	16.8	17.5	17.5	18.2
6	17.0	17.7	17.7	18.4	17.0	17.7	17.7	18.4	16.9	17.6	17.6	18.3	16.8	17.5	17.5	18.2
7	17.1	17.7	17.7	18.4	17.0	17.7	17.7	18.4	16.9	17.6	17.6	18.3	16.8	17.5	17.5	18.2
8	17.1	17.8	17.8	18.4	17.0	17.7	17.7	18.4	16.9	17.6	17.6	18.3	16.8	17.5	17.5	18.2
9	17.2	17.9	17.9	18.5	17.1	17.7	17.7	18.4	16.9	17.6	17.6	18.3	16.8	17.5	17.5	18.2
10	17.3	17.9	17.9	18.6	17.2	17.8	17.8	18.4	17.0	17.6	17.6	18.3	16.8	17.5	17.5	18.2
11	17.4	18.0	18.0	18.7	17.3	17.9	17.9	18.5	17.1	17.7	17.7	18.3	16.9	17.5	17.5	18.2
12	17.5	18.1	18.1	18.8	17.4	18.0	18.0	18.6	17.2	17.8	17.8	18.4	16.9	17.6	17.6	18.2
13	17.6	18.3	18.3	18.9	17.5	18.1	18.1	18.7	17.2	17.9	17.9	18.5	17.0	17.6	17.6	18.2
14	17.7	18.4	18.4	19.0	17.6	18.2	18.2	18.8	17.3	17.9	17.9	18.6	17.1	17.7	17.7	18.3
15	17.9	18.5	18.5	19.1	17.7	18.3	18.3	18.9	17.4	18.0	18.0	18.6	17.2	17.8	17.8	18.4
16	18.0	18.6	18.6	19.2	17.8	18.4	18.4	19.0	17.5	18.1	18.1	18.7	17.2	17.8	17.8	18.4
17	18.1	18.7	18.7	19.3	17.9	18.5	18.5	19.1	17.6	18.2	18.2	18.8	17.3	17.9	17.9	18.5
18	18.2	18.8	18.8	19.4	18.0	18.6	18.6	19.2	17.7	18.3	18.3	18.9	17.4	18.0	18.0	18.6
19	18.3	19.0	19.0	19.6	18.1	18.7	18.7	19.3	17.8	18.4	18.4	19.0	17.5	18.1	18.1	18.7
20	18.5	19.1	19.1	19.7	18.2	18.8	18.8	19.4	17.9	18.5	18.5	19.1	17.6	18.2	18.2	18.8
21	18.6	19.2	19.2	19.8	18.3	18.9	18.9	19.5	18.0	18.6	18.6	19.2	17.6	18.2	18.2	18.8
22	18.7	19.3	19.3	19.9	18.4	19.0	19.0	19.6	18.1	18.7	18.7	19.3	17.7	18.3	18.3	18.9
23	18.8	19.4	19.4	20.0	18.6	19.2	19.2	19.8	18.2	18.8	18.8	19.4	17.8	18.4	18.4	19.0
24	18.9	19.5	19.5	20.2	18.7	19.3	19.3	19.9	18.3	18.9	18.9	19.5	17.9	18.5	18.5	19.1
25	19.1	19.7	19.7	20.3	18.8	19.4	19.4	20.0	18.4	19.0	19.0	19.6	18.0	18.6	18.6	19.2
26	19.2	19.8	19.8	20.4	18.9	19.5	19.5	20.1	18.5	19.1	19.1	19.7	18.0	18.6	18.6	19.2
27	19.3	19.9	19.9	20.5	19.0	19.6	19.6	20.2	18.6	19.2	19.2	19.8	18.1	18.7	18.7	19.3
28	19.4	20.0	20.0	20.6	19.1	19.7	19.7	20.3	18.7	19.3	19.3	19.9	18.2	18.8	18.8	19.4
29	19.5	20.1	20.1	20.7	19.2	19.8	19.8	20.4	18.8	19.4	19.4	20.0	18.3	18.9	18.9	19.5
30	19.5	20.1	20.1	20.7	19.2	19.8	19.8	20.4	18.8	19.4	19.4	20.0	18.3	18.9	18.9	19.5

Table 35

Pipe Size = 120"

Height of Backfill H Above Top of Pipe, Feet	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	17.8	18.6	18.6	19.3	17.8	18.5	18.5	19.3	17.7	18.4	18.4	19.2	17.6	18.3	18.3	19.1
6	17.8	18.6	18.6	19.3	17.8	18.5	18.5	19.3	17.7	18.4	18.4	19.2	17.6	18.3	18.3	19.1
7	17.8	18.6	18.6	19.3	17.8	18.5	18.5	19.3	17.7	18.4	18.4	19.2	17.6	18.3	18.3	19.1
8	17.9	18.6	18.6	19.3	17.8	18.5	18.5	19.3	17.7	18.4	18.4	19.2	17.6	18.3	18.3	19.1
9	18.0	18.7	18.7	19.3	17.9	18.5	18.5	19.3	17.7	18.4	18.4	19.2	17.6	18.3	18.3	19.1
10	18.1	18.7	18.7	19.4	17.9	18.6	18.6	19.3	17.8	18.4	18.4	19.2	17.6	18.3	18.3	19.1
11	18.2	18.8	18.8	19.5	18.0	18.7	18.7	19.3	17.8	18.5	18.5	19.2	17.6	18.3	18.3	19.1
12	18.3	18.9	18.9	19.6	18.1	18.8	18.8	19.4	17.9	18.6	18.6	19.2	17.7	18.3	18.3	19.1
13	18.4	19.0	19.0	19.7	18.2	18.9	18.9	19.5	18.0	18.6	18.6	19.3	17.8	18.4	18.4	19.1
14	18.5	19.1	19.1	19.8	18.3	19.0	19.0	19.6	18.1	18.7	18.7	19.4	17.8	18.5	18.5	19.1
15	18.6	19.3	19.3	19.9	18.4	19.1	19.1	19.7	18.2	18.8	18.8	19.5	17.9	18.5	18.5	19.2
16	18.7	19.4	19.4	20.0	18.5	19.2	19.2	19.8	18.3	18.9	18.9	19.5	18.0	18.6	18.6	19.3
17	18.8	19.5	19.5	20.1	18.6	19.3	19.3	19.9	18.3	19.0	19.0	19.6	18.0	18.7	18.7	19.3
18	19.0	19.6	19.6	20.3	18.7	19.4	19.4	20.0	18.4	19.1	19.1	19.7	18.1	18.8	18.8	19.4
19	19.1	19.7	19.7	20.4	18.9	19.5	19.5	20.1	18.5	19.2	19.2	19.8	18.2	18.8	18.8	19.5
20	19.2	19.8	19.8	20.5	19.0	19.6	19.6	20.2	18.6	19.3	19.3	19.9	18.3	18.9	18.9	19.6
21	19.3	20.0	20.0	20.6	19.1	19.7	19.7	20.3	18.7	19.4	19.4	20.0	18.4	19.0	19.0	19.6
22	19.4	20.1	20.1	20.7	19.2	19.8	19.8	20.5	18.8	19.5	19.5	20.1	18.5	19.1	19.1	19.7
23	19.6	20.2	20.2	20.8	19.3	19.9	19.9	20.6	18.9	19.6	19.6	20.2	18.5	19.2	19.2	19.8
24	19.7	20.3	20.3	21.0	19.4	20.0	20.0	20.7	19.0	19.6	19.6	20.3	18.6	19.2	19.2	19.9
25	19.8	20.4	20.4	21.1	19.5	20.1	20.1	20.8	19.1	19.7	19.7	20.4	18.7	19.3	19.3	20.0
26	19.9	20.6	20.6	21.2	19.6	20.3	20.3	20.9	19.2	19.8	19.8	20.5	18.8	19.4	19.4	20.0
27	20.0	20.7	20.7	21.3	19.7	20.4	20.4	21.0	19.3	19.9	19.9	20.6	18.9	19.5	19.5	20.1
28	20.2	20.8	20.8	21.4	19.8	20.5	20.5	21.1	19.4	20.0	20.0	20.7	19.0	19.6	19.6	20.2
29	20.3	20.9	20.9	21.6	20.0	20.6	20.6	21.2	19.5	20.1	20.1	20.8	19.0	19.7	19.7	20.3
30	20.3	20.9	20.9	21.6	20.0	20.6	20.6	21.2	19.5	20.1	20.1	20.8	19.0	19.7	19.7	20.3

Table 36

Pipe Size = 126"

Height of Backfill H Above Top of Pipe, Feet

	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	18.8	19.5	19.5	20.3	18.7	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
6	18.8	19.5	19.5	20.3	18.7	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
7	18.8	19.5	19.5	20.3	18.7	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
8	18.8	19.5	19.5	20.3	18.7	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
9	18.8	19.6	19.6	20.3	18.7	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
10	18.9	19.6	19.6	20.3	18.8	19.5	19.5	20.3	18.6	19.4	19.4	20.2	18.5	19.3	19.3	20.1
11	19.0	19.7	19.7	20.4	18.9	19.6	19.6	20.3	18.7	19.4	19.4	20.2	18.5	19.3	19.3	20.1
12	19.1	19.8	19.8	20.5	19.0	19.7	19.7	20.4	18.8	19.4	19.4	20.2	18.5	19.3	19.3	20.1
13	19.2	19.9	19.9	20.6	19.1	19.8	19.8	20.4	18.8	19.5	19.5	20.2	18.6	19.3	19.3	20.1
14	19.3	20.0	20.0	20.7	19.2	19.8	19.8	20.5	18.9	19.6	19.6	20.3	18.7	19.4	19.4	20.1
15	19.5	20.1	20.1	20.8	19.3	19.9	19.9	20.6	19.0	19.7	19.7	20.4	18.7	19.4	19.4	20.1
16	19.6	20.3	20.3	20.9	19.4	20.0	20.0	20.7	19.1	19.8	19.8	20.4	18.8	19.5	19.5	20.2
17	19.7	20.4	20.4	21.0	19.5	20.2	20.2	20.8	19.2	19.9	19.9	20.5	18.9	19.6	19.6	20.2
18	19.8	20.5	20.5	21.2	19.6	20.3	20.3	20.9	19.3	20.0	20.0	20.6	19.0	19.6	19.6	20.3
19	19.9	20.6	20.6	21.3	19.7	20.4	20.4	21.0	19.4	20.0	20.0	20.7	19.0	19.7	19.7	20.4
20	20.1	20.7	20.7	21.4	19.8	20.5	20.5	21.1	19.5	20.1	20.1	20.8	19.1	19.8	19.8	20.5
21	20.2	20.8	20.8	21.5	19.9	20.6	20.6	21.3	19.6	20.2	20.2	20.9	19.2	19.9	19.9	20.5
22	20.3	21.0	21.0	21.6	20.0	20.7	20.7	21.4	19.7	20.3	20.3	21.0	19.3	20.0	20.0	20.6
23	20.4	21.1	21.1	21.8	20.1	20.8	20.8	21.5	19.8	20.4	20.4	21.1	19.4	20.0	20.0	20.7
24	20.5	21.2	21.2	21.9	20.2	20.9	20.9	21.6	19.9	20.5	20.5	21.2	19.5	20.1	20.1	20.8
25	20.7	21.3	21.3	22.0	20.4	21.0	21.0	21.7	20.0	20.6	20.6	21.3	19.5	20.2	20.2	20.9
26	20.8	21.4	21.4	22.1	20.5	21.1	21.1	21.8	20.0	20.7	20.7	21.4	19.6	20.3	20.3	20.9
27	20.9	21.6	21.6	22.2	20.6	21.2	21.2	21.9	20.1	20.8	20.8	21.5	19.7	20.4	20.4	21.0
28	21.0	21.7	21.7	22.3	20.7	21.4	21.4	22.0	20.2	20.9	20.9	21.6	19.8	20.4	20.4	21.1
29	21.1	21.8	21.8	22.5	20.8	21.5	21.5	22.1	20.3	21.0	21.0	21.7	19.9	20.5	20.5	21.2
30	21.1	21.8	21.8	22.5	20.8	21.5	21.5	22.1	20.3	21.0	21.0	21.7	19.9	20.5	20.5	21.2

Table 37

Pipe Size = 132"

Transition Widths (FT)

Height of Backfill H Above Top of Pipe, Feet

	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	19.7	20.5	20.5	21.3	19.6	20.4	20.4	21.3	19.5	20.3	20.3	21.3	19.4	20.2	20.2	21.1
6	19.7	20.5	20.5	21.3	19.6	20.4	20.4	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
7	19.7	20.5	20.5	21.3	19.6	20.4	20.4	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
8	19.7	20.5	20.5	21.3	19.6	20.4	20.4	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
9	19.7	20.5	20.5	21.3	19.6	20.4	20.4	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
10	19.8	20.5	20.5	21.3	19.7	20.4	20.4	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
11	19.9	20.6	20.6	21.4	19.7	20.5	20.5	21.3	19.5	20.3	20.3	21.2	19.4	20.2	20.2	21.1
12	20.0	20.7	20.7	21.4	19.8	20.6	20.6	21.3	19.6	20.3	20.3	21.2	19.4	20.2	20.2	21.1
13	20.1	20.8	20.8	21.5	19.9	20.6	20.6	21.4	19.7	20.4	20.4	21.2	19.5	20.2	20.2	21.1
14	20.2	20.9	20.9	21.6	20.0	20.7	20.7	21.5	19.8	20.5	20.5	21.2	19.5	20.2	20.2	21.1
15	20.3	21.0	21.0	21.7	20.1	20.8	20.8	21.5	19.9	20.6	20.6	21.3	19.6	20.3	20.3	21.1
16	20.4	21.1	21.1	21.8	20.2	20.9	20.9	21.6	19.9	20.7	20.7	21.4	19.7	20.4	20.4	21.1
17	20.5	21.2	21.2	22.0	20.3	21.0	21.0	21.7	20.0	20.7	20.7	21.4	19.7	20.4	20.4	21.1
18	20.7	21.4	21.4	22.1	20.4	21.1	21.1	21.8	20.1	20.8	20.8	21.5	19.8	20.5	20.5	21.2
19	20.8	21.5	21.5	22.2	20.5	21.2	21.2	21.9	20.2	20.9	20.9	21.6	19.9	20.6	20.6	21.3
20	20.9	21.6	21.6	22.3	20.6	21.3	21.3	22.1	20.3	21.0	21.0	21.7	20.0	20.7	20.7	21.4
21	21.0	21.7	21.7	22.4	20.8	21.5	21.5	22.2	20.4	21.1	21.1	21.8	20.0	20.7	20.7	21.4
22	21.1	21.8	21.8	22.5	20.9	21.6	21.6	22.3	20.5	21.2	21.2	21.9	20.1	20.8	20.8	21.5
23	21.3	22.0	22.0	22.7	21.0	21.7	21.7	22.4	20.6	21.3	21.3	22.0	20.2	20.9	20.9	21.6
24	21.4	22.1	22.1	22.8	21.1	21.8	21.8	22.5	20.7	21.4	21.4	22.1	20.3	21.0	21.0	21.7
25	21.5	22.2	22.2	22.9	21.2	21.9	21.9	22.6	20.8	21.5	21.5	22.2	20.4	21.1	21.1	21.8
26	21.6	22.3	22.3	23.0	21.3	22.0	22.0	22.7	20.9	21.6	21.6	22.3	20.5	21.1	21.1	21.8
27	21.7	22.4	22.4	23.1	21.4	22.1	22.1	22.8	21.0	21.7	21.7	22.4	20.5	21.2	21.2	21.9
28	21.9	22.6	22.6	23.3	21.5	22.2	22.2	22.9	21.1	21.8	21.8	22.5	20.6	21.3	21.3	22.0
29	22.0	22.7	22.7	23.4	21.6	22.3	22.3	23.0	21.2	21.9	21.9	22.6	20.7	21.4	21.4	22.1
30	22.0	22.7	22.7	23.4	21.6	22.3	22.3	23.0	21.2	21.9	21.9	22.6	20.7	21.4	21.4	22.1

Table 38

Pipe Size = 138"

Height of Backfill H Above Top of Pipe, Feet	Transition Widths (FT)															
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	20.6	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	21.1
6	20.6	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
7	20.6	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
8	20.6	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
9	20.6	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
10	20.7	21.5	21.5	22.3	20.5	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
11	20.7	21.5	21.5	22.3	20.6	21.4	21.4	22.3	20.4	21.3	21.3	22.2	20.3	21.2	21.2	22.1
12	20.8	21.6	21.6	22.4	20.7	21.4	21.4	22.3	20.5	21.3	21.3	22.2	20.3	21.2	21.2	22.1
13	20.9	21.7	21.7	22.5	20.8	21.5	21.5	22.3	20.5	21.3	21.3	22.2	20.3	21.2	21.2	22.1
14	21.0	21.8	21.8	22.6	20.9	21.6	21.6	22.4	20.6	21.4	21.4	22.2	20.4	21.2	21.2	22.1
15	21.2	21.9	21.9	22.7	21.0	21.7	21.7	22.5	20.7	21.4	21.4	22.2	20.4	21.2	21.2	22.1
16	21.3	22.0	22.0	22.8	21.1	21.8	21.8	22.6	20.8	21.5	21.5	22.3	20.5	21.2	21.2	22.1
17	21.4	22.1	22.1	22.9	21.2	21.9	21.9	22.7	20.9	21.6	21.6	22.4	20.6	21.3	21.3	22.1
18	21.5	22.2	22.2	23.0	21.3	22.0	22.0	22.8	21.0	21.7	21.7	22.4	20.6	21.4	21.4	22.1
19	21.6	22.4	22.4	23.1	21.4	22.1	22.1	22.9	21.1	21.8	21.8	22.5	20.7	21.5	21.5	22.2
20	21.7	22.5	22.5	23.2	21.5	22.2	22.2	23.0	21.1	21.9	21.9	22.6	20.8	21.5	21.5	22.3
21	21.9	22.6	22.6	23.3	21.6	22.3	22.3	23.1	21.2	22.0	22.0	22.7	20.9	21.6	21.6	22.3
22	22.0	22.7	22.7	23.4	21.7	22.4	22.4	23.2	21.3	22.1	22.1	22.8	21.0	21.7	21.7	22.4
23	22.1	22.8	22.8	23.6	21.8	22.6	22.6	23.3	21.4	22.2	22.2	22.9	21.0	21.8	21.8	22.5
24	22.2	23.0	23.0	23.7	21.9	22.7	22.7	23.4	21.5	22.3	22.3	23.0	21.1	21.9	21.9	22.6
25	22.3	23.1	23.1	23.8	22.0	22.8	22.8	23.5	21.6	22.4	22.4	23.1	21.2	21.9	21.9	22.7
26	22.5	23.2	23.2	23.9	22.1	22.9	22.9	23.6	21.7	22.5	22.5	23.2	21.3	22.0	22.0	22.7
27	22.6	23.3	23.3	24.0	22.3	23.0	23.0	23.7	21.8	22.5	22.5	23.3	21.4	22.1	22.1	22.8
28	22.7	23.4	23.4	24.2	22.4	23.1	23.1	23.8	21.9	22.6	22.6	23.4	21.5	22.2	22.2	22.9
29	22.8	23.6	23.6	24.3	22.5	23.2	23.2	23.9	22.0	22.7	22.7	23.5	21.5	22.3	22.3	23.0
30	22.8	23.6	23.6	24.3	22.5	23.2	23.2	23.9	22.0	22.7	22.7	23.5	21.5	22.3	22.3	23.0

Table 39

Pipe Size = 144"

Transition Widths (FT)																
	Ku' = 0.165				Ku' = 0.150				Ku' = 0.130				Ku' = 0.110			
	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 1**	**Type 2**	**Type 3**	**Type 4**
5	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
6	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
7	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
8	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
9	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
10	21.5	22.4	22.4	23.4	21.4	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
11	21.6	22.4	22.4	23.4	21.5	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
12	21.7	22.5	22.5	23.4	21.5	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
13	21.8	22.6	22.6	23.4	21.6	22.4	22.4	23.3	21.4	22.3	22.3	23.2	21.3	22.2	22.2	23.1
14	21.9	22.7	22.7	23.5	21.7	22.5	22.5	23.3	21.5	22.3	22.3	23.2	21.3	22.2	22.2	23.1
15	22.0	22.8	22.8	23.6	21.8	22.6	22.6	23.4	21.5	22.3	22.3	23.2	21.3	22.2	22.2	23.1
16	22.1	22.9	22.9	23.7	21.9	22.7	22.7	23.5	21.6	22.4	22.4	23.2	21.3	22.2	22.2	23.1
17	22.2	23.0	23.0	23.8	22.0	22.8	22.8	23.6	21.7	22.5	22.5	23.3	21.4	22.2	22.2	23.1
18	22.3	23.1	23.1	23.9	22.1	22.9	22.9	23.7	21.8	22.6	22.6	23.4	21.5	22.3	22.3	23.1
19	22.5	23.2	23.2	24.0	22.2	23.0	23.0	23.8	21.9	22.7	22.7	23.4	21.6	22.3	22.3	23.1
20	22.6	23.4	23.4	24.1	22.3	23.1	23.1	23.9	22.0	22.8	22.8	23.5	21.6	22.4	22.4	23.2
21	22.7	23.5	23.5	24.2	22.4	23.2	23.2	24.0	22.1	22.9	22.9	23.6	21.7	22.5	22.5	23.3
22	22.8	23.6	23.6	24.4	22.6	23.3	23.3	24.1	22.2	22.9	22.9	23.7	21.8	22.6	22.6	23.3
23	22.9	23.7	23.7	24.5	22.7	23.4	23.4	24.2	22.3	23.0	23.0	23.8	21.9	22.6	22.6	23.4
24	23.1	23.8	23.8	24.6	22.8	23.5	23.5	24.3	22.4	23.1	23.1	23.9	22.0	22.7	22.7	23.5
25	23.2	23.9	23.9	24.7	22.9	23.6	23.6	24.4	22.5	23.2	23.2	24.0	22.0	22.8	22.8	23.6
26	23.3	24.1	24.1	24.8	23.0	23.8	23.8	24.5	22.6	23.3	23.3	24.1	22.1	22.9	22.9	23.6
27	23.4	24.2	24.2	25.0	23.1	23.9	23.9	24.6	22.7	23.4	23.4	24.2	22.2	23.0	23.0	23.7
28	23.5	24.3	24.3	25.1	23.2	24.0	24.0	24.7	22.8	23.5	23.5	24.3	22.3	23.0	23.0	23.8
29	23.7	24.4	24.4	25.2	23.3	24.1	24.1	24.8	22.9	23.6	23.6	24.4	22.4	23.1	23.1	23.9
30	23.7	24.4	24.4	25.2	23.3	24.1	24.1	24.8	22.9	23.6	23.6	24.4	22.4	23.1	23.1	23.9

Height of Backfill H Above Top of Pipe, Feet

Table 40

DESIGN VALUES OF SETTLEMENT RATIO

Installation and Foundation Condition	Settlement Ratio r_{sd}	
	Usual Range	Design Value
Positive Projecting	0.0 to +1.0	
Rock or Unyielding Soil	+1.0	+1.0
*Ordinary Soil	+0.5 to +0.8	+0.7
Yielding Soil	0.0 to +0.5	+0.3
Zero Projecting		0.0
Negative Projecting	−1.0 to 0.0	
$p' = 0.5$		−0.1
$p' = 1.0$		−0.3
$p' = 1.5$		−0.5
$p' = 2.0$		−1.0

The value of the settlement ratio depends on the degree of compaction of the fill material adjacent to the sides of the pipe. With good construction methods resulting in proper compaction of bedding and sidefill materials, a settlement ratio design value of +0.5 is recommended.

Table 41

DESIGN VALUES OF COEFFICIENT OF COHESION

Type of Soil	Values of c
Clay	
Soft	40
Medium	250
Hard	1000
Sand	
Loose Dry	0
Silty	100
Dense	300
Top Soil	
Saturated	100

Table 42

HIGHWAY LOADS ON CIRCULAR PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE D IN INCHES	B_c (ft.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													PIPE SIZE D IN INCHES
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
12	1.33	3780	2080	1470	1080	760	550	450	380	290	230	190	160	130	12
15	1.63	4240	2360	1740	1280	900	660	540	450	350	280	230	190	160	15
18	1.92	4110	2610	1970	1460	1030	750	620	520	400	320	260	220	190	18
21	2.21	3920	2820	2190	1620	1150	840	690	580	450	360	300	250	210	21
24	2.50	4100	3010	2400	1780	1270	930	760	640	500	400	330	280	240	24
27	2.79	3880	2940	2590	1930	1380	1010	830	700	560	440	360	300	260	27
30	3.08	3620	2830	2770	2070	1480	1080	890	750	590	480	390	330	280	30
33	3.38	3390	2930	2950	2200	1580	1160	960	810	630	510	420	360	300	33
36	3.67	3190	2810	2930	2330	1670	1230	1020	860	670	550	450	380	330	36
39	3.96	3010	2670	2850	2440	1760	1290	1070	910	710	580	480	410	350	39
42	4.25	2860	2550	2770	2560	1840	1360	1130	950	750	610	510	430	370	42
48	4.83	2590	2330	2620	2480	1990	1470	1230	1040	820	670	560	470	410	48
54	5.42	2360	2150	2490	2360	2050	1580	1320	1120	890	730	610	520	440	54
60	6.00	2170	1990	2450	2250	1960	1680	1400	1190	950	780	650	560	480	60
66	6.58	2010	1850	2520	2160	1880	1640	1480	1260	1010	830	700	590	510	66
72	7.17	1870	1730	2580	2190	1810	1570	1510	1330	1060	880	740	630	540	72
78	7.75	1750	1630	2630	2240	1770	1520	1460	1390	1110	920	780	660	570	78
84	8.33	1650	1540	2730	2290	1810	1460	1410	1360	1160	960	810	690	600	84
90	8.92	1550	1460	2530	2330	1850	1470	1360	1310	1210	1000	850	720	630	90
96	9.50	1470	1380	2410	2290	1880	1500	1330	1270	1250	1040	880	750	650	96
102	10.08	1390	1320	2300	2190	1910	1530	1350	1240	1290	1070	910	780	680	102
108	10.67	1320	1260	2200	2090	1830	1560	1380	1230	1330	1110	940	810	700	108
114	11.25	1260	1200	2110	2010	1760	1540	1410	1260	1362	1140	970	830	730	114
120	11.83	1210	1150	2020	1930	1700	1480	1420	1280	1400	1170	990	860	750	120
126	12.42	1160	1100	1940	1860	1640	1430	1380	1300	1430	1200	1020	880	770	126
132	13.00	1110	1060	1870	1800	1580	1380	1330	1290	1460	1220	1040	900	790	132
138	13.58	1070	1020	1800	1730	1530	1340	1290	1250	1490	1250	1070	920	810	138
144	14.17	1020	980	1740	1670	1480	1300	1250	1210	1470	1280	1090	940	830	144

DATA:
1. Unsurfaced roadway.
2. Loads—AASHTO HS 20, two 16,000 lb. dual-tired wheels, 4 ft. on centers, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

NOTES:
1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads:
   a. For H = 0.5 and 1.0 ft., a single 16,000 lb. dual-tired wheel.
   b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on centers.
   c. For H > 4.0 ft. alternate loading.
3. Truck live loads for H = 10.0 ft. or more are insignificant.

Table 43

HIGHWAY LOADS ON HORIZONTAL ELLIPTICAL PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE S X R IN INCHES	Equiv. Dia. (in.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													PIPE SIZE S X R IN INCHES
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
23X14	18	4940	3380	2490	1840	1300	940	770	950	500	400	330	270	230	23X14
30X19	24	4610	3450	3060	2270	1610	1170	960	810	630	510	420	350	290	30X19
34X22	27	4300	3640	3330	2470	1750	1280	1050	880	690	550	460	380	320	34X22
38X24	30	4040	3450	3270	2650	1890	1380	1140	960	750	600	500	420	350	38X24
42X27	33	3840	3310	3200	2820	2010	1470	1210	1020	800	640	530	450	380	42X27
45X29	36	3560	3100	3090	2890	2160	1580	1310	1100	860	700	580	490	410	45X29
49X32	39	3380	2960	3010	2820	2280	1670	1380	1170	920	740	610	520	440	49X32
53X34	42	3210	2830	2950	2750	2380	1760	1460	1230	970	780	650	550	470	53X34
60X38	48	2930	2610	3110	2630	2280	1920	1590	1350	1060	860	720	610	520	60X38
68X43	54	2690	2410	3250	2690	2190	1890	1720	1460	1150	940	780	660	570	68X43
76X48	60	2480	2250	3380	2810	2180	1820	1730	1560	1240	1010	840	710	610	76X48
83X53	66	2310	2100	3480	2910	2270	1770	1680	1600	1320	1080	900	770	660	83X53
91X58	72	2160	1980	3370	3010	2350	1840	1620	1550	1390	1140	960	810	700	91X58
98X63	78	2020	1860	3190	2980	2420	1900	1660	1510	1460	1210	1010	860	740	98X63
106X68	84	1910	1760	3030	2840	2440	1960	1720	1520	1530	1260	1060	900	780	106X68
113X72	90	1800	1670	2890	2710	2340	2010	1770	1560	1600	1320	1110	950	820	113X72
121X77	96	1710	1590	2760	2590	2240	1930	1820	1610	1660	1370	1150	990	850	121X77
128X82	102	1630	1530	2650	2500	2160	1870	1780	1650	1710	1420	1200	1020	890	128X82
136X87	108	1560	1460	2540	2400	2090	1810	1720	1640	1760	1460	1240	1060	920	136X87
143X92	114	1490	1400	2440	2310	2010	1740	1660	1590	1800	1510	1280	1090	950	143X92
151X97	120	1420	1340	2350	2230	1940	1690	1610	1540	1810	1550	1320	1130	980	151X97
166X106	132	1310	1240	2180	2080	1820	1580	1510	1450	1730	1600	1390	1190	1040	166X106
180X116	144	1210	1150	2030	1940	1700	1490	1430	1370	1650	1560	1440	1250	1090	180X116

DATA:

1. Unsurfaced roadway.
2. Loads—AASHTO HS 20, two 16,000 lb. dual-tired wheels, 4 ft. on centers, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

NOTES:

1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads:
   a. For H = 0.5 and 1.0 ft., a single 16,000 lb. dual-tired wheel.
   b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on centers.
   c. For H > 4.0 ft. alternate loading.
3. Truck live loads for H = 10.0 ft. or more are insignificant.

Table 44

HIGHWAY LOADS ON VERTICAL ELLIPTICAL PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE S X R IN INCHES	Equiv. Dia. (in.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													PIPE SIZE S X R IN INCHES
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
29X45	36	2720	2250	2460	1850	1330	980	820	690	550	450	370	310	270	29X45
32X49	39	2560	2290	2560	1930	1390	1030	860	730	580	470	390	330	280	32X49
34X53	42	2420	2200	2530	2010	1450	1070	900	760	600	490	410	350	300	34X53
38X60	48	2180	2000	2380	2150	1550	1160	970	820	650	540	450	380	330	38X60
43X68	54	1990	1840	2250	2140	1650	1230	1030	880	700	580	480	410	360	43X68
48X76	60	1830	1700	2140	2040	1740	1300	1090	930	750	620	520	440	380	48X76
53X83	66	1690	1570	2040	1940	1700	1360	1140	980	790	650	550	470	410	53X83
58X91	72	1570	1470	1930	1850	1630	1420	1190	1020	820	680	580	490	430	58X91
63X98	78	1460	1380	1900	1770	1560	1370	1240	1060	860	710	600	520	450	63X98
68X106	84	1370	1300	1920	1700	1500	1310	1270	1100	890	740	630	540	470	68X106
72X113	90	1290	1230	1950	1680	1440	1270	1220	1130	920	770	650	560	490	72X113
77X121	96	1220	1160	1970	1700	1390	1220	1160	1140	950	790	680	580	510	77X121
82X128	102	1160	1110	1950	1720	1380	1180	1140	1110	970	820	690	600	520	82X128
87X136	108	1110	1060	1870	1730	1390	1140	1110	1080	1000	840	710	620	540	87X136
92X143	114	1060	1010	1790	1720	1410	1140	1070	1040	1020	860	730	630	550	92X143
97X151	120	1010	970	1710	1650	1430	1150	1040	1010	1040	880	750	650	570	97X151
106X166	132	920	890	1580	1530	1350	1180	1060	960	1080	910	780	680	600	106X166
116X180	144	850	820	1470	1420	1260	1110	1080	970	1120	950	810	710	620	116X180

DATA:
1. Unsurfaced roadway.
2. Loads—AASHTO HS 20, two 16,000 lb. dual-tired wheels, 4 ft. on centers, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

NOTES:
1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads:
   a. For H = 0.5 and 1.0 ft., a single 16,000 lb. dual-tired wheel.
   b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on centers.
   c. For H> 4.0 ft. alternate loading.
3. Truck live loads for H=10.0 ft. or more are insignificant.

Table 45

HIGHWAY LOADS ON ARCH PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE S X R IN INCHES	Equiv. Dia. (in.)	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET													PIPE SIZE S X R IN INCHES
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
18X11	15	4910	2960	2090	1530	1080	780	640	530	410	330	270	220	190	18X11
22X13	18	4930	3330	2420	1780	1260	910	750	630	480	390	320	260	220	22X13
26X15	21	5200	3640	2750	2030	1440	1050	860	720	560	450	360	300	260	26X15
29X18	24	4800	3440	2930	2160	1530	1120	920	770	600	480	400	330	280	27X18
36X22	30	4220	3580	3330	2580	1840	1340	1110	930	720	580	480	400	340	36X22
44X27	36	3790	3270	3180	2950	2110	1540	1270	1070	840	680	560	470	400	44X27
51X31	42	3400	2980	3020	2830	2340	1720	1420	1200	940	760	630	530	450	51X31
58X36	48	3090	2730	3110	2700	2330	1880	1560	1320	1040	840	700	590	500	58X36
65X40	54	2860	2550	3250	2680	2250	1940	1680	1420	1120	910	760	640	550	65X40
73X45	60	2620	2360	3380	2810	2170	1870	1770	1530	1210	990	820	700	600	73X45
88X54	72	2280	2080	3530	3020	2360	1840	1660	1590	1370	1130	940	800	690	88X54
102X62	84	2030	1870	3200	2990	2510	1970	1720	1520	1510	1250	1040	890	770	102X62
115X72	90	1820	1690	2910	2730	2360	2020	1790	1580	1610	1330	1120	950	820	115X72
122X78	96	1710	1600	2760	2600	2250	1940	1820	1610	1660	1370	1160	990	850	122X78
138X88	108	1550	1450	2530	2390	2080	1800	1710	1640	1780	1480	1250	1070	930	138X88
154X97	120	1410	1330	2330	2220	1930	1680	1600	1540	1810	1570	1330	1140	990	154X97
169X 106	132	1340	1270	2220	2110	1850	1610	1540	1480	1750	1600	1390	1200	1040	169X106

DATA:
1. Unsurfaced roadway.
2. Loads—AASHTO HS 20, two 16,000 lb. dual-tired wheels, 4 ft. on centers, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

NOTES:
1. Interpolate for intermediate pipe sizes and/or fill heights.
2. Critical loads:
    a. For H = 0.5 and 1.0 ft., a single 16,000 lb. dual-tired wheel.
    b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on centers.
    c. For H > 4.0 ft. alternate loading.
3. Truck live loads for H = 10.0 ft. or more are insignificant.

Table 46

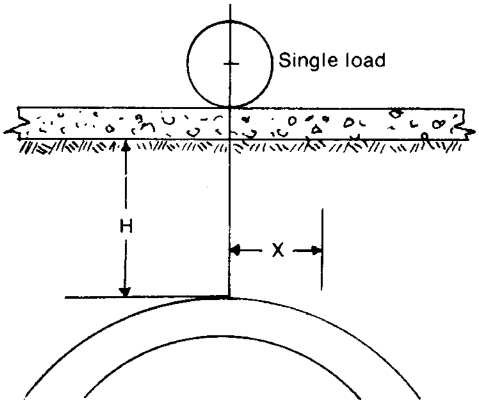
PRESSURE COEFFICIENTS FOR A SINGLE LOAD

Values of C

$p = \frac{CP}{R_S^2}$ pounds per square foot

P = wheel load, pounds

R_S = radius of stiffness of rigid pavement slab, feet



$\frac{H}{R_S}$	X/Rs										
	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
0.0	.113	.105	.089	.068	.048	.032	.020	.011	.006	.002	.000
0.4	.101	.095	.082	.065	.047	.033	.021	.011	.004	.001	.000
0.8	.089	.084	.074	.061	.045	.033	.022	.012	.005	.002	.001
1.2	.076	.072	.065	.054	.043	.032	.022	.014	.008	.005	.003
1.6	.062	.059	.054	.047	.039	.030	.022	.016	.011	.007	.005
2.0	.051	.049	.046	.042	.035	.028	.022	.016	.011	.008	.006
2.4	.043	.041	.039	.036	.030	.026	.021	.016	.011	.008	.006
2.8	.037	.036	.033	.031	.027	.023	.019	.015	.011	.009	.006
3.2	.032	.030	.029	.026	.024	.021	.018	.014	.011	.009	.007
3.6	.027	.026	.025	.023	.021	.019	.016	.014	.011	.009	.007
4.0	.024	.023	.022	.020	.019	.018	.015	.013	.011	.009	.007
4.4	.020	.020	.019	.018	.017	.015	.014	.012	.010	.009	.007
4.8	.018	.017	.017	.016	.015	.013	.012	.011	.009	.008	.007
5.2	.015	.015	.014	.014	.013	.012	.011	.010	.008	.007	.006
5.6	.014	.013	.013	.012	.011	.010	.010	.009	.008	.007	.006
6.0	.012	.012	.011	.011	.010	.009	.009	.008	.007	.007	.006
6.4	.011	.010	.010	.010	.009	.008	.008	.007	.007	.006	.005
6.8	.010	.009	.009	.009	.008	.008	.007	.007	.006	.006	.005
7.2	.009	.008	.008	.008	.008	.007	.007	.006	.006	.006	.005
7.6	.008	.008	.008	.007	.007	.007	.006	.006	.006	.005	.005
8.0	.007	.007	.007	.007	.006	.006	.006	.006	.005	.005	.005

Table 47

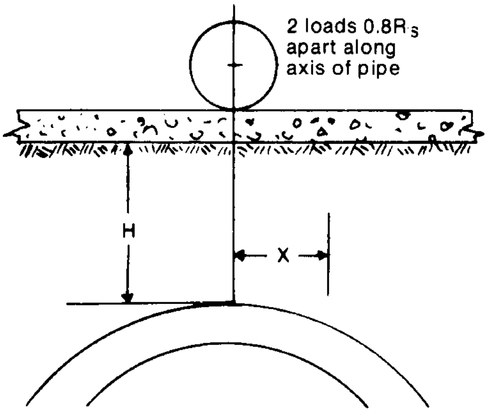
PRESSURE COEFFICIENTS FOR TWO LOADS SPACED $0.8R_S$ APART

Values of C

$p = \frac{CP}{R_S^2}$ pounds per square foot

P = wheel load, pounds

R_S = radius of stiffness of rigid pavement slab, feet



$\frac{H}{R_S}$	X/R_S										
	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
0.0	.210	.198	.168	.130	.092	.062	.038	.022	.011	.004	.000
0.4	.190	.181	.156	.126	.092	.064	.040	.023	.010	.002	.000
0.8	.168	.160	.140	.117	.088	.063	.042	.024	.010	.003	.001
1.2	.144	.139	.124	.106	.083	.062	.043	.027	.013	.007	.004
1.6	.118	.115	.105	.094	.076	.060	.044	.030	.020	.014	.009
2.0	.098	.095	.089	.081	.070	.056	.043	.032	.023	.017	.012
2.4	.083	.080	.076	.069	.061	.050	.040	.031	.023	.017	.012
2.8	.071	.069	.066	.060	.053	.045	.037	.029	.022	.017	.012
3.2	.061	.059	.057	.052	.046	.040	.034	.028	.022	.017	.013
3.6	.052	.051	.049	.046	.041	.036	.032	.027	.022	.018	.014
4.0	.045	.044	.042	.040	.037	.034	.030	.026	.022	.018	.015
4.4	.039	.038	.037	.035	.033	.030	.027	.024	.021	.017	.015
4.8	.034	.034	.033	.031	.029	.027	.024	.021	.019	.016	.014
5.2	.030	.029	.028	.027	.025	.023	.021	.019	.017	.015	.013
5.6	.026	.026	.025	.024	.022	.021	.019	.018	.016	.014	.012
6.0	.023	.023	.022	.021	.020	.019	.017	.016	.015	.013	.011
6.4	.021	.021	.020	.019	.018	.017	.016	.015	.014	.012	.011
6.8	.019	.019	.018	.018	.017	.016	.015	.014	.013	.012	.010
7.2	.017	.017	.016	.016	.015	.014	.013	.013	.012	.011	.010
7.6	.016	.015	.015	.015	.014	.013	.012	.012	.011	.010	.009
8.0	.014	.014	.014	.013	.013	.012	.012	.011	.010	.010	.009

Table 48

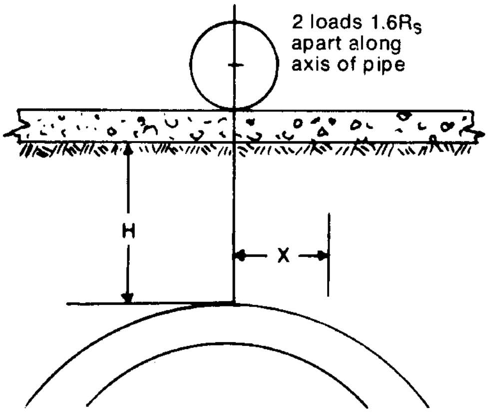
PRESSURE COEFFICIENTS FOR TWO LOADS SPACED 1.6R$_S$ APART

Values of C

$p = \frac{CP}{R_S^2}$ pounds per square foot

P = wheel load, pounds

R_S = radius of stiffness of rigid pavement slab, feet



$\frac{H}{R_S}$	X/R$_S$										
	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
0.0	.178	.167	.142	.112	.080	.054	.034	.019	.009	.004	.000
0.4	.164	.156	.136	.109	.080	.056	.036	.019	.008	.002	.000
0.8	.147	.141	.126	.103	.078	.057	.037	.020	.008	.002	.001
1.2	.128	.124	.106	.094	.074	.056	.039	.023	.012	.006	.004
1.6	.108	.105	.097	.082	.070	.054	.040	.028	.019	.014	.009
2.0	.092	.090	.084	.075	.065	.052	.040	.030	.022	.017	.012
2.4	.079	.076	.072	.065	.056	.047	.038	.029	.022	.017	.012
2.8	.068	.066	.062	.058	.050	.043	.035	.028	.022	.017	.012
3.2	.058	.056	.054	.050	.044	.038	.032	.027	.022	.017	.012
3.6	.050	.049	.047	.044	.040	.035	.030	.026	.022	.017	.013
4.0	.043	.042	.041	.039	.036	.033	.030	.026	.022	.018	.015
4.4	.038	.037	.036	.034	.032	.029	.026	.023	.020	.016	.014
4.8	.033	.032	.031	.030	.028	.026	.024	.021	.018	.015	.013
5.2	.029	.028	.027	.026	.025	.023	.021	.019	.016	.014	.012
5.6	.025	.025	.024	.023	.022	.020	.019	.017	.015	.013	.012
6.0	.023	.022	.022	.021	.019	.018	.017	.016	.014	.013	.011
6.4	.020	.020	.019	.019	.018	.016	.015	.015	.013	.012	.011
6.8	.018	.018	.018	.017	.016	.015	.014	.013	.012	.011	.010
7.2	.017	.016	.016	.015	.015	.014	.013	.013	.012	.011	.010
7.6	.015	.015	.014	.014	.014	.013	.012	.012	.011	.010	.010
8.0	.014	.014	.013	.013	.013	.012	.011	.011	.010	.010	.009

Table 49

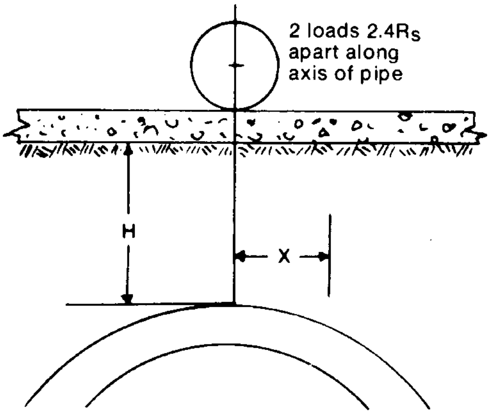
PRESSURE COEFFICIENTS FOR TWO LOADS SPACED 2.4R_S APART

Values of C

$p = \frac{CP}{R_S^2}$ pounds per square foot

P = wheel load, pounds

R_S = radius of stiffness of rigid pavement slab, feet



$\frac{H}{R_S}$	X/R_S										
	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
0.0	.137	.130	.112	.088	.065	.044	.028	.014	.007	.003	.000
0.4	.130	.125	.109	.087	.066	.047	.028	.013	.005	.001	.000
0.8	.121	.117	.104	.085	.066	.048	.030	.014	.006	.002	.001
1.2	.109	.105	.096	.079	.064	.048	.033	.018	.012	.006	.005
1.6	.095	.092	.084	.072	.060	.047	.035	.025	.018	.012	.009
2.0	.083	.081	.077	.068	.057	.046	.035	.026	.020	.015	.010
2.4	.070	.069	.065	.059	.052	.044	.034	.026	.020	.015	.011
2.8	.062	.060	.058	.053	.046	.039	.033	.027	.020	.015	.011
3.2	.053	.052	.050	.046	.041	.035	.032	.026	.020	.016	.012
3.6	.046	.045	.044	.042	.038	.034	.030	.026	.021	.017	.013
4.0	.040	.040	.039	.037	.035	.032	.029	.025	.021	.017	.014
4.4	.036	.035	.034	.033	.031	.028	.025	.022	.019	.016	.013
4.8	.031	.031	.030	.029	.027	.025	.022	.020	.017	.015	.012
5.2	.027	.027	.026	.025	.024	.022	.020	.018	.016	.014	.012
5.6	.024	.023	.023	.022	.021	.020	.018	.017	.015	.013	.011
6.0	.022	.021	.021	.020	.019	.018	.017	.015	.014	.012	.011
6.4	.019	.019	.019	.018	.017	.016	.015	.014	.013	.012	.010
6.8	.018	.017	.017	.016	.016	.015	.014	.013	.012	.011	.010
7.2	.016	.016	.016	.015	.014	.014	.013	.012	.011	.010	.009
7.6	.015	.014	.014	.014	.013	.013	.012	.011	.011	.010	.009
8.0	.013	.013	.013	.013	.012	.012	.011	.011	.010	.009	.009

Table 50

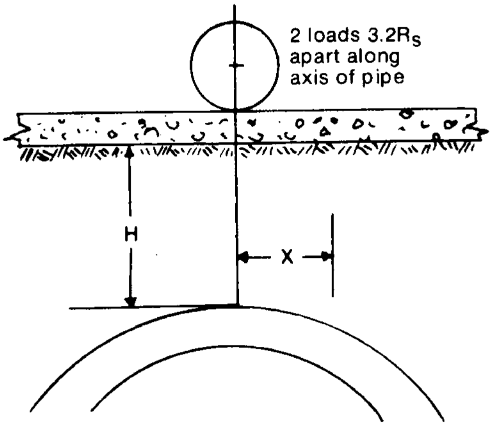
PRESSURE COEFFICIENTS FOR TWO LOADS SPACED 3.2R$_S$ APART

Values of C

$p = \frac{CP}{R_S^2}$ pounds per square foot

P = wheel load, pounds

R_S = radius of stiffness of rigid pavement slab, feet



$\frac{H}{R_S}$	X/R$_S$										
	0.0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
0.0	.097	.093	.080	.065	.048	.032	.020	.011	.004	.000	.000
0.4	.096	.092	.079	.067	.050	.034	.020	.010	.003	.000	.000
0.8	.092	.088	.078	.066	.051	.036	.021	.010	.003	.000	.000
1.2	.086	.082	.074	.066	.050	.038	.025	.014	.007	.003	.001
1.6	.077	.075	.068	.060	.049	.039	.030	.021	.015	.011	.007
2.0	.070	.068	.063	.057	.048	.040	.031	.023	.017	.013	.009
2.4	.061	.060	.056	.051	.045	.038	.030	.023	.017	.013	.010
2.8	.056	.054	.052	.048	.042	.036	.029	.023	.018	.013	.010
3.2	.048	.046	.044	.041	.037	.032	.028	.023	.018	.014	.010
3.6	.043	.041	.040	.038	.034	.030	.027	.022	.019	.015	.012
4.0	.038	.037	.036	.035	.032	.029	.026	.022	.019	.016	.013
4.4	.033	.033	.032	.031	.029	.027	.024	.020	.018	.015	.013
4.8	.029	.029	.028	.027	.025	.023	.021	.018	.016	.014	.012
5.2	.025	.025	.025	.024	.022	.021	.019	.017	.015	.013	.012
5.6	.022	.022	.022	.021	.020	.018	.017	.016	.014	.012	.011
6.0	.020	.020	.020	.020	.020	.017	.016	.015	.013	.011	.011
6.4	.018	.018	.018	.018	.018	.016	.015	.014	.012	.011	.010
6.8	.016	.016	.016	.016	.016	.014	.014	.013	.012	.010	.010
7.2	.015	.015	.015	.015	.015	.013	.013	.012	.011	.010	.009
7.6	.014	.014	.013	.013	.013	.012	.012	.011	.010	.009	.009
8.0	.013	.013	.012	.012	.012	.011	.011	.010	.010	.009	.008

Table 51

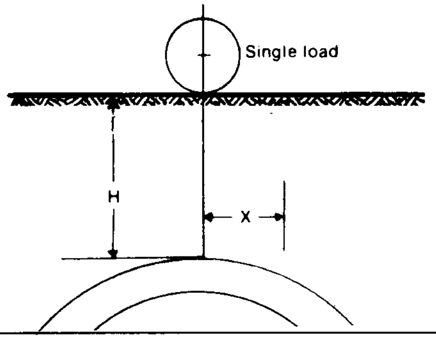
PRESSURE COEFFICIENTS FOR A SINGLE LOAD APPLIED ON SUBGRADE OR FLEXIBLE PAVEMENT

Values of *C*

$p_{(H,X)} = Cp_o$ lb. per sq.ft.

p_o = tire pressure lb. per sq.ft.

r = radius of the circle of pressure at the surface, feet



H/r	X/r 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
0.0	1.000	1.000	.000	.000	.000	.000	.000	.000
0.5	.911	.425	.010	.001	.000	.000	.000	.000
1.0	.646	.350	.050	.005	.001	.000	.000	.000
1.5	.424	.250	.075	.012	.004	.001	.000	.000
2.0	.284	.198	.075	.020	.007	.003	.001	.001
2.5	.200	.145	.070	.026	.010	.004	.002	.001
3.0	.146	.110	.066	.029	.013	.006	.003	.002
3.5	.110	.101	.060	.031	.015	.008	.004	.002
4.0	.087	.081	.054	.031	.017	.009	.005	.003
5.0	.057	.054	.041	.028	.017	.011	.006	.004
6.0	.040	.039	.032	.024	.017	.011	.007	.005
7.0	.030	.029	.025	.020	.015	.011	.008	.005
8.0	.023	.023	.020	.017	.013	.010	.008	.006
9.0	.018	.018	.016	.014	.012	.009	.007	.006
10.0	.015	.015	.014	.012	.010	.009	.007	.006

Table 52

VALUES OF RADIUS OF STIFFNESS R_S IN INCHES FOR RIGID PAVEMENT SLAB

Slab h (in.)	Values of k								
	50	100	150	200	250	300	350	400	500
6	34.84	29.30	26.47	24.63	23.30	22.26	21.42	20.72	19.59
6.5	36.99	31.11	28.11	26.16	24.74	23.64	22.74	22.00	20.80
7	39.11	32.89	29.72	27.65	26.15	24.99	24.04	23.25	21.99
7.5	41.19	34.63	31.29	29.12	27.54	26.32	25.32	24.49	23.16
8	43.23	36.35	32.85	30.57	28.91	27.62	26.58	25.70	24.31
8.5	45.24	38.04	34.37	31.99	30.25	28.91	27.81	26.90	25.44
9	47.22	39.71	35.88	33.39	31.58	30.17	29.03	28.08	26.55
9.5	49.17	41.35	37.36	34.77	32.89	31.42	30.23	29.24	27.65
10	51.10	42.97	38.83	36.14	34.17	32.65	31.42	30.39	28.74
10.5	53.01	44.57	40.28	37.48	35.45	33.87	32.59	31.52	29.81
11	54.89	46.16	41.71	38.81	36.71	35.07	33.75	32.64	30.87
11.5	56.75	47.72	43.12	40.13	37.95	36.26	34.89	33.74	31.91
12	58.59	49.27	44.52	41.43	39.18	37.44	36.02	34.84	32.95
12.5	60.41	50.80	45.90	42.72	40.40	38.60	37.14	35.92	33.97
13	62.22	52.32	47.27	43.99	41.61	39.75	38.25	36.99	34.99
13.5	64.00	53.82	48.63	45.26	42.80	40.89	39.35	38.06	35.99
14	65.77	55.31	49.98	46.51	43.98	42.02	40.44	39.11	36.99
14.5	67.53	56.78	51.31	47.75	45.16	43.15	41.51	40.15	37.97
15	69.27	58.25	52.63	48.98	46.32	44.26	42.58	41.19	38.95
15.5	70.99	59.70	53.94	50.20	47.47	45.36	43.64	42.21	39.92
16	72.70	61.13	55.24	51.41	48.62	46.45	44.70	43.23	40.88
16.5	74.40	62.56	56.53	52.61	49.75	47.54	45.74	44.24	41.84
17	76.08	63.98	57.81	53.80	50.88	48.61	46.77	45.24	42.78
17.5	77.75	65.38	59.08	54.98	52.00	49.68	47.80	46.23	43.72
18	79.41	66.78	60.35	56.16	53.11	50.74	48.82	47.22	44.66
19	82.70	69.54	62.84	58.48	55.31	52.84	50.84	49.17	46.51
20	85.95	72.27	65.30	60.77	57.47	54.92	52.84	51.10	48.33
21	89.15	74.97	67.74	63.04	59.62	56.96	54.81	53.01	50.13
22	92.31	77.63	70.14	65.28	61.73	58.98	56.75	54.89	51.91
23	95.44	80.26	72.52	67.49	63.83	60.98	58.68	56.75	53.67
24	98.54	82.86	74.87	69.68	65.90	62.96	60.58	58.59	55.41

$R_S = \sqrt[4]{\frac{Eh^3}{12(1-u^2)k}}$ where $E = 4{,}000{,}000$ psi, $u = 0.15$ therefore $R_s = 24.1652\sqrt[4]{\frac{h^3}{k}}$

Table 53

Aircraft Loads On Circular Pipe Under Rigid Pavement

Pounds Per Linear Foot

Height of Fill Measured From Top of Pipe To Surface of Subgrade

	Height of Fill **H** Above Top of Grade									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
12	1892	1789	1623	1453	1266	1130	998	877	773	686
15	2304	2154	1975	1779	1542	1377	1216	1069	942	835
18	2714	2537	2327	2084	1817	1622	1433	1260	1111	984
21	3122	2918	2677	2397	2091	1865	1649	1451	1279	1090
24	3527	3297	3025	2709	2363	2110	1863	1640	1447	1280
27	3932	3567	3371	2931	2635	2352	2076	1829	1615	1427
30	4333	4049	3714	3328	2905	2592	2288	2016	1782	1575
33	4732	4421	4055	3636	3175	2832	2498	2203	1949	1722
36	5128	4790	4395	3941	3442	3069	2707	2388	2115	1868
42	5912	5520	5065	4546	3973	3540	3120	2755	2446	2160
48	6682	6237	5725	5142	4496	4003	3528	3118	2774	2449
54	7437	6940	6371	5726	5010	4459	3930	3477	3097	2735
60	8174	7628	7004	6297	5512	4905	4325	3831	3415	3018
66	8892	8298	7621	6855	6002	5341	4714	4180	3729	3297
72	9588	8948	8220	7396	6480	5767	5095	4522	4037	3571
78	10260	9577	8799	7921	6943	6183	5468	4857	4338	3840
84	10900	10180	9358	8427	7392	6587	5831	5184	4632	4105
90	11520	10760	9894	8916	7827	6980	6186	5503	4920	4365
96	12100	11310	10410	9385	8246	7362	6531	5813	5199	4620
102	12660	11840	10900	9837	8615	7732	6867	6116	5471	4870
108	13190	12340	11370	10270	9042	8090	7193	6409	5735	5112
114	13540	12680	11690	10560	9312	8338	7419	6614	5919	5279
120	14010	13120	12110	10960	9676	8674	7727	6892	6170	5507
126	14450	13540	12510	11340	10020	8998	8024	7162	6413	5726
138	15230	14300	13240	12030	10680	9607	8583	7672	6877	6143
144	15580	14640	13560	12340	10980	9889	8842	7910	7095	6342

0,000 Pound Dual-Tandem Gear Assembly. 190 pounds per square inch tire pressure. 26-inch c/c spacing between dual tires. 66-inch spacing between for and aft tandem tires. k-300 pounds per cubic inch. R_S-37.44 inches. h-12 inches. E-4,000,000 pounds per uare inch. u-0.15. Interpolate for intermediate fill heigths.

Table 54

Aircraft Loads Horizonal Elliptical Pipe Under Rigid Pavement

Pounds Per Linear Foot

Height of Fill Measured From Top of Pipe To Surface of Subgrade

	Height of Fill **H** Above Top of Grade									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
14x23	3354	3136	2875	2576	2247	2006	1771	1560	1375	1216
19x30	4276	3996	3664	3285	2867	2559	2258	2989	1759	1554
22x34	4789	4474	4104	3679	3213	2866	2528	2229	1973	1742
24x38	5297	4949	4538	4072	3557	3172	2798	2467	2187	1931
27x42	5745	5365	4922	4417	3660	3440	3032	2677	2376	2097
29x45	6244	5829	5349	4803	4199	3739	3295	2911	2587	2284
32x49	6737	6288	5772	5185	4533	4036	3557	3144	2797	2469
34x53	7223	6741	6188	5561	4864	4329	3816	3375	3005	2654
38x60	8070	7530	6914	6217	5441	4842	4269	3781	3370	2978
43x68	8993	8392	7707	6933	6071	5403	4769	4229	3773	3336
48x76	9879	9221	8471	7623	6680	5947	5256	4667	4167	3687
53x83	10630	9925	9121	8212	7202	6415	5677	5045	4507	3992
58x91	11430	10680	9819	8847	7765	6925	6136	5458	4879	4324
63x98	12100	11310	10410	9385	8246	7362	6531	5813	5199	4620
68x106	12810	11980	11040	9963	8765	7836	6962	6200	5547	4940
72x113	13400	12540	11560	10450	9205	8240	7330	6532	5846	5213
77x121	14010	13120	12110	10690	9676	8674	7727	6892	6170	5507
82x128	14480	13570	12540	11360	10040	9021	8045	7181	6430	5741
87x136	14970	14040	12990	11790	10450	9396	8389	7495	6715	5997
92x143	15390	14450	13380	12160	10810	9730	8696	7875	6971	6229
97x151	15810	14860	13780	12550	11180	10080	9019	8072	7245	6481
106x166	16490	15520	14440	13210	11830	10690	9574	8586	7729	6931
116x180	17000	16030	14960	13740	12350	11180	10040	10925	8145	7323

0,000 Pound Dual-Tandem Gear Assembly. 190 pounds per square inch tire pressure. 26-inch c/c spacing between dual tires. 66-inch spacing between for and aft tandem tires. k-300 pounds per cubic inch. R_S-37.44 inches. h-12 inches. E-4,000,000 pounds per uare inch. u-0.15. Interpolate for intermediate fill heigths.

Table 55

Aircraft Loads On Arch Pipe Under Rigid Pavement

Pounds Per Linear Foot

Height of Fill Measured From Top of Pipe To Surface of Subgrade

	Height of Fill **H** Above Top of Grade									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
11x18	2656	2483	2277	2039	1778	1588	1403	1234	1087	962
13-$^{1}/_{2}$x22	3180	2973	2727	2442	2130	1908	1679	1478	1303	1153
15-$^{1}/_{2}$x26	3701	3460	3173	2843	2481	2214	1955	1722	1519	1343
18x28-$^{1}/_{2}$	4047	3782	3469	3109	2712	2421	2137	1882	1663	1470
22-$^{1}/_{2}$x36-$^{1}/_{4}$	5043	4698	4322	3876	3385	3019	2662	2348	2104	1836
26-$^{5}/_{8}$x43-$^{3}/_{4}$	5954	5559	5136	4610	4030	3590	3164	2794	2482	2191
31-$^{5}/_{16}$x51-$^{1}/_{8}$	6914	6452	5923	5321	4653	4142	3650	3228	2872	2536
36x58-$^{1}/_{2}$	7808	7286	6689	6014	5262	4683	4122	3654	3257	2878
40x65	8587	8013	7358	6617	5794	5155	4548	4031	3595	3178
45x73	9490	8857	8135	7320	6412	5707	5040	4474	3993	3532
54x88	11080	10350	9513	8569	7518	6701	5934	5276	4715	4180
62x102	12420	11620	10690	9645	8479	7575	6724	5987	5355	4764
72x115	13470	12610	11620	10510	9258	8289	7374	6573	5882	5246
77-$^{1}/_{4}$x122	14010	13120	12110	10960	9676	8674	7727	6892	6170	5507
87-$^{1}/_{8}$x138	15080	14150	13090	11880	10540	9481	8468	7567	6780	6056
96-$^{7}/_{8}$x154	15940	14990	13910	12680	11300	10190	9122	8167	7334	6562
106-$^{1}/_{2}$x168-$^{3}/_{4}$	16440	15480	14390	13170	11780	10640	9535	8551	7695	6899

0,000 Pound Dual-Tandem Gear Assembly. 190 pounds per square inch tire pressure. 26-inch c/c spacing between dual tires. 66-inch spacing between for and aft tandem tires. k-300 pounds per cubic inch. R_S-37.44 inches. h-12 inches. E-4,000,000 pounds per uare inch. u-0.15. Interpolate for intermediate fill heigths.

Table 56

RAILROAD LOADS ON CIRCULAR PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE—INSIDE DIAMETER D IN INCHES	HEIGHT OF FILL H ABOVE TOP OF PIPE IN FEET																	PIPE SIZE—INSIDE DIAMETER D IN INCHES
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	
12	3630	3400	3060	2700	2340	2010	1720	1480	1260	1090	880	720	590	490	420	290	210	12
15	4430	4140	3720	3300	2860	2450	2100	1800	1540	1330	1070	880	720	600	510	350	250	15
18	5220	4890	4390	3890	3370	2890	2480	2130	1820	1570	1260	1030	840	710	610	410	300	18
21	6020	5630	5060	4470	3880	3330	2850	2450	2100	1810	1450	1190	970	810	700	480	340	21
24	6810	6370	5730	5070	4390	3770	3230	2770	2370	2050	1640	1350	1100	920	790	540	390	24
27	7610	7120	6400	5660	4900	4210	3610	3100	2650	2290	1830	1500	1230	1030	890	600	430	27
30	8400	7860	7070	6250	5420	4640	3980	3420	2930	2520	2020	1660	1360	1140	980	670	480	30
33	9200	8610	7740	6840	5930	5080	4360	3740	3200	2760	2220	1820	1480	1240	1070	730	520	33
36	10000	9350	8400	7430	6450	5520	4740	4070	3480	3000	2410	1980	1610	1350	1160	790	570	36
42	11600	10800	9740	8610	7470	6400	5500	4710	4030	3480	2790	2290	1870	1570	1350	920	660	42
48	13200	12300	11100	9790	8500	7280	6250	5360	4590	3960	3170	2600	2130	1780	1530	1040	750	48
54	14800	13800	12400	11000	9520	8160	7000	6000	5140	4440	3560	2920	2380	2000	1720	1160	840	54
60	16400	15300	13800	12200	10500	9040	7750	6650	5690	4910	3940	3230	2640	2210	1900	1290	930	60
66	17900	16800	15100	13300	11600	9920	8510	7300	6250	5390	4320	3550	2900	2430	2090	1420	1020	66
72	19500	18300	16400	14500	12600	10800	9260	7950	6800	5870	4710	3860	3150	2640	2270	1540	1110	72
78	21100	19800	17800	15700	13600	11700	10000	8590	7350	6350	5090	4180	3410	2860	2460	1670	1200	78
84	22700	21200	19100	16900	14600	12600	10800	9240	7900	6820	5470	4490	3670	3070	2640	1800	1290	84
90	24300	22700	20400	18100	15700	13400	11500	9890	8460	7300	5860	4800	3920	3290	2820	1920	1380	90
96	25900	24200	21800	19300	16700	14300	12300	10500	9010	7780	6240	5120	4180	3500	3010	2050	1470	96
102	27500	25700	23100	20400	17700	15200	13000	11200	9560	8250	6620	5430	4440	3720	3200	2180	1560	102
108	29100	27200	24500	21600	18800	16100	13800	11800	10100	8740	7010	5750	4690	3940	3380	2300	1650	108
114	30200	28300	25400	22500	19500	16700	14300	12300	10500	9070	7280	5970	4880	4090	3510	2390	1710	114
120	31800	29800	26800	23700	20500	17600	15100	12900	11100	9560	7660	6290	5130	4300	3700	2520	1800	120
126	33400	31200	28100	24800	21500	18500	15800	13600	11600	10000	8040	6600	5390	4520	3880	2640	1890	126
132	35000	32700	29400	26000	22500	19300	16600	14200	12200	10500	8420	6910	5650	4730	4060	2770	1980	132
138	36600	34200	30800	27200	23600	20200	17300	14900	12700	11000	8810	7230	5900	4950	4250	2890	2070	138
144	38200	35700	32100	28400	24600	21100	18100	15500	13300	11500	9190	7540	6160	5160	4430	3020	2160	144

Cooper E80 design loading consisting of four 80,000-pound axles spaced 5 feet c/c. Locomotive load assumed uniformity distributed over an area 8 feet x 20 feet. Weight of track structure assumed to be 200 pounds per linear foot. Impact included. Height of fill measured from top of pipe to bottom of ties. Interpolate for intermediate pipe sizes and/or fill heights.

Table 57

RAILROAD LOADS ON HORIZONTAL ELLIPTICAL PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE – INSIDE RISE X SPAN R X S IN INCHES	HEIGHT OF FILL H ABOVE TOP OF PIE																	PIPE SIZE – INSIDE RISE X SPAN R X S IN INCHES
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	
14X23	6470	6060	5440	4810	4170	3580	3070	2630	2250	1940	1560	1280	1040	880	760	510	370	14X23
19X30	8290	7760	6970	6170	5350	4580	3930	3370	2890	2490	2000	1640	1340	1120	960	660	470	19X30
22X34	9310	8710	7830	6930	6010	5150	4420	3790	3240	2800	2240	1840	1500	1260	1080	740	530	22X34
24X38	10300	9670	8690	7690	6670	5710	4900	4200	3600	3110	2490	2040	1670	1400	1200	820	590	24X38
27X42	11200	10500	9460	8360	7250	6220	5330	4570	3910	3380	2710	2220	1820	1520	1310	890	640	27X42
29X45	12300	11500	10300	9120	7910	6780	5820	4910	4270	3680	3000	2420	1980	1660	1420	970	700	29X45
32X49	13300	12400	11200	9880	8570	7340	6300	5410	4630	3990	3200	2630	2140	1800	1540	1050	750	32X49
34X53	14300	13400	12000	10600	9230	7910	6780	5820	4980	4300	3450	2830	2310	1940	1660	1130	810	34X53
38X60	16100	15100	13600	12000	10400	8910	7650	6560	5610	4850	3890	3190	2600	2180	1870	1280	910	38X60
43X68	18200	17000	15300	13500	11700	10000	8620	7390	6330	5460	4380	3590	2930	2460	2110	1440	1030	43X68
48X76	20200	18900	17000	15000	13000	11200	9580	8220	7040	6070	4870	4000	3260	2740	2350	1600	1150	48X76
53X83	22000	20600	18500	16400	14200	12200	10400	8960	7670	6620	5310	4360	3560	2980	2560	1740	1250	53X83
58X91	24100	22500	20200	17900	15500	13300	11400	9790	8380	7230	5800	4760	3890	3260	2800	1900	1360	58X91
63X98	25900	24200	21800	19300	16700	14300	12300	10500	9010	7780	6240	5120	4180	3500	3010	2050	1470	63X98
68X106	27900	26100	23500	20800	18000	15500	13300	11400	9730	8380	6730	5520	4510	3780	3250	2210	1580	68X106
72X113	29800	27800	25000	22100	19200	16500	14100	12100	10400	8940	7170	5880	4800	4030	3460	2350	1690	72X113
77X121	31800	29800	26800	23700	20500	17600	15100	12900	11100	9560	7660	6290	5130	4300	3700	2520	1800	77X121
82X128	33500	31300	28200	24900	21600	18500	15900	13600	11700	10100	8070	6620	5410	4530	3890	2650	1900	82X128
87X136	35400	33200	29800	26300	22900	19600	16800	14400	12300	10600	8540	7010	5720	4800	4120	2800	2010	87X136
92X143	37300	34900	31300	27700	24000	20600	17700	15200	13000	11200	8980	7370	6010	5040	4330	2950	2110	92X143
97X151	39300	36800	33100	29200	25300	21700	18600	16000	13700	11800	9470	7770	6340	5320	4570	3110	2230	97X151
106X166	43100	40400	36300	32100	27800	23800	20500	17600	15000	12300	10400	8530	6970	5840	5010	3410	2440	106X166
116X180	46800	43800	39400	34800	30200	25900	22200	19000	16300	14100	11300	9250	7550	6330	5440	3700	2640	116X180

Cooper E80 design loading consisting of four 80,000 pound axles spaced 5 feet c/c. Locomotive load assumed uniformly distributed over an area 8 feet x 20 feet. Weight of track structure assumed to be 200 pounds per linear foot. Impact included. Height of fill measured from top of pipe to bottom of ties. Interpolate for intermediate pipe sizes and/or fill heights.

Table 58

RAILROAD LOADS ON ARCH PIPE

POUNDS PER LINEAR FOOT

PIPE SIZE — INSIDE RISE X SPAN **R** X **S** IN INCHES	HEIGHT OF FILL **H** ABOVE TOP OF PIPE IN FEET																	PIPE SIZE — INSIDE RISE X SPAN **R** X **S** IN INCHES
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	25	30	
11X18	5110	4780	4300	3800	3300	2820	2420	2080	1780	1540	1230	1010	820	700	600	400	290	11X18
13X22	6130	5740	5160	4560	3960	3390	2910	2500	2140	1840	1480	1210	990	830	710	480	350	13X22
15X26	7150	6690	6020	5320	4610	3960	3390	2910	2490	2150	1720	1410	1160	970	830	570	410	15X26
18X29	7840	7330	6590	5830	5050	4330	3720	3190	2730	2350	1890	1550	1260	1060	910	620	440	18X29
22X36	9820	9190	8260	7300	6340	5430	4660	4000	3420	2950	2370	1940	1590	1330	1140	780	560	22X36
27X44	11800	11000	9880	8740	7580	6500	5570	4780	4090	3530	2830	2320	1900	1590	1370	930	670	27X44
31X51	13700	12800	11500	10200	8810	7550	6470	5560	4750	4100	3290	2700	2200	1850	1590	1080	770	31X51
36X58	15600	14600	13100	11600	10000	8600	7380	6330	5420	4670	3750	3070	2510	2110	1810	1230	880	36X58
40X65	17300	16100	14500	12800	11100	9540	8180	7020	6010	5190	4160	3410	2790	2340	2010	1370	980	40X65
45X73	19300	18100	16200	14400	12400	10700	9150	7850	6720	5800	4650	3820	3120	2610	2240	1520	1100	45X73
54X88	23200	21700	19500	17200	15000	12800	11000	9440	8080	6970	5590	4590	3740	3140	2700	1830	1310	54X88
62X102	26800	25100	22500	19900	17300	14800	12700	10900	9330	8050	6460	5300	4330	3630	3110	2120	1520	62X102
72X115	30000	28000	25200	22300	19300	16600	14200	12200	10400	9010	7220	5930	4840	4060	3480	2370	1700	72X115
78X122	31800	29800	26800	23700	20500	17600	15100	12900	11100	9560	7660	6290	5130	4300	3700	2520	1800	78X122
88X138	35900	33600	30200	26700	23100	19800	17000	14600	12500	10800	8650	7100	5800	4860	4170	2840	2030	88X138
97X154	40000	37400	33600	29700	25800	22100	19000	16300	13900	12000	9630	7910	6450	5410	4650	3160	2270	97X154
106X169	42900	40100	36100	31900	27600	23700	20300	17400	14900	12900	10300	8480	6920	5800	4980	3390	2430	106X169

Cooper E80 design loading consisting of four 80,000 pound axles spaced 5 feet c/c. Locomotive load assumed uniformly distributed over an area 8 feet x 20 feet. Weight of track structure assumed to be 200 pounds per linear foot. Impact included. Height of fill measured from top of pipe to bottom of ties. Interpolate for intermediate pipe sizes and/or fill heights.

Table 59

BEDDING FACTORS FOR VERTICAL ELLIPTICAL PIPE POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS B BEDDING					CLASS C BEDDING					$\frac{H}{B_c}$
						$p = 0.9$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	—	—	—	—	—	—	—	—	—	—	0.5
1.0	—	3.66	3.66	3.66	3.66	—	2.70	2.70	2.70	2.70	1.0
1.5	—	3.66	3.66	3.66	3.66	2.70	2.70	2.70	2.70	2.70	1.5
2.0	3.66	3.66	3.66	3.66	3.66	2.70	2.70	2.70	2.70	2.70	2.0
3.0	3.66	3.66	3.66	3.54	3.26	2.70	2.70	2.70	2.64	2.48	3.0
5.0	3.66	3.66	3.61	3.37	3.13	2.70	2.70	2.68	2.54	2.40	5.0
10.0	3.66	3.66	3.46	3.27	3.03	2.70	2.70	2.59	2.48	2.34	10.0
15.0	3.66	3.66	3.52	3.21	3.00	2.70	2.70	2.57	2.45	2.32	15.0
						$p = 0.7$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	—	—	—	—	—	2.53	2.53	2.53	2.53	2.53	0.5
1.0	3.35	3.35	3.35	3.35	3.35	2.53	2.53	2.53	2.53	2.53	1.0
1.5	3.35	3.35	3.25	3.16	3.16	2.53	2.53	2.47	2.42	2.42	1.5
2.0	3.35	3.27	3.01	2.91	2.91	2.53	2.48	2.33	2.27	2.27	2.0
3.0	3.35	3.13	2.94	2.80	2.68	2.53	2.40	2.29	2.20	2.13	3.0
5.0	3.35	3.05	2.85	2.74	2.63	2.53	2.36	2.23	2.17	2.10	5.0
10.0	3.35	2.97	2.80	2.71	2.59	2.53	2.31	2.22	2.14	2.07	10.0
15.0	3.35	2.95	2.78	2.68	2.58	2.53	2.30	2.21	2.13	2.06	15.0
						$p = 0.5$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.80	2.80	2.80	2.80	2.80	2.20	2.20	2.20	2.20	2.20	0.5
1.0	2.77	2.48	2.48	2.48	2.48	2.18	2.00	2.00	2.00	2.00	1.0
1.5	2.67	2.46	2.43	2.40	2.40	2.12	1.98	1.97	1.95	1.95	1.5
2.0	2.63	2.44	2.37	2.34	2.34	2.10	1.97	1.93	1.91	1.91	2.0
3.0	2.59	2.41	2.36	2.31	2.27	2.07	1.96	1.92	1.89	1.86	3.0
5.0	2.55	2.40	2.33	2.30	2.26	2.04	1.95	1.90	1.88	1.85	5.0
10.0	2.53	2.38	2.32	2.29	2.25	2.03	1.94	1.90	1.87	1.84	10.0
15.0	2.52	2.38	2.31	2.28	2.24	2.02	1.93	1.90	1.87	1.84	15.0
						$p = 0.3$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.18	2.17	2.16	2.16	2.16	1.80	1.79	1.79	1.79	1.79	0.5
1.0	2.15	2.10	2.10	2.10	2.10	1.78	1.74	1.74	1.74	1.74	1.0
1.5	2.14	2.10	2.09	2.08	2.08	1.77	1.74	1.74	1.73	1.73	1.5
2.0	2.13	2.10	2.08	2.07	2.07	1.77	1.74	1.73	1.73	1.73	2.0
3.0	2.13	2.09	2.08	2.07	2.06	1.76	1.74	1.73	1.72	1.72	3.0
5.0	2.12	2.09	2.08	2.07	2.06	1.76	1.74	1.73	1.72	1.71	5.0
10.0	2.12	2.09	2.08	2.06	2.05	1.76	1.74	1.73	1.72	1.71	10.0
15.0	2.12	2.09	2.07	2.06	2.05	1.76	1.74	1.73	1.72	1.71	15.0
						ZERO PROJECTING					
	1.98					1.66					

Table 60

BEDDING FACTORS FOR HORIZONTAL ELLIPTICAL PIPE POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS B BEDDING					CLASS C BEDDING					$\frac{H}{B_c}$
$p = 0.9$											
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.72	2.65	2.65	2.65	2.65	2.14	2.10	2.10	2.10	2.10	0.5
1.0	2.58	2.49	2.49	2.49	2.49	2.05	2.00	2.00	2.00	2.00	1.0
1.5	2.34	2.46	2.42	2.40	2.38	2.03	1.97	1.95	1.94	1.92	1.5
2.0	2.52	2.44	2.41	2.39	2.37	2.01	1.96	1.95	1.93	1.92	2.0
3.0	2.50	2.43	2.40	2.38	2.34	2.00	1.96	1.94	1.92	1.90	3.0
5.0	2.48	2.42	2.39	2.36	2.33	1.99	1.95	1.93	1.91	1.89	5.0
10.0	2.47	2.41	2.37	2.35	2.33	1.98	1.94	1.92	1.91	1.89	10.0
15.0	2.46	2.40	2.36	2.35	2.32	1.98	1.94	1.92	1.91	1.89	15.0
$p = 0.7$											
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.46	2.42	2.42	2.42	2.42	1.98	1.95	1.95	1.95	1.95	0.5
1.0	2.40	2.35	2.35	2.35	2.35	1.94	1.90	1.90	1.90	1.90	1.0
1.5	2.38	2.33	2.31	2.30	2.28	1.92	1.89	1.88	1.87	1.86	1.5
2.0	2.37	2.32	2.31	2.29	2.28	1.92	1.89	1.88	1.87	1.86	2.0
3.0	2.36	2.32	2.30	2.29	2.27	1.91	1.88	1.87	1.86	1.85	3.0
5.0	2.35	2.32	2.29	2.28	2.26	1.90	1.88	1.87	1.86	1.84	5.0
10.0	2.34	2.31	2.28	2.27	2.26	1.90	1.88	1.86	1.85	1.84	10.0
15.0	2.34	2.31	2.28	2.27	2.25	1.90	1.88	1.86	1.85	1.84	15.0
$p = 0.5$											
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.27	2.25	2.25	2.25	2.25	1.85	1.84	1.84	1.84	1.84	0.5
1.0	2.25	2.23	2.23	2.23	2.23	1.84	1.82	1.82	1.82	1.82	1.0
1.5	2.24	2.22	2.21	2.21	2.20	1.83	1.82	1.81	1.81	1.80	1.5
2.0	2.24	2.22	2.21	2.20	2.20	1.83	1.82	1.81	1.81	1.80	2.0
3.0	2.24	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.81	1.80	3.0
5.0	2.23	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.80	1.80	5.0
10.0	2.23	2.22	2.20	2.20	2.19	1.83	1.82	1.81	1.80	1.80	10.0
15.0	2.23	2.21	2.20	2.20	2.19	1.82	1.81	1.81	1.80	1.80	15.0
$p = 0.3$											
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.16	2.16	2.16	2.16	2.16	1.78	1.78	1.78	1.78	1.78	0.5
1.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.0
1.5	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.5
2.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	2.0
3.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	3.0
5.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	5.0
10.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	10.0
15.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	15.0
ZERO PROJECTING											
	2.12					1.75					

Table 61

BEDDING FACTORS FOR ARCH PIPE POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS B BEDDING					CLASS C BEDDING					$\frac{H}{B_c}$
						$p = 0.9$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.72	2.65	2.65	2.65	2.65	2.14	2.10	2.10	2.10	2.10	0.5
1.0	2.58	2.49	2.49	2.49	2.49	2.05	2.00	2.00	2.00	2.00	1.0
1.5	2.34	2.46	2.42	2.40	2.38	2.03	1.97	1.95	1.94	1.92	1.5
2.0	2.52	2.44	2.41	2.39	2.37	2.01	1.96	1.95	1.93	1.92	2.0
3.0	2.50	2.43	2.40	2.38	2.34	2.00	1.96	1.94	1.92	1.90	3.0
5.0	2.48	2.42	2.39	2.36	2.33	1.99	1.95	1.93	1.91	1.89	5.0
10.0	2.47	2.41	2.37	2.35	2.33	1.98	1.94	1.92	1.91	1.89	10.0
15.0	2.46	2.40	2.36	2.35	2.32	1.98	1.94	1.92	1.91	1.89	15.0
						$p = 0.7$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.46	2.42	2.42	2.42	2.42	1.98	1.95	1.95	1.95	1.95	0.5
1.0	2.40	2.35	2.35	2.35	2.35	1.94	1.90	1.90	1.90	1.90	1.0
1.5	2.38	2.33	2.31	2.30	2.28	1.92	1.89	1.88	1.87	1.86	1.5
2.0	2.37	2.32	2.31	2.29	2.28	1.92	1.89	1.88	1.87	1.86	2.0
3.0	2.36	2.32	2.30	2.29	2.27	1.91	1.88	1.87	1.86	1.85	3.0
5.0	2.35	2.32	2.29	2.28	2.26	1.90	1.88	1.87	1.86	1.84	5.0
10.0	2.34	2.31	2.28	2.27	2.26	1.90	1.88	1.86	1.85	1.84	10.0
15.0	2.34	2.31	2.28	2.27	2.25	1.90	1.88	1.86	1.85	1.84	15.0
						$p = 0.5$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.27	2.25	2.25	2.25	2.25	1.85	1.84	1.84	1.84	1.84	0.5
1.0	2.25	2.23	2.23	2.23	2.23	1.84	1.82	1.82	1.82	1.82	1.0
1.5	2.24	2.22	2.21	2.21	2.20	1.83	1.82	1.81	1.81	1.80	1.5
2.0	2.24	2.22	2.21	2.20	2.20	1.83	1.82	1.81	1.81	1.80	2.0
3.0	2.24	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.81	1.80	3.0
5.0	2.23	2.22	2.21	2.20	2.19	1.83	1.82	1.81	1.80	1.80	5.0
10.0	2.23	2.22	2.20	2.20	2.19	1.83	1.82	1.81	1.80	1.80	10.0
15.0	2.23	2.21	2.20	2.20	2.19	1.82	1.81	1.81	1.80	1.80	15.0
						$p = 0.3$					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	
0.5	2.16	2.16	2.16	2.16	2.16	1.78	1.78	1.78	1.78	1.78	0.5
1.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.0
1.5	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	1.5
2.0	2.16	2.15	2.15	2.15	2.15	1.78	1.77	1.77	1.77	1.77	2.0
3.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	3.0
5.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	5.0
10.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	10.0
15.0	2.16	2.15	2.15	2.15	2.14	1.78	1.77	1.77	1.77	1.77	15.0
						ZERO PROJECTING					
	2.12					1.75					

Table 62

The following Fill Height Tables have been developed by the American Concrete Pipe Association (ACPA) using the indirect design method in accordance with Section 12.10.4.3 of the AASHTO LRFD Bridge Design Specification, 4th Edition, 2007 with 2008 Interim. Live load was distributed through the pipe in accordance with Chapter 4 of the ACPA Concrete Pipe Design Manual.

Fill Height Tables are based on:

1. γs = 120 pcf
2. AASHTO HL-93 live load
3. Positive Projecting Embankment Condition - this gives conservative results in comparison to trench conditions
4. A Type 1 installation requires greater soil stiffness from the surrounding soils than the Type 2, 3, and 4 installations, and is thus harder to achieve. Therefore, field verification of soil properties and compaction levels should be performed.

Type 1 Bedding

▨ Class I
▨ Class II
▨ Class III
▨ Class IV
▨ Class V
☐ Special Design

Pipe i.d. (inches)	Fill Height (feet) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
12	1850	1100	800	700	650	625	650	675	700	750	800	825	900	950	1000
15	1725	1025	775	675	625	625	625	650	700	725	775	825	875	925	975
18	1550	975	750	650	600	600	625	650	675	725	775	800	875	925	975
21	1300	950	725	625	600	600	625	650	675	725	750	800	875	925	950
24	1150	925	700	625	600	600	625	650	675	725	750	800	875	925	950
27	1025	900	700	625	600	600	625	650	675	725	750	800	875	925	975
30	975	825	675	625	600	600	625	650	675	725	775	825	875	925	975
33	925	775	675	600	600	600	625	650	700	725	775	825	875	925	975
36	900	725	675	600	600	600	625	650	700	725	775	825	900	950	975
42	825	650	650	600	600	600	625	650	700	750	775	825	900	950	1000
48	875	650	600	600	600	600	625	675	700	750	800	825	900	950	1000
54	825	650	550	600	600	600	650	675	725	750	800	875	925	950	1000
60	825	650	550	550	600	625	650	675	725	775	800	875	925	975	1025
66	825	675	550	550	600	625	650	700	725	775	825	900	925	975	1025
72	800	700	550	550	600	625	675	700	750	775	825	900	950	1000	1050
78	725	675	600	600	600	625	675	700	750	800	875	900	950	1000	1050
84	700	650	625	600	625	650	675	725	750	800	875	925	975	1025	1075
90	650	650	625	600	625	650	675	725	775	825	875	925	975	1025	1075
96	625	625	625	625	625	650	700	725	775	825	900	950	1000	1050	1100
102	625	625	625	625	650	675	700	750	800	825	900	950	1000	1050	1100
108	650	600	625	625	650	675	725	750	800	875	925	975	1025	1075	1150

Table 63

Fill Height Tables are based on:

1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 1 Bedding

Class I
Class II
Class III
Class IV
Class V
Special Design

Pipe i.d. (inches)	Fill Height (feet) 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
12	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
15	800	850	900	950	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475
18	800	850	900	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475
21	800	850	900	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1450
24	800	850	900	950	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475
27	800	850	900	950	1000	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475
30	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1325	1375	1425	1475
33	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
36	825	875	925	975	1025	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
42	825	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525
48	825	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525
54	825	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525
60	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550
66	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550
72	850	925	950	1000	1050	1100	1150	1200	1250	1300	1375	1425	1475	1525	1575
78	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525	1575
84	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525	1575
90	875	925	975	1025	1075	1125	1175	1225	1275	1325	1375	1425	1475	1525	1600
96	875	925	975	1025	1075	1125	1175	1250	1300	1350	1400	1450	1500	1550	1600

Table 64

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 1 Bedding

▨ Class I
▨ Class II
▨ Class III
▨ Class IV
▨ Class V
☐ Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
12	1550	1600	1650	1700	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225
15	1525	1575	1625	1675	1725	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200
18	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200
21	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2175
24	1525	1575	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200
27	1525	1575	1625	1675	1725	1775	1825	1875	1900	1950	2000	2050	2100	2150	2200
30	1525	1575	1625	1675	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225
33	1550	1600	1650	1700	1750	1800	1850	1900	1950	1975	2025	2075	2125	2175	2225
36	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250
42	1575	1625	1675	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250
48	1575	1625	1675	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225	2275
54	1575	1625	1675	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225	2275
60	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250	2300
66	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250	2325
72	1625	1675	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225	2275	2325
78	1625	1675	1725	1775	1825	1875	1925	1975	2025	2075	2125	2175	2225	2300	2350
84	1625	1675	1725	1775	1825	1900	1950	2000	2050	2100	2150	2200	2250	2300	2350
90	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250	2300	2350
96	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100	2175	2225	2275	2325	2375

Table 65

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft³
2. AASHTO HS20 live load
3. Embankment installation

Type 1 Bedding

▨	Class I
▨	Class II
▨	Class III
▨	Class IV
▨	Class V
☐	Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
12	2275	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975
15	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2725	2775	2825	2875	2925
18	2225	2275	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925
21	2225	2275	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925
24	2250	2300	2350	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925
27	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2775	2825	2875	2925
30	2275	2325	2375	2425	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950
33	2275	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975
36	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
42	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
48	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975	3025
54	2325	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975	3025
60	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000	3050
66	2375	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975	3025	3075
72	2375	2425	2475	2525	2575	2625	2675	2750	2800	2850	2900	2950	3000	3050	3100
78	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000	3050	3100
84	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2975	3025	3075	3125
90	2400	2450	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975	3025	3075	3125
96	2425	2475	2525	2575	2625	2675	2725	2775	2825	2875	2925	2975	3050	3100	3150

Table 66

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft³
2. AASHTO HS20 live load
3. Embankment installation

Type 2 Bedding

▨	Class I
▨	Class II
▨	Class III
▨	Class IV
▨	Class V
☐	Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
12	1150	650	475	475	500	525	575	650	700	750	825	900	950	1025	1100
15	1075	625	475	450	475	525	575	625	700	750	825	875	950	1025	1075
18	1025	600	450	450	475	525	575	625	700	750	825	875	950	1025	1075
21	1000	575	450	450	475	525	575	625	700	750	825	875	950	1025	1075
24	950	575	450	450	475	525	575	650	700	775	825	900	950	1025	1100
27	900	550	450	450	475	525	575	650	700	775	825	900	975	1025	1100
30	850	550	450	450	475	525	575	650	700	775	825	900	975	1025	1100
33	800	550	425	450	475	525	575	650	700	775	850	900	975	1050	1100
36	775	525	425	450	475	525	600	650	725	775	850	900	975	1050	1125
42	675	525	425	450	475	525	600	650	725	775	850	925	975	1050	1125
48	625	500	425	450	475	550	600	650	725	775	850	925	975	1050	1125
54	600	475	425	450	500	550	600	650	725	800	850	925	1000	1050	1125
60	575	450	425	450	500	550	600	675	725	800	850	925	1000	1075	1125
66	575	450	400	450	500	550	600	675	725	800	875	950	1000	1075	1150
72	575	450	400	450	500	550	600	675	750	800	875	950	1025	1075	1150
78	525	450	400	450	500	550	625	675	750	800	875	950	1025	1075	1150
84	475	425	400	450	500	550	625	675	750	825	875	950	1025	1075	1150
90	450	425	400	450	500	550	625	675	750	825	875	950	1025	1100	1150
96	425	425	400	450	500	550	625	675	750	825	875	950	1025	1100	1175

Table 67

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft³
2. AASHTO HS20 live load
3. Embankment installation

Type 2 Bedding

▨ Class I
▨ Class II
▨ Class III
▨ Class IV
▨ Class V
□ Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
12	1150	1225	1275	1350	1425	1500	1550	1625	1700	1750	1825	1900	1975	2050	2125
15	1150	1200	1275	1325	1400	1475	1550	1625	1675	1750	1825	1875	1950	2025	2100
18	1150	1200	1275	1350	1400	1475	1550	1600	1675	1750	1825	1875	1950	2025	2100
21	1150	1200	1275	1350	1400	1475	1550	1625	1675	1750	1825	1900	1975	2025	2100
24	1150	1225	1300	1350	1425	1500	1550	1625	1700	1775	1850	1900	1975	2050	2125
27	1150	1225	1300	1350	1425	1500	1575	1625	1700	1775	1850	1925	1975	2050	2125
30	1150	1225	1300	1350	1425	1500	1575	1650	1700	1775	1850	1925	2000	2050	2125
33	1150	1225	1300	1375	1425	1500	1575	1650	1725	1800	1850	1925	2000	2075	2150
36	1175	1250	1300	1375	1450	1525	1600	1650	1725	1800	1875	1950	2000	2075	2150
42	1175	1250	1325	1375	1450	1525	1600	1675	1725	1800	1875	1950	2025	2075	2150
48	1175	1250	1325	1400	1450	1525	1600	1675	1725	1800	1875	1950	2025	2100	2150
54	1175	1250	1325	1400	1450	1525	1600	1675	1750	1825	1875	1950	2025	2100	2175
60	1200	1250	1325	1400	1475	1550	1600	1675	1750	1825	1900	1975	2050	2100	2175
66	1200	1275	1350	1400	1475	1550	1625	1700	1775	1825	1900	1975	2050	2125	2200
72	1200	1275	1350	1425	1500	1550	1625	1700	1775	1850	1925	2000	2050	2125	2200
78	1200	1275	1350	1425	1500	1575	1625	1700	1775	1850	1925	2000	2050	2125	2200
84	1225	1275	1350	1425	1500	1575	1625	1700	1775	1850	1925	2000	2075	2125	2200
90	1225	1275	1350	1425	1500	1575	1650	1700	1775	1850	1925	2000	2075	2125	2200
96	1225	1300	1350	1425	1500	1575	1650	1700	1775	1850	1925	2000	2075	2150	2200

Table 68

Fill Height Tables are based on:

1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 2 Bedding

▒	Class I	▒	Class IV
▓	Class II	░	Class V
▒	Class III	☐	Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
12	2175	2250	2325	2400	2450	2525	2600	2675	2750	2800	2875	2950	3025	3100	3150
15	2150	2225	2300	2375	2450	2500	2575	2650	2725	2775	2850	2925	3000	3075	3125
18	2150	2225	2300	2375	2450	2500	2575	2650	2725	2775	2850	2925	3000	3050	3125
21	2175	2250	2300	2375	2450	2525	2600	2650	2725	2800	2875	2925	3000	3075	3150
24	2200	2250	2325	2400	2475	2550	2600	2675	2750	2825	2900	2950	3025	3100	3175
27	2200	2275	2325	2400	2475	2550	2625	2675	2750	2825	2900	2975	3025	3100	3175
30	2200	2275	2350	2400	2475	2550	2625	2700	2750	2825	2900	2975	3050	3125	3175
33	2200	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	2975	3050	3125	3200
36	2225	2300	2375	2425	2500	2575	2650	2725	2800	2850	2925	3000	3075	3150	3225
42	2225	2300	2375	2450	2500	2575	2650	2725	2800	2850	2925	3000	3075	3150	3225
48	2225	2300	2375	2450	2525	2575	2650	2725	2800	2875	2950	3000	3075	3150	3225
54	2250	2300	2375	2450	2525	2600	2675	2725	2800	2875	2950	3025	3100	3175	3225
60	2250	2325	2400	2475	2525	2600	2675	2750	2825	2900	2975	3025	3100	3175	3250
66	2275	2325	2400	2475	2550	2625	2700	2775	2825	2900	2975	3050	3125	3200	3275
72	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	3000	3075	3125	3200	3275
78	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	3000	3075	3125	3200	3275
84	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	3000	3075	3125	3200	3275
90	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	3000	3075	3125	3200	3275
96	2275	2350	2425	2500	2575	2625	2700	2775	2850	2925	3000	3075	3125	3200	3275

Table 69

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 3 Bedding

▨ Class I
▨ Class II
▨ Class III
▨ Class IV
▨ Class V
☐ Special Design

	Fill Height (feet)																	
Pipe i.d. (inches)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
12	1175	700	550	550	600	650	725	800	875	950	1050	1125	1200	1300	1375	1475	1550	1650
15	1100	675	525	550	575	650	700	775	875	950	1025	1100	1200	1275	1375	1450	1525	1600
18	1050	650	525	525	575	650	700	775	850	950	1025	1100	1200	1275	1350	1425	1525	1600
21	1000	625	500	525	575	650	700	775	850	950	1025	1100	1200	1275	1350	1425	1525	1600
24	975	600	500	525	575	650	700	775	850	950	1025	1100	1200	1275	1350	1450	1525	1600
27	925	600	500	525	575	650	700	800	875	950	1025	1125	1200	1275	1375	1450	1525	1600
30	875	600	500	525	575	650	725	800	875	950	1050	1125	1200	1300	1375	1450	1525	1625
33	825	575	500	525	575	650	725	800	875	950	1050	1125	1225	1300	1375	1450	1550	1625
36	800	575	500	525	575	650	725	800	875	975	1050	1150	1225	1300	1400	1475	1550	1650
42	700	575	500	525	600	650	725	800	900	975	1050	1150	1225	1325	1400	1475	1575	1650
48	650	550	500	525	600	650	725	825	900	975	1075	1150	1250	1325	1425	1475	1575	1650
54	625	525	500	525	600	675	750	825	900	1000	1075	1150	1250	1350	1425	1500	1575	1675
60	625	500	500	525	600	675	750	825	925	1000	1075	1175	1250	1350	1425	1500	1600	1700
66	600	500	475	550	600	675	750	850	925	1000	1100	1175	1275	1350	1450	1525	1600	1700
72	600	500	475	550	600	675	775	850	925	1025	1100	1200	1275	1375	1450	1525	1625	1725
78	550	500	475	550	600	675	775	850	925	1025	1100	1200	1300	1375	1475	1550	1625	1725
84	525	500	475	550	625	700	775	850	950	1025	1100	1200	1300	1375	1475	1550	1625	1725
90	475	500	475	550	625	700	775	850	950	1025	1125	1200	1300	1375	1475	1550	1625	1725
96	450	475	475	550	625	700	775	850	950	1025	1125	1200	1300	1375	1475	1550	1650	1725

Table 70

Fill Height Tables are based on:

1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 3 Bedding

▨ Class I
▨ Class II
▨ Class III
▨ Class IV
▨ Class V
☐ Special Design

Pipe i.d. (inches)	Fill Height (feet)																
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
12	1725	1825	1900	2000	2075	2175	2250	2350	2425	2525	2600	2700	2800	2875	2975	3050	3150
15	1700	1775	1875	1950	2050	2125	2225	2300	2400	2475	2575	2675	2750	2850	2925	3025	3100
18	1675	1775	1850	1950	2025	2125	2200	2300	2375	2475	2550	2650	2725	2825	2900	3000	3075
21	1675	1775	1850	1950	2025	2125	2200	2300	2375	2475	2550	2650	2750	2825	2900	3000	3075
24	1700	1775	1875	1950	2025	2125	2200	2300	2375	2475	2550	2650	2725	2825	2900	3000	3075
27	1700	1775	1875	1950	2050	2125	2225	2300	2400	2475	2575	2650	2750	2825	2925	3000	3100
30	1700	1800	1875	1975	2050	2150	2225	2325	2400	2500	2575	2675	2750	2850	2950	3025	3125
33	1725	1800	1900	1975	2075	2150	2250	2350	2425	2525	2600	2700	2775	2875	2950	3050	3125
36	1750	1825	1925	2000	2100	2175	2275	2350	2450	2525	2625	2725	2800	2900	2975	3075	3150
42	1750	1825	1925	2000	2100	2175	2275	2375	2450	2550	2625	2725	2800	2900	3000	3075	3175
48	1750	1850	1925	2025	2100	2200	2275	2375	2475	2550	2650	2725	2825	2900	3000	3100	3175
54	1750	1850	1950	2025	2125	2200	2300	2400	2475	2575	2650	2750	2850	2925	3025	3100	3200
60	1775	1875	1950	2050	2125	2225	2325	2400	2500	2575	2675	2775	2850	2950	3025	3125	3225
66	1800	1875	1975	2050	2150	2250	2325	2425	2525	2600	2700	2775	2875	2975	3050	3150	3250
72	1800	1900	2000	2075	2175	2250	2350	2450	2525	2625	2725	2800	2900	3000	3075	3175	3250
78	1800	1900	2000	2075	2175	2250	2350	2450	2525	2625	2725	2800	2900	3000	3075	3175	3250
84	1800	1900	2000	2075	2175	2275	2350	2450	2525	2625	2725	2800	2900	3000	3075	3175	3275
90	1825	1900	2000	2075	2175	2275	2350	2450	2550	2625	2725	2800	2900	3000	3075	3175	3275
96	1825	1900	2000	2100	2175	2275	2350	2450	2550	2625	2725	2800	2900	3000	3075	3175	3275

Table 71

Fill Height Tables are based on:

1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

Type 4 Bedding

Class I
Class II
Class III
Class IV
Class V
Special Design

	Fill Height (feet)														
Pipe i.d. (inches)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
12	1550	950	750	800	875	950	1075	1200	1325	1450	1575	1700	1825	1950	2100
15	1450	900	750	775	850	950	1050	1150	1275	1400	1525	1650	1775	1900	2050
18	1375	850	725	750	825	925	1050	1150	1250	1375	1500	1625	1750	1900	2025
21	1325	850	700	750	825	925	1025	1125	1250	1375	1500	1600	1750	1875	2000
24	1275	825	700	725	800	900	1000	1125	1250	1350	1475	1600	1725	1850	1975
27	1150	800	700	725	800	900	1000	1125	1225	1350	1475	1600	1725	1850	1975
30	1025	800	675	725	800	900	1000	1100	1225	1350	1475	1600	1700	1850	1950
33	925	775	675	725	800	900	1000	1100	1225	1350	1475	1600	1700	1825	1950
36	850	750	675	725	800	900	1000	1100	1225	1350	1450	1575	1700	1825	1950
42	750	750	650	725	800	900	1000	1100	1225	1350	1450	1575	1700	1825	1950
48	700	675	650	725	800	900	1000	1100	1225	1350	1450	1575	1700	1825	1950
54	675	625	650	725	800	900	1000	1100	1225	1350	1450	1575	1700	1825	1950
60	675	600	650	700	800	900	1000	1100	1225	1350	1450	1575	1700	1825	1950
66	650	575	625	700	800	900	1000	1125	1225	1350	1475	1600	1700	1825	1950
72	650	575	600	700	800	900	1000	1125	1225	1350	1475	1600	1700	1825	1950
78	625	575	600	700	800	900	1000	1125	1250	1350	1475	1600	1700	1825	1950
84	575	575	600	700	800	900	1025	1125	1250	1350	1475	1600	1725	1850	1950
90	550	575	600	700	800	900	1025	1125	1250	1375	1475	1600	1725	1850	1950
96	525	575	600	700	800	925	1025	1150	1250	1375	1500	1600	1725	1850	1975

Table 72

Class I
Class II
Class III
Class IV
Class V
Special Design

Type 4 Bedding

Fill Height Tables are based on:
1. A soil weight of 120 lbs/ft^3
2. AASHTO HS20 live load
3. Embankment installation

	Fill Height (feet)							
Pipe i.d. (inches)	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
12	2225	2350	2500	2625	2775	2700	3025	3175
15	2175	2300	2450	2550	2700	2825	2950	3100
18	2125	2275	2400	2525	2650	2775	2900	3050
21	2125	2250	2375	2500	2625	2750	2875	3000
24	2100	2225	2350	2475	2600	2725	2850	2975
27	2075	2200	2325	2450	2575	2700	2825	2950
30	2075	2200	2325	2450	2575	2700	2825	2950
33	2075	2200	2325	2450	2575	2700	2825	2950
36	2075	2200	2325	2450	2550	2675	2800	2925
42	2050	2175	2300	2425	2550	2675	2800	2925
48	2050	2175	2300	2425	2550	2675	2800	2925
54	2050	2175	2300	2425	2550	2675	2800	2925
60	2050	2175	2300	2425	2550	2650	2775	2900
66	2050	2175	2300	2425	2550	2675	2775	2900
72	2050	2175	2300	2425	2550	2675	2800	2900
78	2075	2175	2300	2425	2550	2675	2800	2900
84	2075	2200	2300	2425	2550	2675	2800	2925
90	2075	2200	2325	2425	2550	2675	2800	2925
96	2075	2200	2325	2450	2550	2675	2800	2925

Figures

Figure 1

CULVERT CAPACITY
10 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 120-INCH CIRCULAR

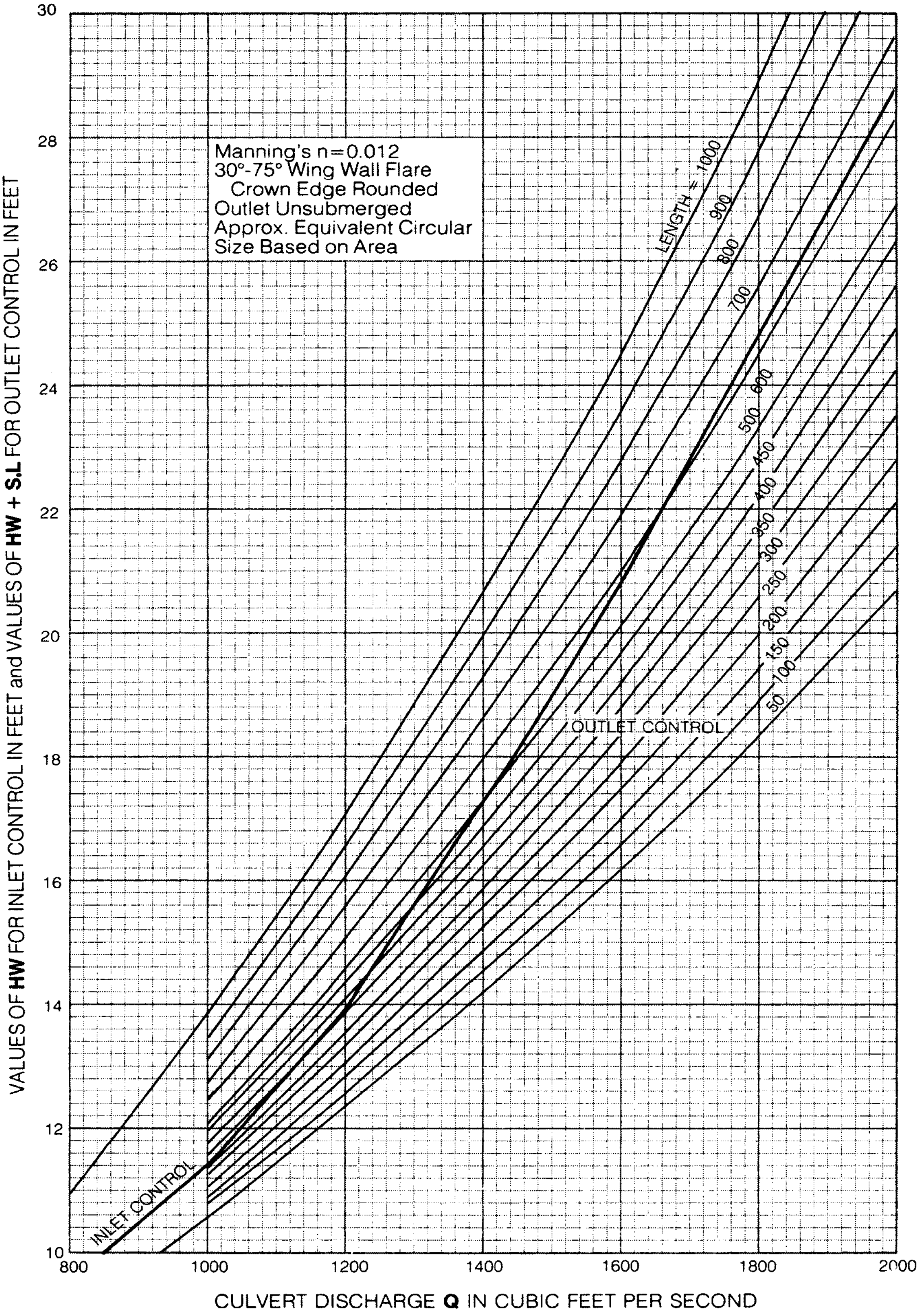


Figure 2

FLOW FOR CIRCULAR PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.010

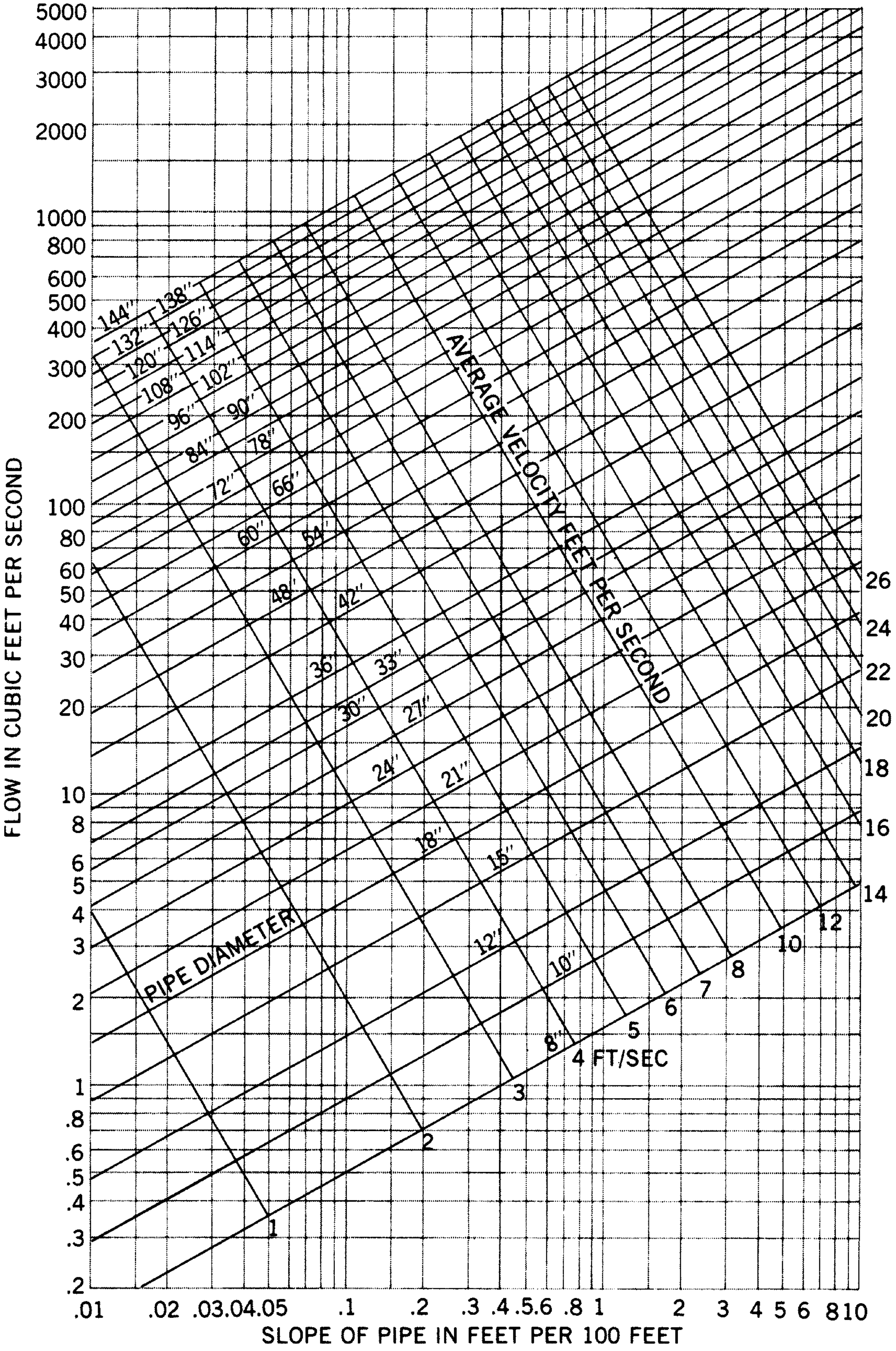


Figure 3

FLOW FOR CIRCULAR PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.011

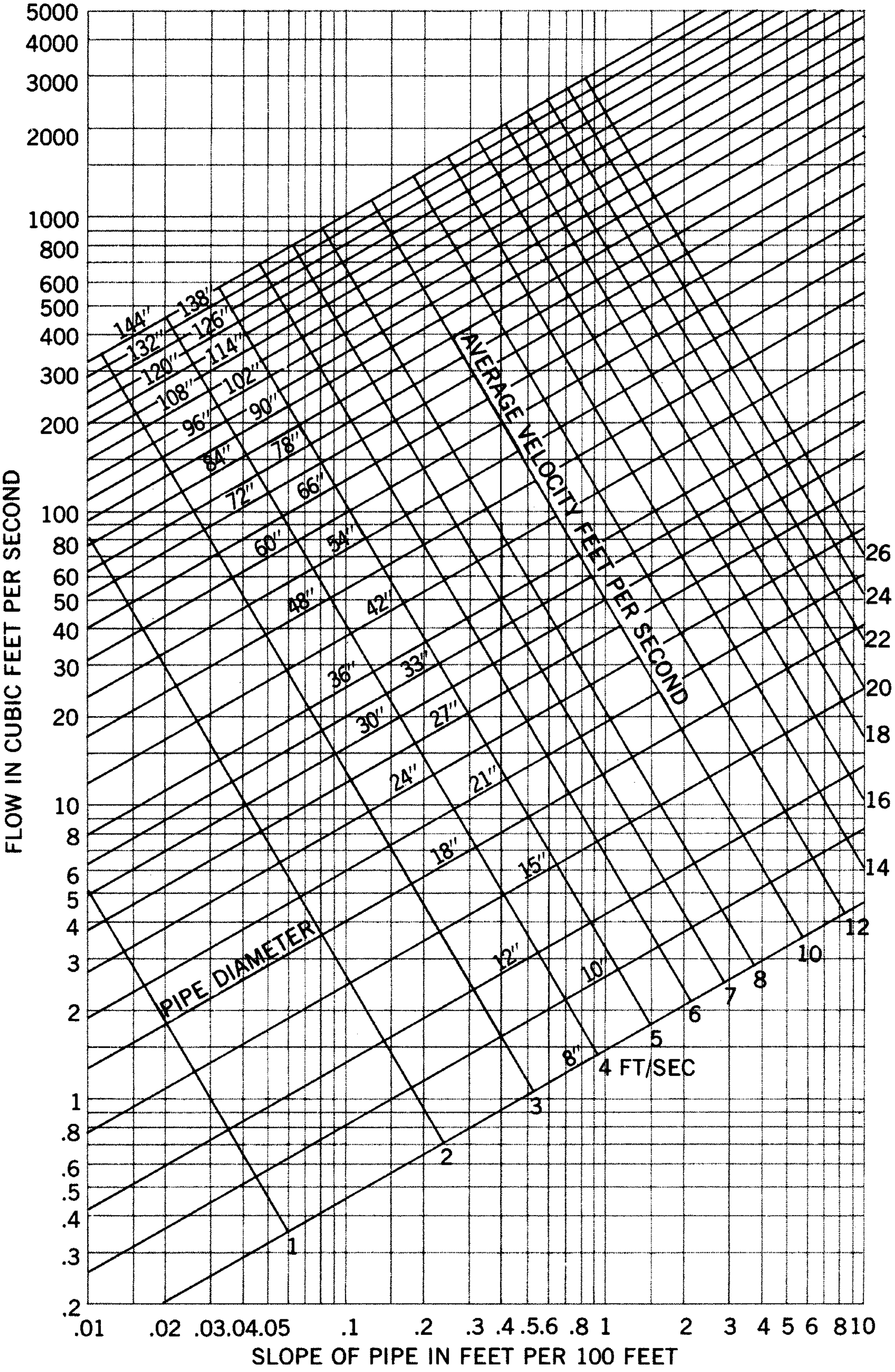


Figure 4

FLOW FOR CIRCULAR PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.012

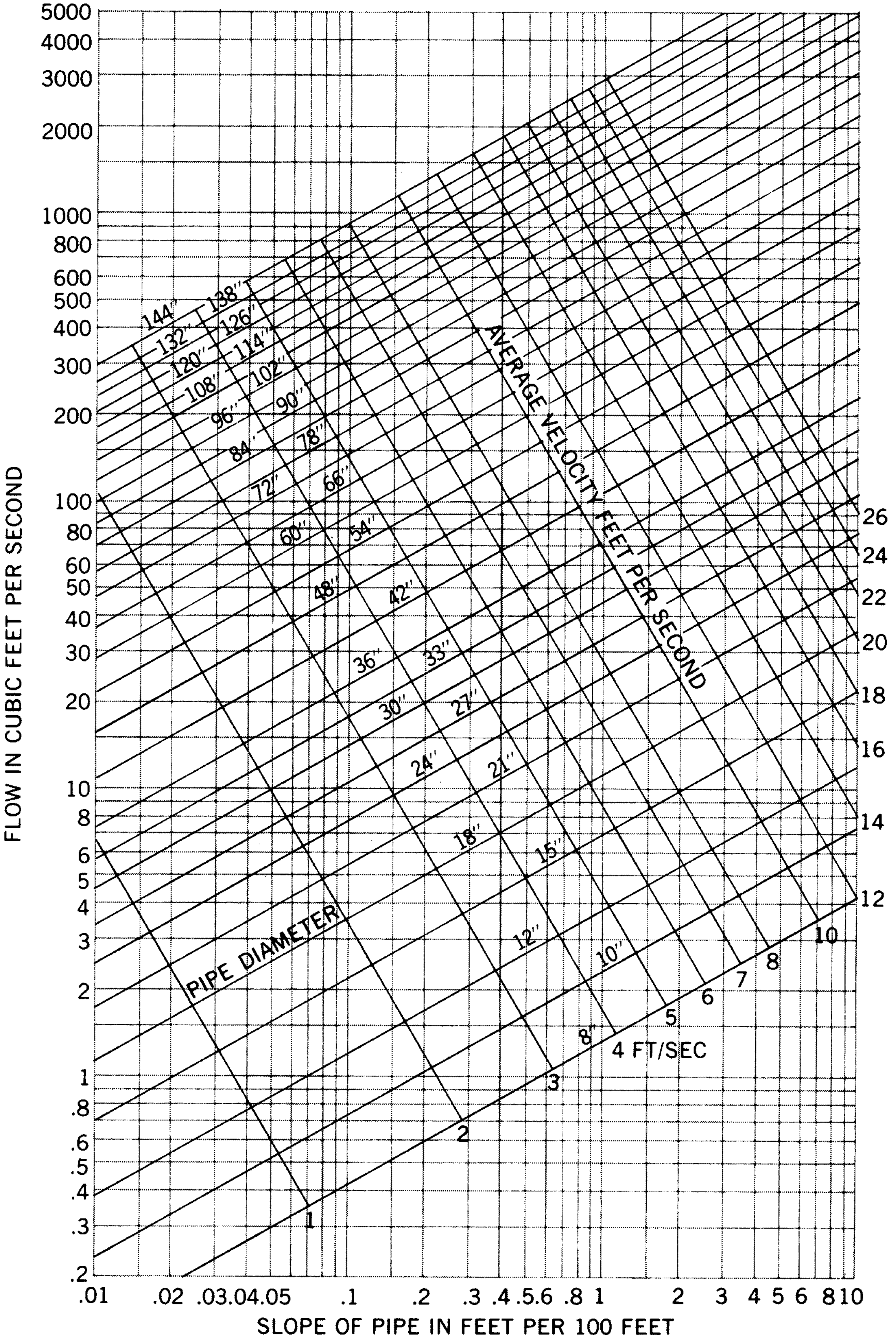


Figure 5

FLOW FOR CIRCULAR PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.013

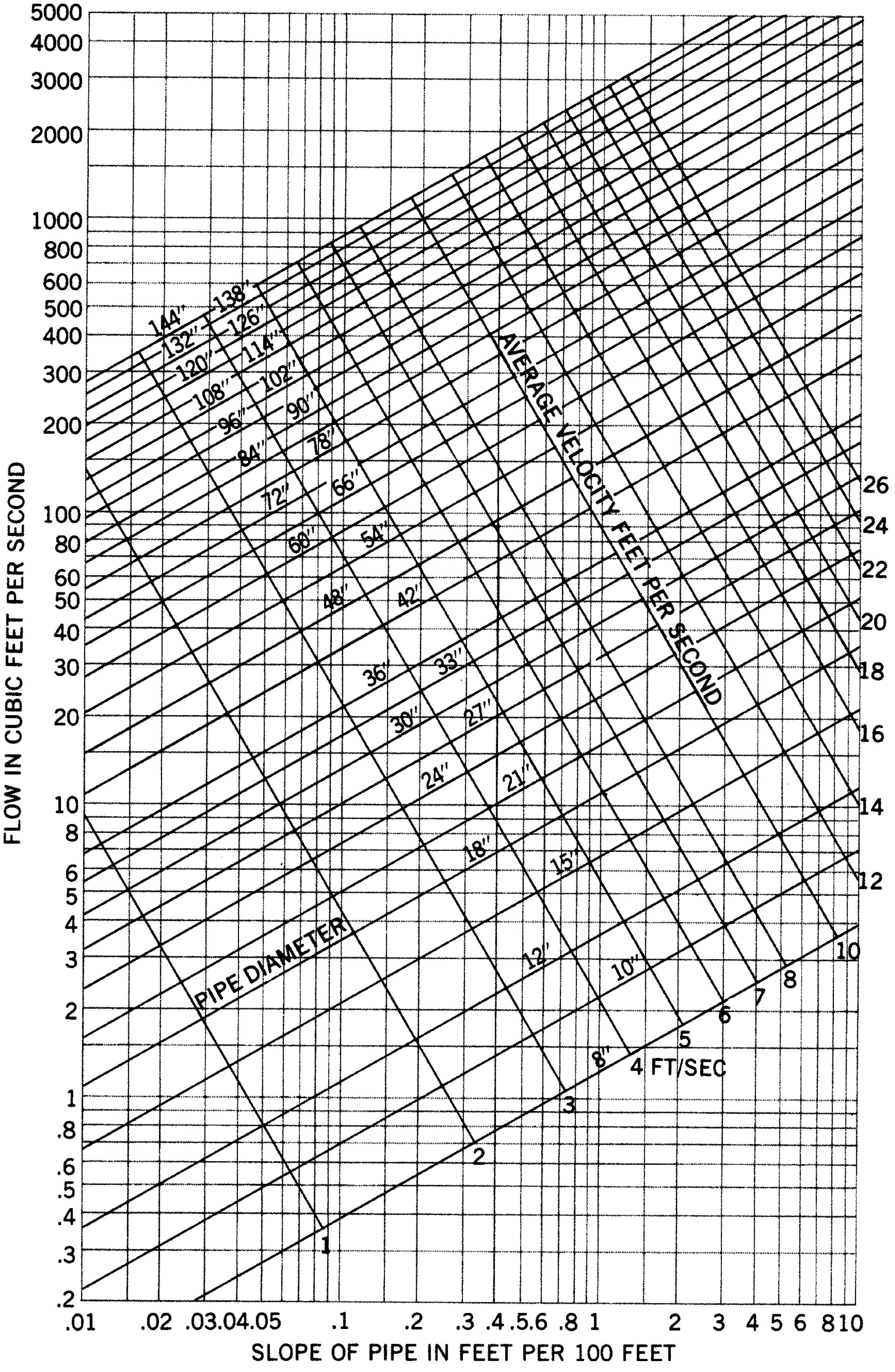


Figure 6

FLOW FOR HORIZONTAL ELLIPTICAL PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.010

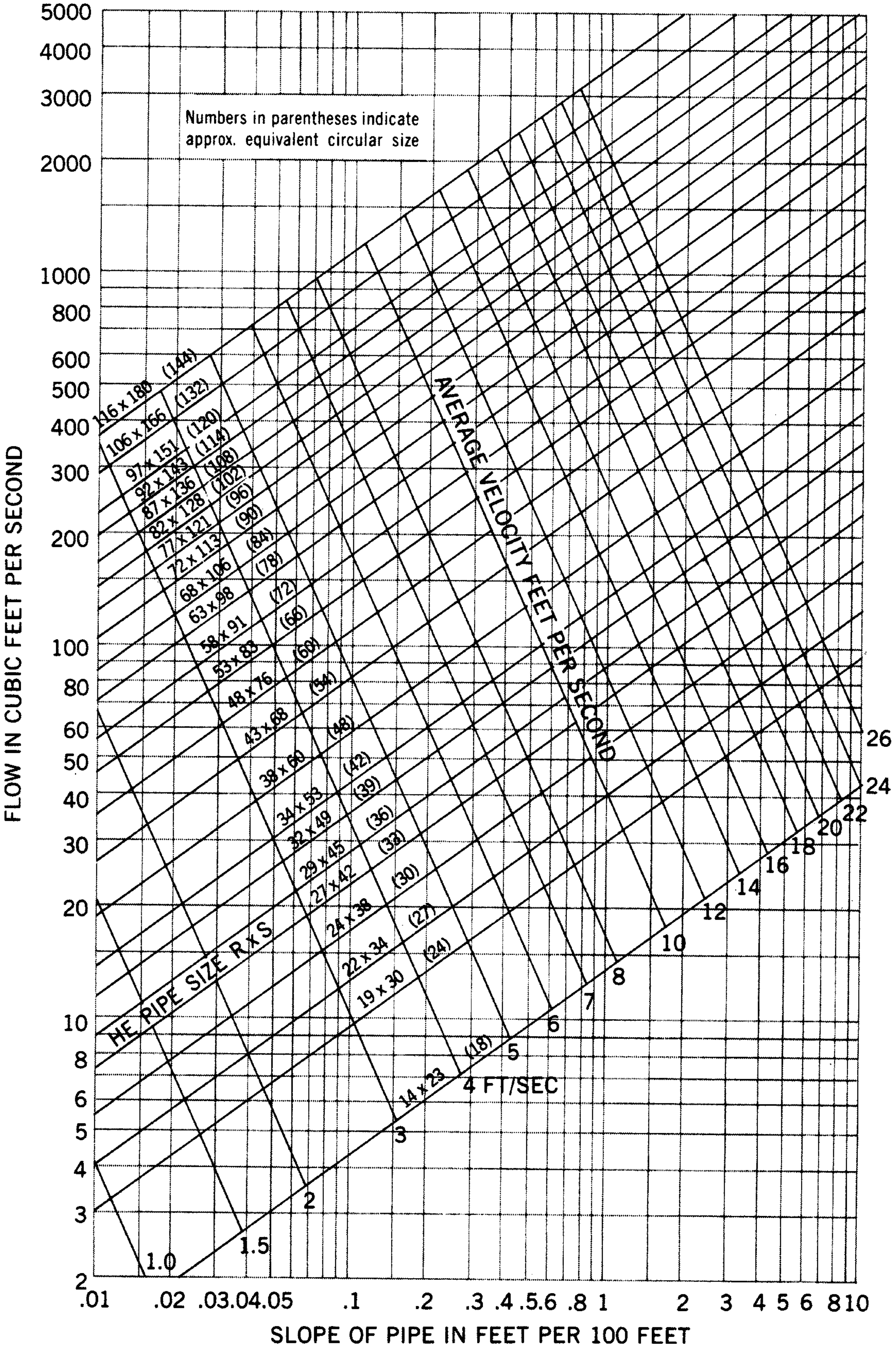


Figure 7

FLOW FOR HORIZONTAL ELLIPTICAL PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.011

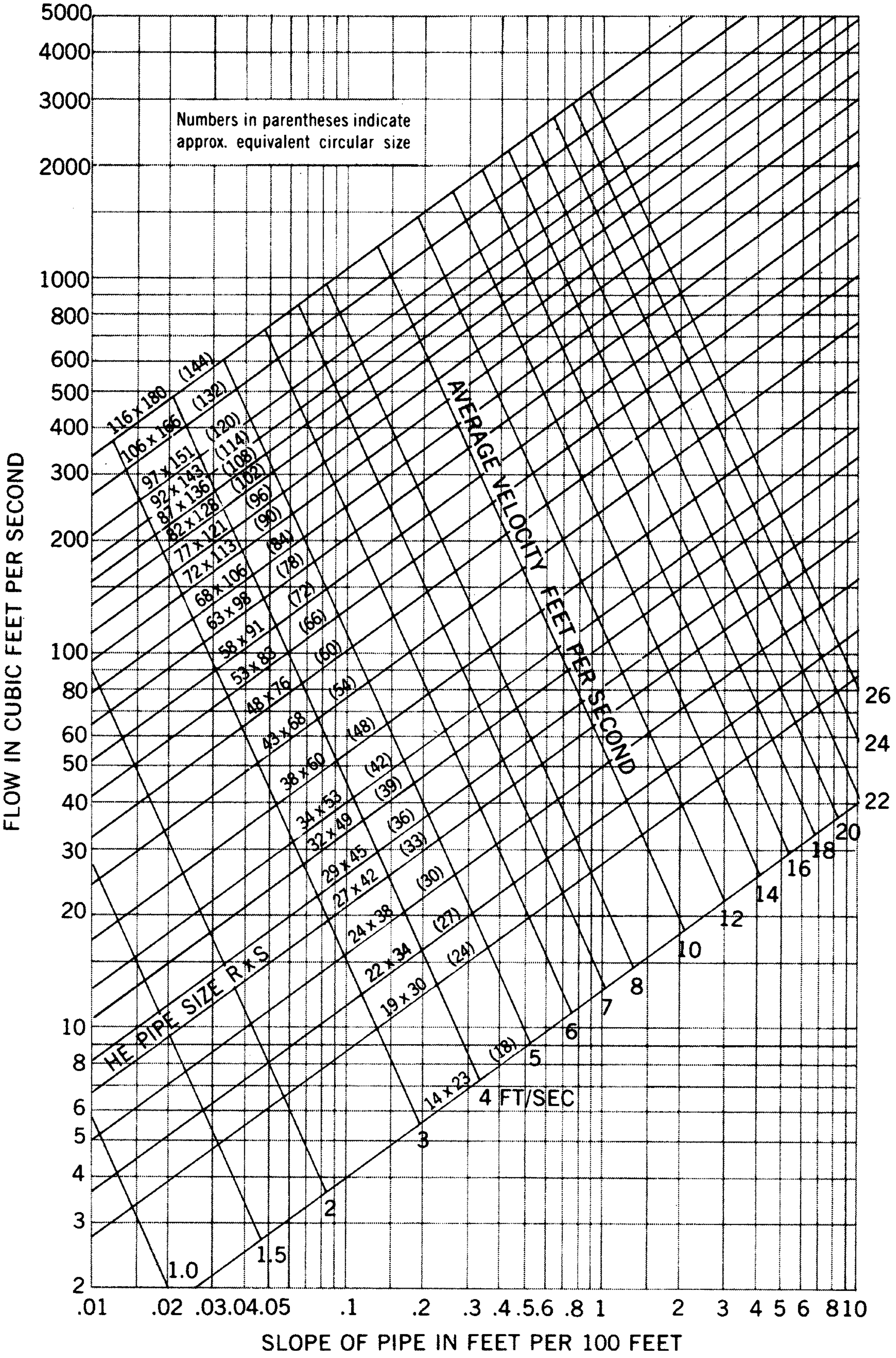


Figure 8

FLOW FOR HORIZONTAL ELLIPTICAL PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.012

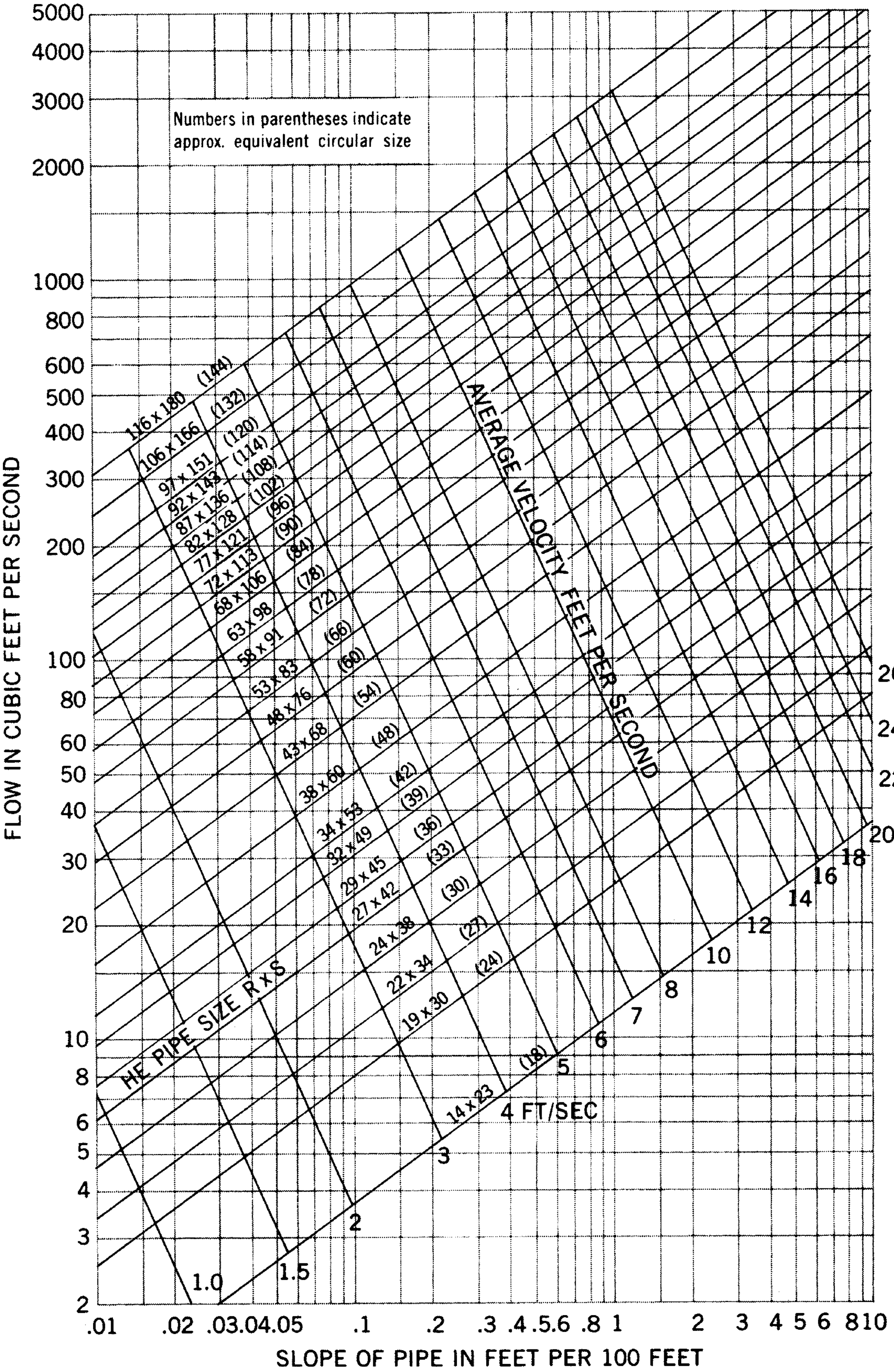


Figure 9

FLOW FOR HORIZONTAL ELLIPTICAL PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.013

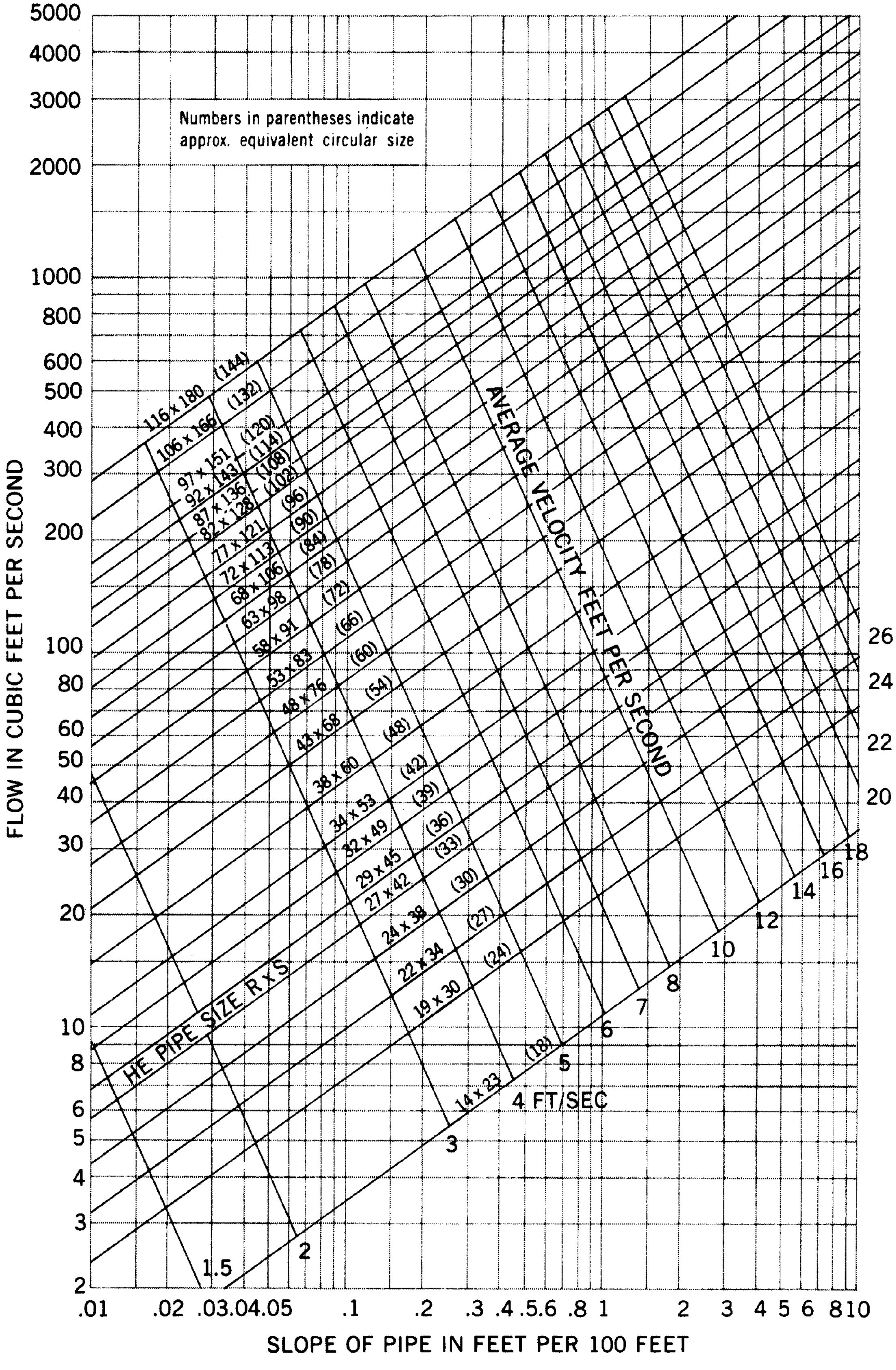


Figure 10

FLOW FOR VERTICAL ELLIPTICAL PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.010

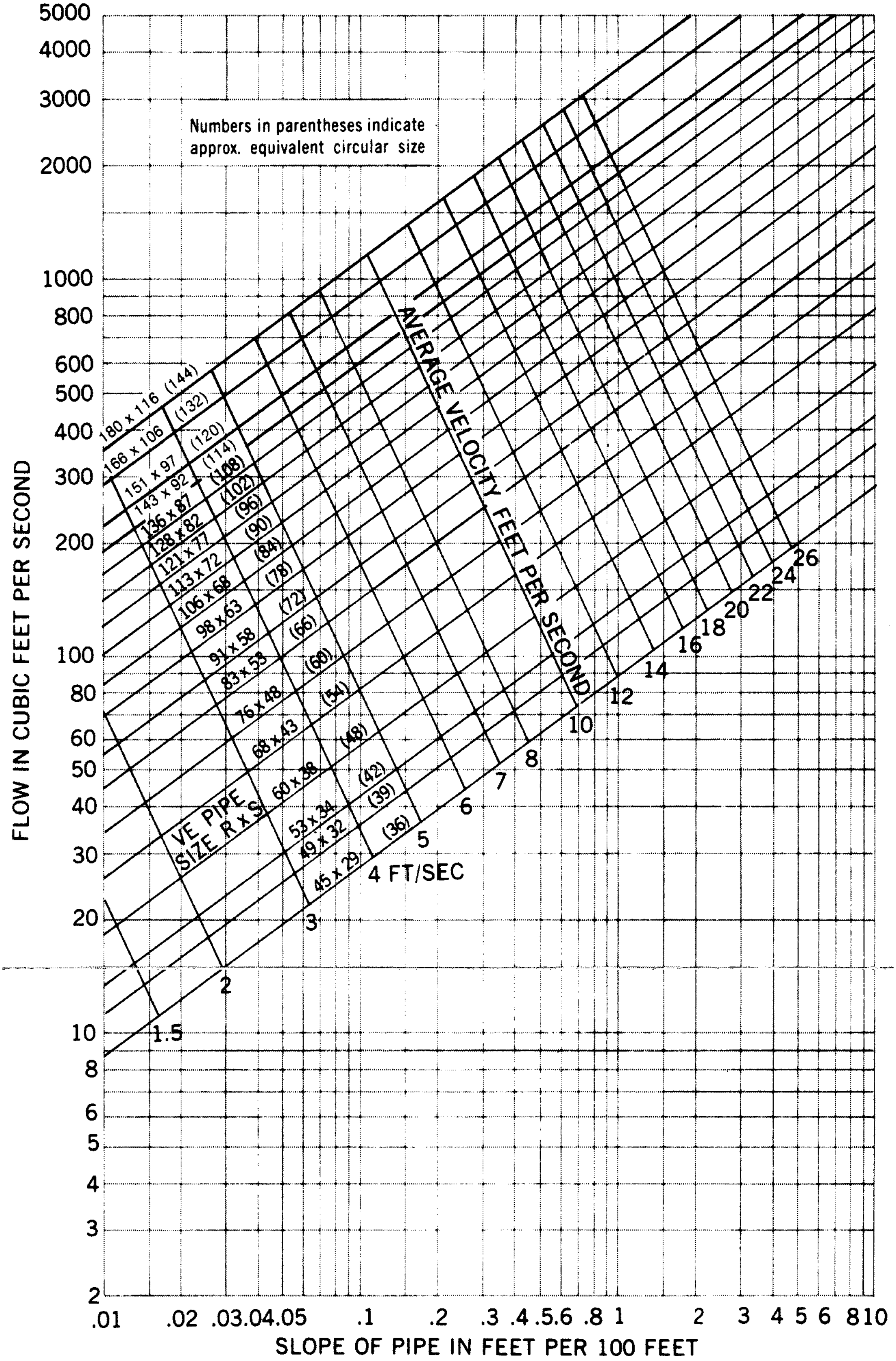


Figure 11

FLOW FOR VERTICAL ELLIPTICAL PIPE FLOWING FULL
BASED ON MANNING'S EQUATION n=0.011

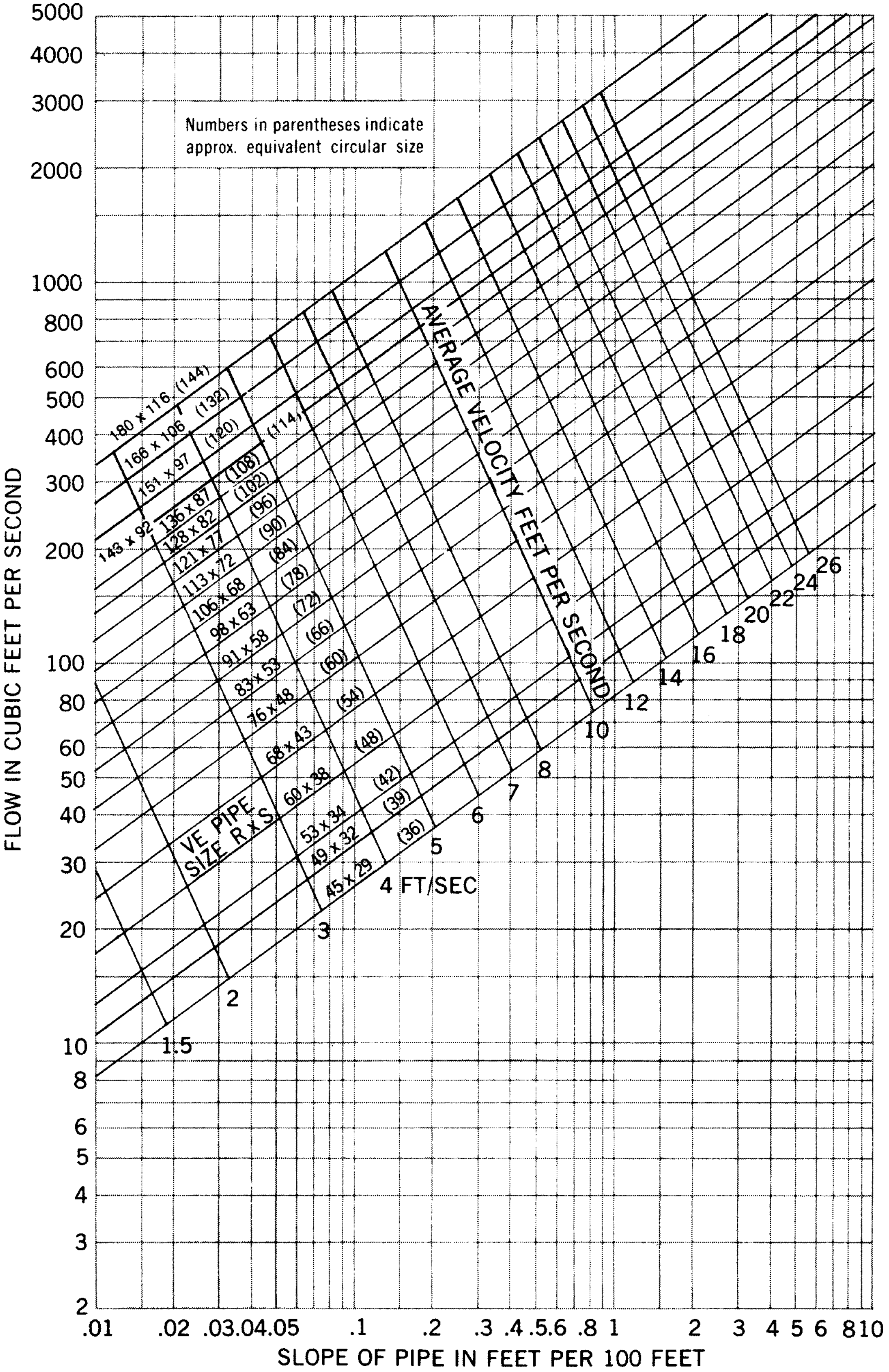
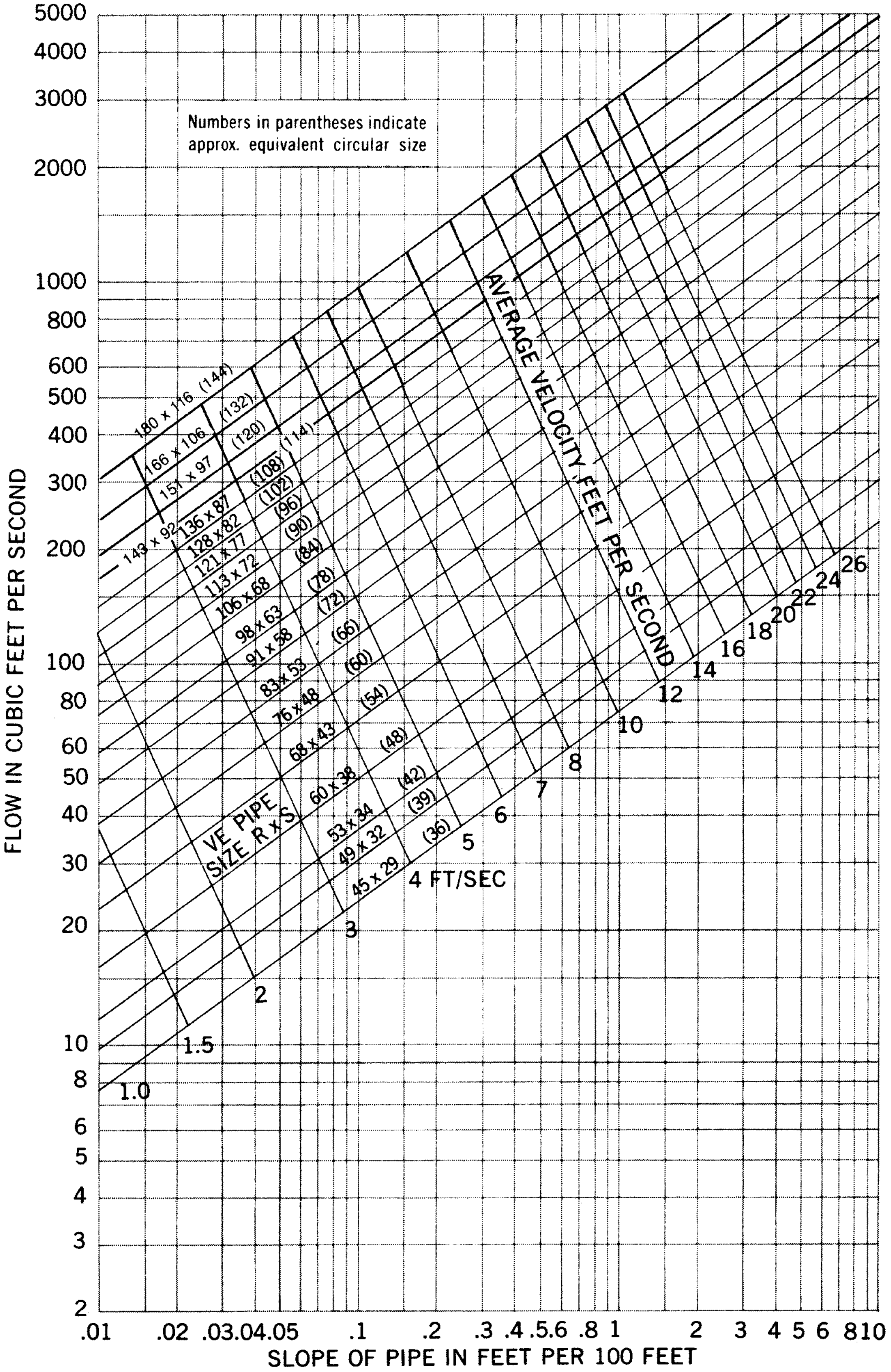


Figure 12

FLOW FOR VERTICAL ELLIPTICAL PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.012



Numbers in parentheses indicate approx. equivalent circular size

Figure 13

FLOW FOR VERTICAL ELLIPTICAL PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.013

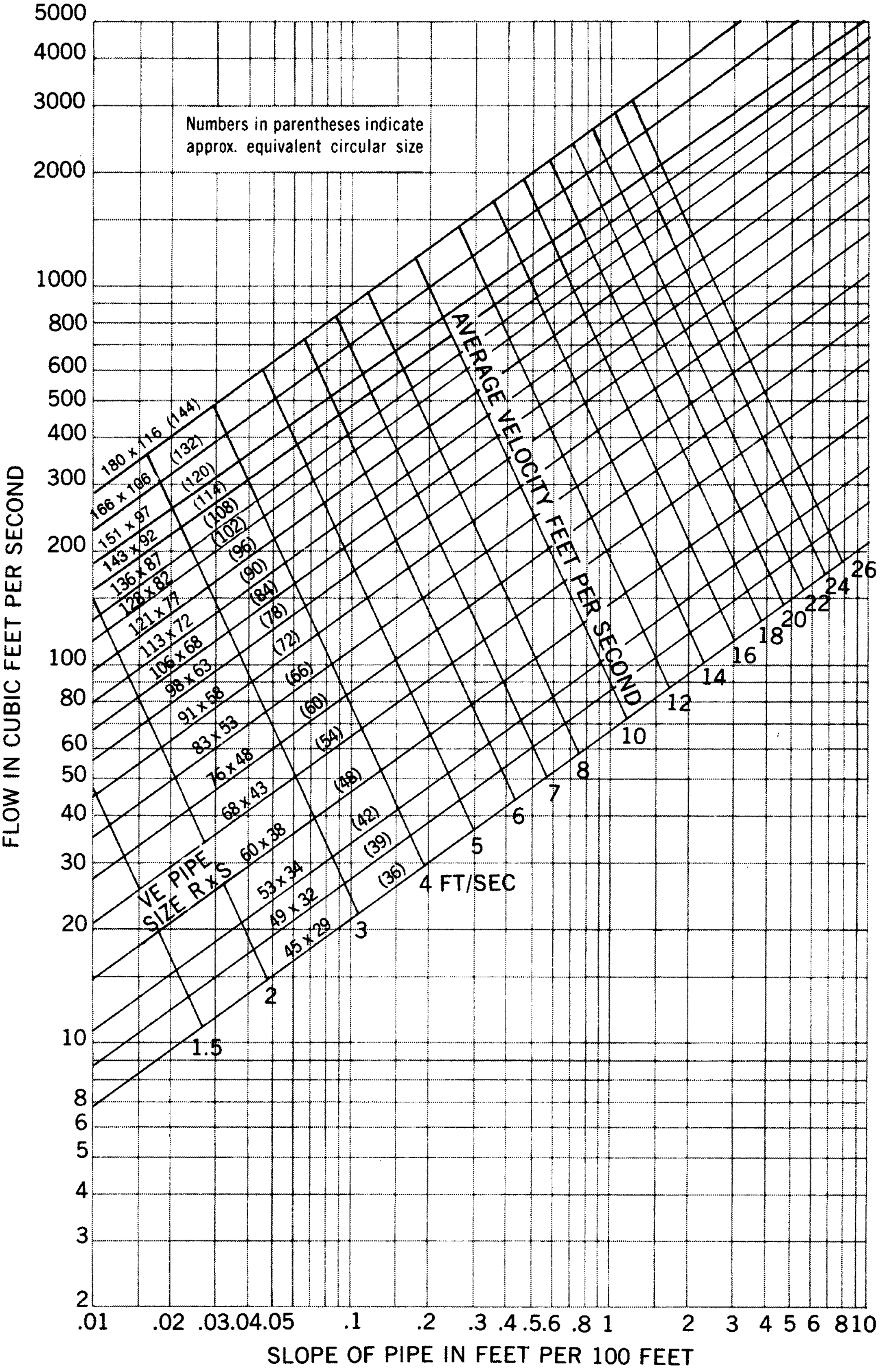
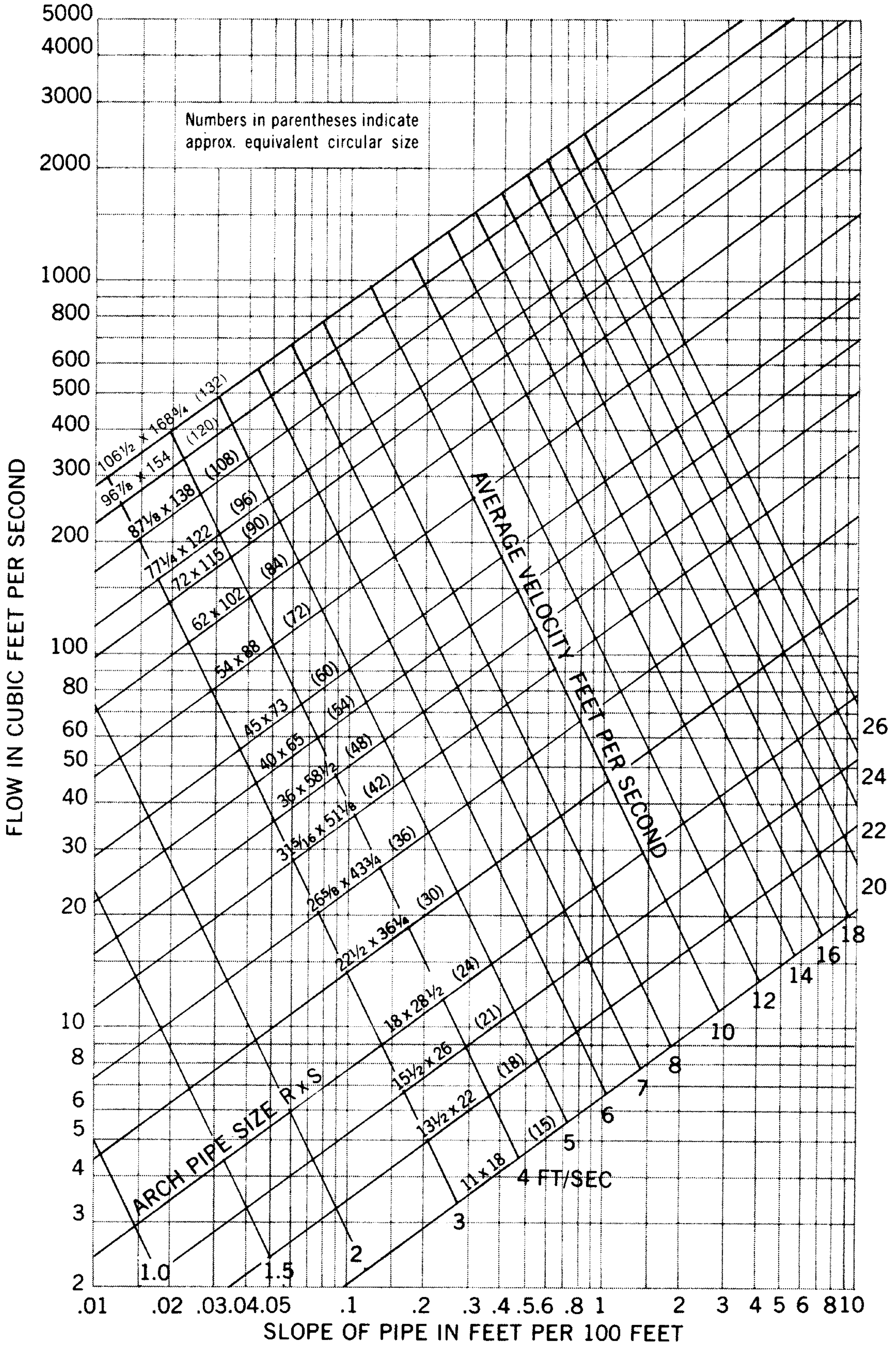


Figure 14



FLOW FOR ARCH PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.010

Figure 15

FLOW FOR ARCH PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.011

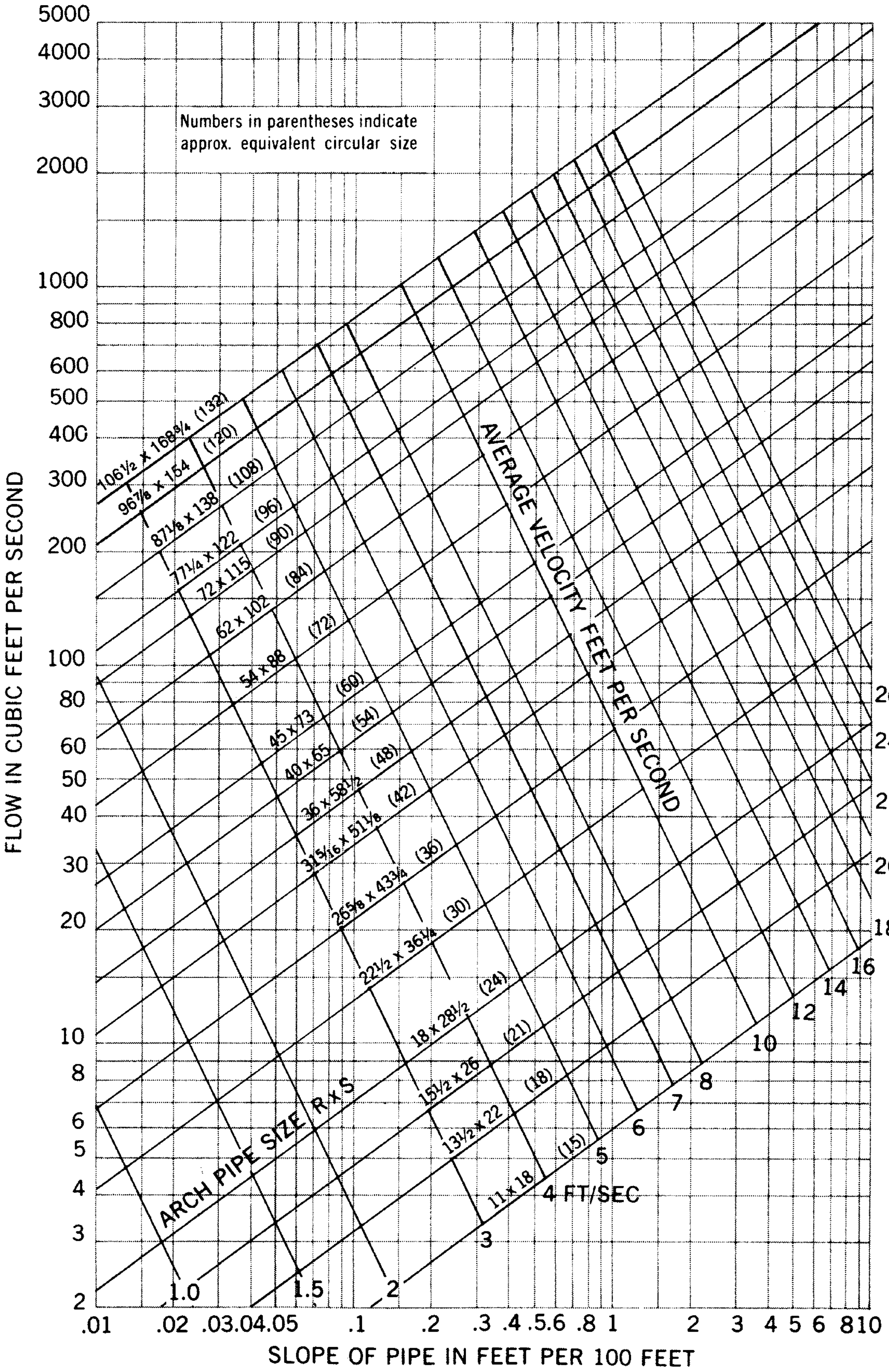


Figure 16

FLOW FOR ARCH PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n 0.012

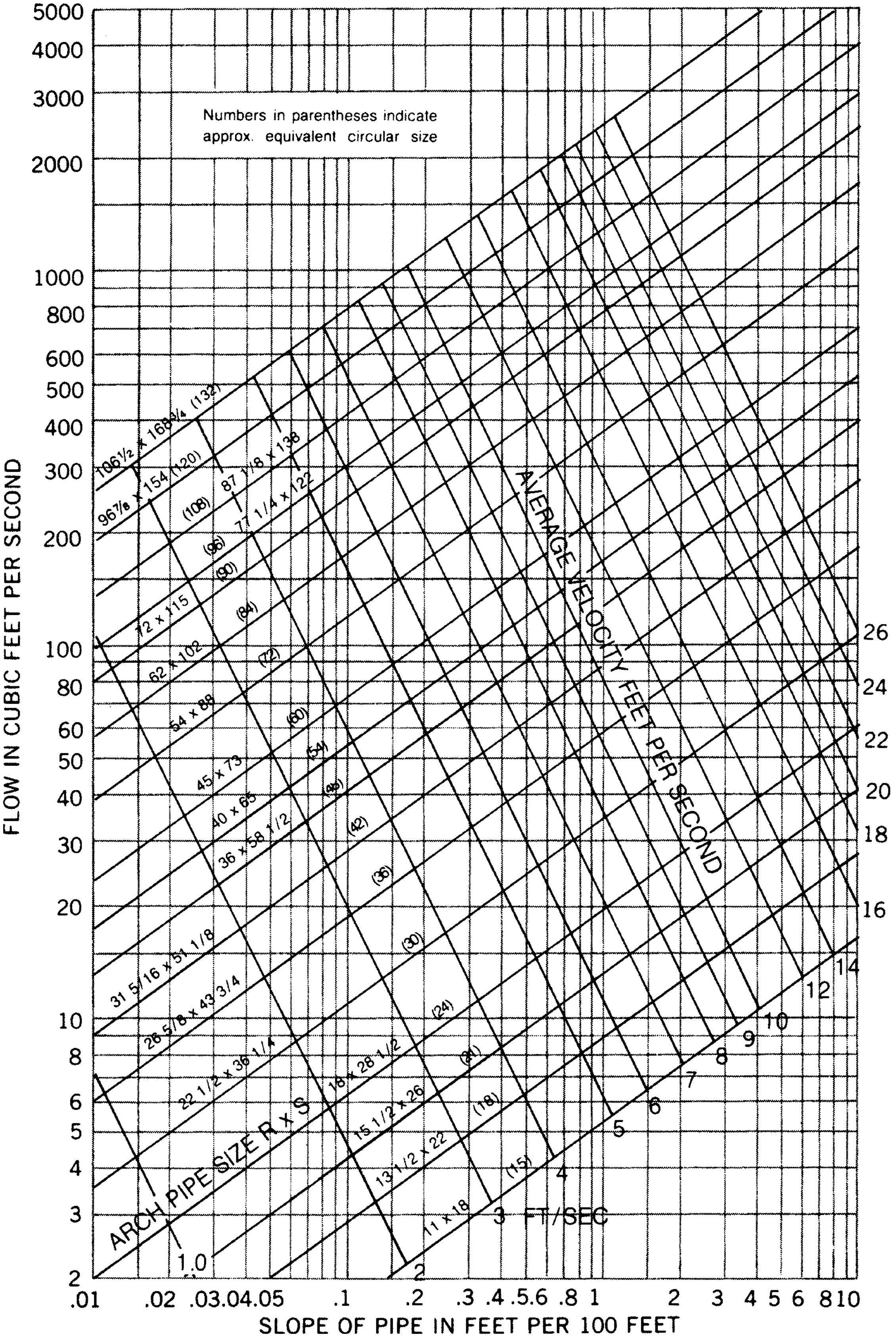


Figure 17

FLOW FOR ARCH PIPE FLOWING FULL

BASED ON MANNING'S EQUATION n=0.013

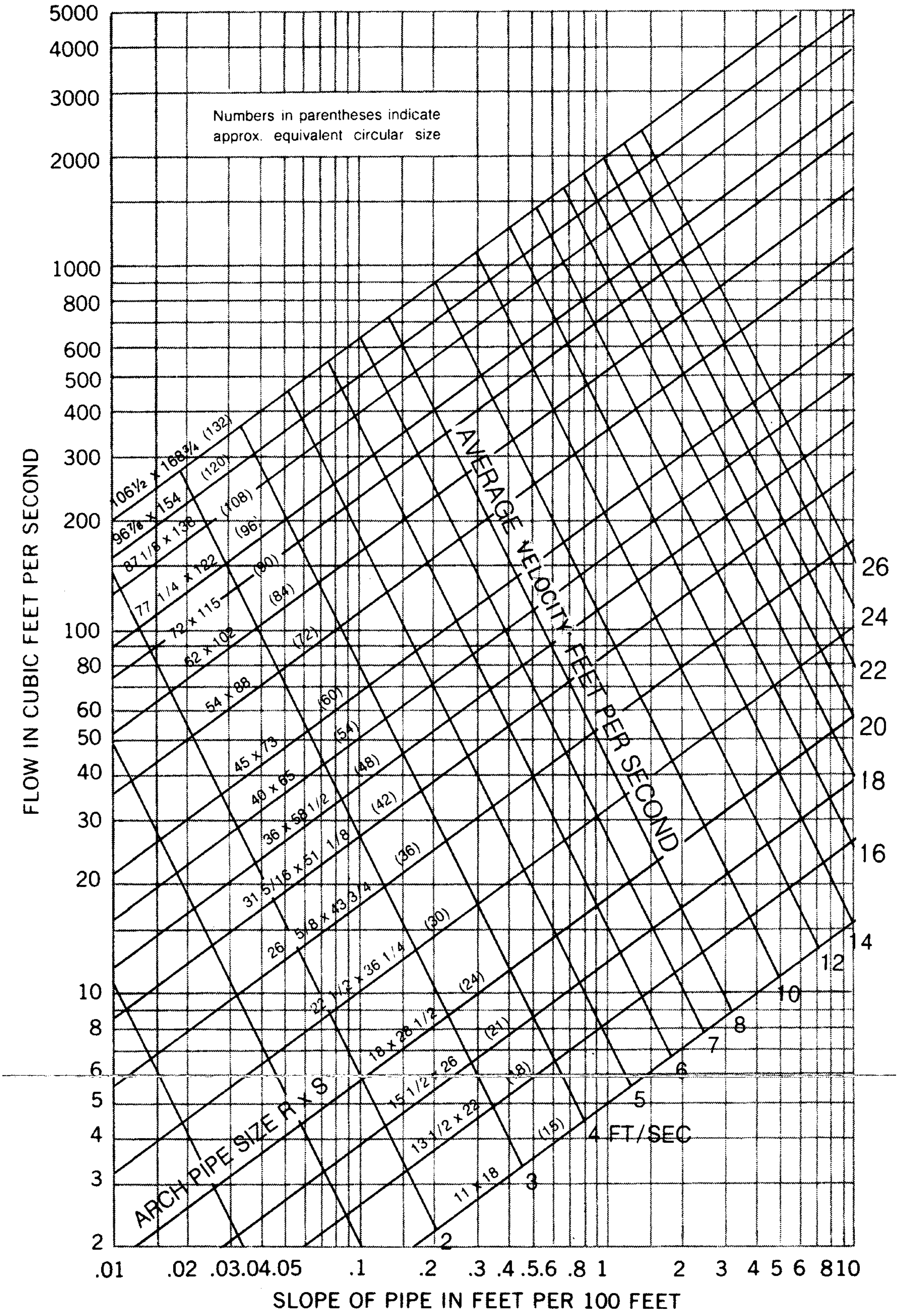


Figure 18.1

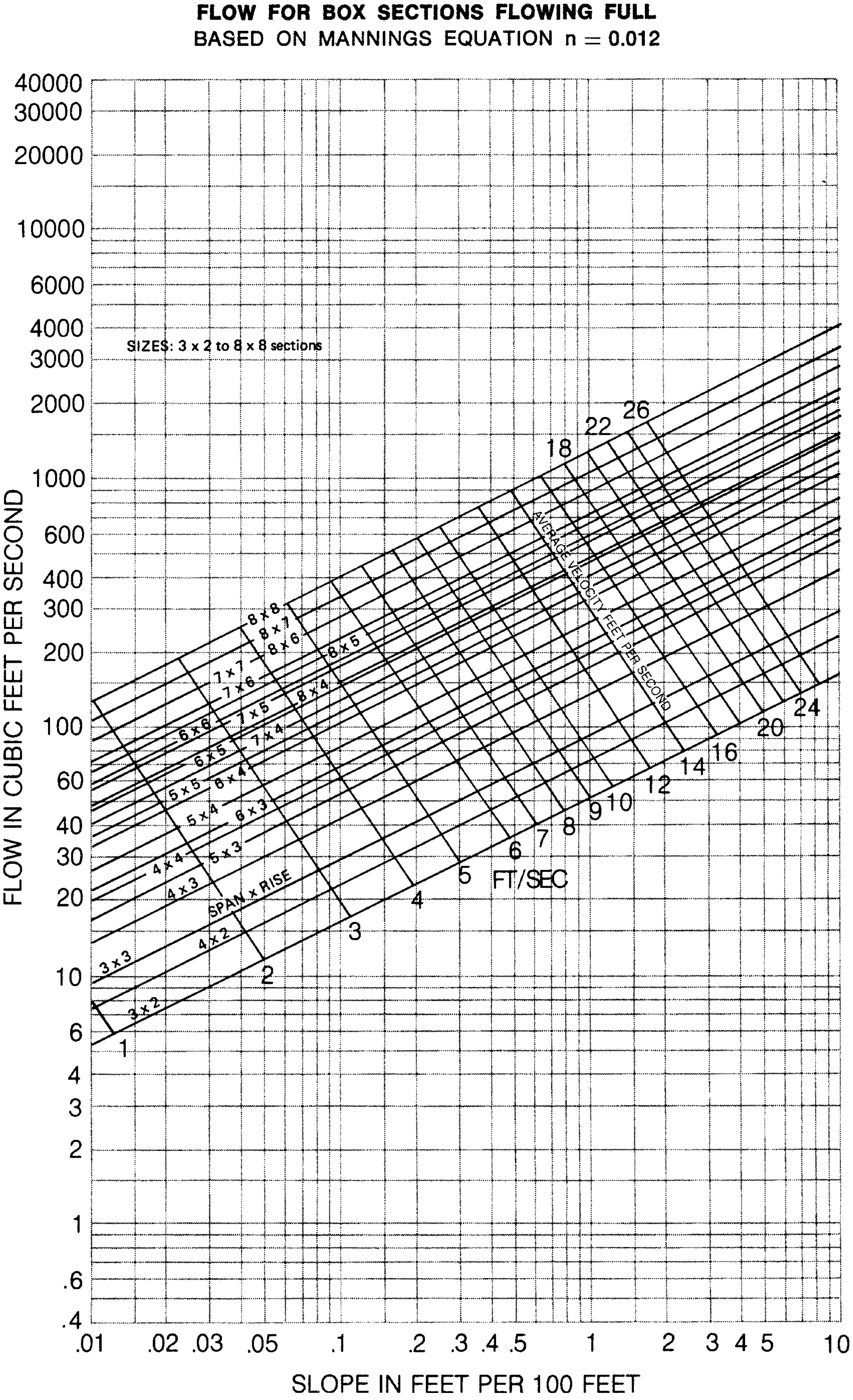

FLOW FOR BOX SECTIONS FLOWING FULL
BASED ON MANNINGS EQUATION n = 0.012
SIZES: 3 x 2 to 8 x 8 sections
FLOW IN CUBIC FEET PER SECOND
SLOPE IN FEET PER 100 FEET
40000
30000
20000
10000
6000
4000
3000
2000
1000
600
400
300
200
100
60
40
30
20
10
6
4
3
2
1
.6
.4
.01
.02
.03
.05
.1
.2
.3
.4
.5
1
2
3
4
5
10
8 x 8
8 x 7
8 x 6
8 x 5
8 x 4
7 x 7
7 x 6
7 x 5
7 x 4
6 x 6
6 x 5
6 x 4
6 x 3
5 x 5
5 x 4
5 x 3
4 x 4
4 x 3
4 x 2
3 x 3
3 x 2
SPAN x RISE
AVERAGE VELOCITY FEET PER SECOND
1
2
3
4
5
6
7
8
9
10
12
14
16
18
20
22
24
26
FT/SEC

Figure 18.2

FLOW FOR BOX SECTIONS FLOWING FULL
BASED ON MANNINGS EQUATION n = 0.012

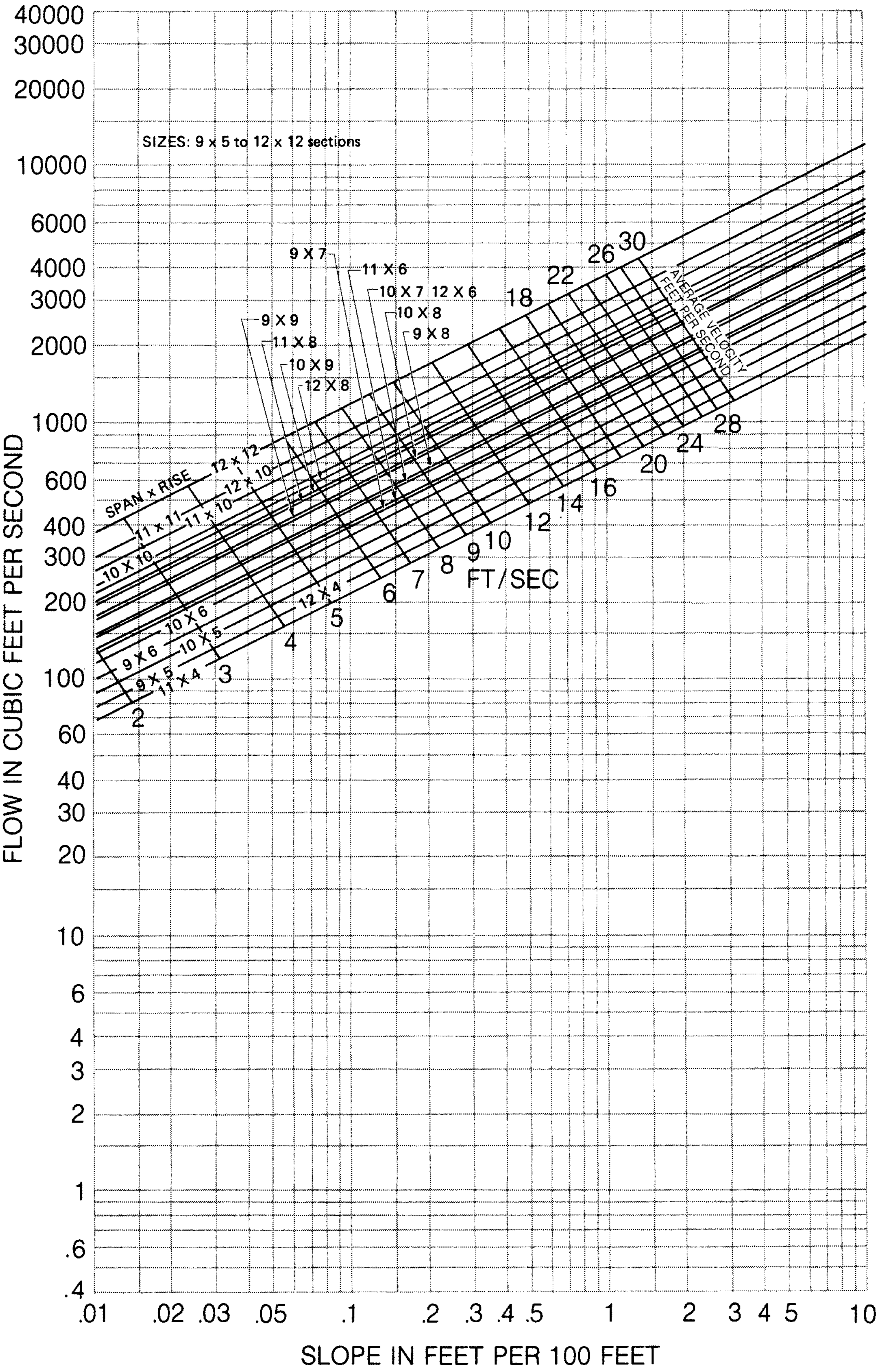


Figure 19.1

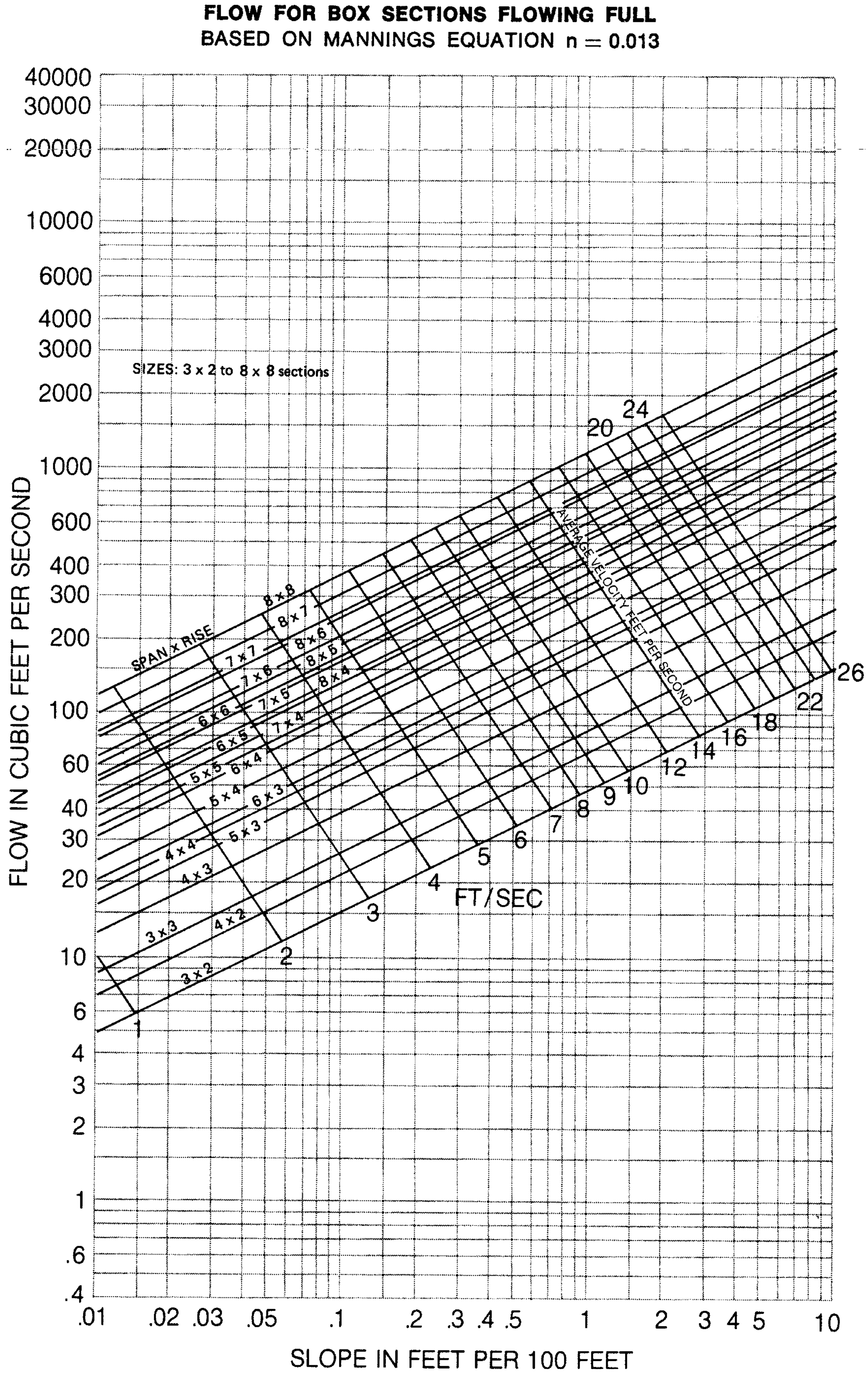

FLOW FOR BOX SECTIONS FLOWING FULL
BASED ON MANNINGS EQUATION n = 0.013
SIZES: 3 x 2 to 8 x 8 sections
SPAN X RISE
8 x 8
8 x 7
7 x 7
8 x 6
7 x 6
8 x 5
8 x 4
6 x 6
7 x 5
6 x 5
7 x 4
5 x 5
6 x 4
5 x 4
6 x 3
4 x 4
5 x 3
4 x 3
3 x 3
4 x 2
3 x 2
AVERAGE VELOCITY FEET PER SECOND
1
2
3
4
5
6
7
8
9
10
12
14
16
18
20
22
24
26
FT/SEC
FLOW IN CUBIC FEET PER SECOND
40000
30000
20000
10000
6000
4000
3000
2000
1000
600
400
300
200
100
60
40
30
20
10
6
4
3
2
1
.6
.4
.01
.02
.03
.05
.1
.2
.3
.4
.5
1
2
3
4
5
10
SLOPE IN FEET PER 100 FEET

Figure 19.2

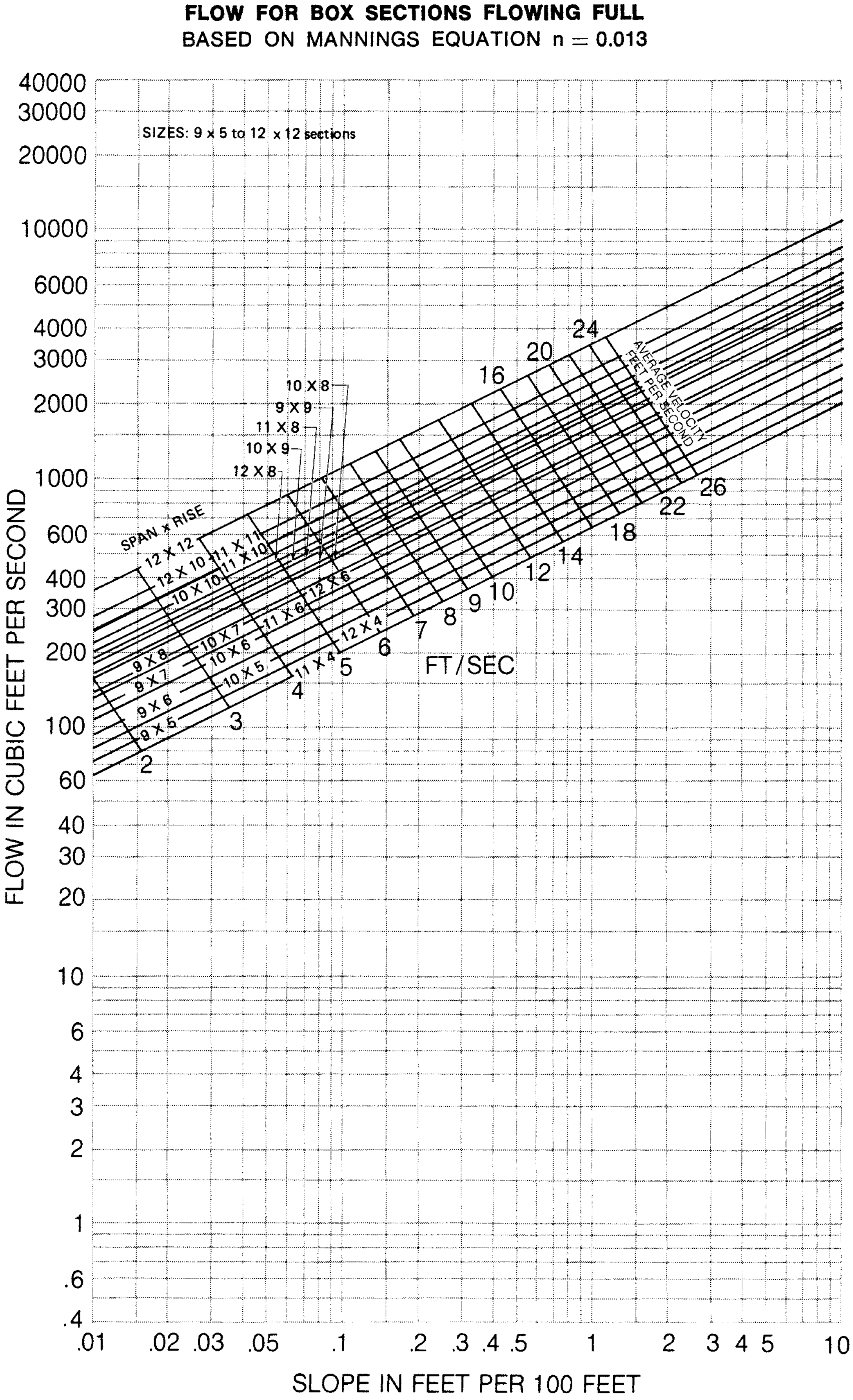

FLOW FOR BOX SECTIONS FLOWING FULL
BASED ON MANNINGS EQUATION n = 0.013
SIZES: 9 x 5 to 12 x 12 sections
SPAN x RISE
12 X 12
12 X 10
11 X 11
11 X 10
10 X 10
10 X 8
9 X 9
11 X 8
10 X 9
12 X 8
12 X 6
11 X 6
10 X 7
10 X 6
10 X 5
12 X 4
11 X 4
9 X 8
9 X 7
9 X 6
9 X 5
2
3
4
5
6
7
8
9
10
12
14
16
18
20
22
24
26
FT/SEC
AVERAGE VELOCITY FEET PER SECOND
40000
30000
20000
10000
6000
4000
3000
2000
1000
600
400
300
200
100
60
40
30
20
10
6
4
3
2
1
.6
.4
FLOW IN CUBIC FEET PER SECOND
.01
.02
.03
.05
.1
.2
.3
.4
.5
1
2
3
4
5
10
SLOPE IN FEET PER 100 FEET

Figure 20

RELATIVE VELOCITY AND FLOW IN CIRCULAR PIPE FOR ANY DEPTH OF FLOW

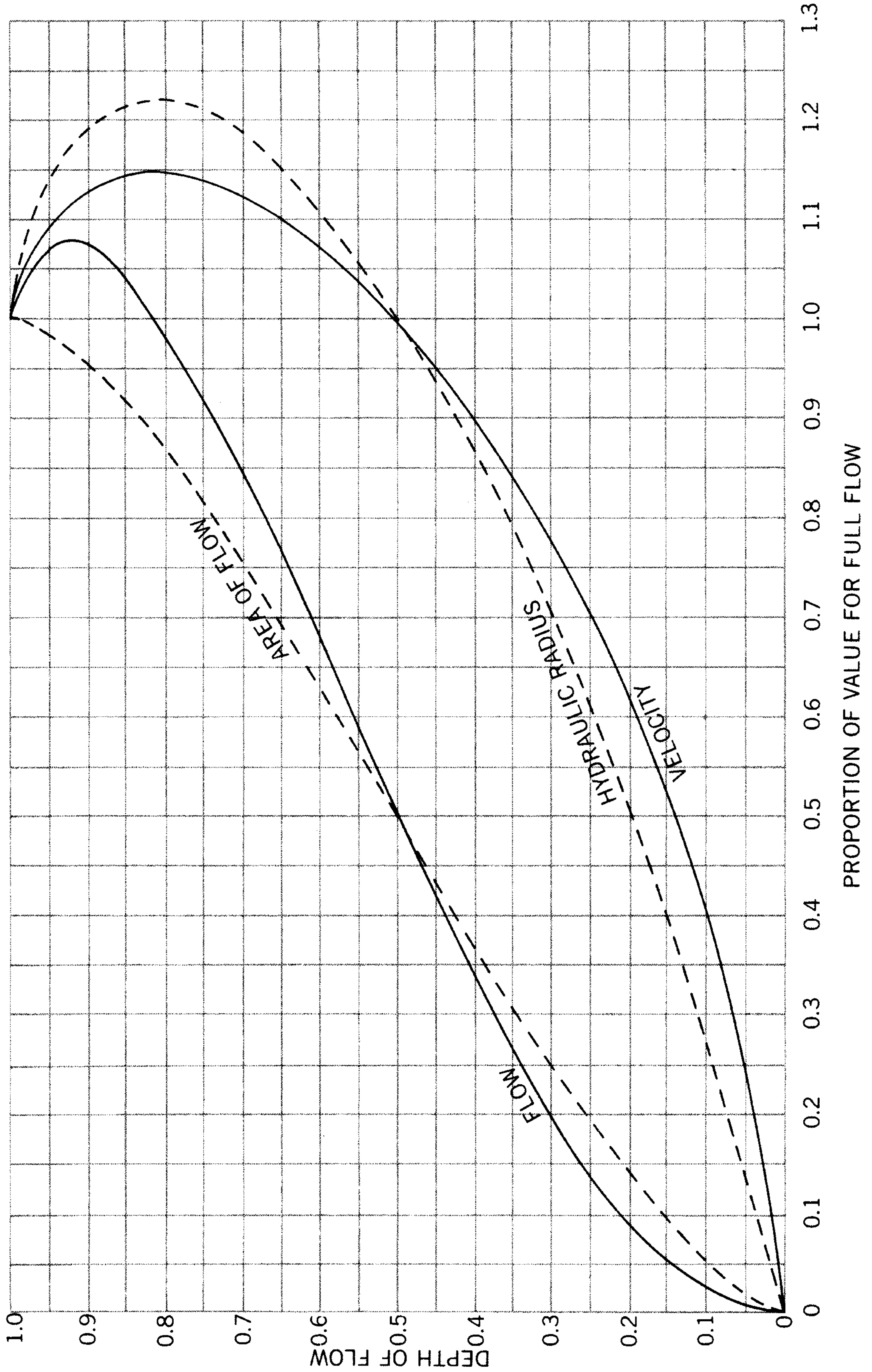


Figure 21

RELATIVE VELOCITY AND FLOW IN
HORIZONTAL ELLIPTICAL PIPE FOR ANY DEPTH OF FLOW

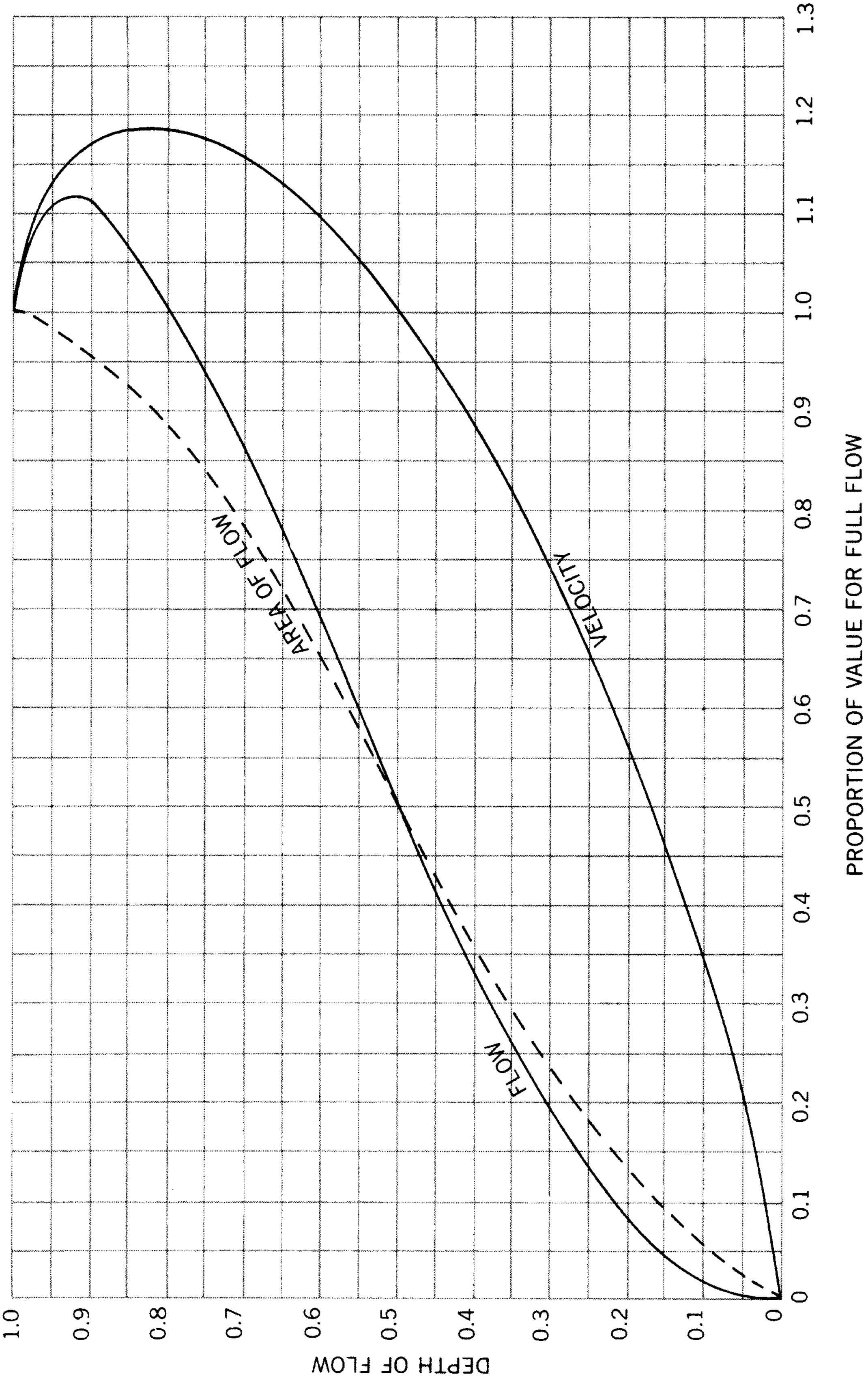


Figure 22

RELATIVE VELOCITY AND FLOW IN VERTICAL ELLIPTICAL PIPE FOR ANY DEPTH OF FLOW

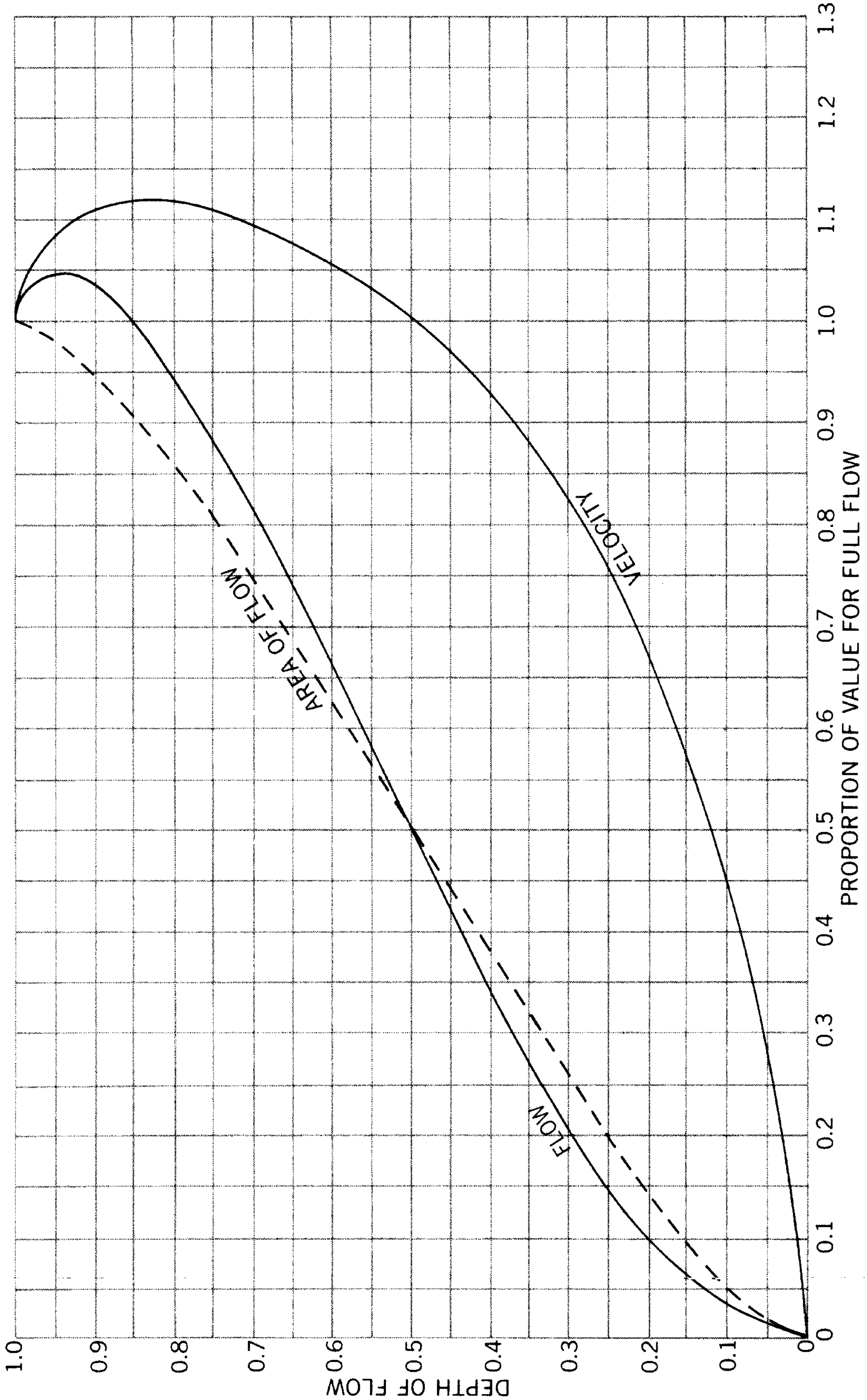


Figure 23

RELATIVE VELOCITY AND FLOW IN ARCH PIPE FOR ANY DEPTH OF FLOW

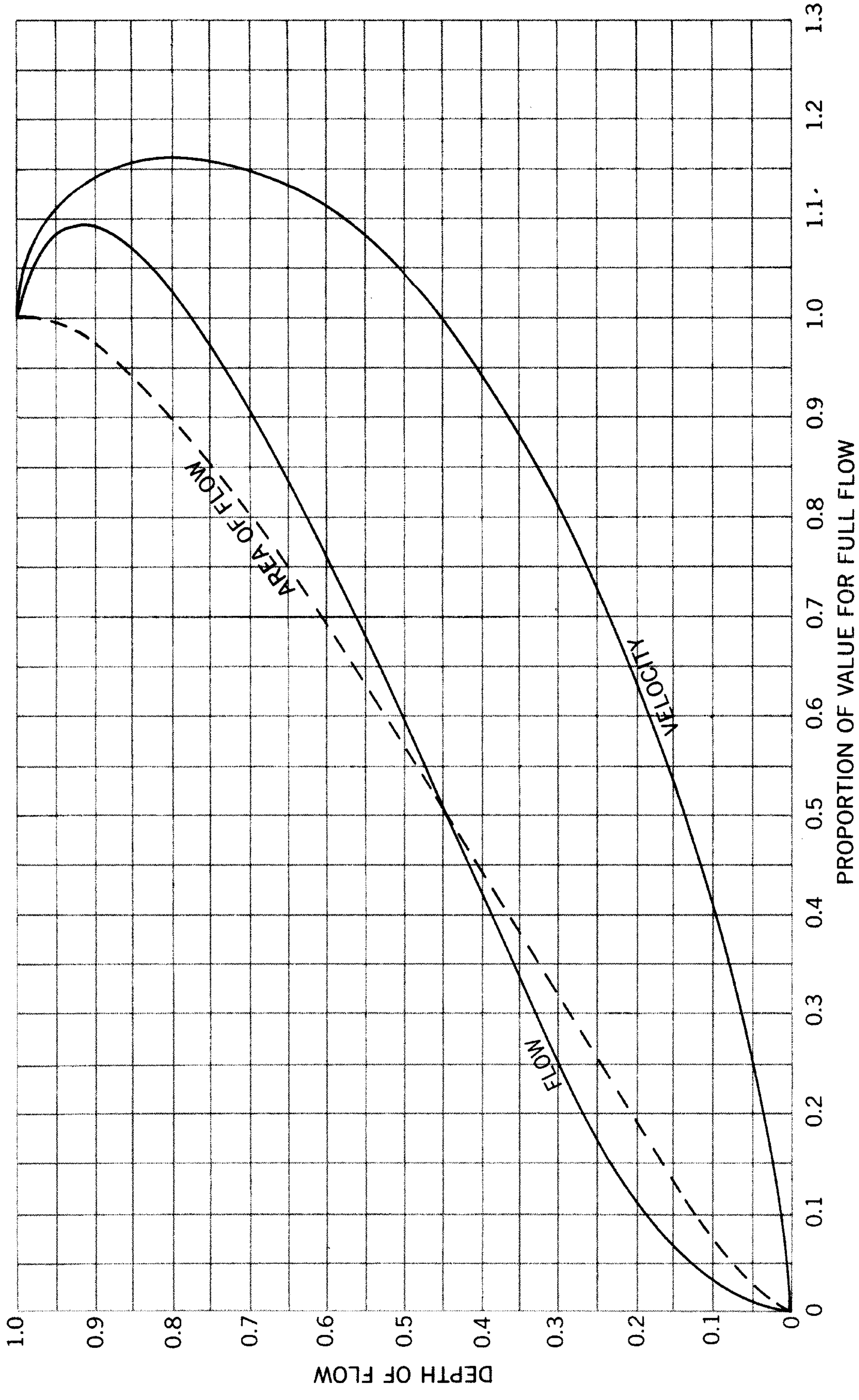


Figure 24.1

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

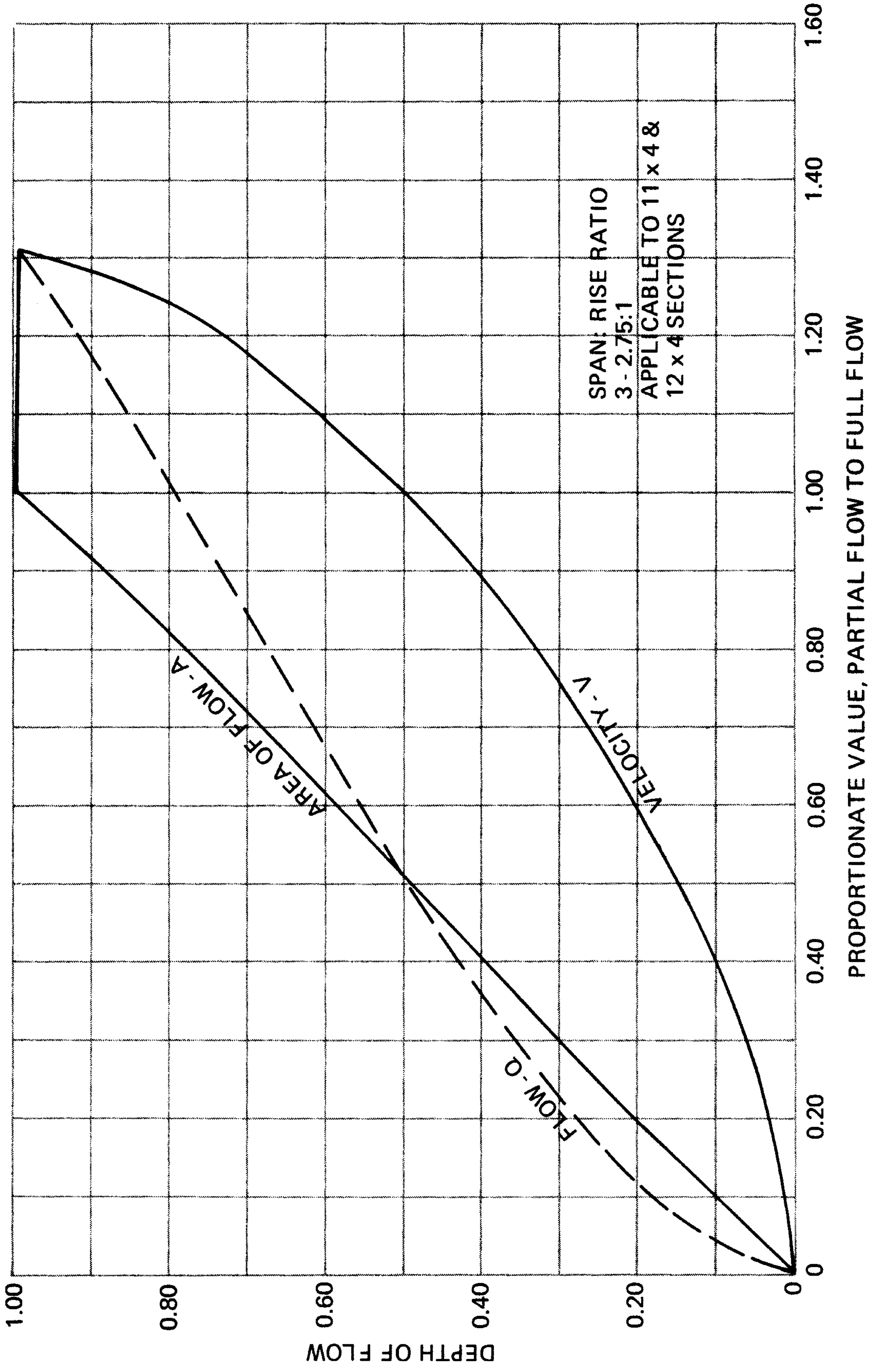


Figure 24.2

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

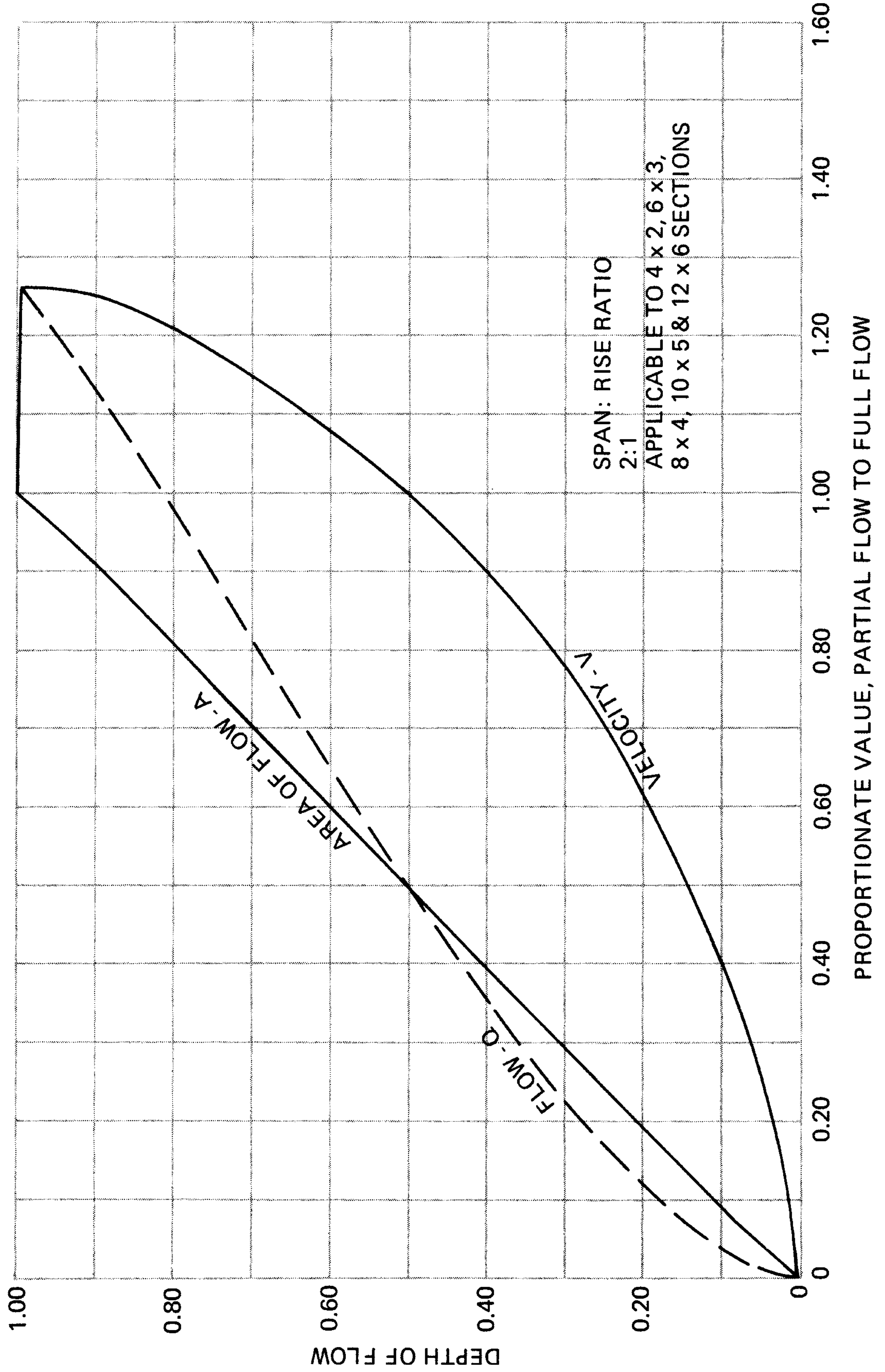


Figure 24.3

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

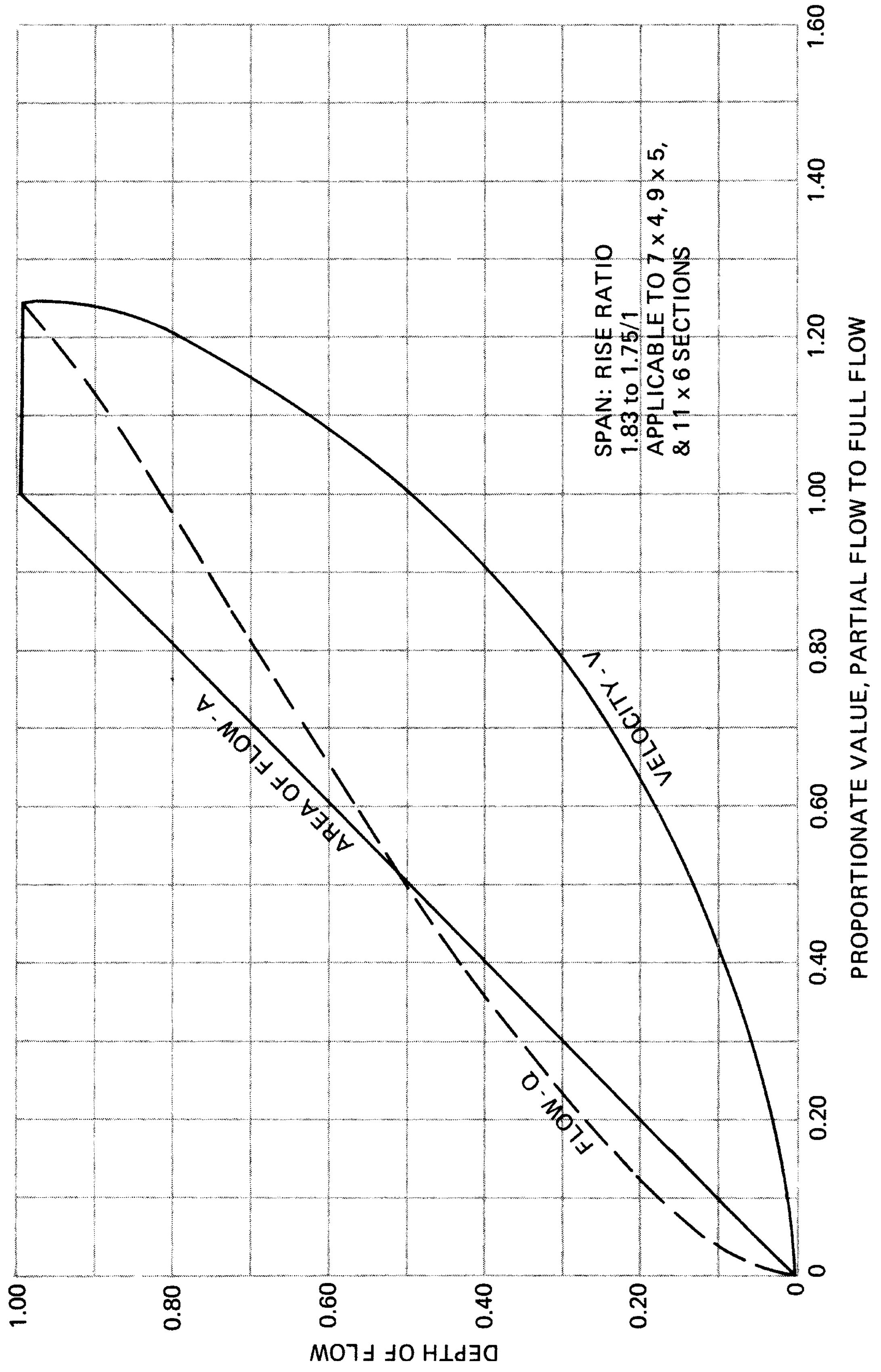


Figure 24.4

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

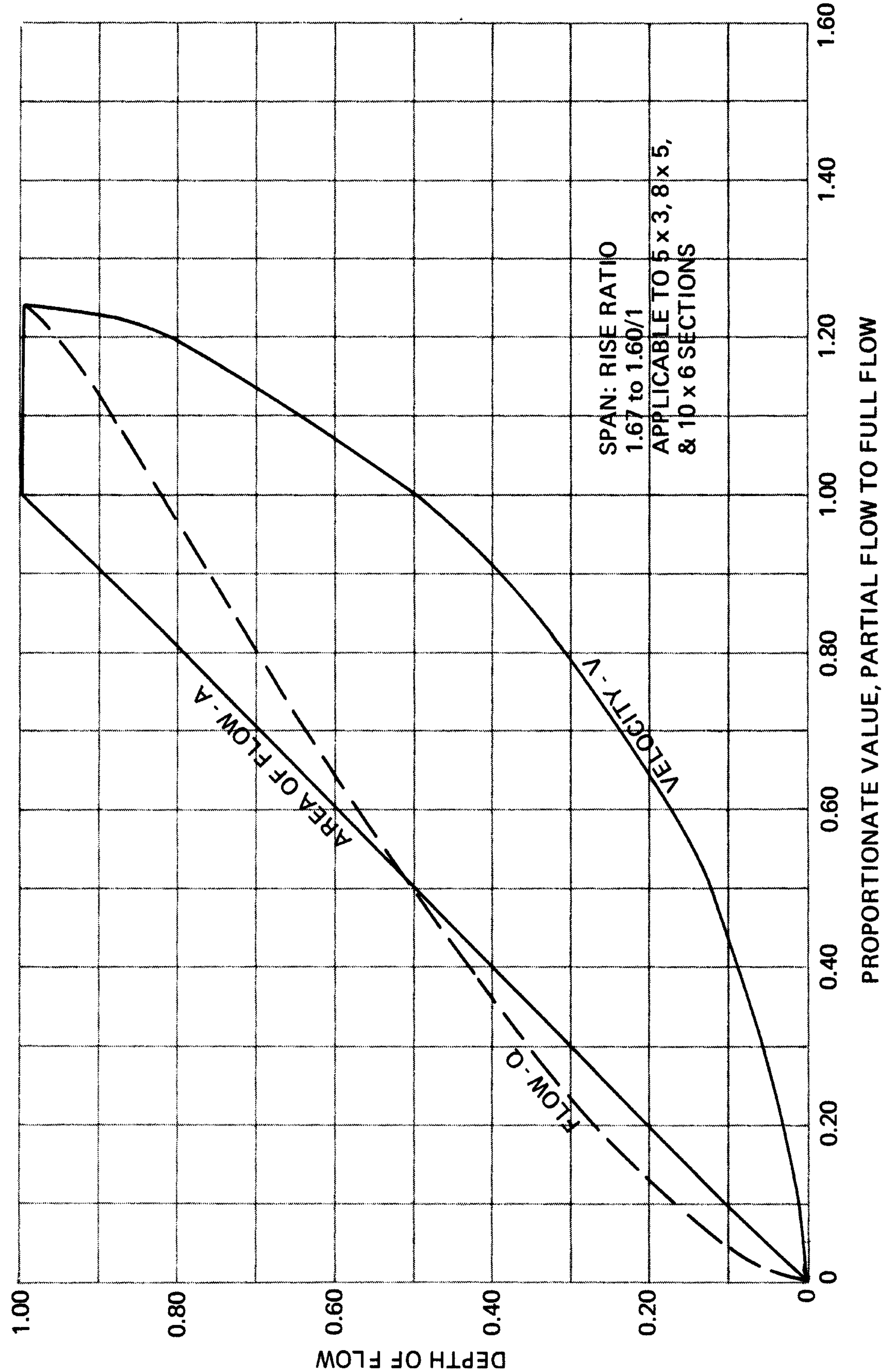


Figure 24.5

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

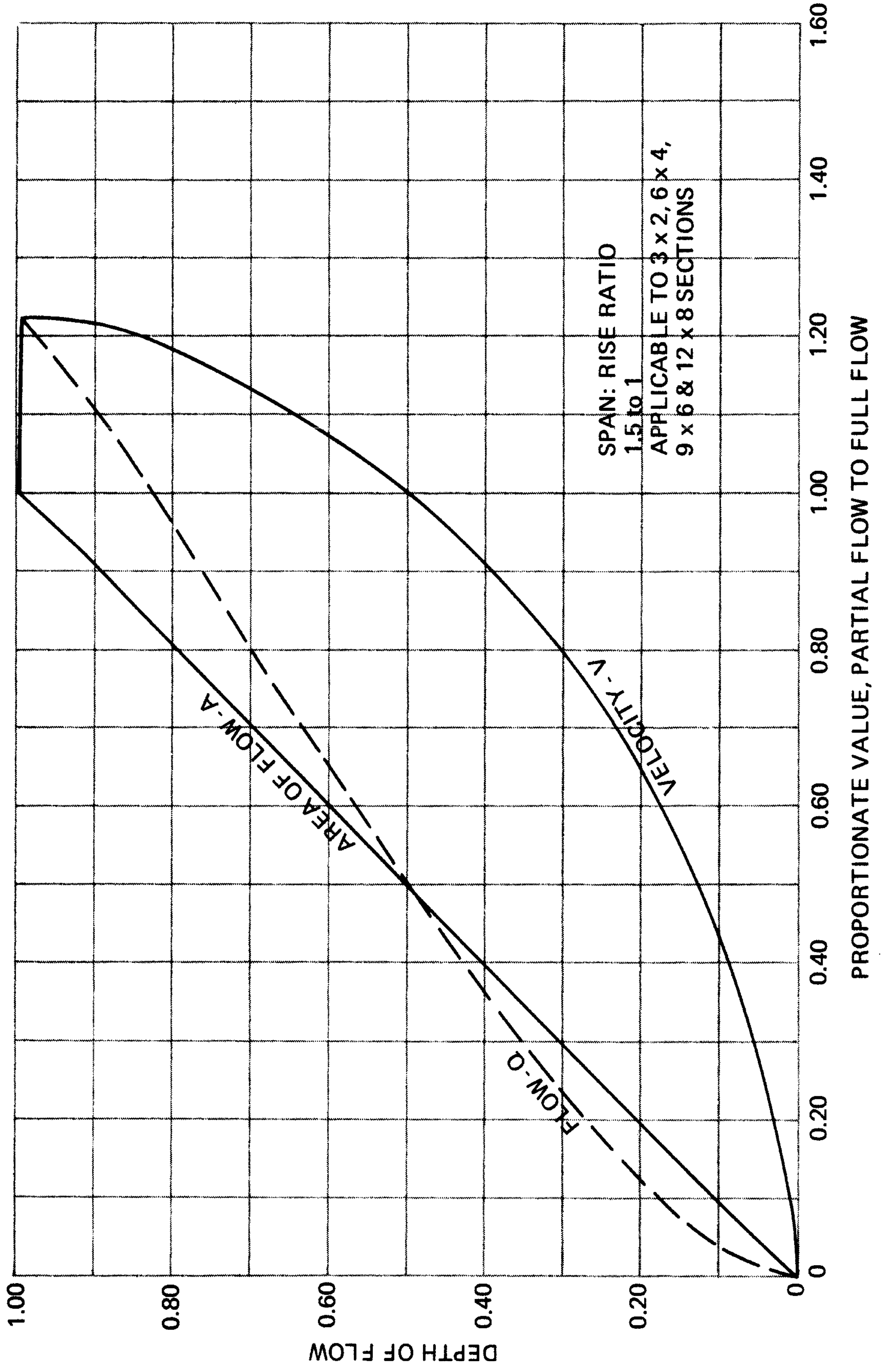


Figure 24.6

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

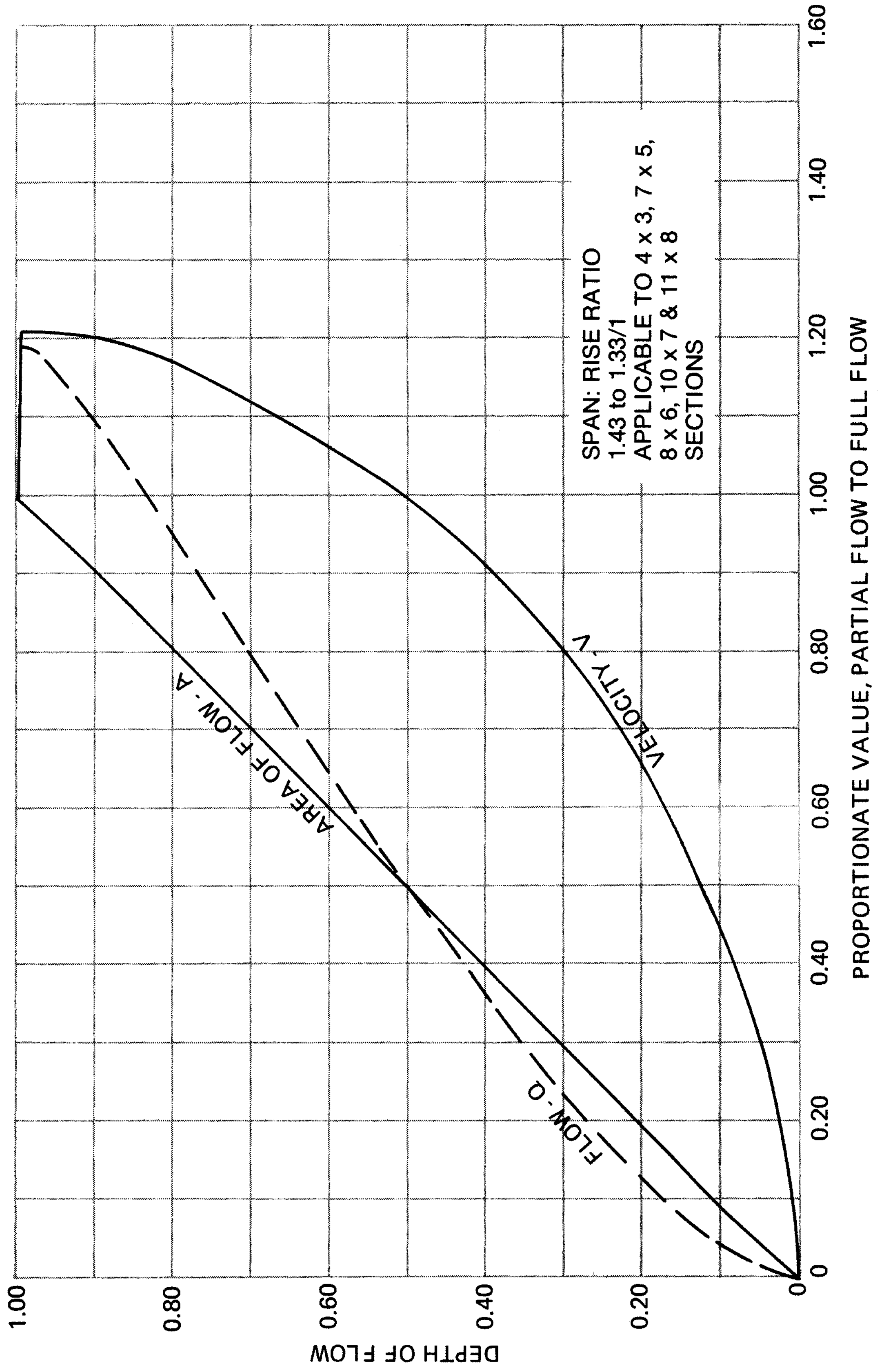


Figure 24.7

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

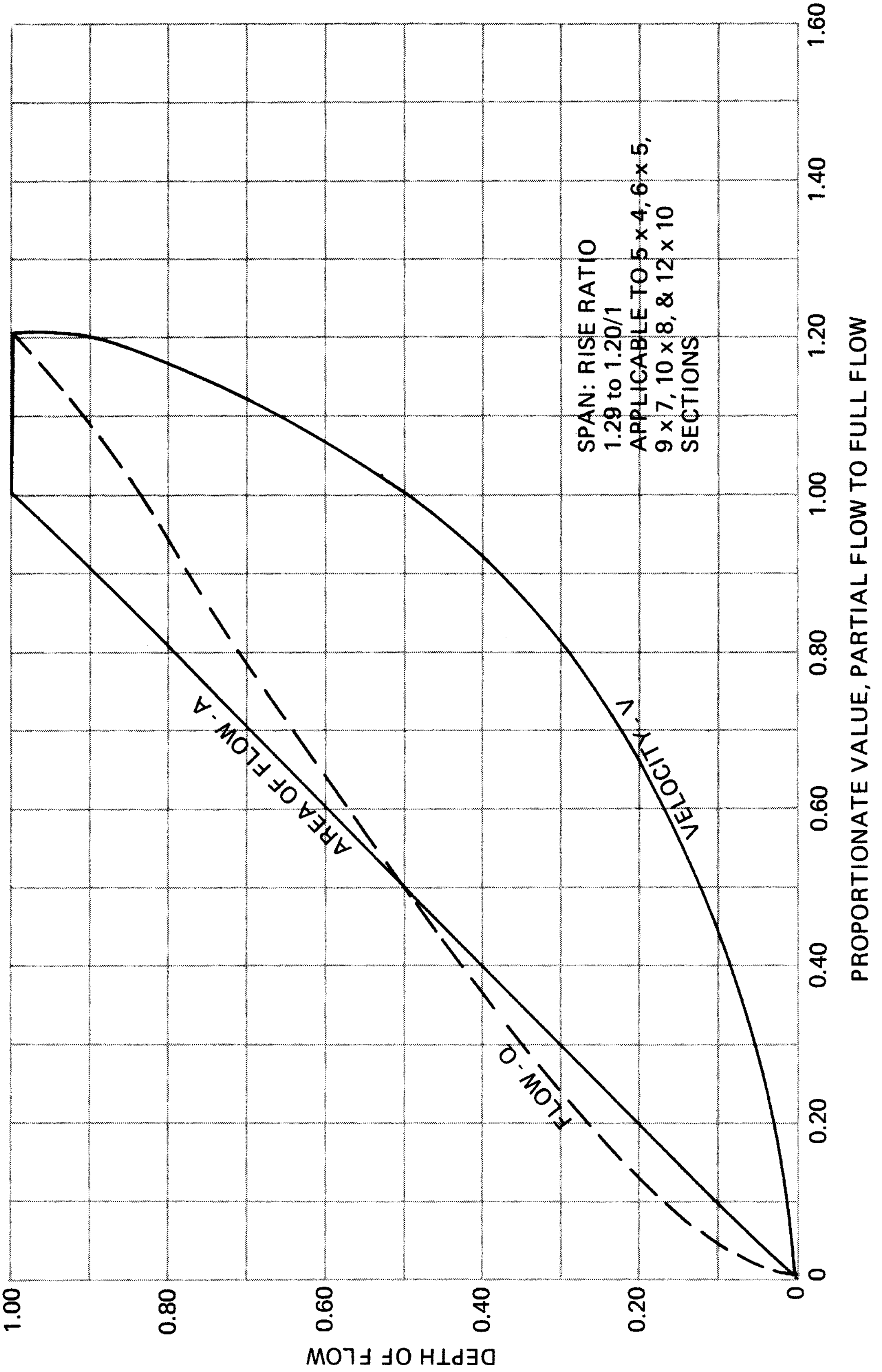
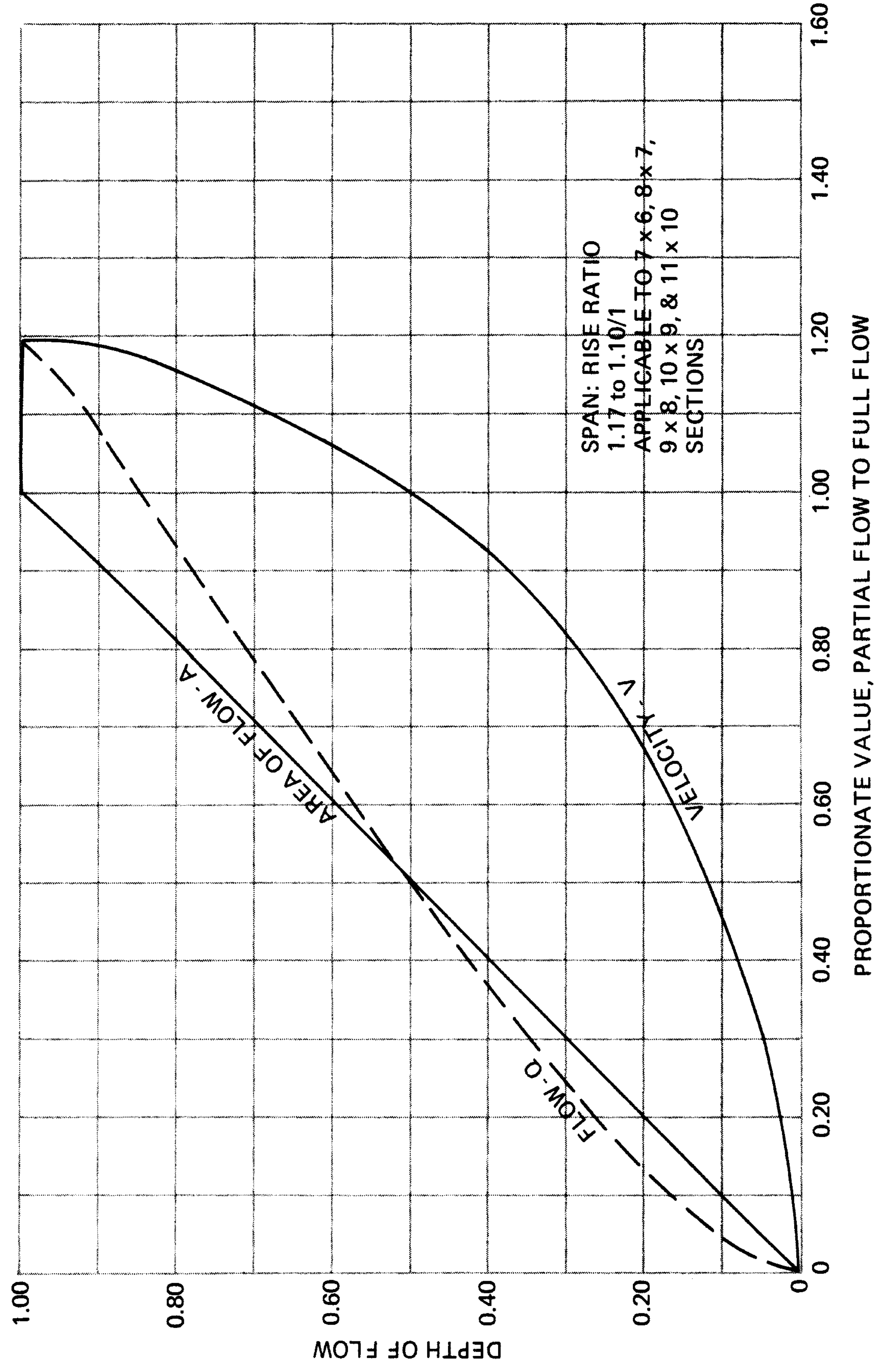


Figure 24.8

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW



SPAN: RISE RATIO
1.17 to 1.10/1
APPLICABLE TO 7 x 6, 8 x 7,
9 x 8, 10 x 9, & 11 x 10
SECTIONS

Figure 24.9

RELATIVE VELOCITY AND FLOW IN PRECAST BOX SECTIONS FOR ANY DEPTH OF FLOW

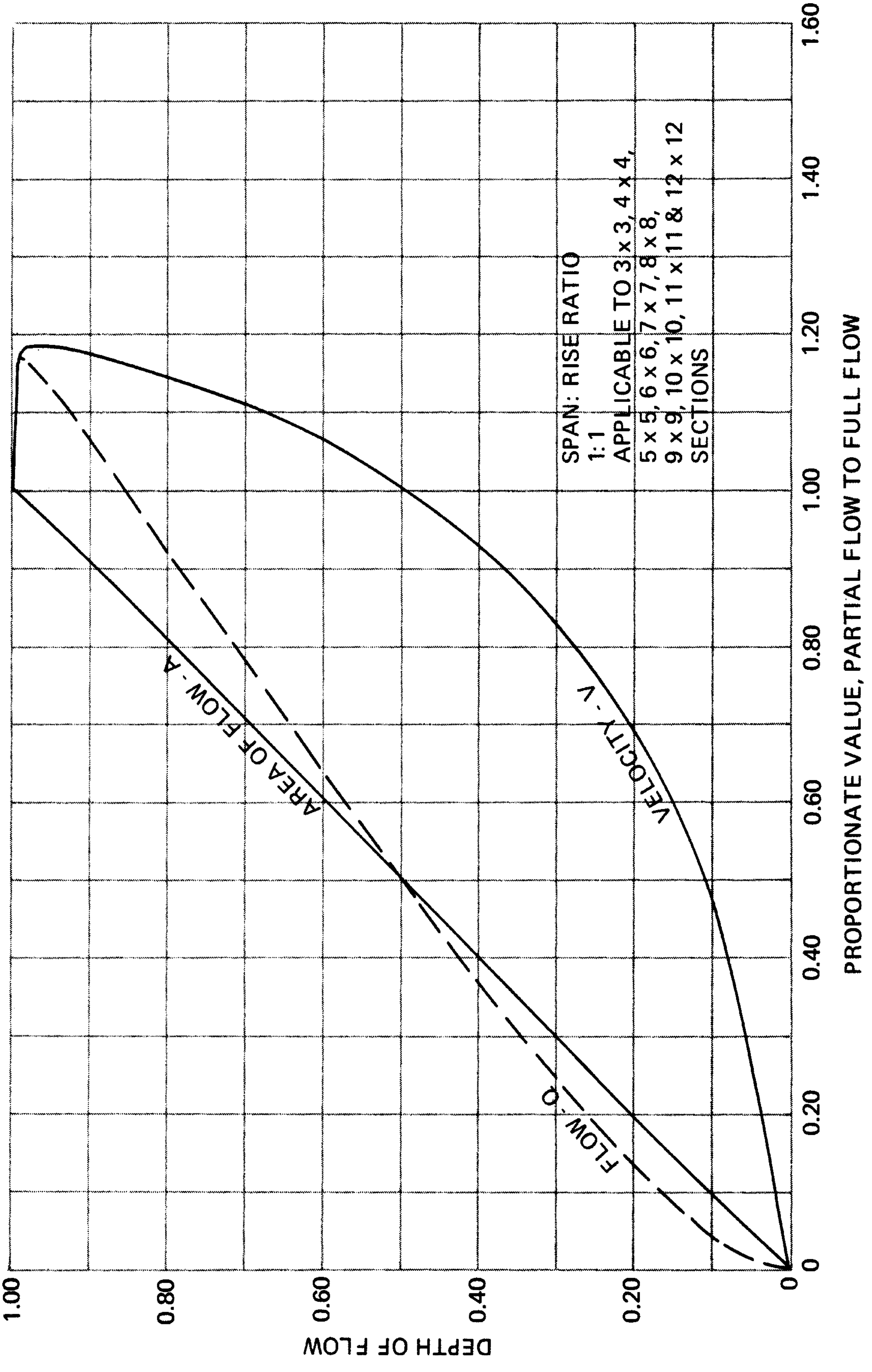
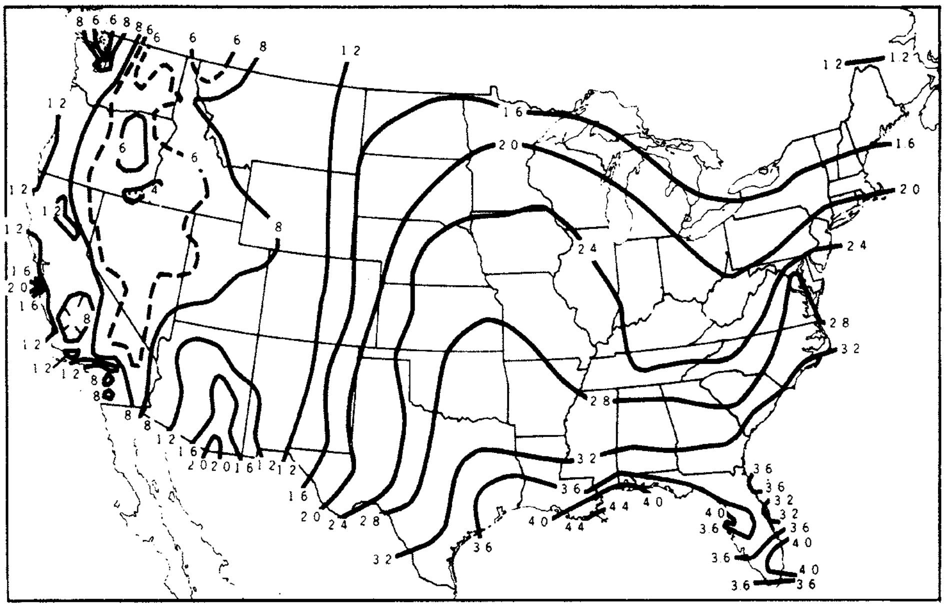


Figure 25

MAP OF THE UNITED STATES
2-YEAR, 30-MINUTE RAINFALL INTENSITY



ADAPTED FROM CHART 2, RAINFALL FREQUENCY ATLAS OF THE UNITED STATES, U.S DEPARTMENT OF COMMERCE, WEATHER BUREAU, TECHNICAL PAPER NO. 40 MAY 1961

Figure 26

INTENSITY-DURATION CURVE

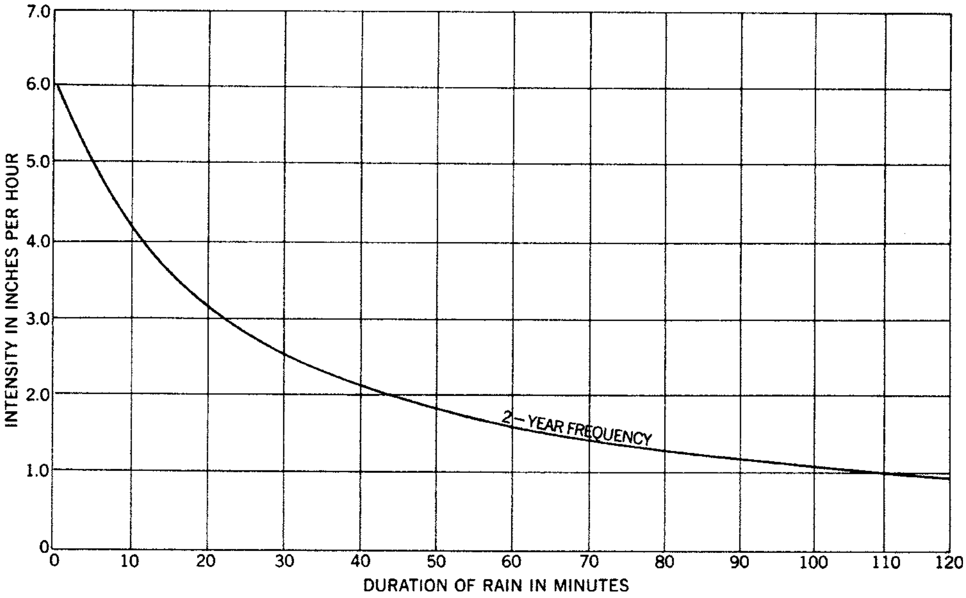


Figure 27

CALIFORNIA CHART "A" FOR CALCULATION OF "DESIGN DISCHARGES"

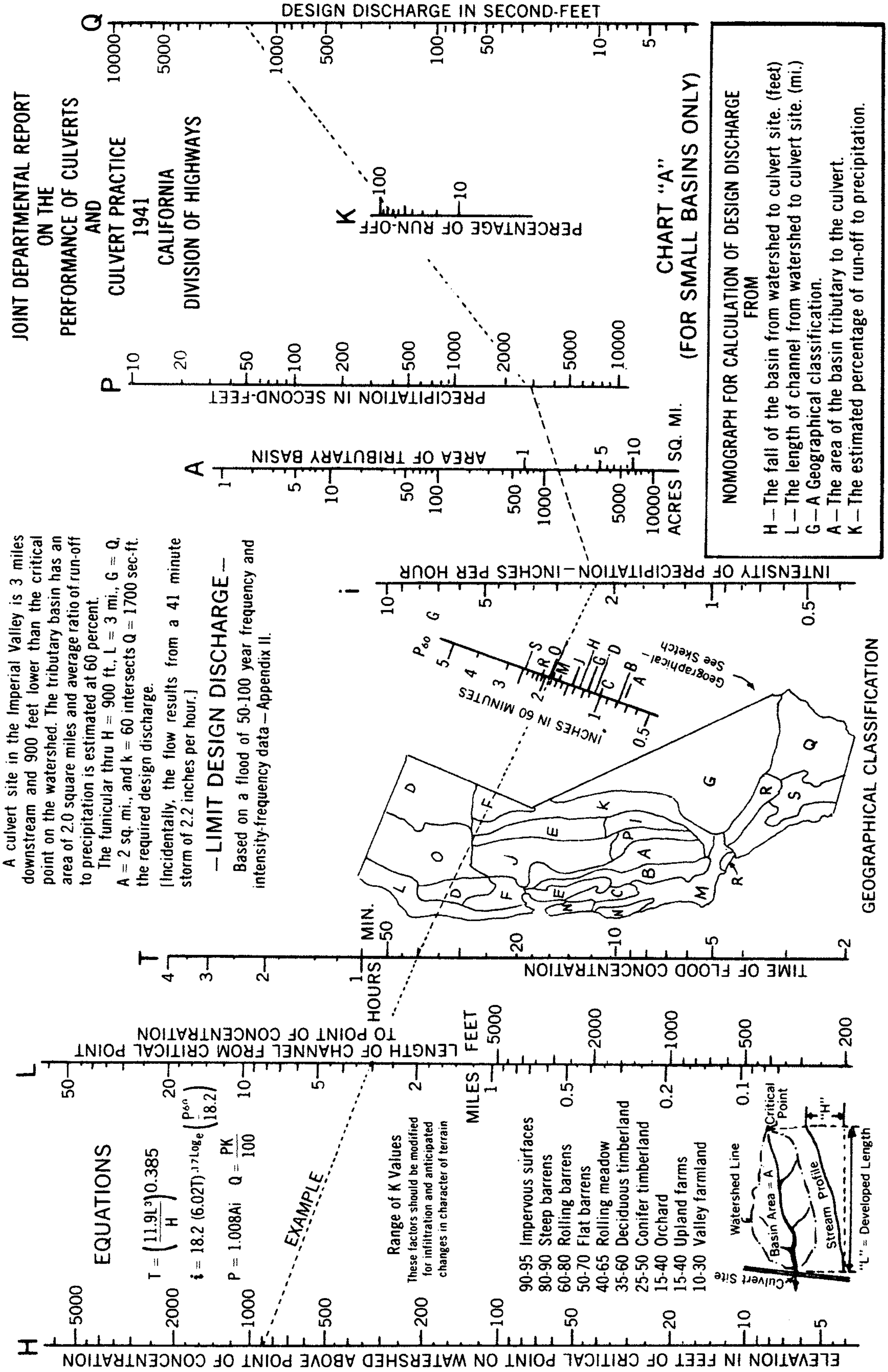


Figure 28

CRITICAL DEPTH
CIRCULAR PIPE

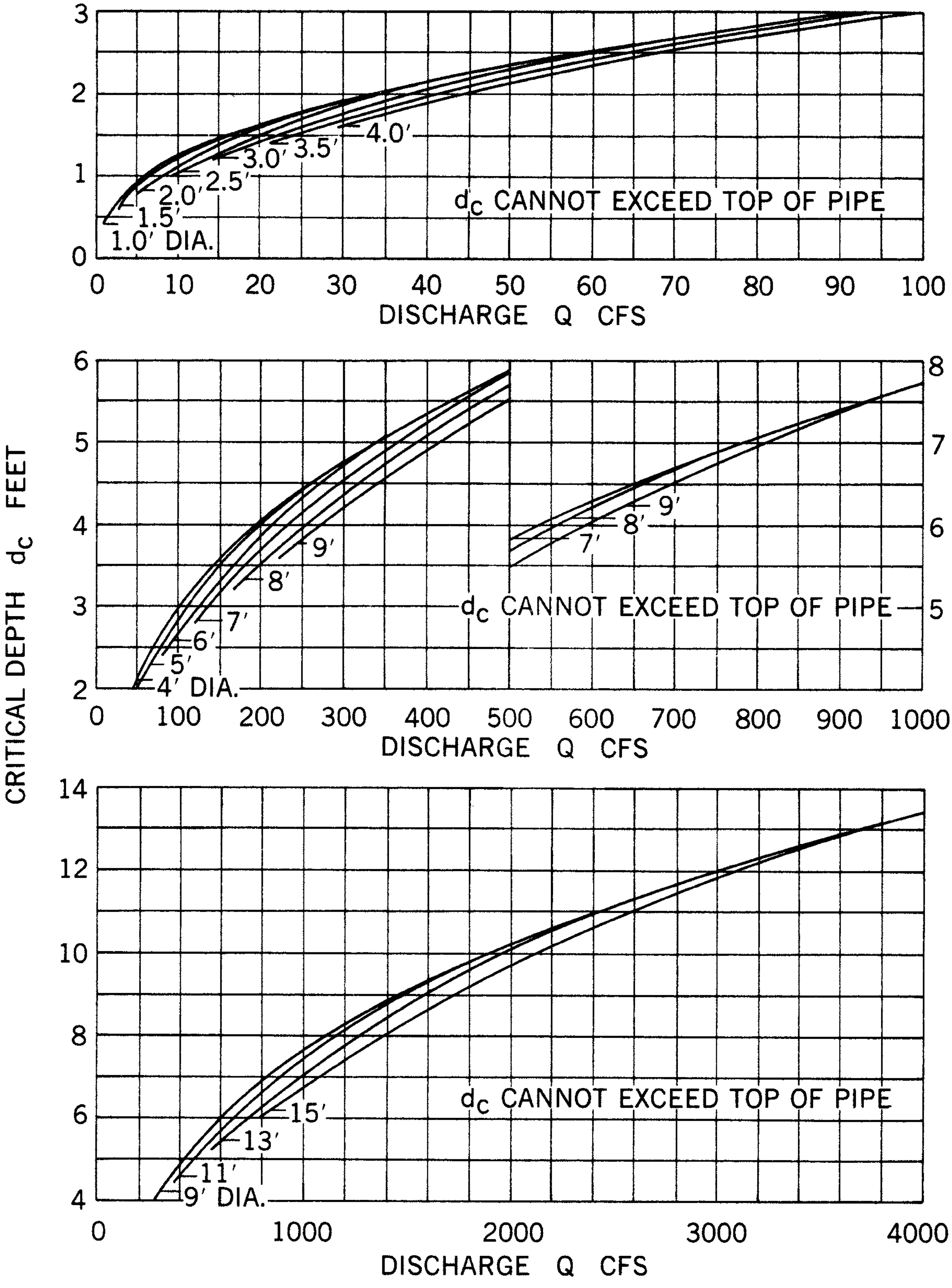


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Figure 29

CRITICAL DEPTH
HORIZONTAL ELLIPTICAL PIPE

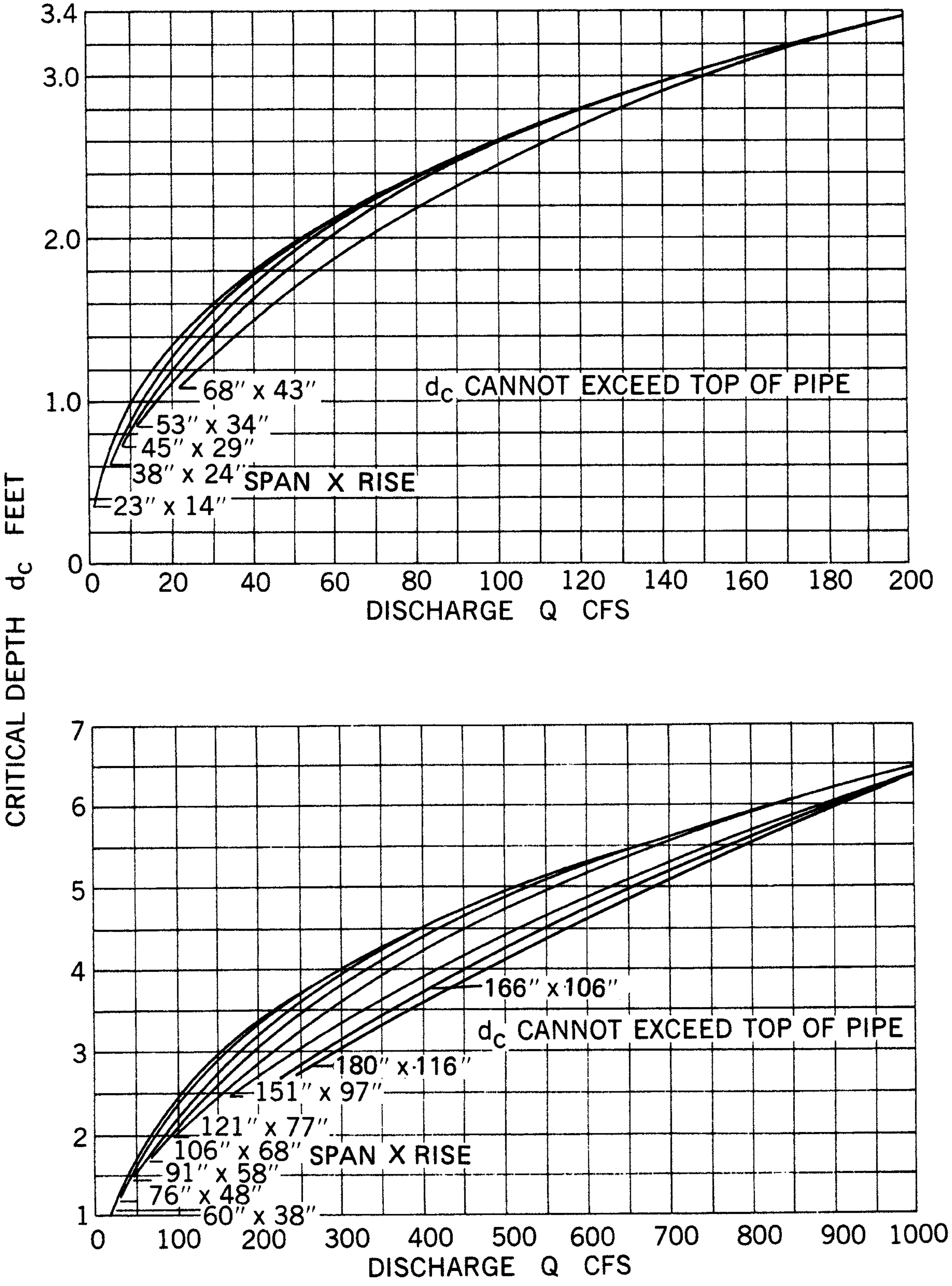

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Figure 30

CRITICAL DEPTH
VERTICAL ELLIPTICAL PIPE

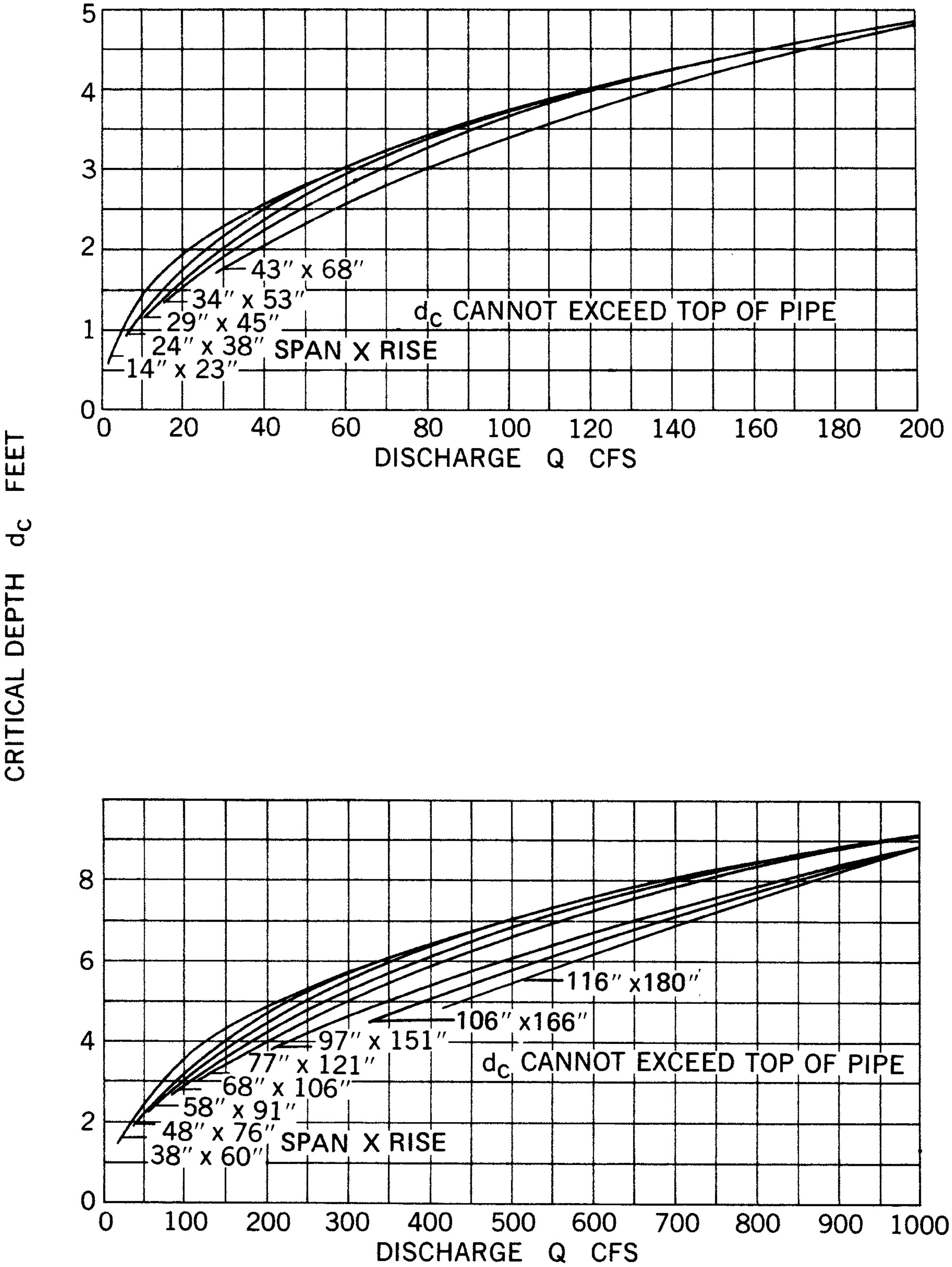

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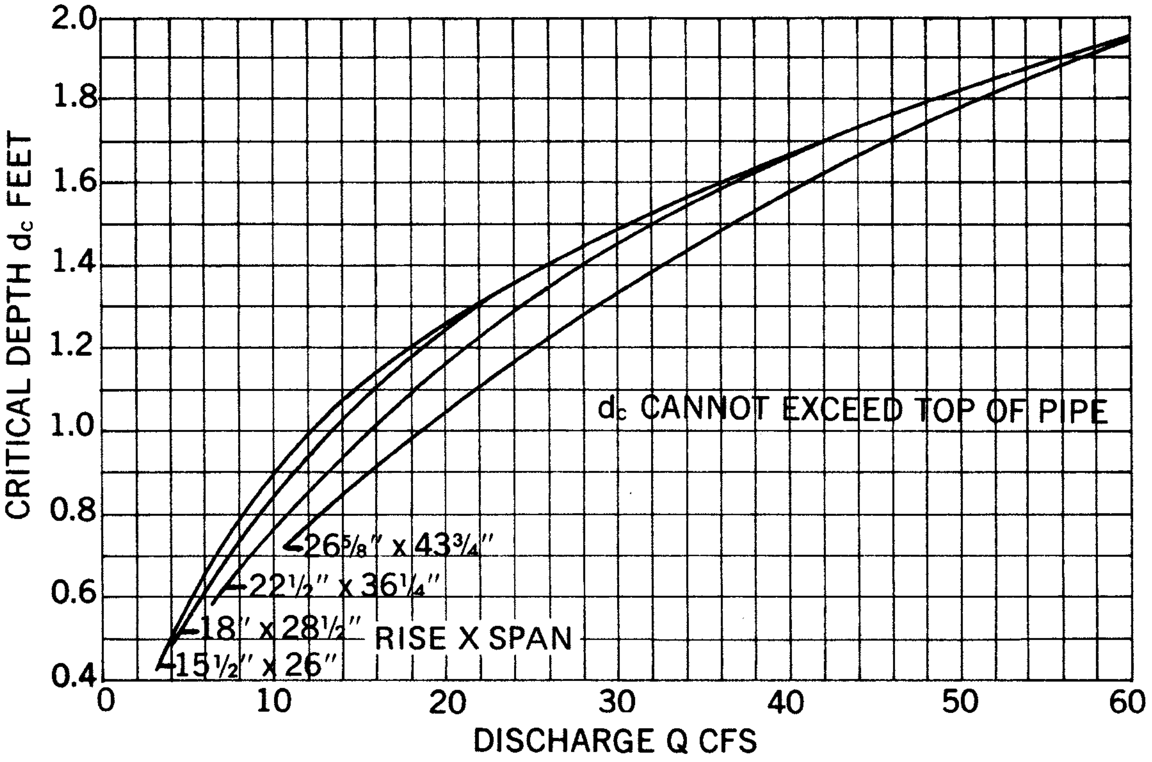
Figure 31.1

**CRITICAL DEPTH
ARCH PIPE**



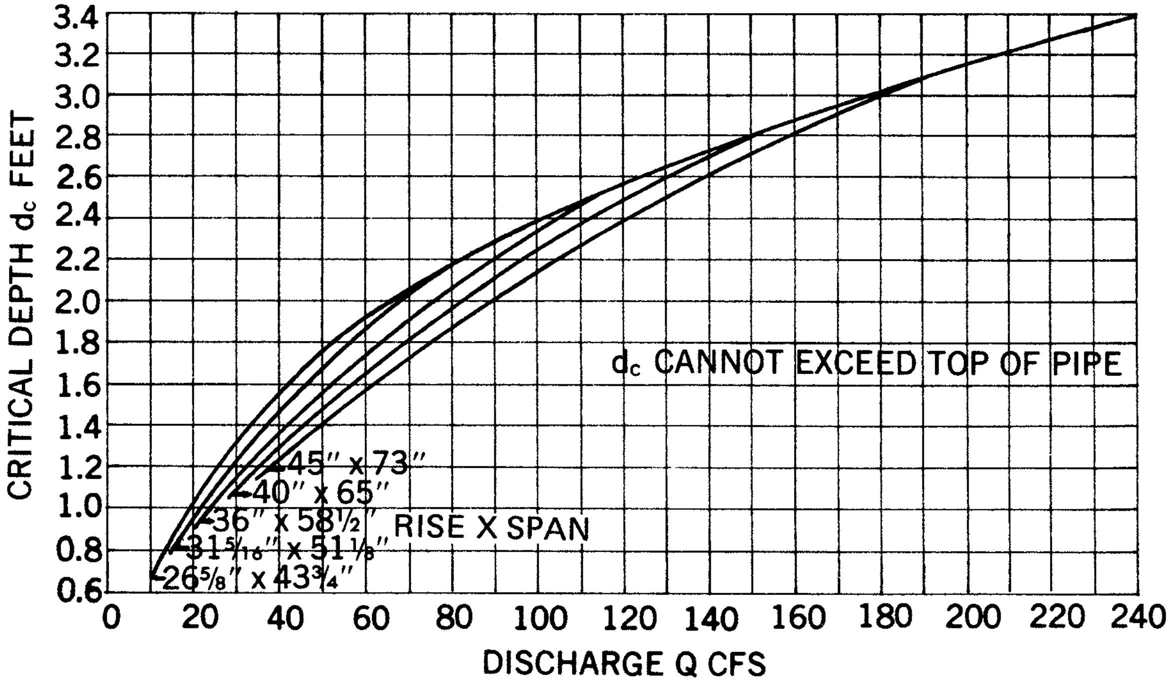


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Figure 31.2

CRITICAL DEPTH
ARCH PIPE

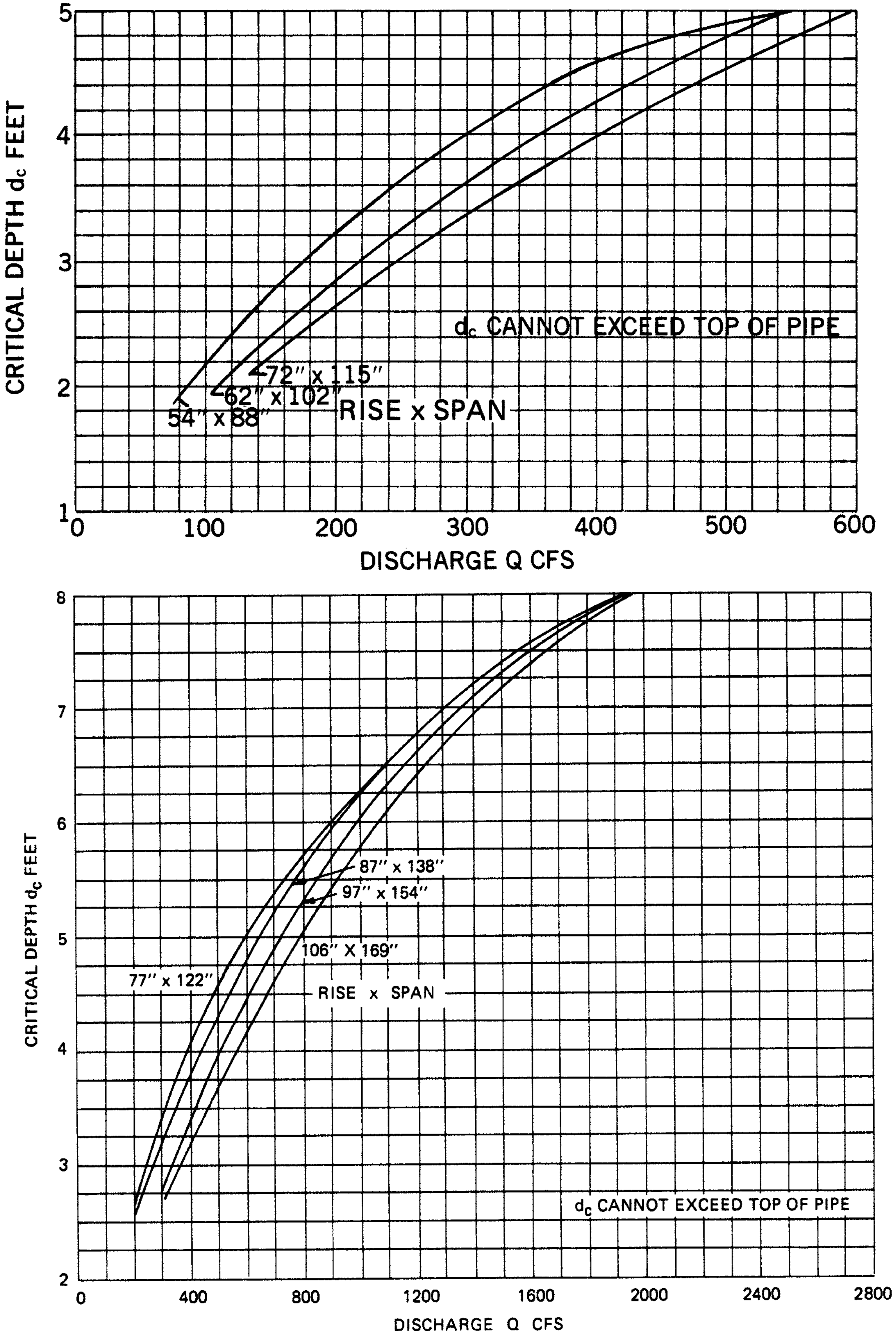

Figure 32

CRITICAL DEPTH—PRECAST CONCRETE BOX SECTIONS

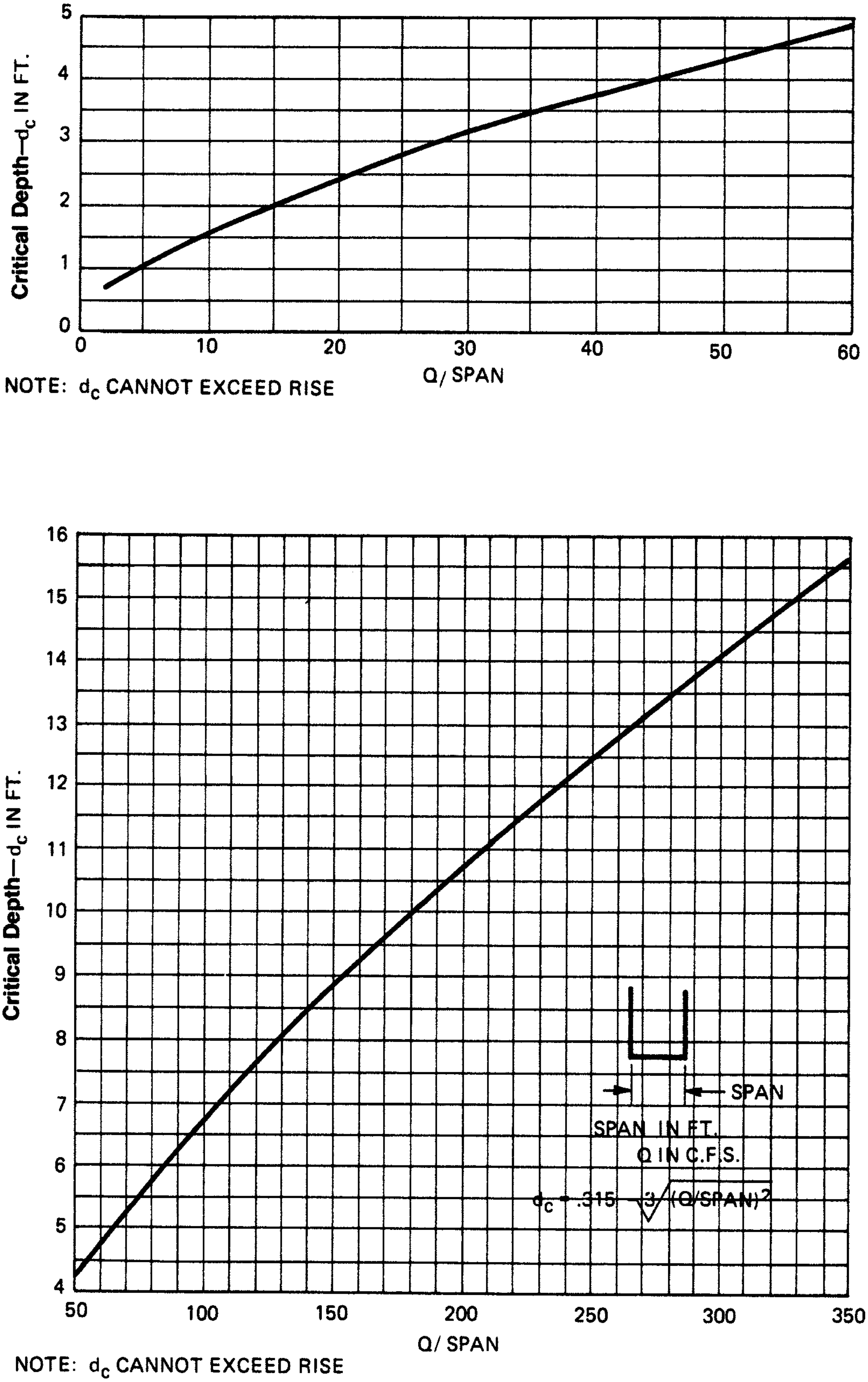

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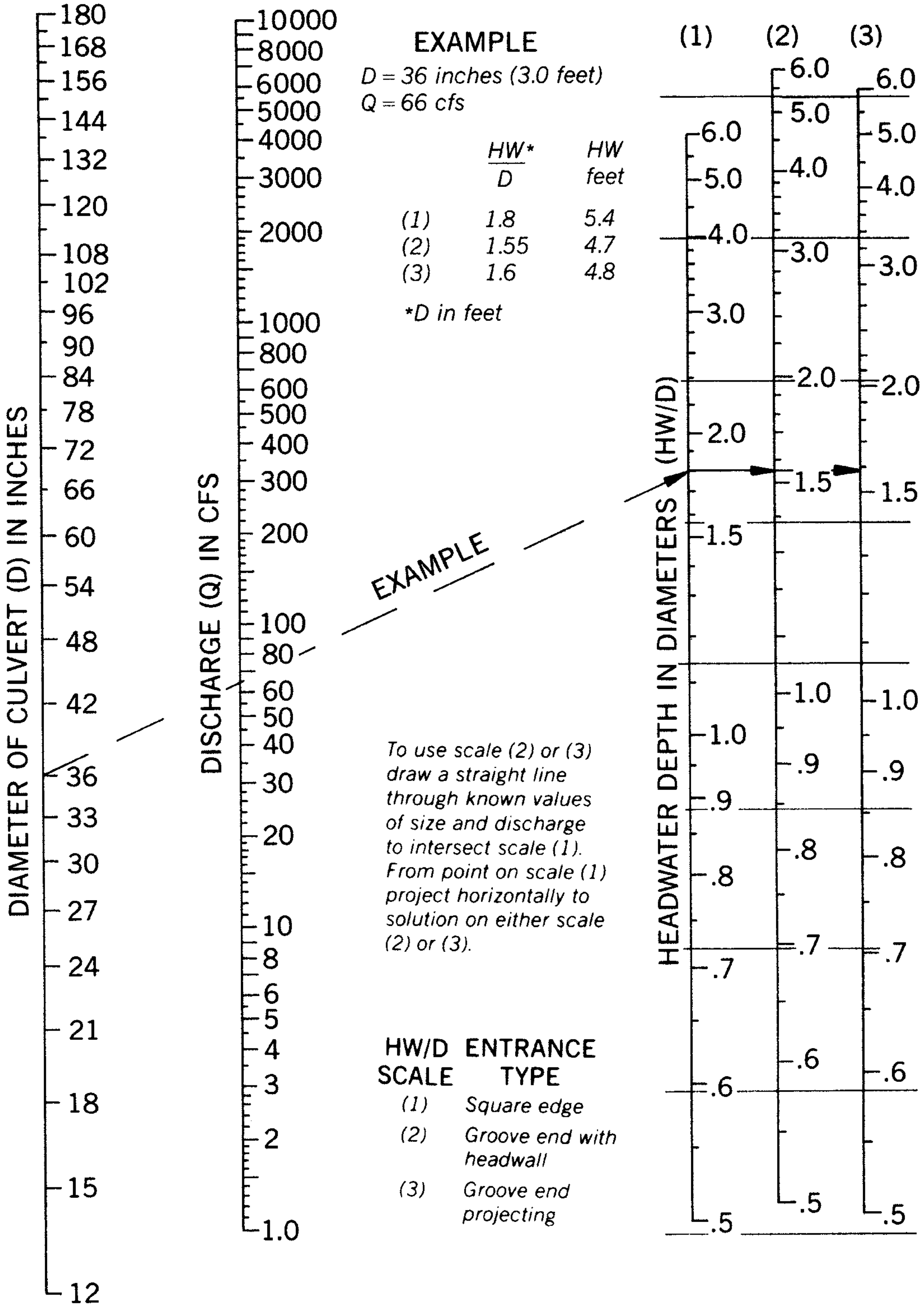
Figure 33

HEADWATER DEPTH FOR CIRCULAR CONCRETE PIPE CULVERTS WITH INLET CONTROL



EXAMPLE

D = 36 inches (3.0 feet)
Q = 66 cfs

	HW*/D	HW feet
(1)	1.8	5.4
(2)	1.55	4.7
(3)	1.6	4.8

**D in feet*

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge
(2)	Groove end with headwall
(3)	Groove end projecting

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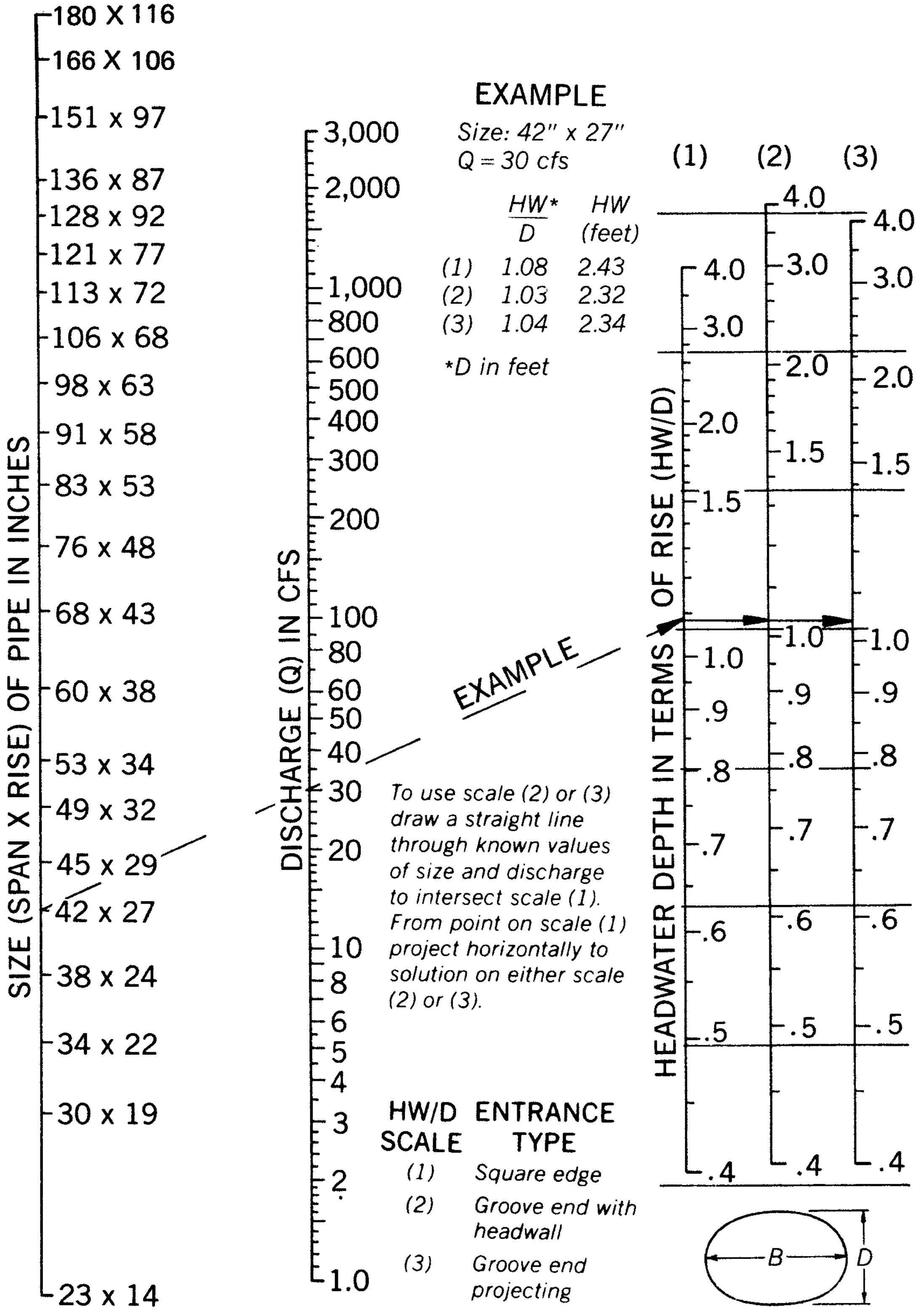
HEADWATER SCALES 2&3
REVISED MAY 1964

Figure 34

HEADWATER DEPTH FOR HORIZONTAL ELLIPTICAL CONCRETE PIPE CULVERTS WITH INLET CONTROL



EXAMPLE

Size: 42" x 27"
Q = 30 cfs

	HW*/D	HW (feet)
(1)	1.08	2.43
(2)	1.03	2.32
(3)	1.04	2.34

**D in feet*

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge
(2)	Groove end with headwall
(3)	Groove end projecting

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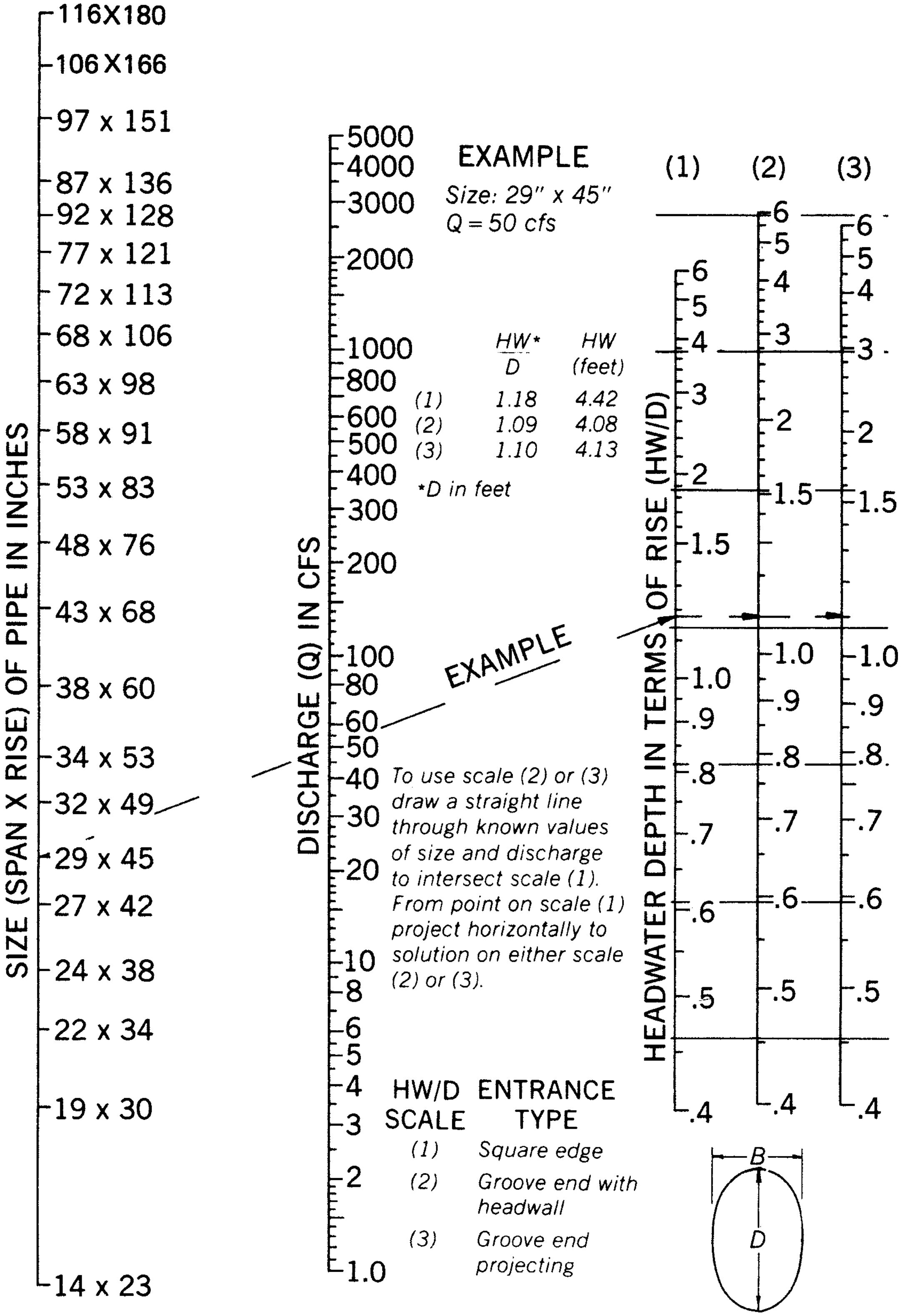
Figure 35

HEADWATER DEPTH FOR VERTICAL ELLIPTICAL CONCRETE PIPE CULVERTS WITH INLET CONTROL



EXAMPLE

Size: 29" x 45"
Q = 50 cfs

	HW*/D	HW (feet)
(1)	1.18	4.42
(2)	1.09	4.08
(3)	1.10	4.13

**D in feet*

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge
(2)	Groove end with headwall
(3)	Groove end projecting

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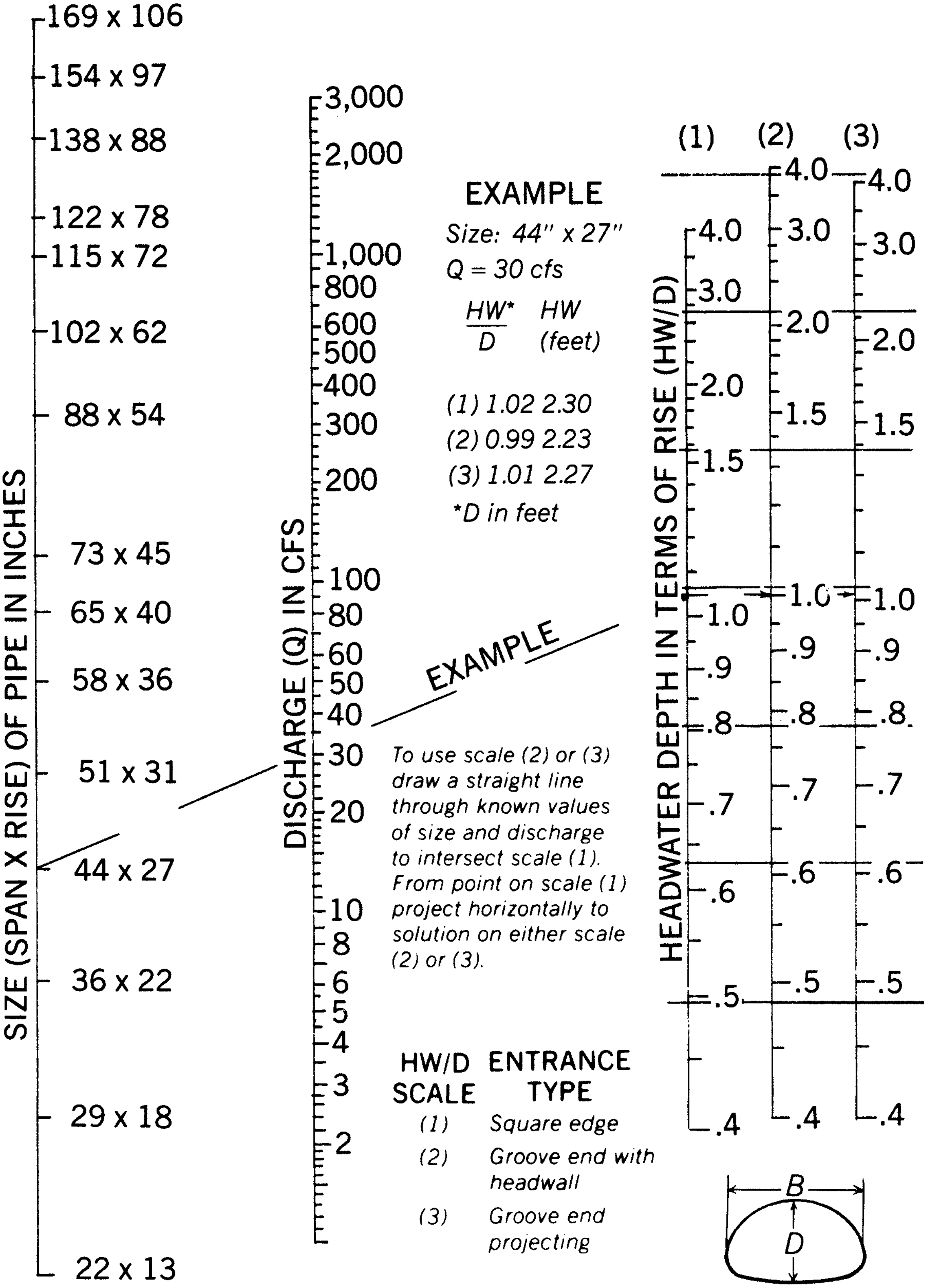
Figure 36

HEADWATER DEPTH FOR CONCRETE ARCH CULVERTS WITH INLET CONTROL



EXAMPLE

Size: 44" x 27"

Q = 30 cfs

HW/D*	*HW (feet)*
(1) 1.02	*2.30*
(2) 0.99	*2.23*
(3) 1.01	*2.27*

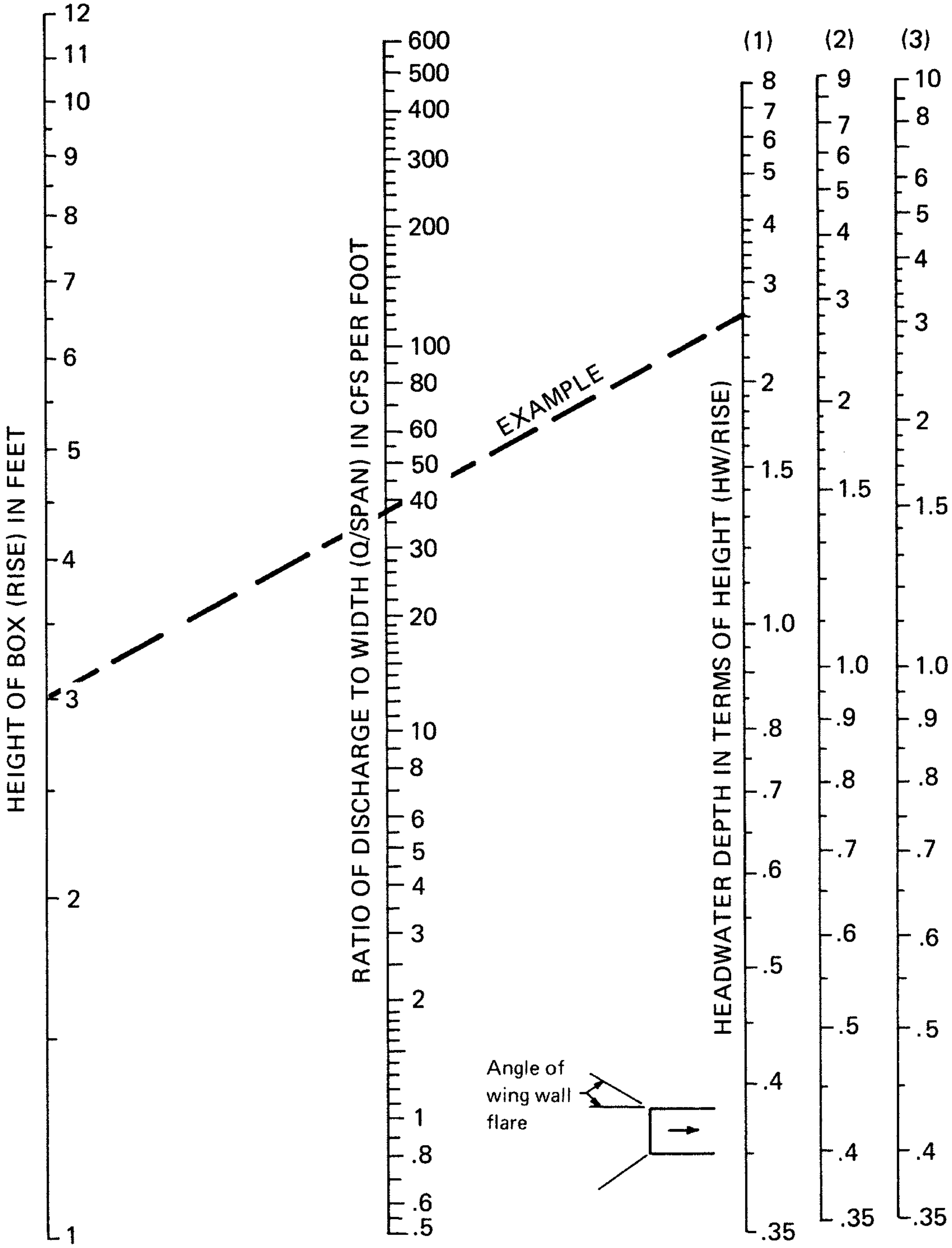
**D in feet*

To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

HW/D SCALE	ENTRANCE TYPE
(1)	*Square edge*
(2)	*Groove end with headwall*
(3)	*Groove end projecting*

Figure 37

HEADWATER DEPTH FOR CONCRETE BOX CULVERTS WITH INLET CONTROL



EXAMPLE

6′ x 3′ Box Q = 225 cfs

Q/Span = 37.5 cfs/ft

Inlet	HW/Rise	HW ft
(1)	2.6	7.8

HW/Rise SCALE	WING WALL FLARE
(1)	30° to 75°
(2)	90° and 15°
(3)	0° (extensions of sides)

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through rise and Q scales, or reverse as illustrated.

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Figure 38

HEAD FOR CIRCULAR CONCRETE PIPE CULVERTS FLOWING FULL

$n = 0.012$

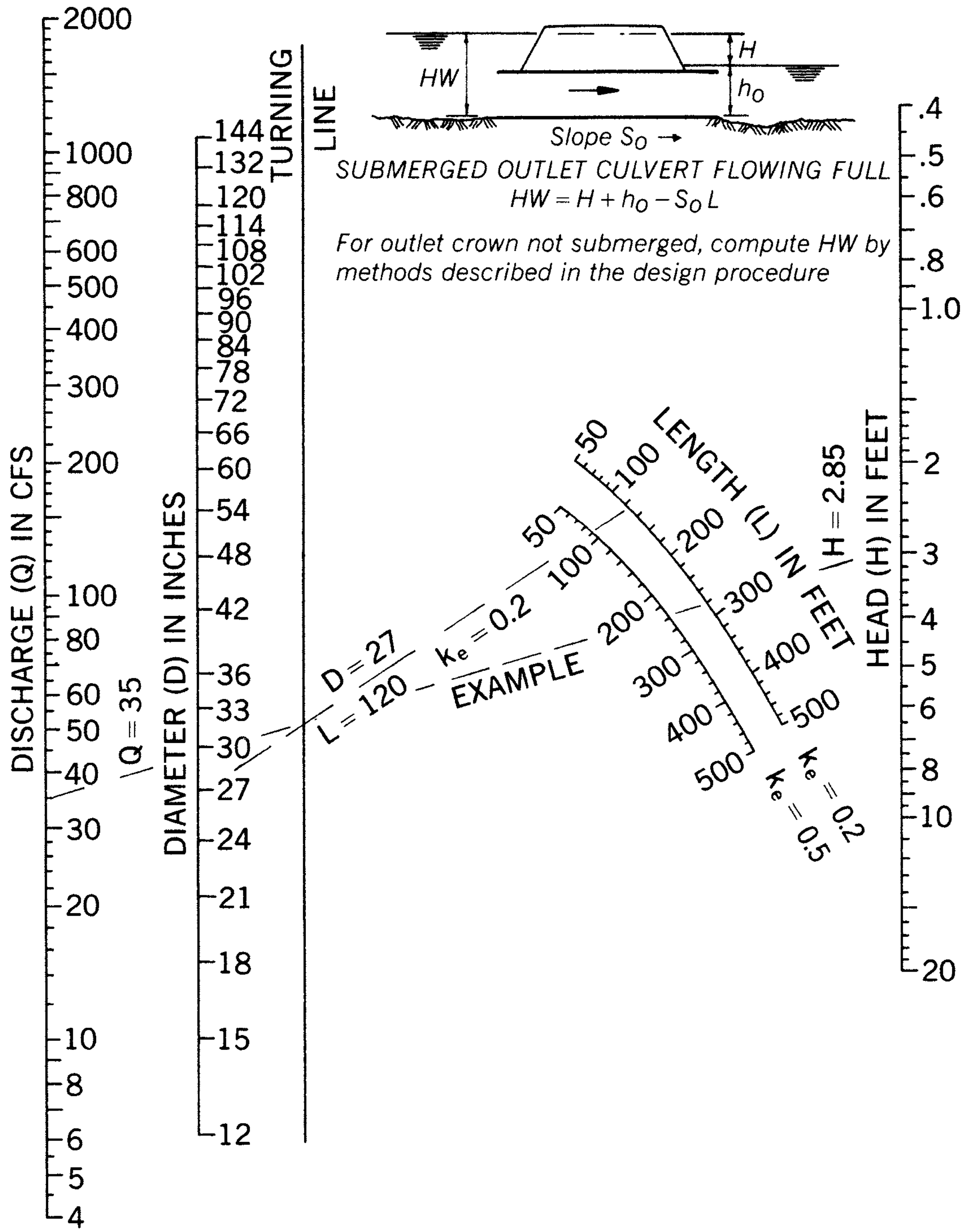

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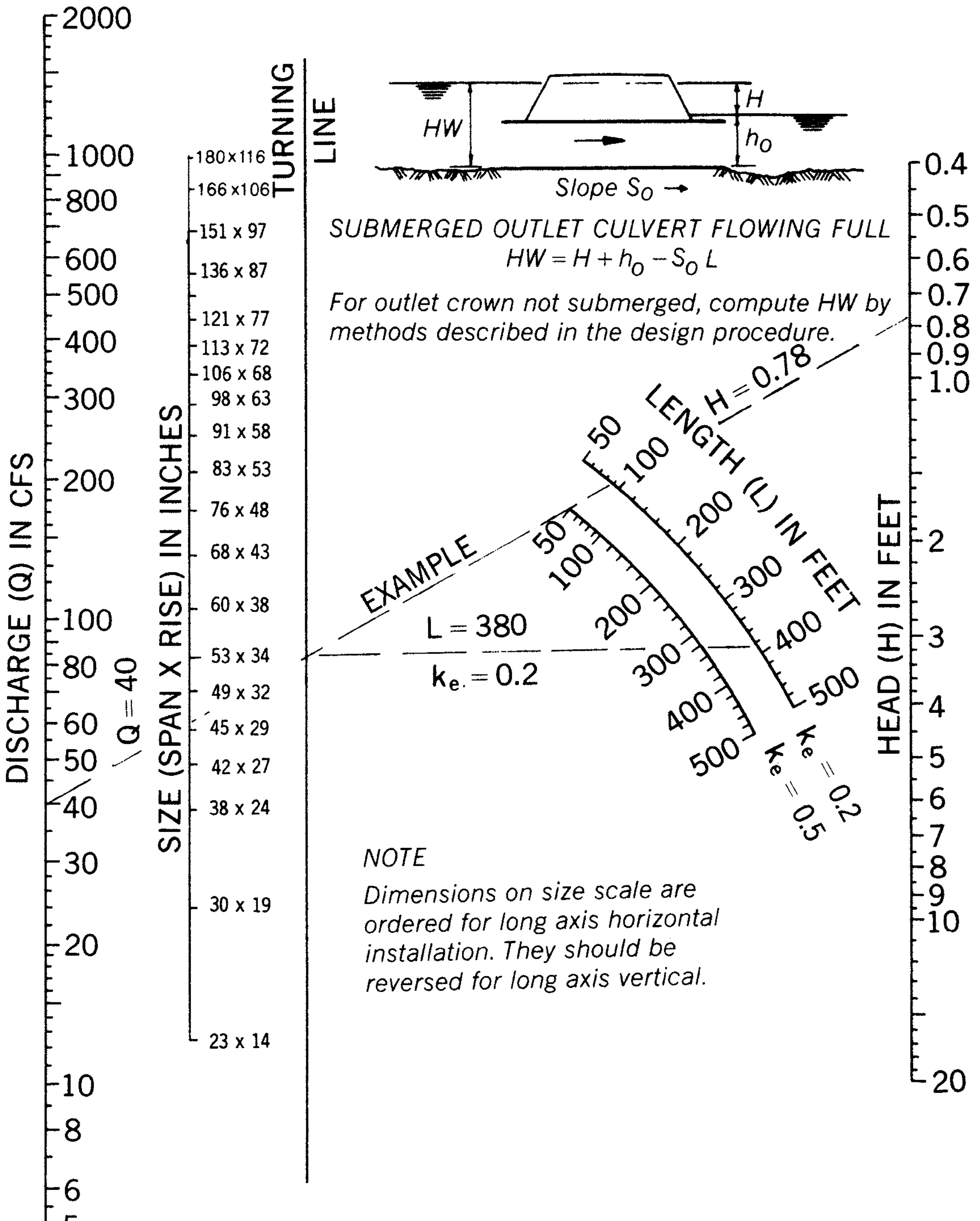
Figure 39

HEAD FOR ELLIPTICAL CONCRETE PIPE CULVERTS FLOWING FULL
n = 0.012



SUBMERGED OUTLET CULVERT FLOWING FULL
$HW = H + h_o - S_o L$

For outlet crown not submerged, compute HW by methods described in the design procedure.

NOTE
Dimensions on size scale are ordered for long axis horizontal installation. They should be reversed for long axis vertical.

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Figure 40

HEAD FOR CONCRETE ARCH CULVERTS FLOWING FULL

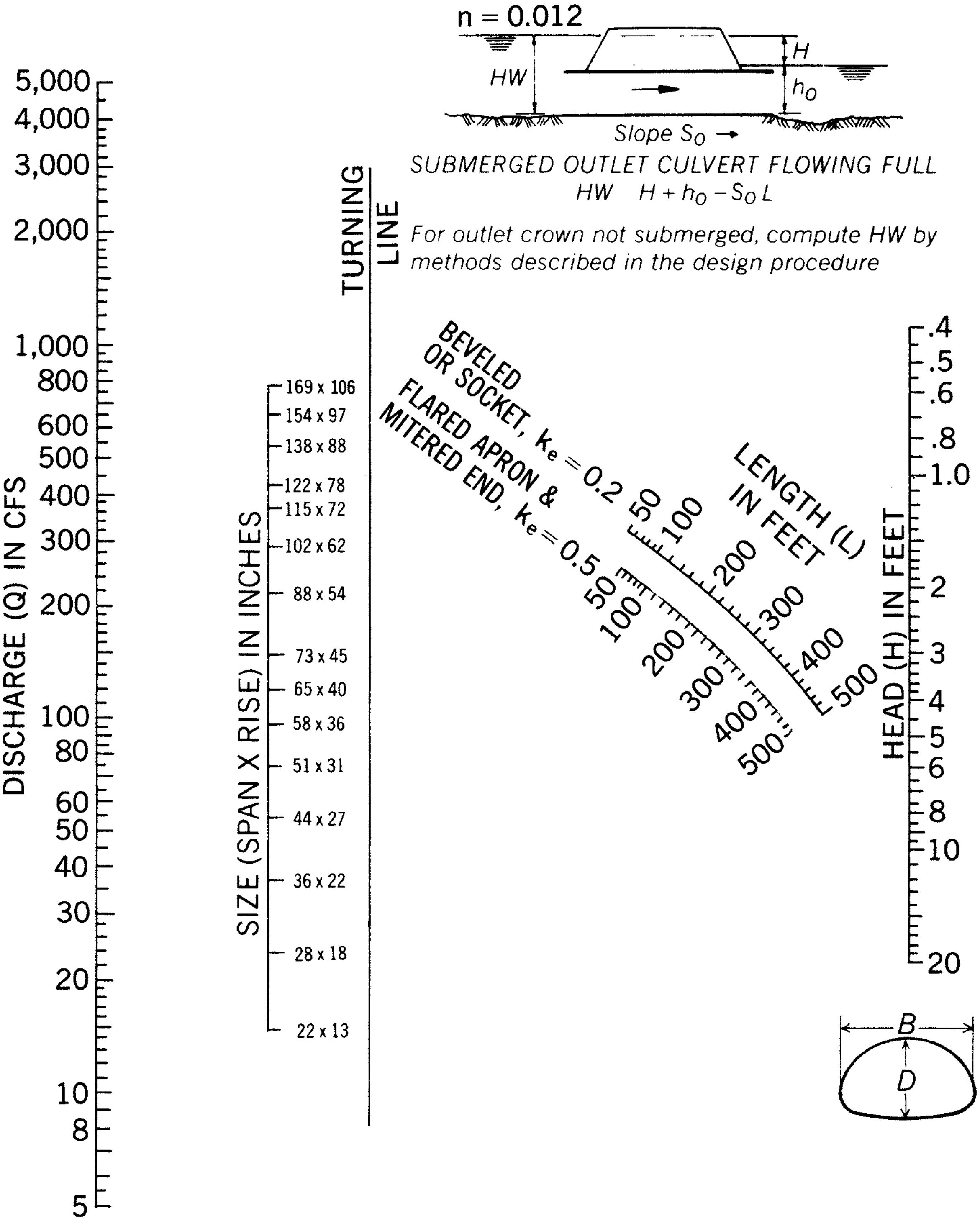


Figure 41

HEAD FOR CONCRETE BOX CULVERTS FLOWING FULL
n = 0.012

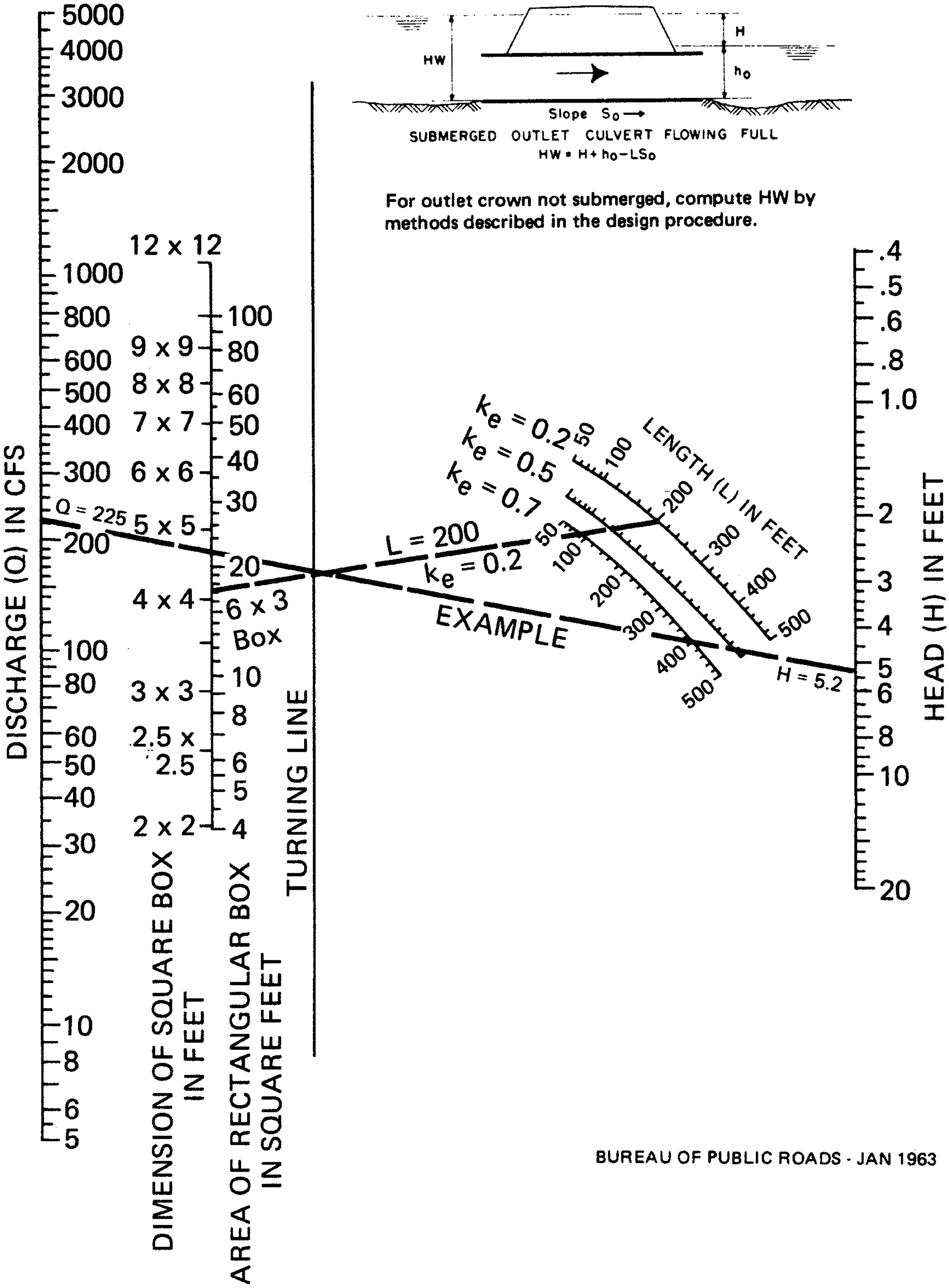


Figure 42

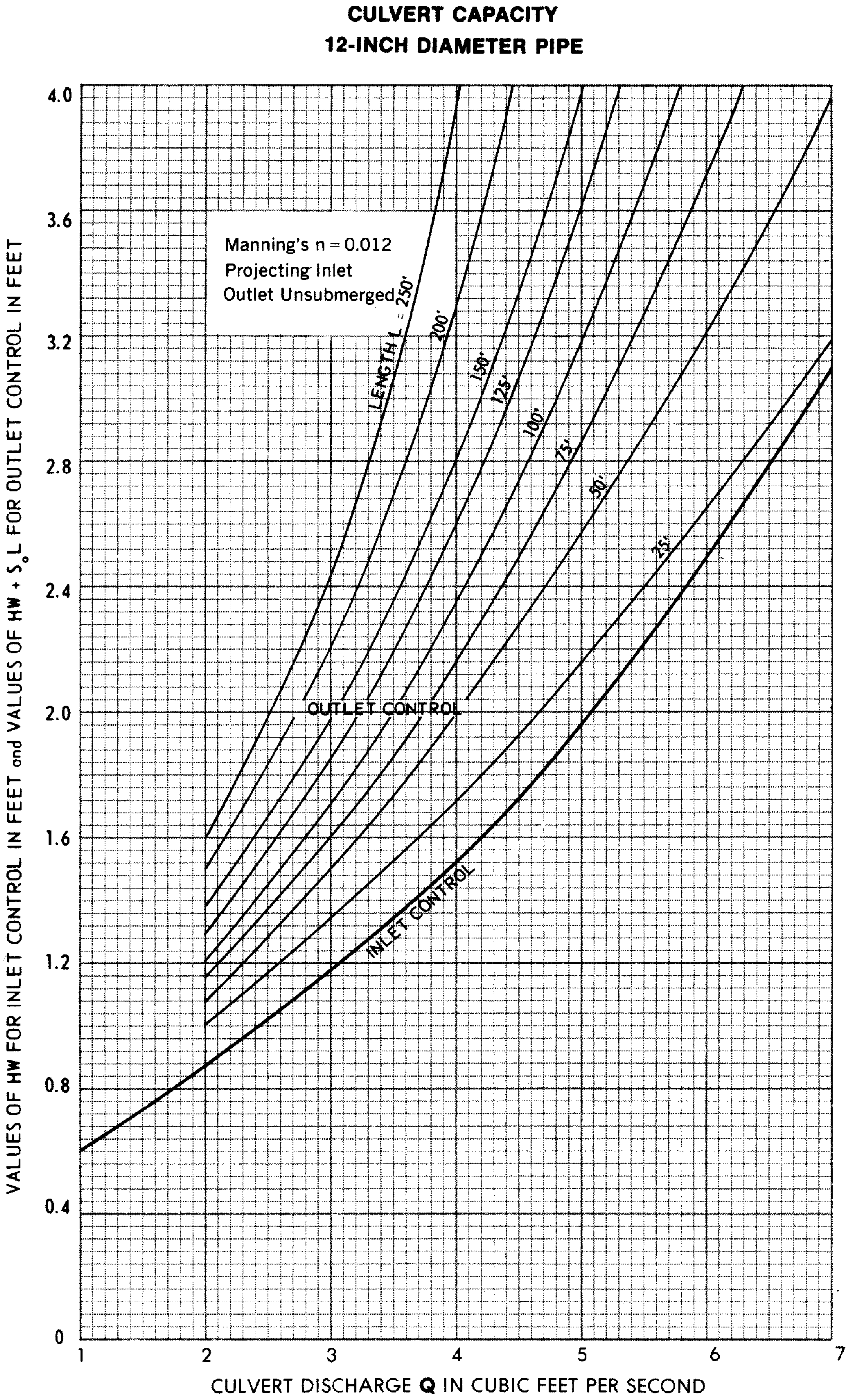

CULVERT CAPACITY
12-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S$_o$ L FOR OUTLET CONTROL IN FEET
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
1
2
3
4
5
6
7
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 43

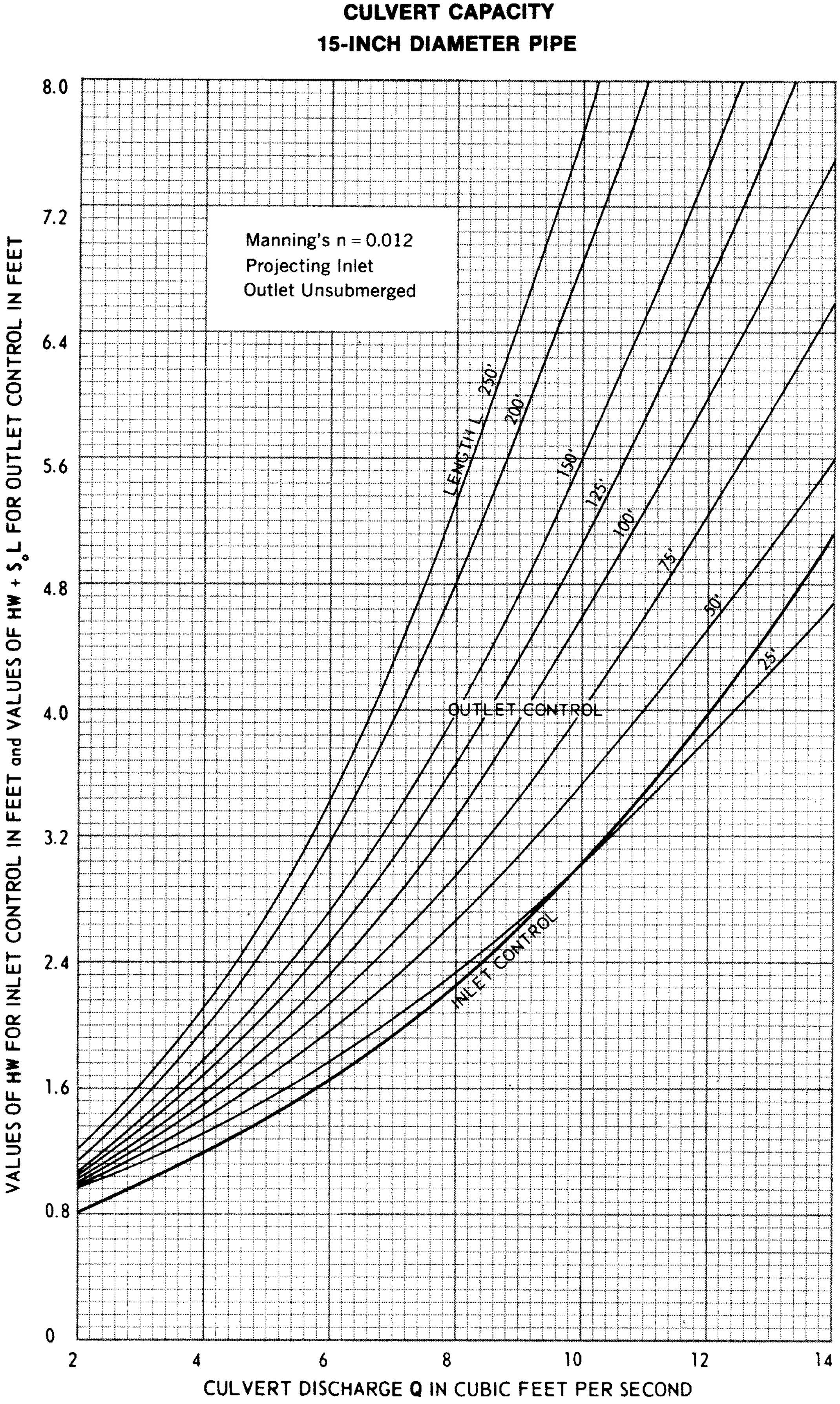

CULVERT CAPACITY
15-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L 250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
8.0
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0
2
4
6
8
10
12
14
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 44

CULVERT CAPACITY
18-INCH DIAMETER PIPE

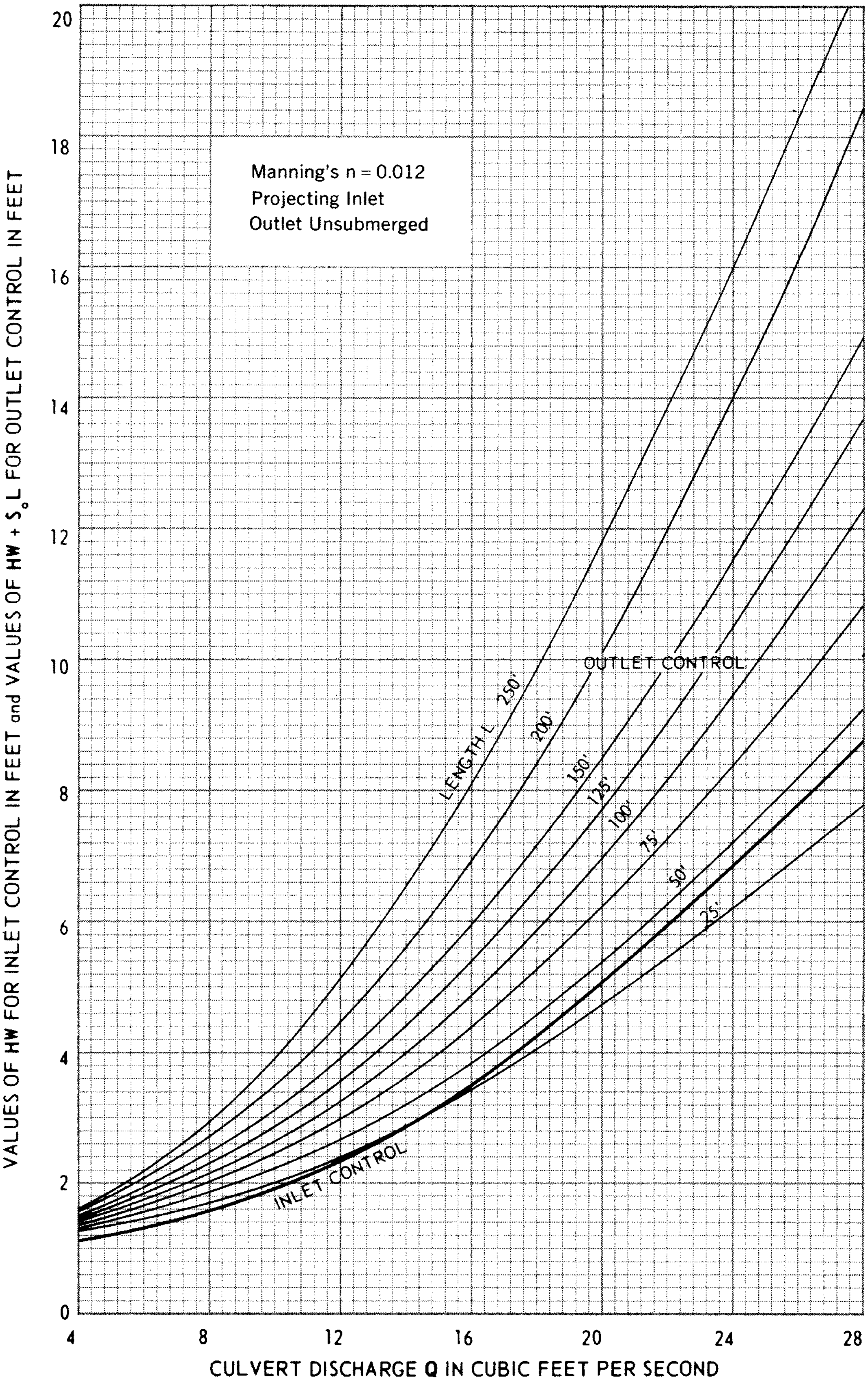


Figure 45

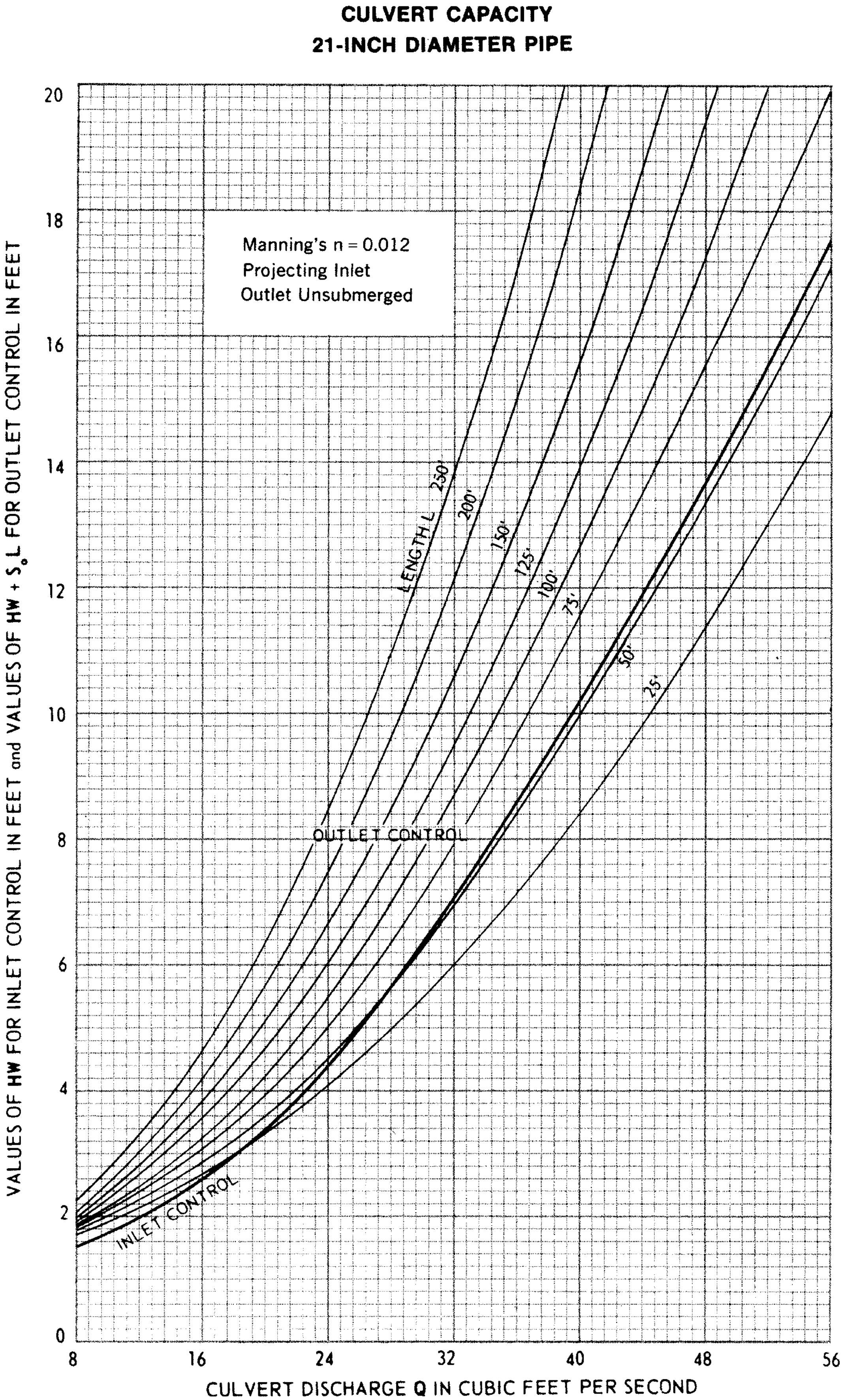

CULVERT CAPACITY
21-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
0
2
4
6
8
10
12
14
16
18
20
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
8
16
24
32
40
48
56

Figure 46

CULVERT CAPACITY
24-INCH DIAMETER PIPE

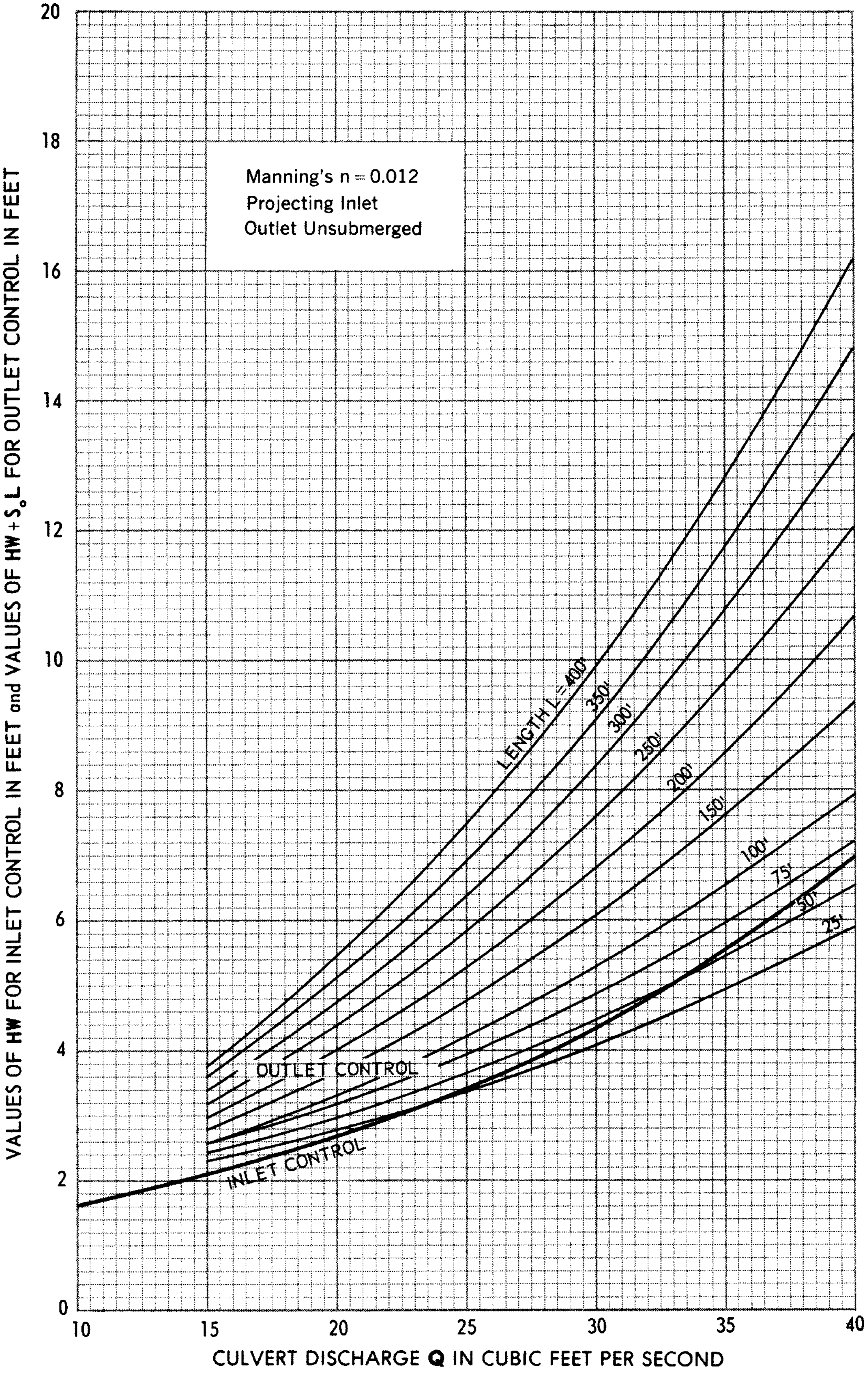


Figure 47

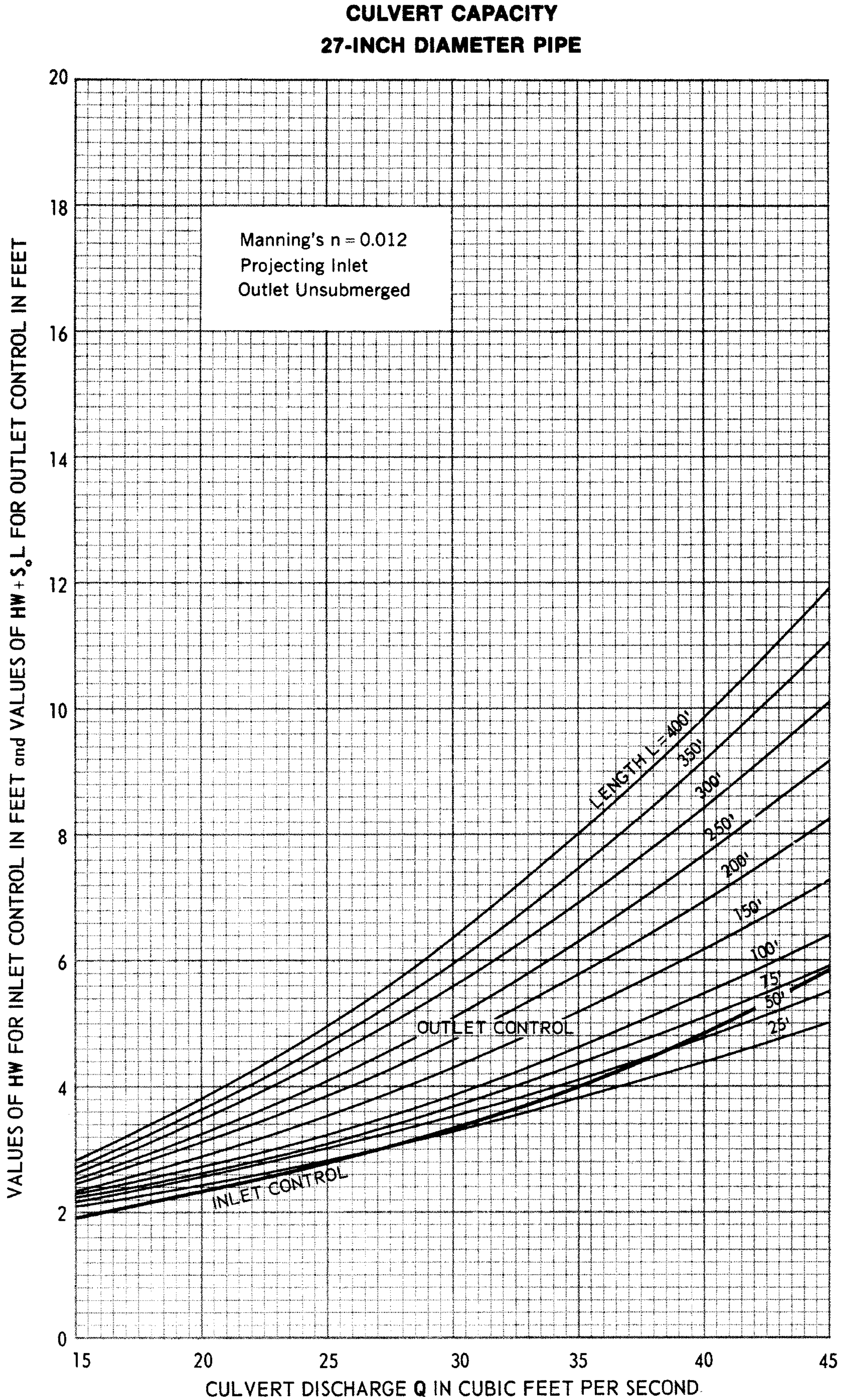

CULVERT CAPACITY
27-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 400'
350'
300'
250'
200'
150'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
0
2
4
6
8
10
12
14
16
18
20
15
20
25
30
35
40
45

Figure 48

CULVERT CAPACITY
30-INCH DIAMETER PIPE

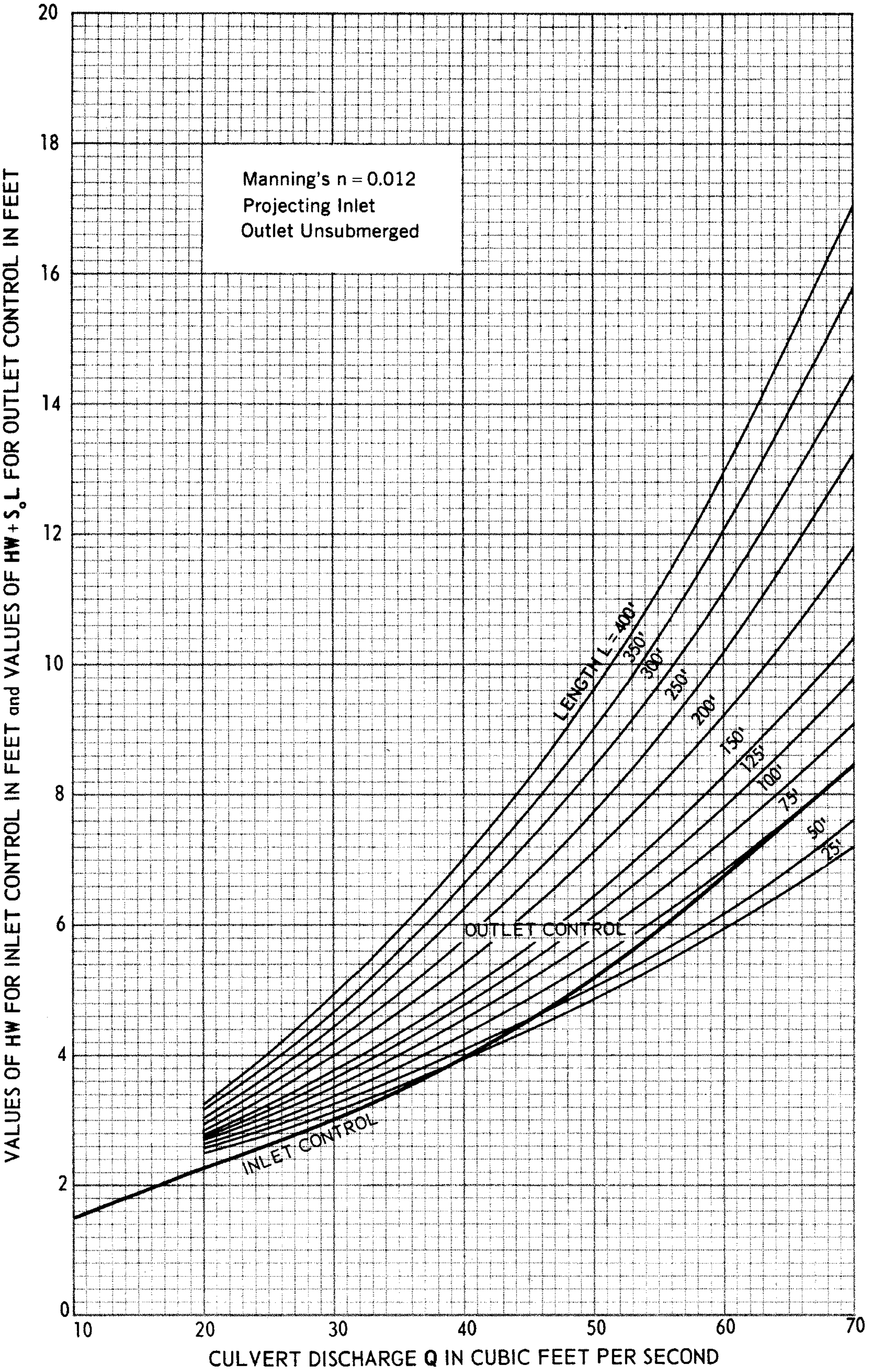


Figure 49

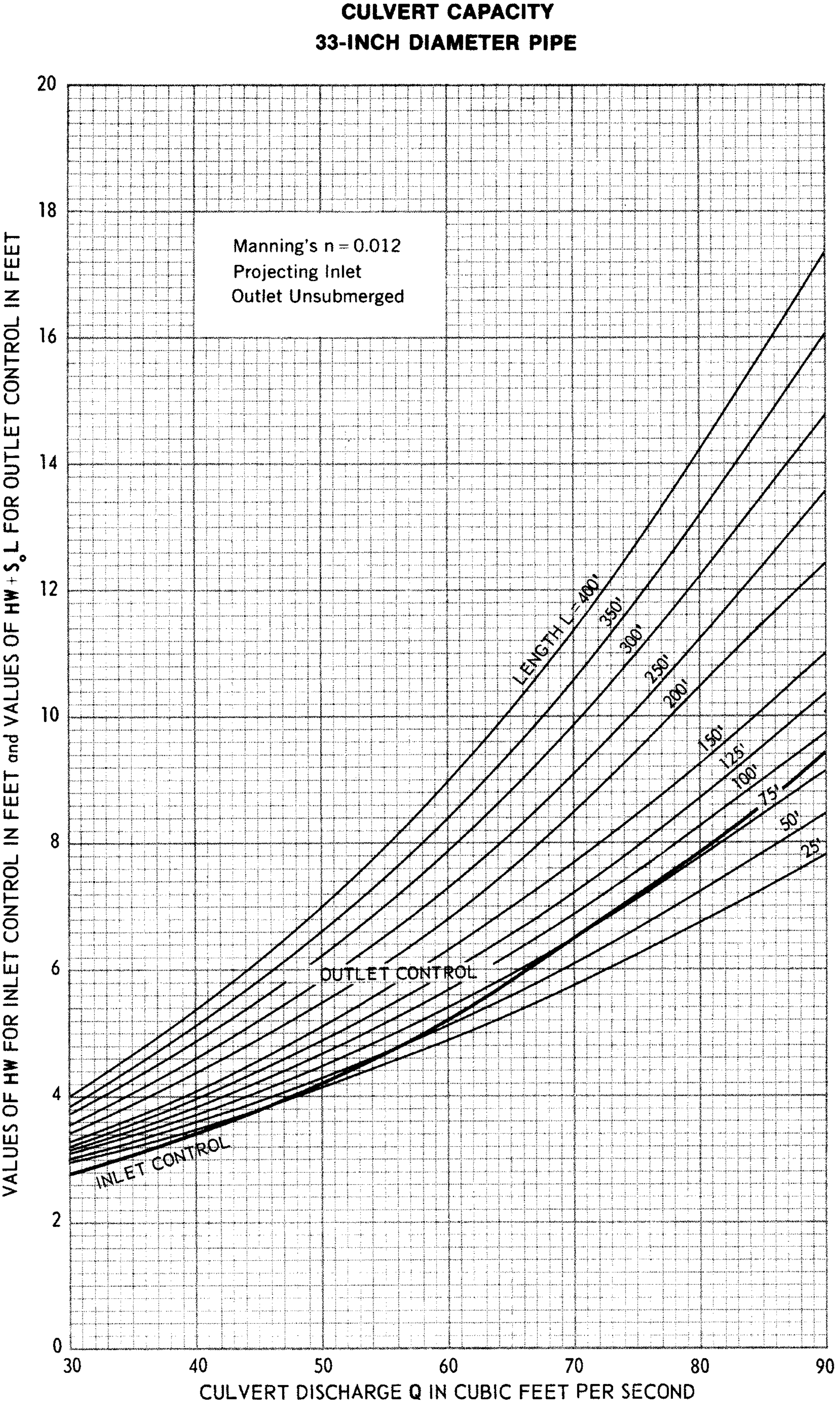

CULVERT CAPACITY
33-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 400'
350'
300'
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
0
2
4
6
8
10
12
14
16
18
20
30
40
50
60
70
80
90

Figure 50

CULVERT CAPACITY
36-INCH DIAMETER PIPE

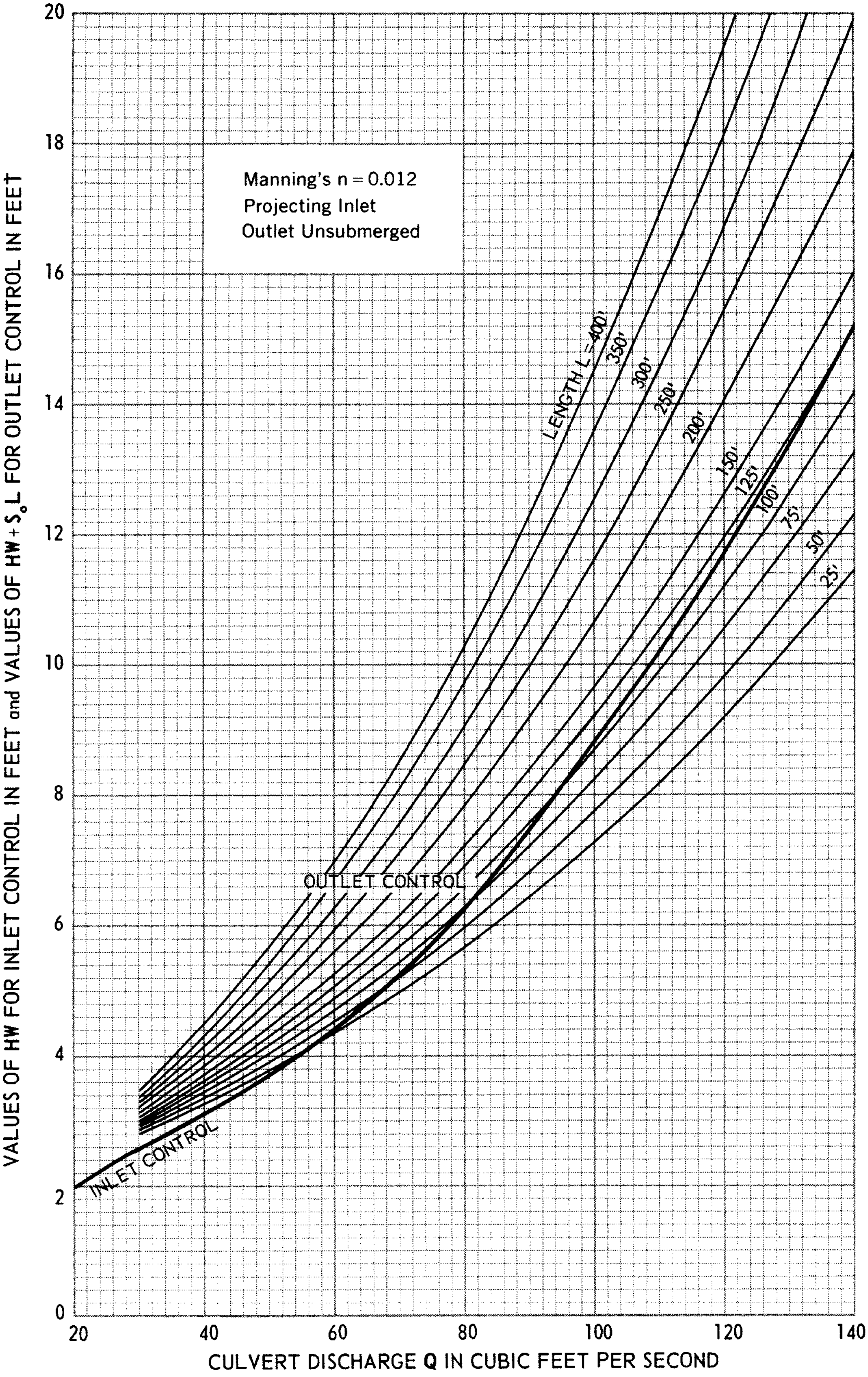


Figure 51

CULVERT CAPACITY
42-INCH DIAMETER PIPE

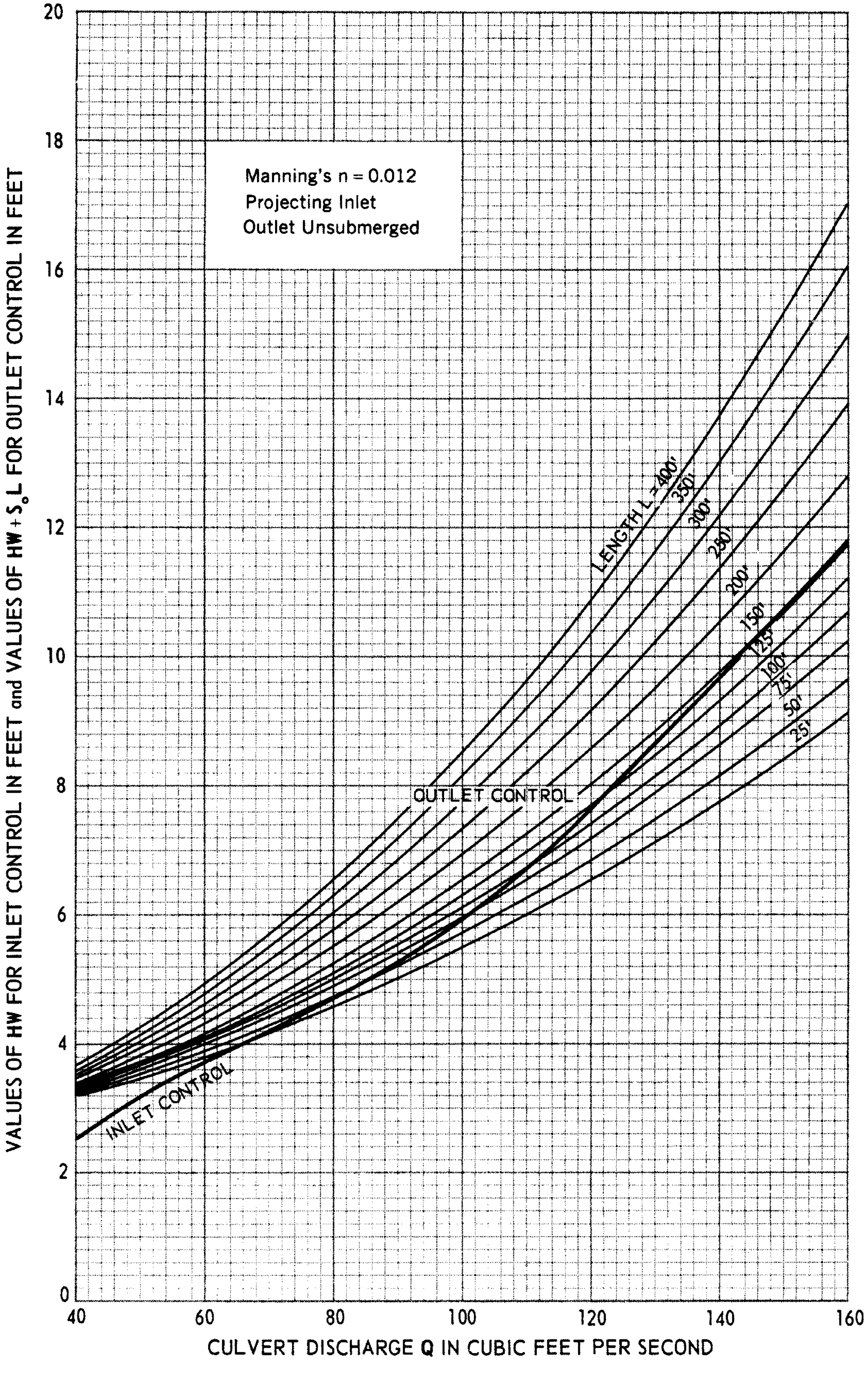


Figure 52

CULVERT CAPACITY
48-INCH DIAMETER PIPE

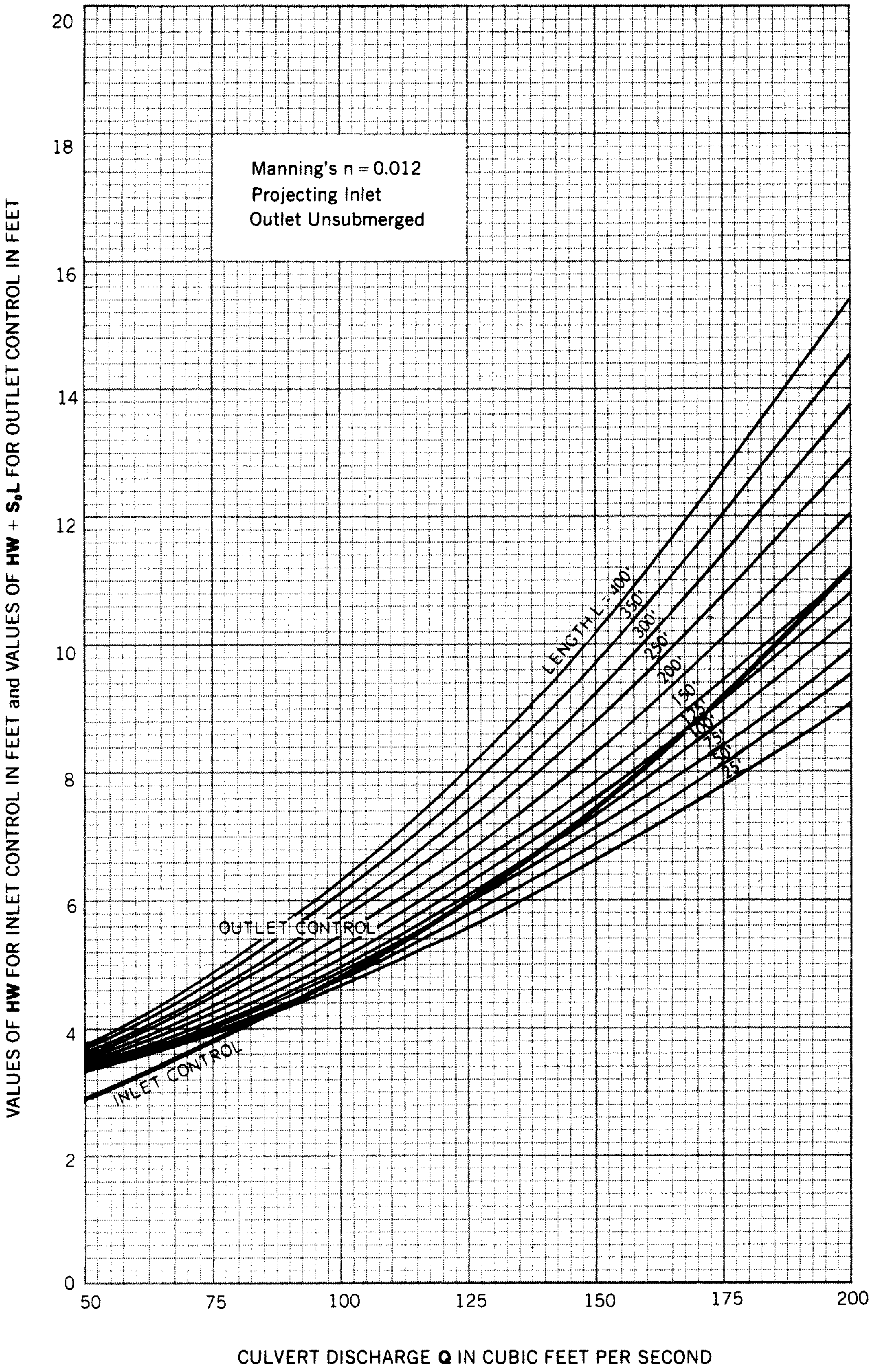


Figure 53

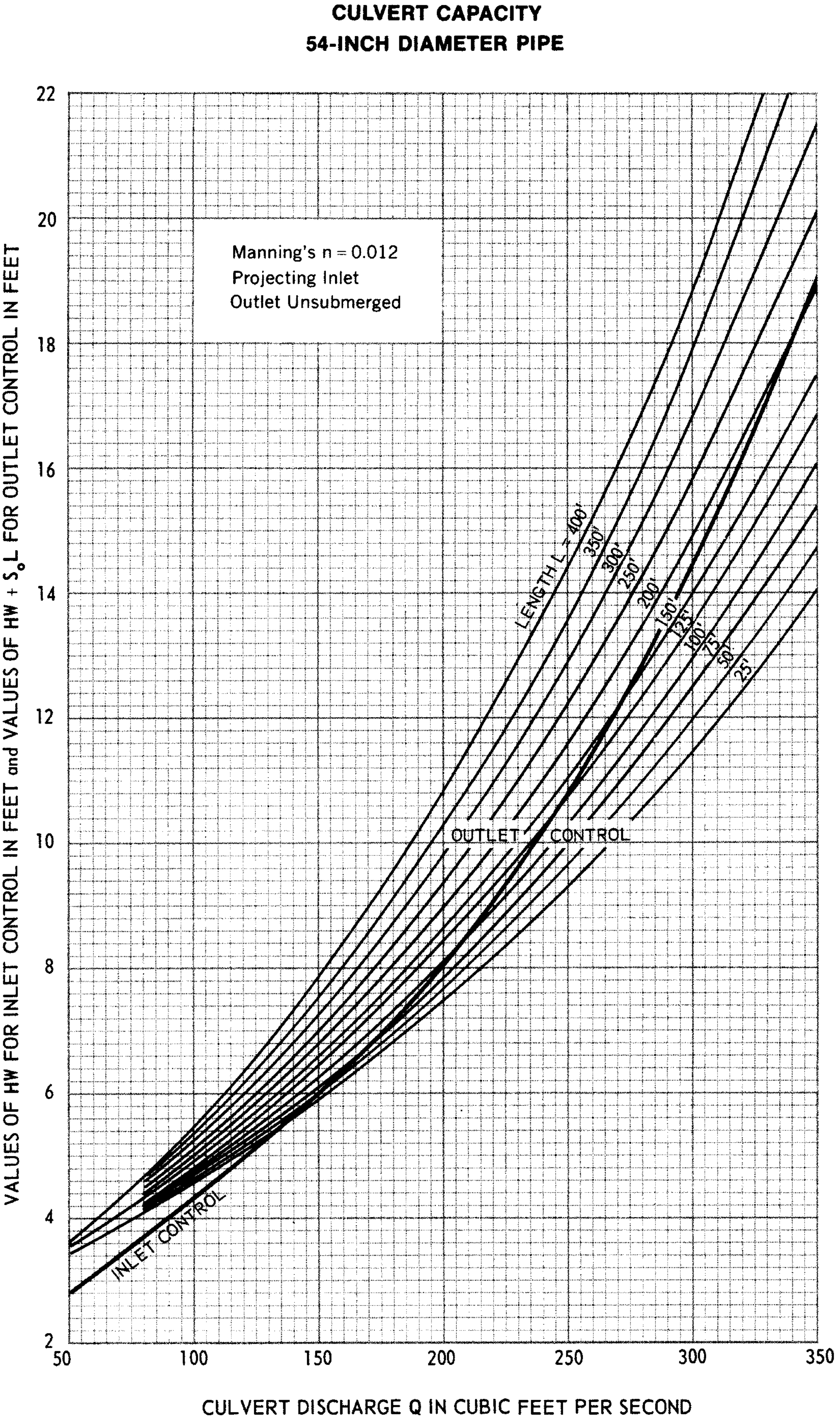

CULVERT CAPACITY
54-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 400'
350'
300'
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
2
4
6
8
10
12
14
16
18
20
22
50
100
150
200
250
300
350
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 54

CULVERT CAPACITY
60-INCH DIAMETER PIPE

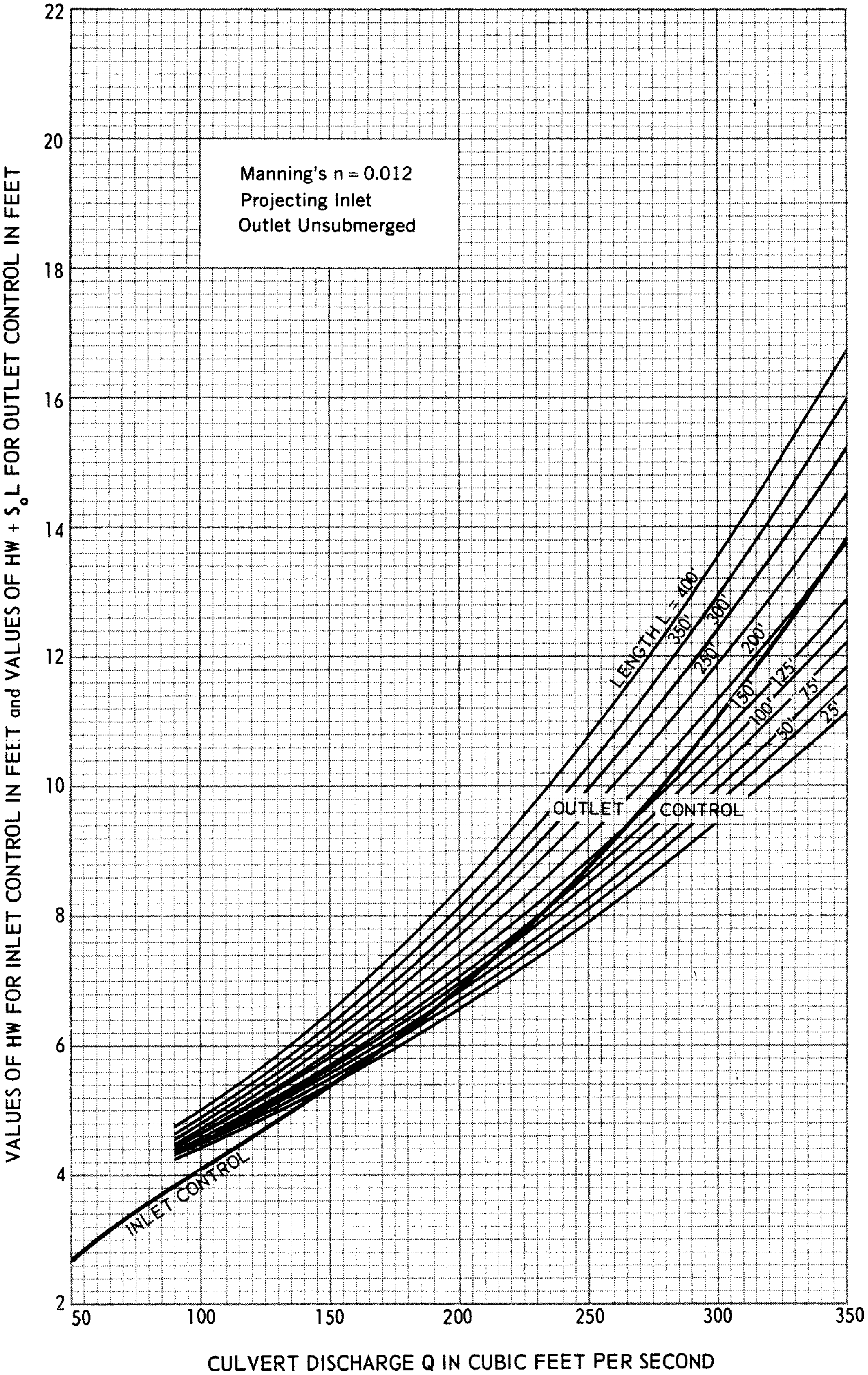


Figure 55

CULVERT CAPACITY
66-INCH DIAMETER PIPE

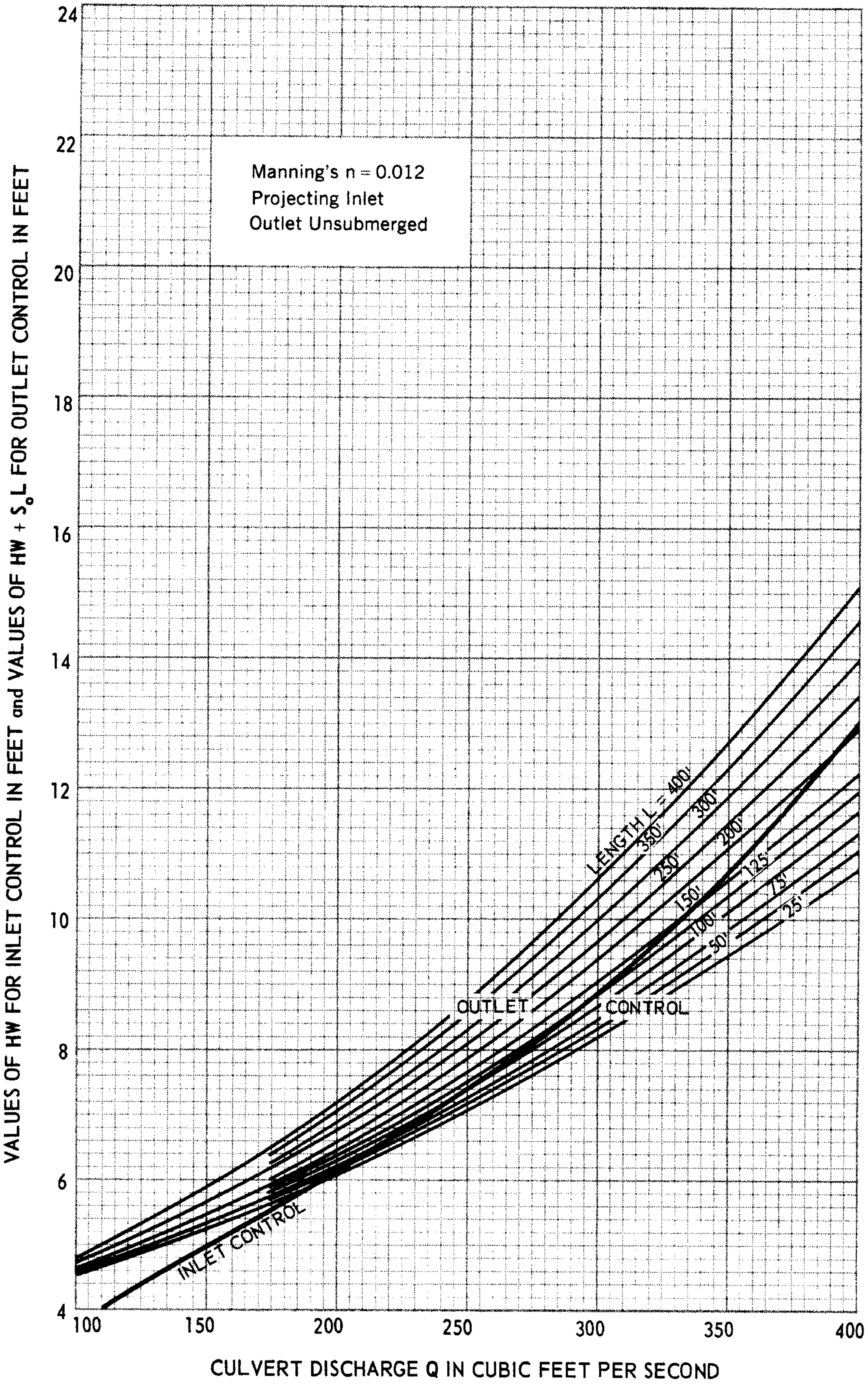


Figure 56

CULVERT CAPACITY
72-INCH DIAMETER PIPE

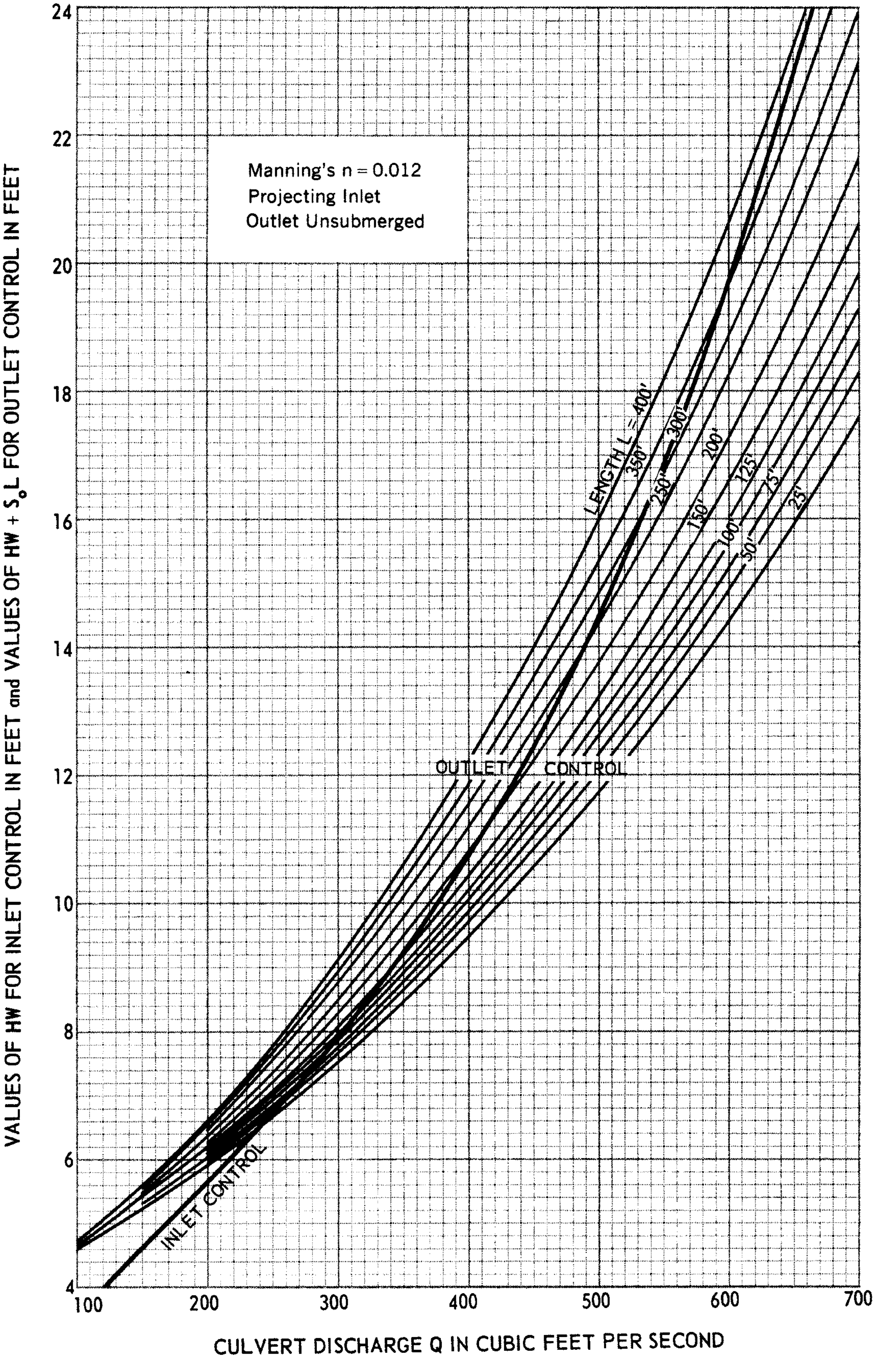


Figure 57

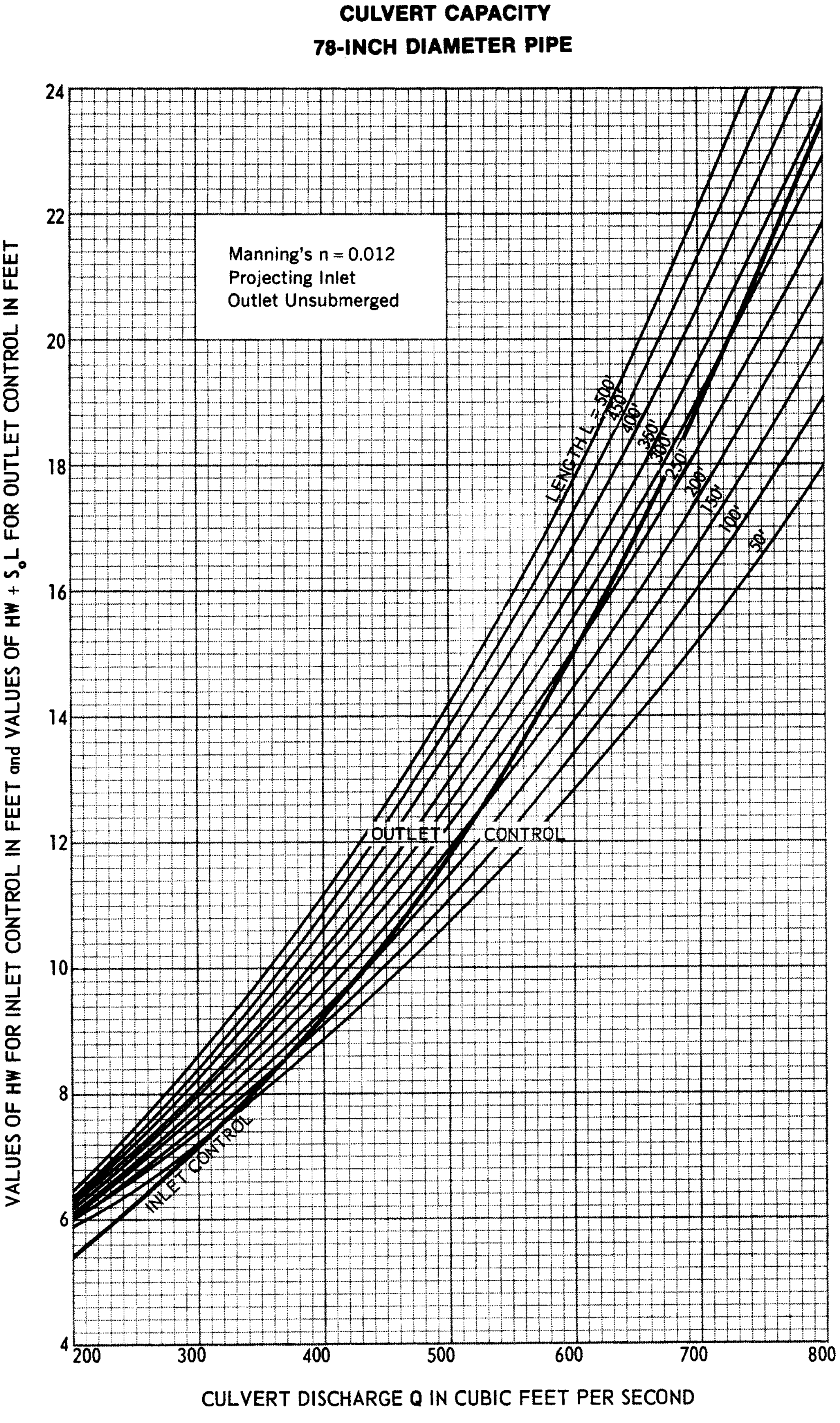

CULVERT CAPACITY
78-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
4
6
8
10
12
14
16
18
20
22
24
200
300
400
500
600
700
800

Figure 58

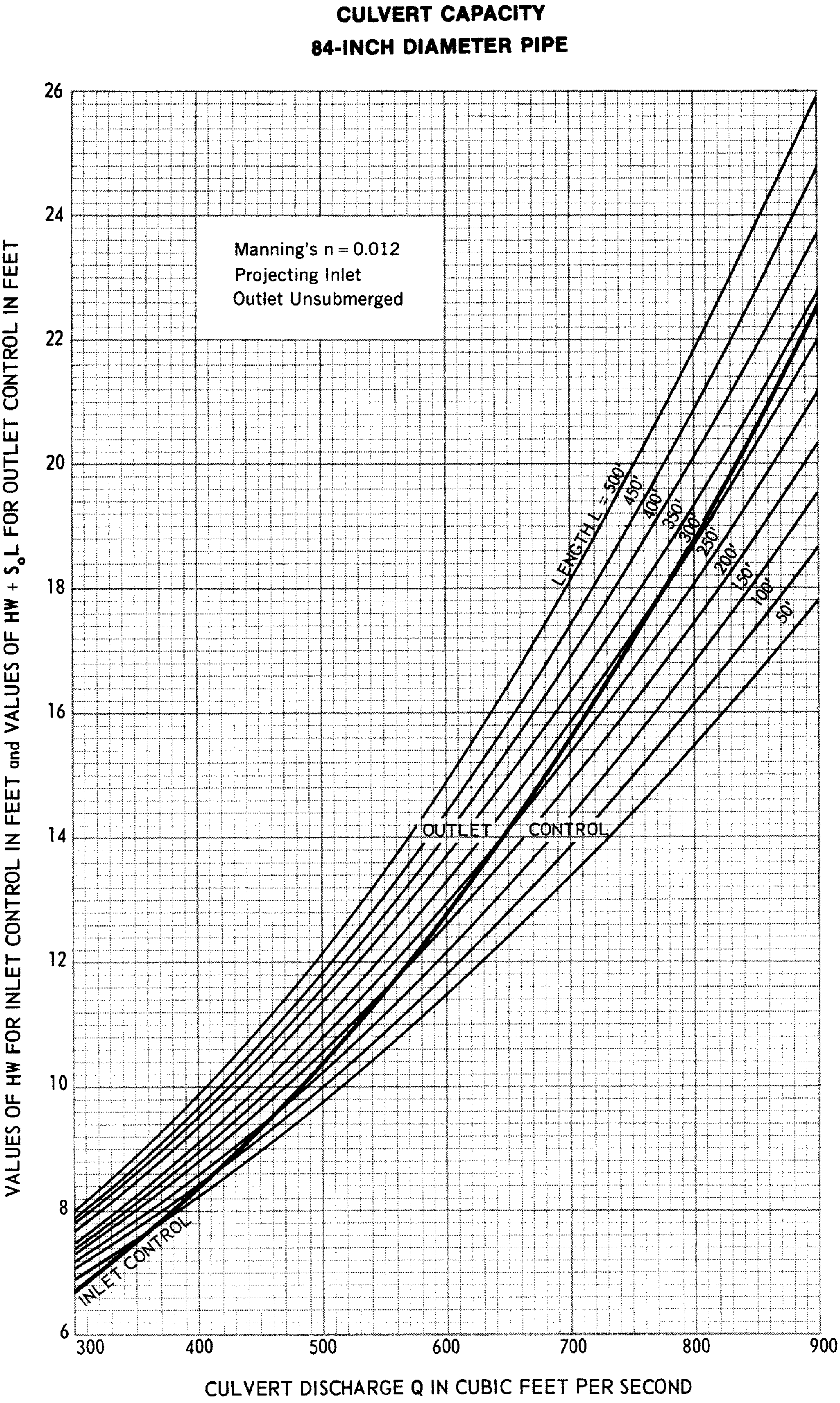

CULVERT CAPACITY
84-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
6
8
10
12
14
16
18
20
22
24
26
300
400
500
600
700
800
900
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 59

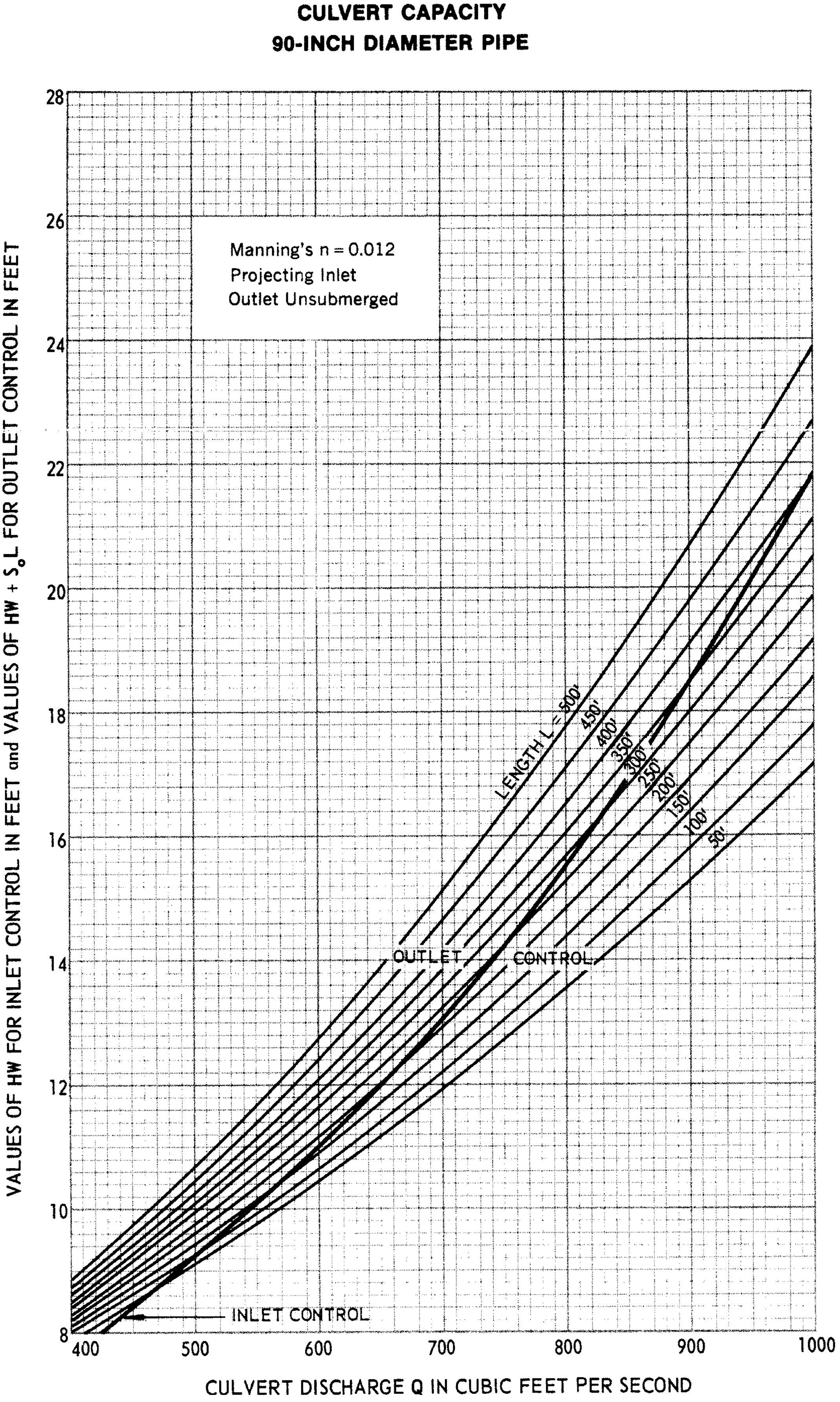

CULVERT CAPACITY
90-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
28
26
24
22
20
18
16
14
12
10
8
400
500
600
700
800
900
1000
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
LENGTH L = 500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL

Figure 60

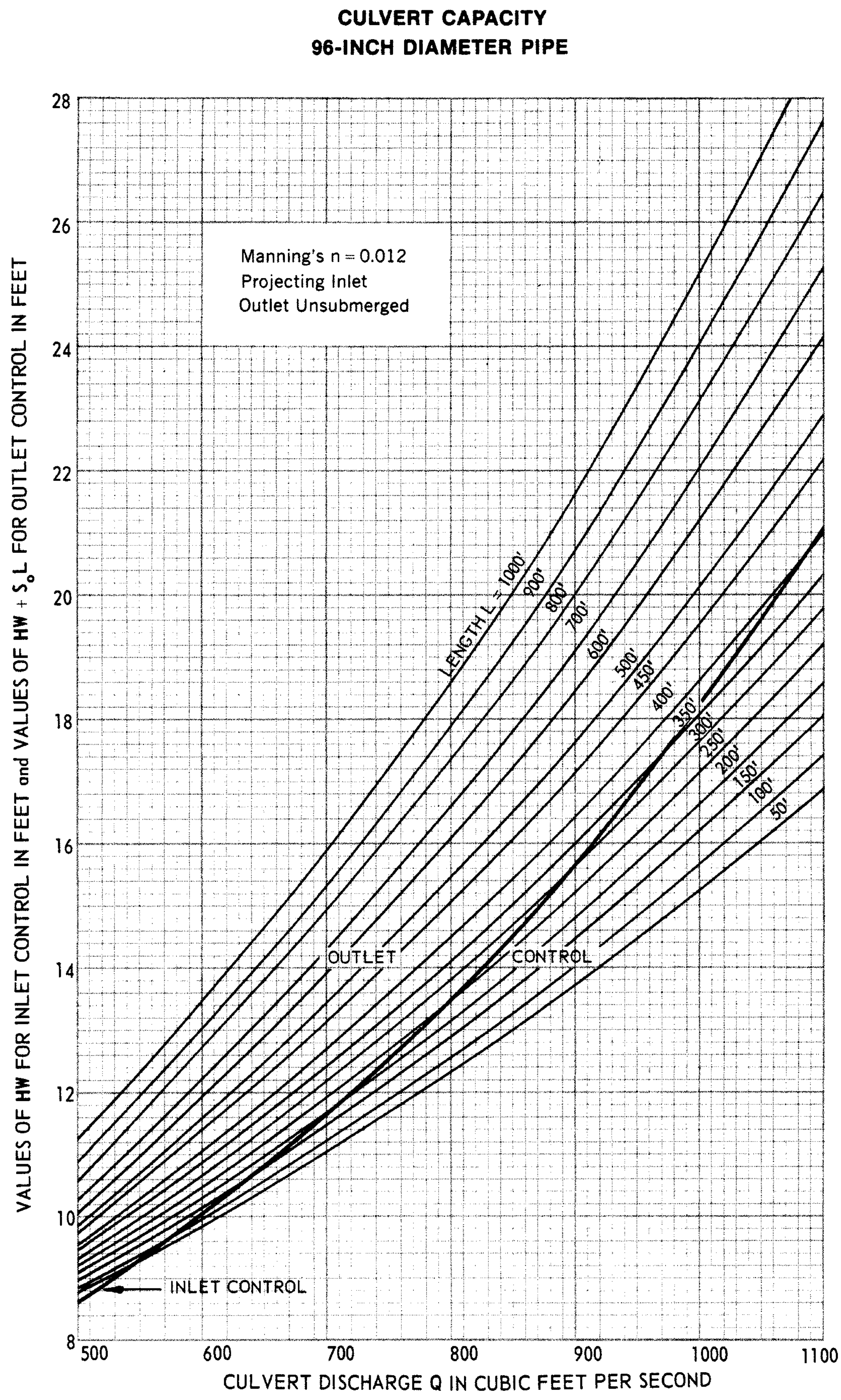

CULVERT CAPACITY
96-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 1000'
900'
800'
700'
600'
500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET
CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
8
10
12
14
16
18
20
22
24
26
28
500
600
700
800
900
1000
1100
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 61

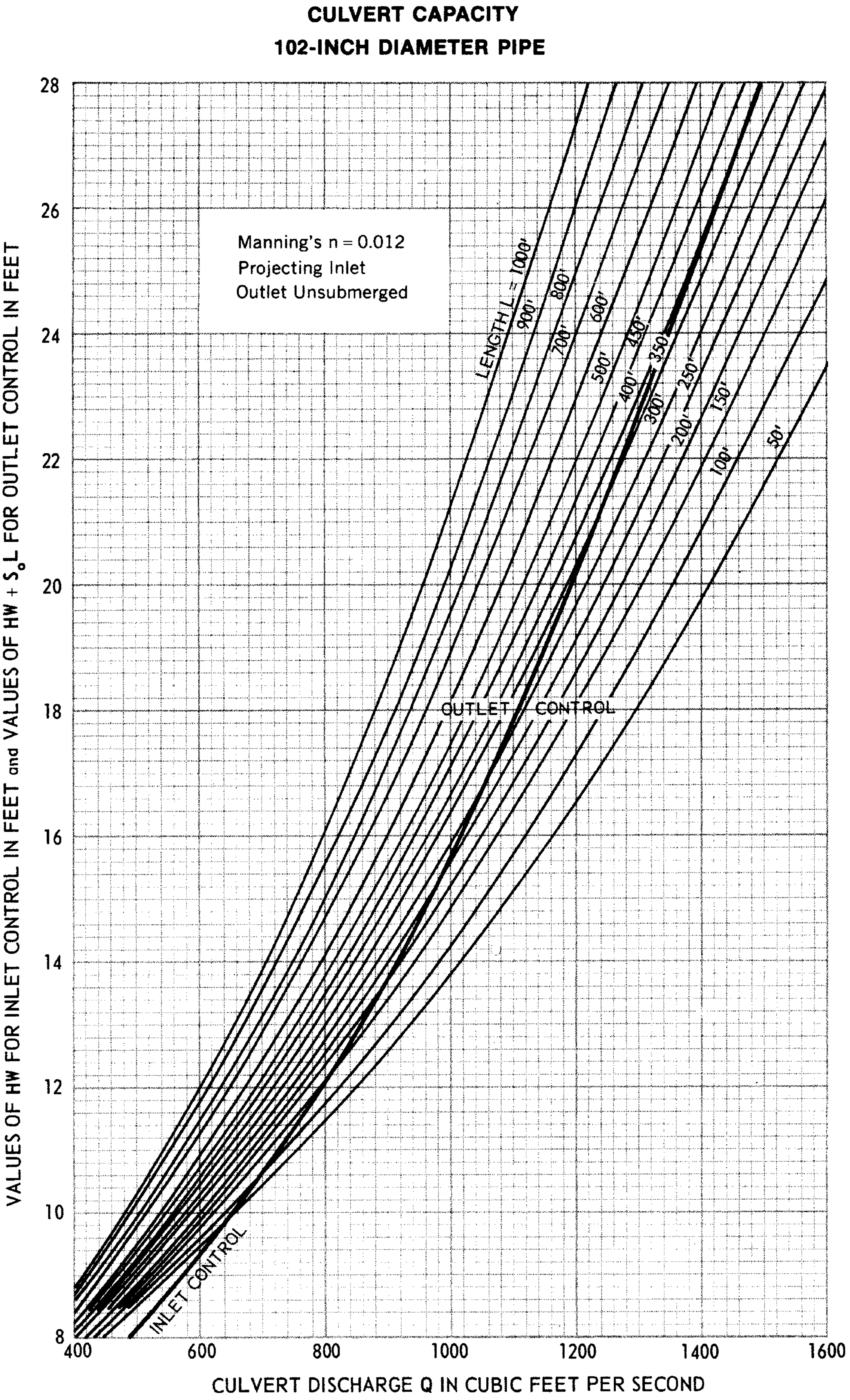

CULVERT CAPACITY
102-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 1000'
900'
800'
700'
600'
500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
8
10
12
14
16
18
20
22
24
26
28
400
600
800
1000
1200
1400
1600
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 62

CULVERT CAPACITY

108-INCH DIAMETER PIPE

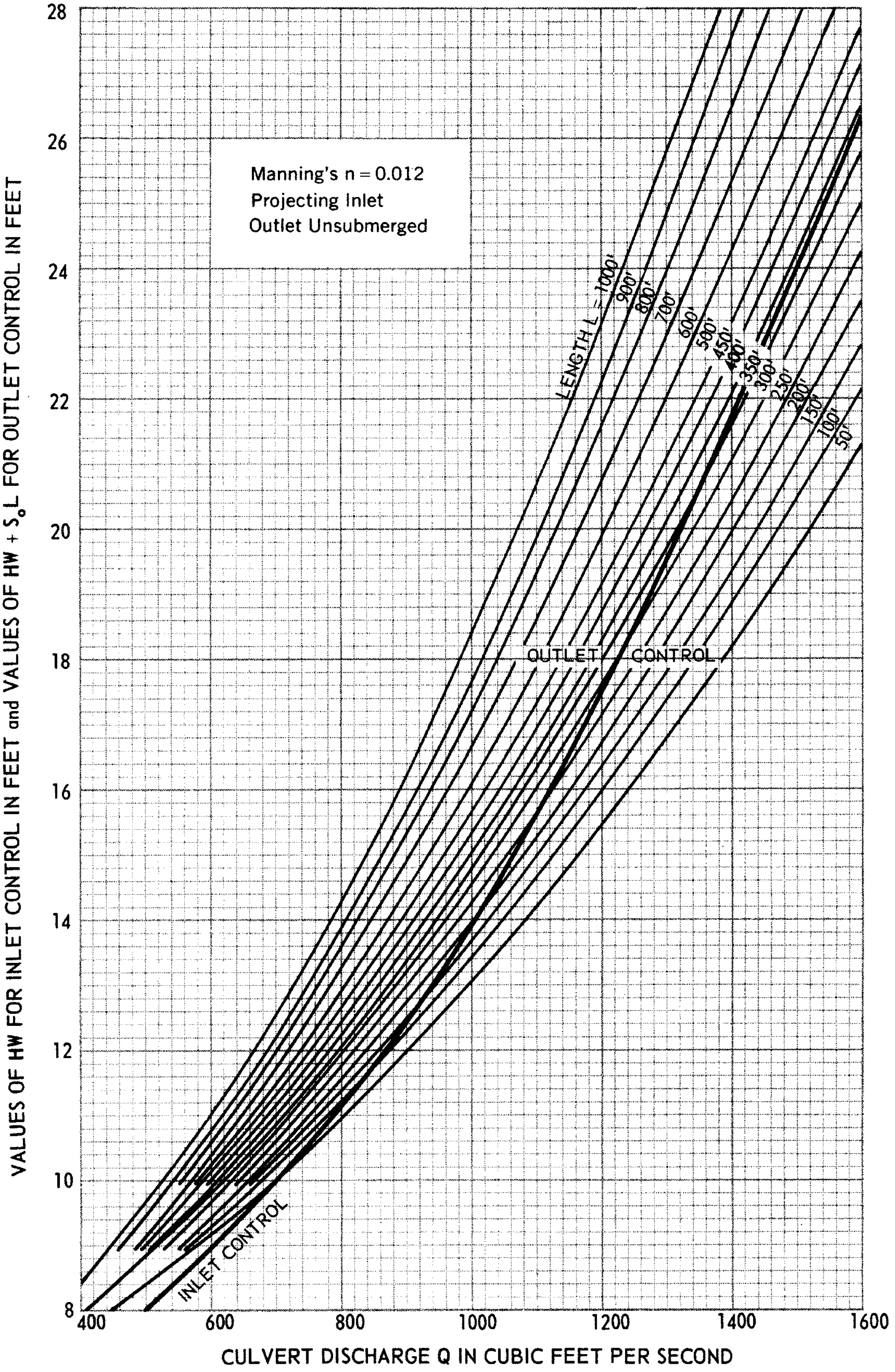


Figure 63

CULVERT CAPACITY
114-INCH DIAMETER PIPE

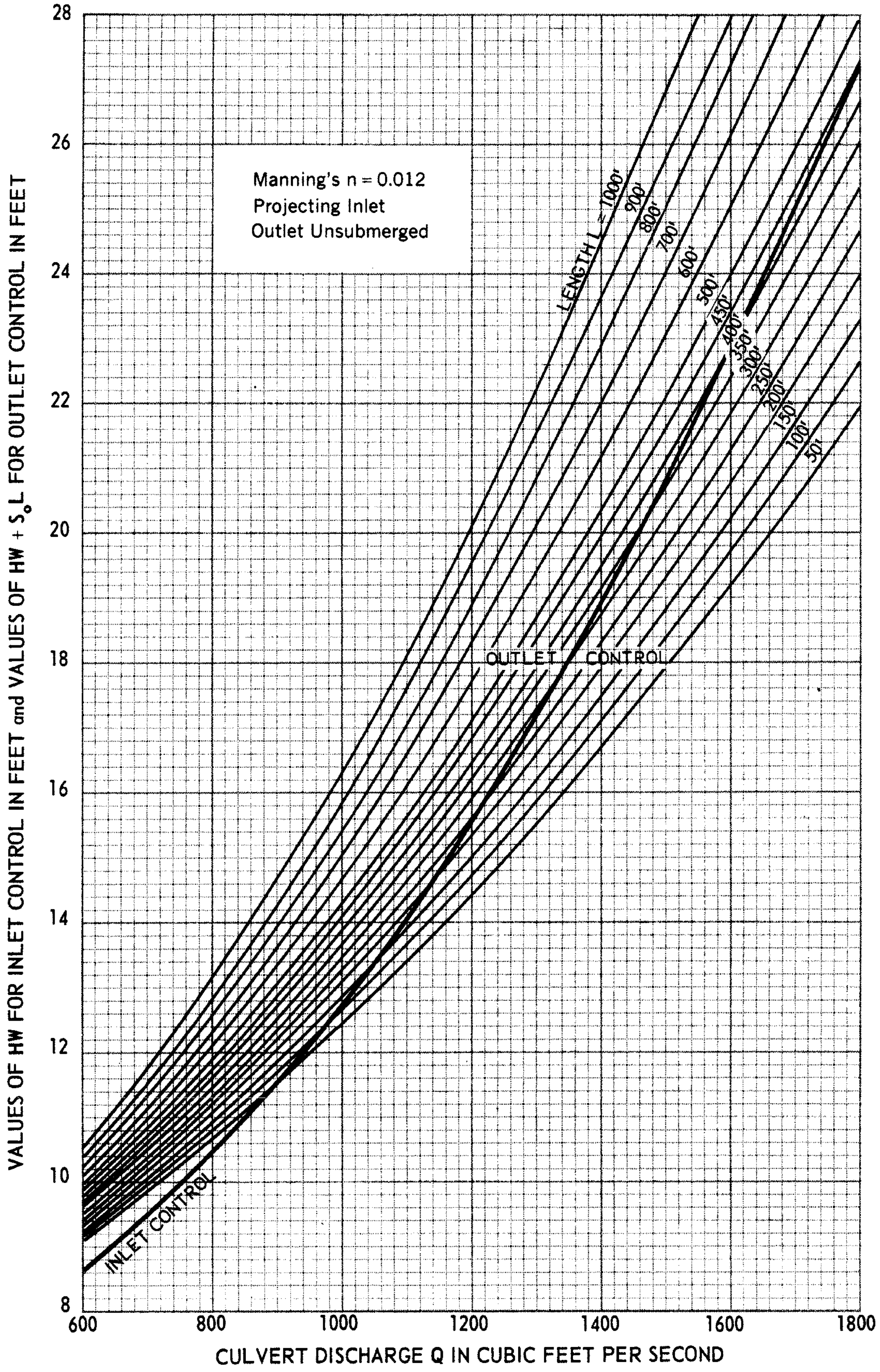


Figure 64

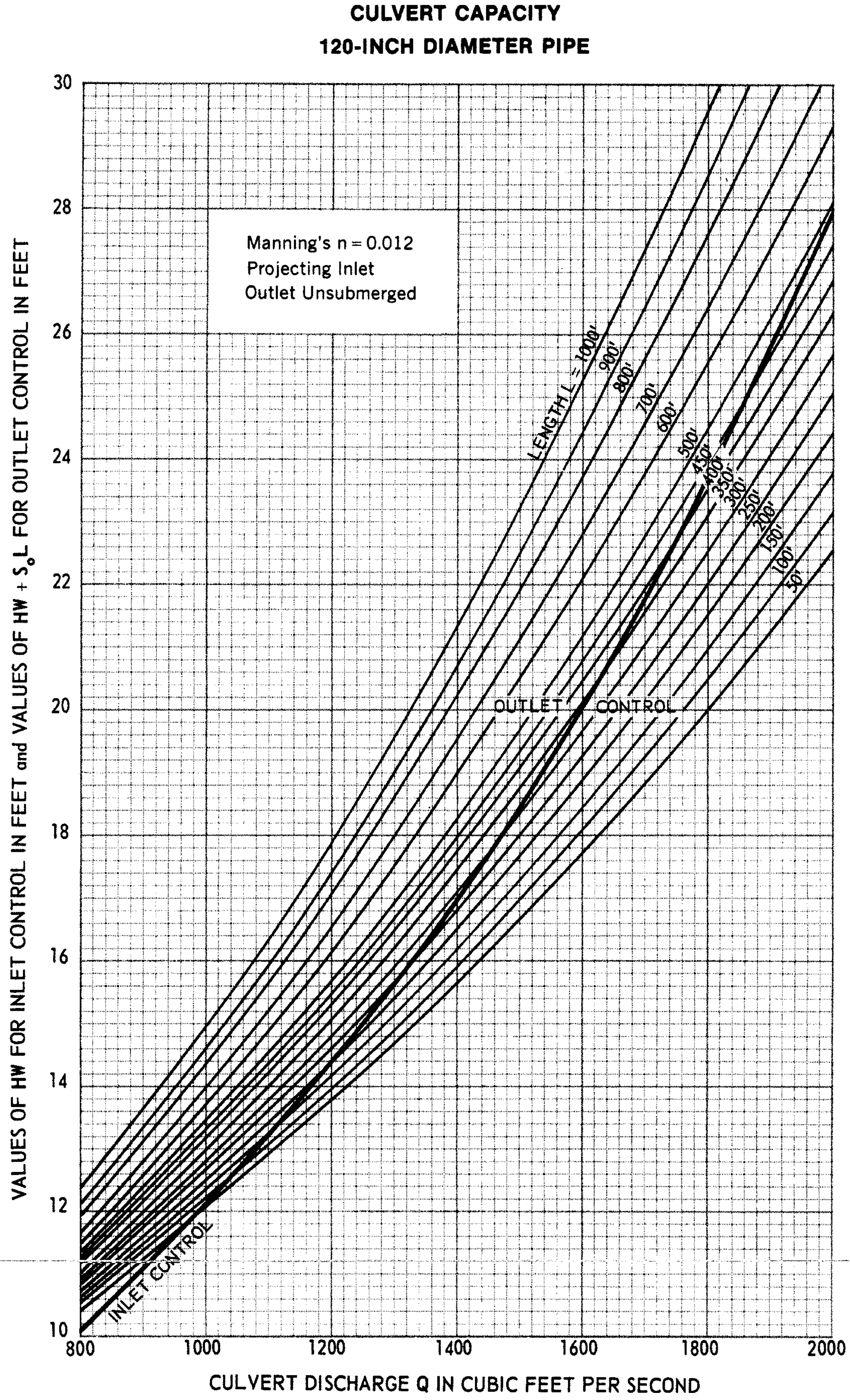

CULVERT CAPACITY
120-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 1000'
900'
800'
700'
600'
500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S_oL FOR OUTLET CONTROL IN FEET
10
12
14
16
18
20
22
24
26
28
30
800
1000
1200
1400
1600
1800
2000
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 65

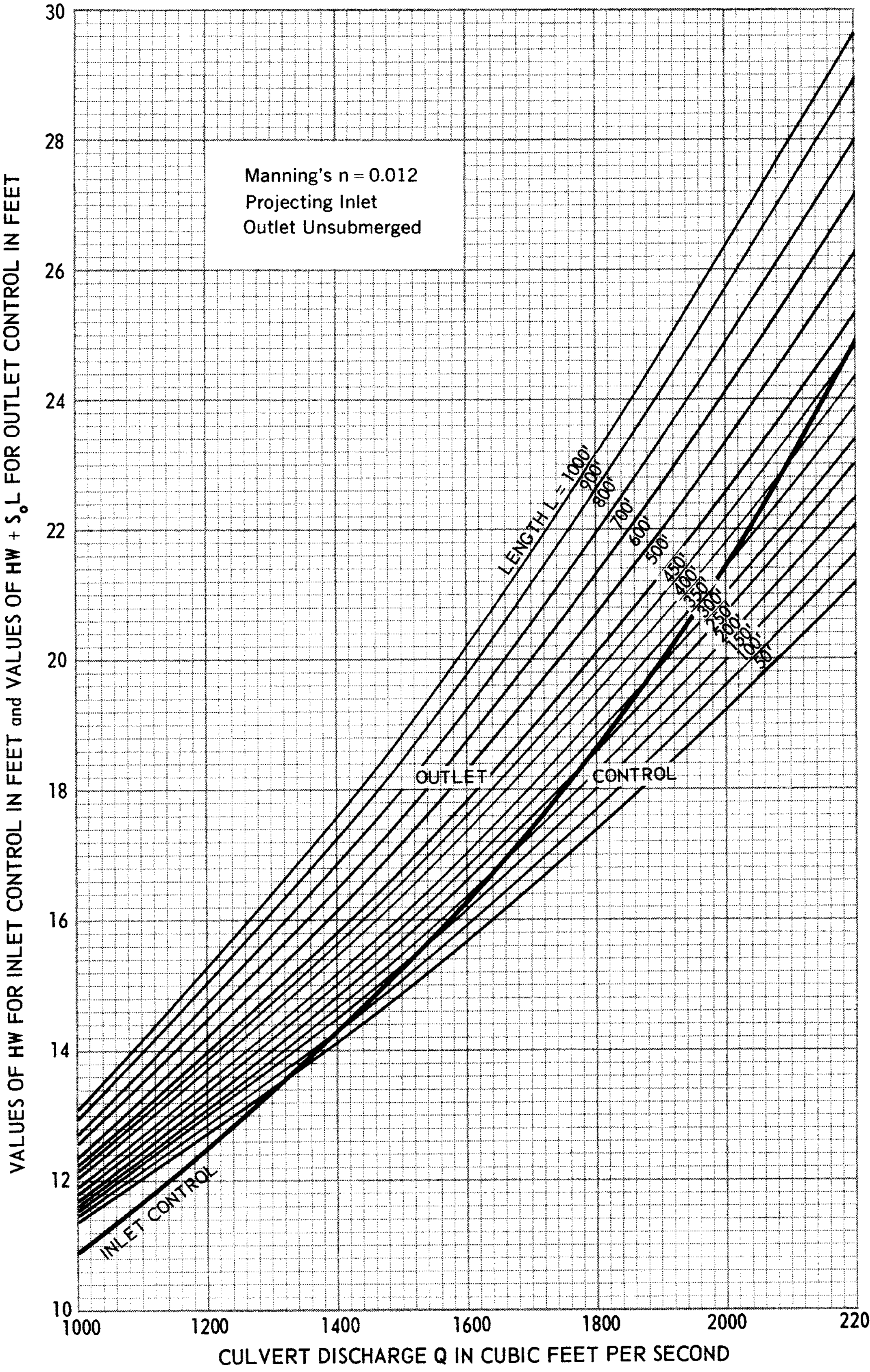

CULVERT CAPACITY
132-INCH DIAMETER PIPE
Manning's n = 0.012
Projecting Inlet
Outlet Unsubmerged
LENGTH L = 1000'
900'
800'
700'
600'
500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
10
12
14
16
18
20
22
24
26
28
30
1000
1200
1400
1600
1800
2000
2200
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 66

CULVERT CAPACITY
144-INCH DIAMETER PIPE

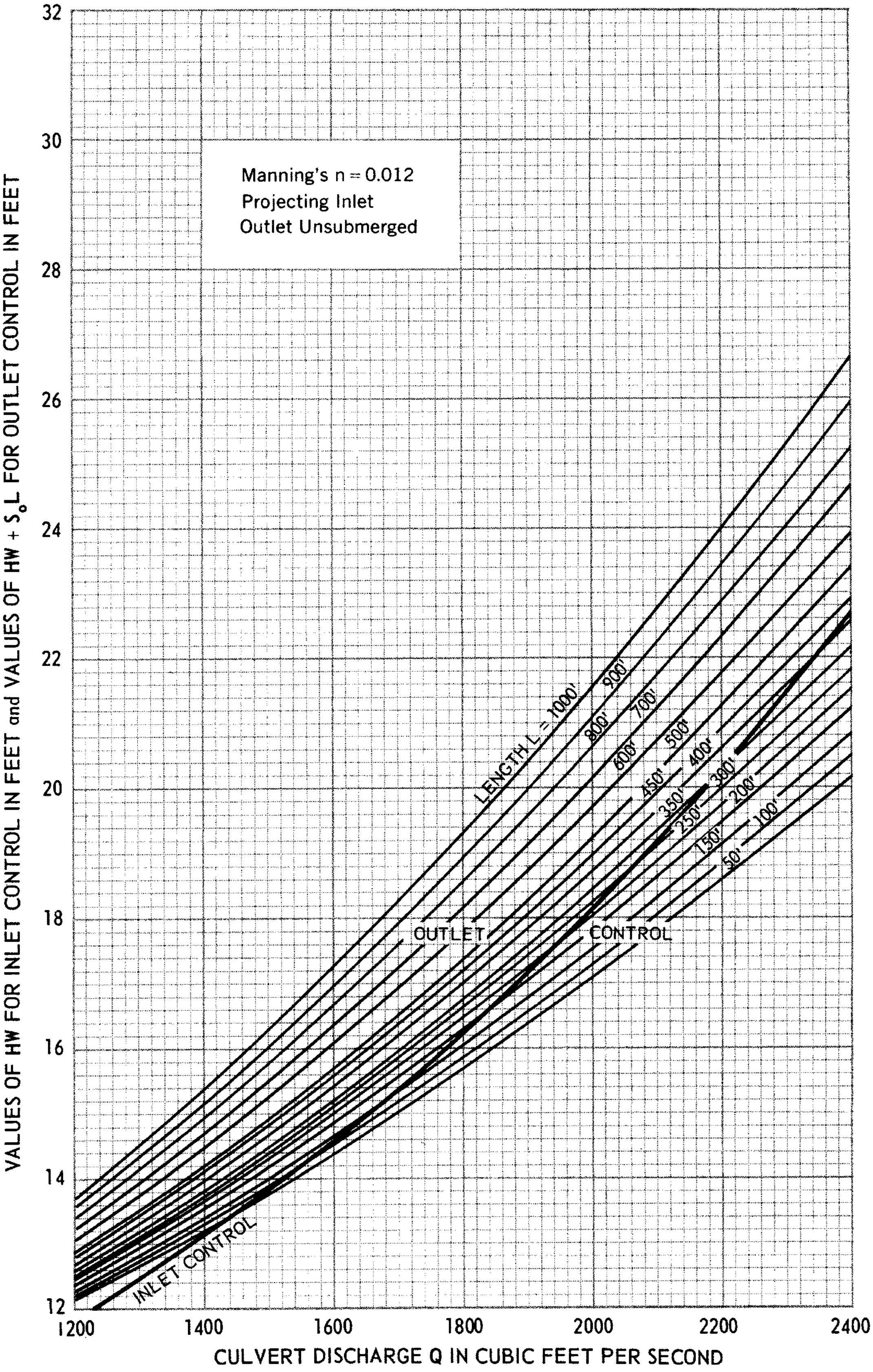


Figure 67

CULVERT CAPACITY
14 x 23-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 18-INCH CIRCULAR

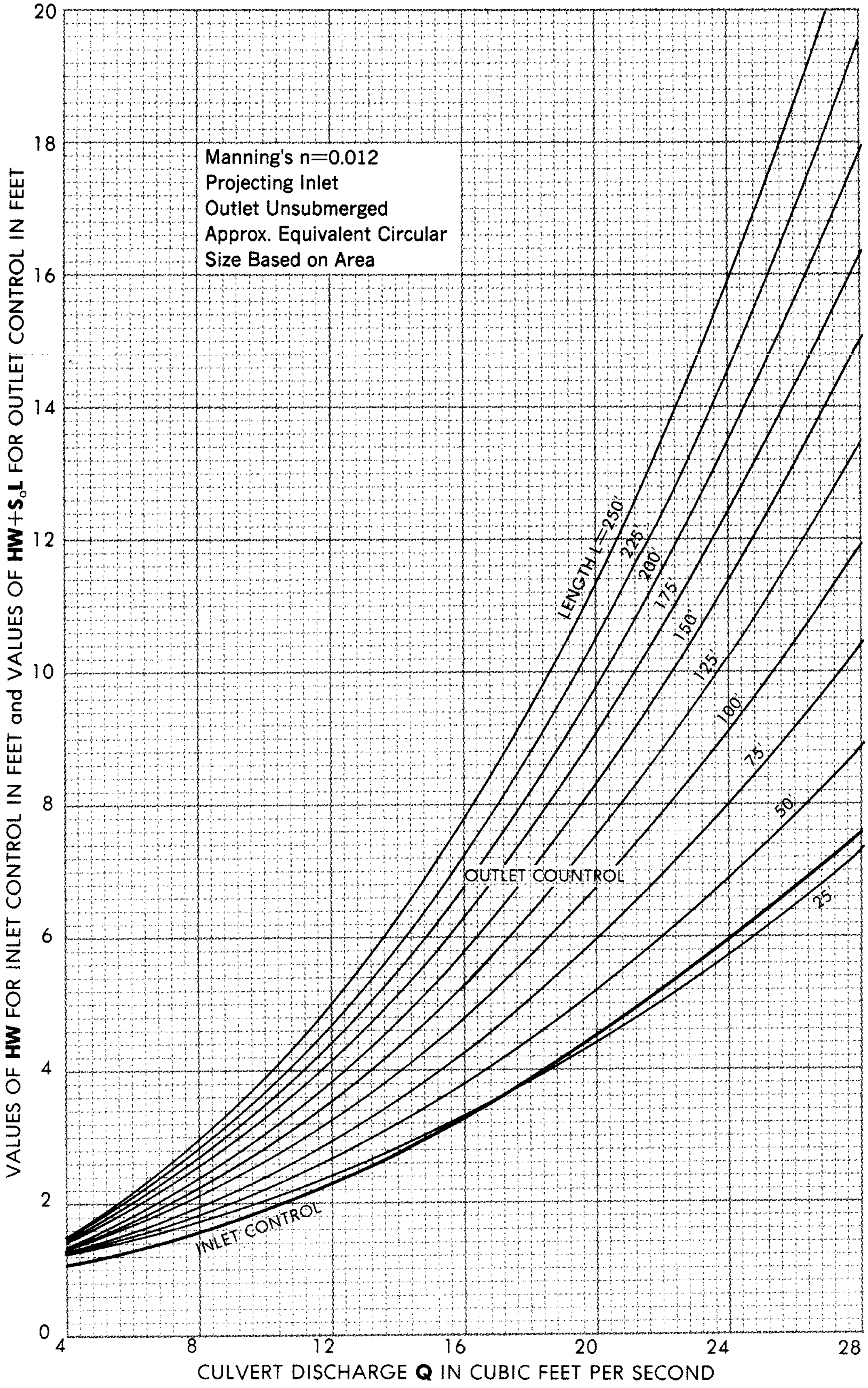


Figure 68

CULVERT CAPACITY
19 x 30-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 24-INCH CIRCULAR

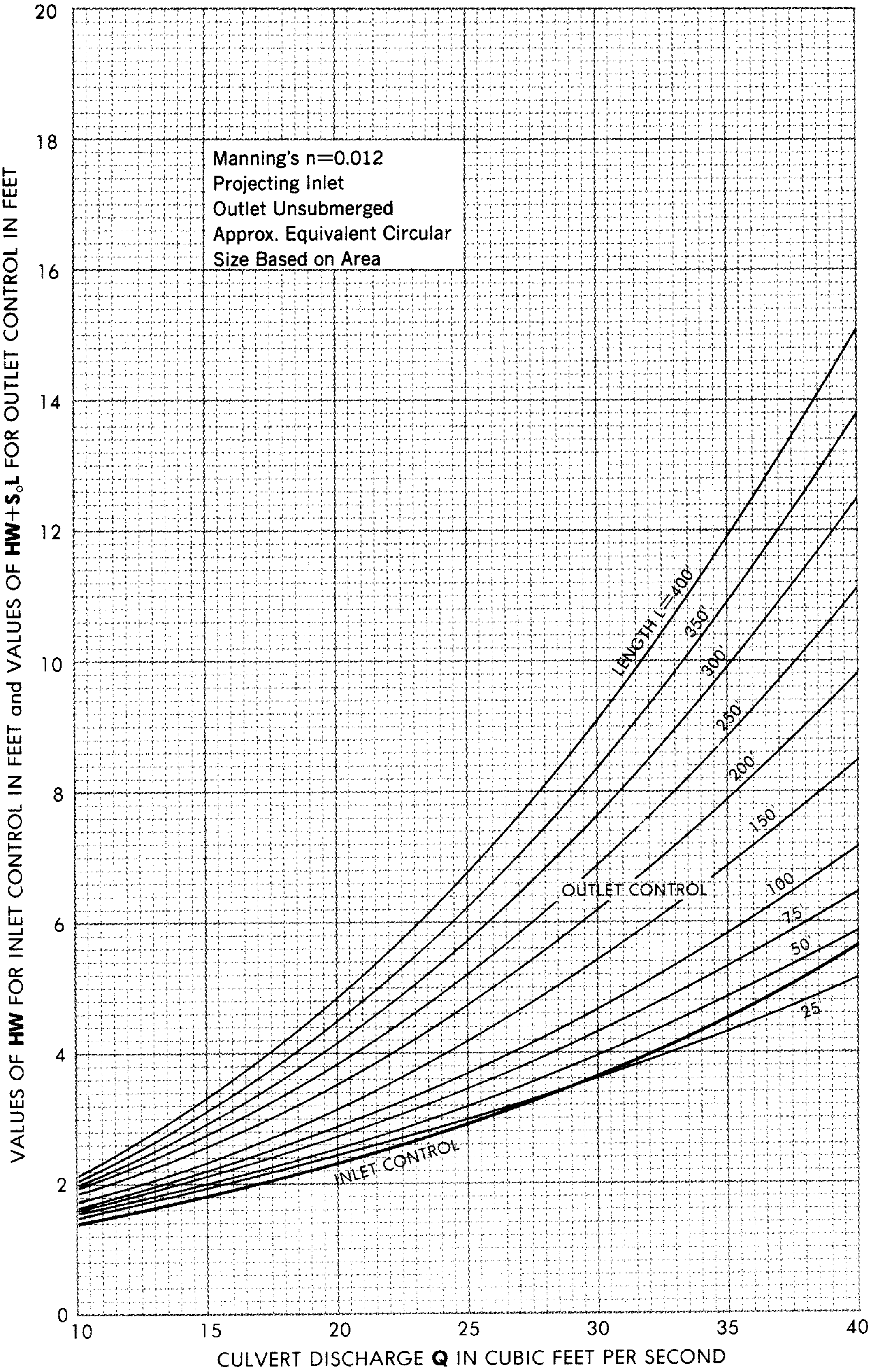


Figure 69

CULVERT CAPACITY
24 x 38-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 30-INCH CIRCULAR

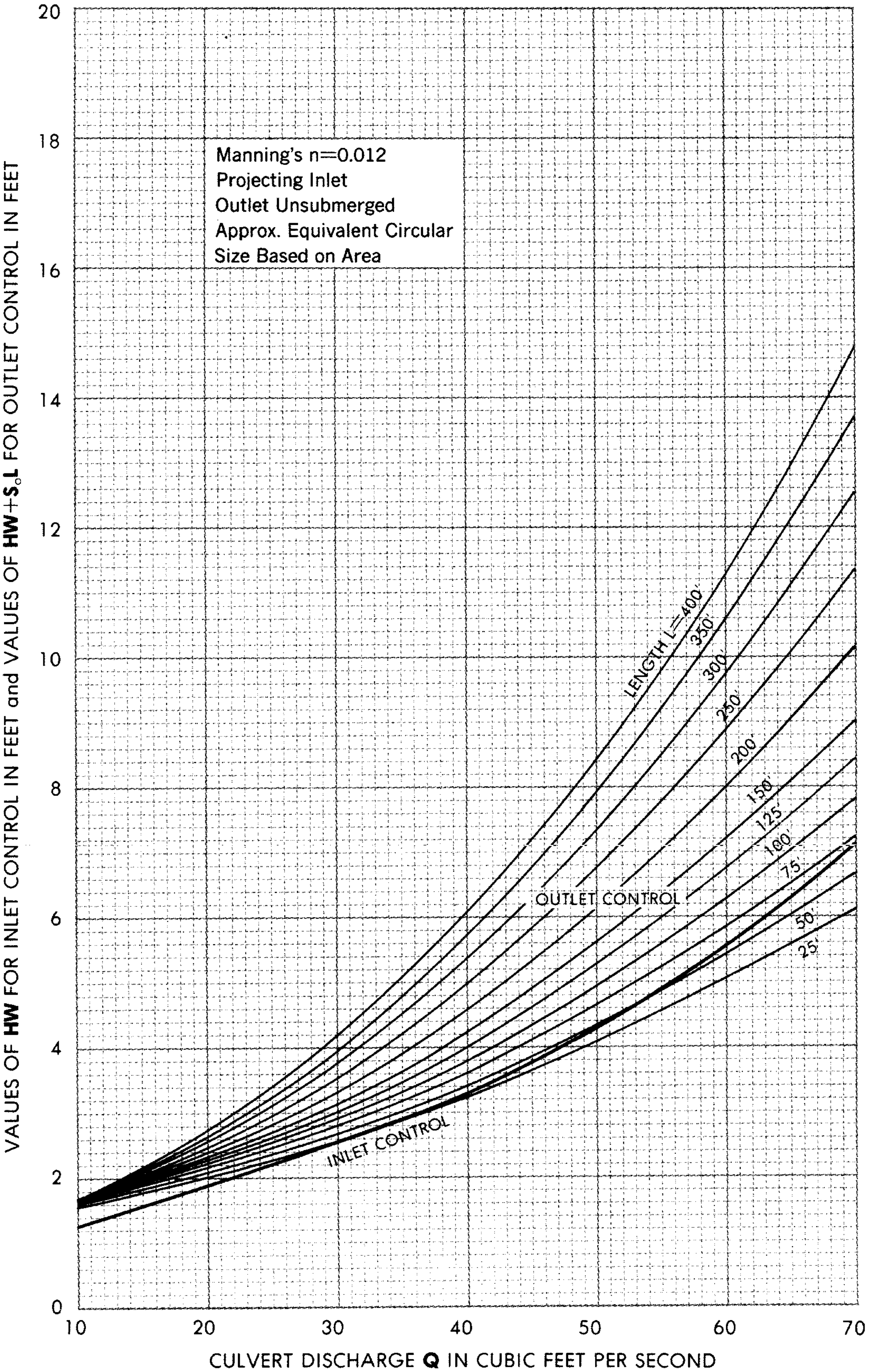


Figure 70

CULVERT CAPACITY
29 x 45-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 36-INCH CIRCULAR

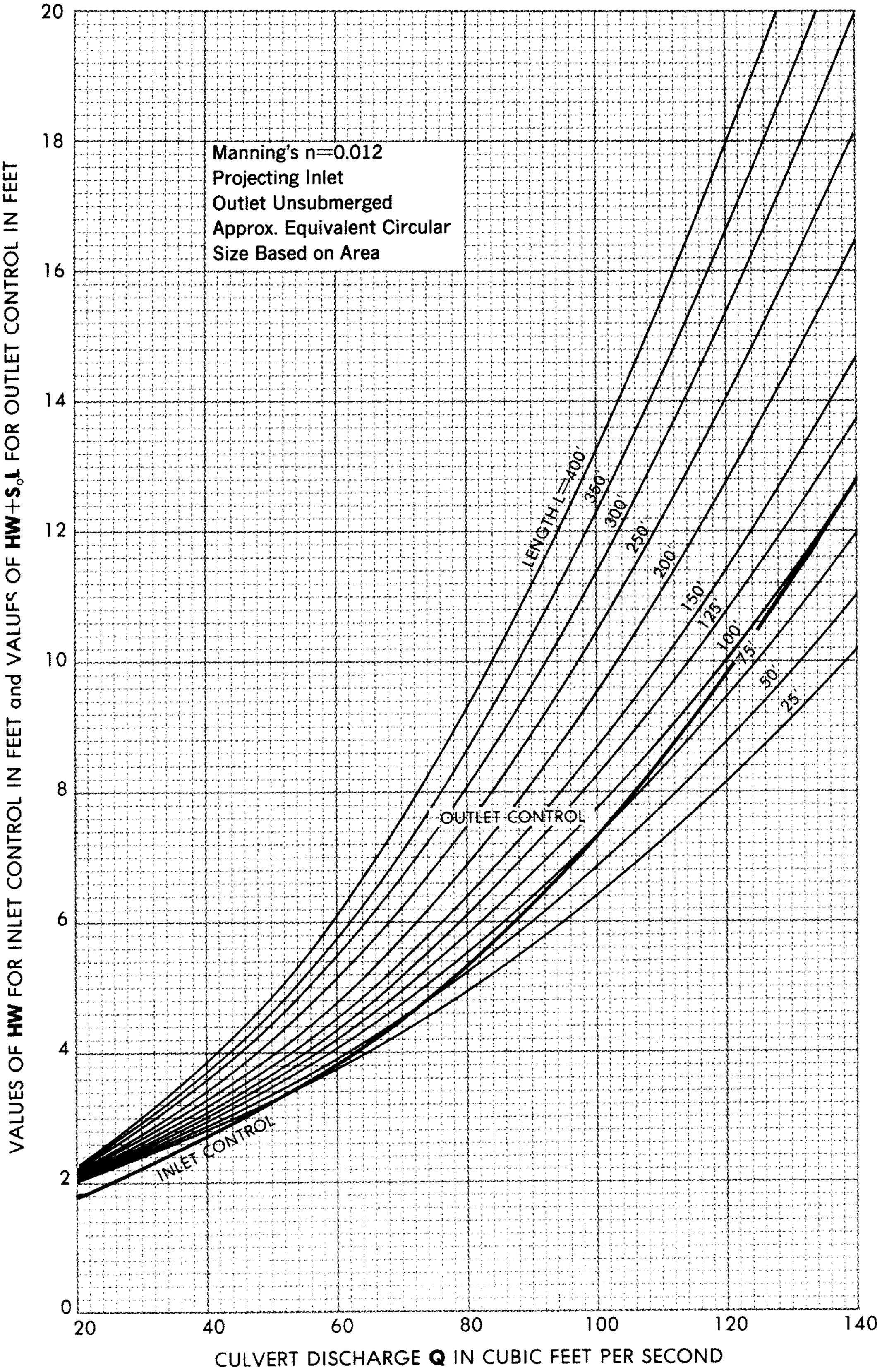


Figure 71

CULVERT CAPACITY
34 x 54-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 42-INCH CIRCULAR

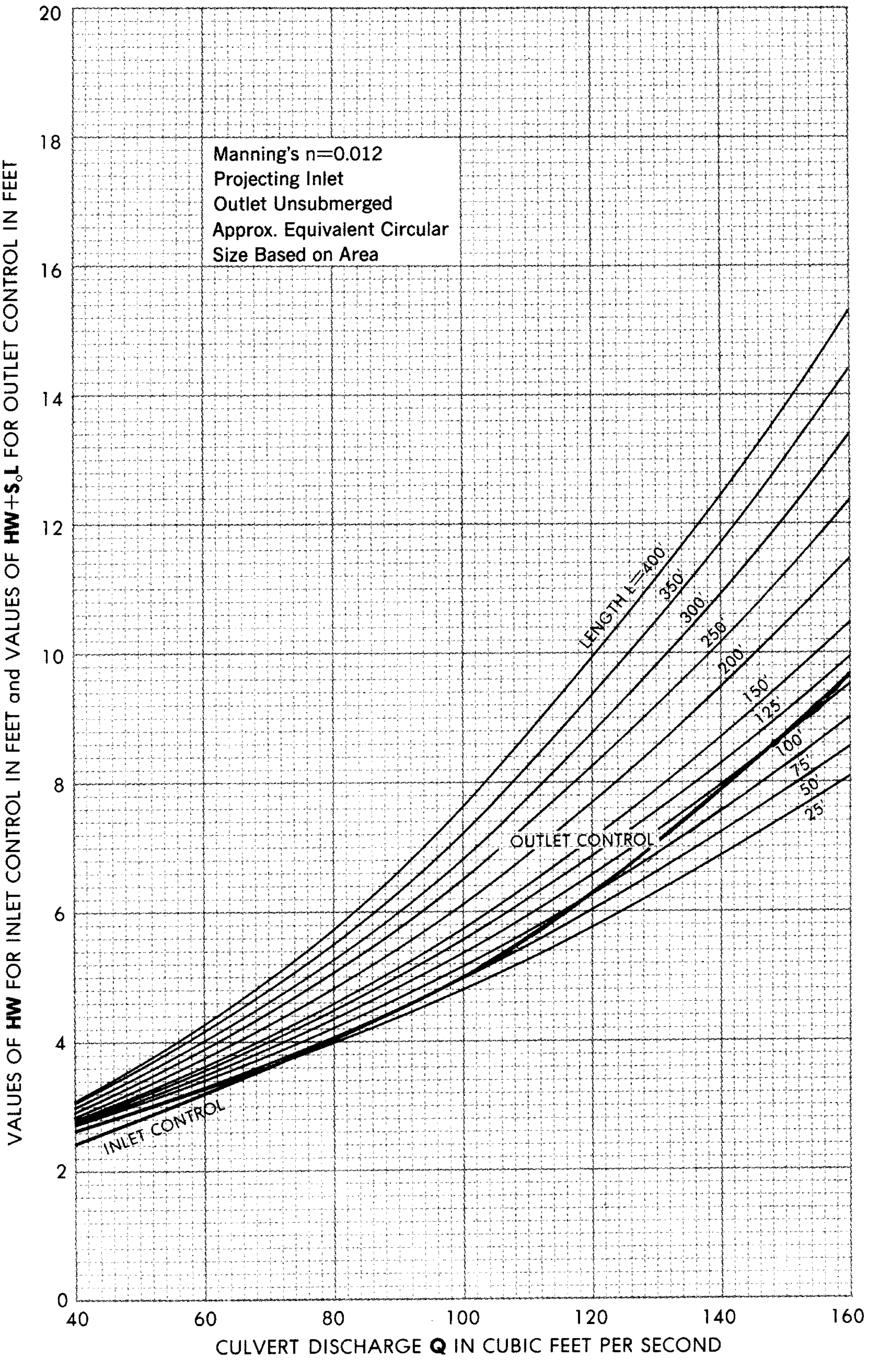


Figure 72

CULVERT CAPACITY
38 x 60-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 48-INCH CIRCULAR

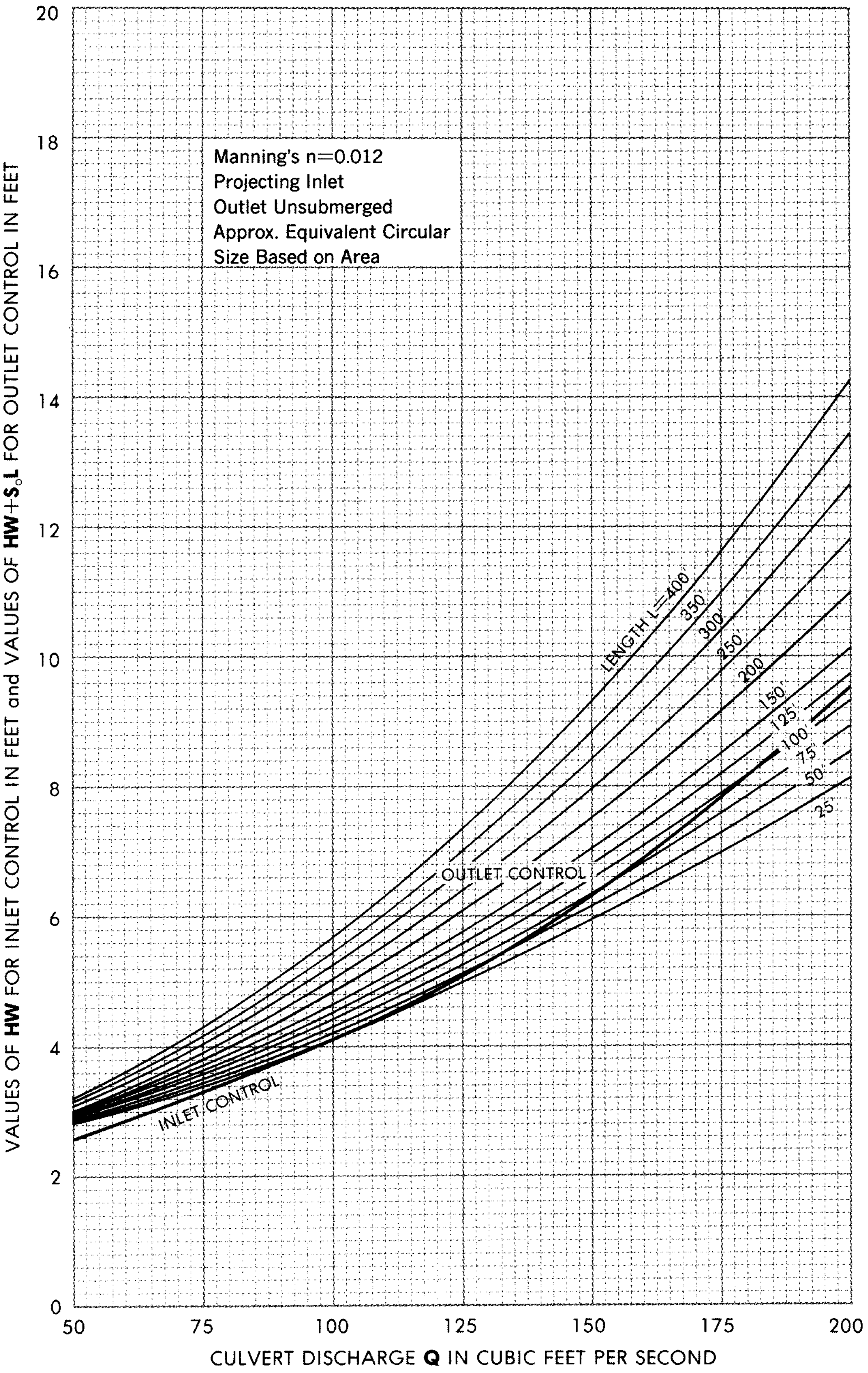


Figure 73

CULVERT CAPACITY
43 x 68-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 54-INCH CIRCULAR

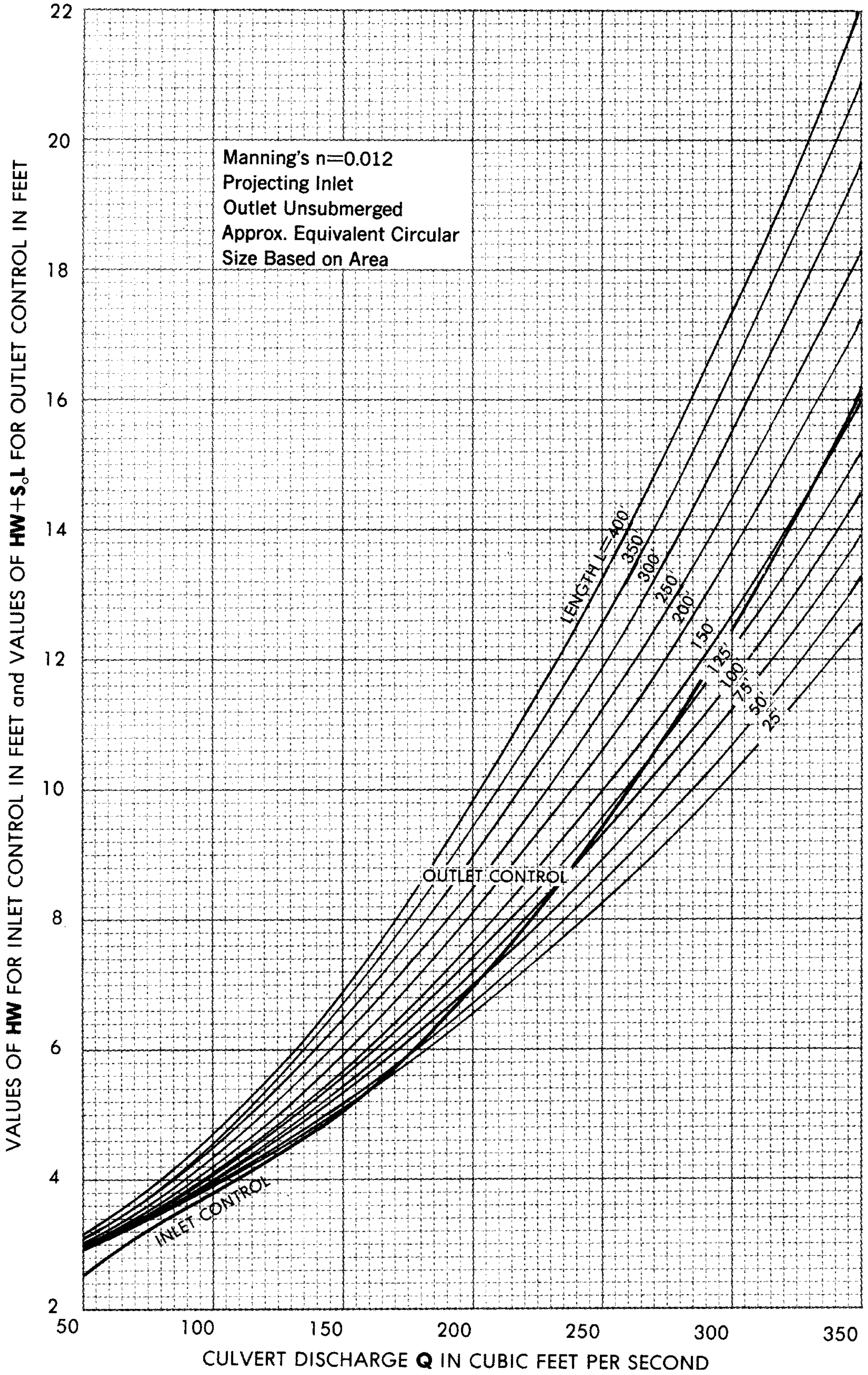


Figure 74

CULVERT CAPACITY
48 x 76-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 60-INCH CIRCULAR

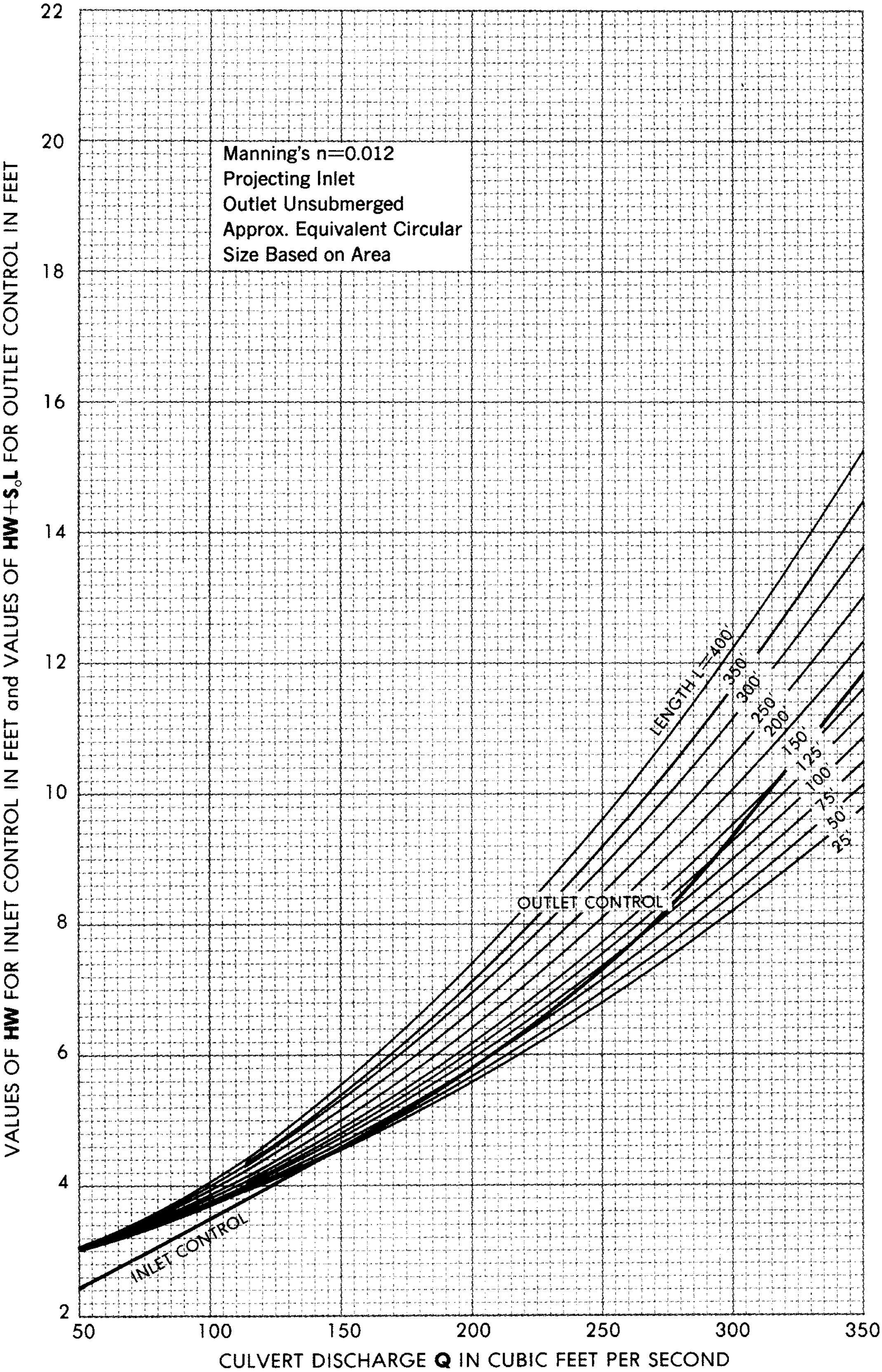


Figure 75

CULVERT CAPACITY
53 x 83-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 66-INCH CIRCULAR

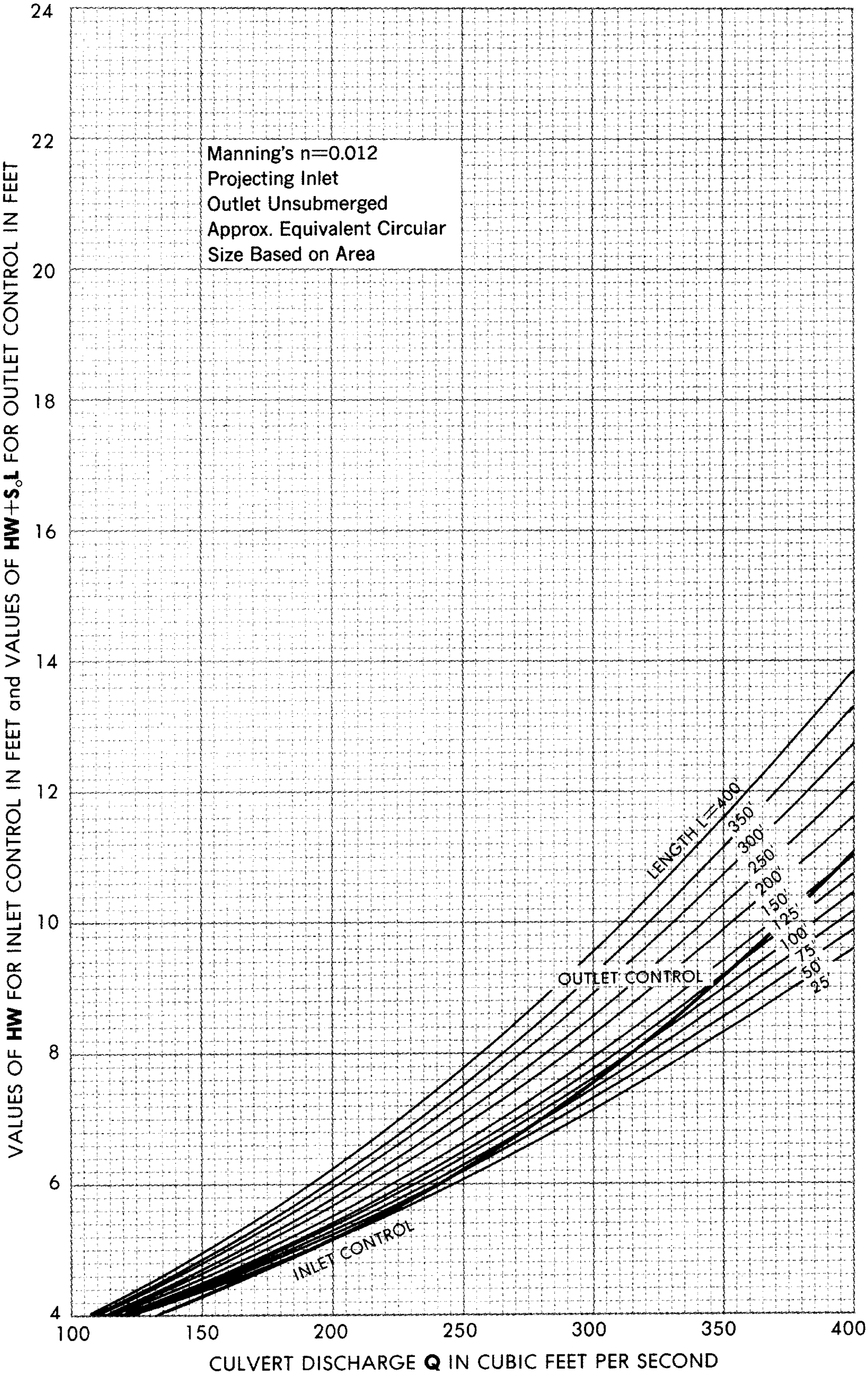


Figure 76

CULVERT CAPACITY
58 x 91-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 72-INCH CIRCULAR

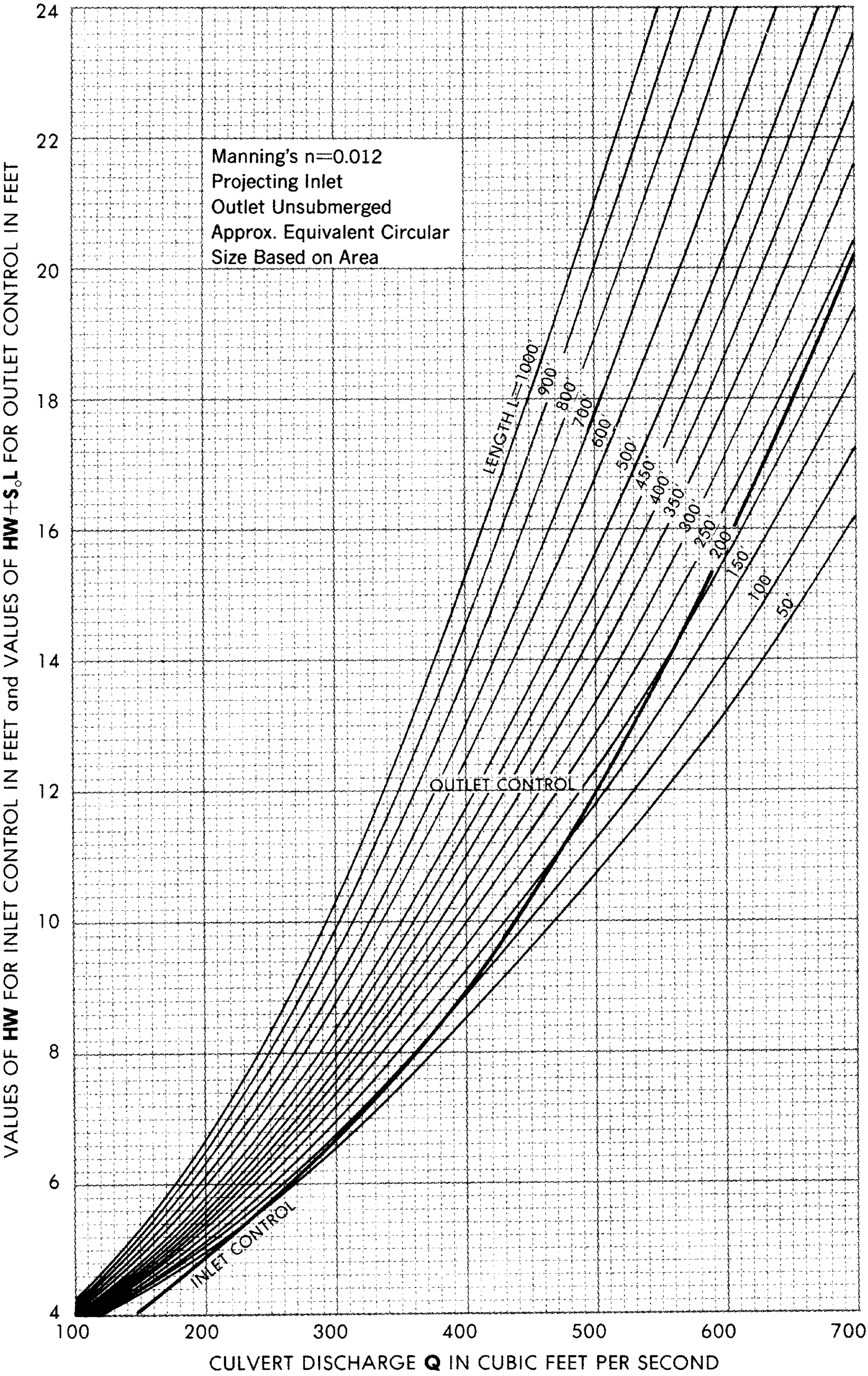


Figure 77

CULVERT CAPACITY
63 x 98-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 78-INCH CIRCULAR

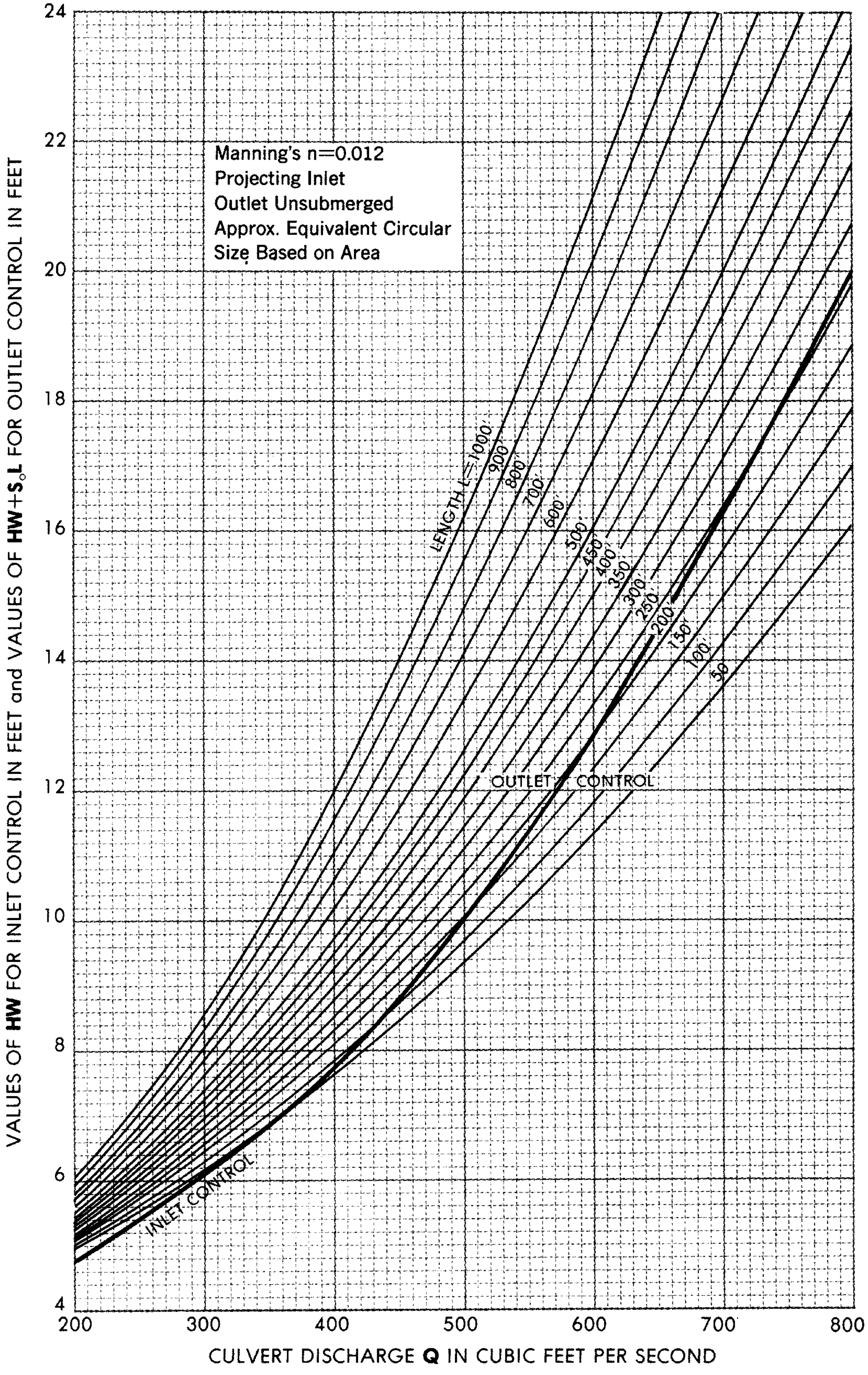


Figure 78

CULVERT CAPACITY
68 x 106-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 84-INCH CIRCULAR

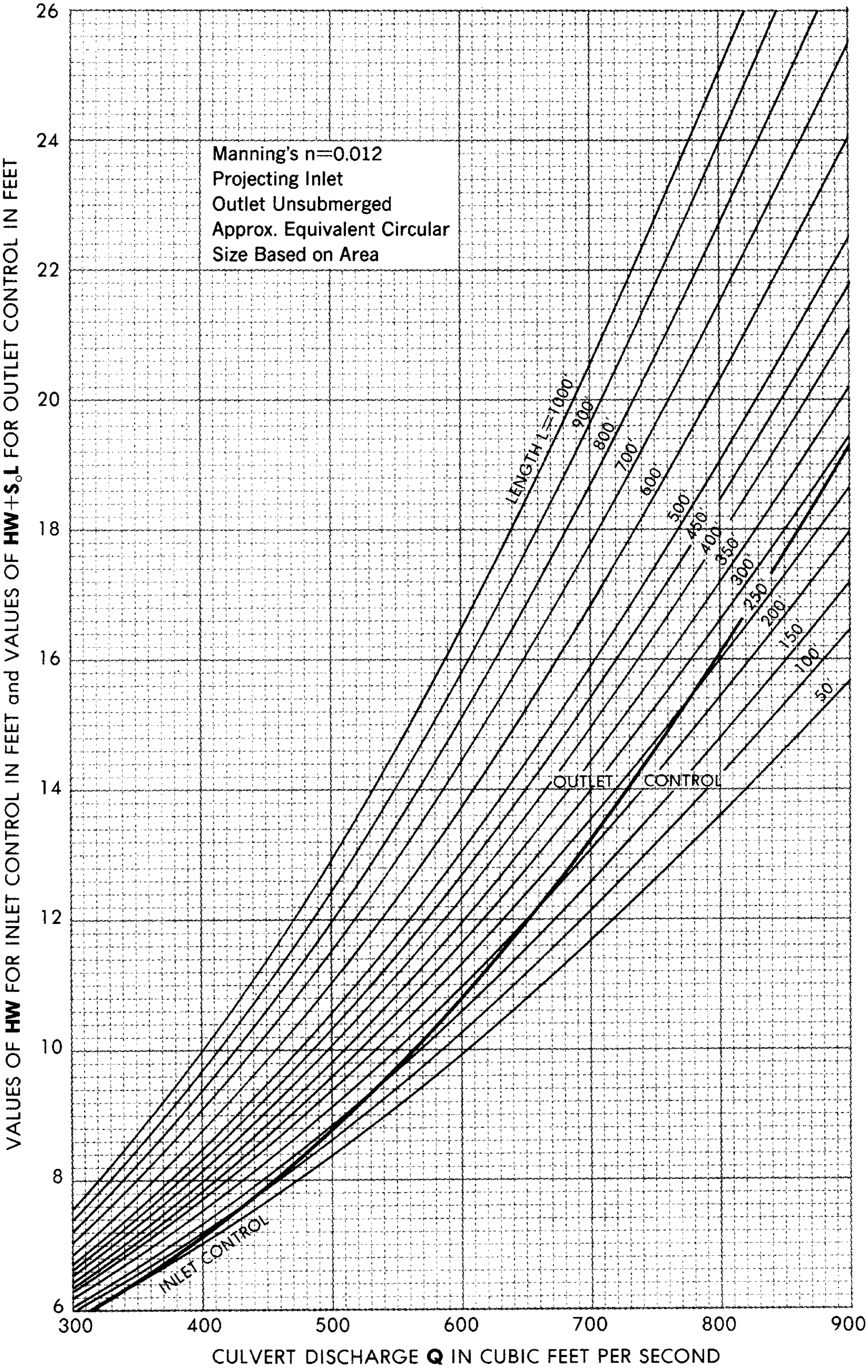


Figure 79

CULVERT CAPACITY
72 x 113-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 90-INCH CIRCULAR

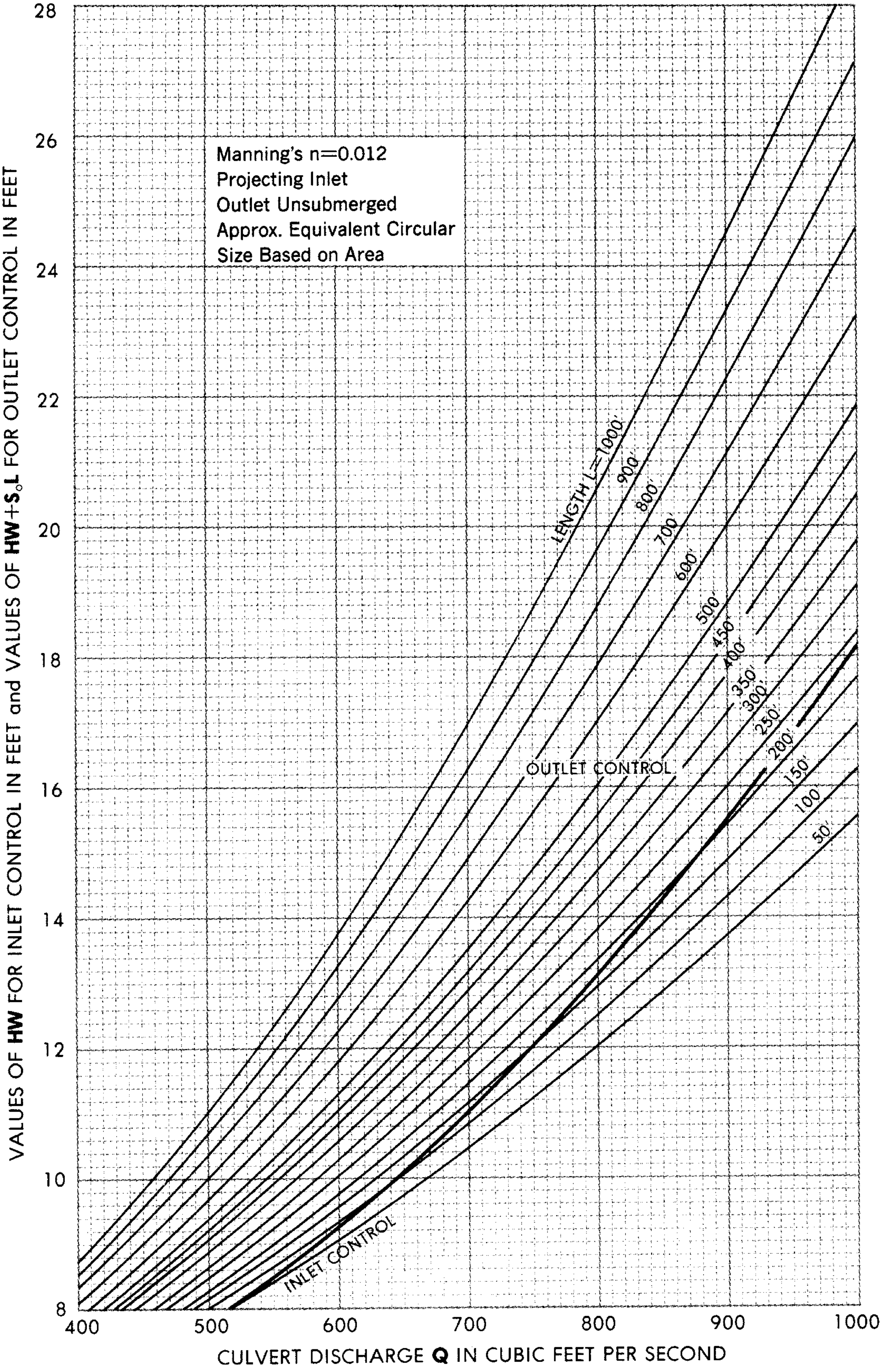


Figure 80

CULVERT CAPACITY
77 x 121-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 96-INCH CIRCULAR

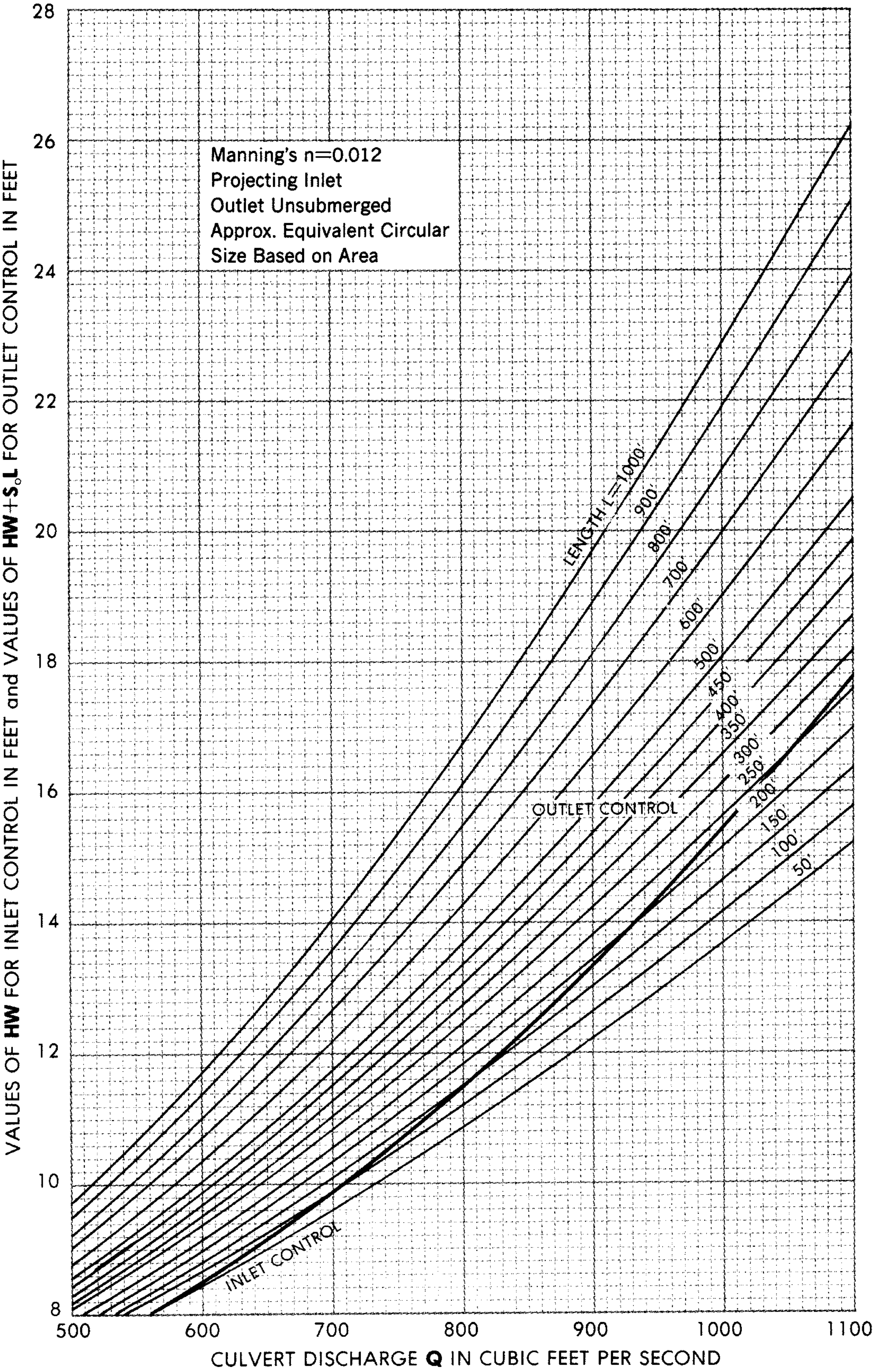


Figure 81

CULVERT CAPACITY
82 x 128-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 102-INCH CIRCULAR

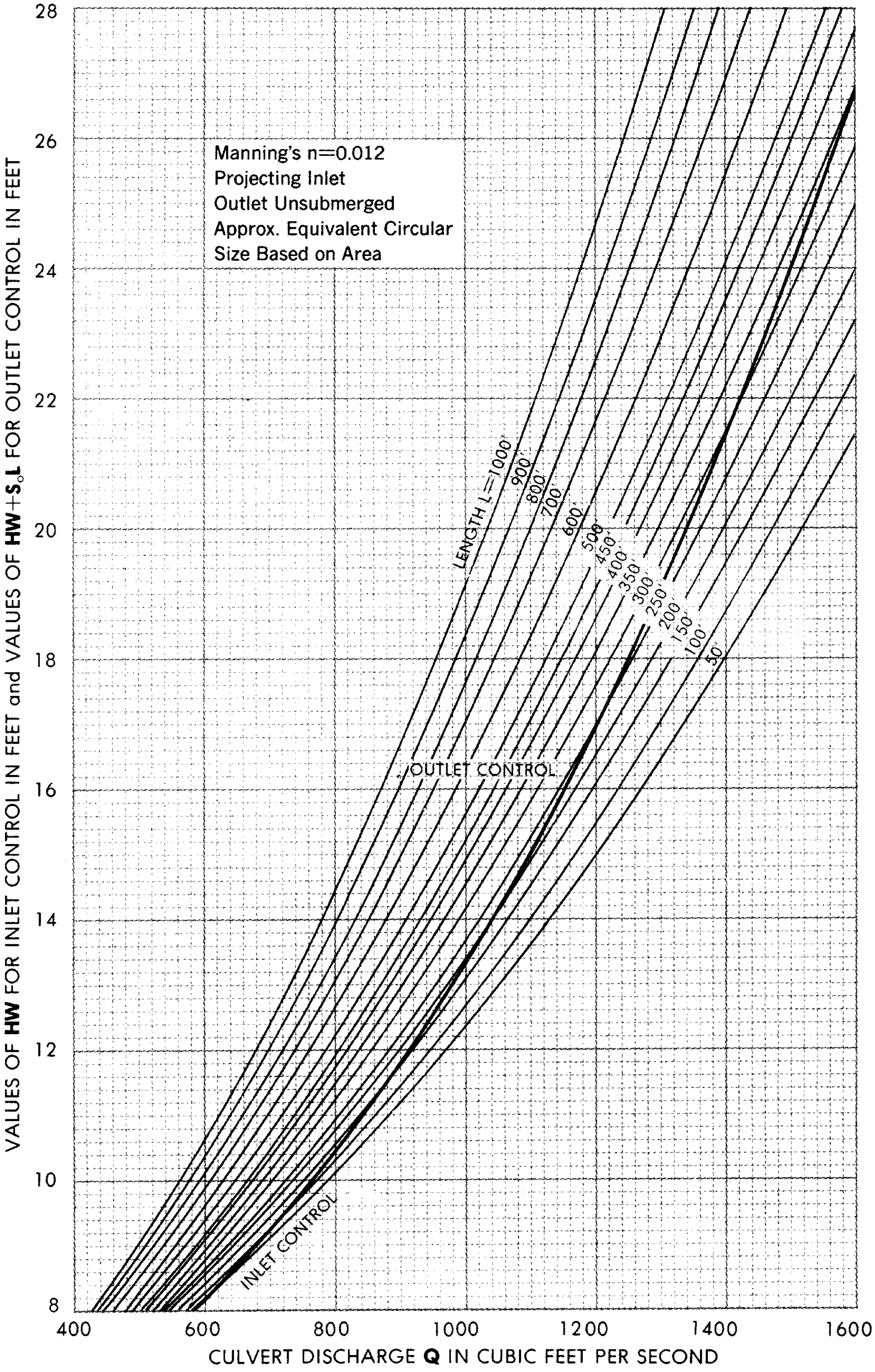


Figure 82

CULVERT CAPACITY
87 x 136-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 108-INCH CIRCULAR

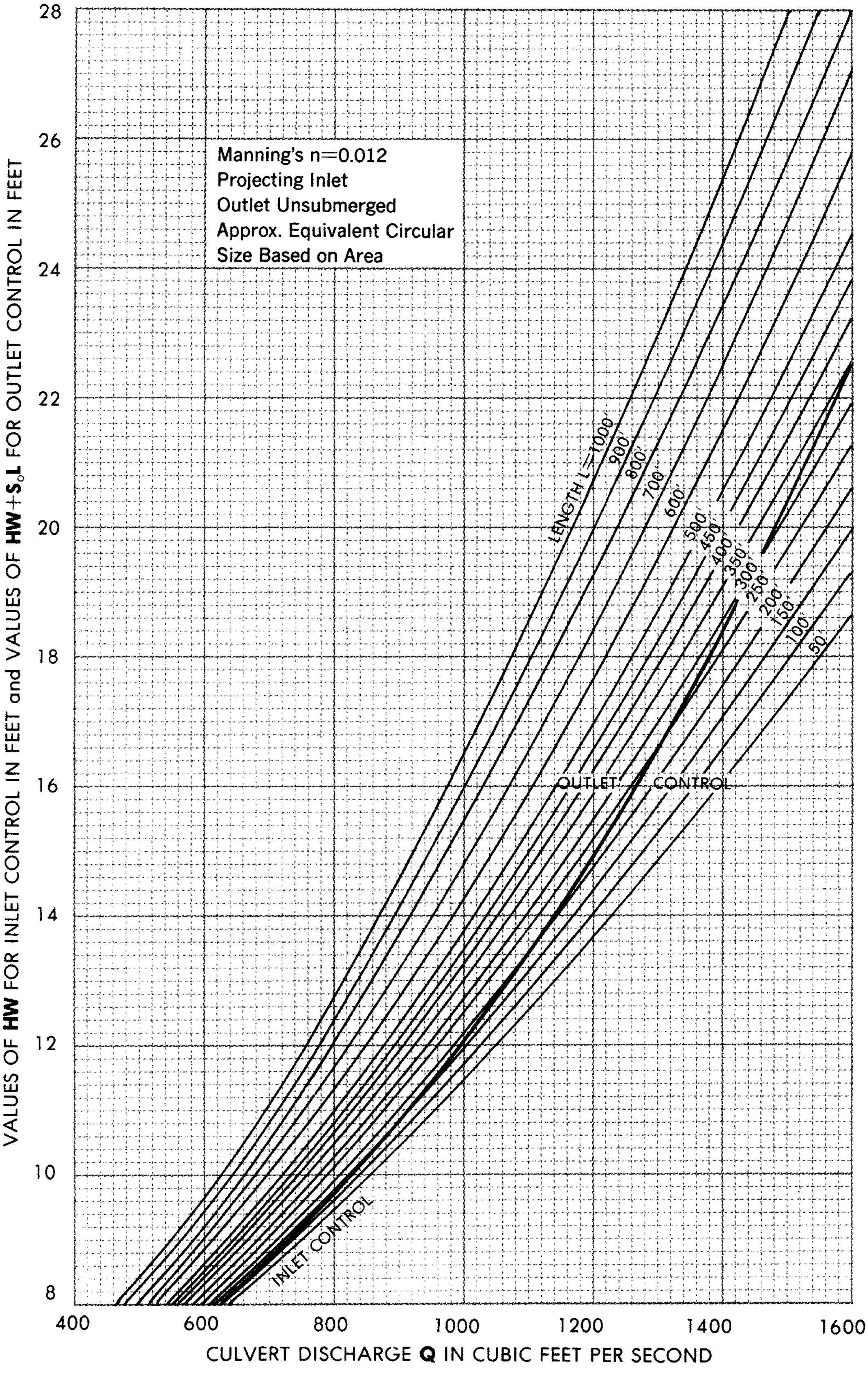


Figure 83

CULVERT CAPACITY
92 x 143-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 114-INCH CIRCULAR

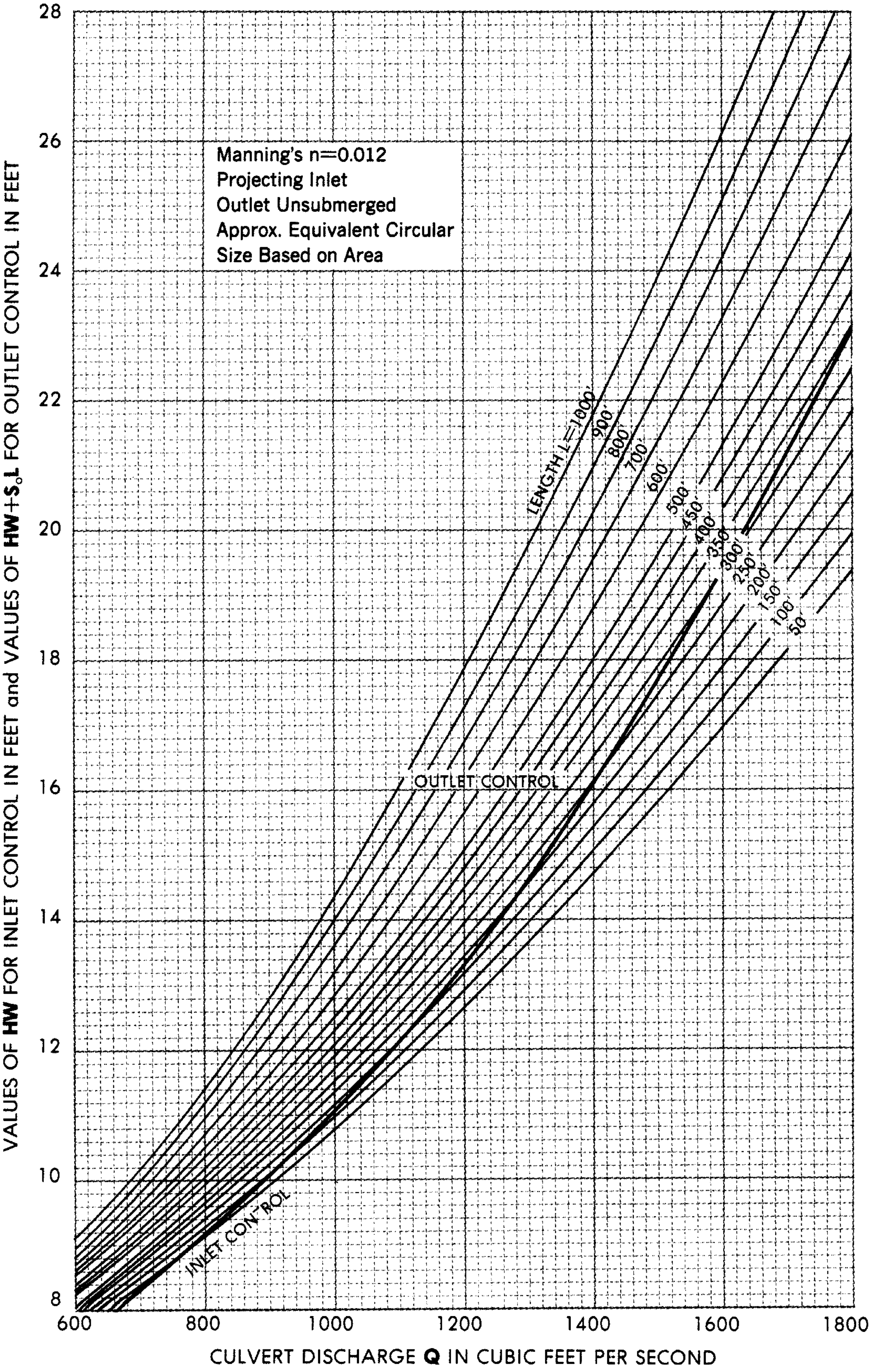


Figure 84

CULVERT CAPACITY
97 x 151-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 120-INCH CIRCULAR

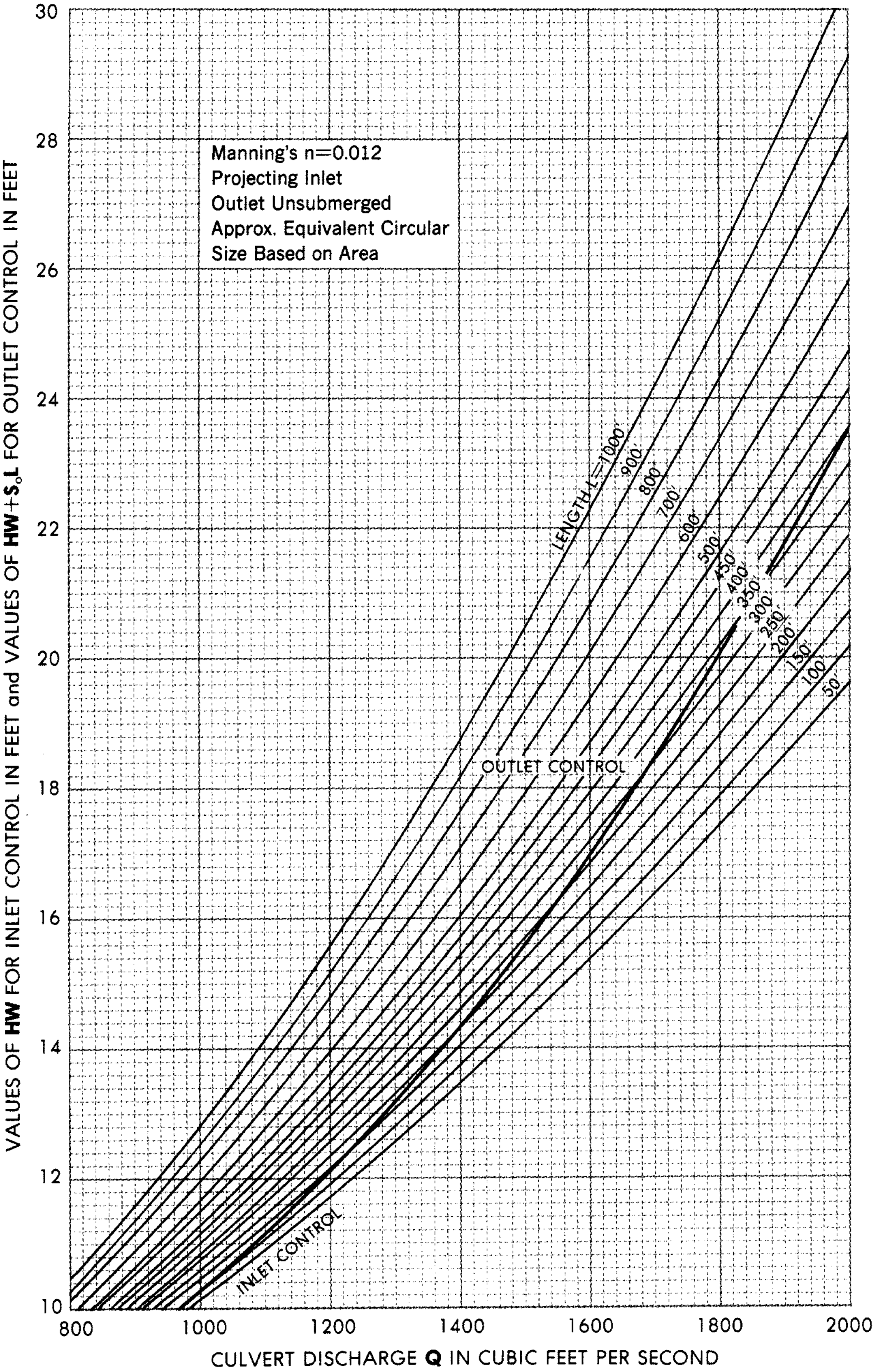


Figure 85

CULVERT CAPACITY
106 x 166-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 132-INCH CIRCULAR

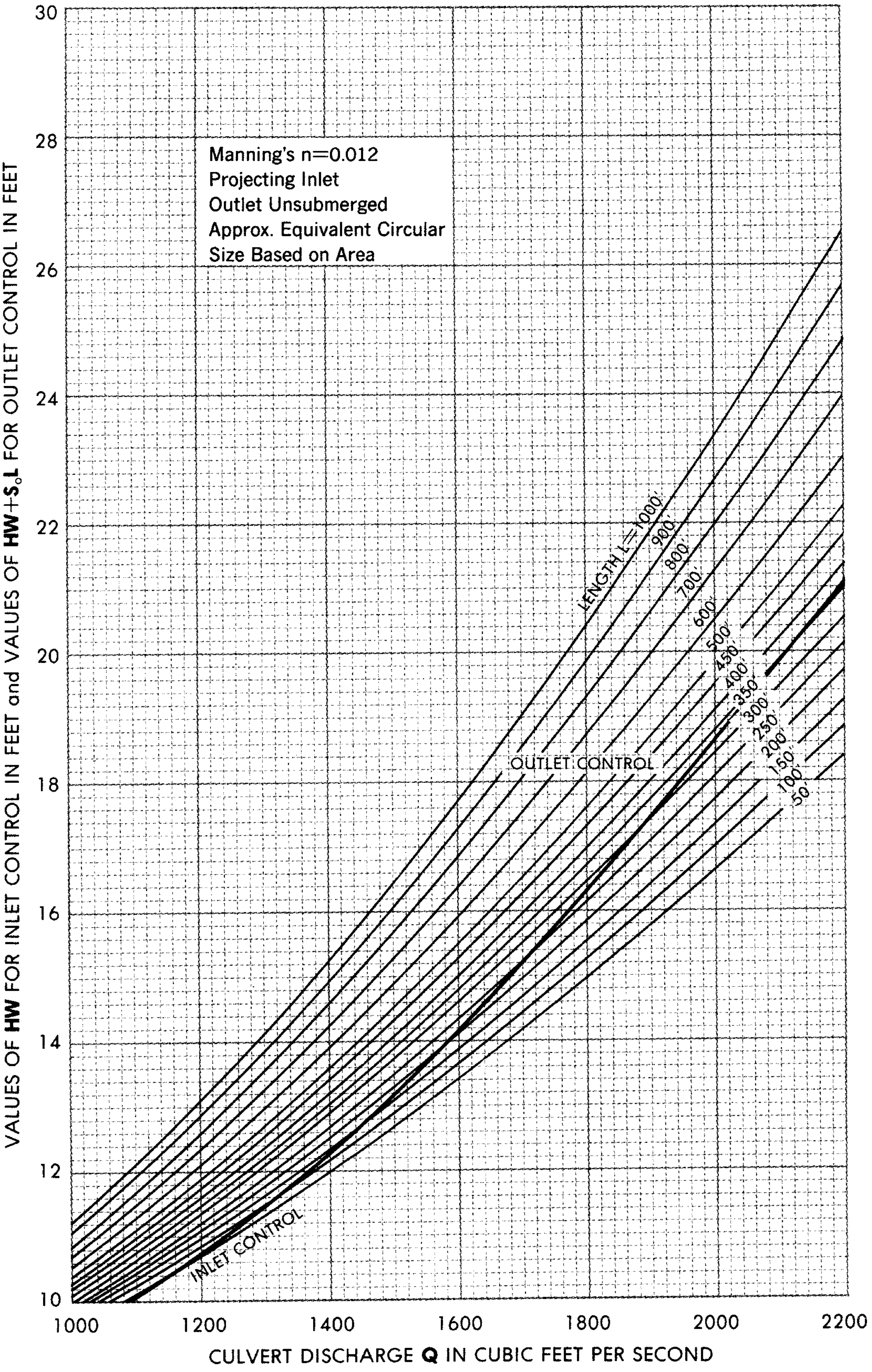


Figure 86

CULVERT CAPACITY
116 x 180-INCH (RISE x SPAN) HORIZONTAL ELLIPTICAL
EQUIVALENT 144-INCH CIRCULAR

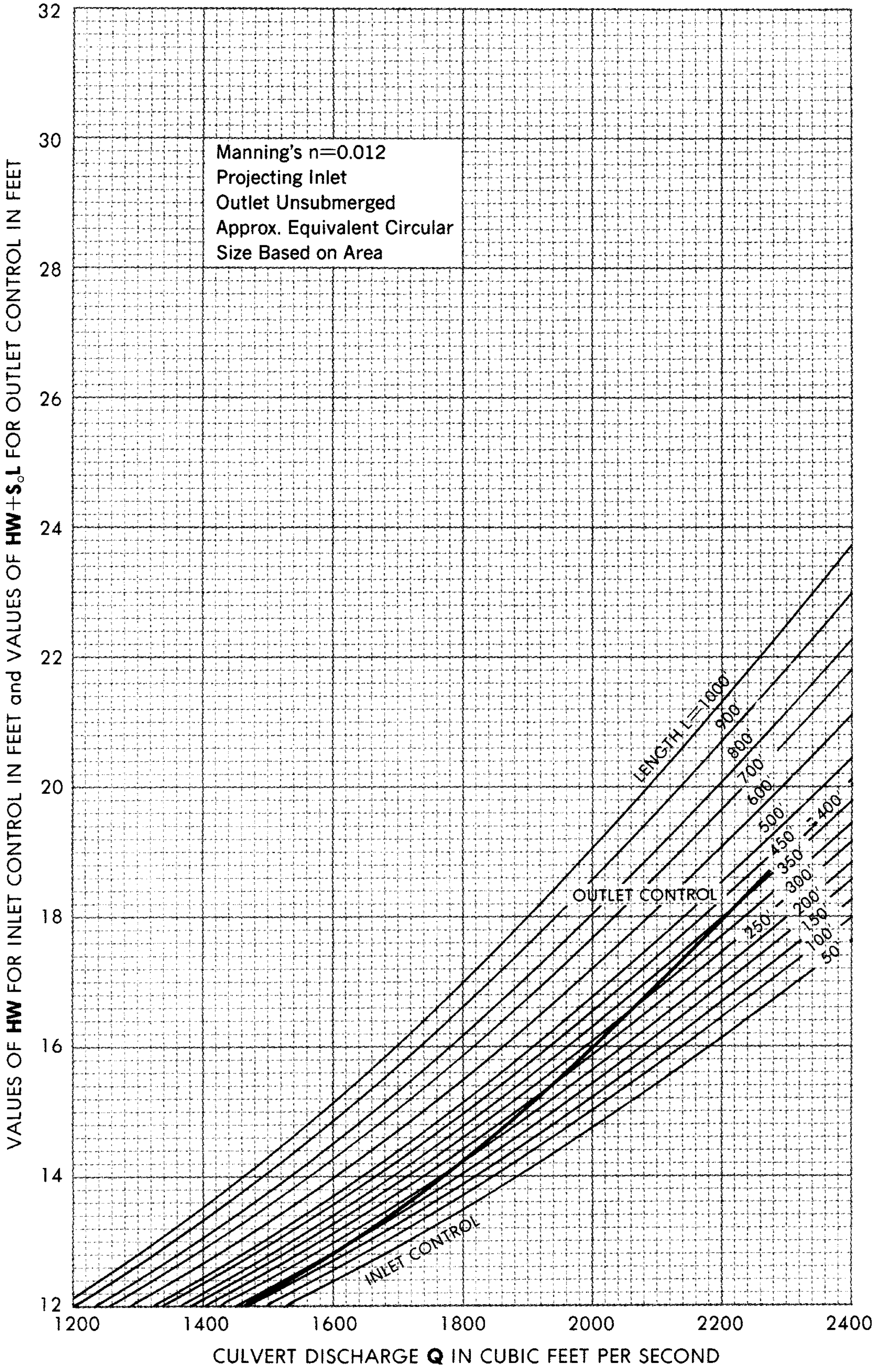


Figure 87

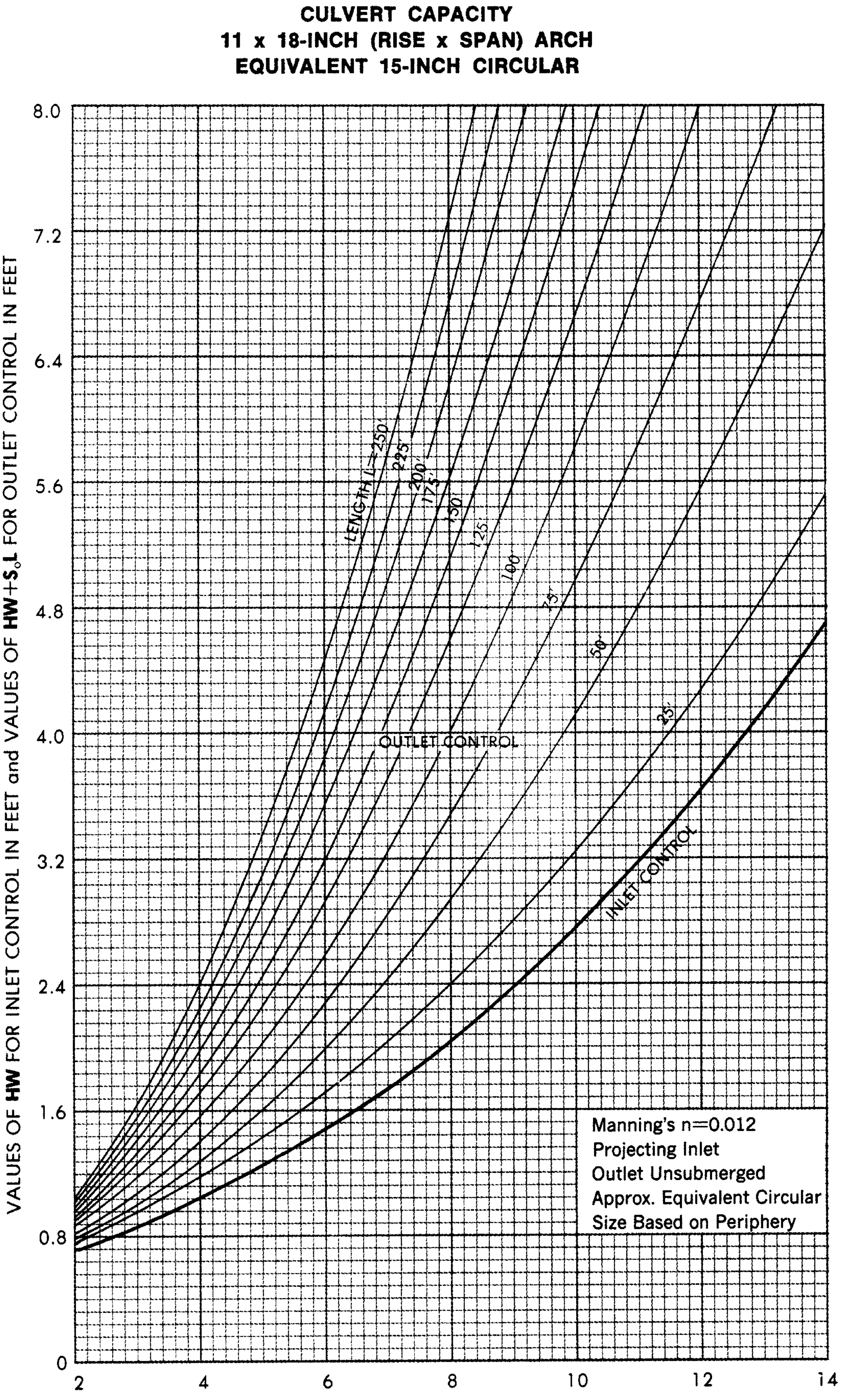

CULVERT CAPACITY
11 x 18-INCH (RISE x SPAN) ARCH
EQUIVALENT 15-INCH CIRCULAR
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S$_o$L FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND
8.0
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0
2
4
6
8
10
12
14
LENGTH L=250'
225'
200'
175'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
Manning's n=0.012
Projecting Inlet
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Periphery

Figure 88

CULVERT CAPACITY
13 x 22-INCH (RISE x SPAN) ARCH
EQUIVALENT 18-INCH CIRCULAR

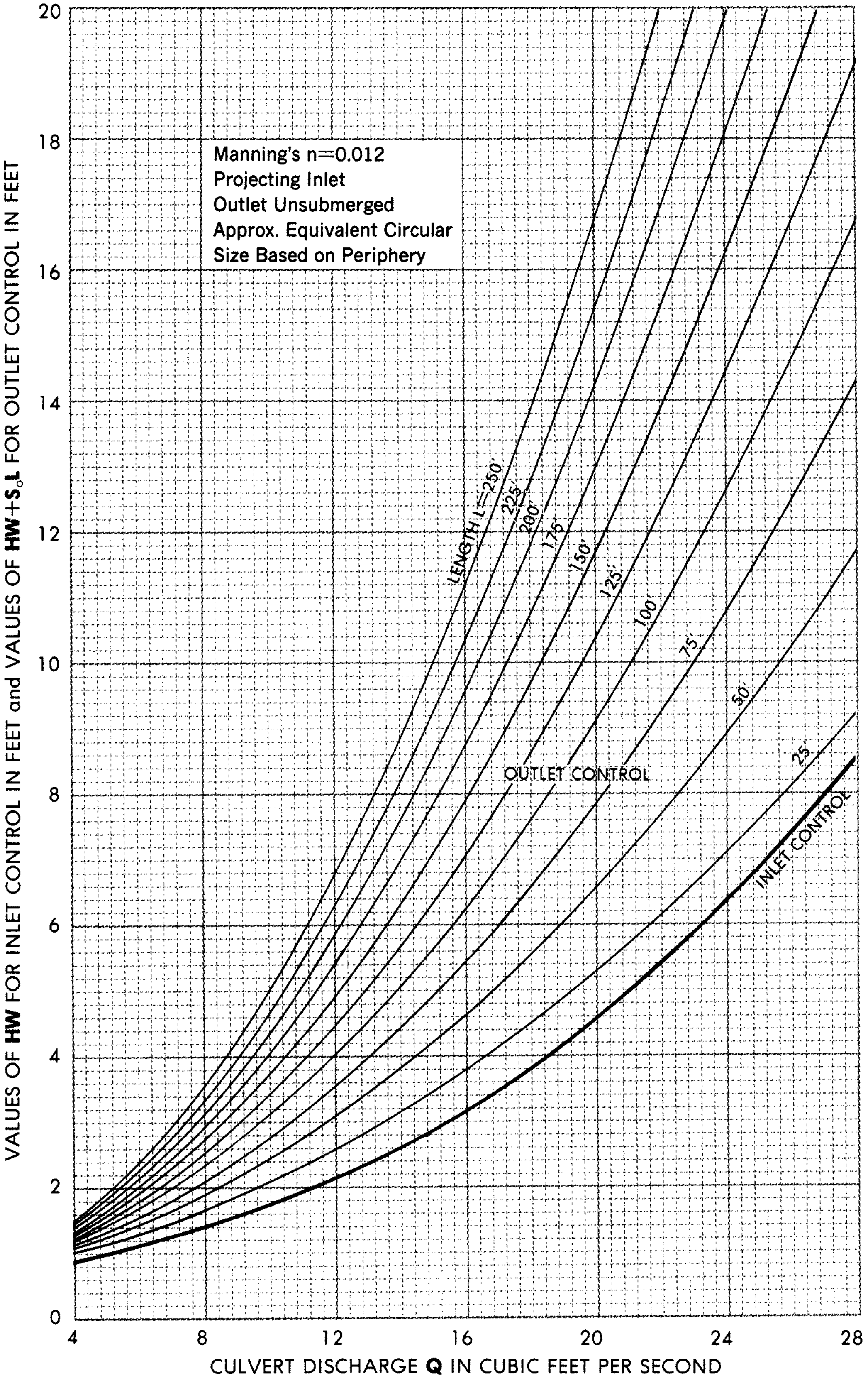


Figure 89

CULVERT CAPACITY
15 x 26-INCH (RISE x SPAN) ARCH
EQUIVALENT 21-INCH CIRCULAR

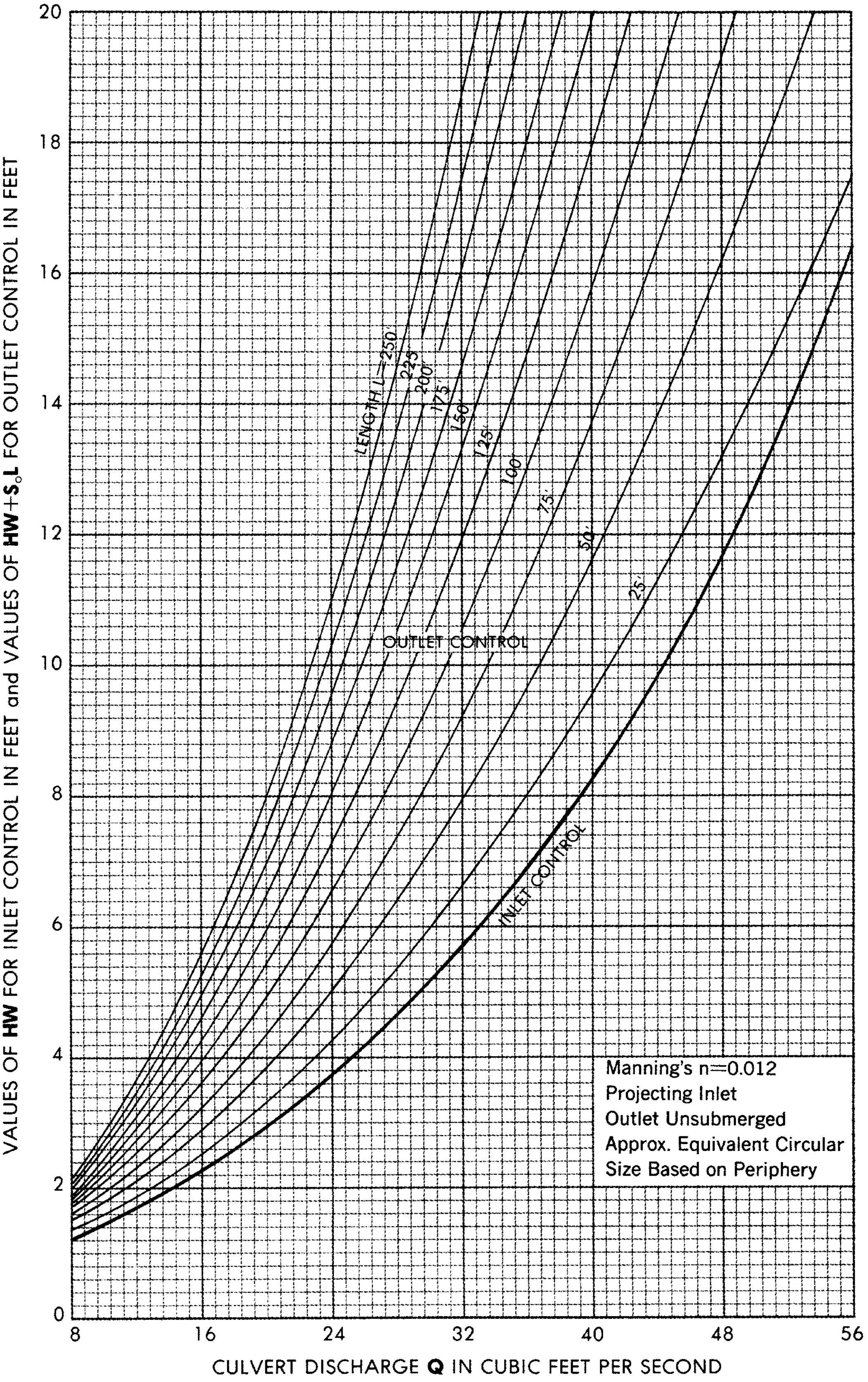


Figure 90

CULVERT CAPACITY
18 x 28-INCH (RISE x SPAN) ARCH
EQUIVALENT 24-INCH CIRCULAR

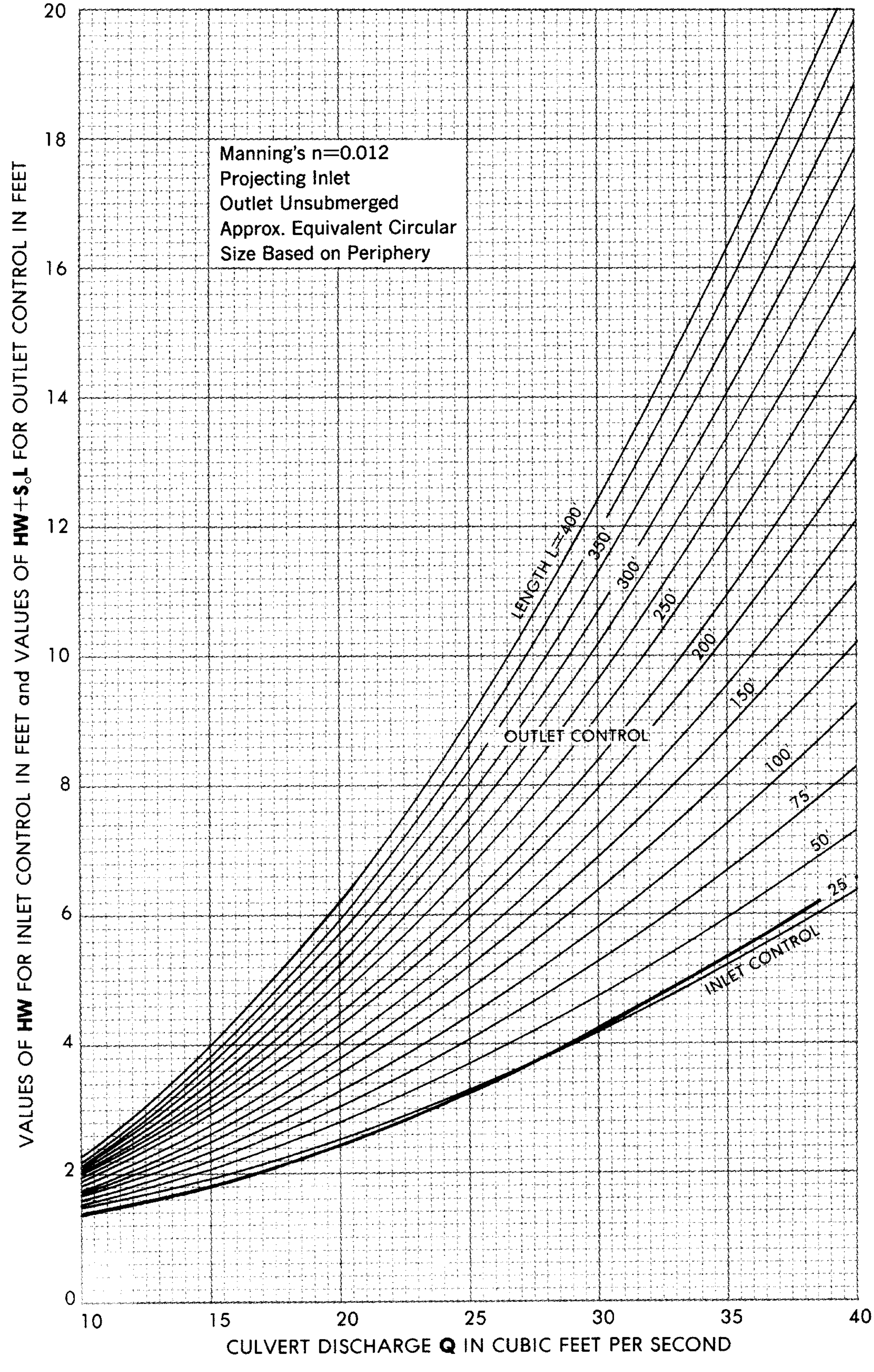


Figure 91

CULVERT CAPACITY
22 x 36-INCH (RISE x SPAN) ARCH
EQUIVALENT 30-INCH CIRCULAR

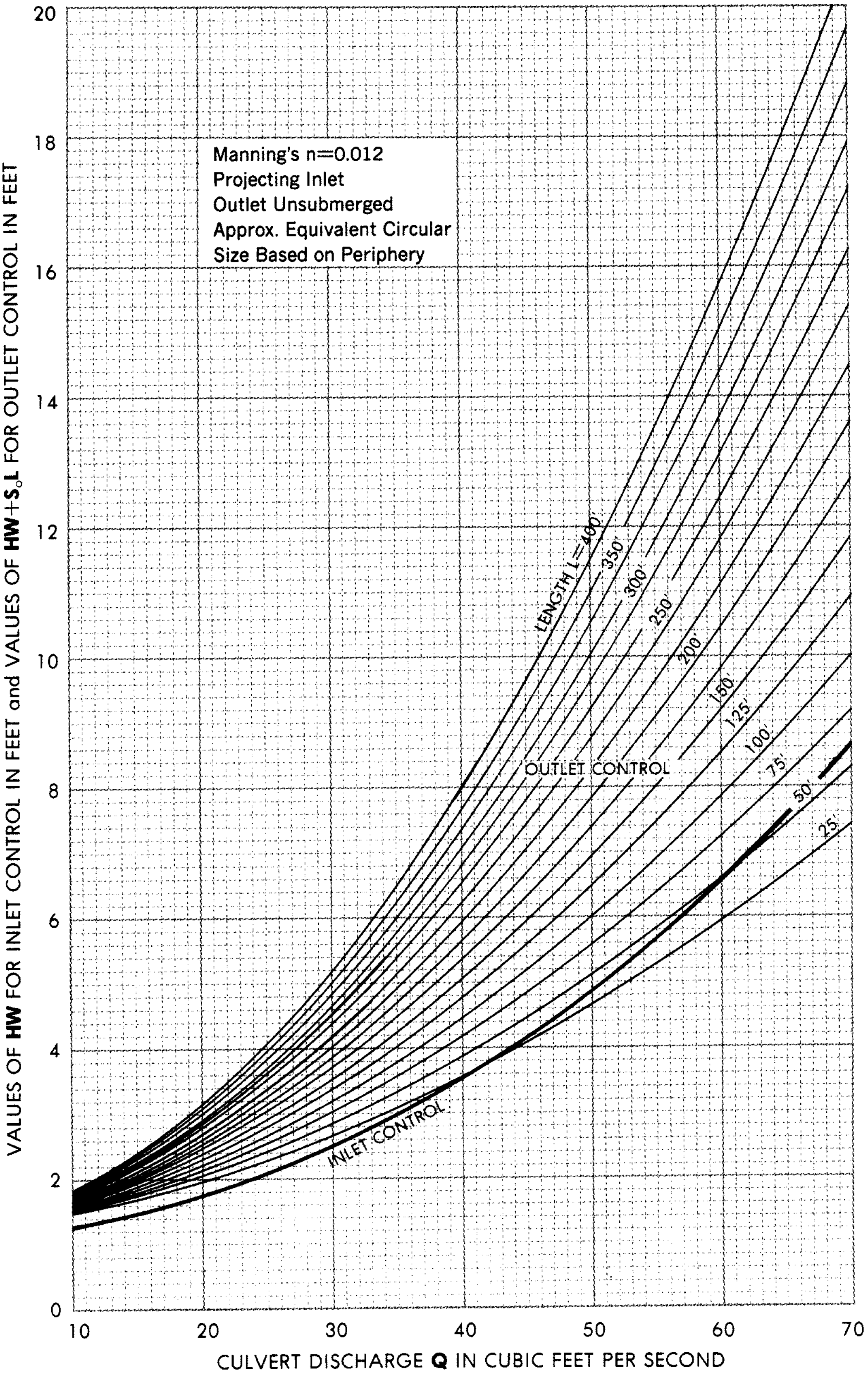


Figure 92

CULVERT CAPACITY
27 x 44-INCH (RISE x SPAN) ARCH
EQUIVALENT 36-INCH CIRCULAR

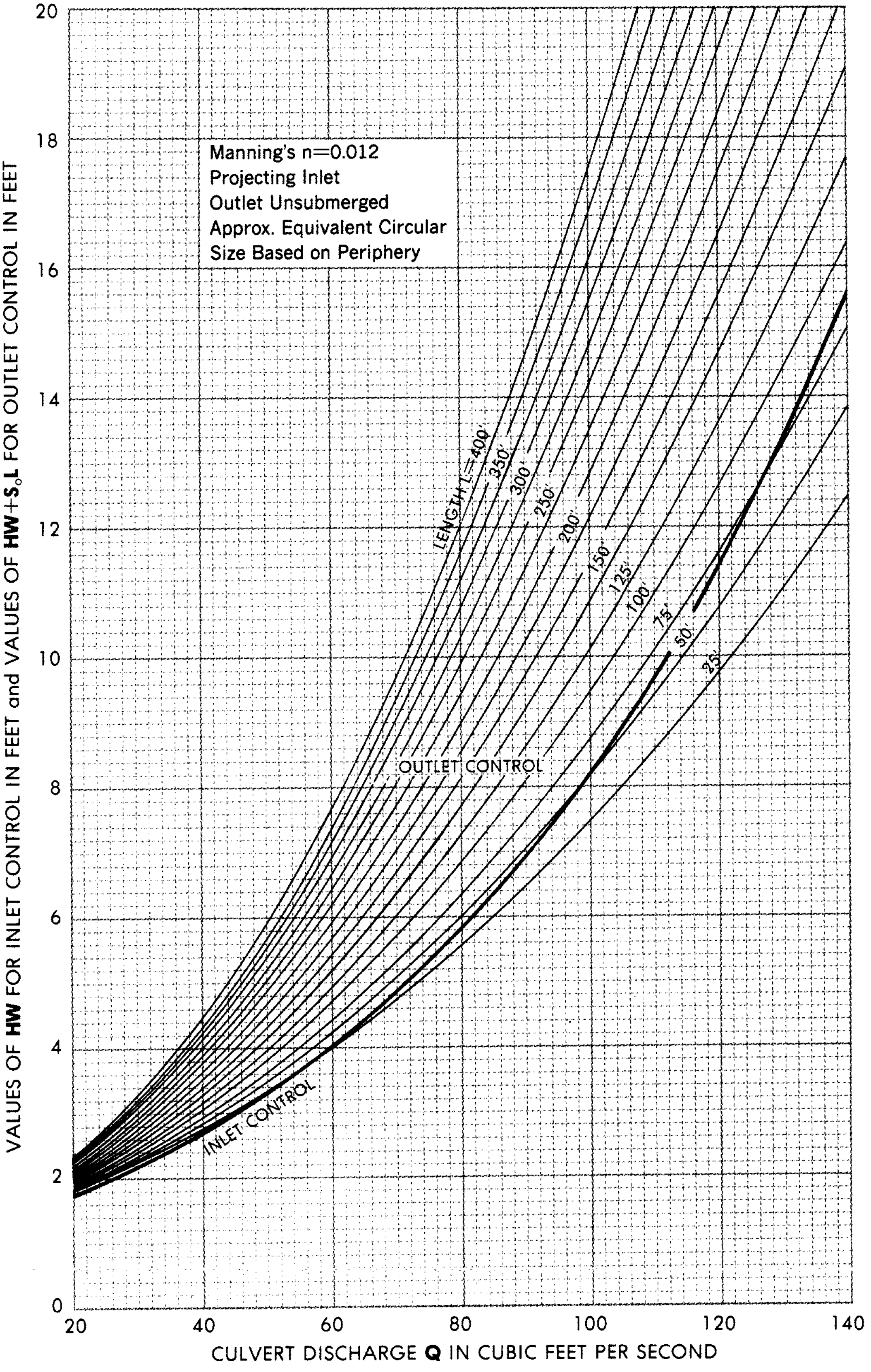


Figure 93

CULVERT CAPACITY
31 x 51-INCH (RISE x SPAN) ARCH
EQUIVALENT 42-INCH CIRCULAR

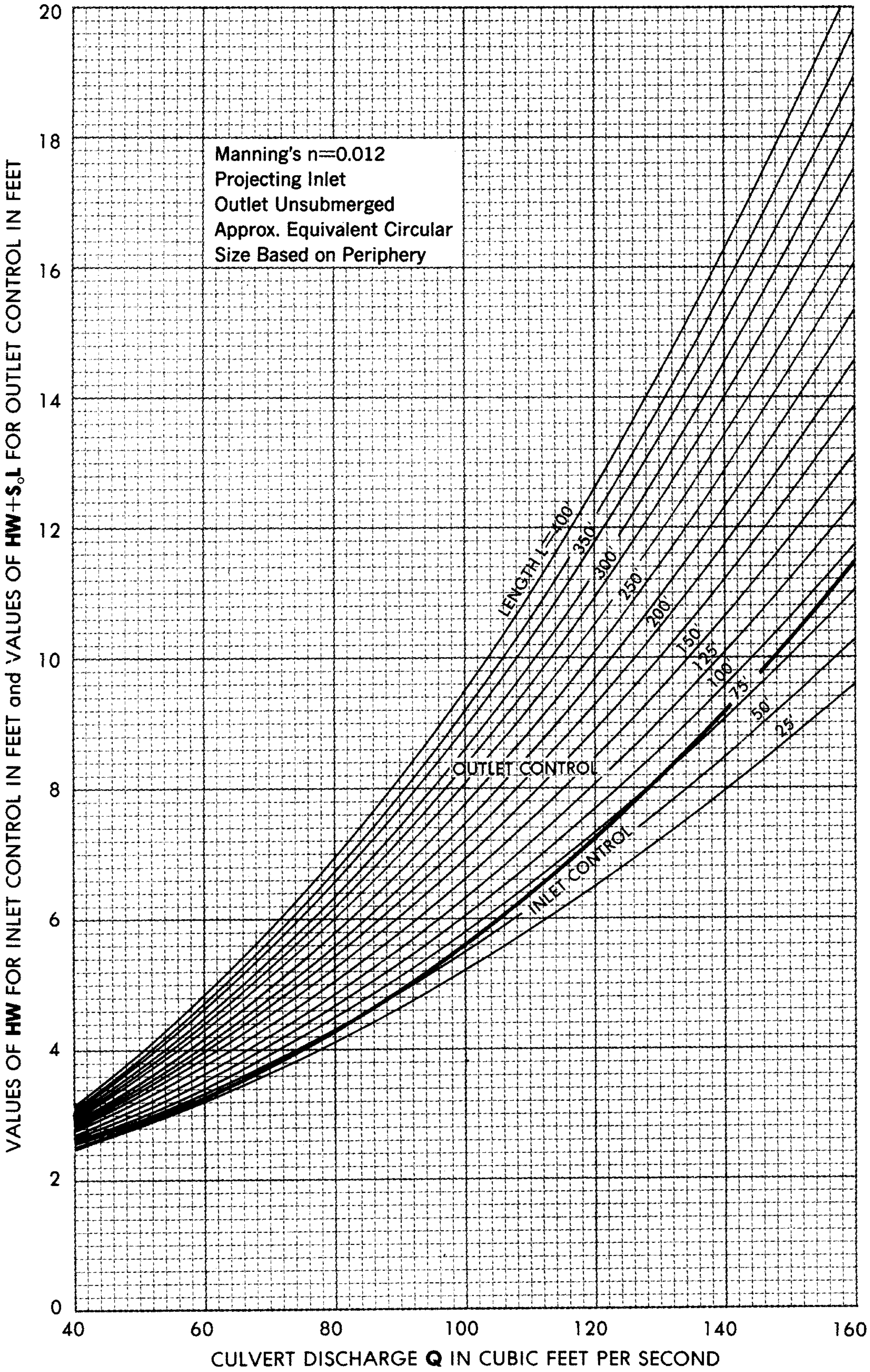


Figure 94

CULVERT CAPACITY
36 x 58-INCH (RISE x SPAN) ARCH
EQUIVALENT 48-INCH CIRCULAR

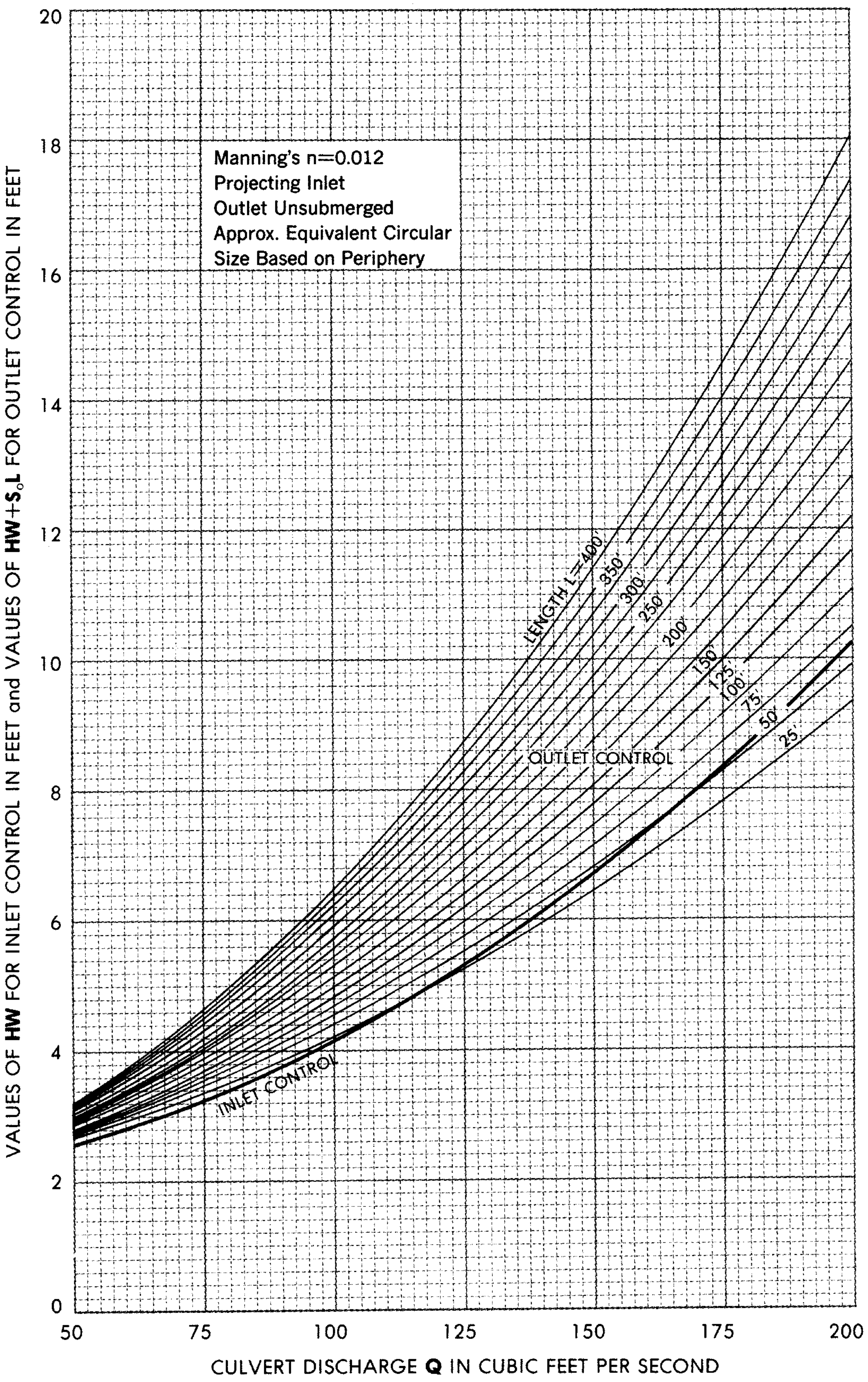


Figure 95

CULVERT CAPACITY
40 x 65-INCH (RISE x SPAN) ARCH
EQUIVALENT 54-INCH CIRCULAR

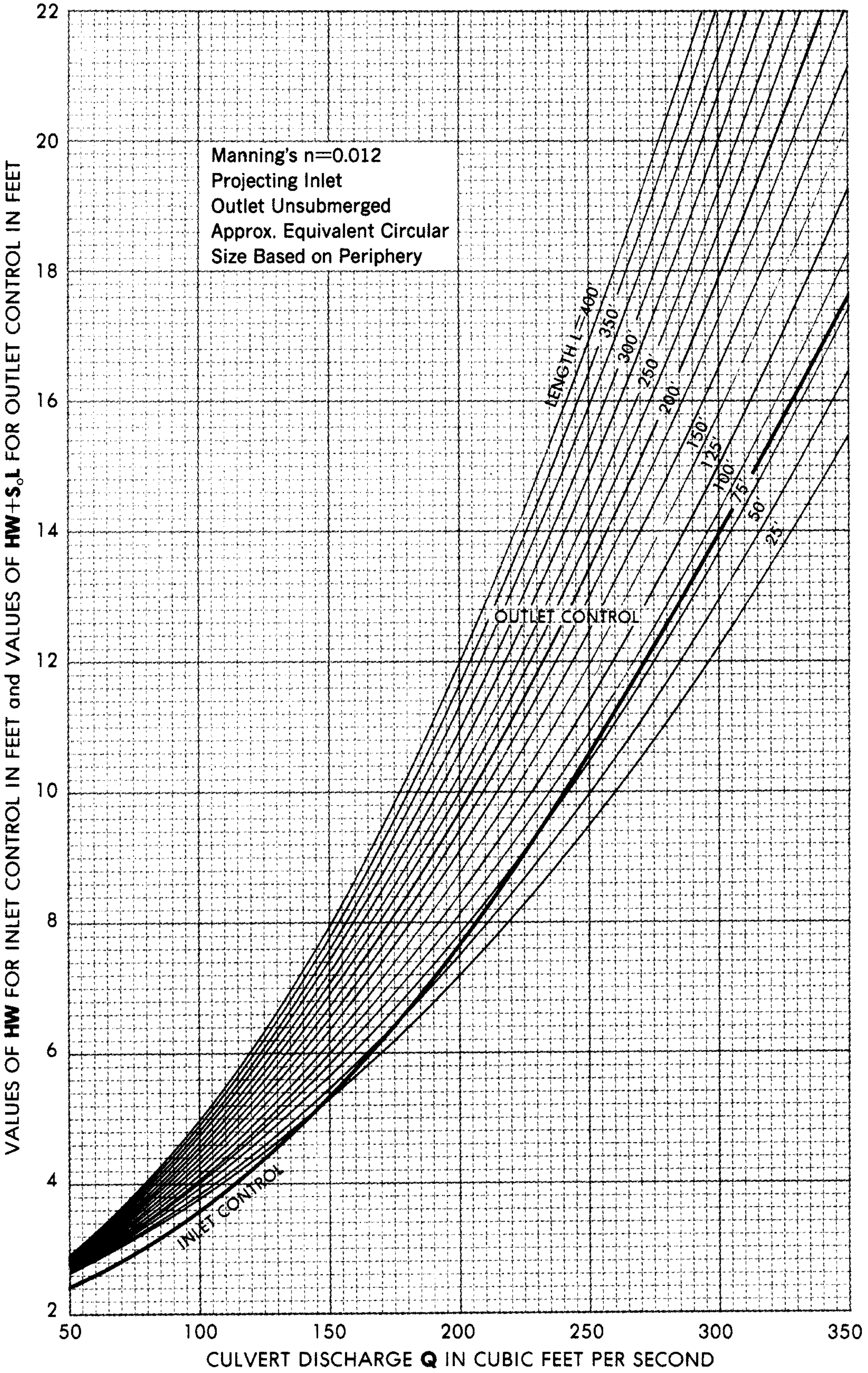


Figure 96

CULVERT CAPACITY
45 x 73-INCH (RISE x SPAN) ARCH
EQUIVALENT 60-INCH CIRCULAR

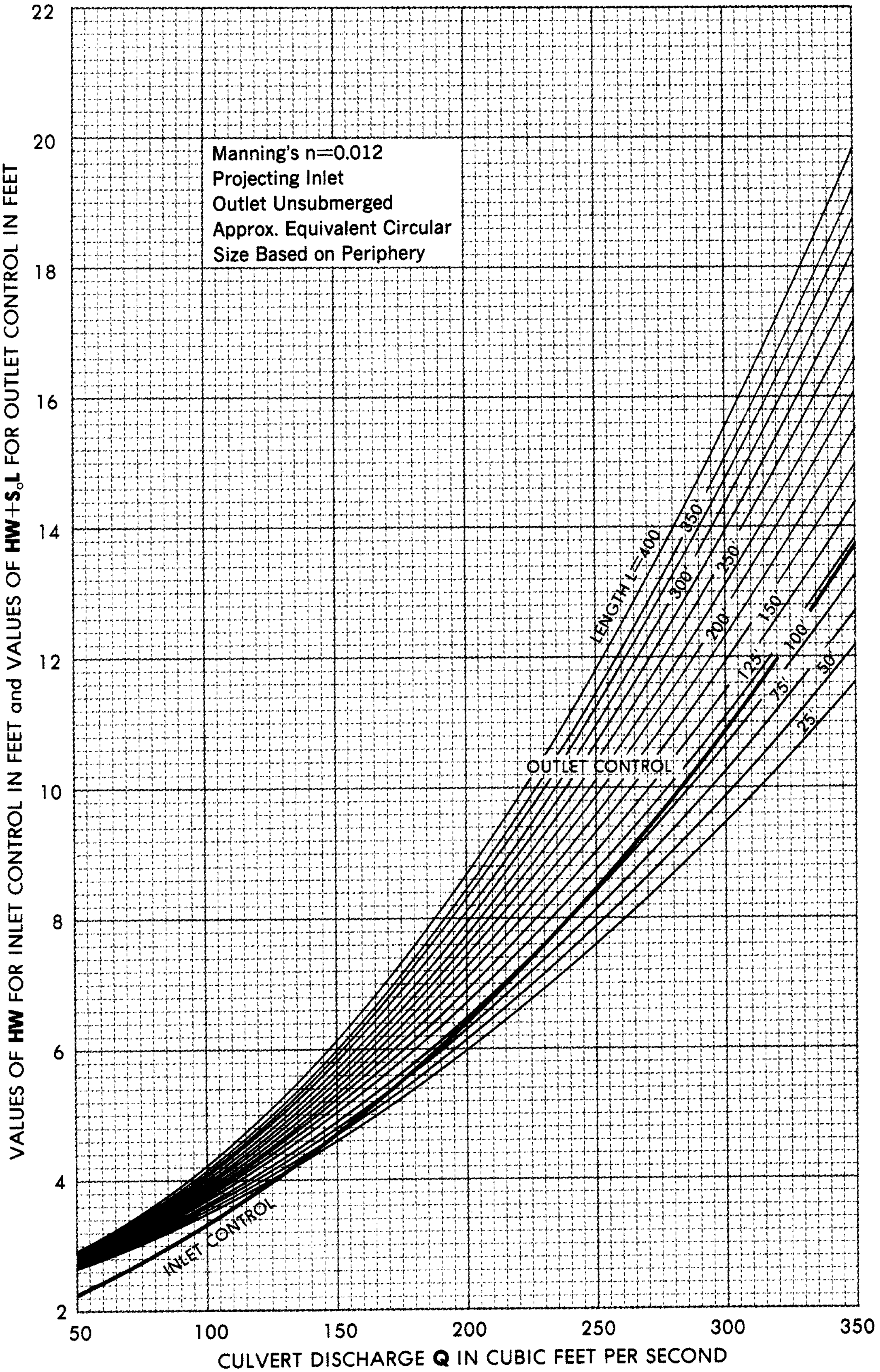


Figure 97

CULVERT CAPACITY
54 x 88-INCH (RISE x SPAN) ARCH
EQUIVALENT 72-INCH CIRCULAR

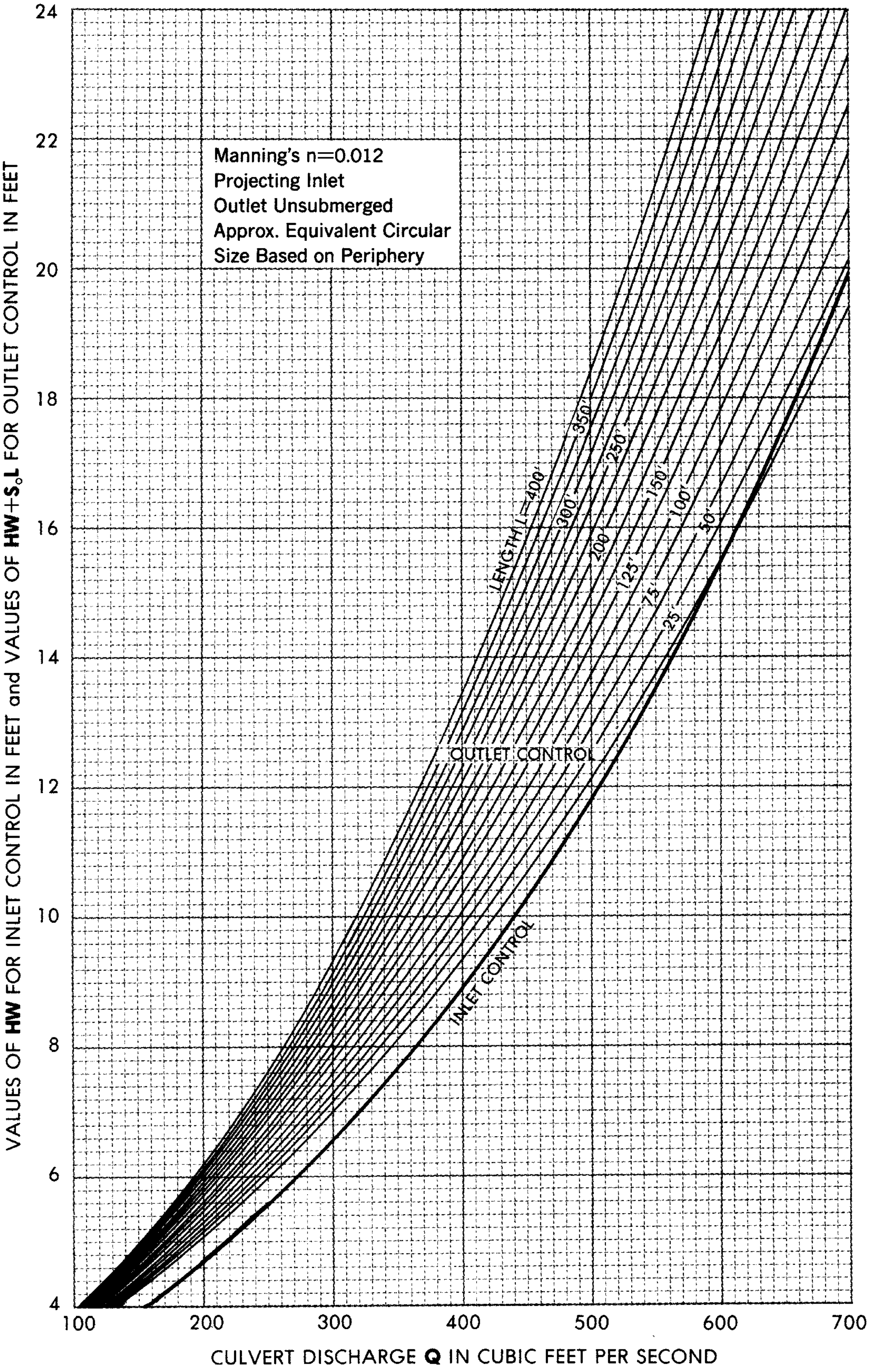


Figure 98

CULVERT CAPACITY
62 x 102-INCH (RISE x SPAN) ARCH
EQUIVALENT 84-INCH CIRCULAR

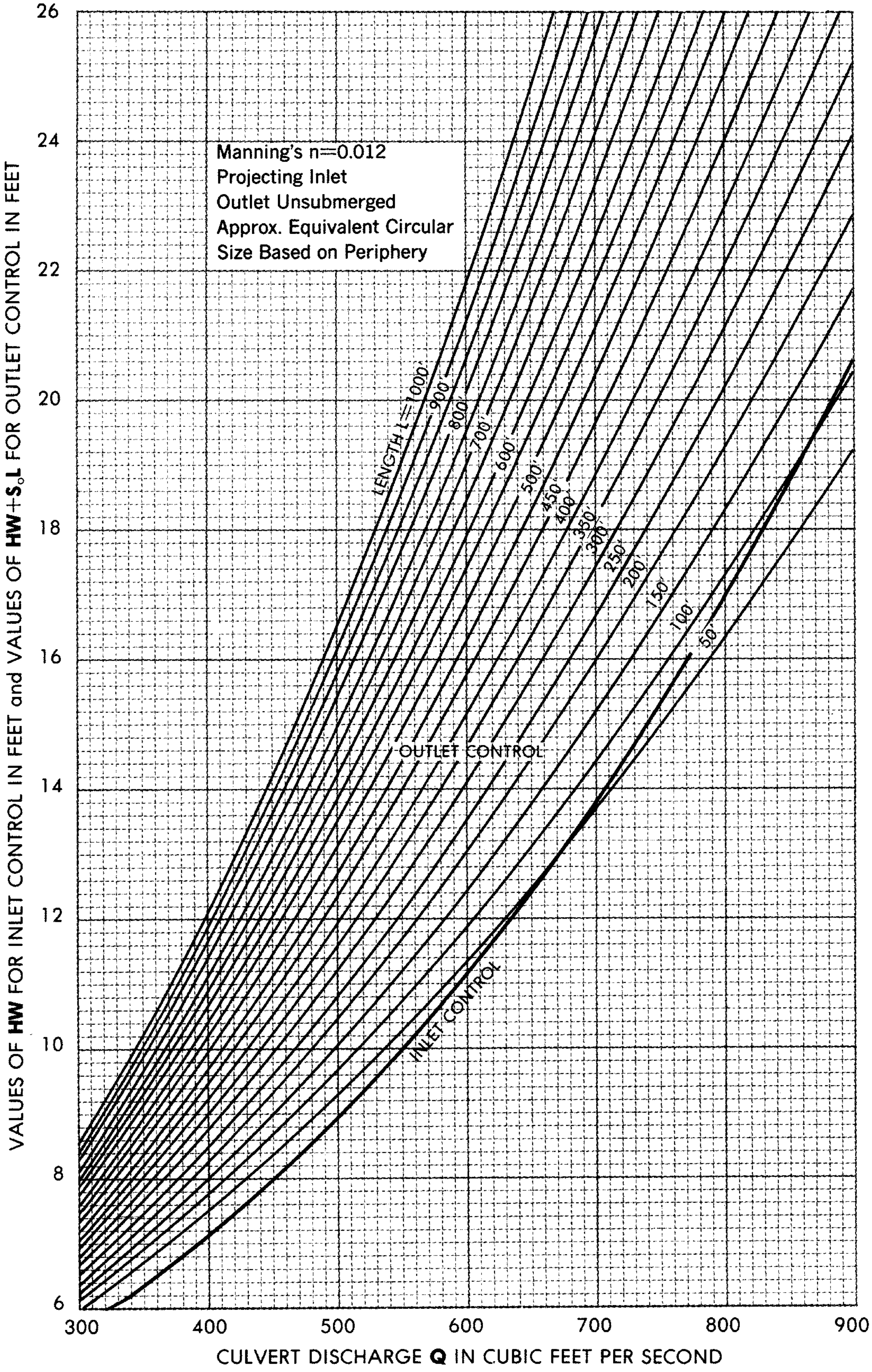


Figure 99

CULVERT CAPACITY
72 x 115-INCH (RISE x SPAN) ARCH
EQUIVALENT 90-INCH CIRCULAR

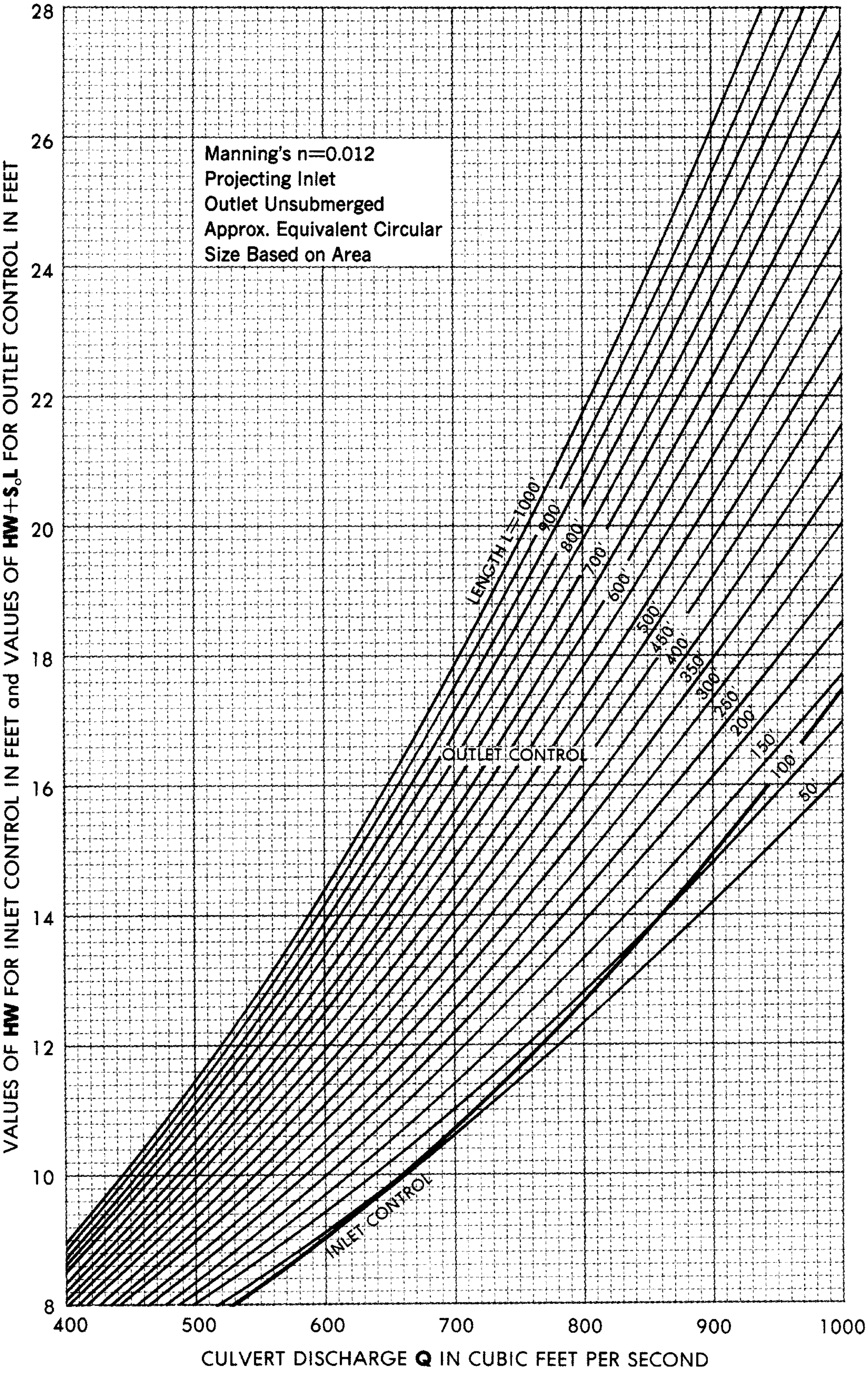


Figure 100

CULVERT CAPACITY
77 x 122-INCH (RISE x SPAN) ARCH
EQUIVALENT 96-INCH CIRCULAR

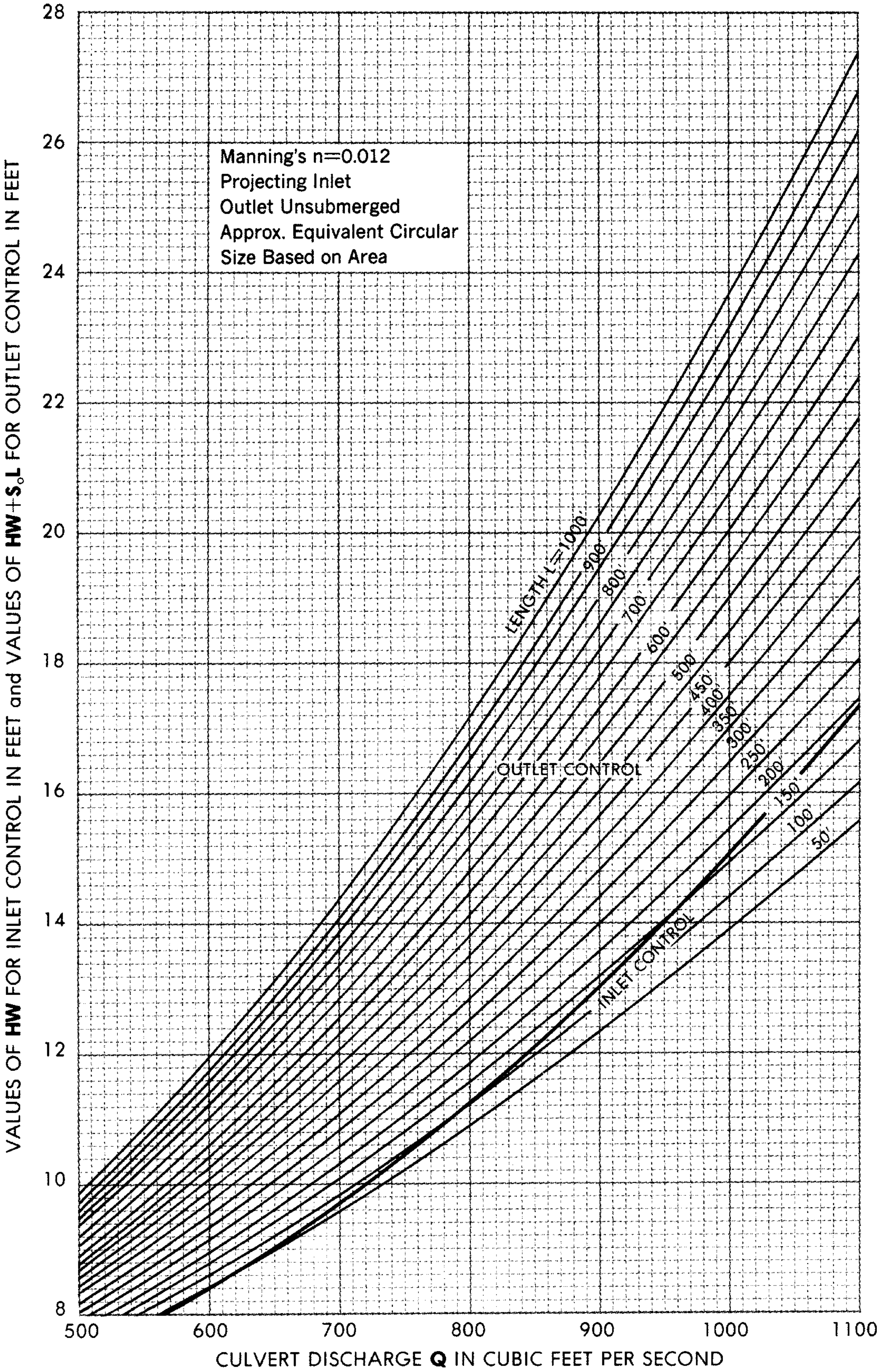


Figure 101

CULVERT CAPACITY
87 x 138-INCH (RISE x SPAN) ARCH
EQUIVALENT 108-INCH CIRCULAR

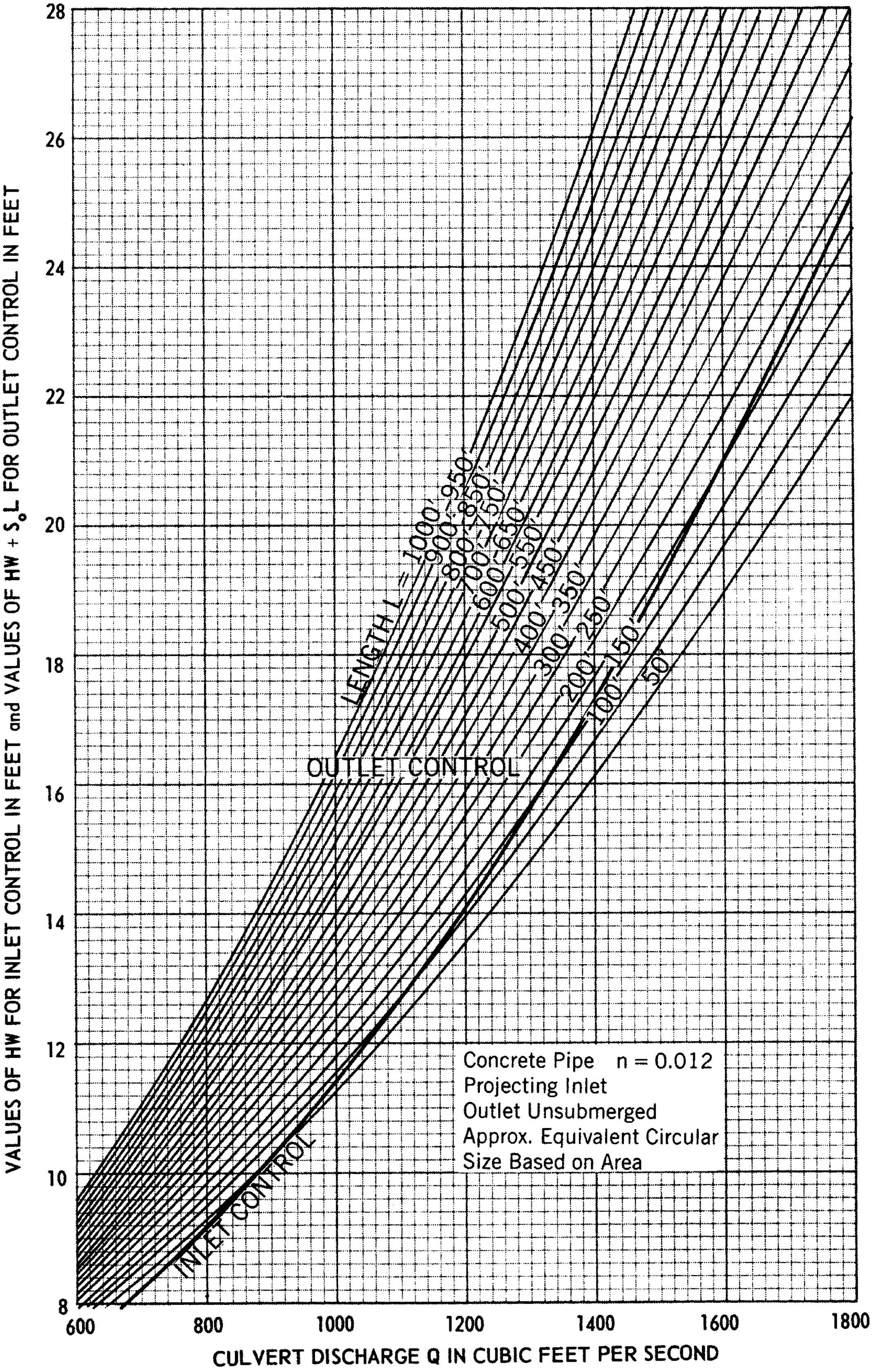


Figure 102

CULVERT CAPACITY
97 x 154-INCH (RISE x SPAN) ARCH
EQUIVALENT 120-INCH CIRCULAR

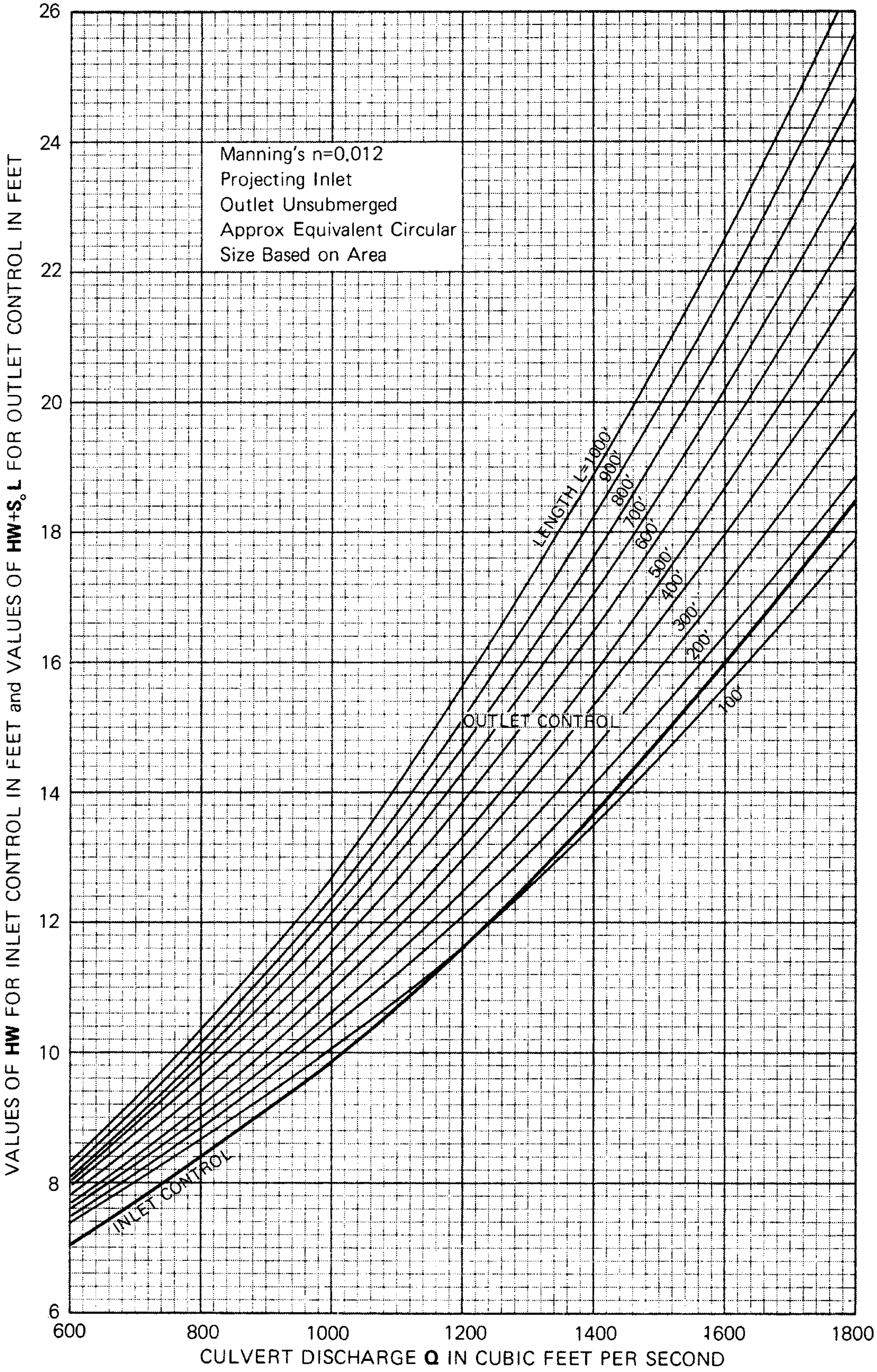


Figure 103

CULVERT CAPACITY
106 x 169-INCH (RISE x SPAN) ARCH
EQUIVALENT 132-INCH CIRCULAR

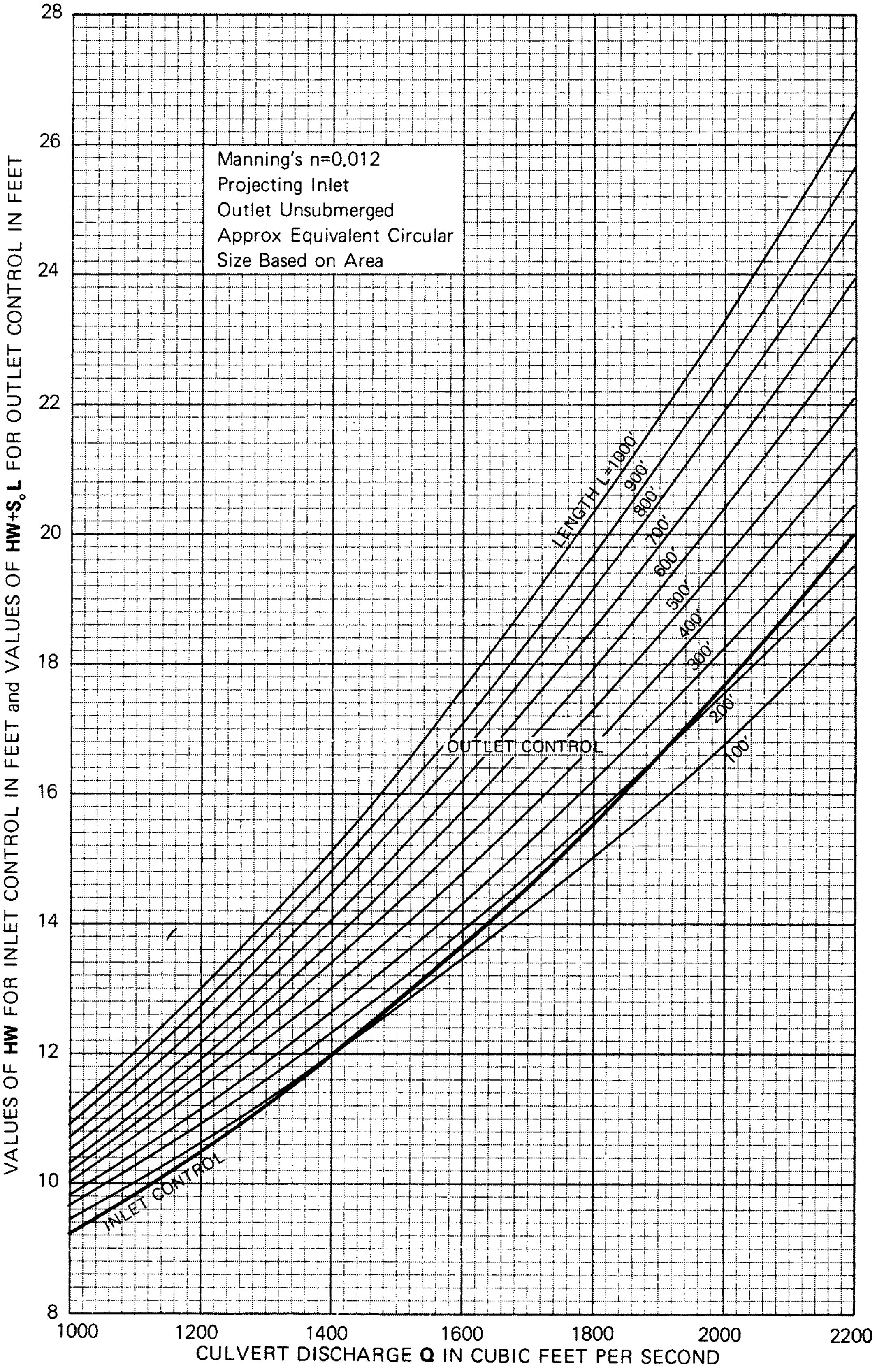


Figure 104

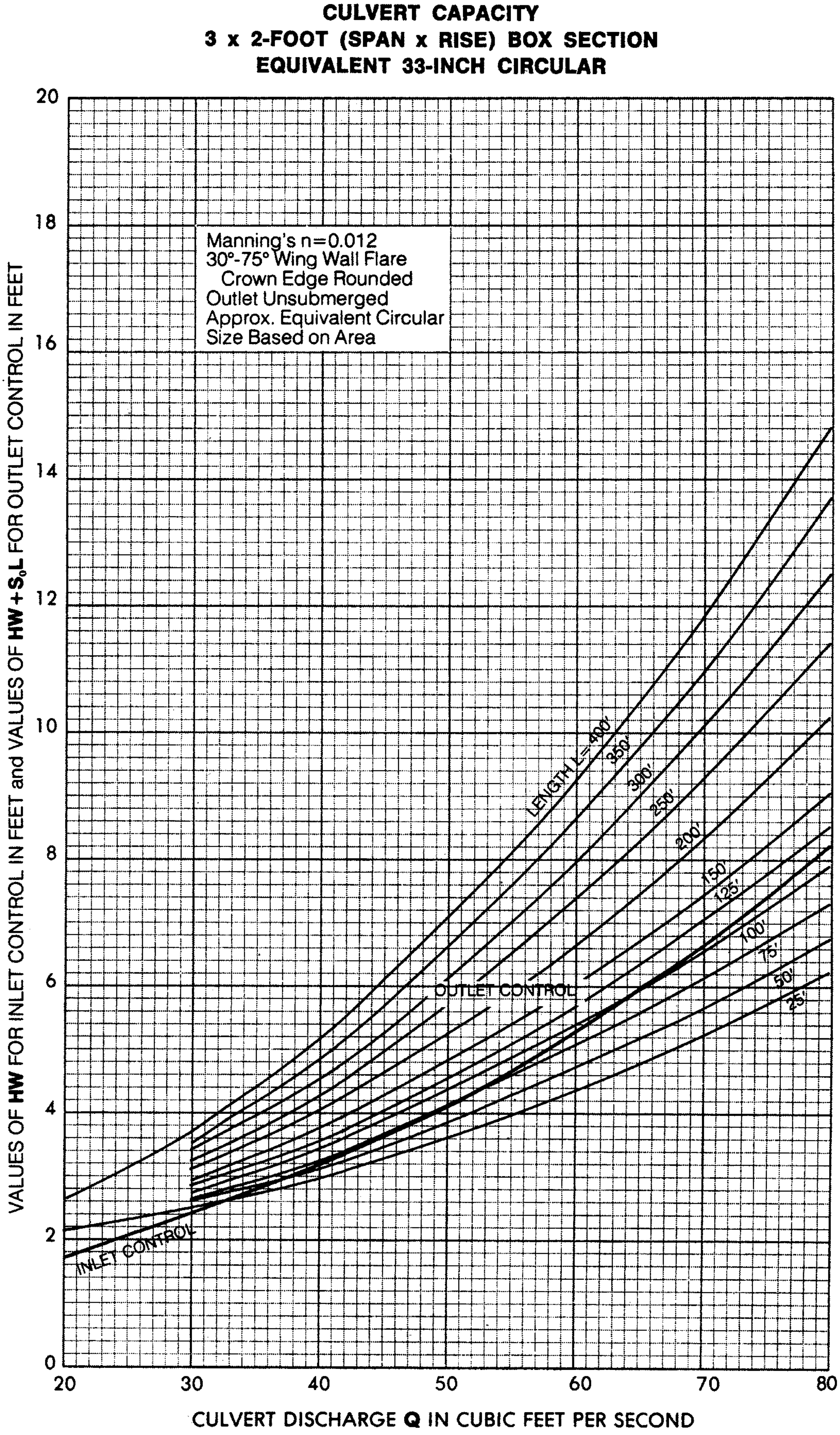

CULVERT CAPACITY
3 x 2-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 33-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L=400'
350'
300'
250'
200'
150
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
0
2
4
6
8
10
12
14
16
18
20
20
30
40
50
60
70
80
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S₀L FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 105

CULVERT CAPACITY
3 x 3-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 39-INCH CIRCULAR

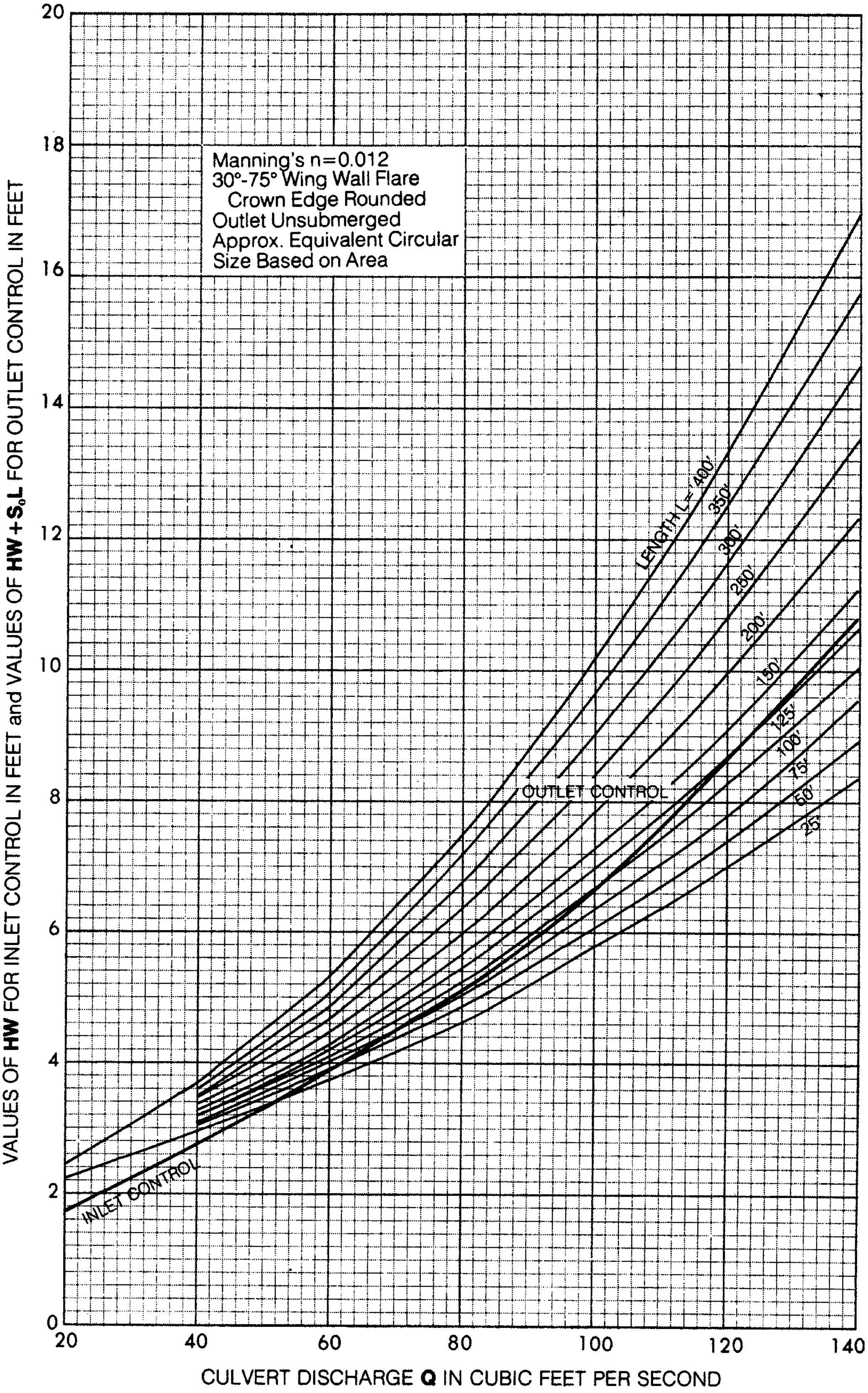


Figure 106

CULVERT CAPACITY
4 x 2-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 36-INCH CIRCULAR

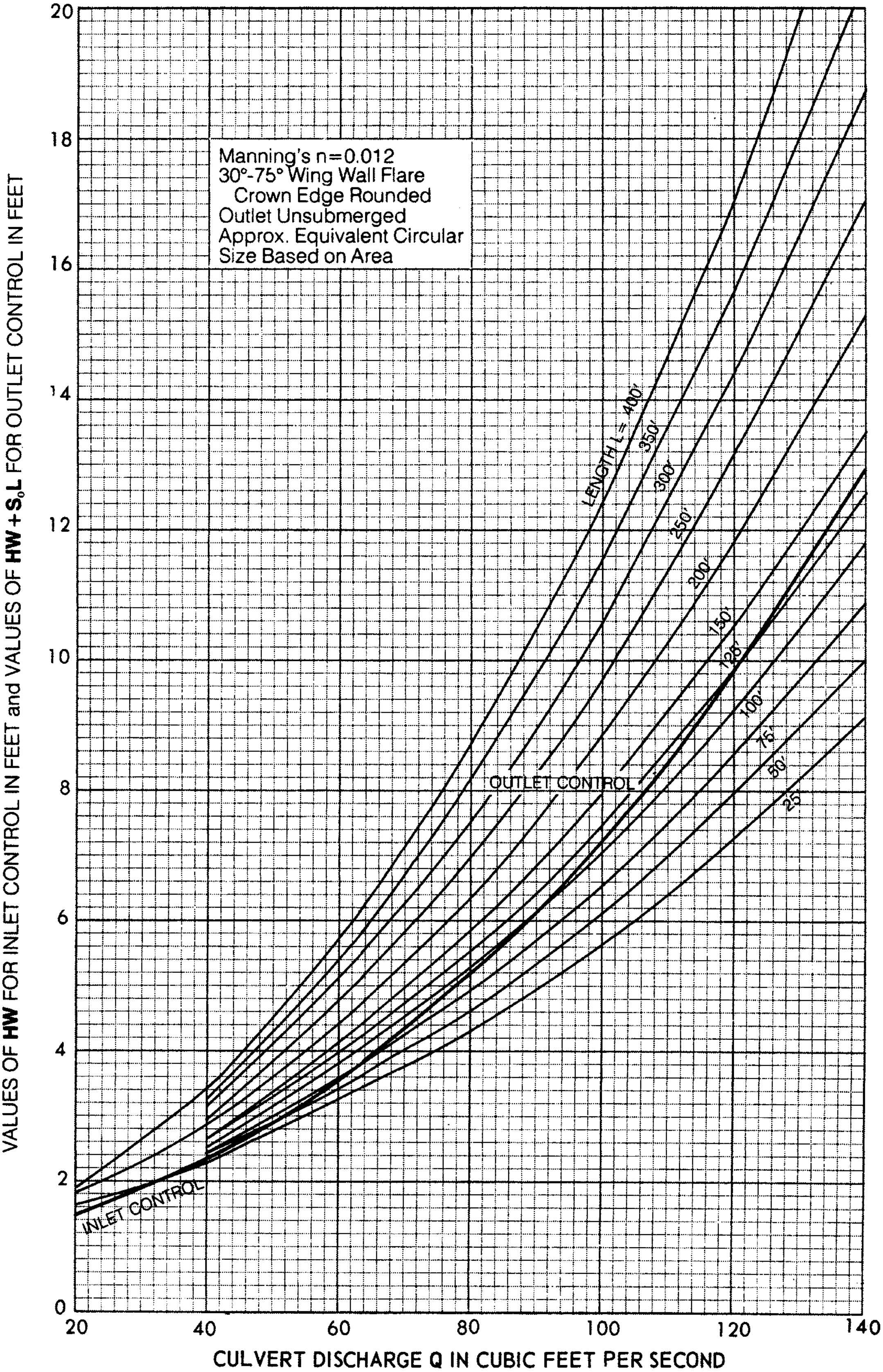


Figure 107

CULVERT CAPACITY
4 x 3-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 42-INCH CIRCULAR

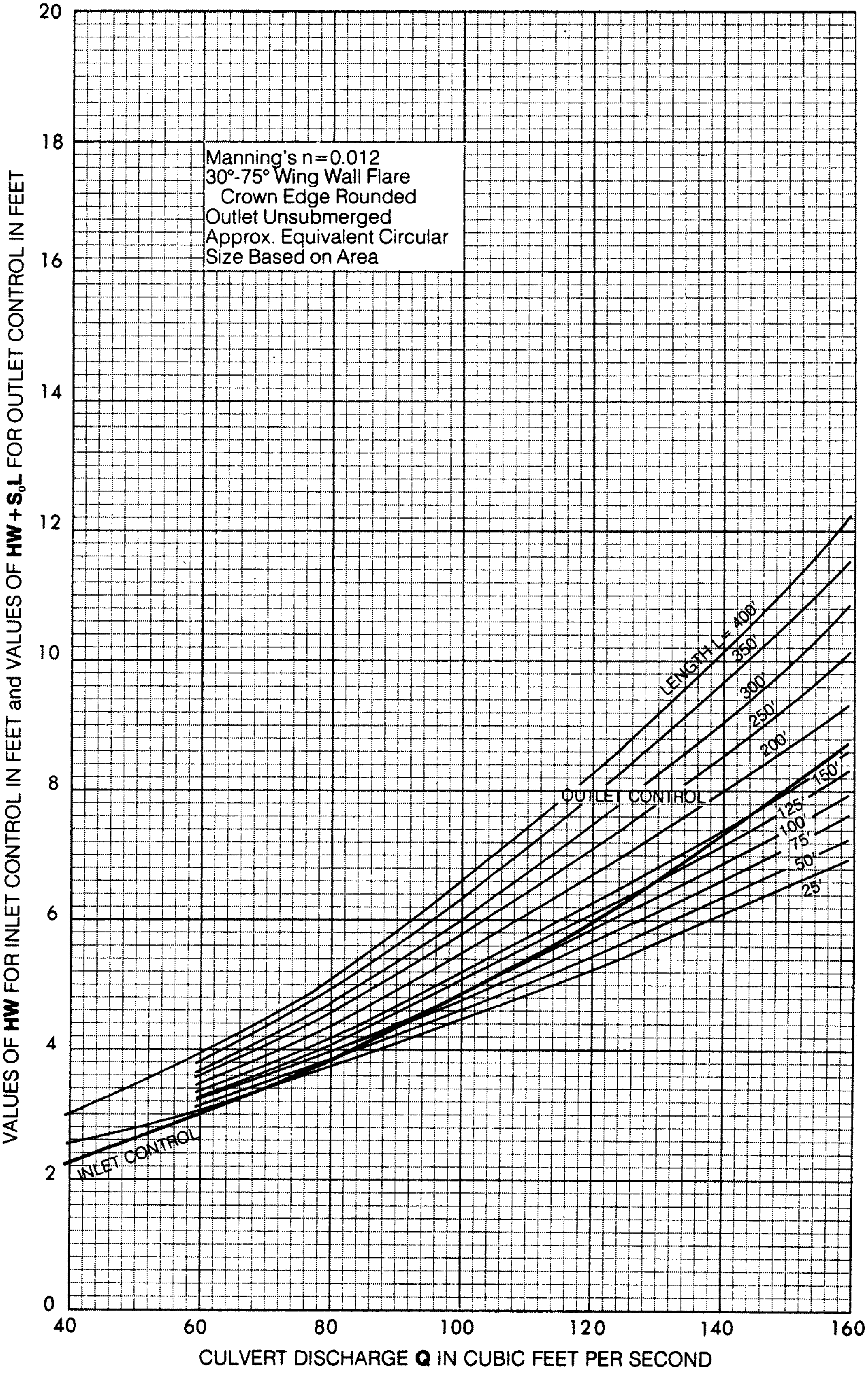


Figure 108

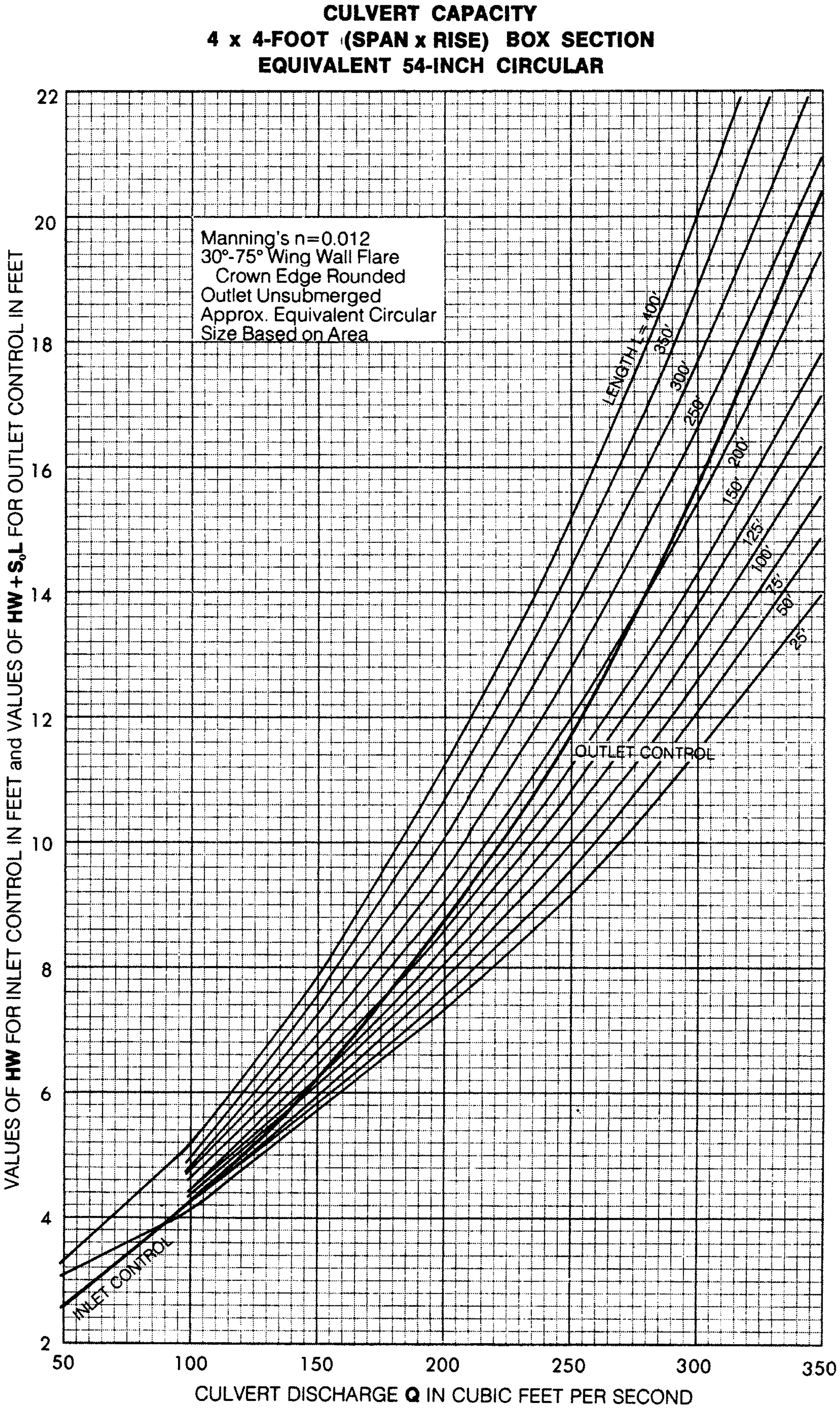

CULVERT CAPACITY
4 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 54-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L = 400'
350'
300'
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
2
4
6
8
10
12
14
16
18
20
22
50
100
150
200
250
300
350
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 109

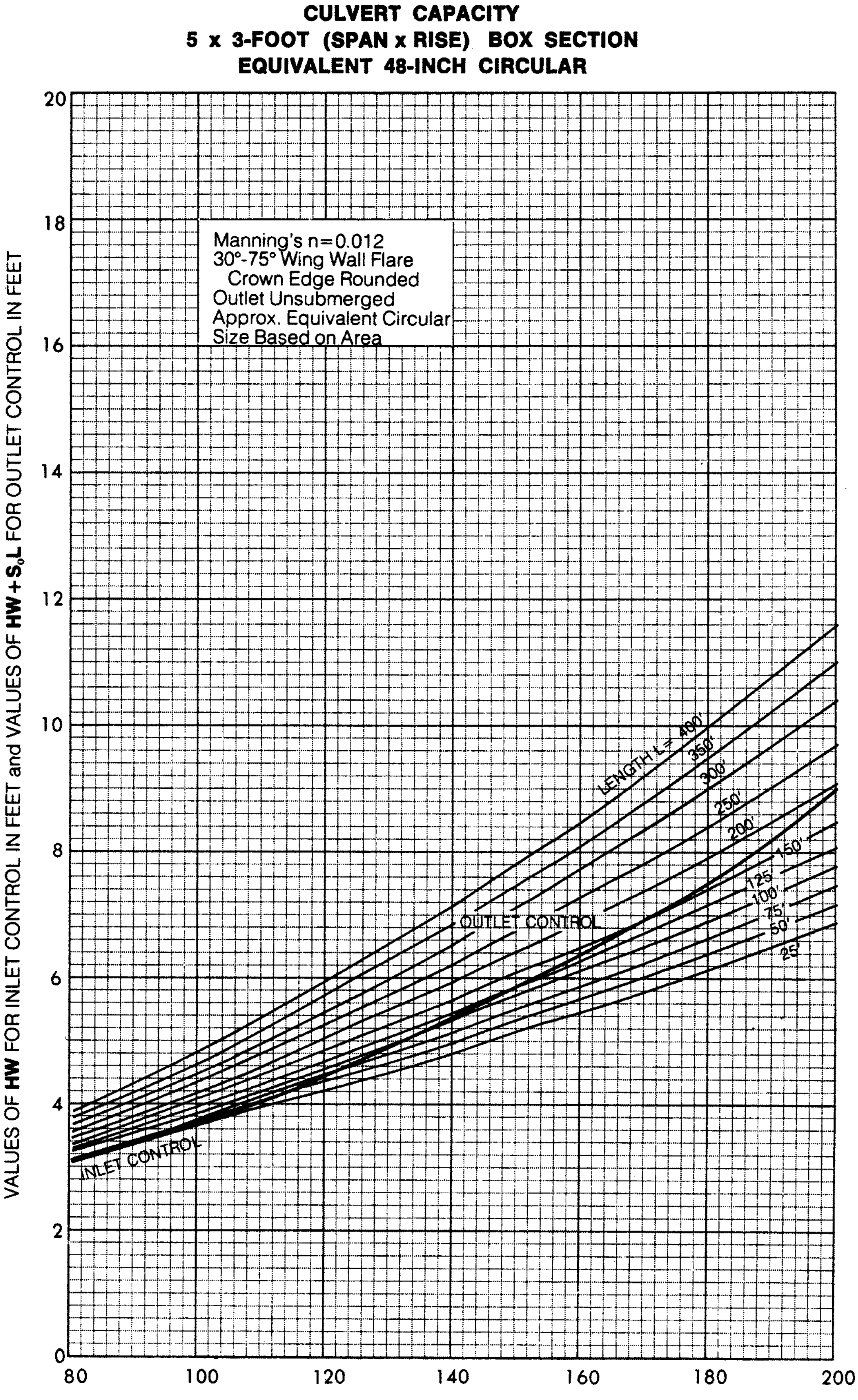

CULVERT CAPACITY
5 x 3-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 48-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L= 400'
350'
300'
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
0
2
4
6
8
10
12
14
16
18
20
80
100
120
140
160
180
200
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S₀L FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 110

CULVERT CAPACITY
5 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 60-INCH CIRCULAR

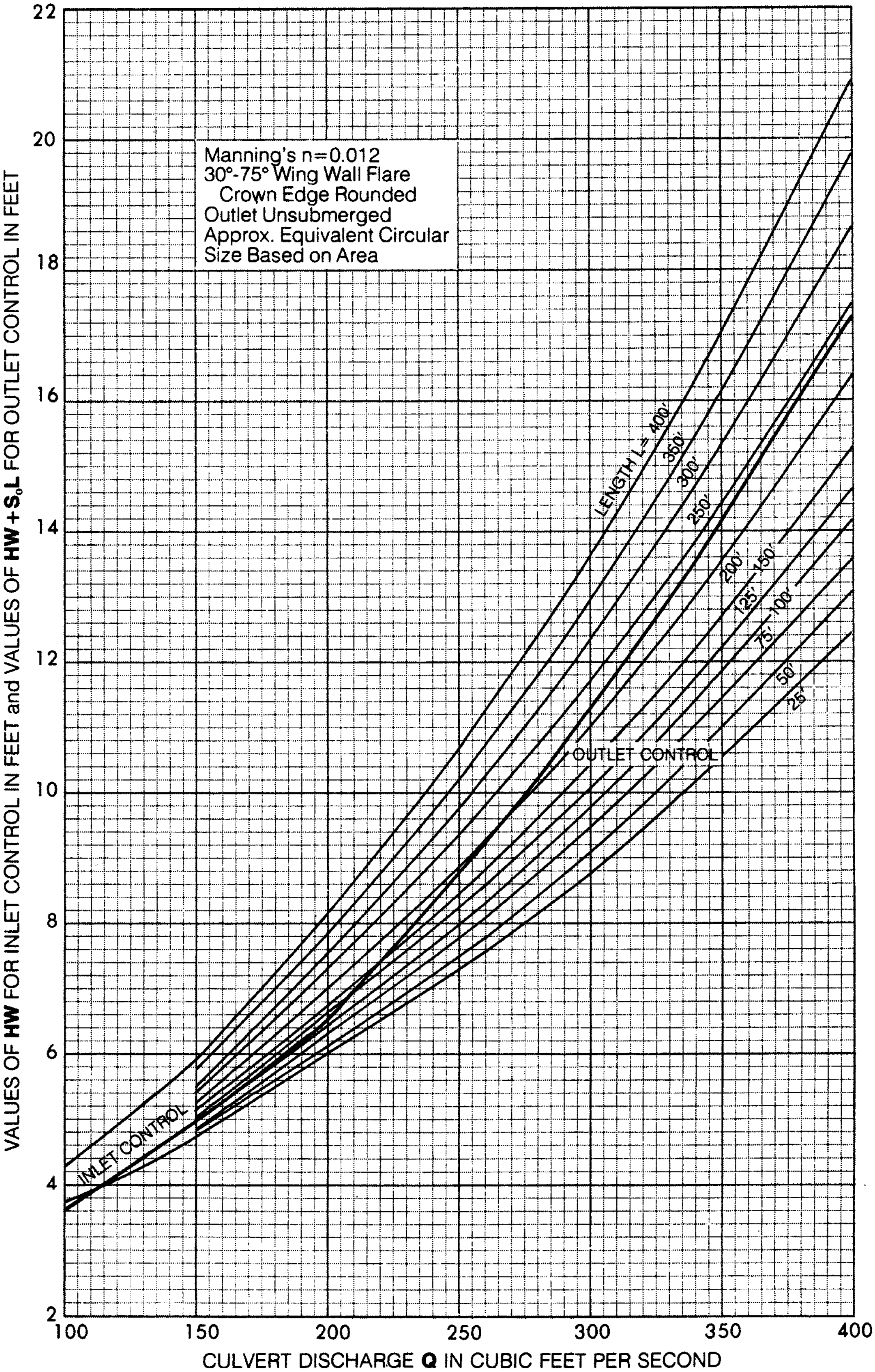


Figure 111

CULVERT CAPACITY
5 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 66-INCH CIRCULAR

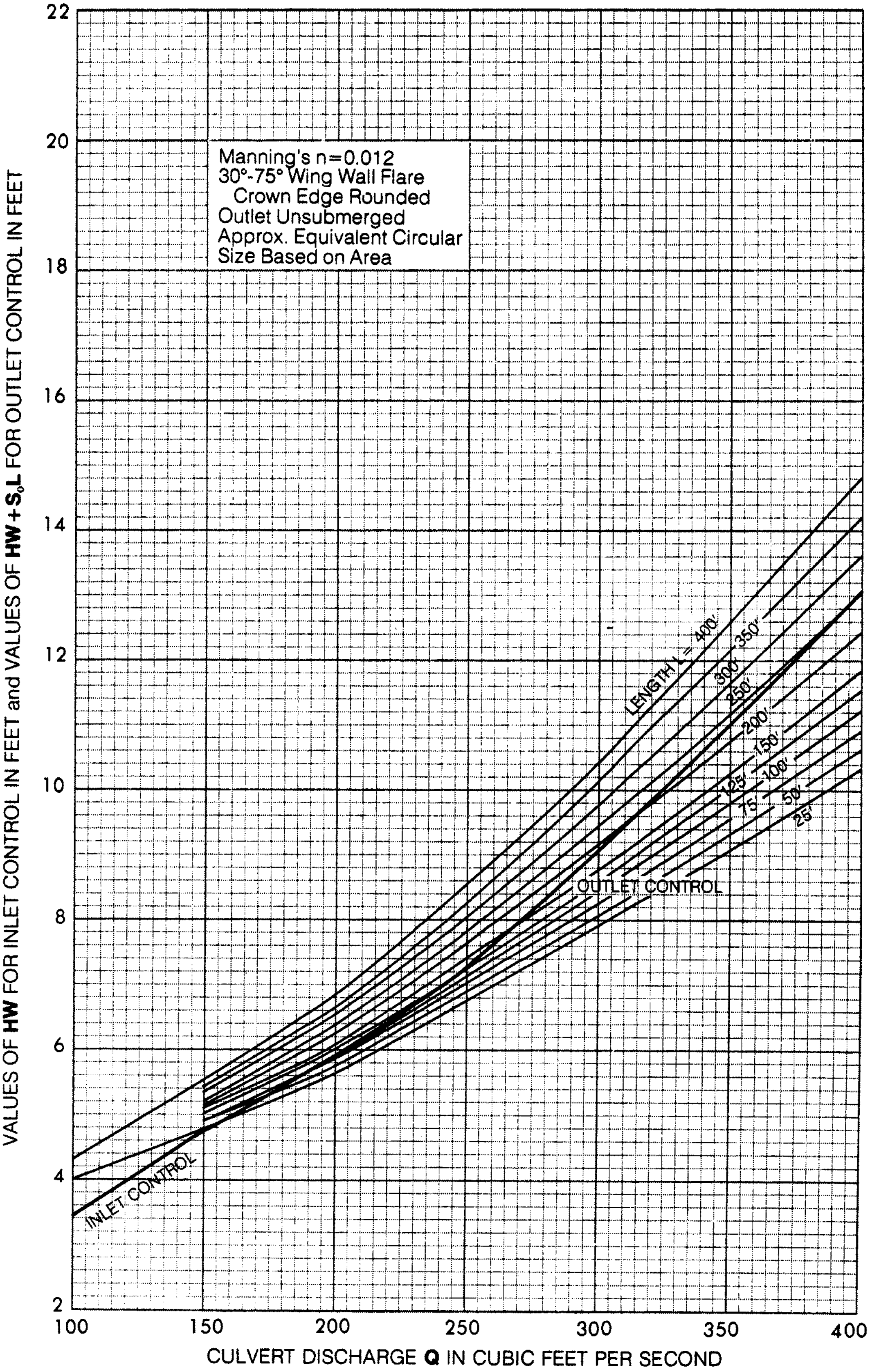


Figure 112

CULVERT CAPACITY
6 x 3-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 57-INCH CIRCULAR

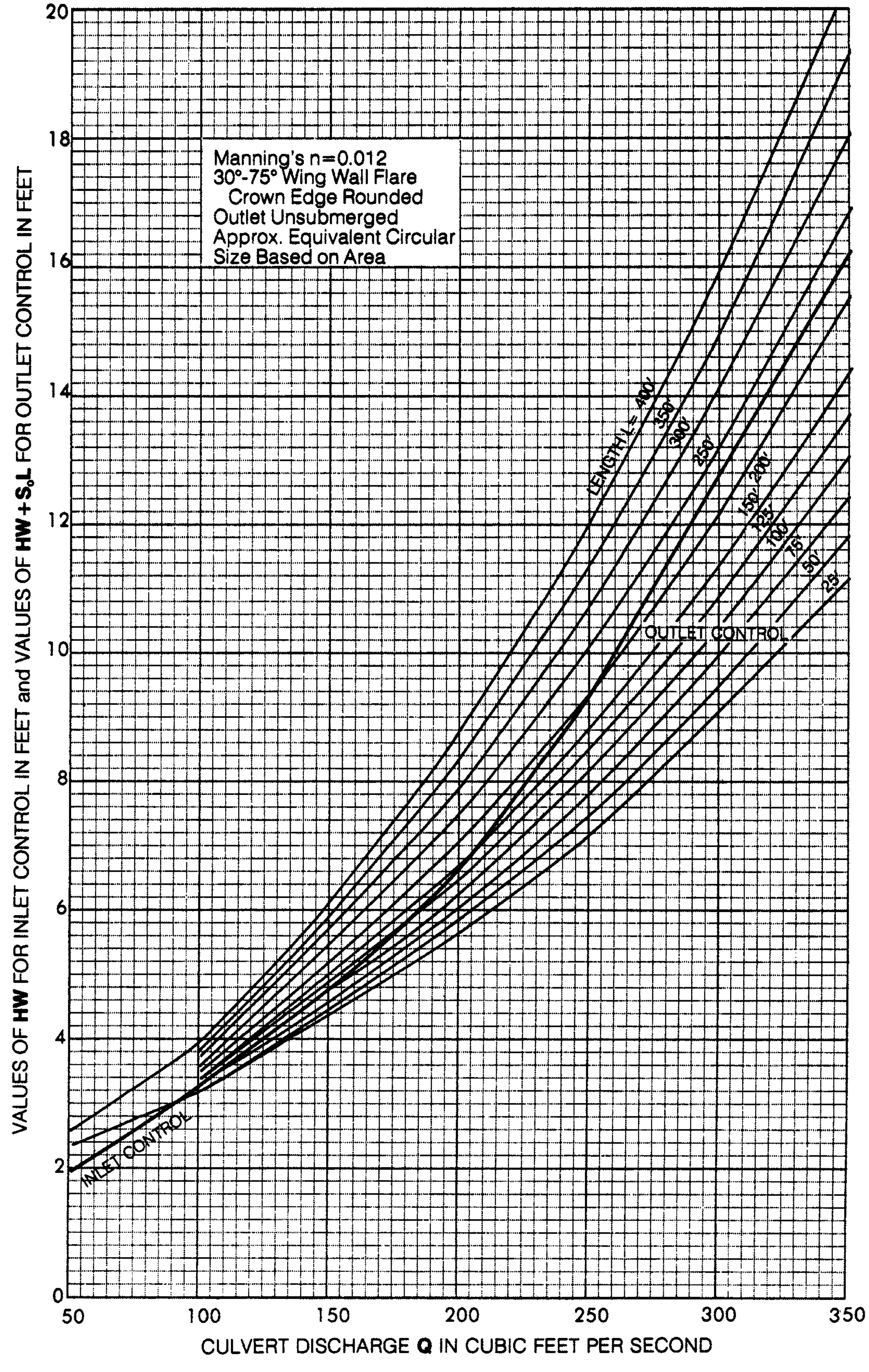


Figure 113

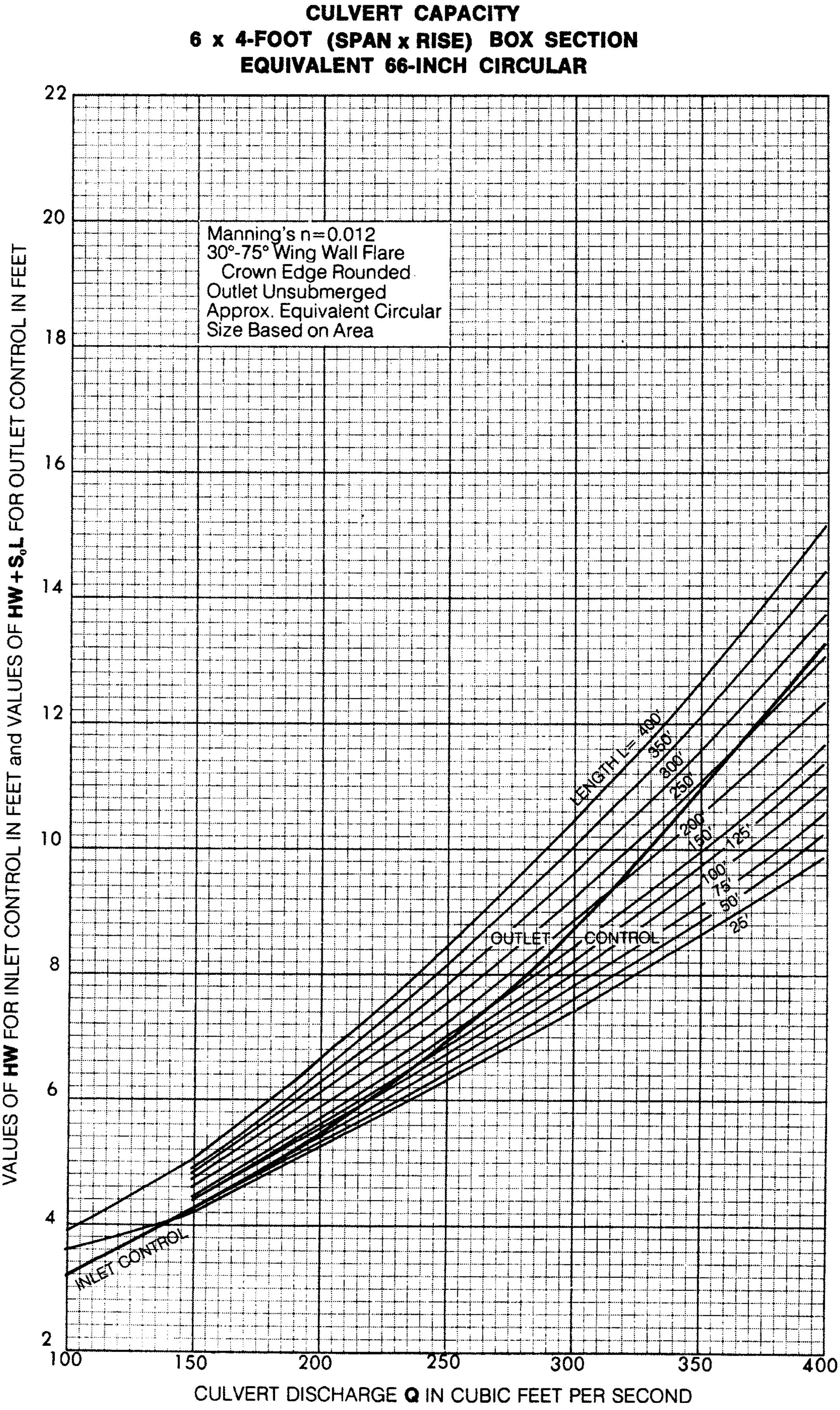

CULVERT CAPACITY
6 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 66-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L= 400'
350'
300'
250'
200'
150'
125'
100'
75'
50'
25'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S₀L FOR OUTLET CONTROL IN FEET
2
4
6
8
10
12
14
16
18
20
22
100
150
200
250
300
350
400
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 114

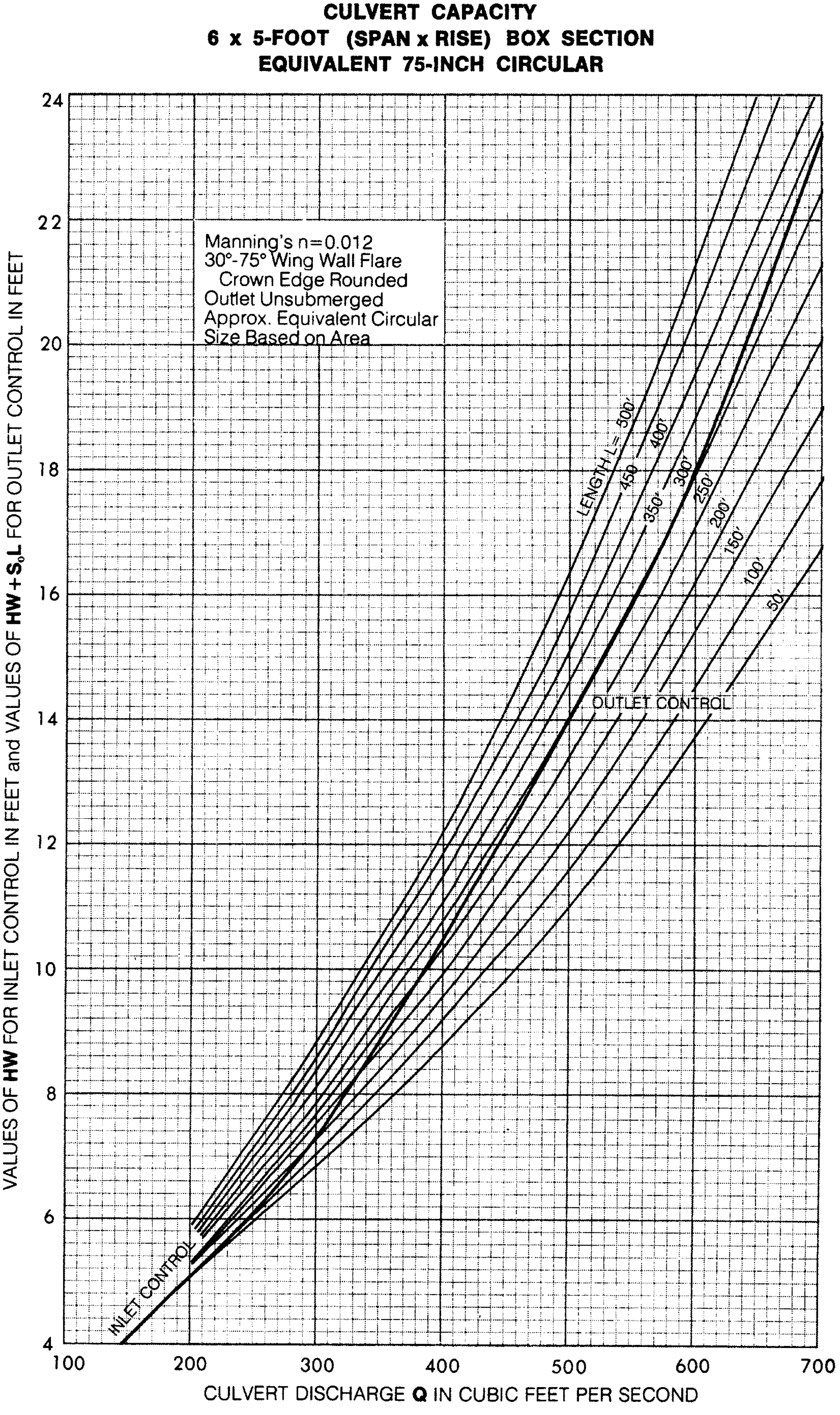

CULVERT CAPACITY
6 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 75-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L=500'
450
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
24
22
20
18
16
14
12
10
8
6
4
100
200
300
400
500
600
700
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S₀L FOR OUTLET CONTROL IN FEET
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 115

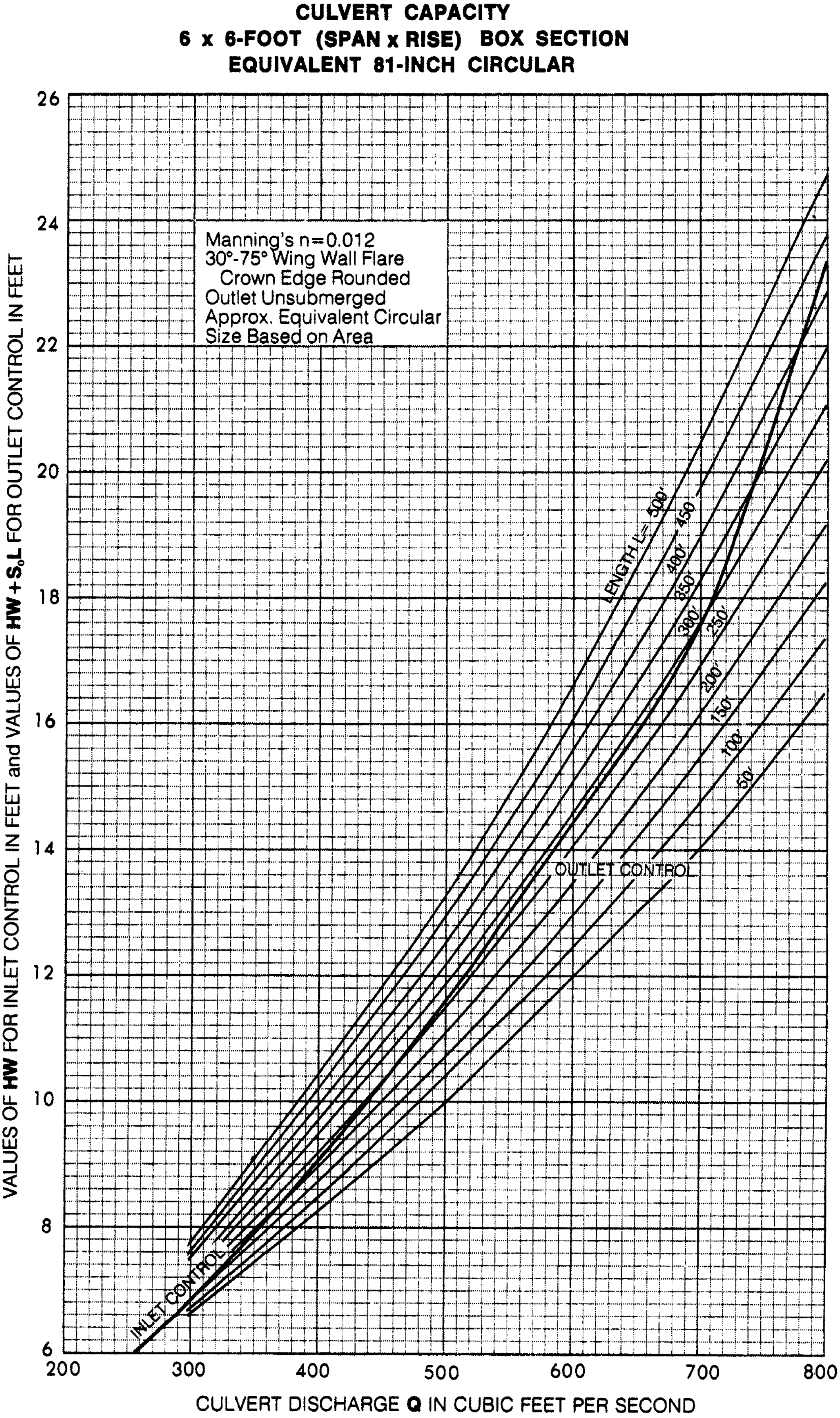

CULVERT CAPACITY
6 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 81-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L= 500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S₀L FOR OUTLET CONTROL IN FEET
26
24
22
20
18
16
14
12
10
8
6
200
300
400
500
600
700
800
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 116

CULVERT CAPACITY
7 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 71-INCH CIRCULAR

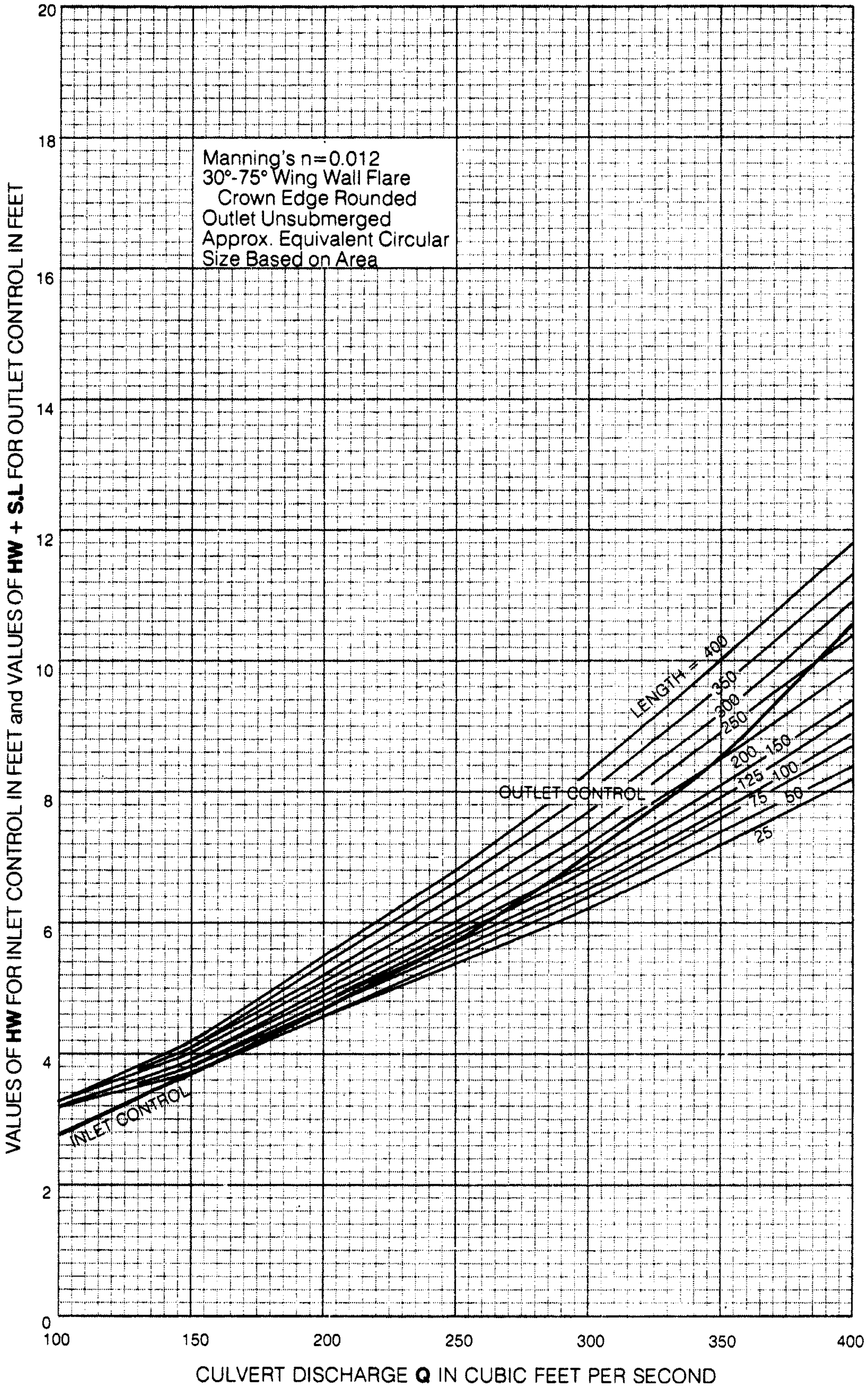


Figure 117

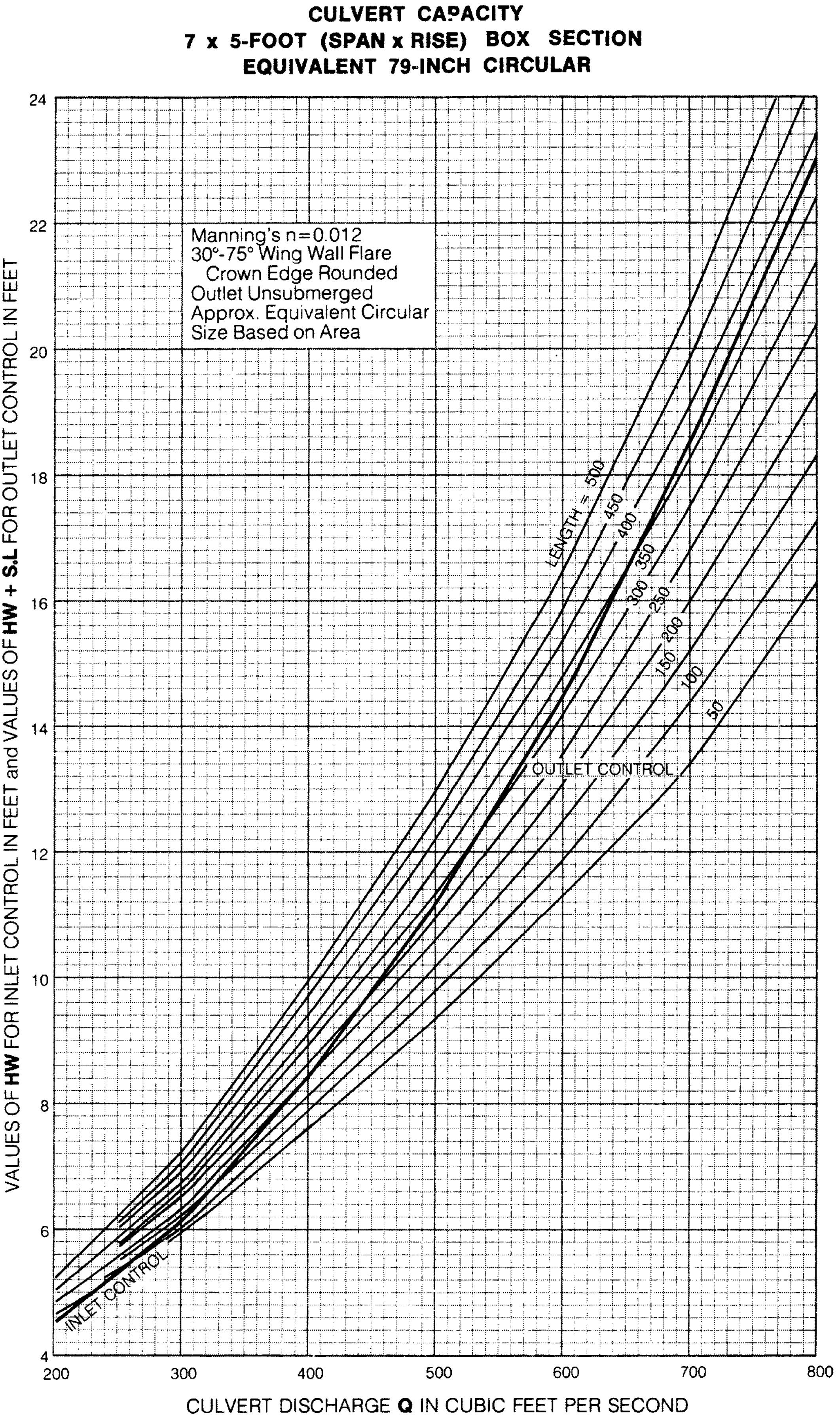

CULVERT CAPACITY
7 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 79-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH = 500
450
400
350
300
250
200
150
100
50
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S.L FOR OUTLET CONTROL IN FEET
4
6
8
10
12
14
16
18
20
22
24
200
300
400
500
600
700
800
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 118

CULVERT CAPACITY
7 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 87-INCH CIRCULAR

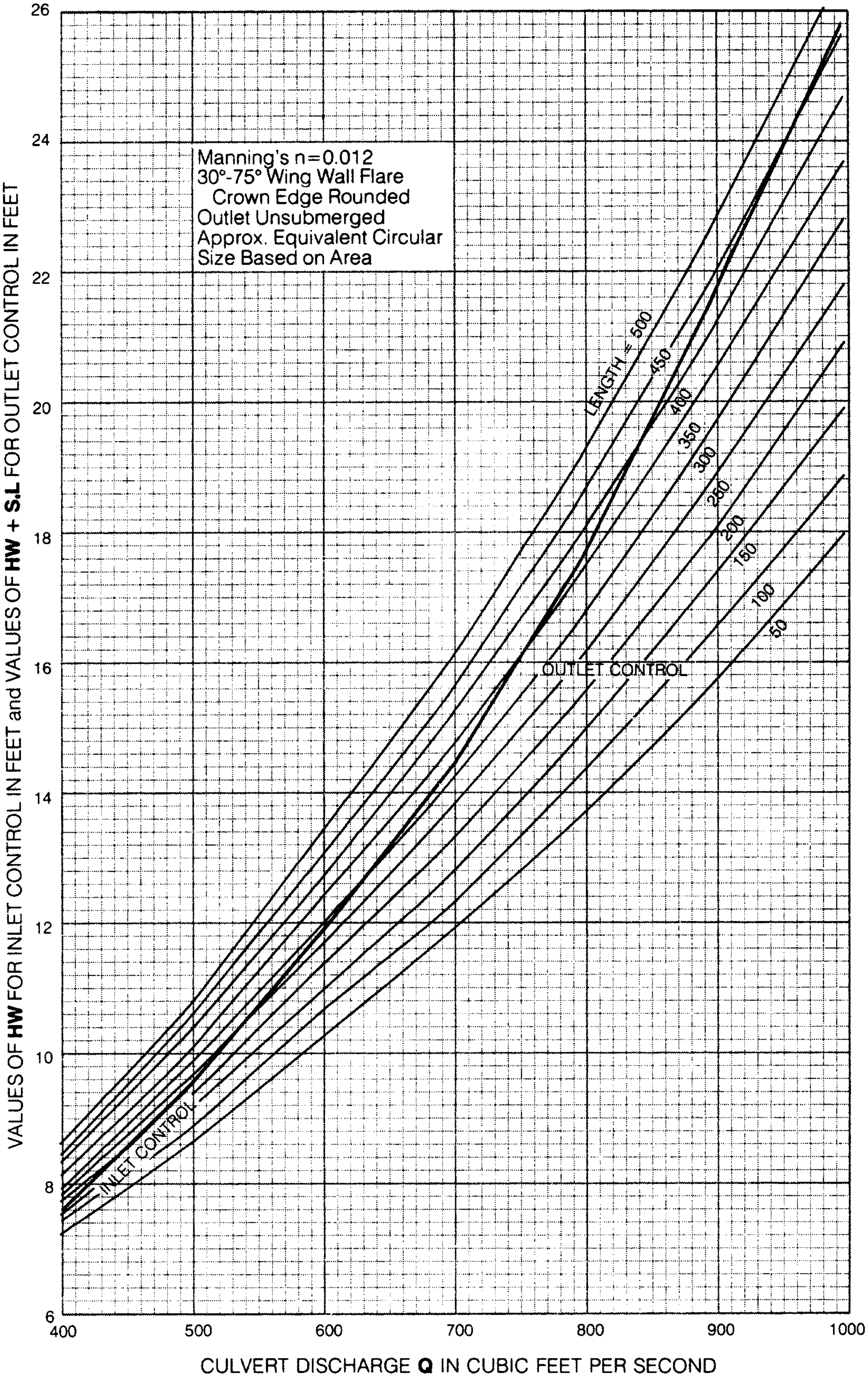


Figure 119

CULVERT CAPACITY
7 x 7-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 94-INCH CIRCULAR

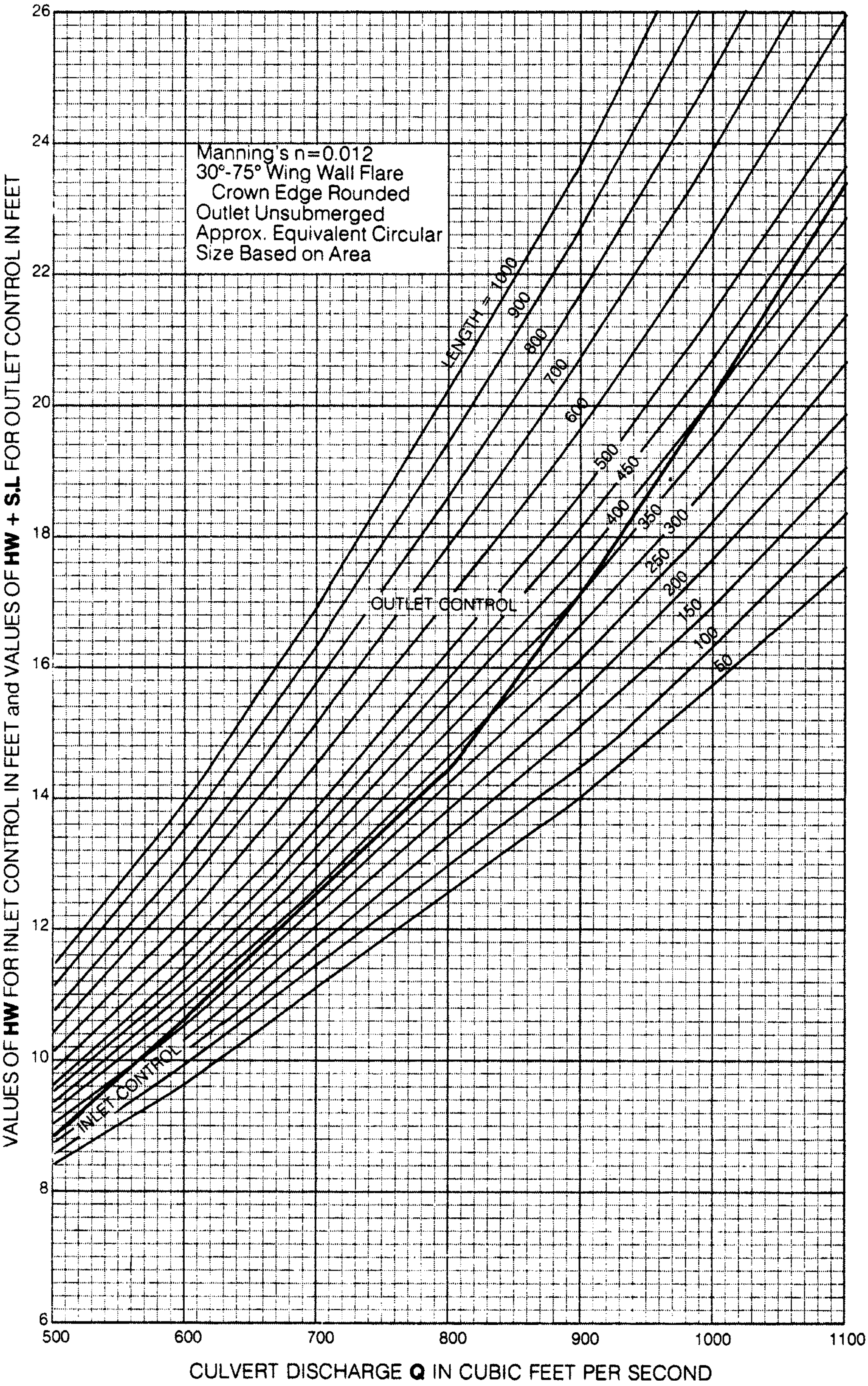


Figure 120

CULVERT CAPACITY
8 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 76-INCH CIRCULAR

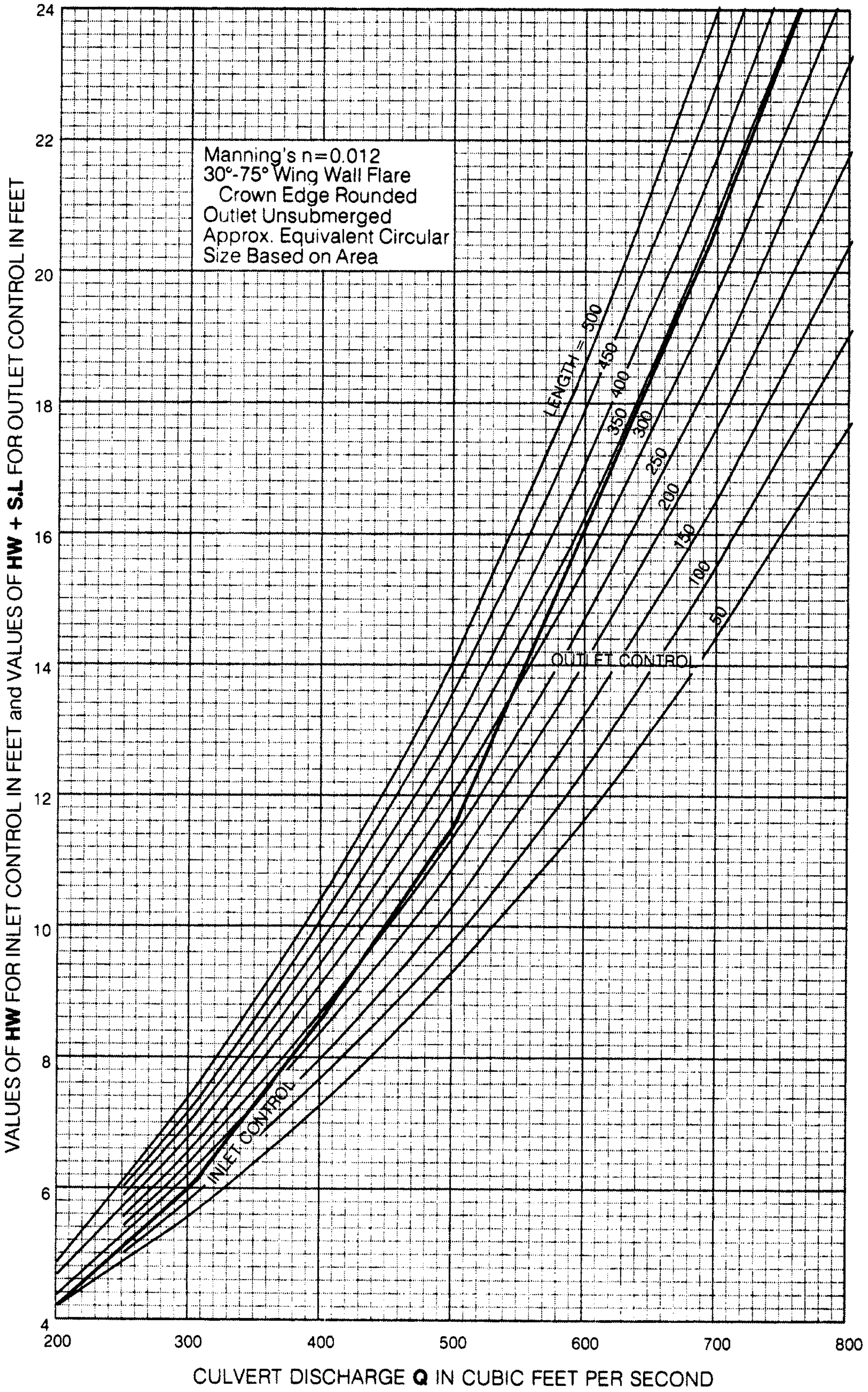


Figure 121

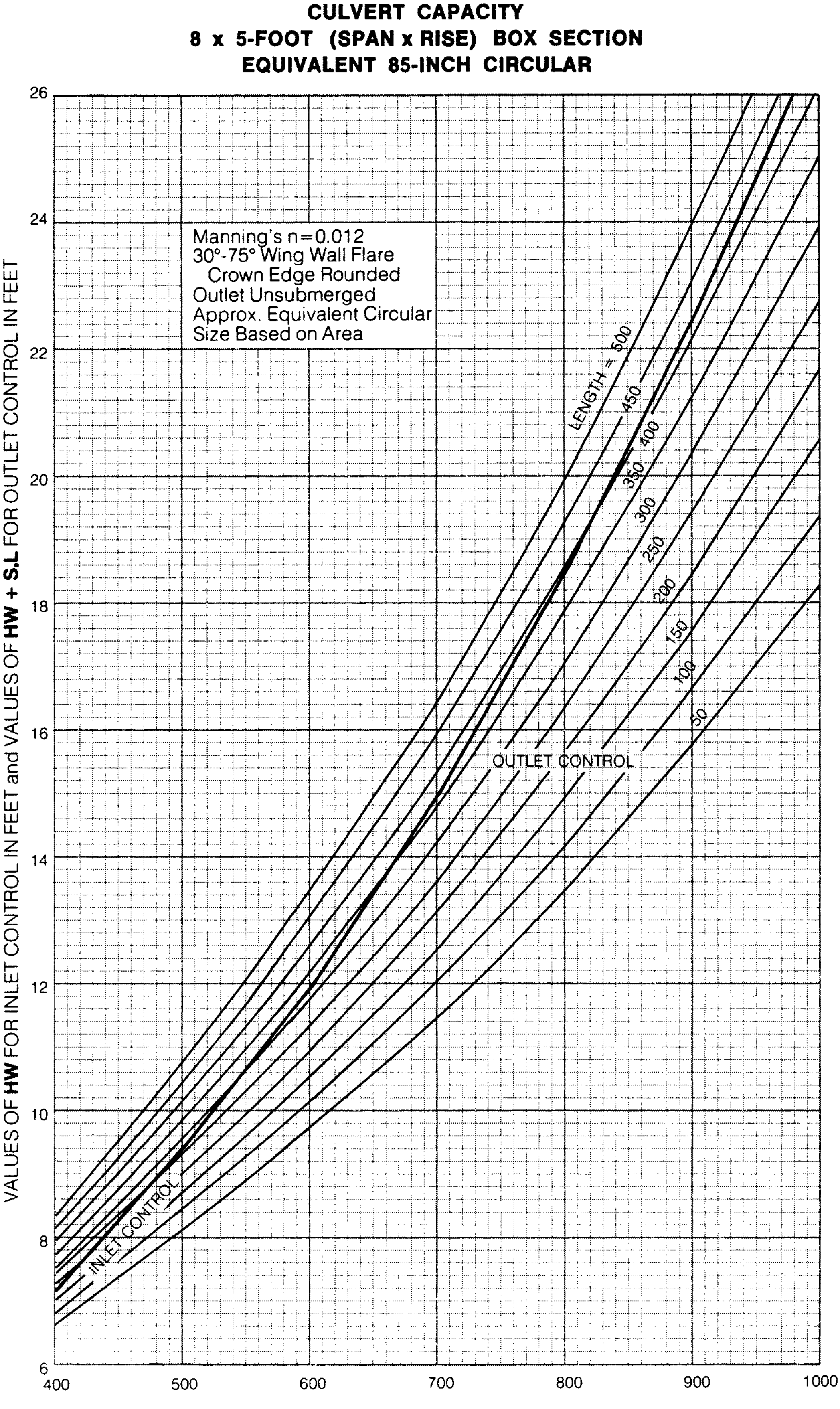
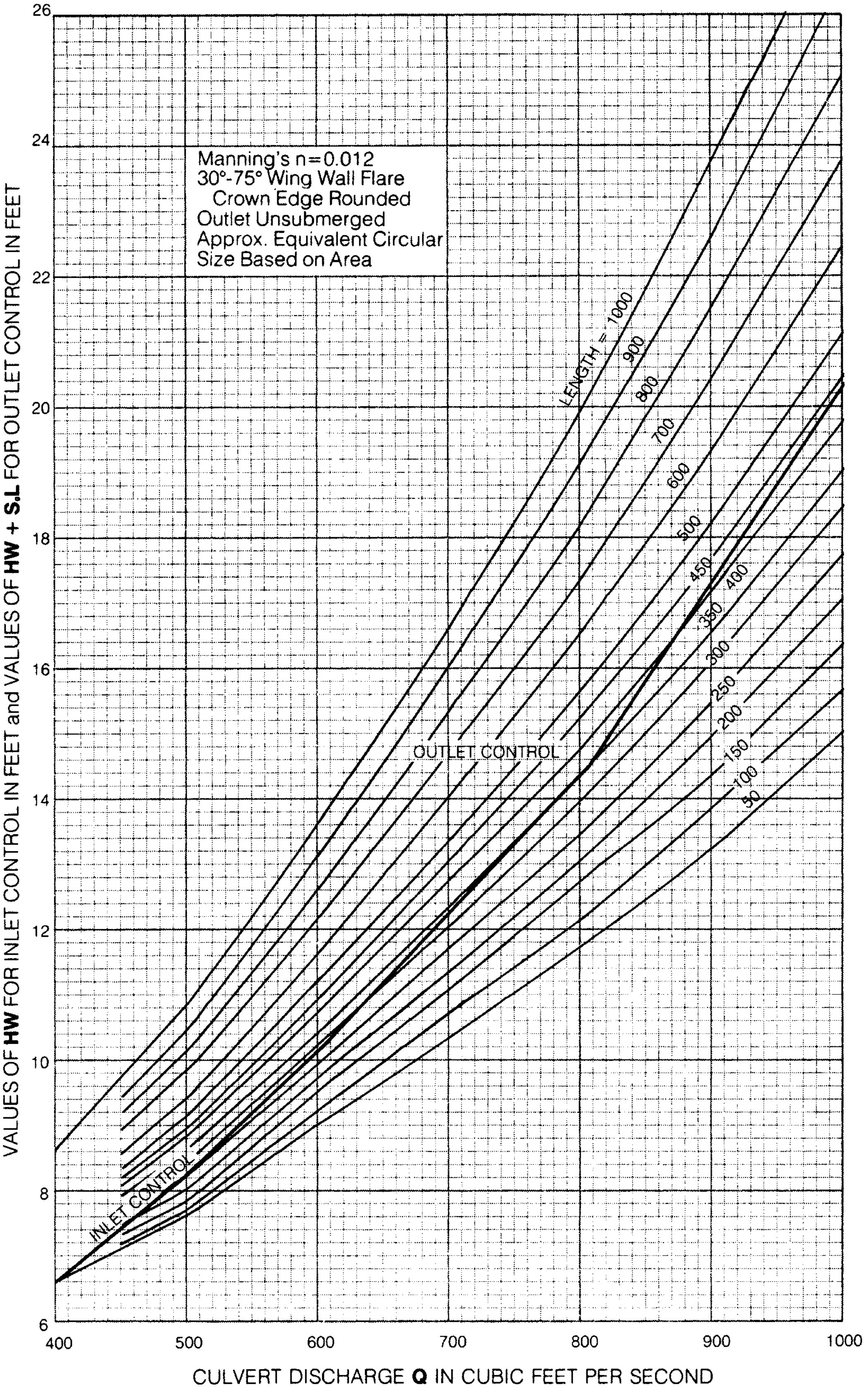

CULVERT CAPACITY
8 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 85-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH = 500
450
400
350
300
250
200
150
100
50
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S.L FOR OUTLET CONTROL IN FEET
6
8
10
12
14
16
18
20
22
24
26
400
500
600
700
800
900
1000
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 122



CULVERT CAPACITY
8 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 93-INCH CIRCULAR

Figure 123

CULVERT CAPACITY
8 x 7-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 101-INCH CIRCULAR

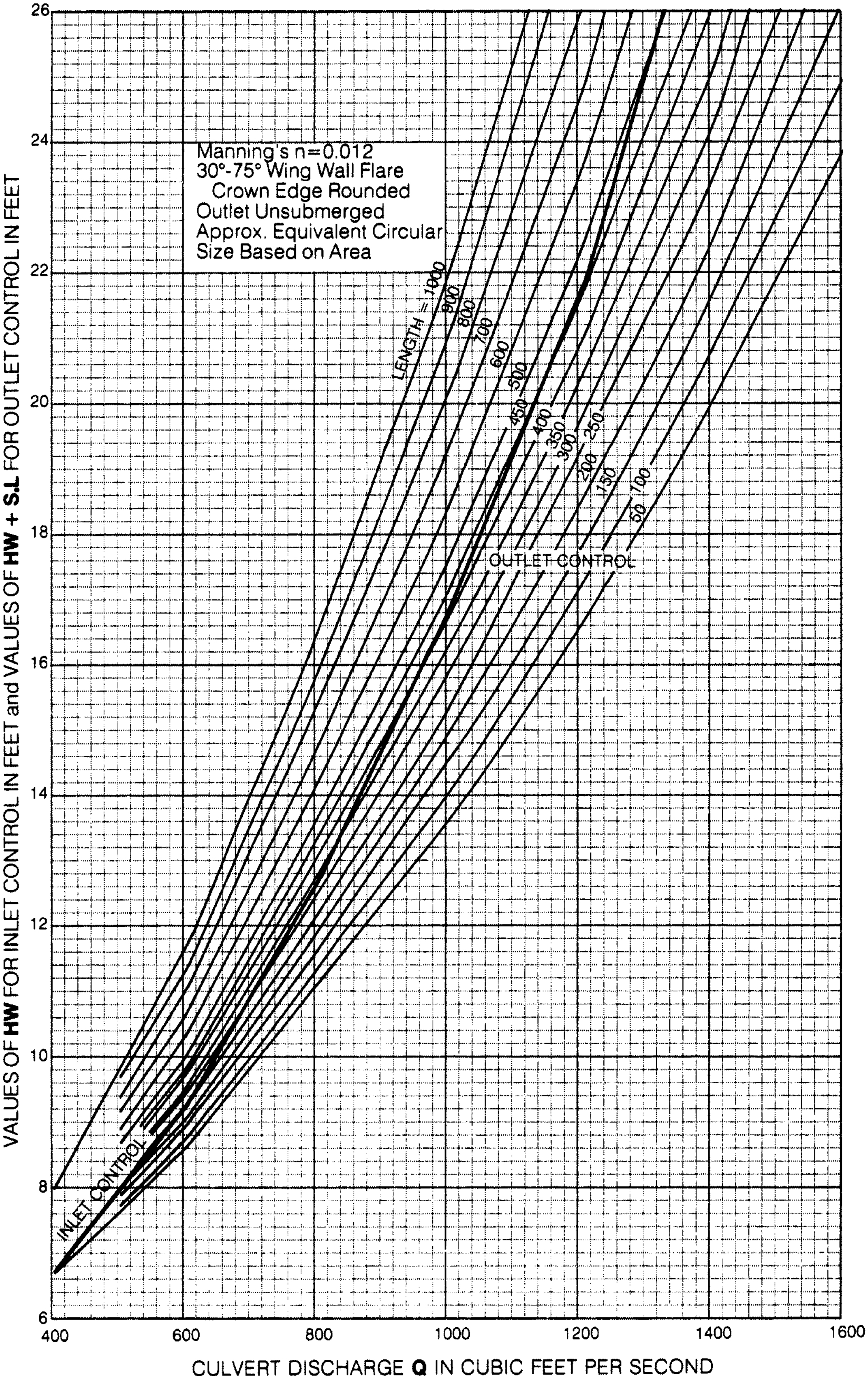


Figure 124

CULVERT CAPACITY
8 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 108-INCH CIRCULAR

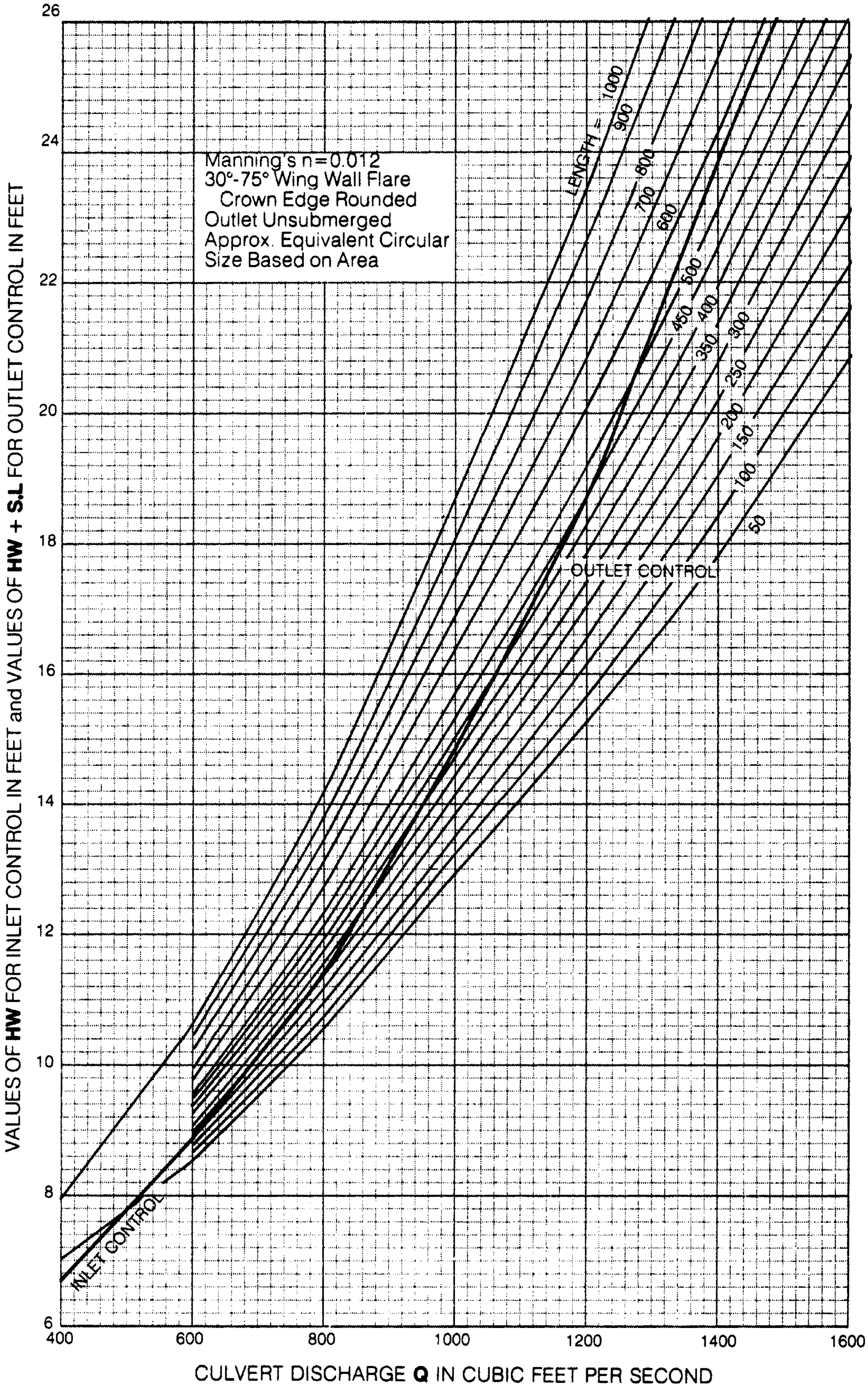


Figure 125

CULVERT CAPACITY
9 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 90-INCH CIRCULAR

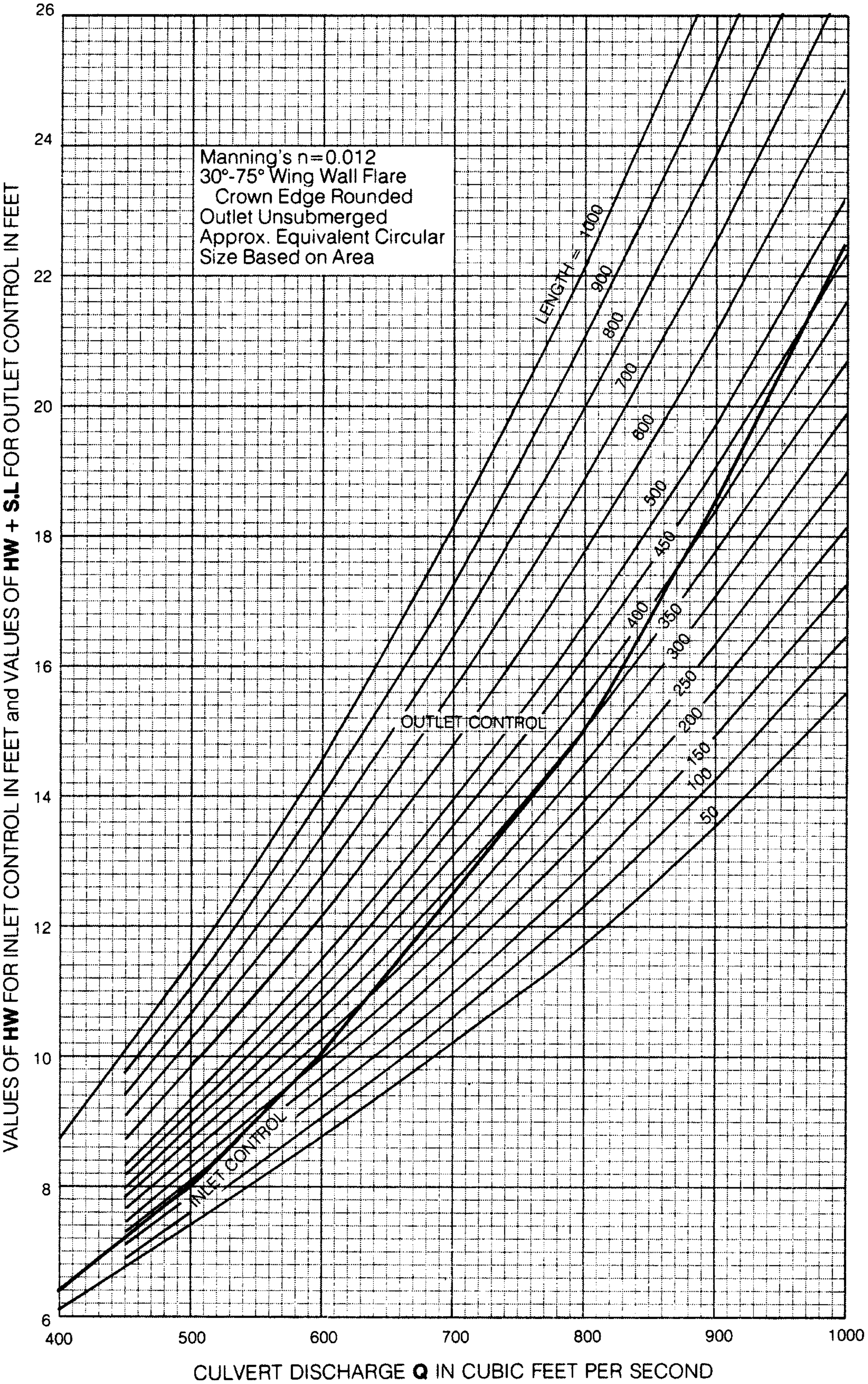


Figure 126

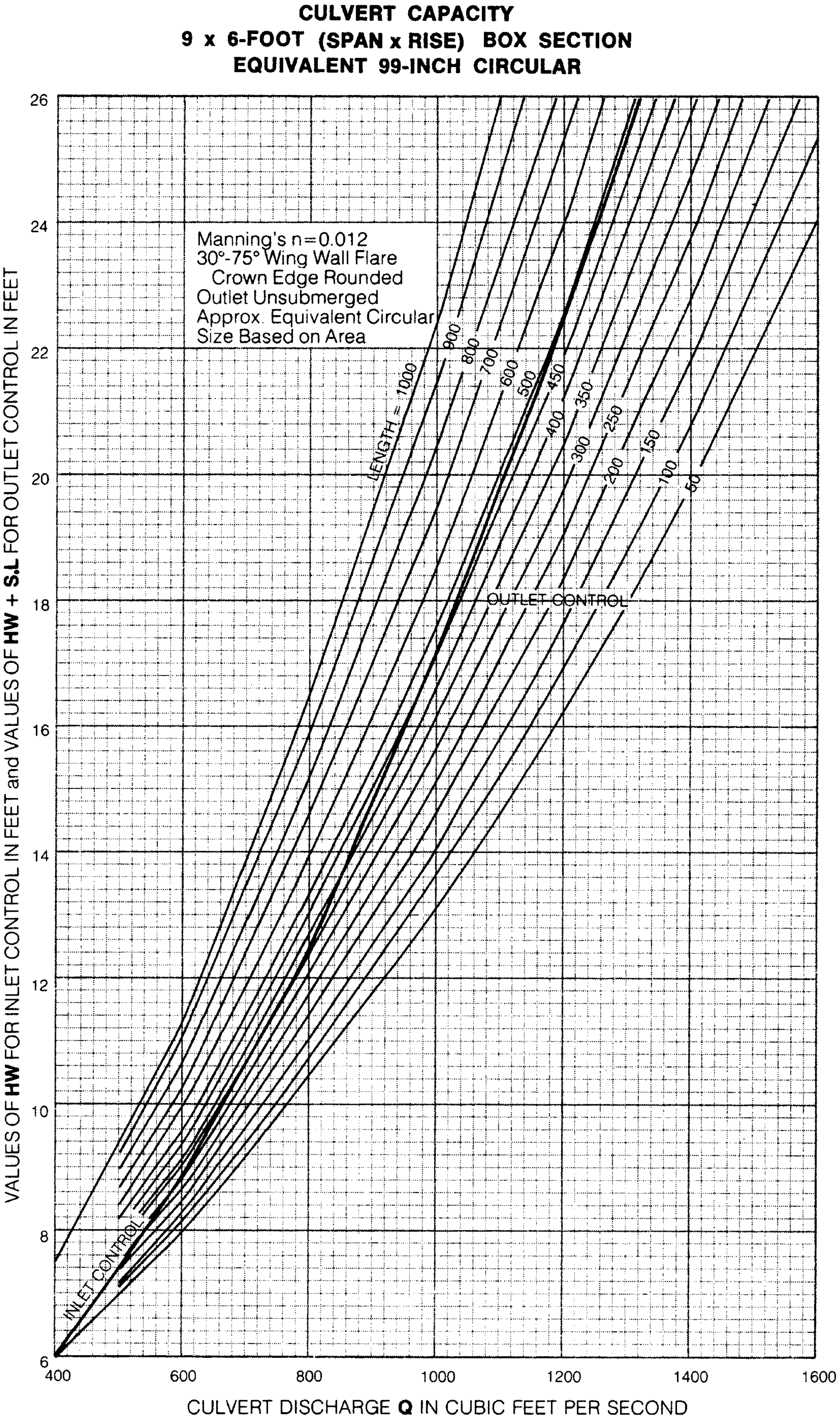

CULVERT CAPACITY
9 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 99-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH = 1000
900
800
700
600
500
450
400
350
300
250
200
150
100
50
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S.L FOR OUTLET CONTROL IN FEET
26
24
22
20
18
16
14
12
10
8
6
400
600
800
1000
1200
1400
1600
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 127

CULVERT CAPACITY
9 x 7-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 107-INCH CIRCULAR

Figure 128

CULVERT CAPACITY
9 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 114-INCH CIRCULAR

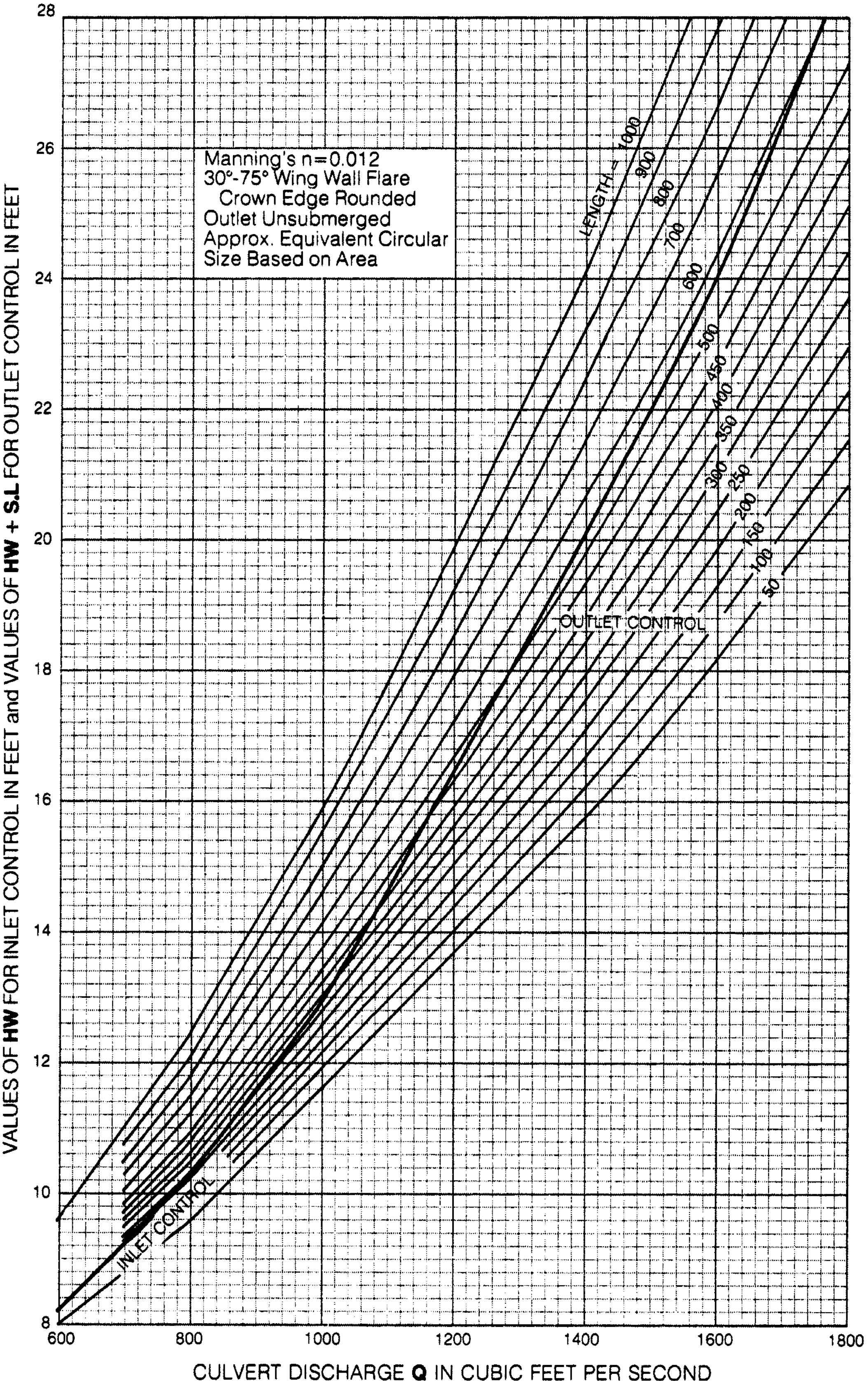


Figure 129

CULVERT CAPACITY
9 x 9-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 121-INCH CIRCULAR

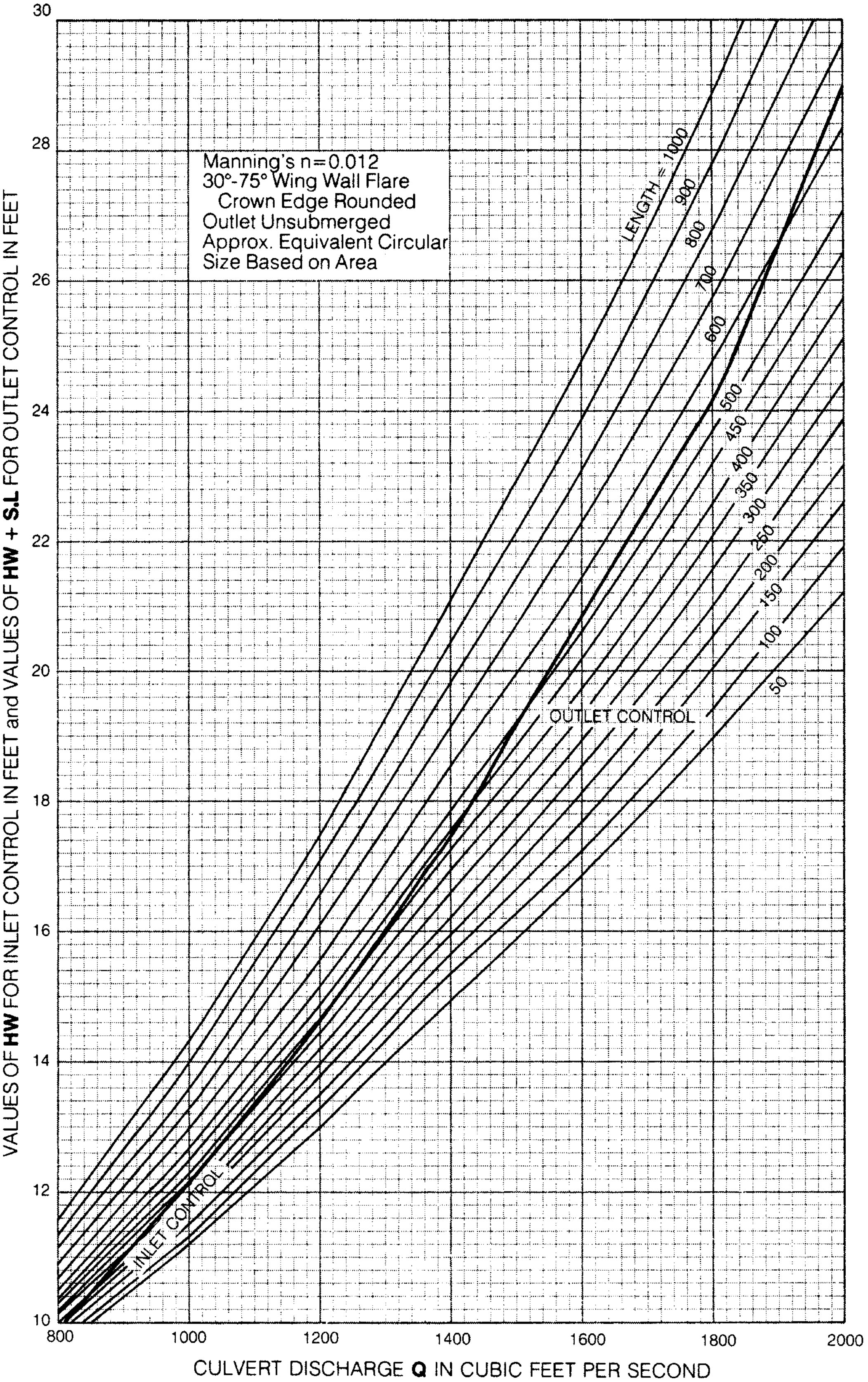


Figure 130

CULVERT CAPACITY
10 x 5-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 94-INCH CIRCULAR

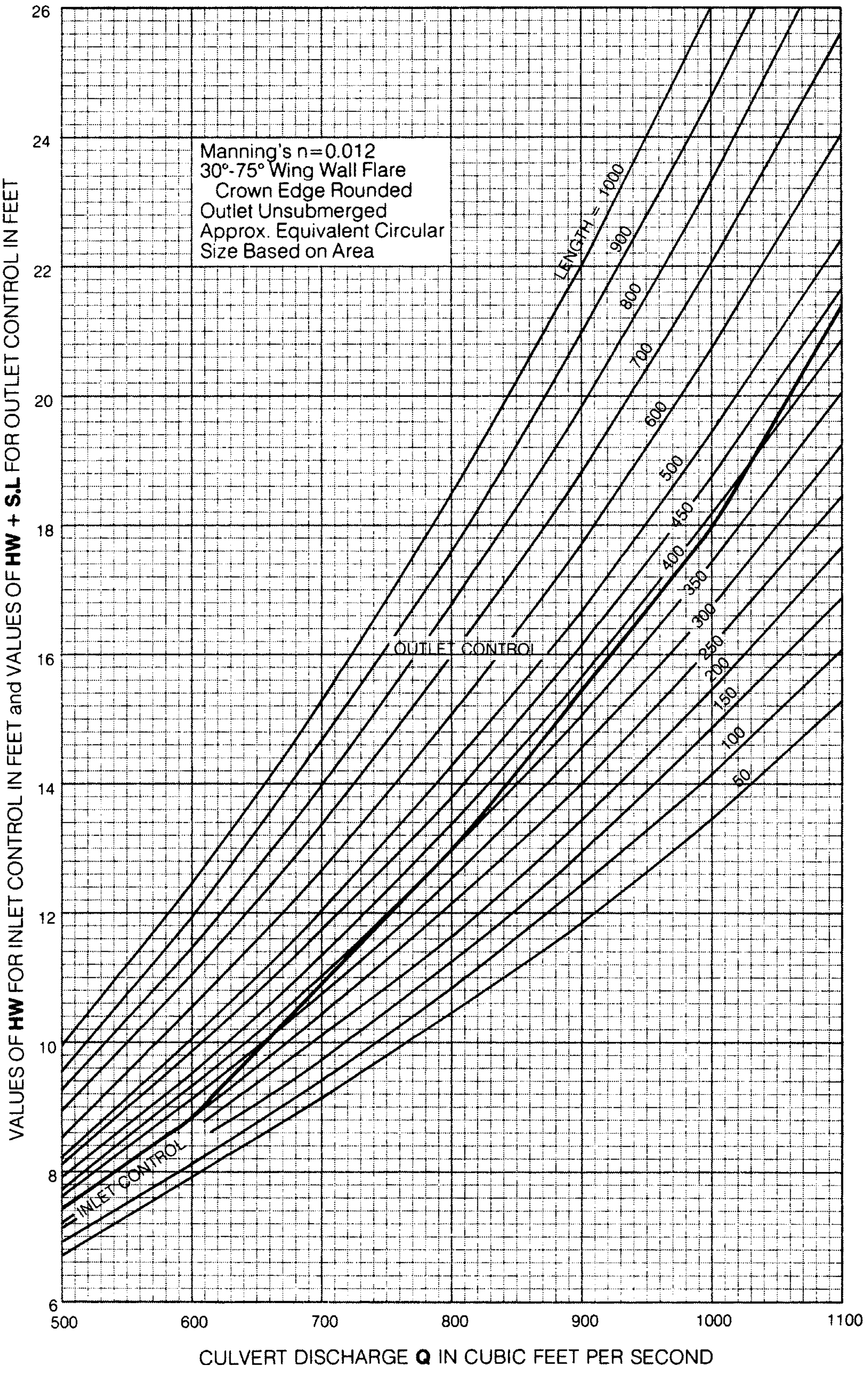
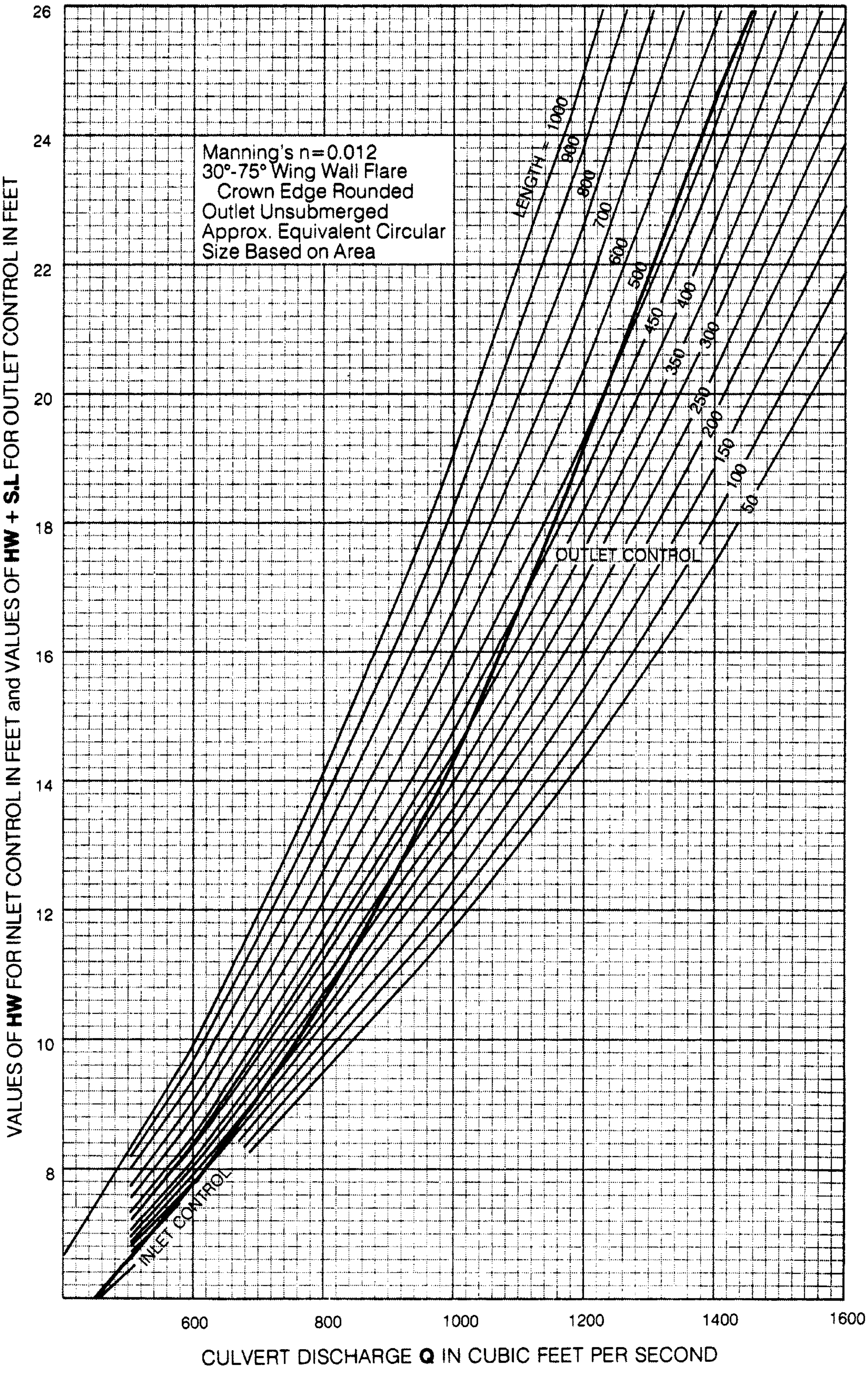


Figure 131

CULVERT CAPACITY
10 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 104-INCH CIRCULAR



Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular Size Based on Area

Figure 132

CULVERT CAPACITY
10 x 7-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 112-INCH CIRCULAR

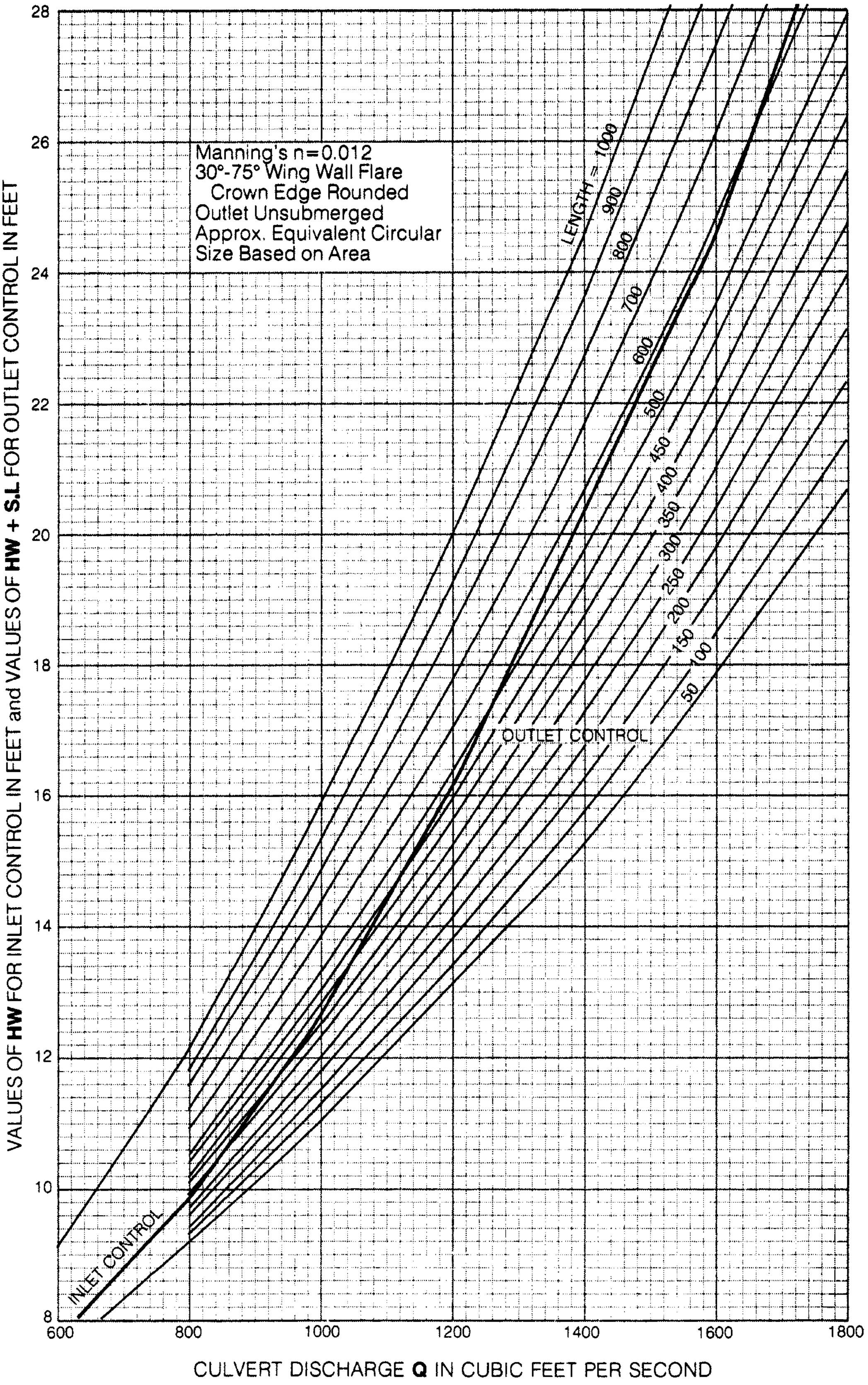
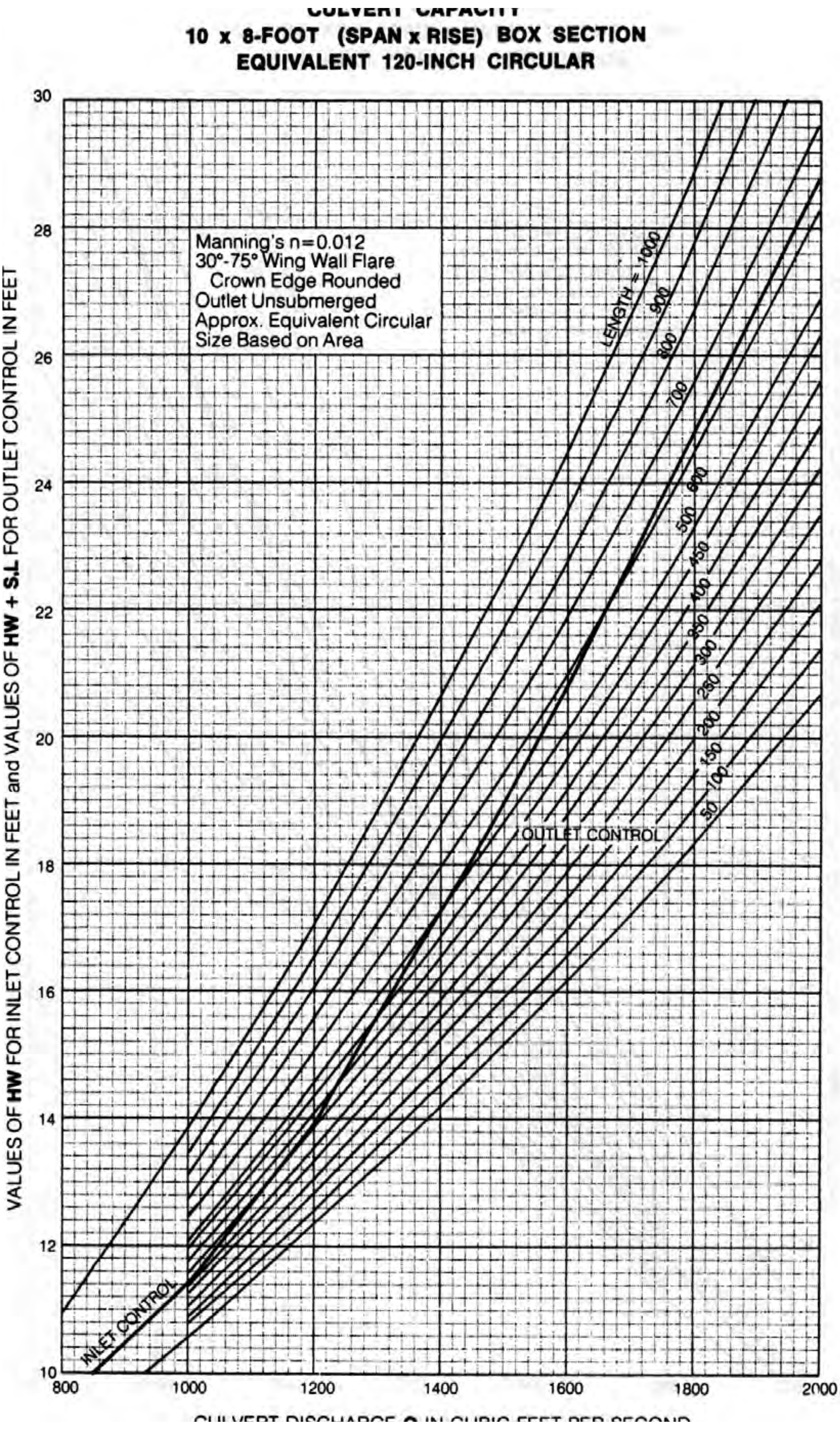


Figure 133



CULVERT CAPACITY
10 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 120-INCH CIRCULAR

Figure 134

CULVERT CAPACITY
10 x 9-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 128-INCH CIRCULAR

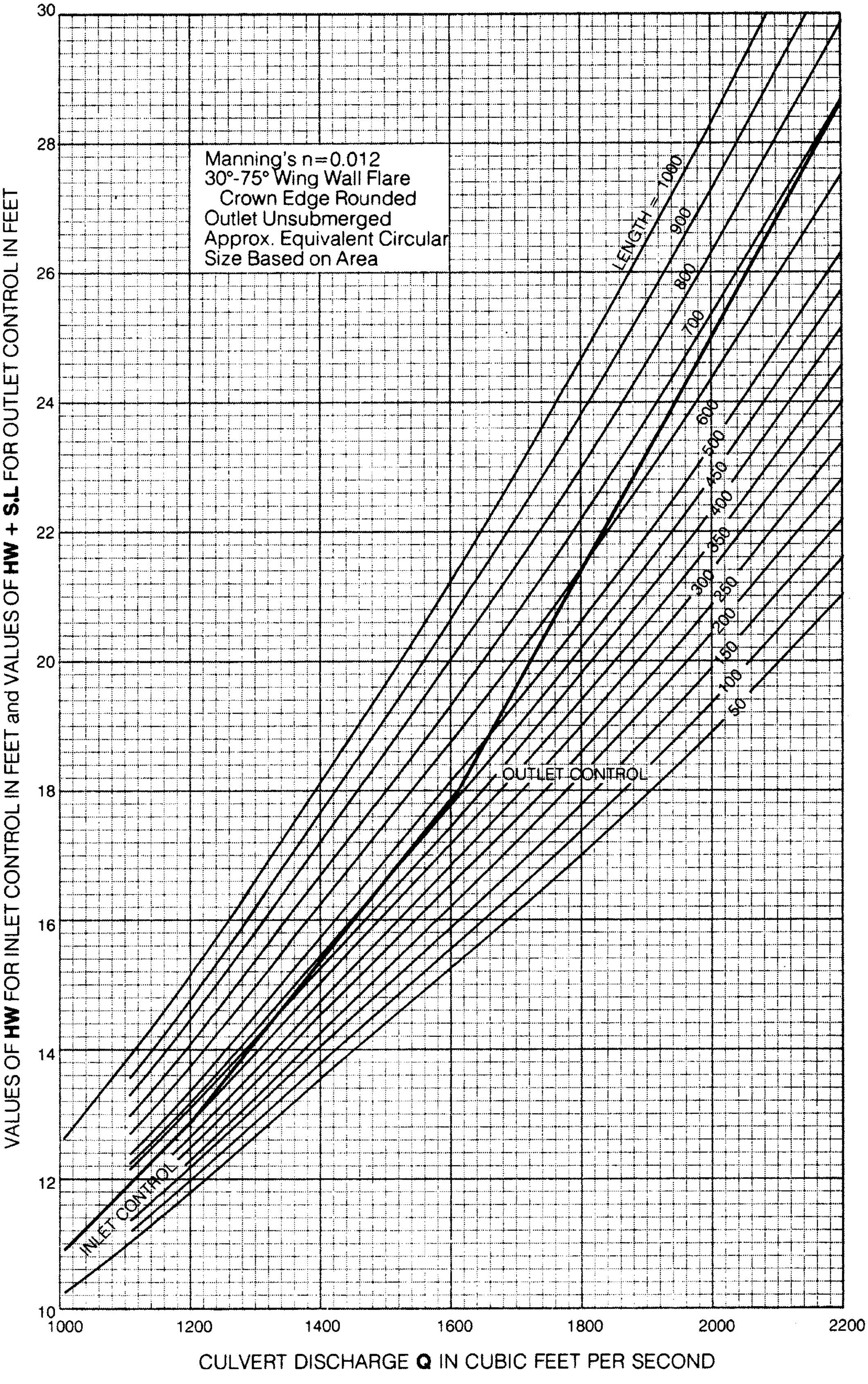


Figure 135

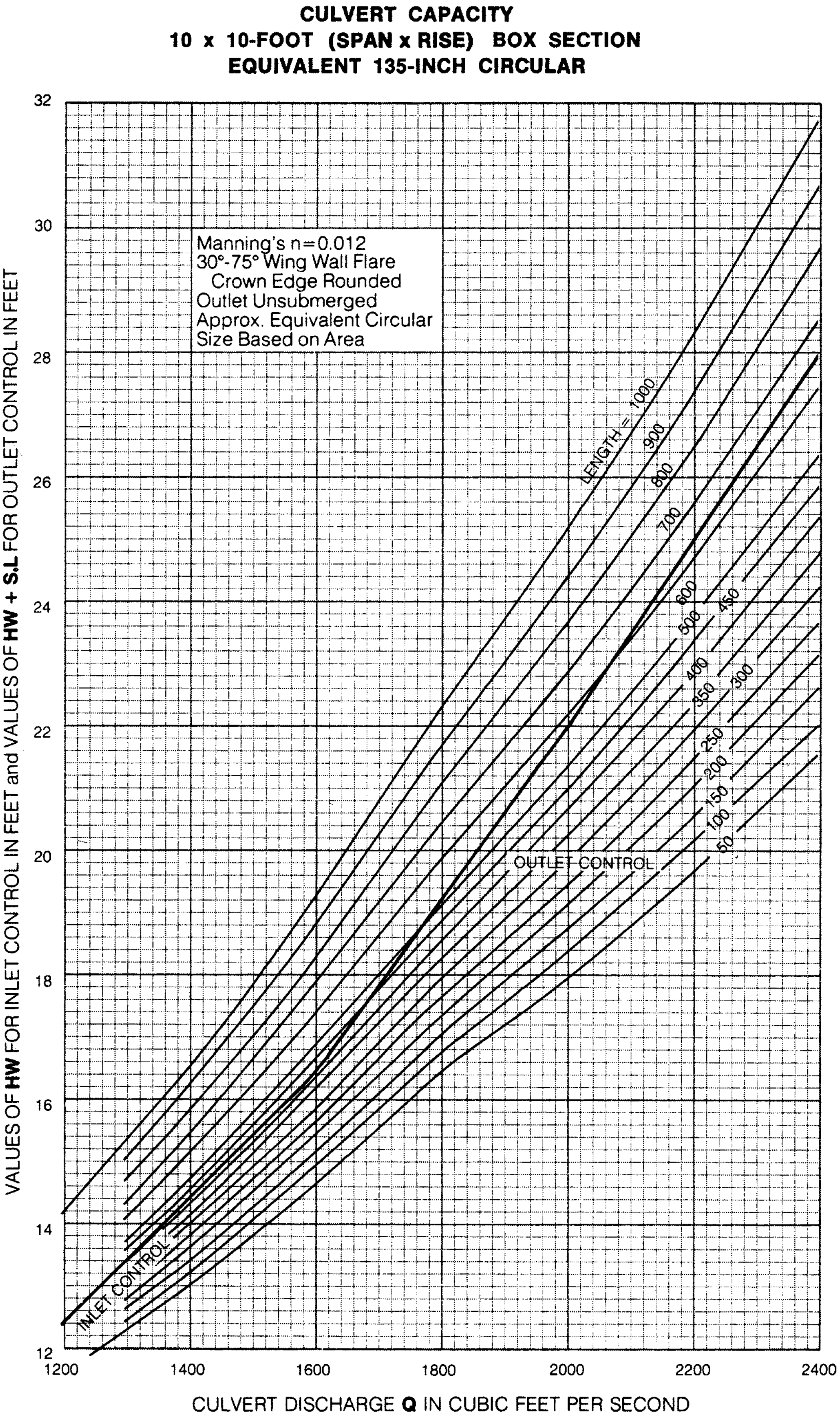

CULVERT CAPACITY
10 x 10-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 135-INCH CIRCULAR
Manning's n=0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH = 1000
900
800
700
600
500
450
400
350
300
250
200
150
100
50
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW + S.L FOR OUTLET CONTROL IN FEET
32
30
28
26
24
22
20
18
16
14
12
1200
1400
1600
1800
2000
2200
2400
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 136

CULVERT CAPACITY
11 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 88-INCH CIRCULAR

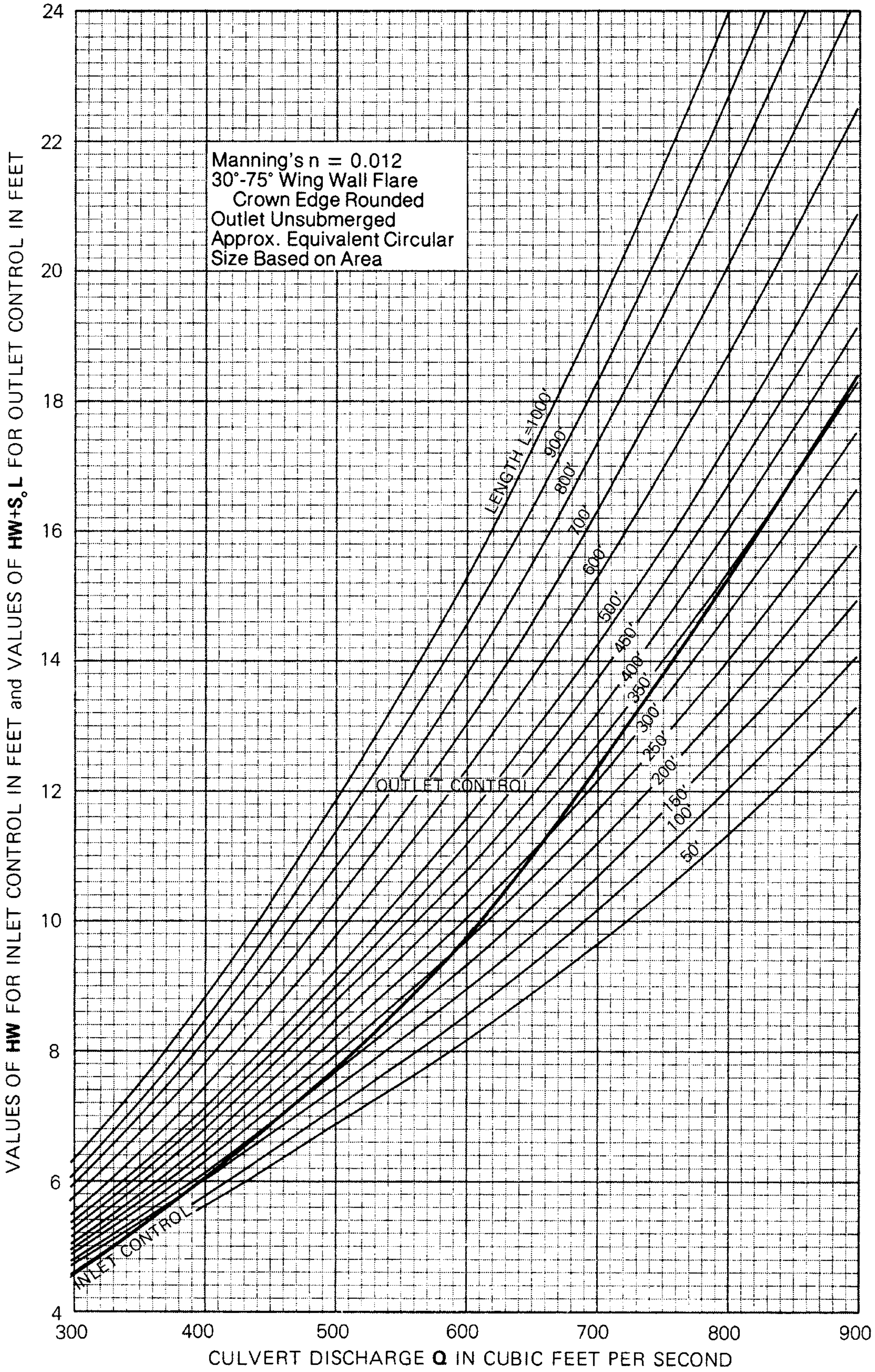


Figure 137

CULVERT CAPACITY
11 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 109-INCH CIRCULAR

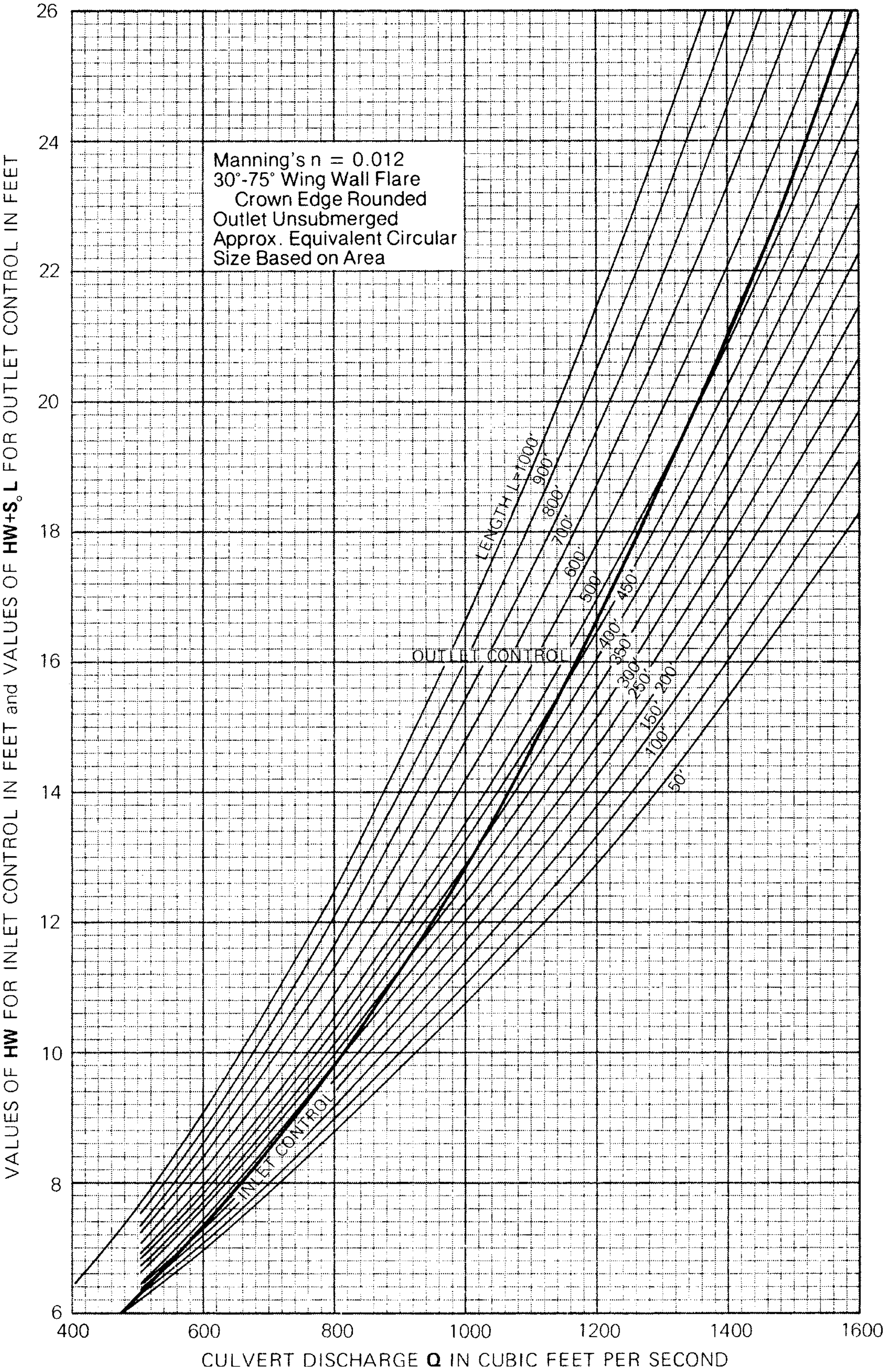


Figure 138

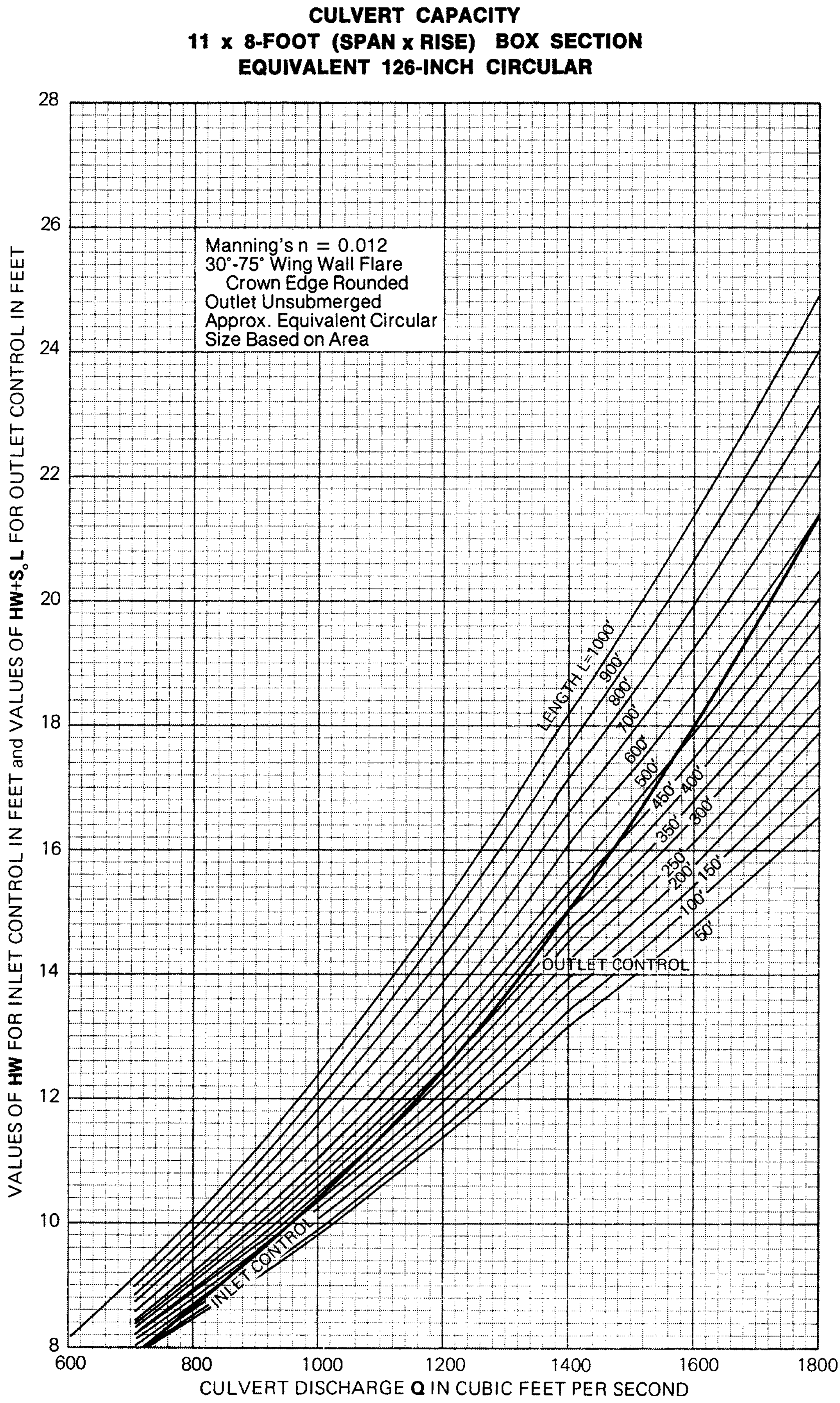

CULVERT CAPACITY
11 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 126-INCH CIRCULAR
Manning's n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area
LENGTH L=1000'
900'
800'
700'
600'
500'
450'
400'
350'
300'
250'
200'
150'
100'
50'
OUTLET CONTROL
INLET CONTROL
VALUES OF HW FOR INLET CONTROL IN FEET and VALUES OF HW+S₀L FOR OUTLET CONTROL IN FEET
28
26
24
22
20
18
16
14
12
10
8
600
800
1000
1200
1400
1600
1800
CULVERT DISCHARGE Q IN CUBIC FEET PER SECOND

Figure 139

CULVERT CAPACITY
11 x 10-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 141-INCH CIRCULAR

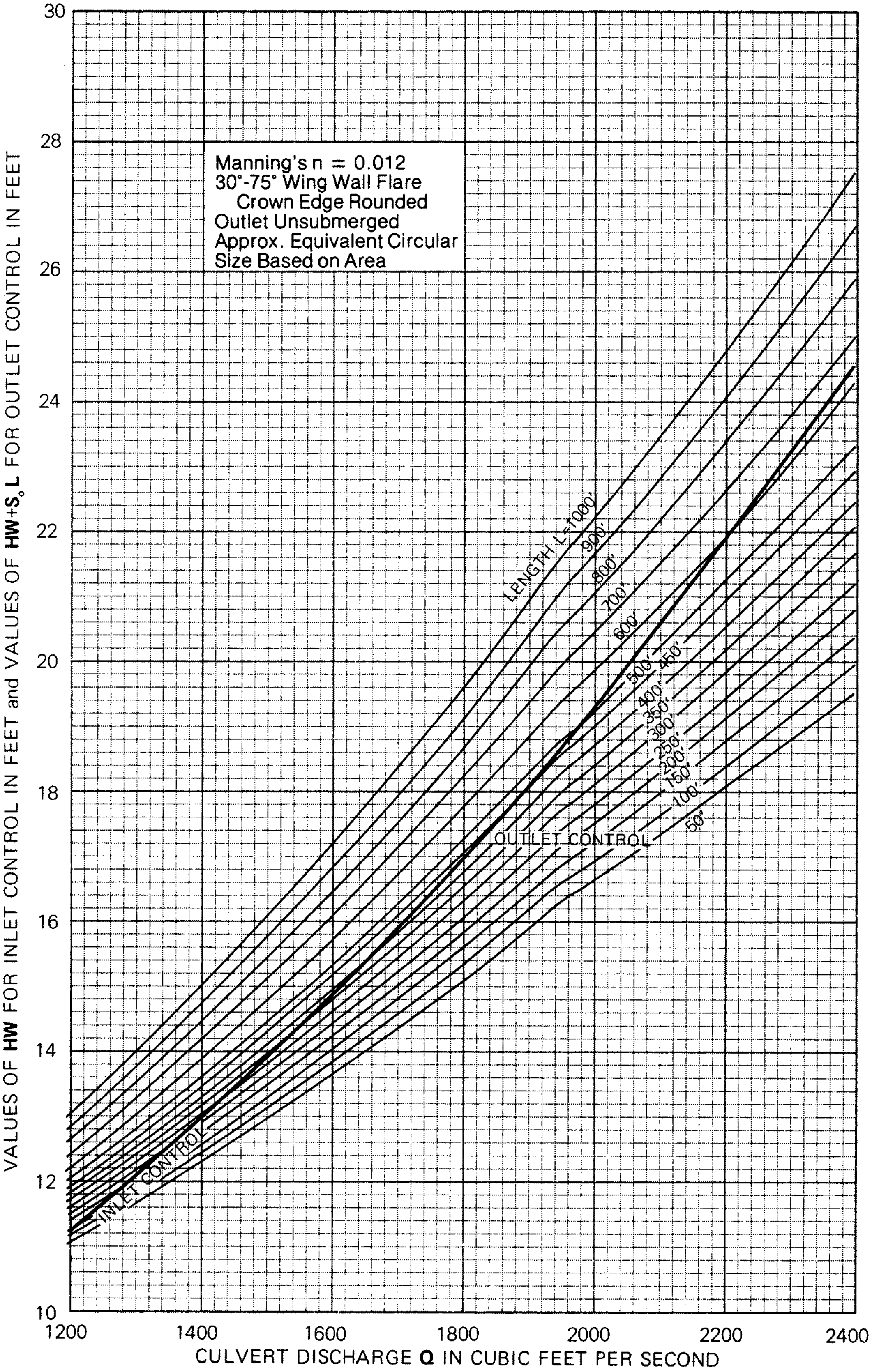
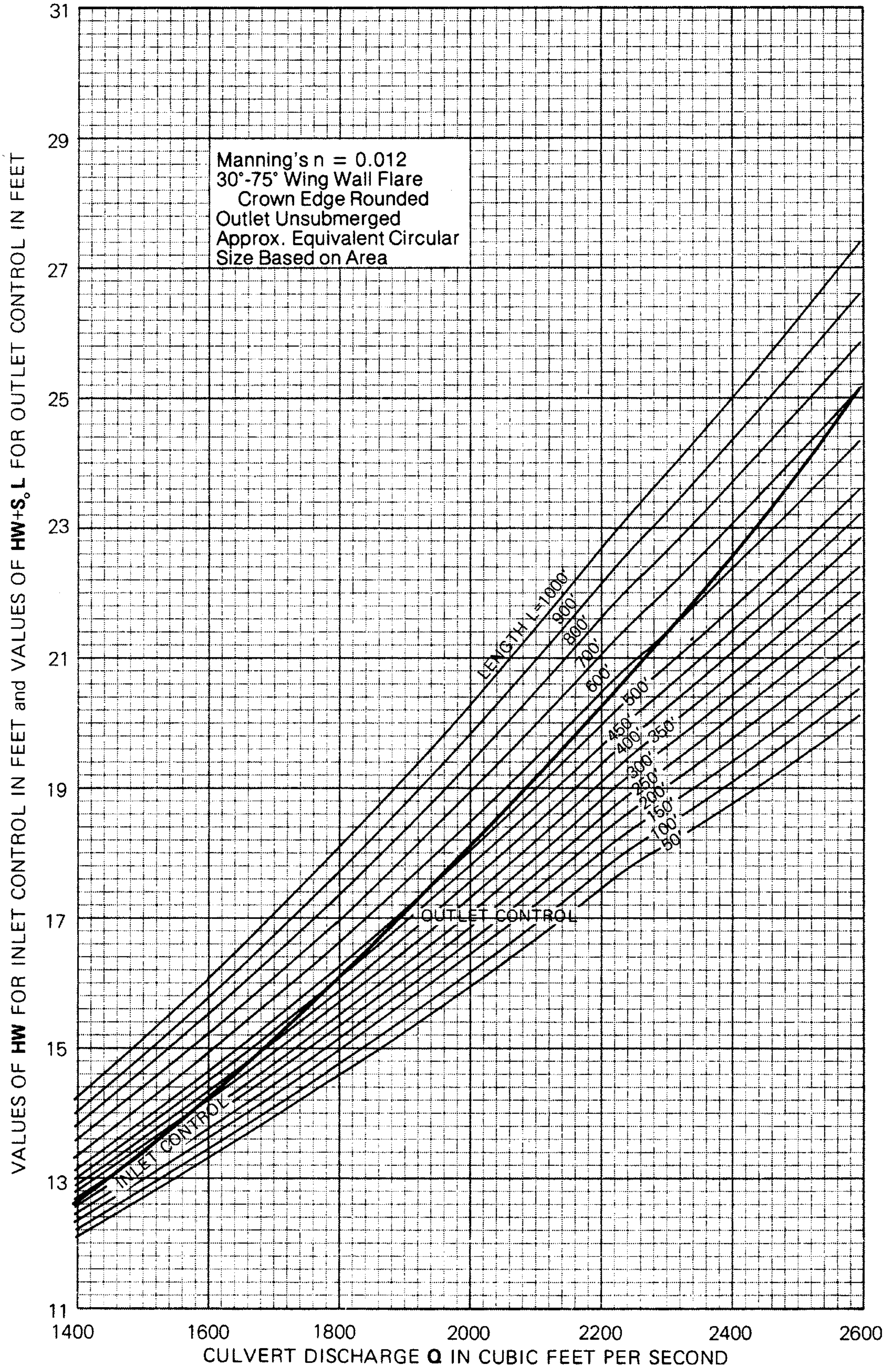


Figure 140



CULVERT CAPACITY
11 x 11-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 148-INCH CIRCULAR

Figure 141

CULVERT CAPACITY
12 x 4-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 92-INCH CIRCULAR

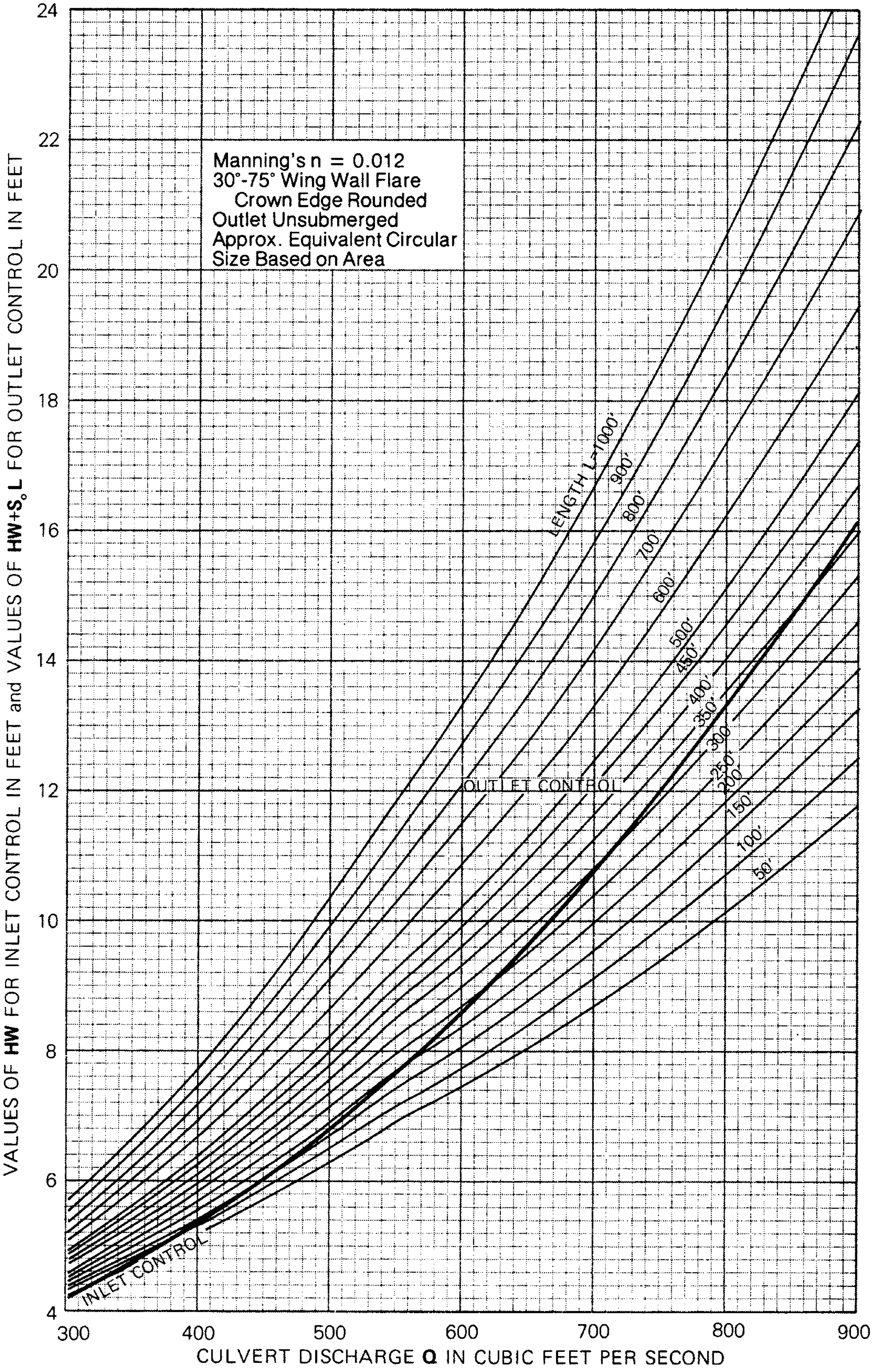
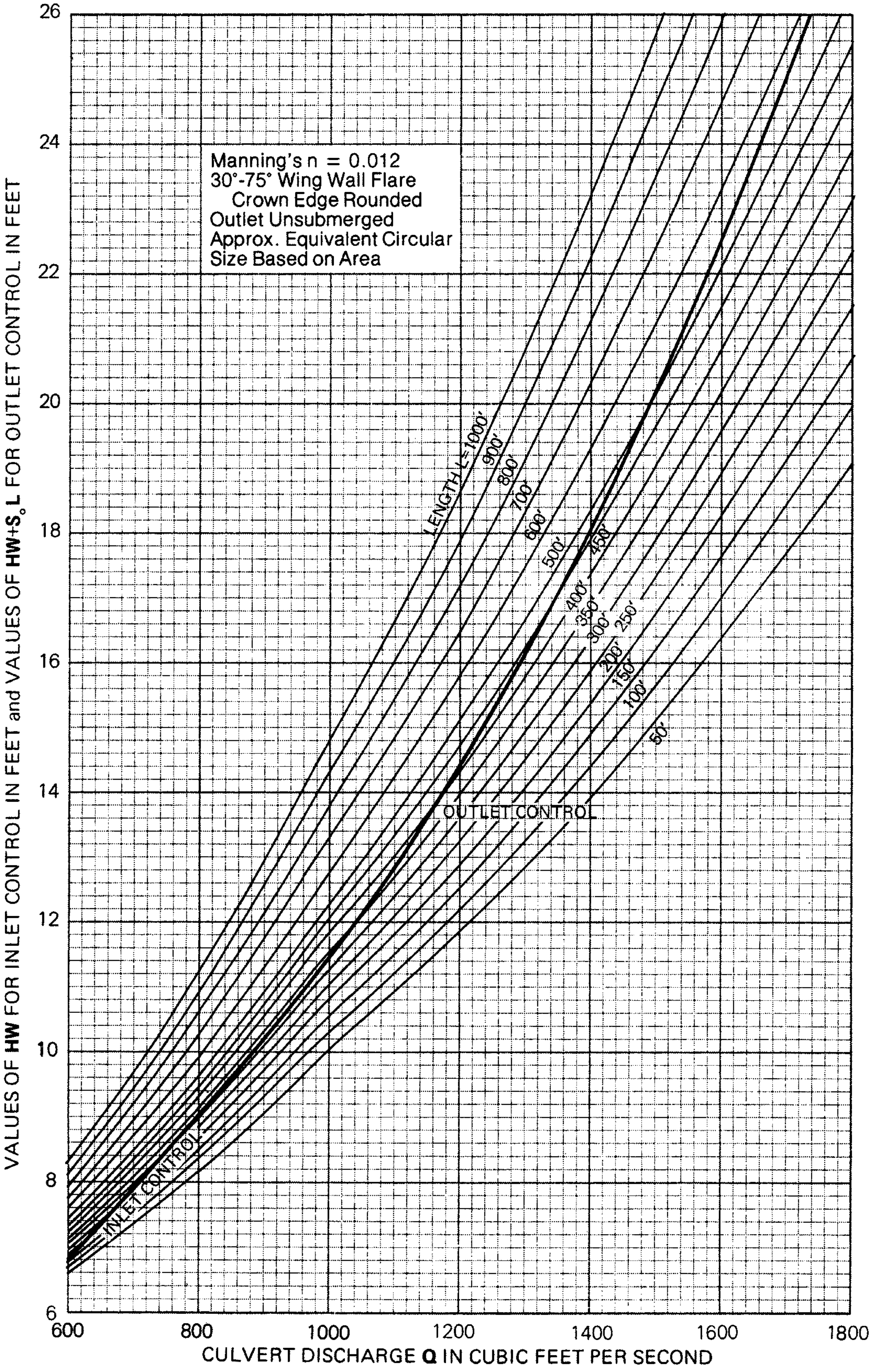


Figure 142

CULVERT CAPACITY
12 x 6-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 113-INCH CIRCULAR



Manning's n = 0.012
30°-75° Wing Wall Flare
Crown Edge Rounded
Outlet Unsubmerged
Approx. Equivalent Circular
Size Based on Area

Figure 143

CULVERT CAPACITY
12 x 8-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 131-INCH CIRCULAR

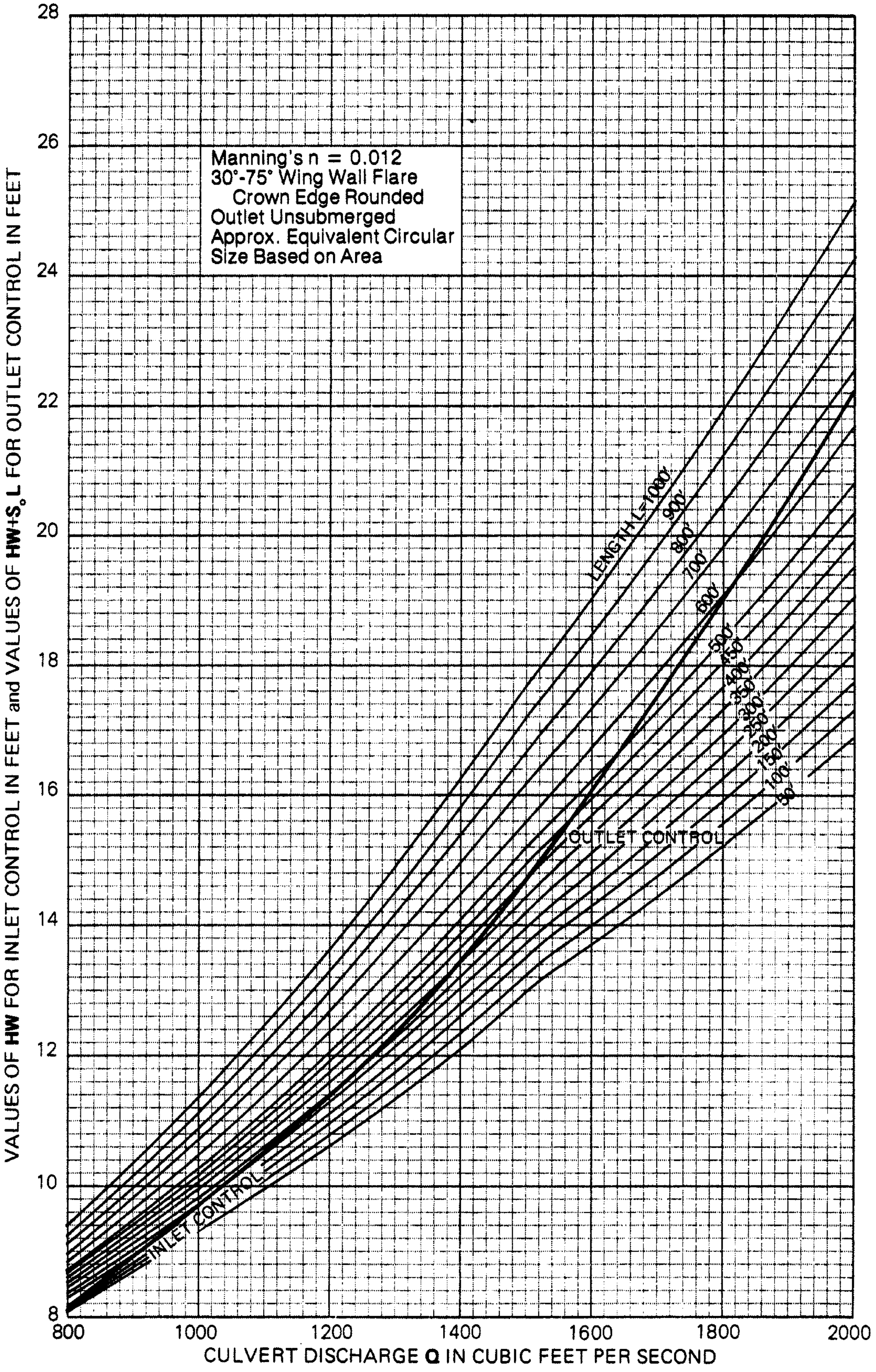


Figure 144

CULVERT CAPACITY
12 x 10-FOOT (SPAN x RISE) BOX CIRCULAR
EQUIVALENT 147-INCH CIRCULAR

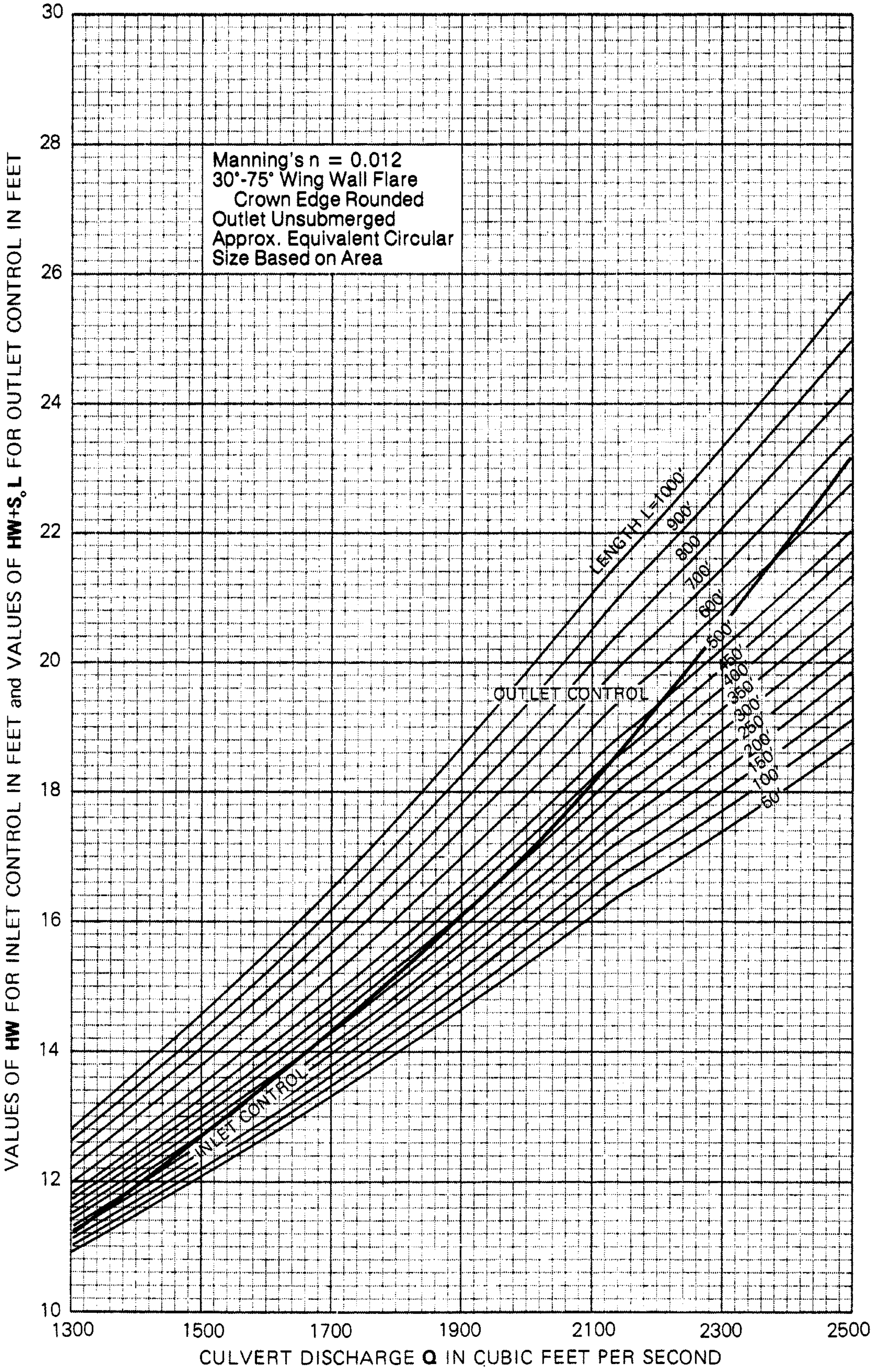


Figure 145

CULVERT CAPACITY
12 x 12-FOOT (SPAN x RISE) BOX SECTION
EQUIVALENT 161-INCH CIRCULAR

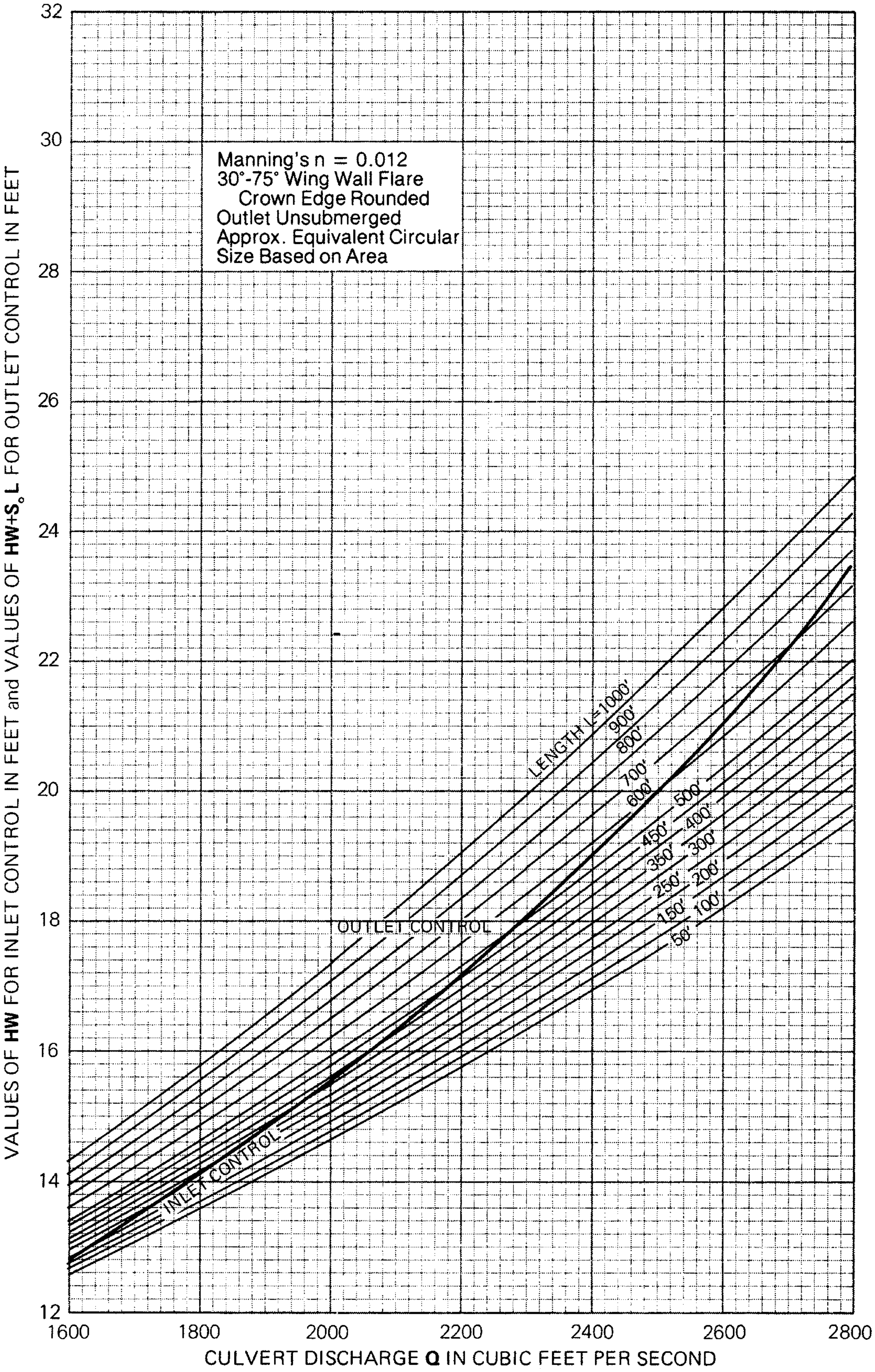


Figure 146

ESSENTIAL FEATURES OF TYPES OF INSTALLATIONS

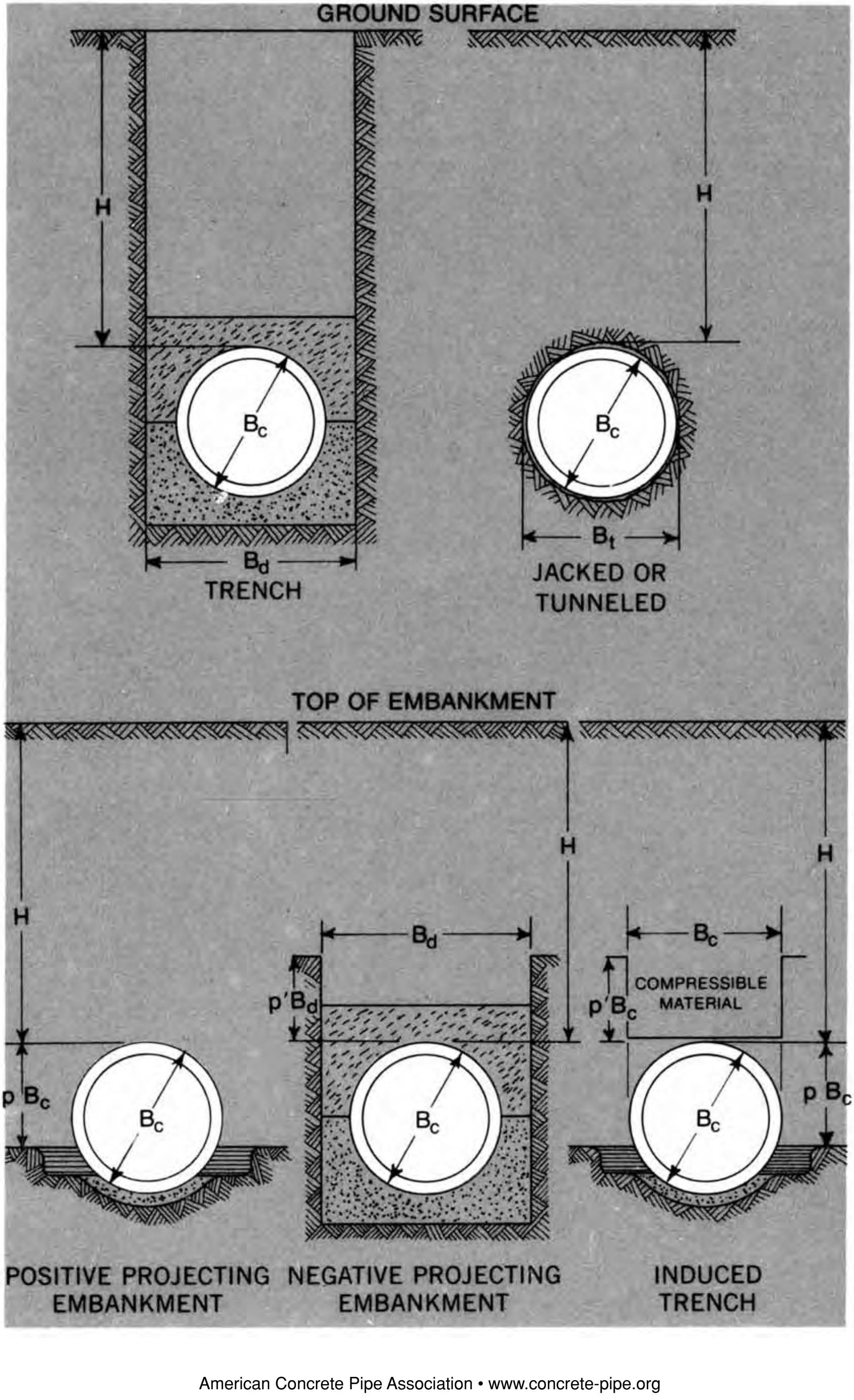
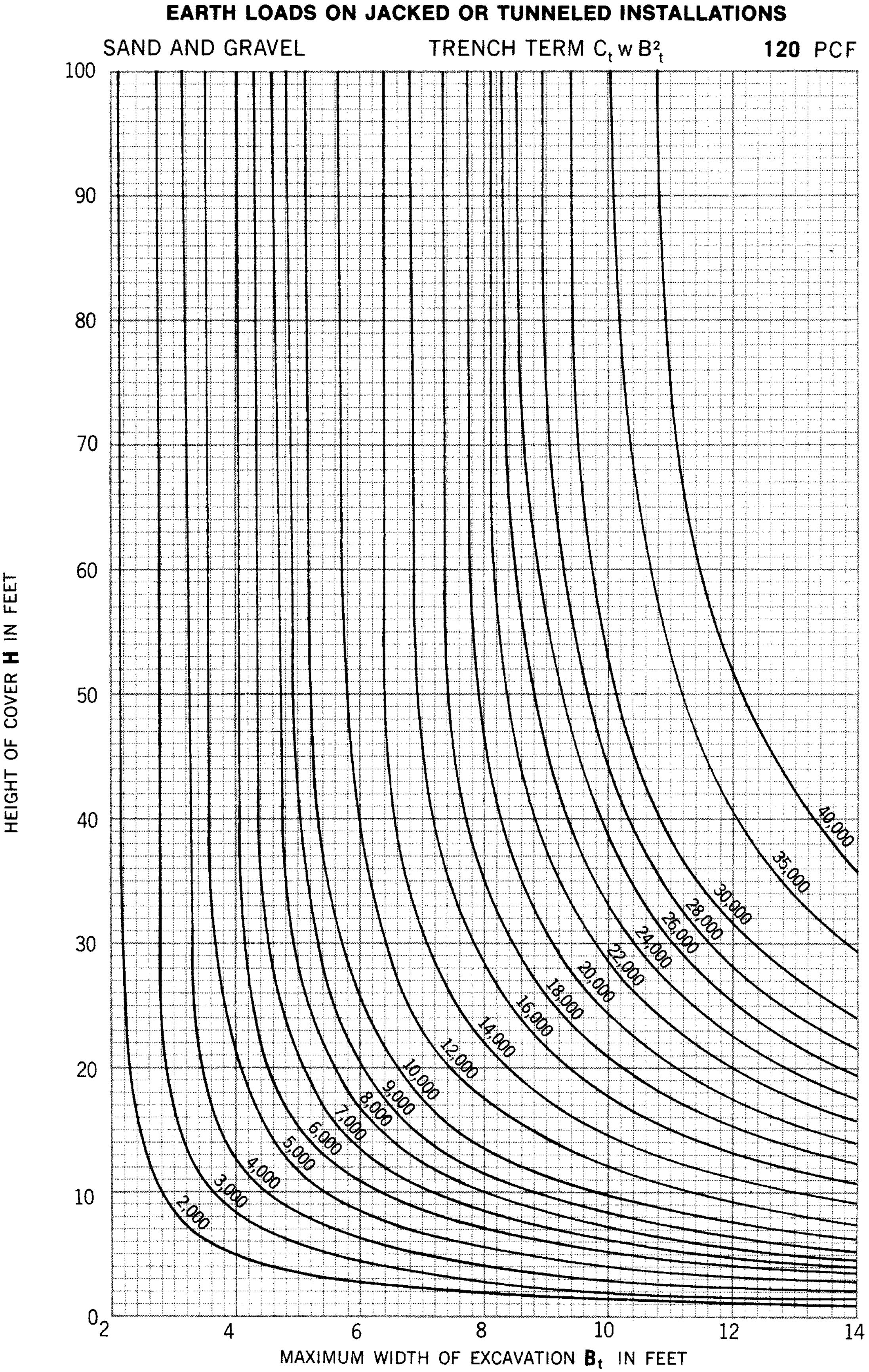


Figure 147



For earth weighing other than 120 pounds per cubic foot, multiply loads by w/120.

Figure 148

EARTH LOADS ON JACKED OR TUNNELED INSTALLATIONS

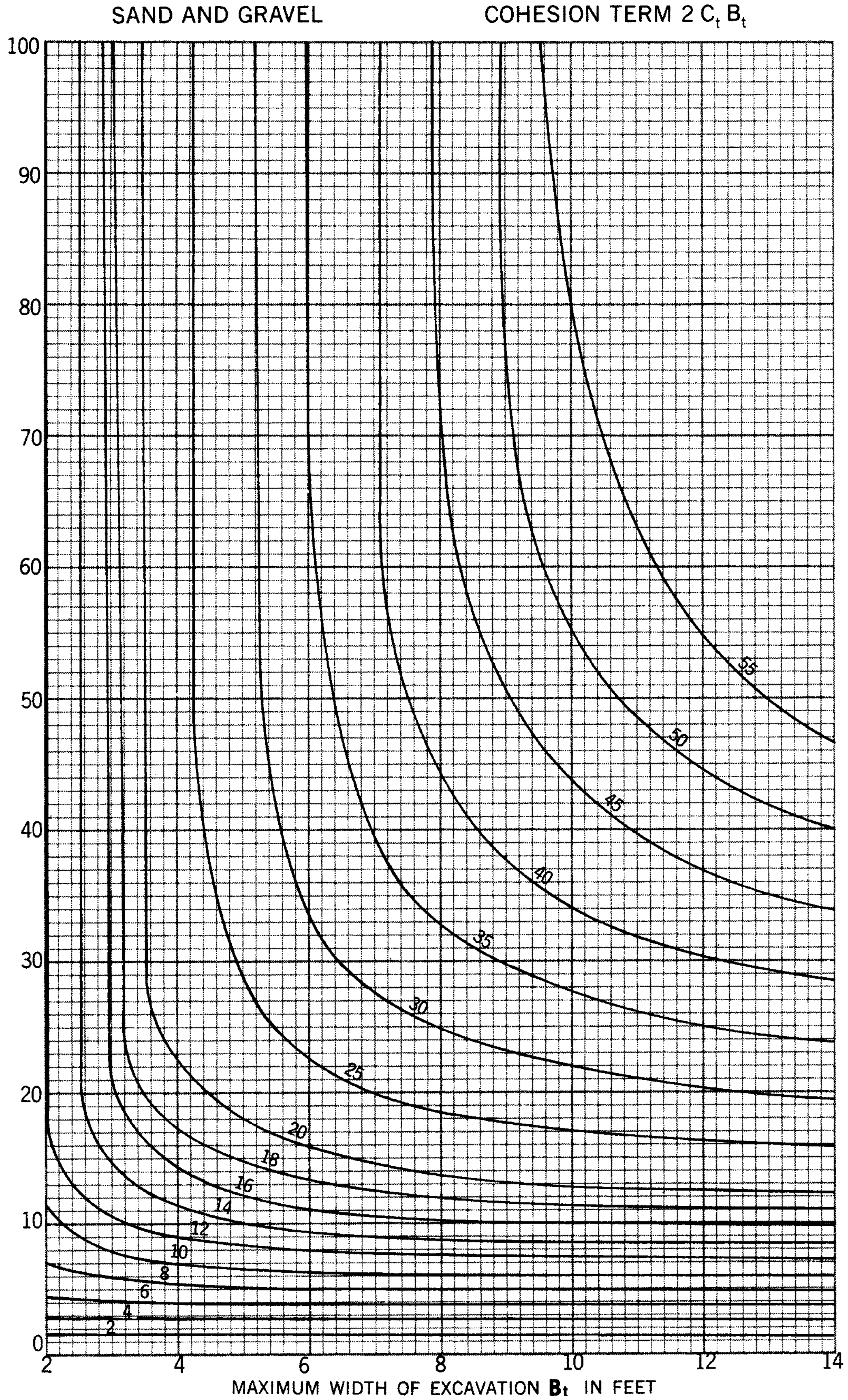
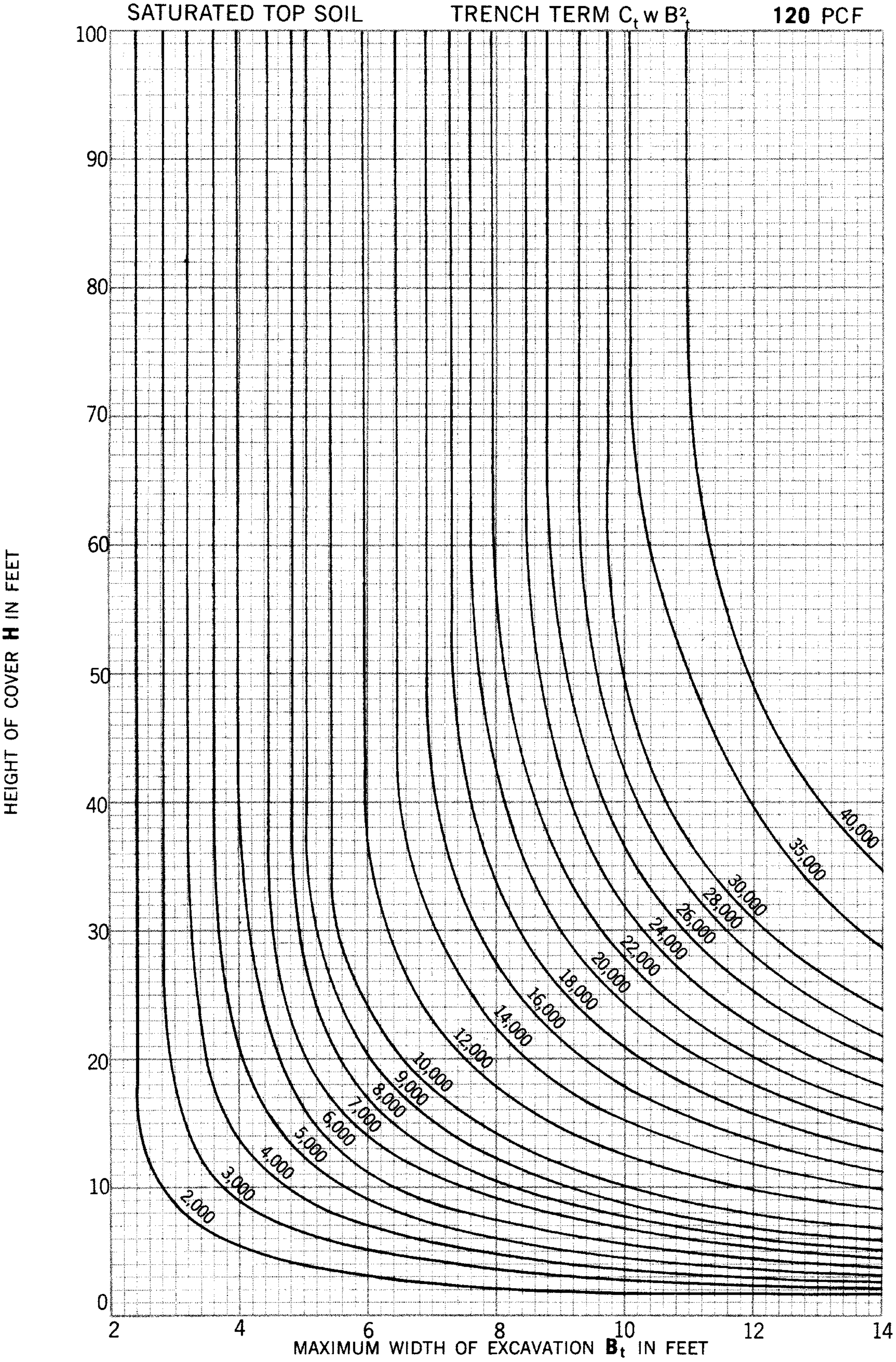


Figure 149

EARTH LOADS ON JACKED OR TUNNELED INSTALLATIONS



For earth weighing other than 120 pounds per cubic foot, multiply loads by w/120.

Figure 150

EARTH LOADS ON JACKED OR TUNNELED INSTALLATIONS

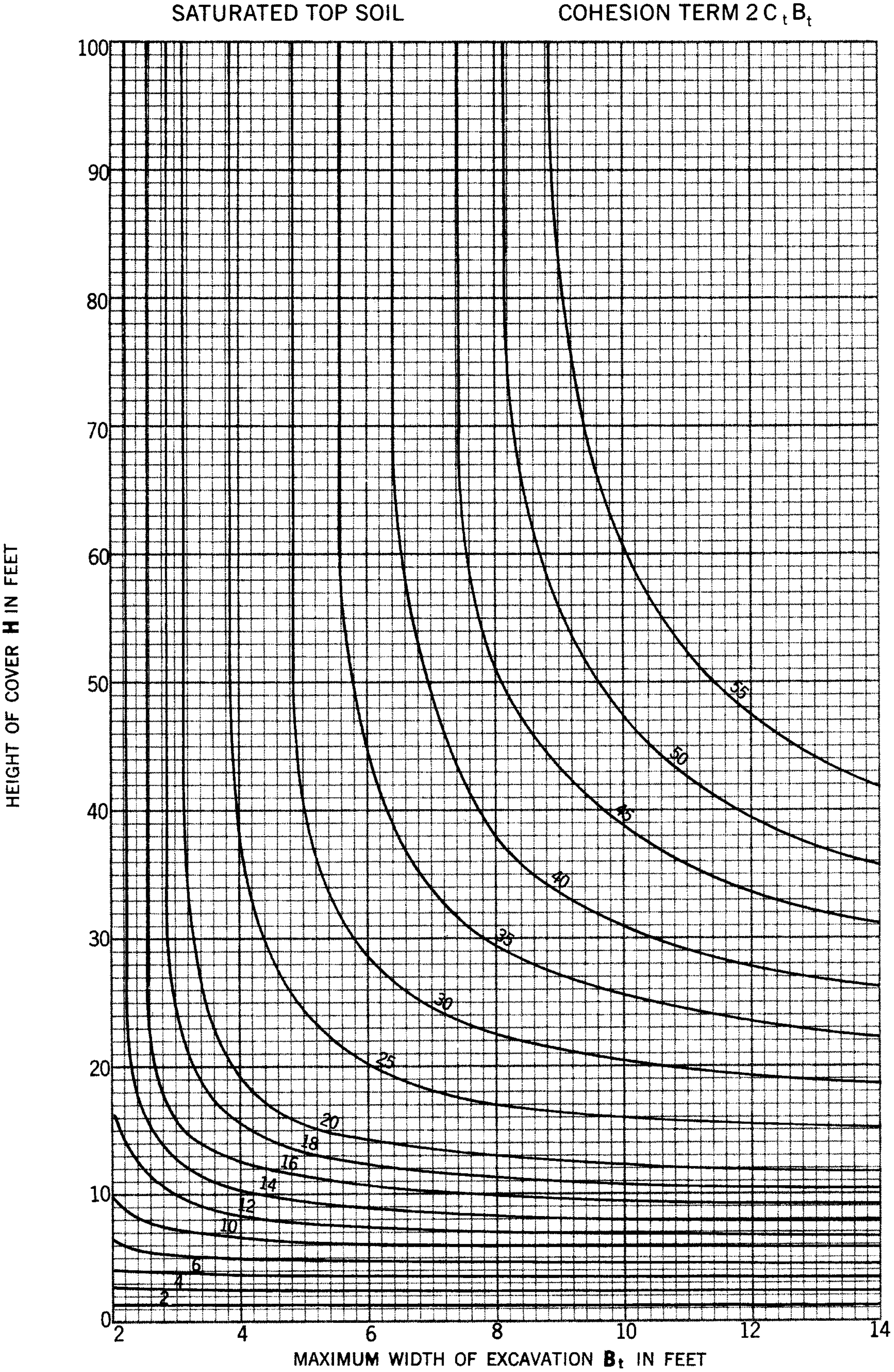
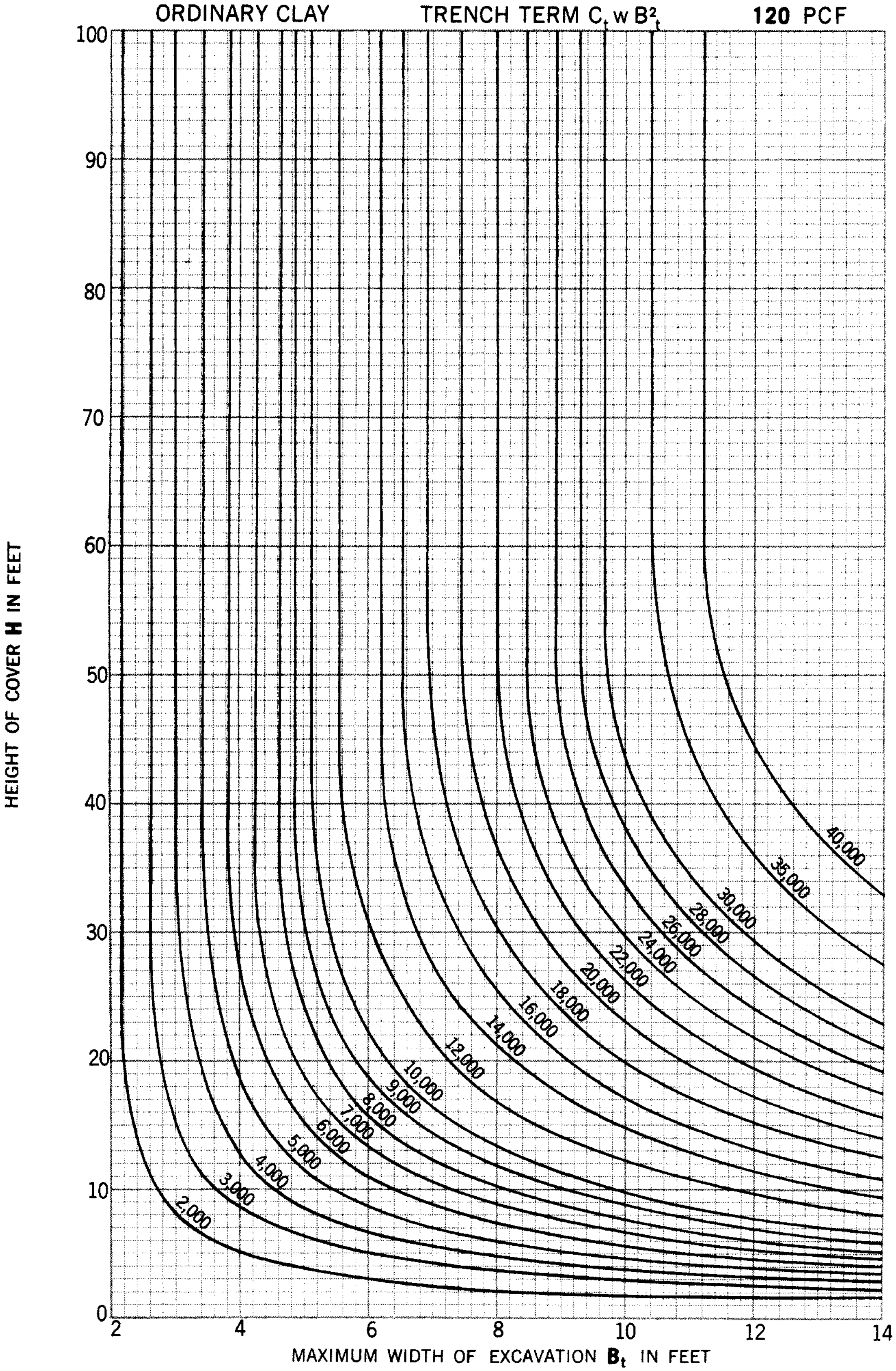


Figure 151

EARTH LOAD ON JACKED OR TUNNELED INSTALLATIONS



For earth weighing other than 120 pounds per cubic foot, multiply loads by w/120.

Figure 152

EARTH LOADS ON JACKED OR TUNNELED INSTALLATIONS

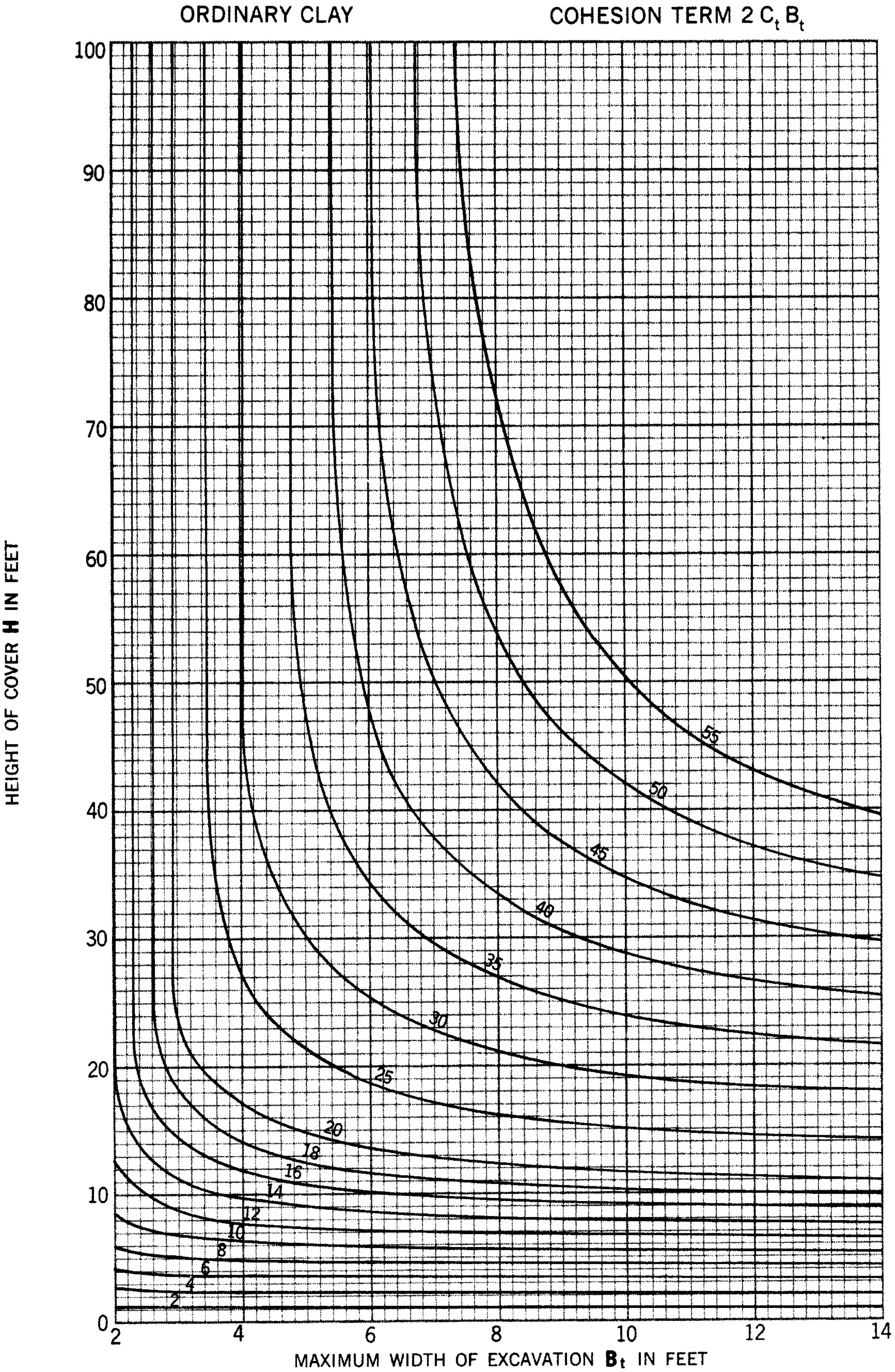
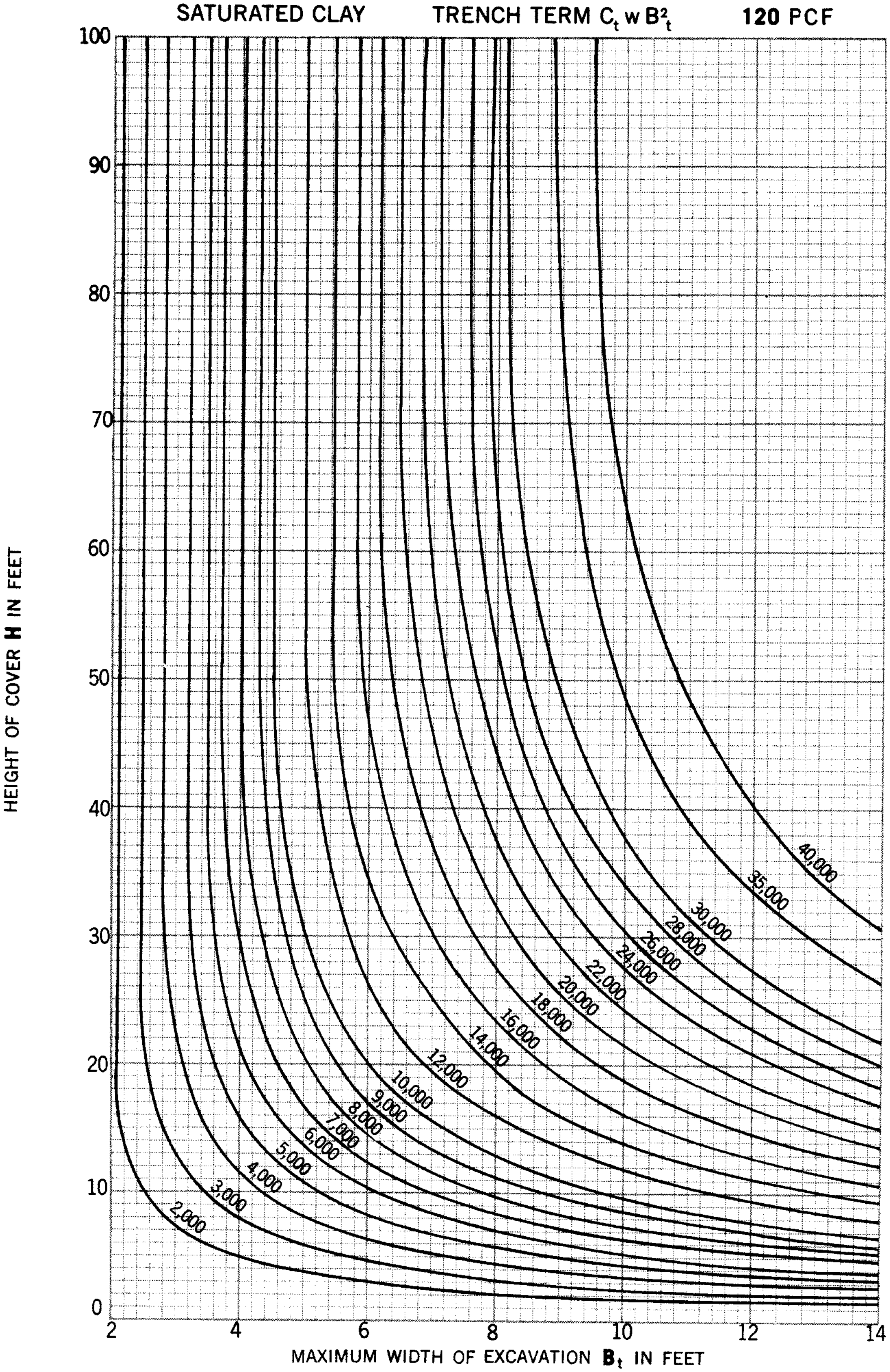


Figure 153

EARTH LOADS JACKED OR TUNNELED INSTALLATIONS



For earth weighing other than 120 pounds per cubic foot, multiply loads by w/120.

Figure 154

EARTH LOADS ON JACKED OR TUNNELED INSTALLATIONS

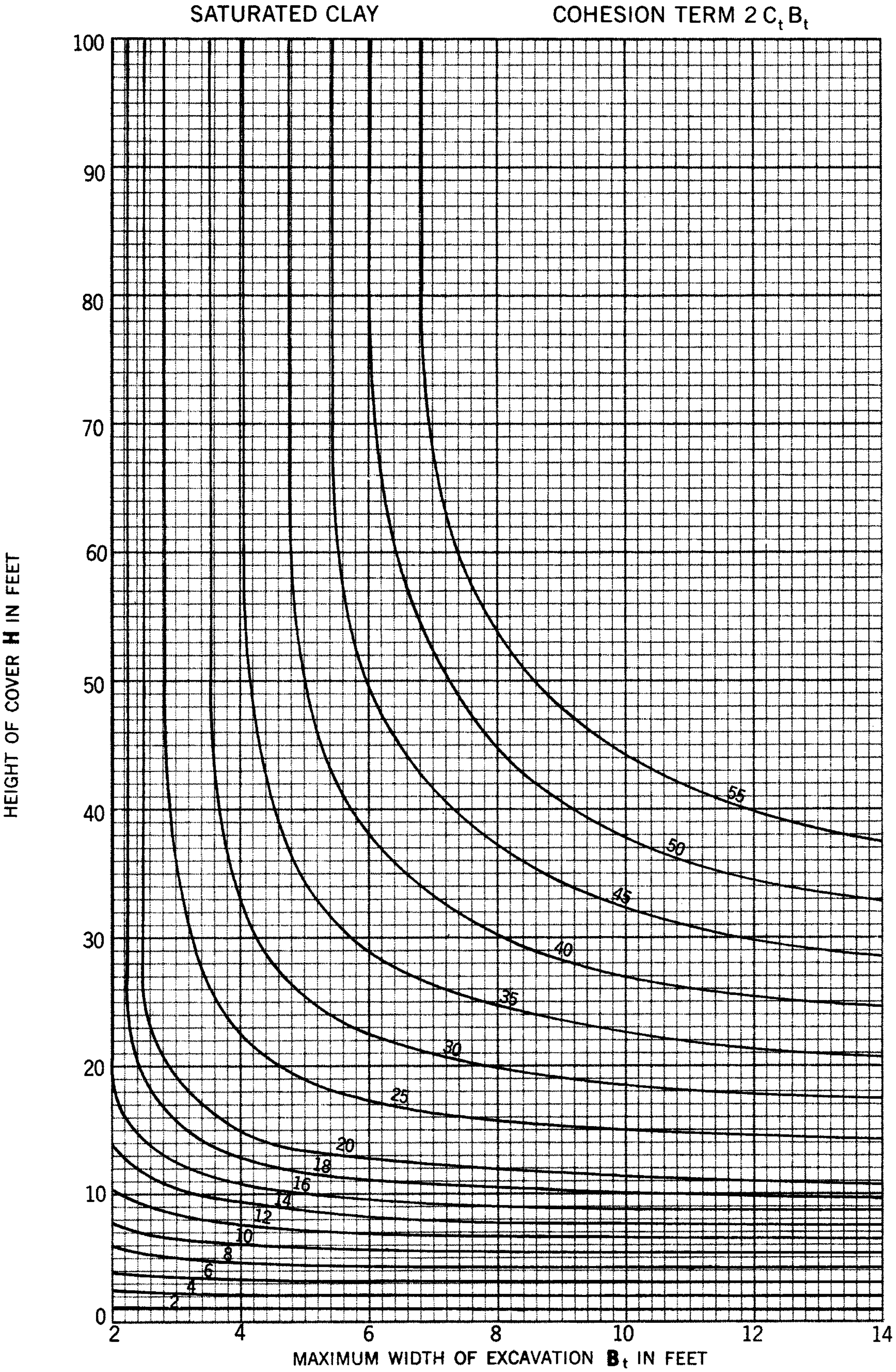
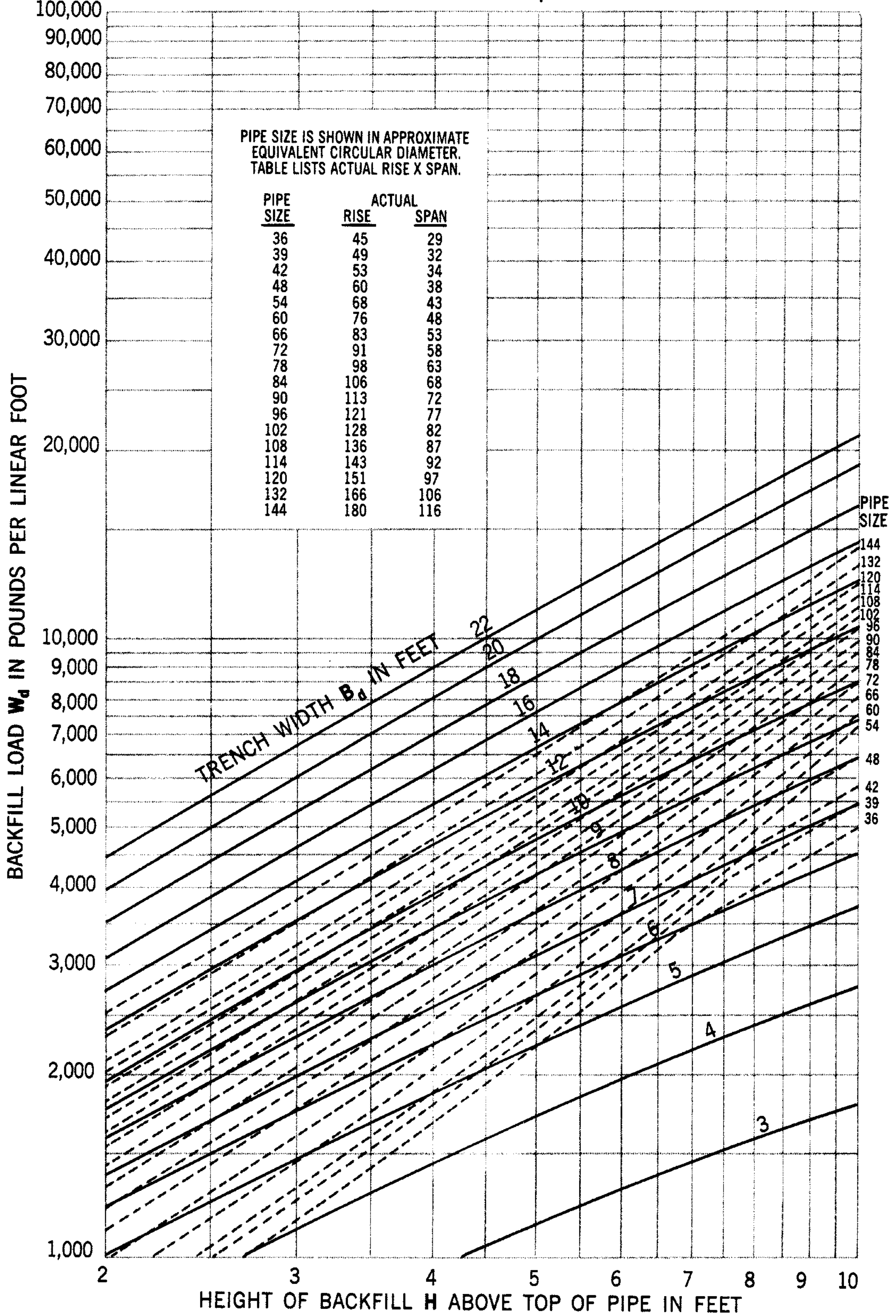


Figure 155

TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SAND AND GRAVEL $K\mu' = 0.165$



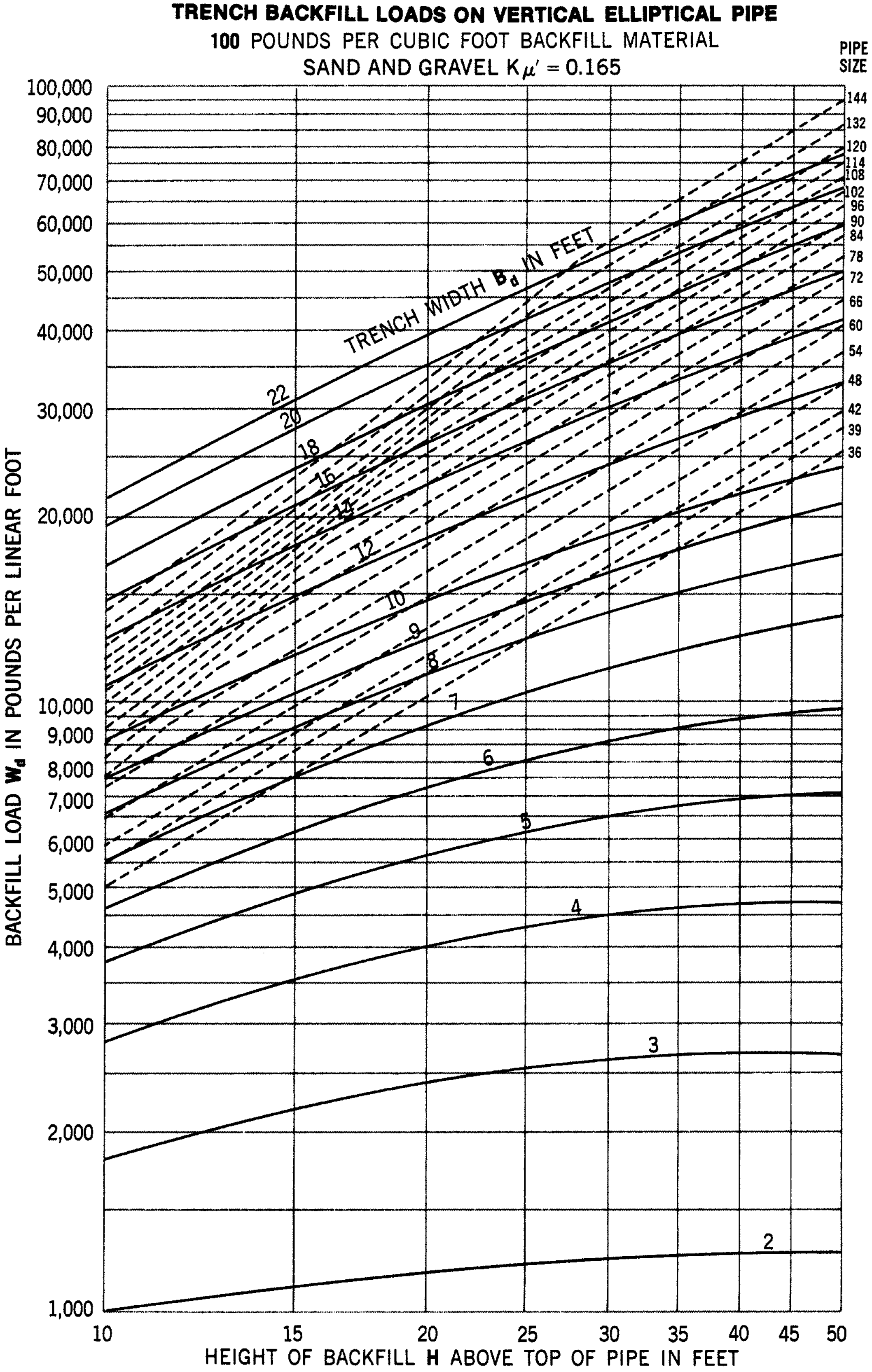
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	SPAN
36	45	29
39	49	32
42	53	34
48	60	38
54	68	43
60	76	48
66	83	53
72	91	58
78	98	63
84	106	68
90	113	72
96	121	77
102	128	82
108	136	87
114	143	92
120	151	97
132	166	106
144	180	116

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 156



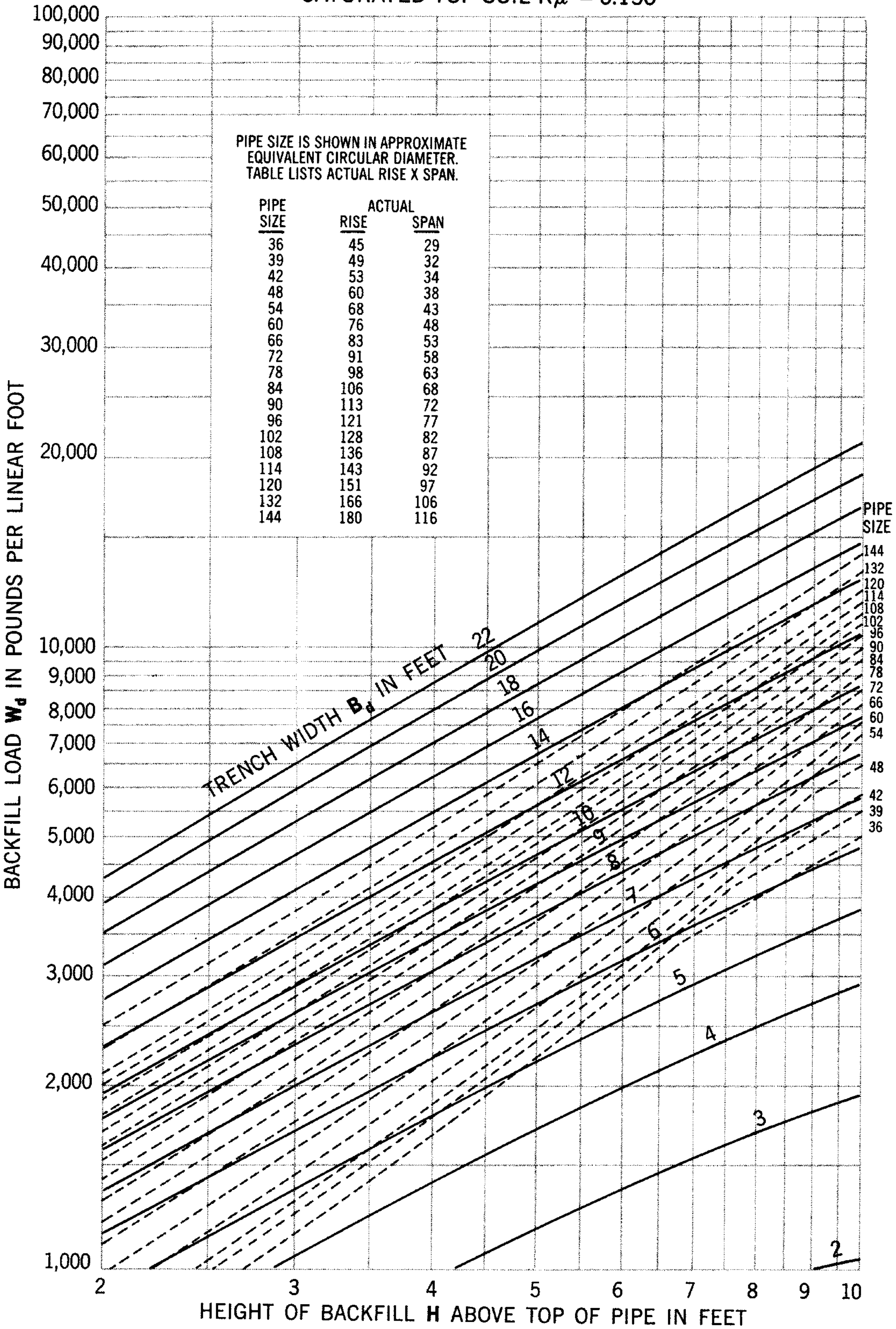
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 157

TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED TOP SOIL $K\mu' = 0.150$



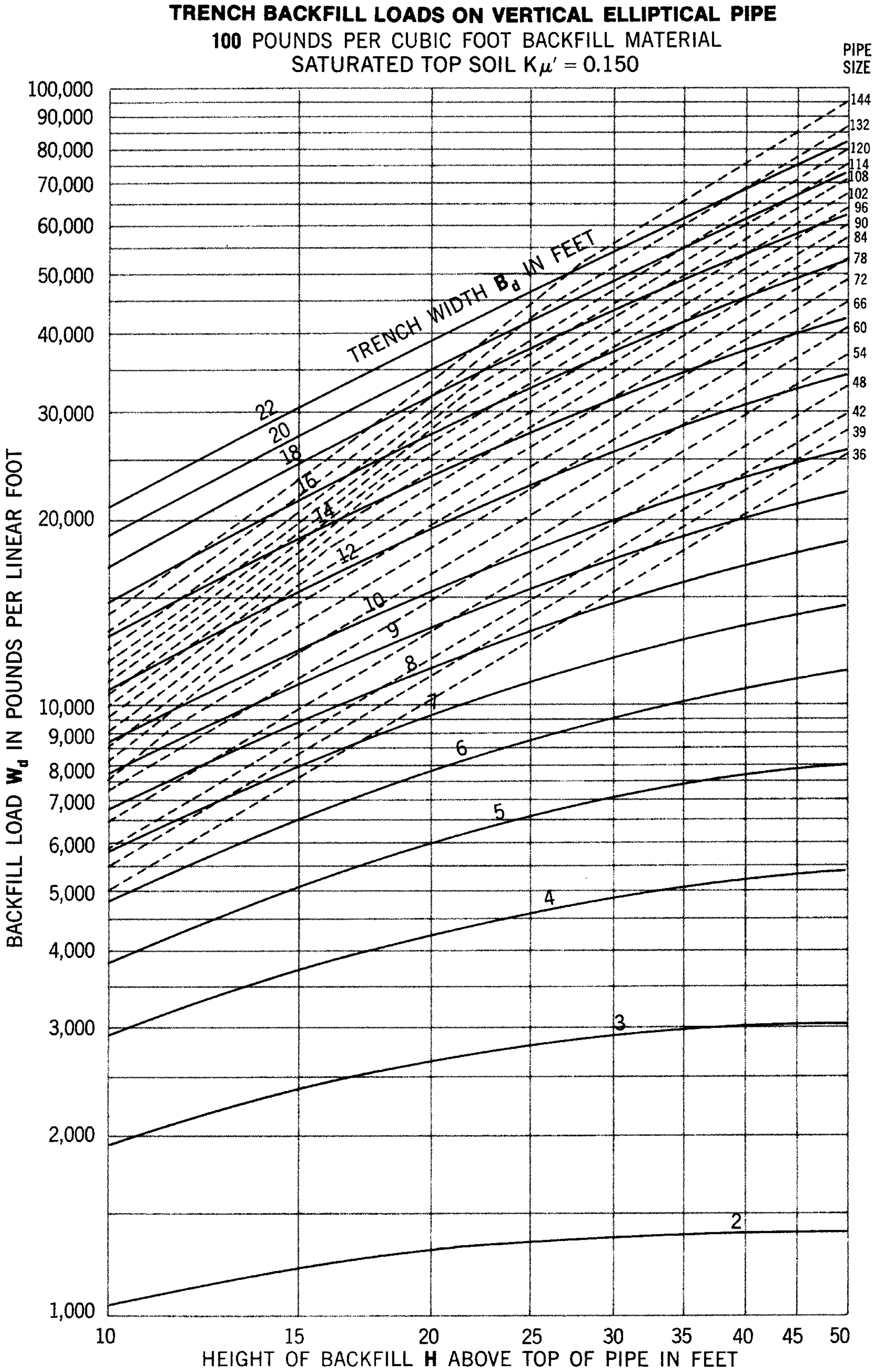
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	SPAN
36	45	29
39	49	32
42	53	34
48	60	38
54	68	43
60	76	48
66	83	53
72	91	58
78	98	63
84	106	68
90	113	72
96	121	77
102	128	82
108	136	87
114	143	92
120	151	97
132	166	106
144	180	116

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 158



TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$

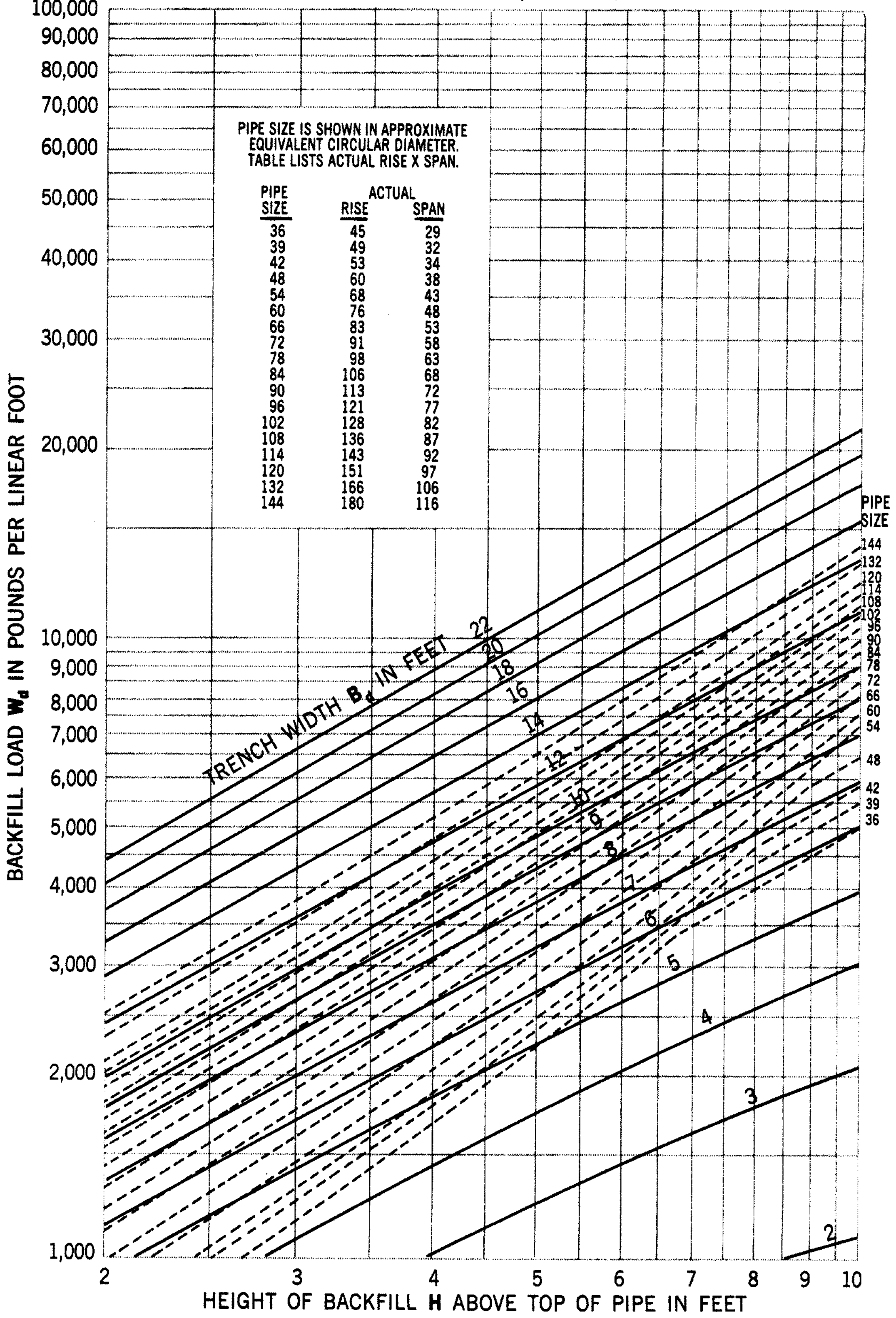
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 159

TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$



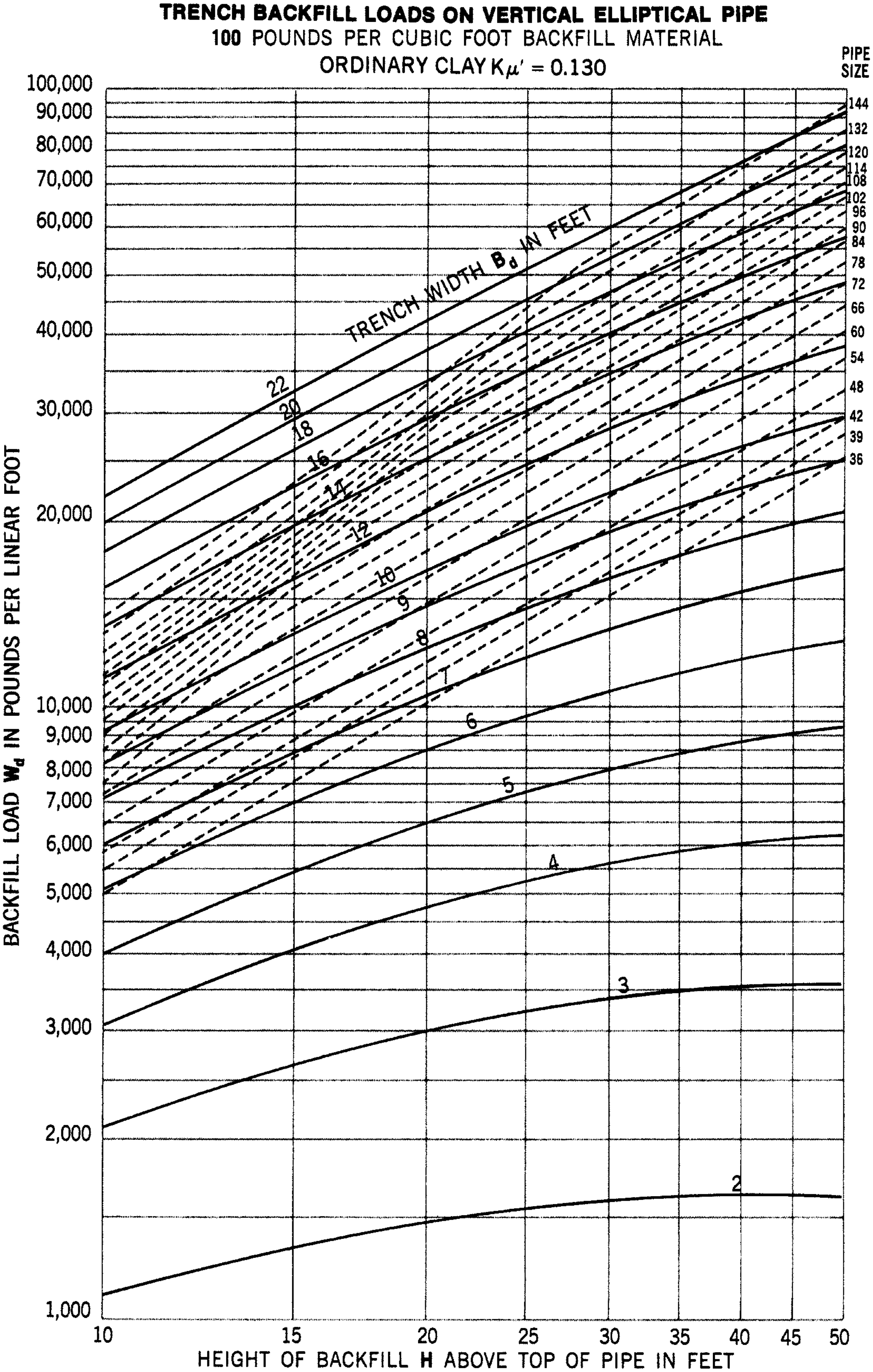
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	SPAN
36	45	29
39	49	32
42	53	34
48	60	38
54	68	43
60	76	48
66	83	53
72	91	58
78	98	63
84	106	68
90	113	72
96	121	77
102	128	82
108	136	87
114	143	92
120	151	97
132	166	106
144	180	116

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 160



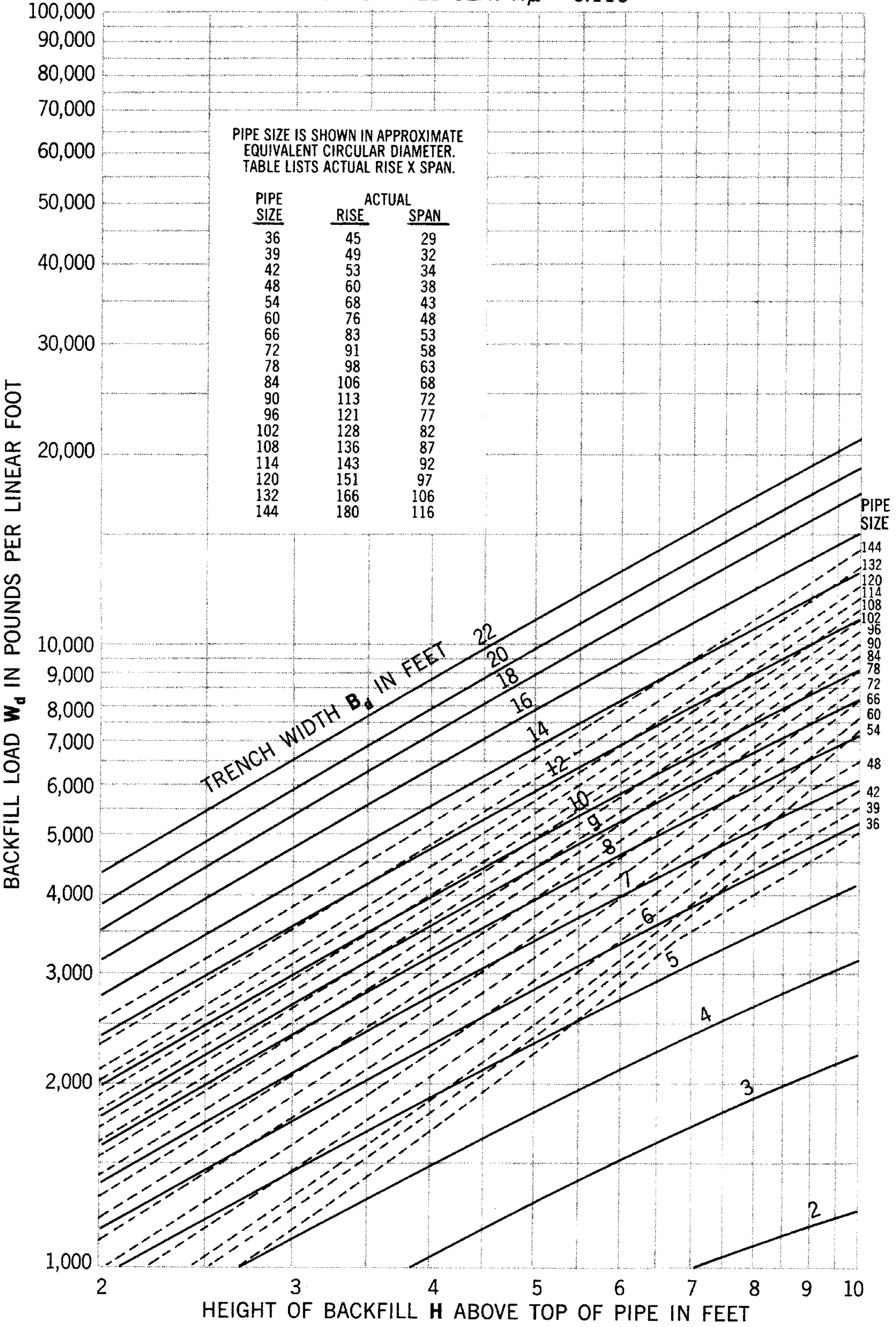
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu$ = 0.19, r_{sd} = 0.7 and p = 0.7 in the embankment equation

Figure 161

TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED CLAY $K\mu' = 0.110$



PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

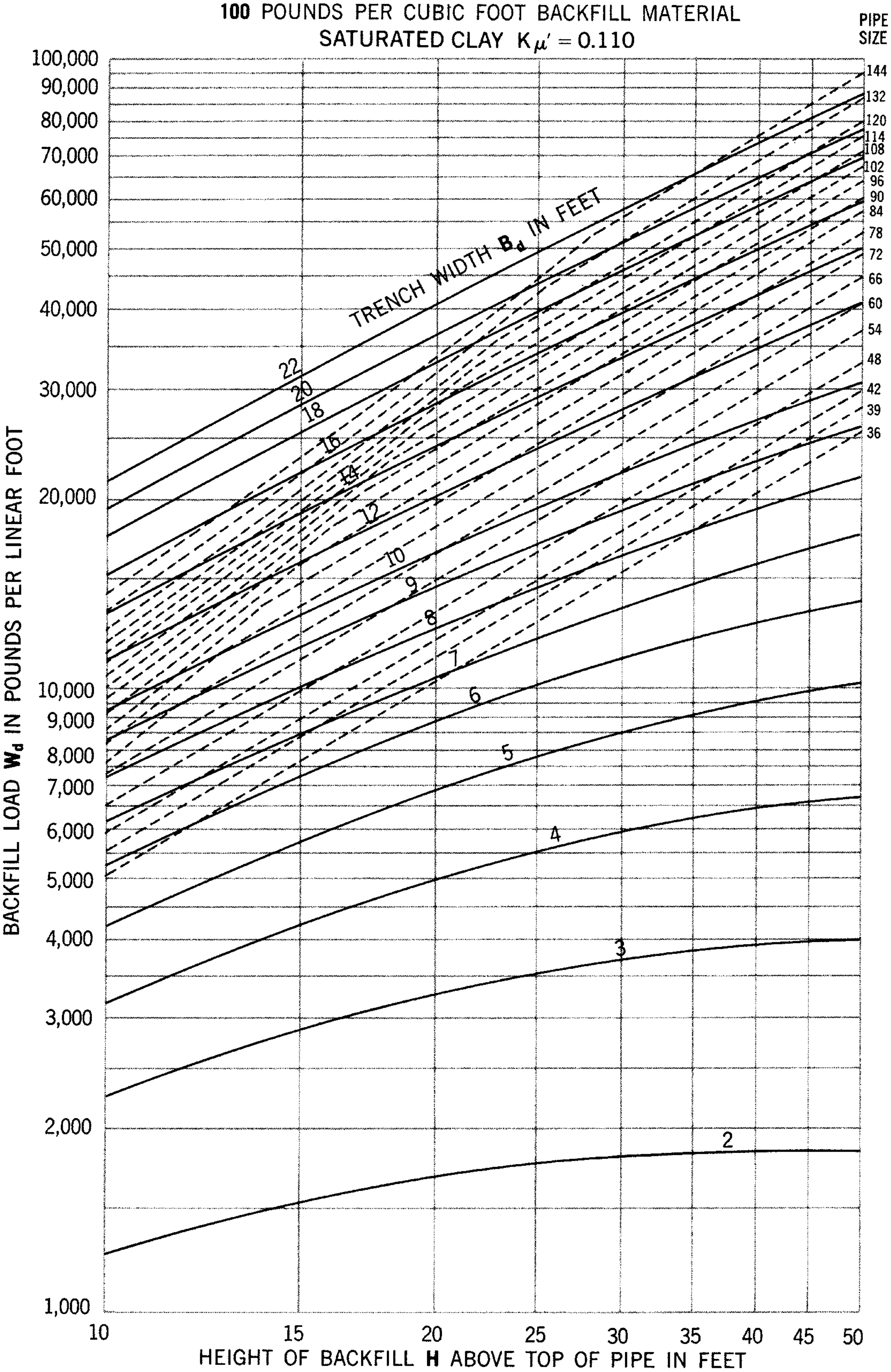
PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
36	45	29
39	49	32
42	53	34
48	60	38
54	68	43
60	76	48
66	83	53
72	91	58
78	98	63
84	106	68
90	113	72
96	121	77
102	128	82
108	136	87
114	143	92
120	151	97
132	166	106
144	180	116

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 162

TRENCH BACKFILL LOADS ON VERTICAL ELLIPTICAL PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED CLAY $K\mu' = 0.110$

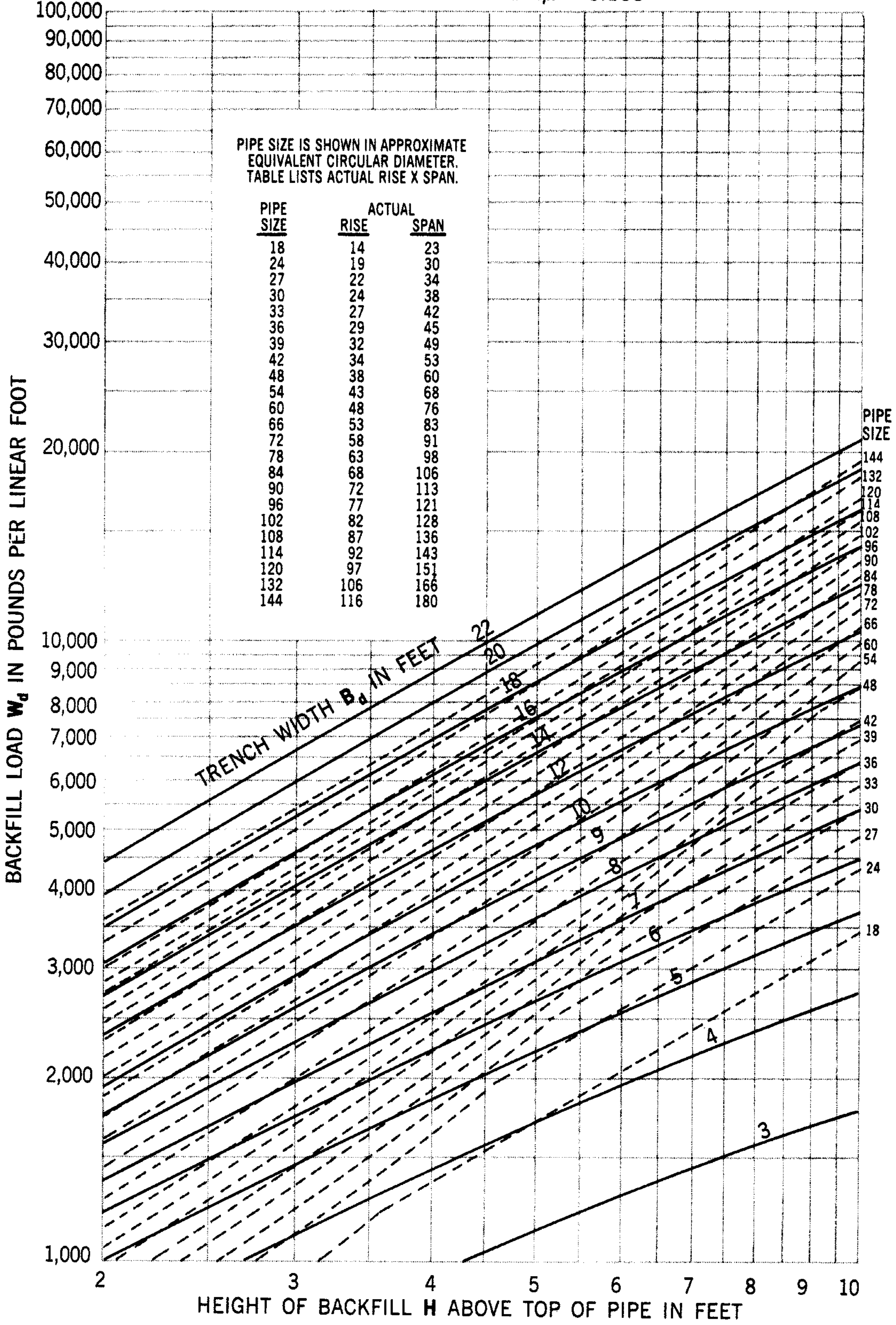


For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 163

TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SAND AND GRAVEL $K\mu' = 0.165$



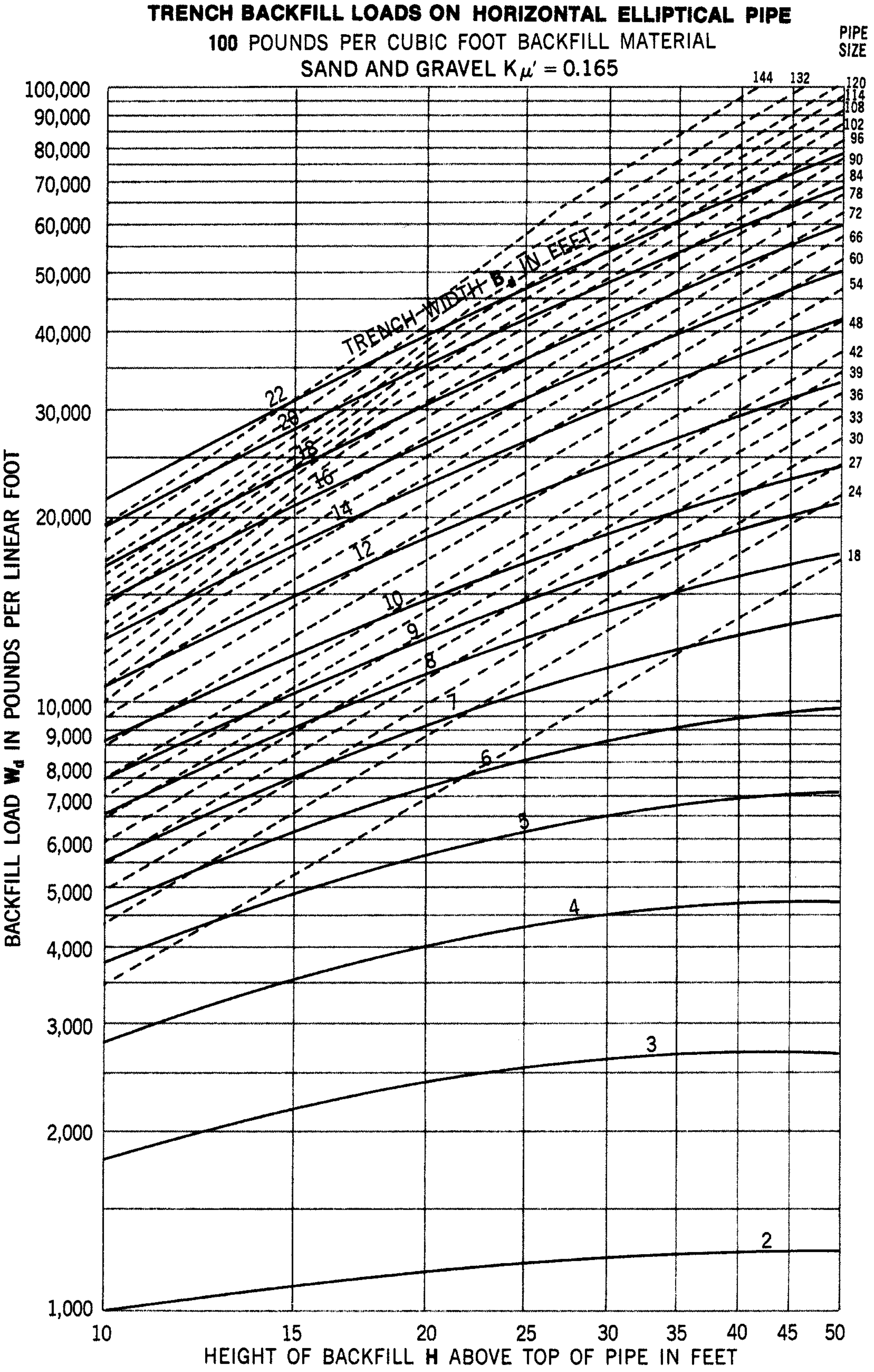
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
18	14	23
24	19	30
27	22	34
30	24	38
33	27	42
36	29	45
39	32	49
42	34	53
48	38	60
54	43	68
60	48	76
66	53	83
72	58	91
78	63	98
84	68	106
90	72	113
96	77	121
102	82	128
108	87	136
114	92	143
120	97	151
132	106	166
144	116	180

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 164

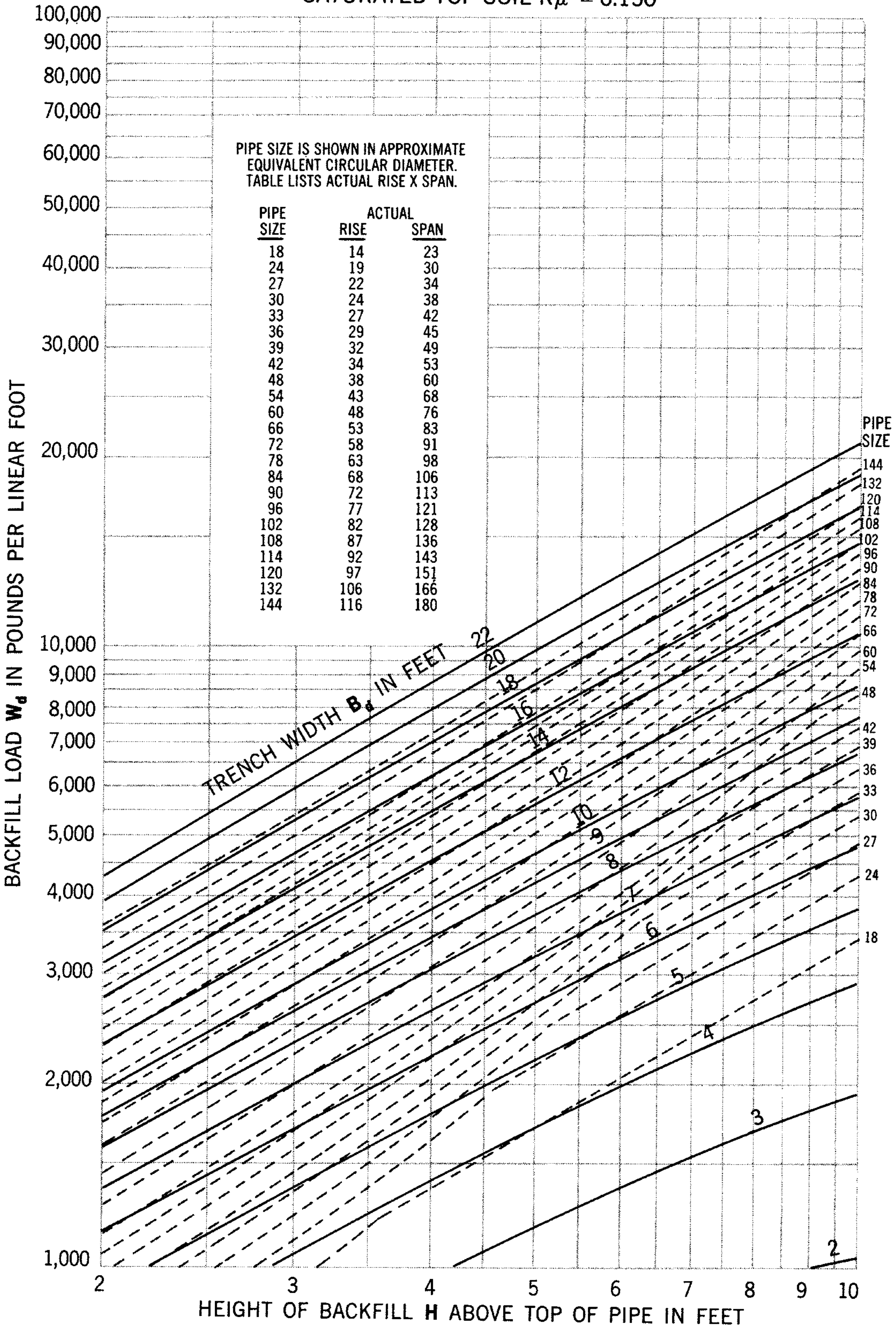


For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 165

TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$



PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
18	14	23
24	19	30
27	22	34
30	24	38
33	27	42
36	29	45
39	32	49
42	34	53
48	38	60
54	43	68
60	48	76
66	53	83
72	58	91
78	63	98
84	68	106
90	72	113
96	77	121
102	82	128
108	87	136
114	92	143
120	97	151
132	106	166
144	116	180

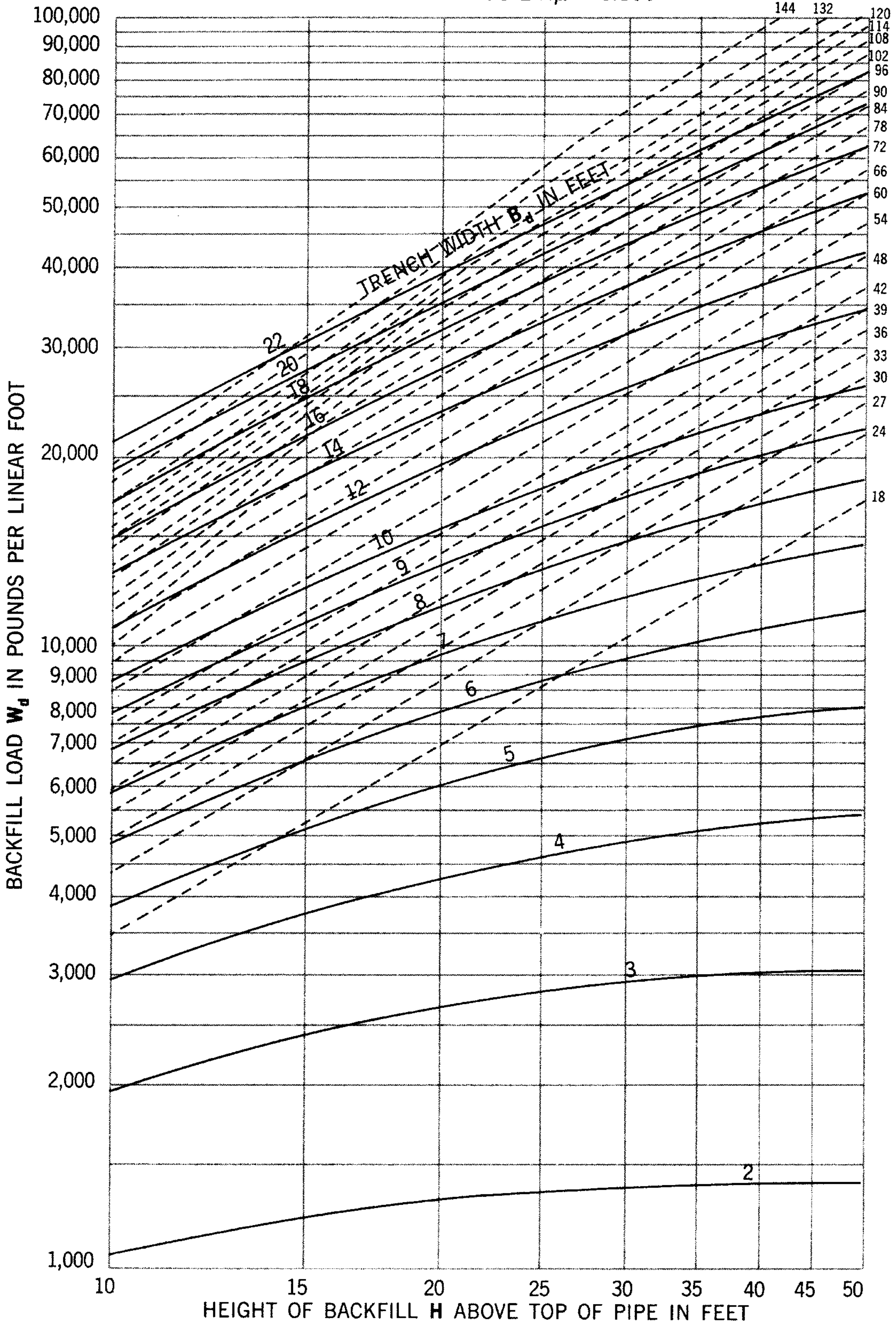
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 166

TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$



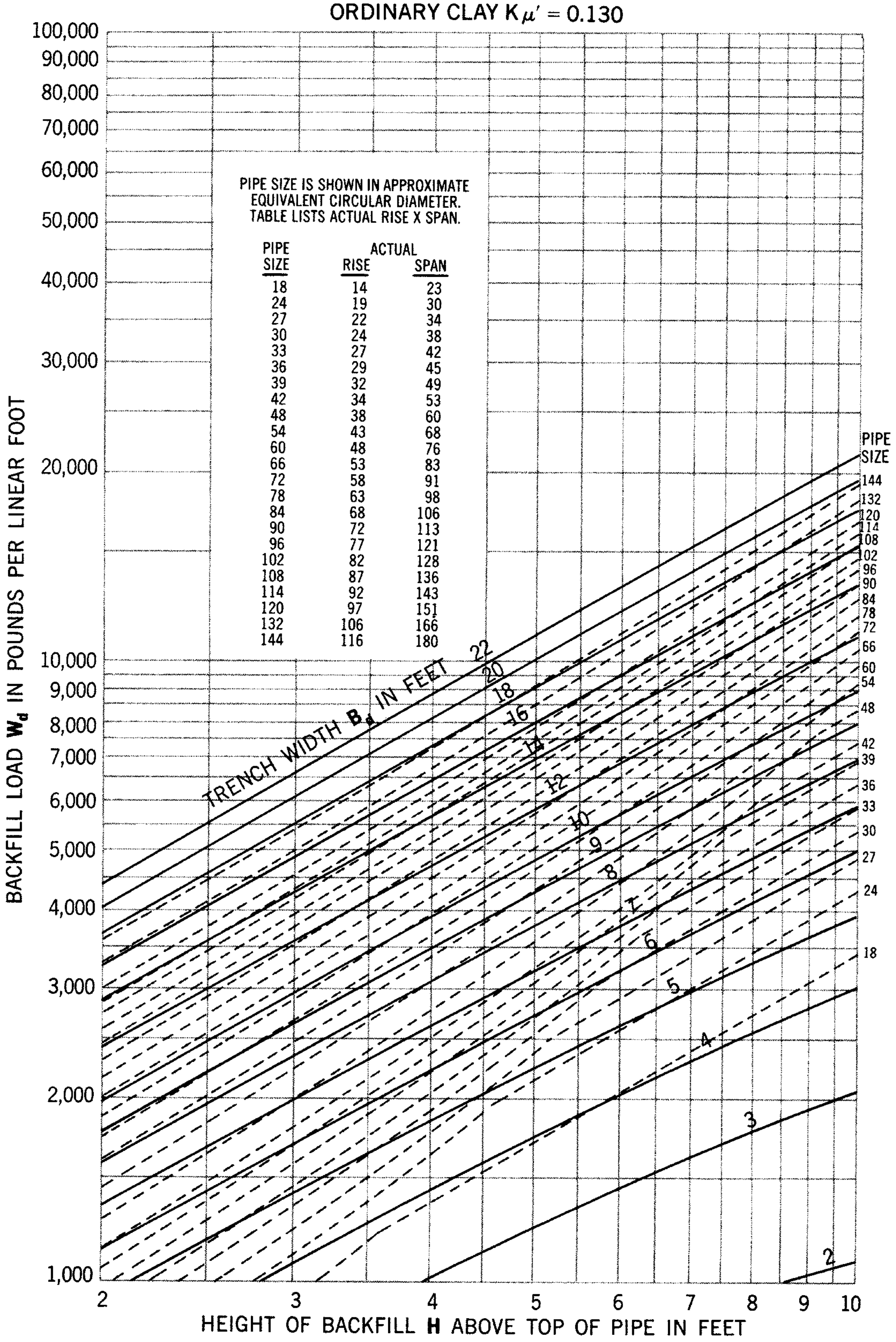
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K_\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 167

TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$



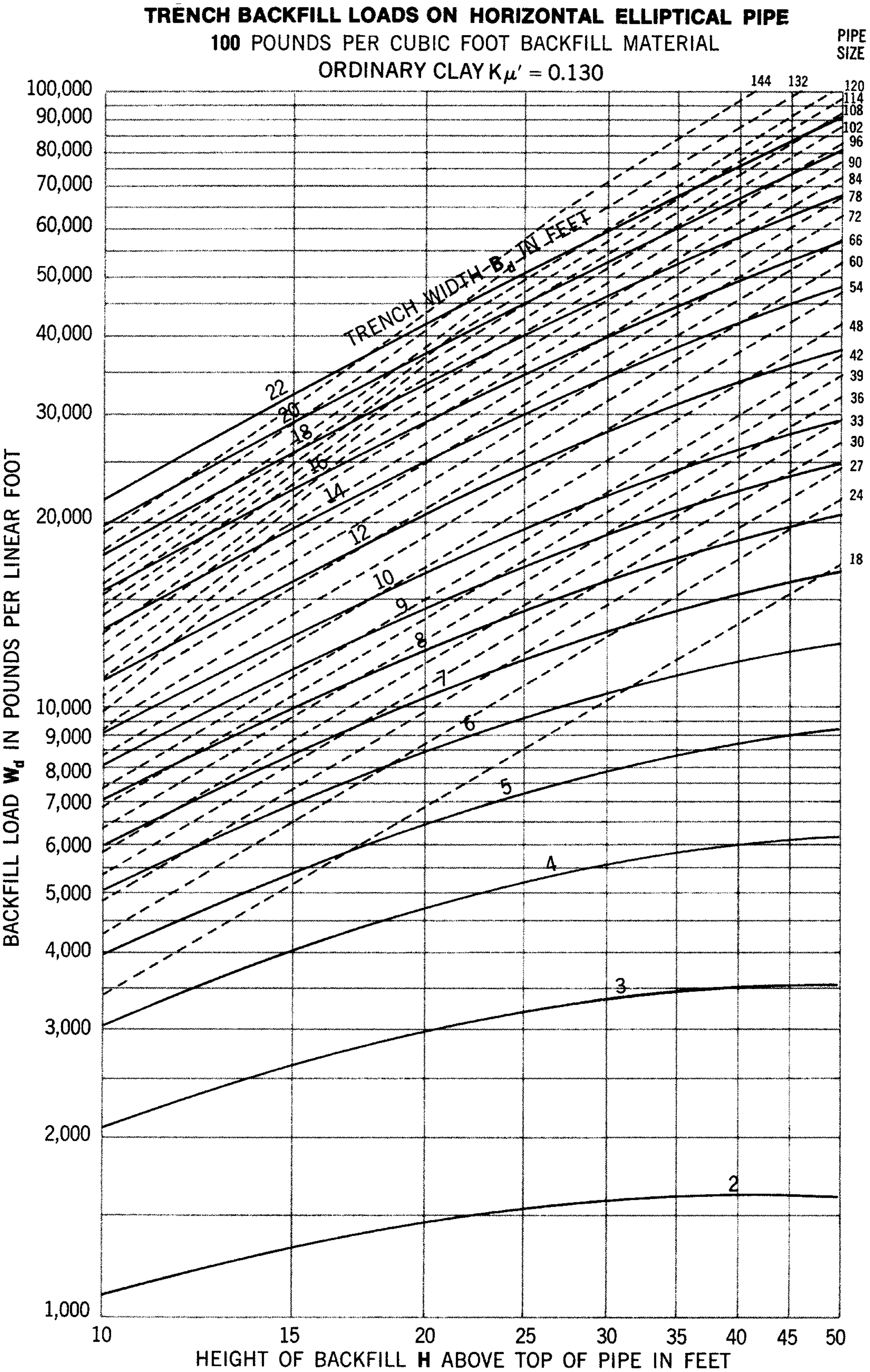
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
18	14	23
24	19	30
27	22	34
30	24	38
33	27	42
36	29	45
39	32	49
42	34	53
48	38	60
54	43	68
60	48	76
66	53	83
72	58	91
78	63	98
84	68	106
90	72	113
96	77	121
102	82	128
108	87	136
114	92	143
120	97	151
132	106	166
144	116	180

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 168



TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
ORDINARY CLAY $K\mu' = 0.130$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

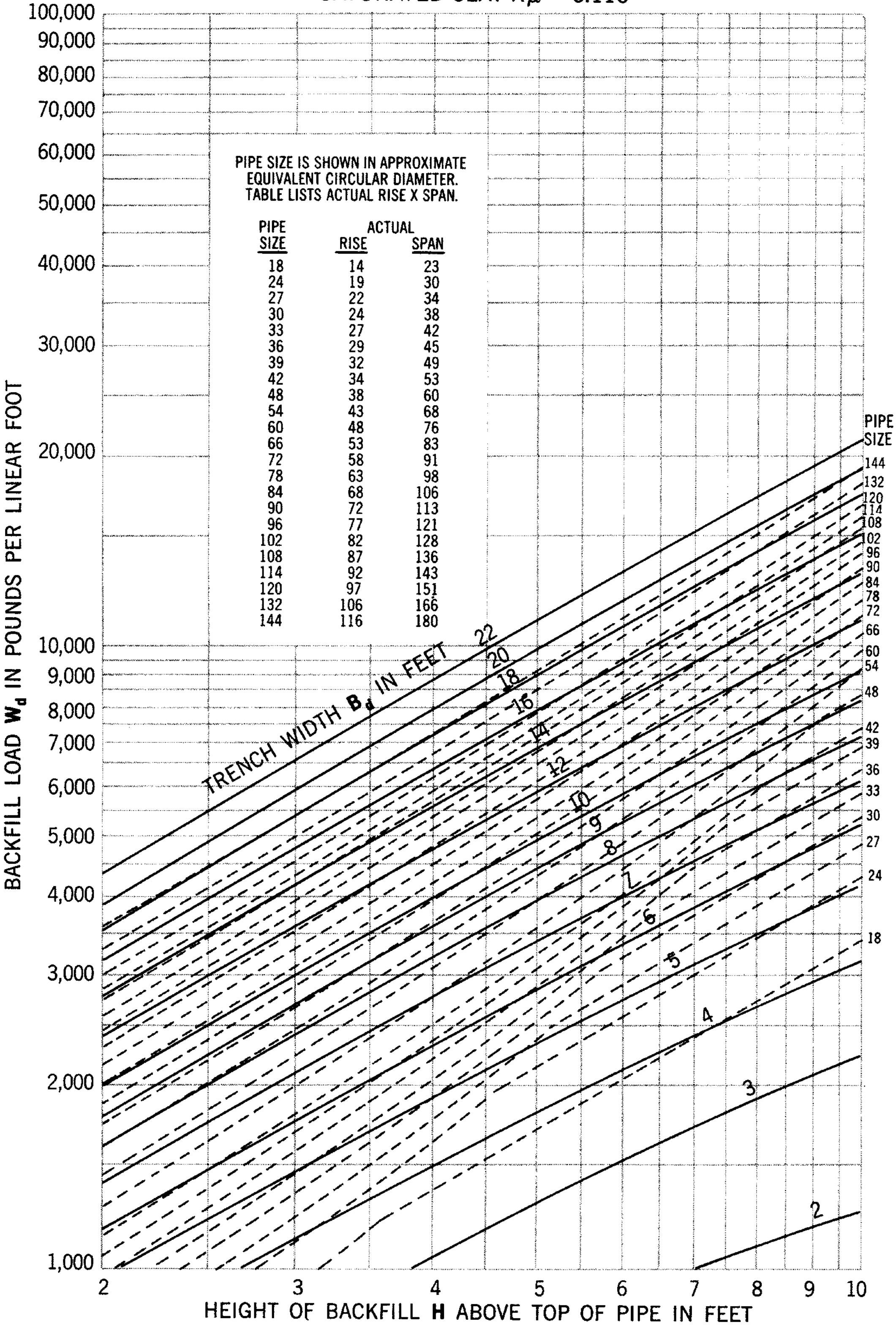
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 169

TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED CLAY $K\mu' = 0.110$



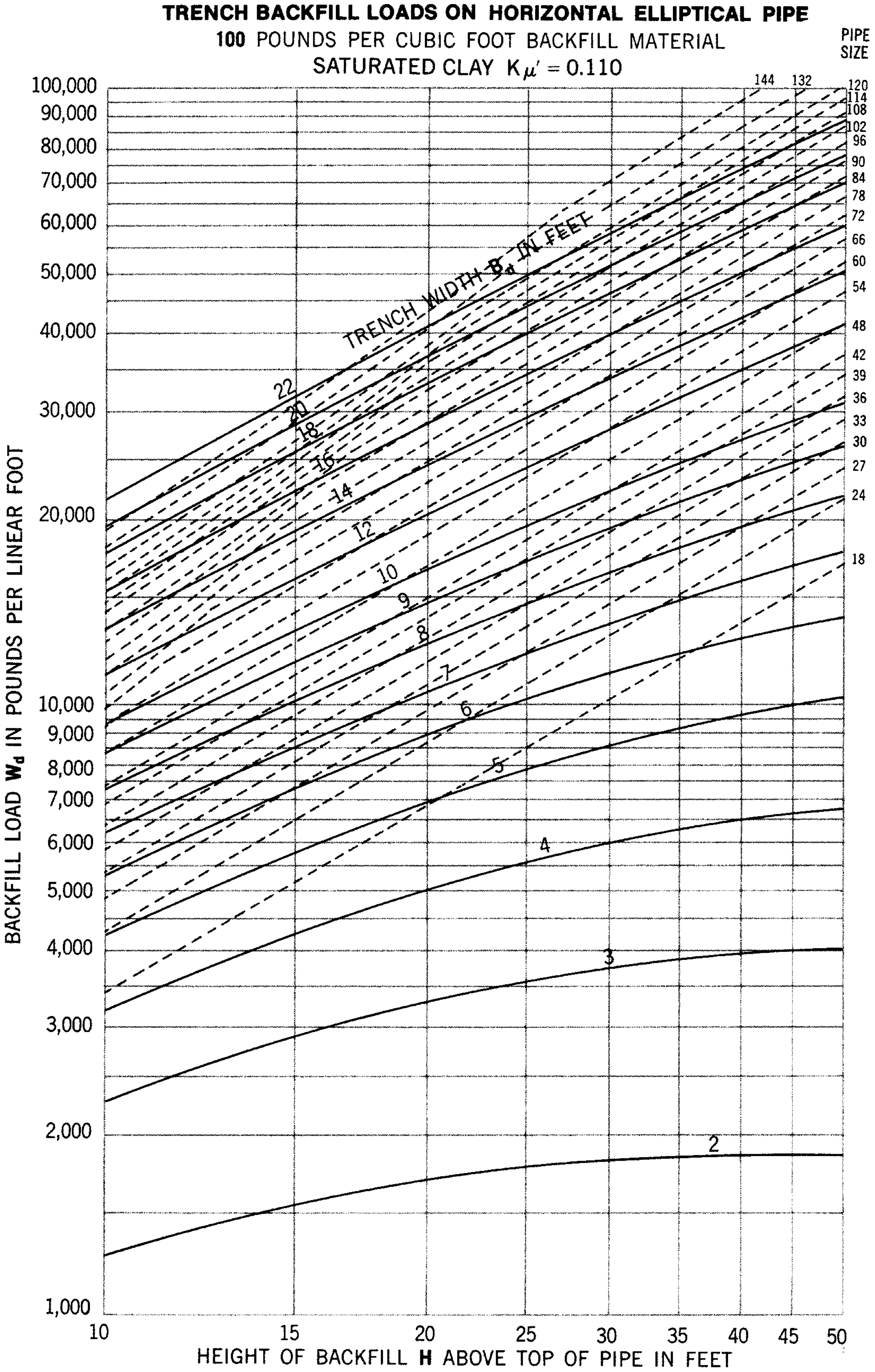
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	SPAN
18	14	23
24	19	30
27	22	34
30	24	38
33	27	42
36	29	45
39	32	49
42	34	53
48	38	60
54	43	68
60	48	76
66	53	83
72	58	91
78	63	98
84	68	106
90	72	113
96	77	121
102	82	128
108	87	136
114	92	143
120	97	151
132	106	166
144	116	180

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 170



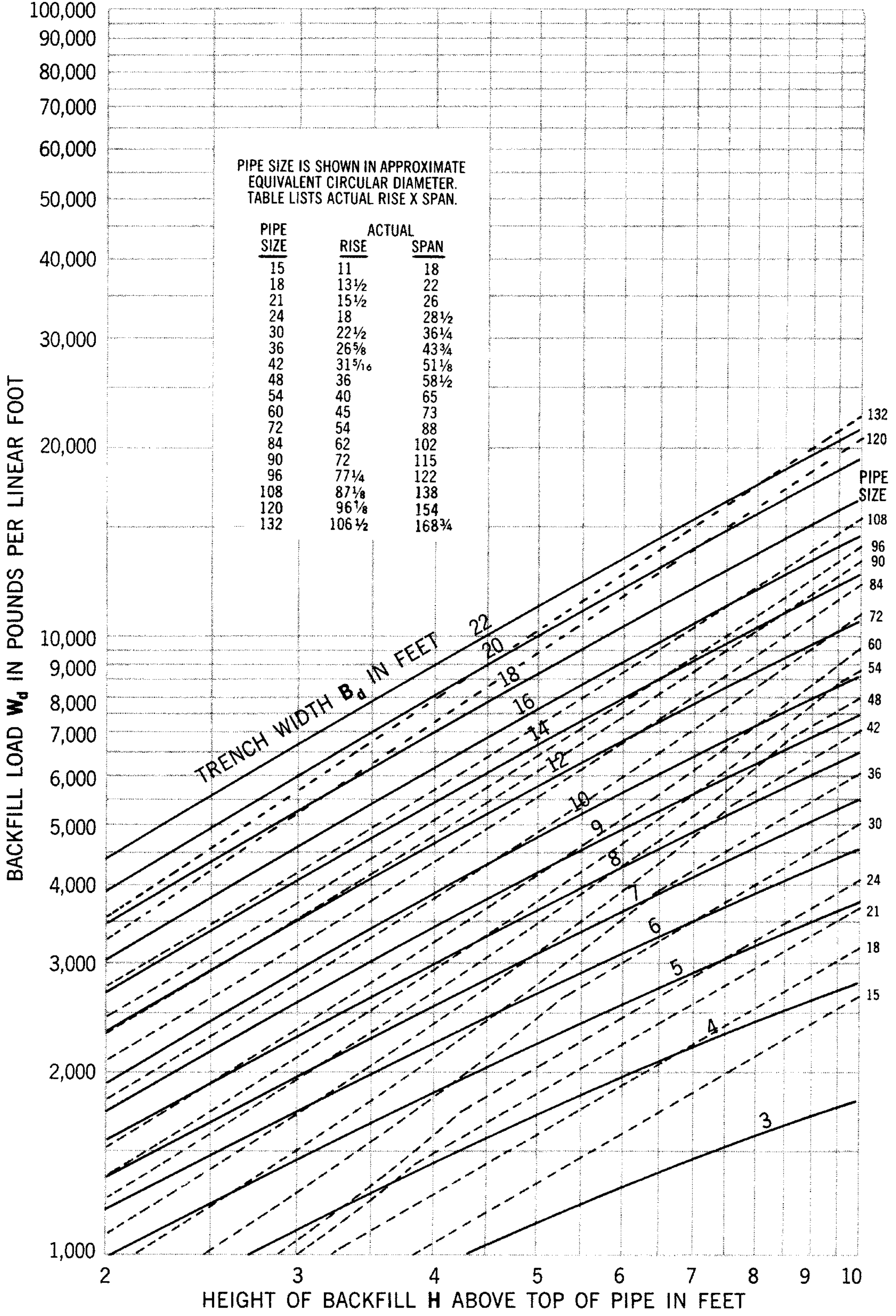
TRENCH BACKFILL LOADS ON HORIZONTAL ELLIPTICAL PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED CLAY $K\mu' = 0.110$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 171

TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SAND AND GRAVEL $K\mu' = 0.165$



PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
15	11	18
18	13½	22
21	15½	26
24	18	28½
30	22½	36¼
36	26⅝	43¾
42	31⁵⁄₁₆	51⅛
48	36	58½
54	40	65
60	45	73
72	54	88
84	62	102
90	72	115
96	77¼	122
108	87⅛	138
120	96⅛	154
132	106½	168¾

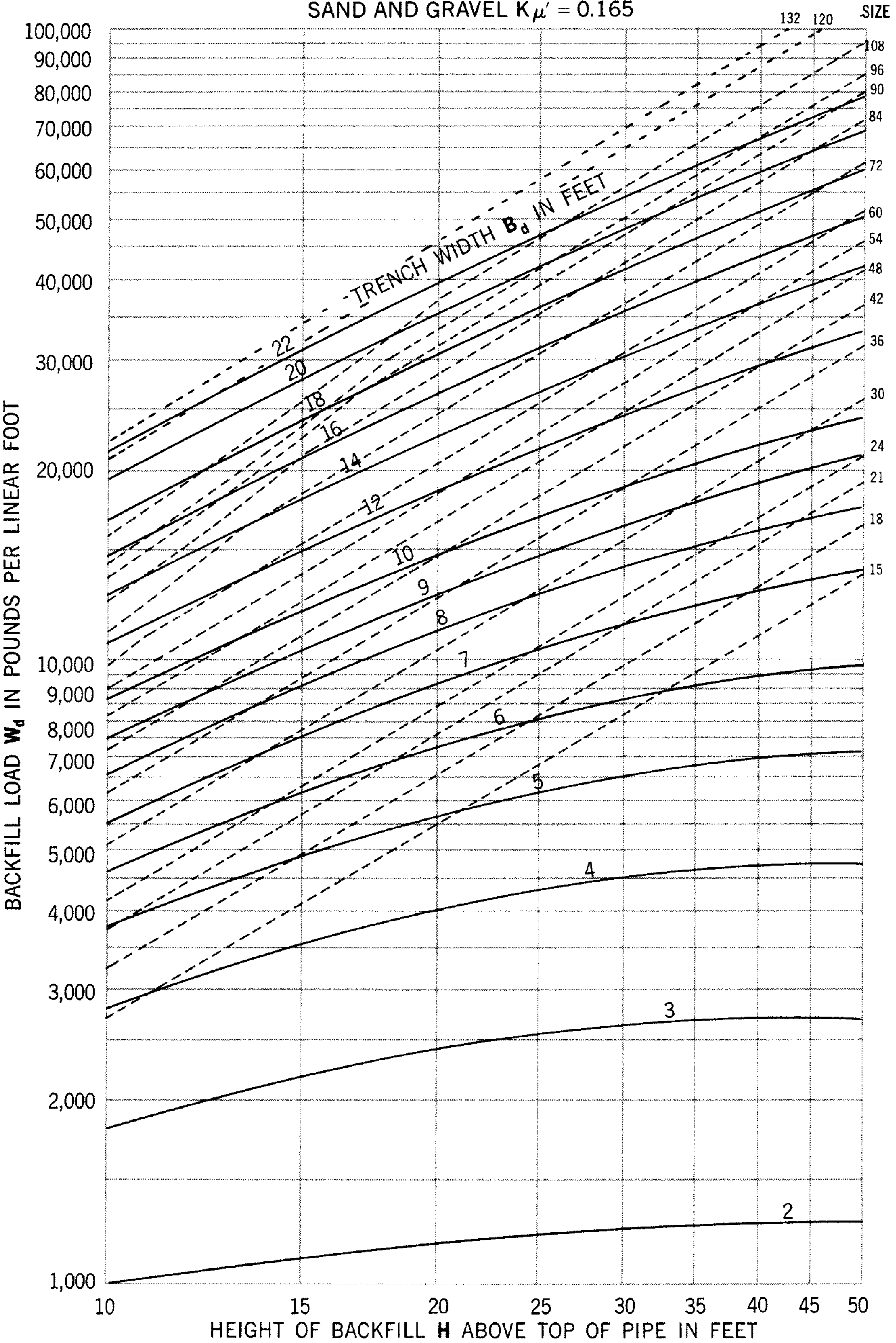
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 172

TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SAND AND GRAVEL $K\mu' = 0.165$



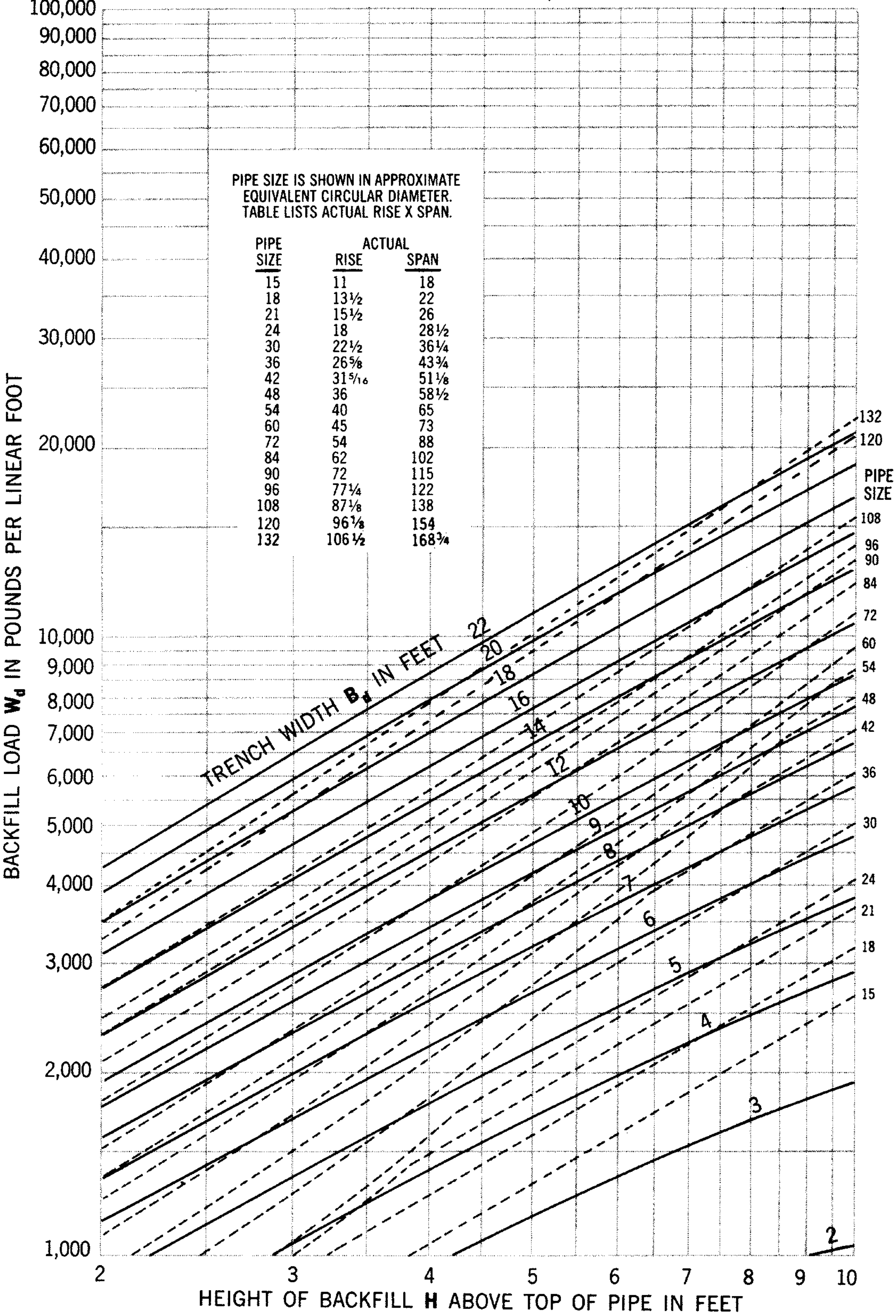
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 173

TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$

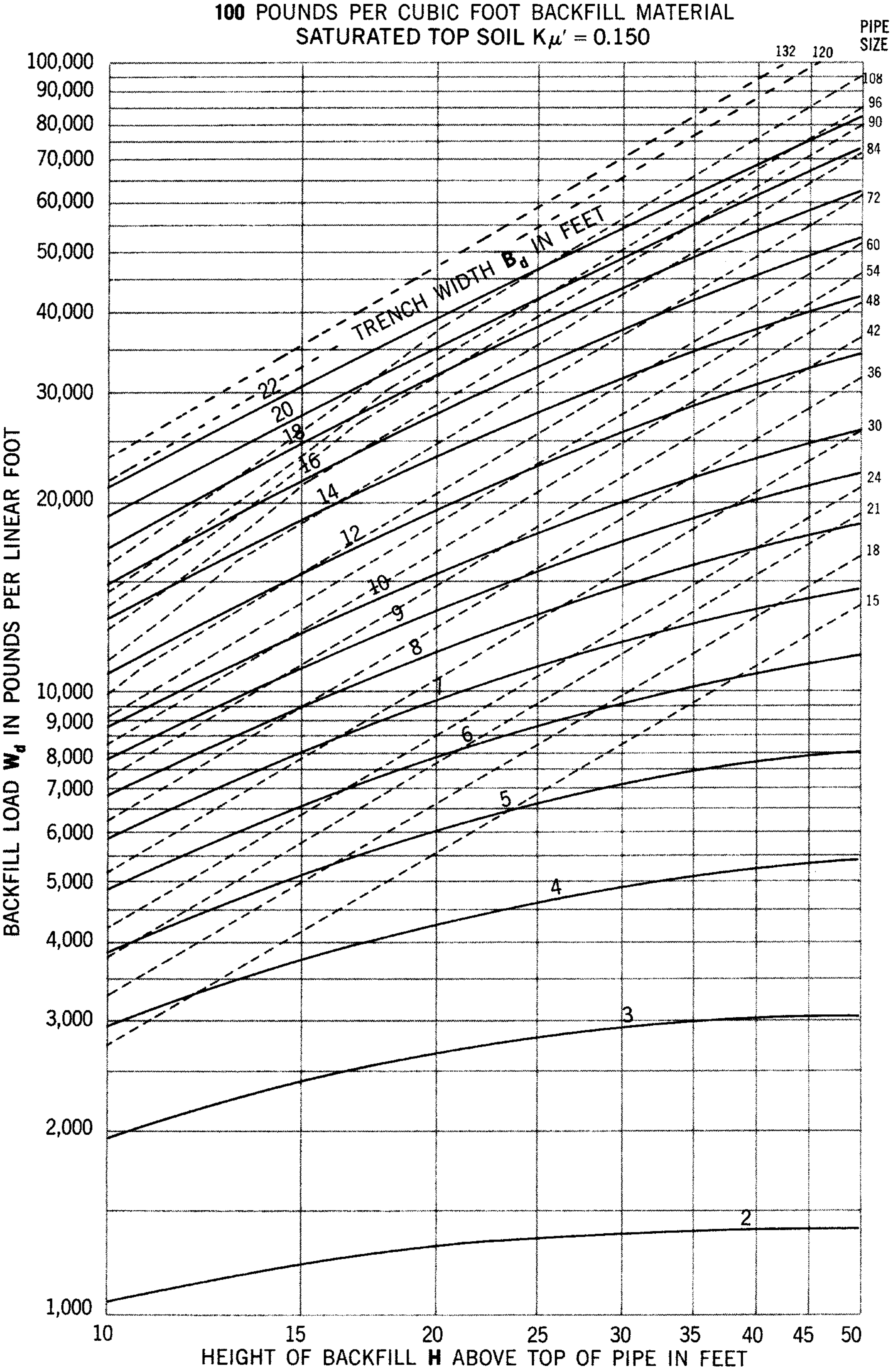


PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
15	11	18
18	13½	22
21	15½	26
24	18	28½
30	22½	36¼
36	26⅝	43¾
42	31⁵⁄₁₆	51⅛
48	36	58½
54	40	65
60	45	73
72	54	88
84	62	102
90	72	115
96	77¼	122
108	87⅛	138
120	96⅞	154
132	106½	168¾

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 174



TRENCH BACKFILL LOADS ON ARCH PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

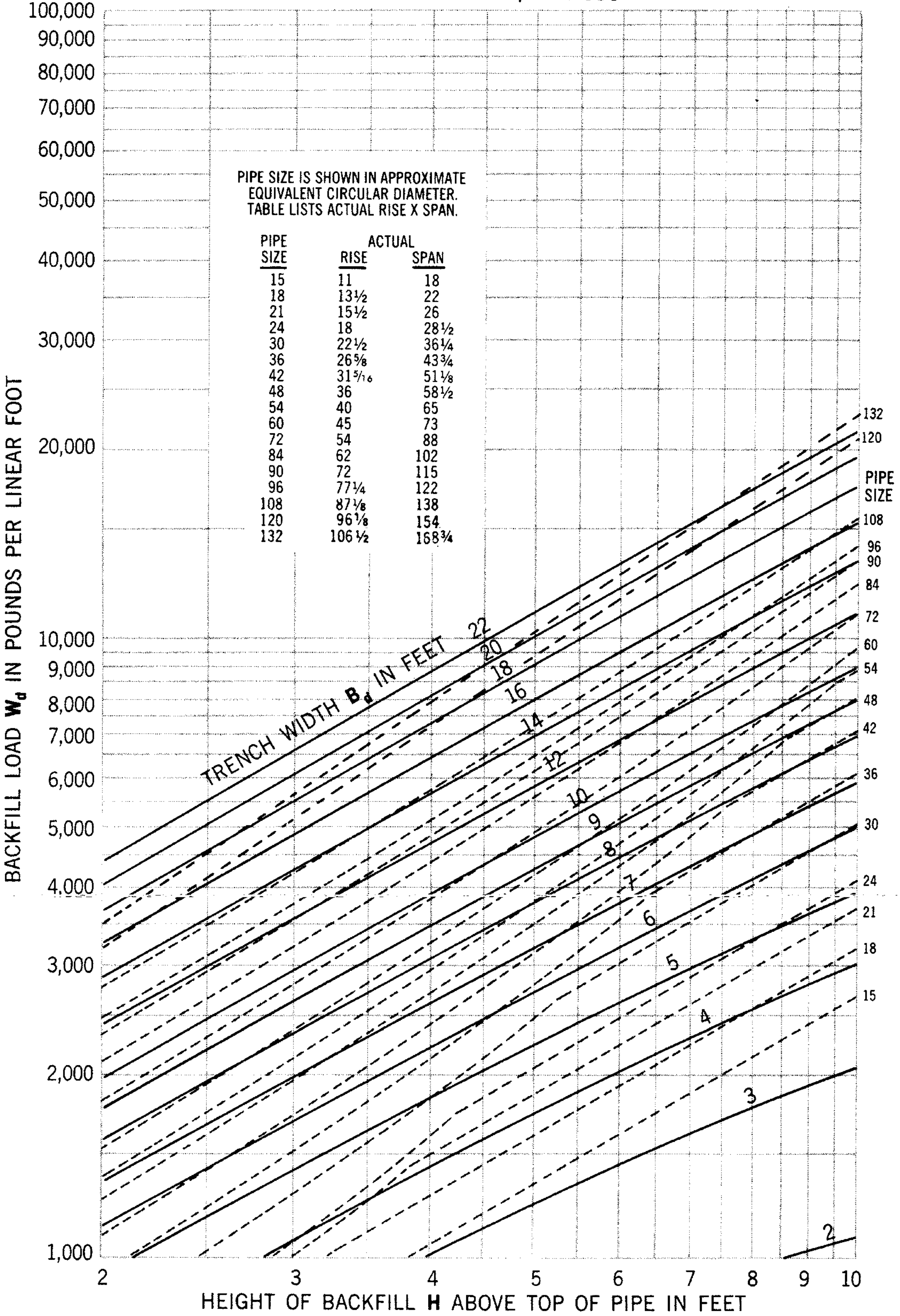
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 175

TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$



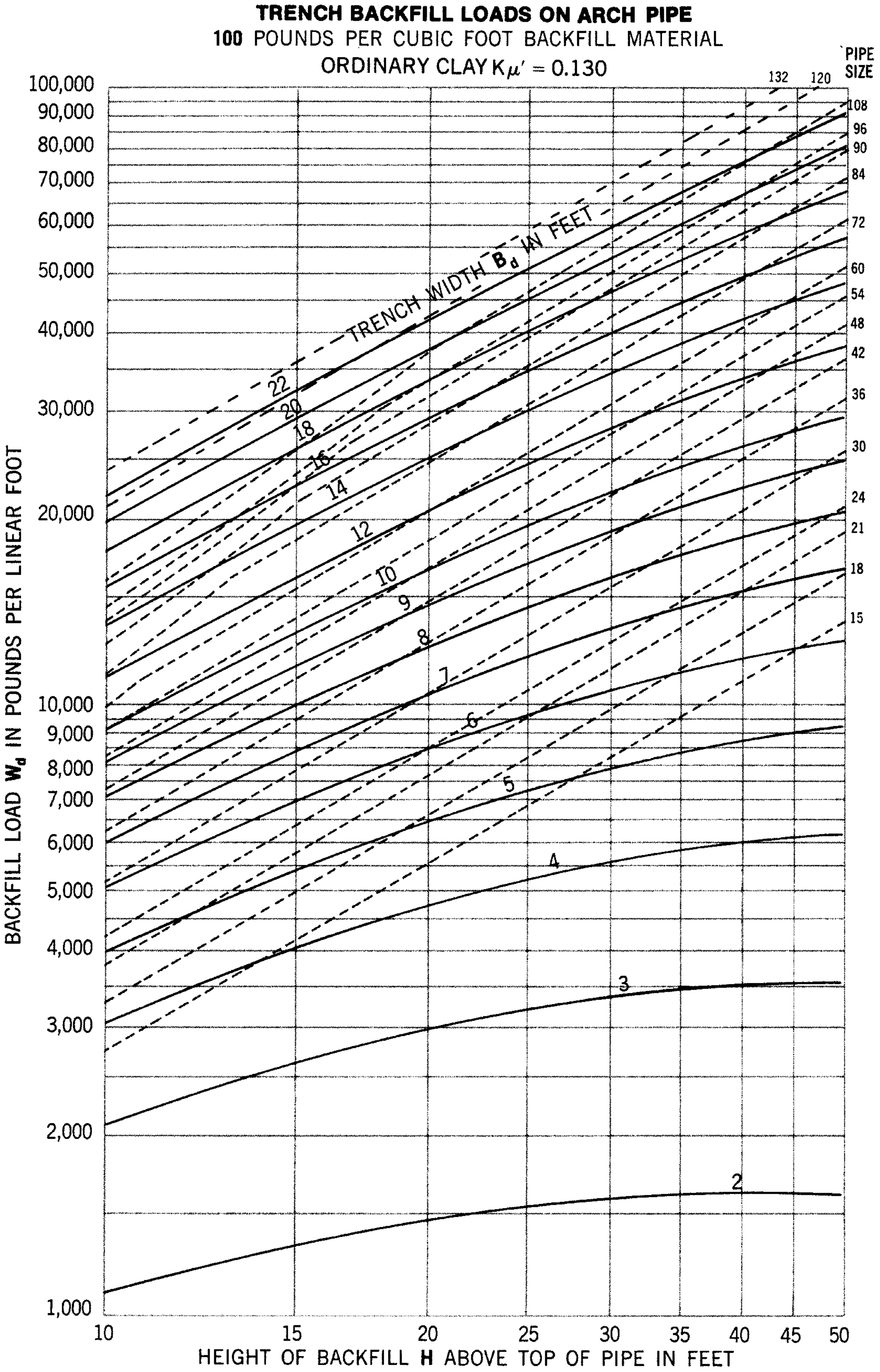
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
15	11	18
18	13½	22
21	15½	26
24	18	28½
30	22½	36¼
36	26⅝	43¾
42	31⁵⁄₁₆	51⅛
48	36	58½
54	40	65
60	45	73
72	54	88
84	62	102
90	72	115
96	77¼	122
108	87⅛	138
120	96⅞	154
132	106½	168¾

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 176



TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

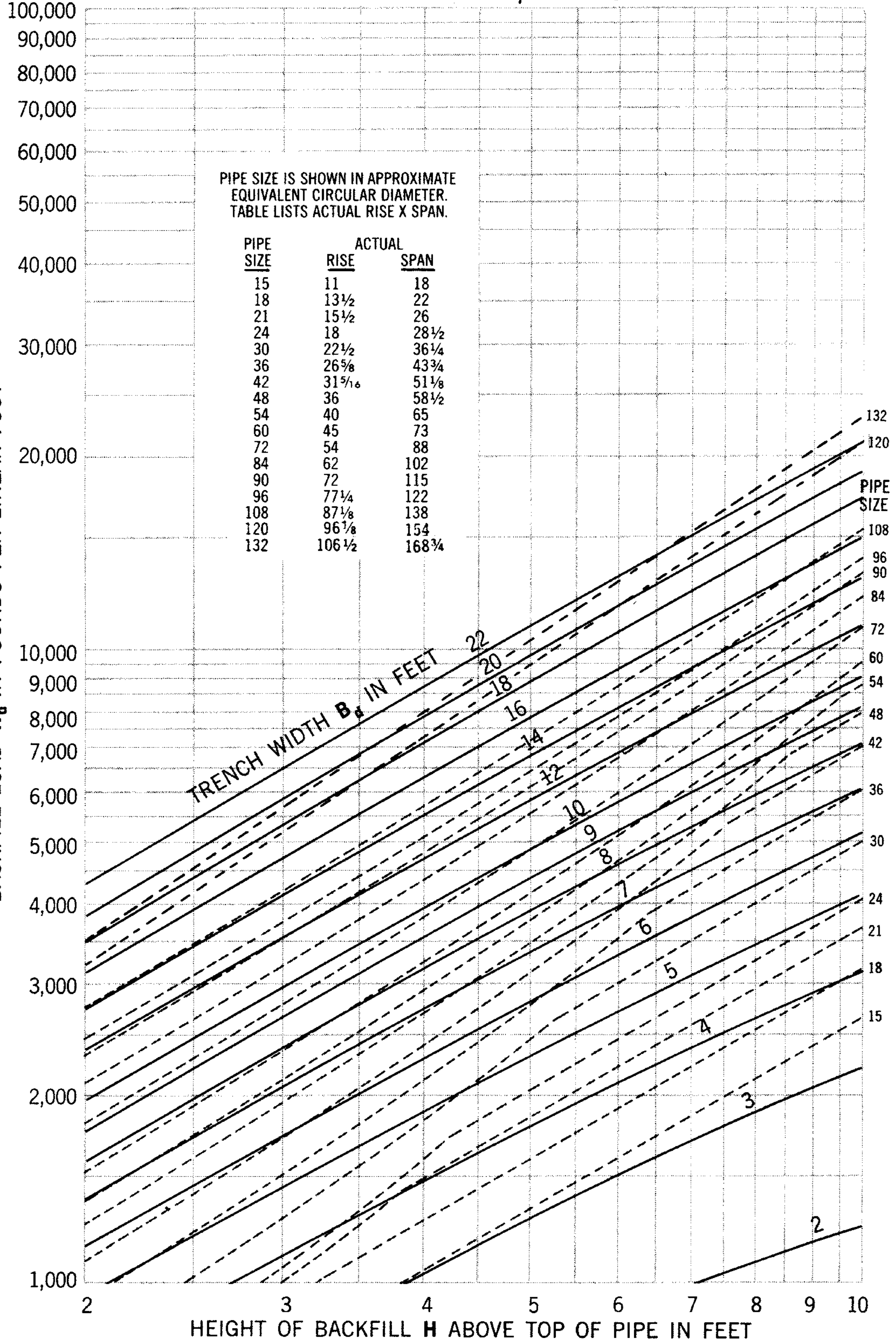
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 177

TRENCH BACKFILL LOADS ON ARCH PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED CLAY $K\mu' = 0.110$



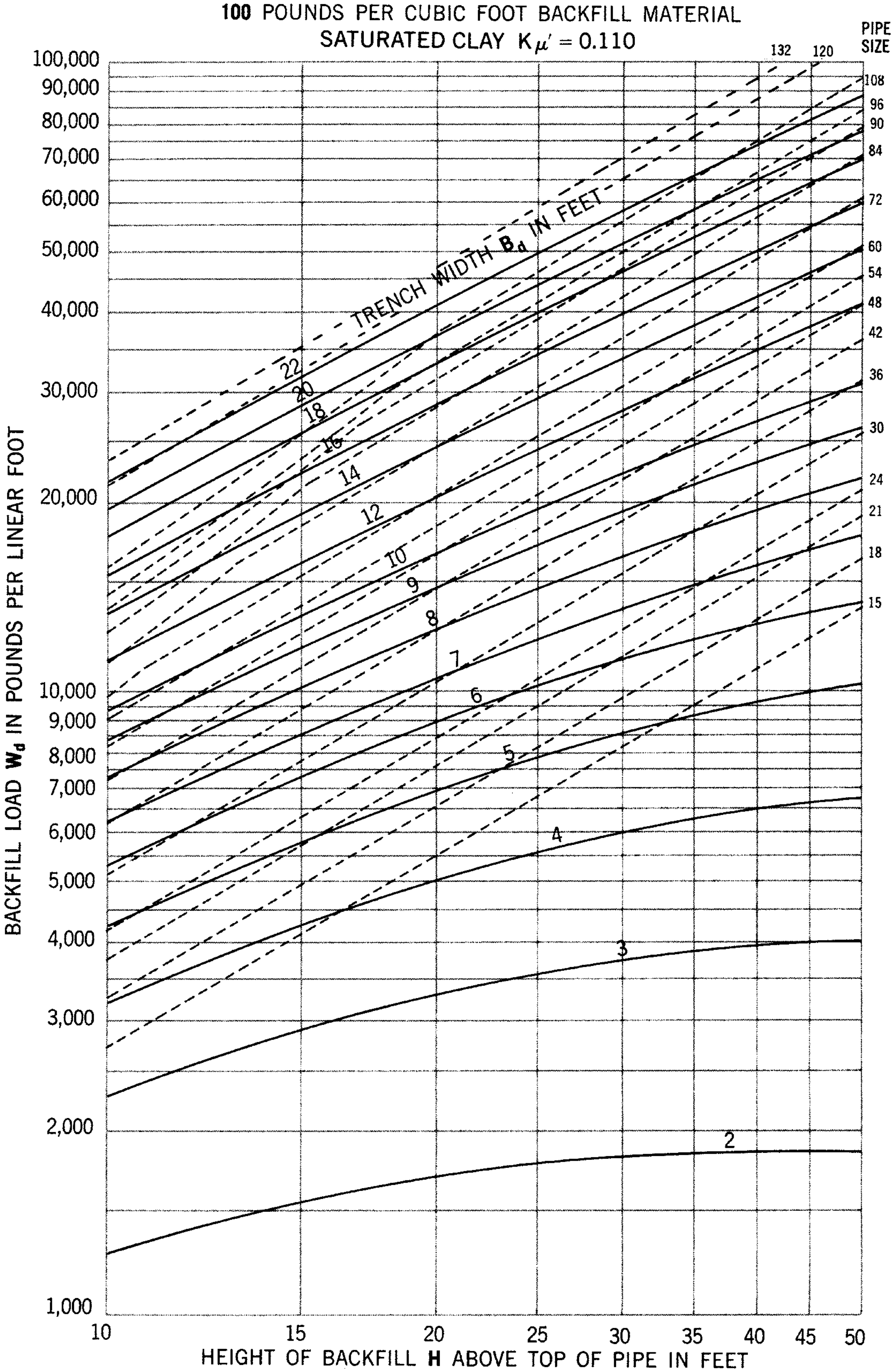
PIPE SIZE IS SHOWN IN APPROXIMATE EQUIVALENT CIRCULAR DIAMETER. TABLE LISTS ACTUAL RISE X SPAN.

PIPE SIZE	ACTUAL RISE	ACTUAL SPAN
15	11	18
18	13½	22
21	15½	26
24	18	28½
30	22½	36¼
36	26⅝	43¾
42	31⁵⁄₁₆	51⅛
48	36	58½
54	40	65
60	45	73
72	54	88
84	62	102
90	72	115
96	77¼	122
108	87⅛	138
120	96⅞	154
132	106½	168¾

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure 178



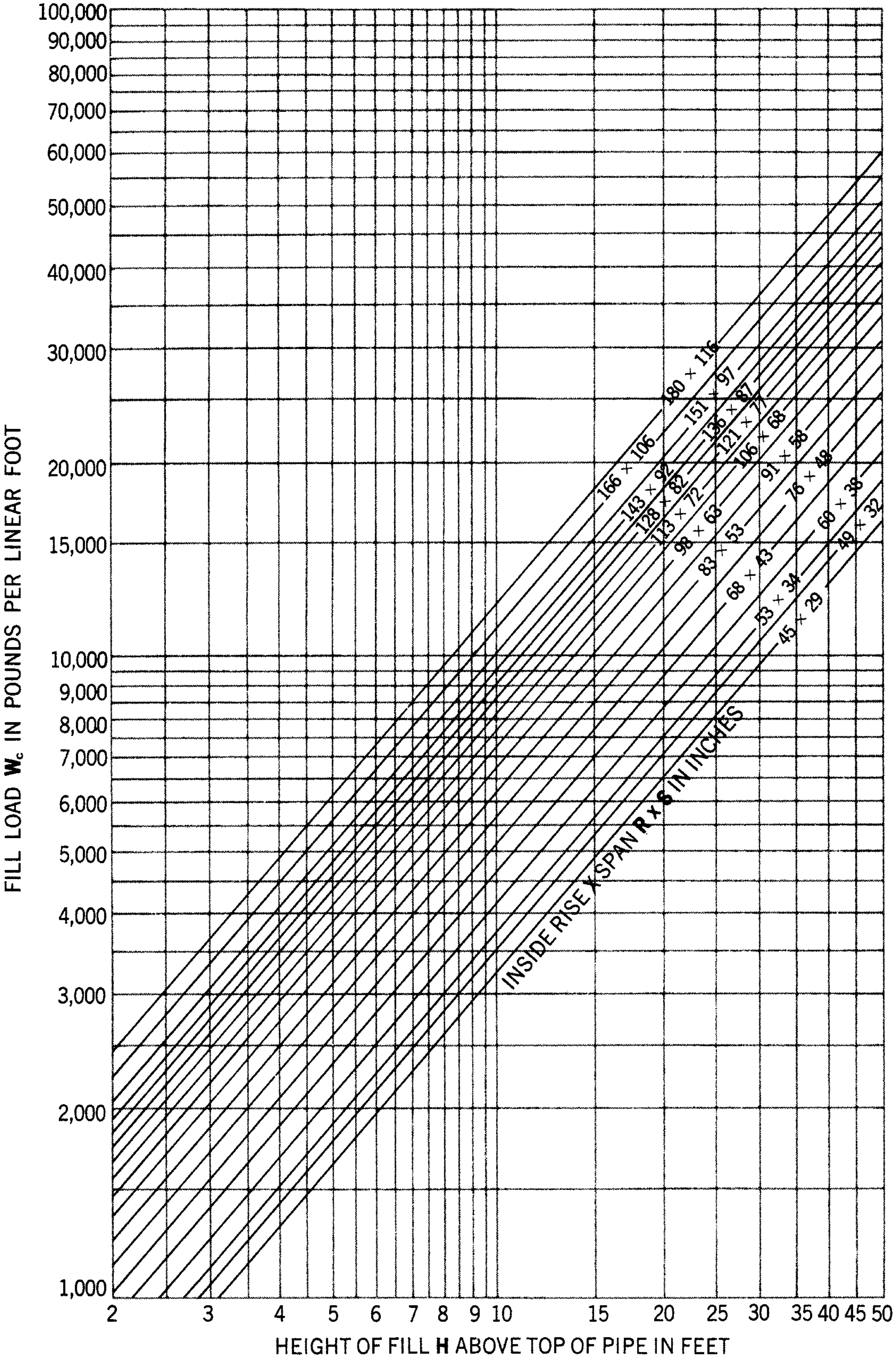
TRENCH BACKFILL LOADS ON ARCH PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED CLAY $K\mu' = 0.110$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure 179

EMBANKMENT FILL LOADS ON VERTICAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0$ **100** POUNDS PER CUBIC FOOT FILL

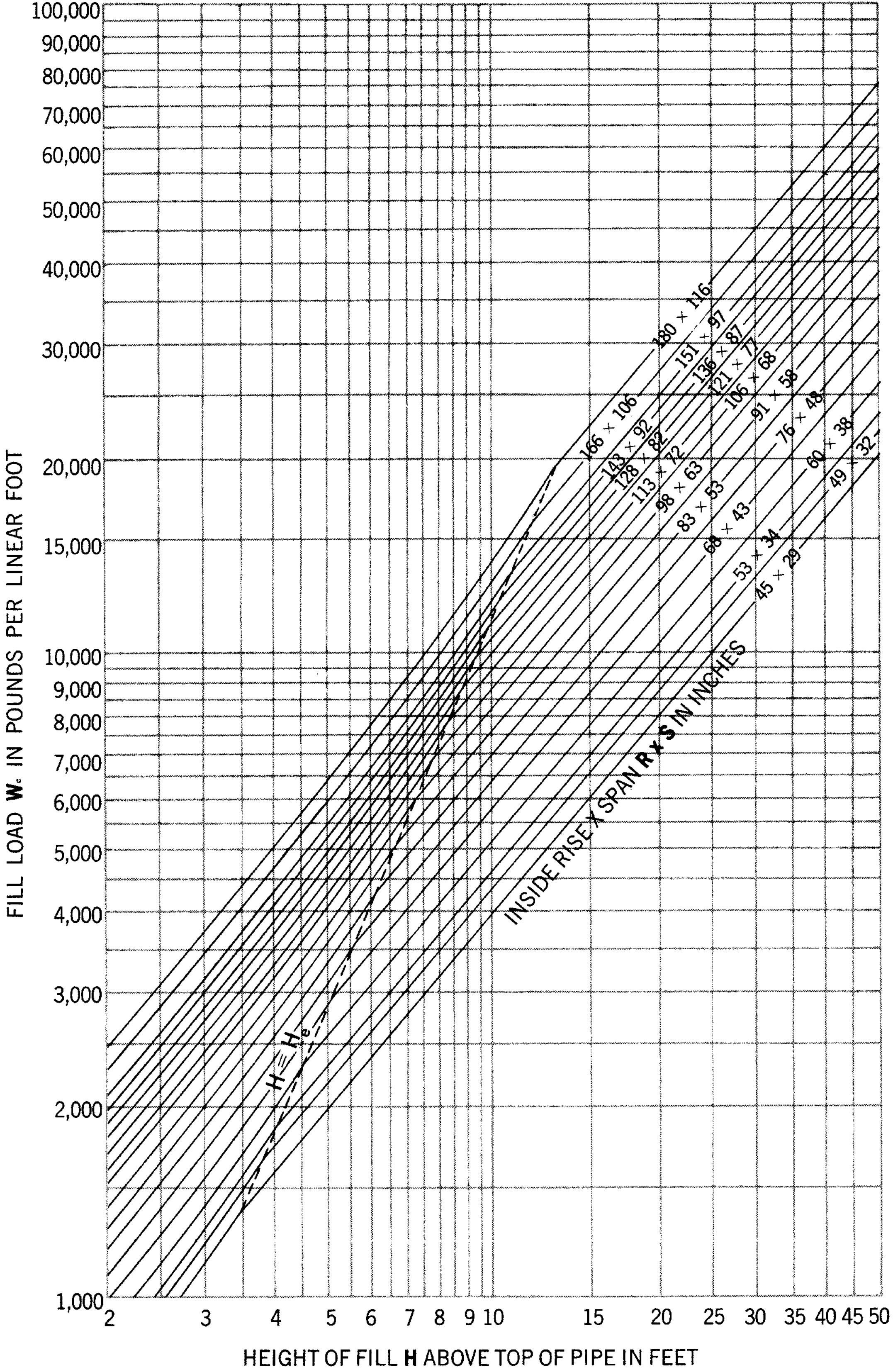


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 180

EMBANKMENT FILL LOADS ON VERTICAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.1$ **100** POUNDS PER CUBIC FOOT FILL

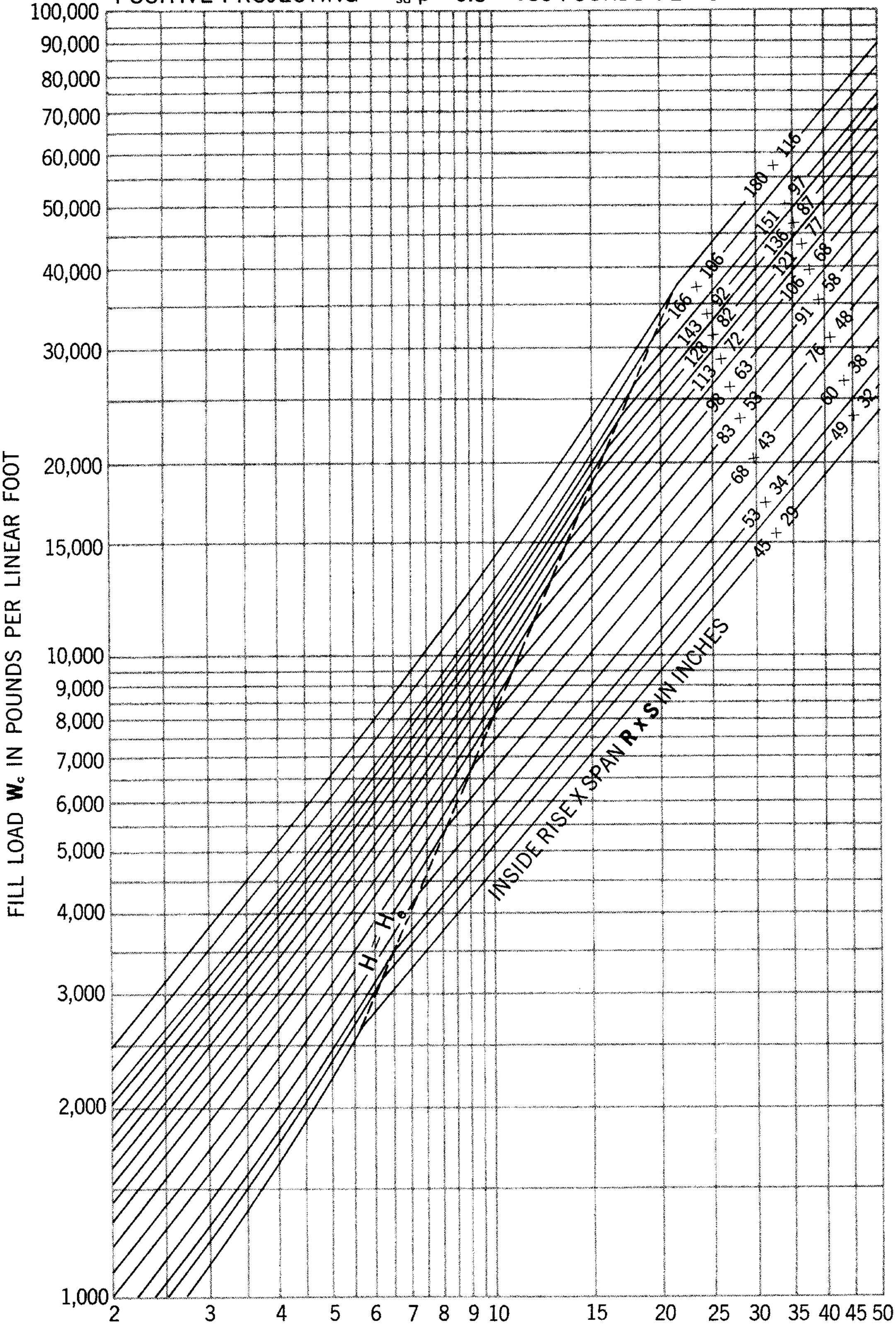


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 181

EMBANKMENT FILL LOADS ON VERTICAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.3$ **100** POUNDS PER CUBIC FOOT FILL

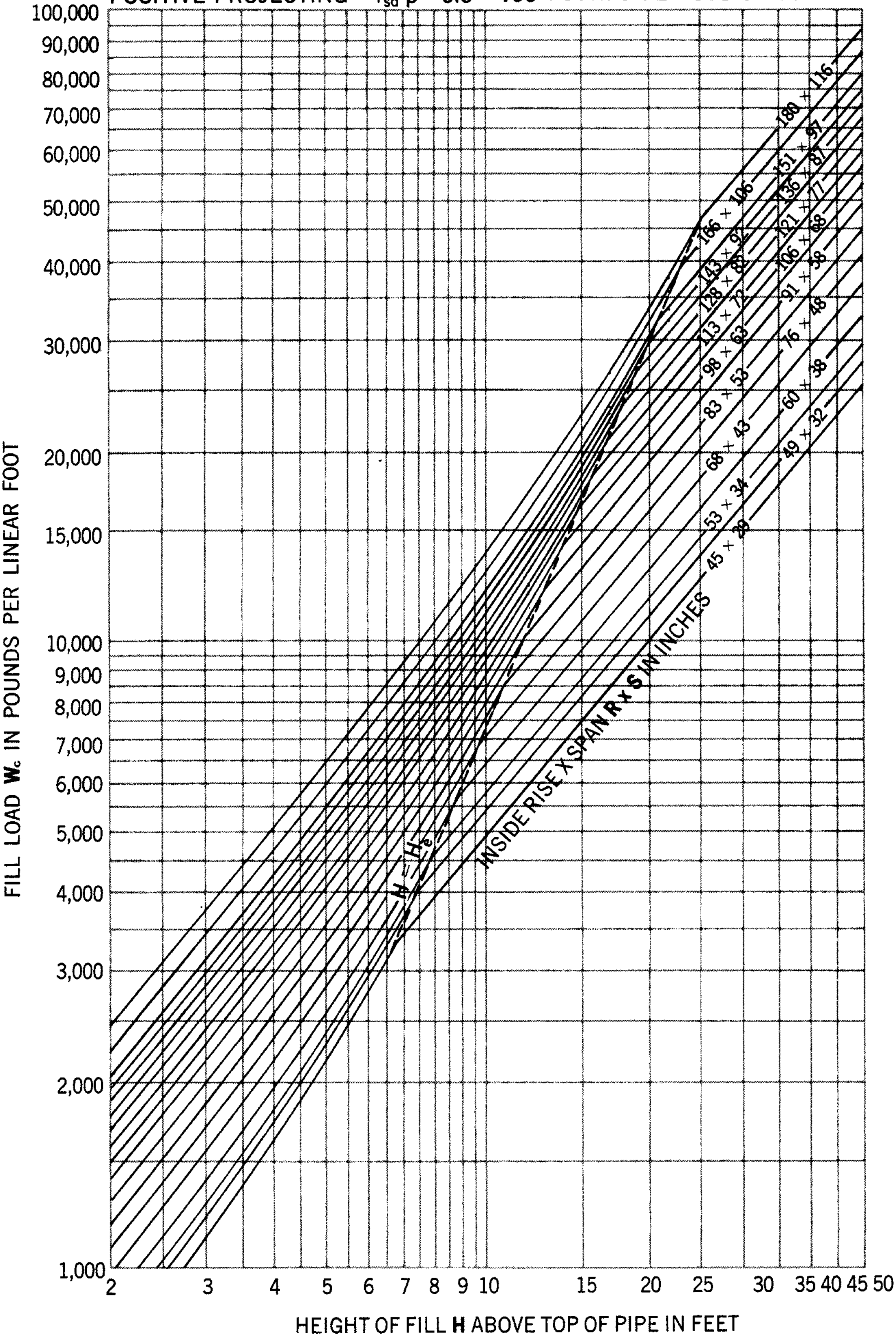


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 182

EMBANKMENT FILL LOADS ON VERTICAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.5$ **100** POUNDS PER CUBIC FOOT FILL

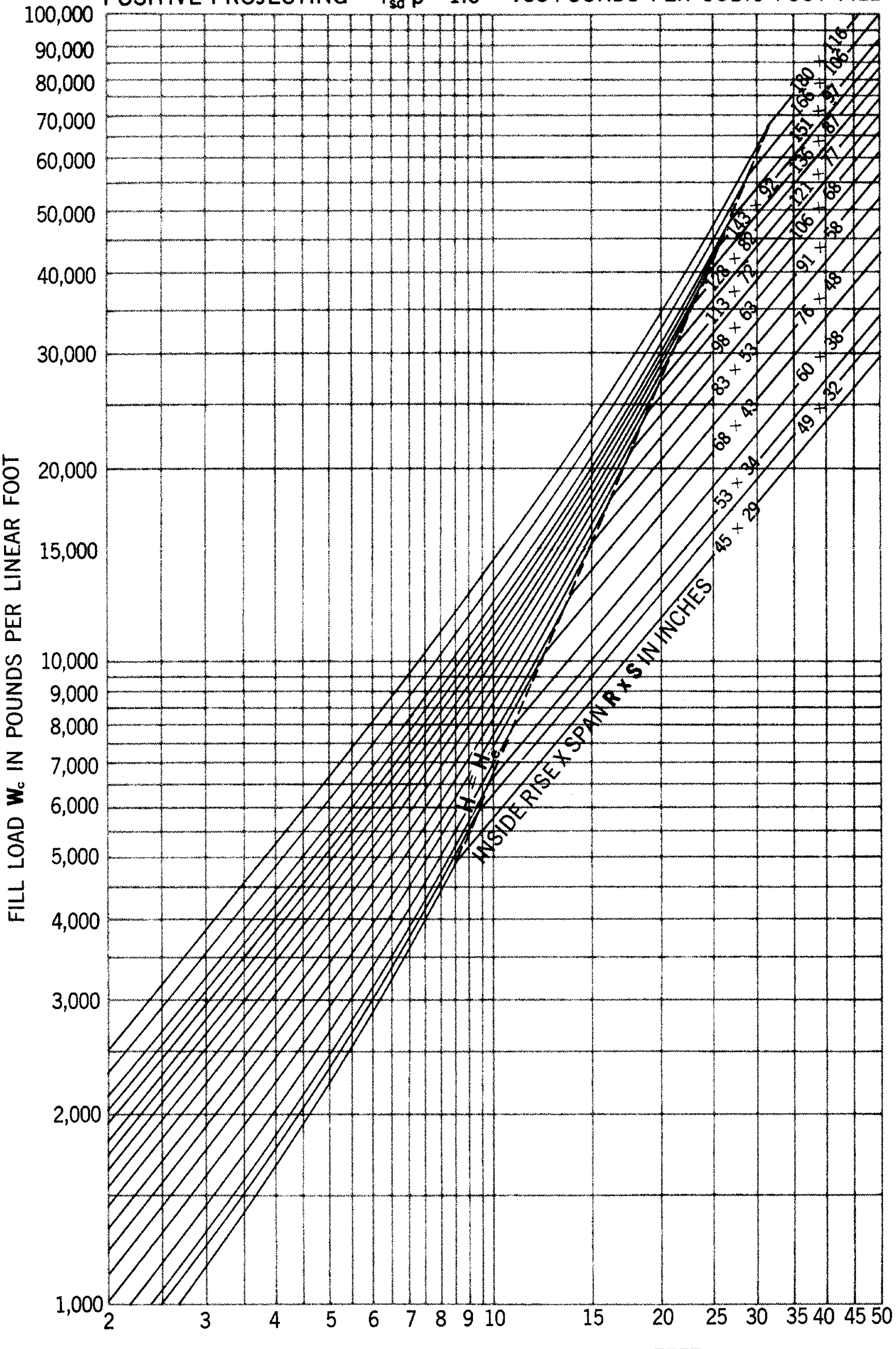


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 183

EMBANKMENT FILL LOADS ON VERTICAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 1.0$ **100** POUNDS PER CUBIC FOOT FILL

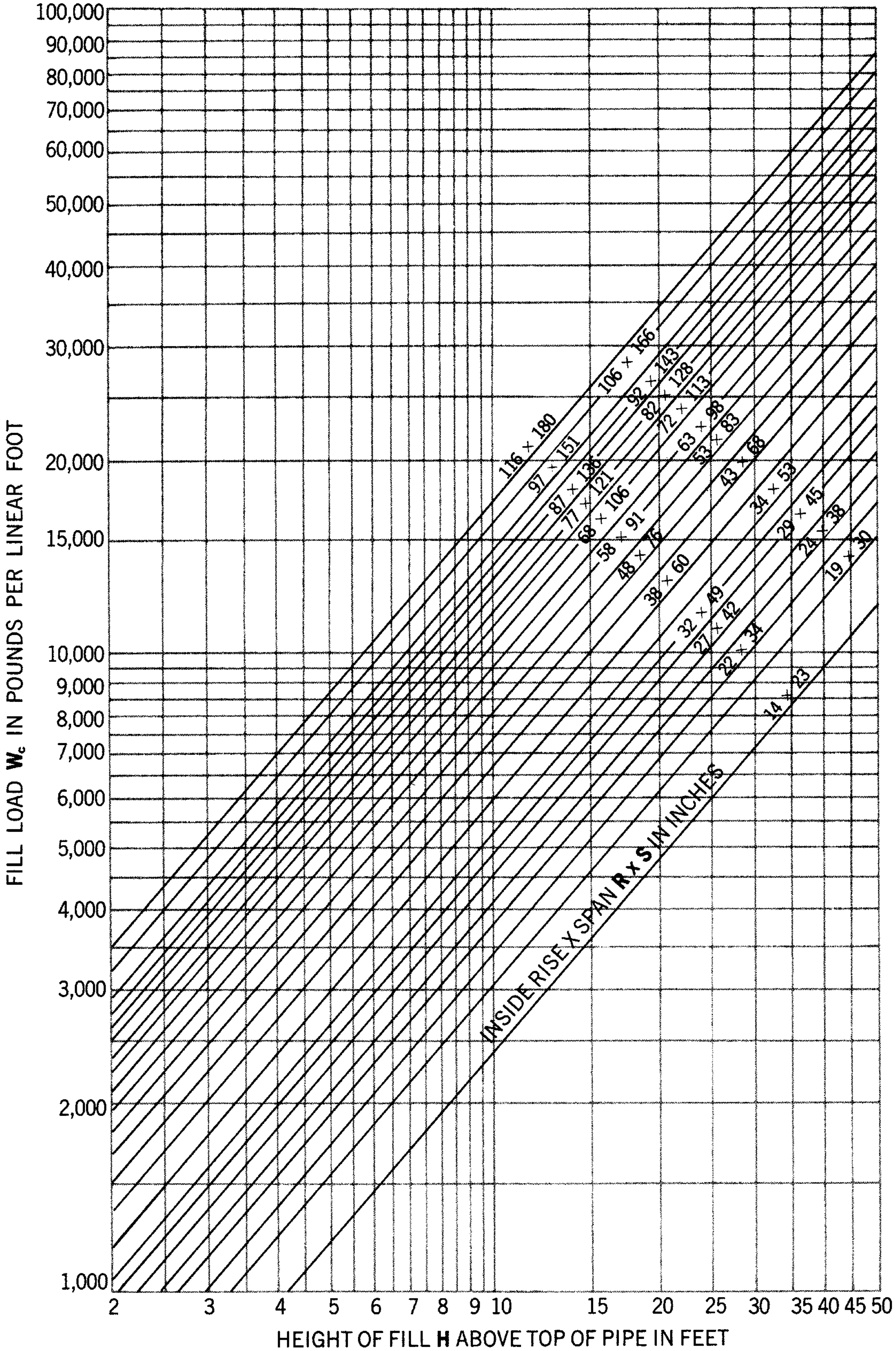


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase Interpolate for intermediate pipe sizes.

Figure 184

EMBANKMENT FILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0$ **100** POUNDS PER CUBIC FOOT FILL

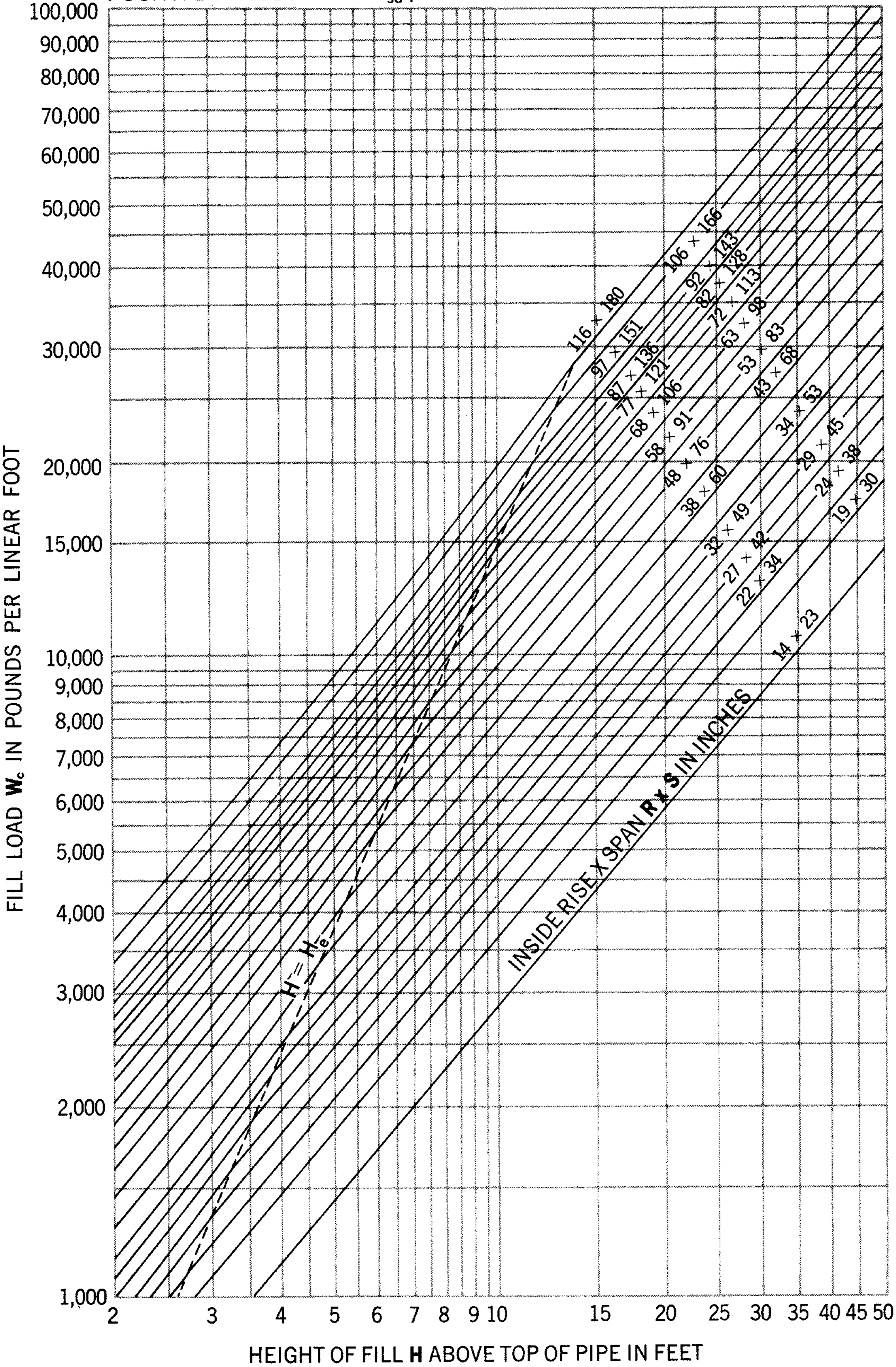


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 185

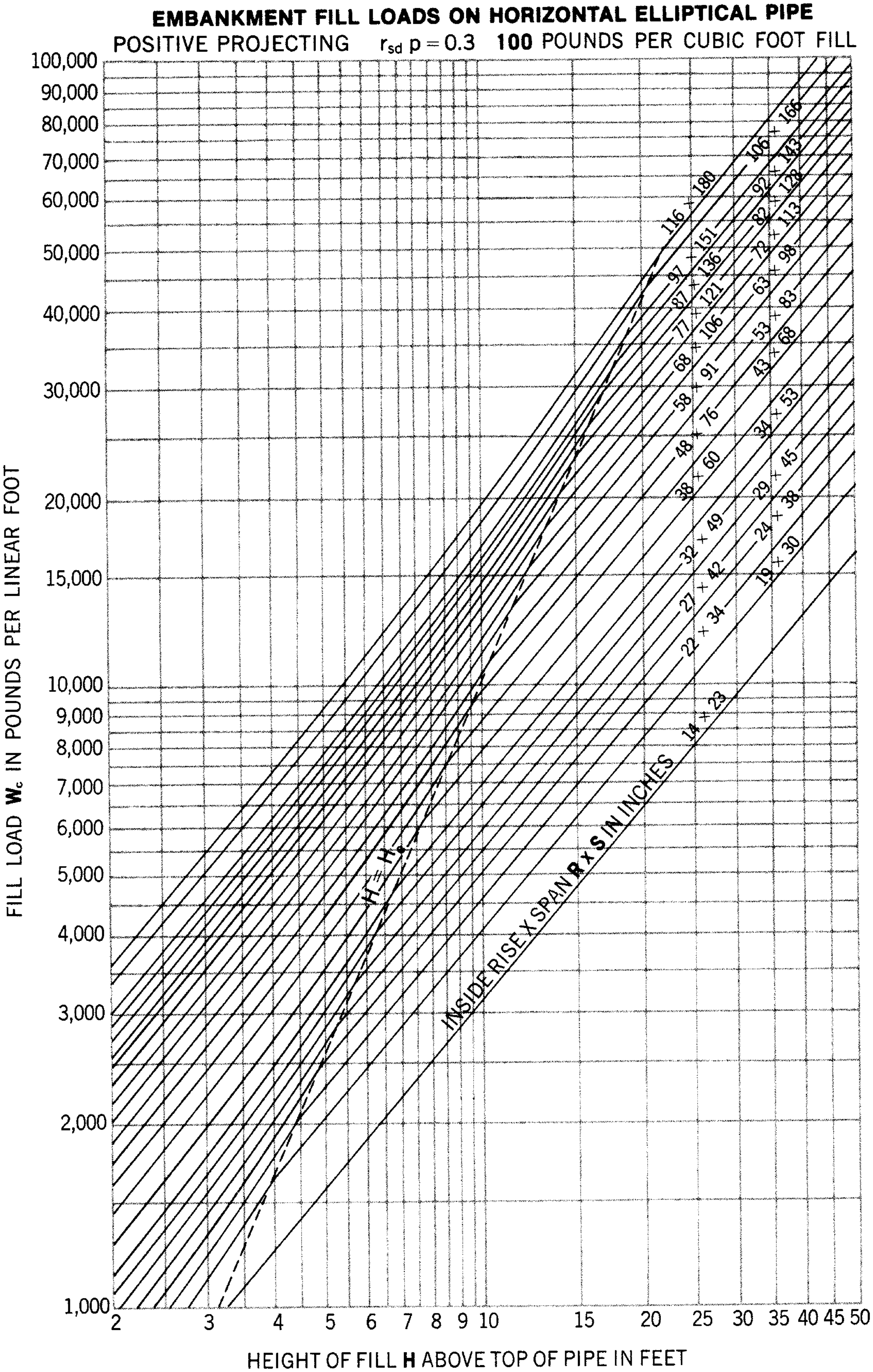
EMBANKMENT FILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.1$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 186

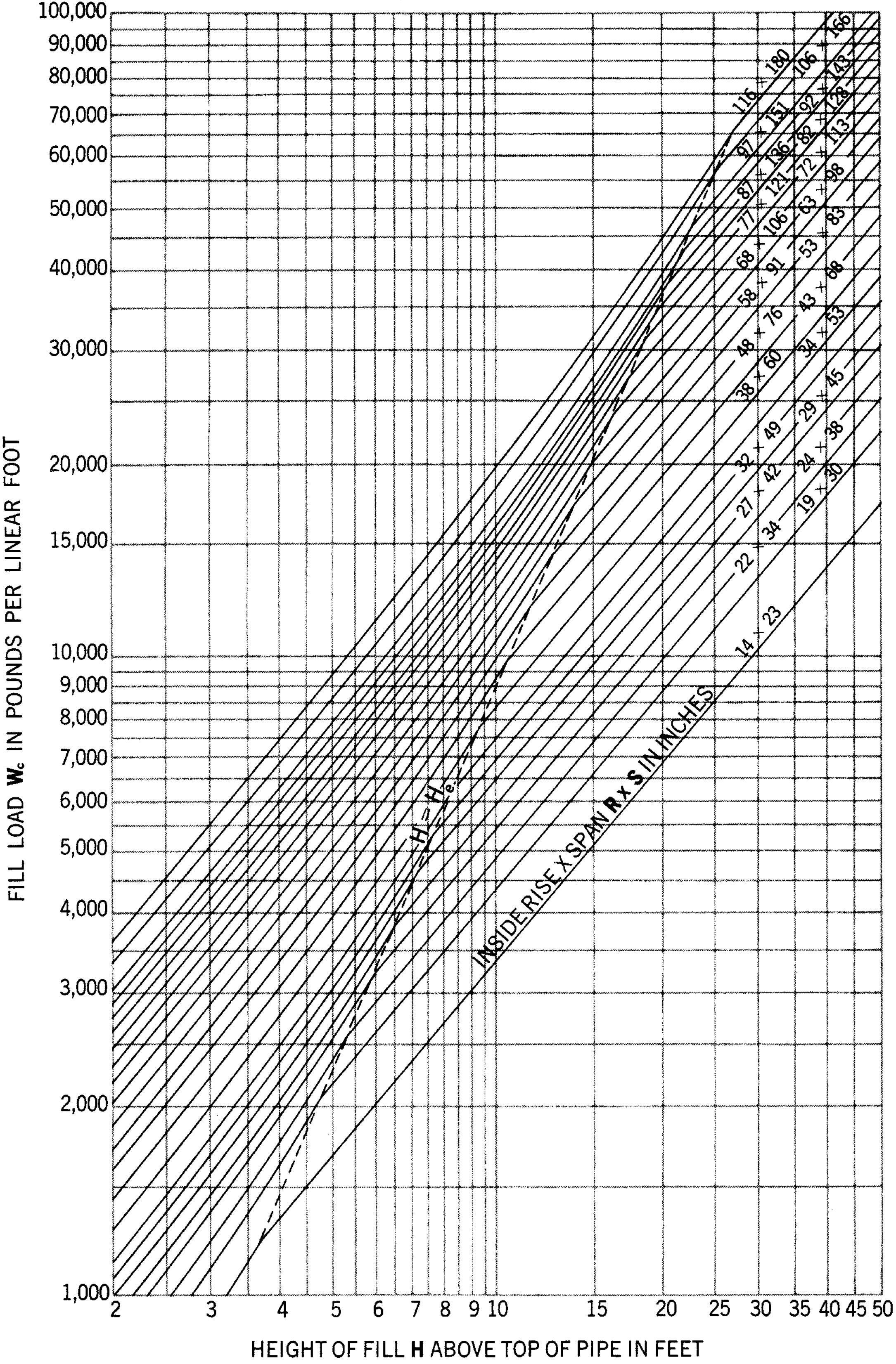


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 187

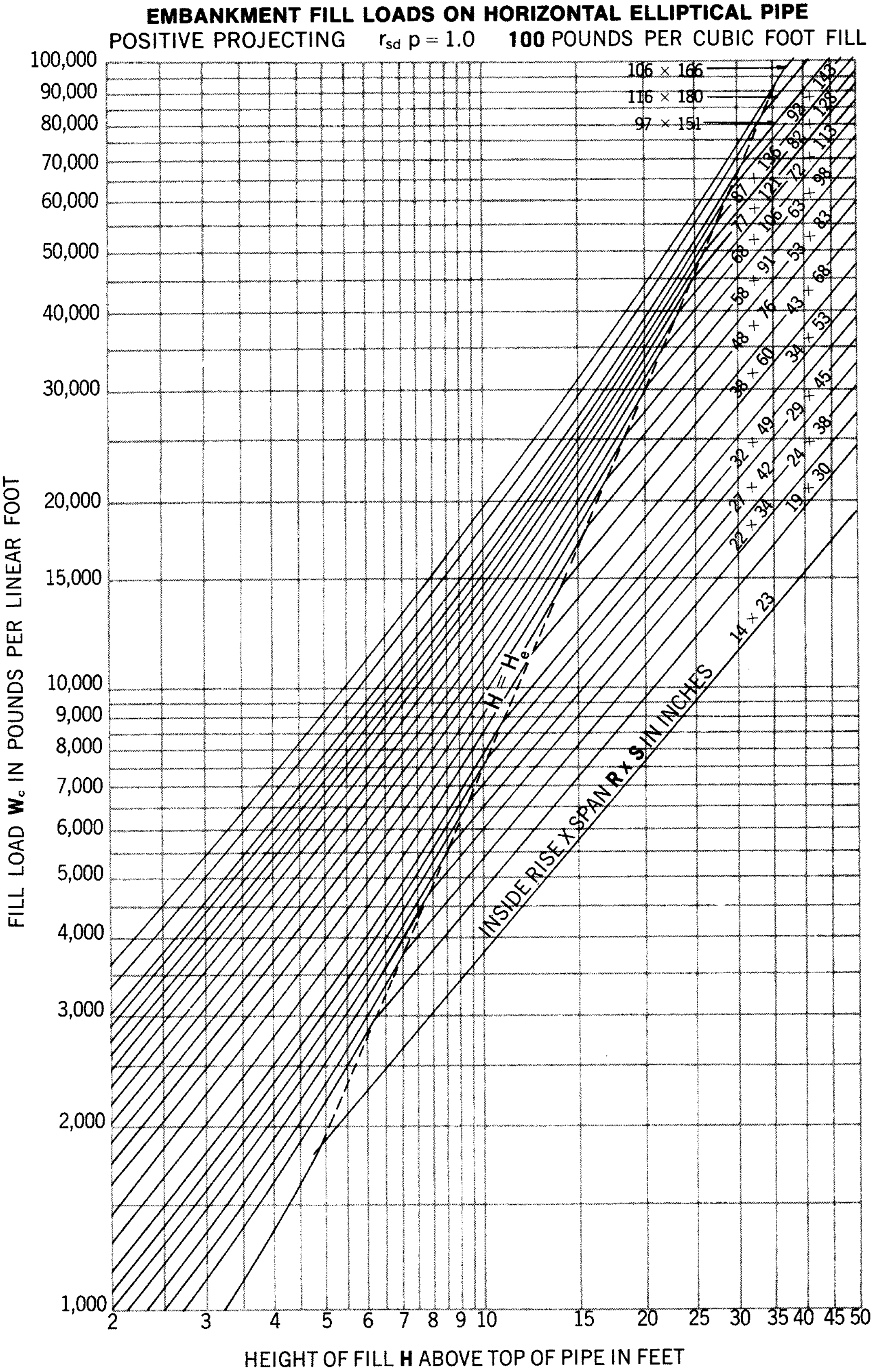
EMBANKMENT FILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.5$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 188



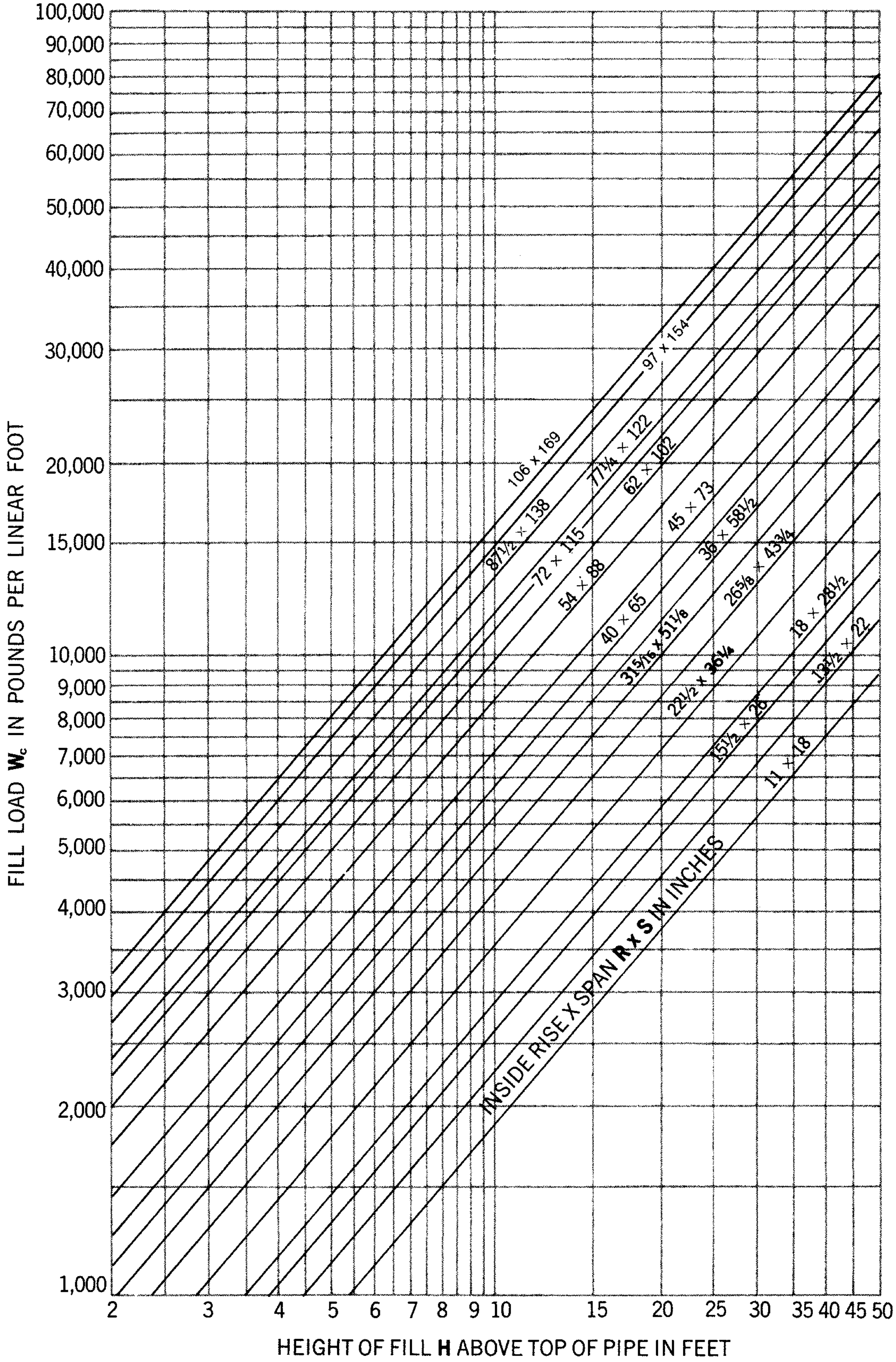
EMBANKMENT FILL LOADS ON HORIZONTAL ELLIPTICAL PIPE

For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 189

EMBANKMENT FILL LOADS ON ARCH PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0$ **100** POUNDS PER CUBIC FOOT FILL

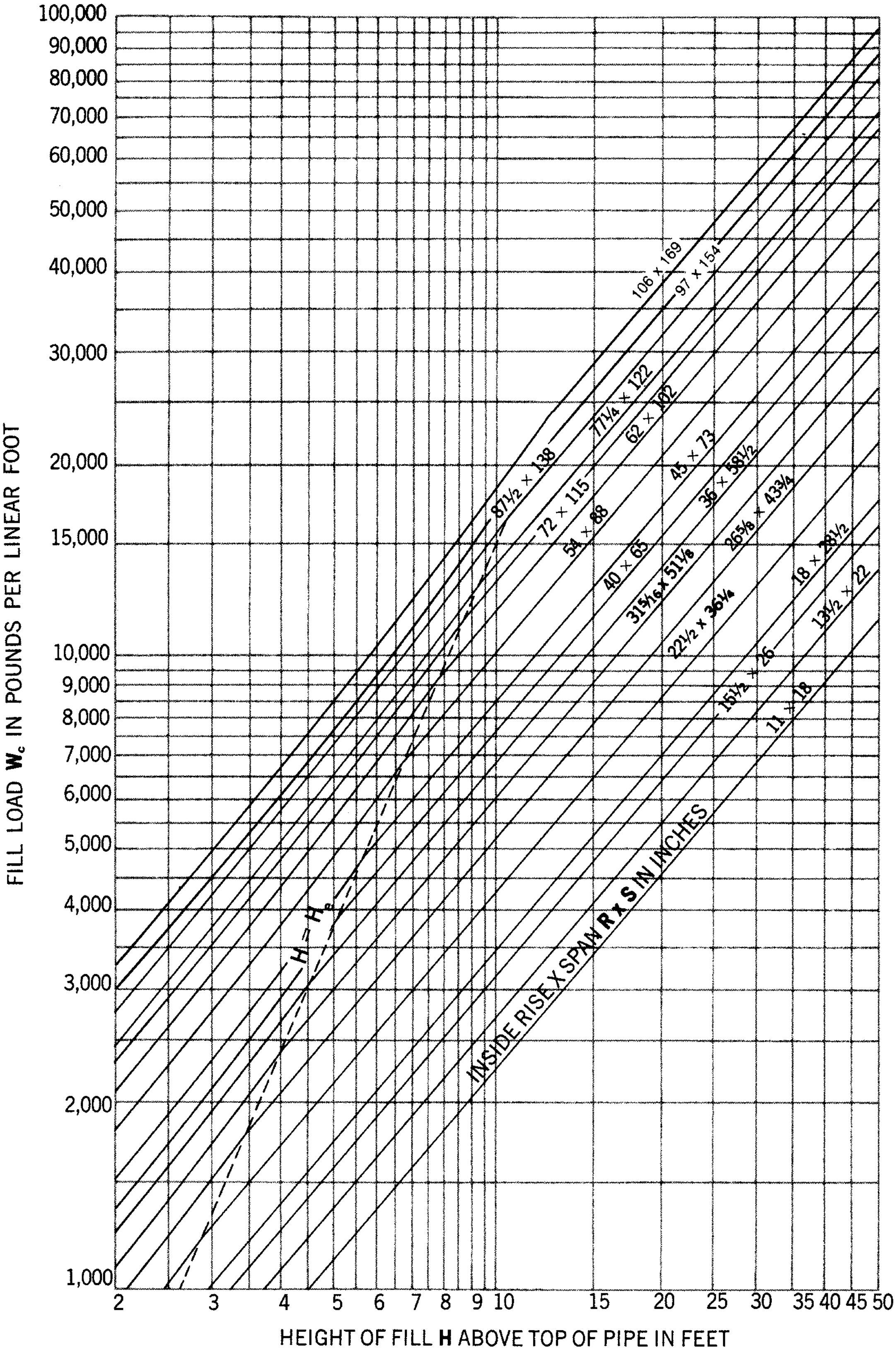


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 190

EMBANKMENT FILL LOADS ON ARCH PIPE

POSITIVE PROJECTING $r_{sd}p = 0.1$ **100** POUNDS PER CUBIC FOOT FILL

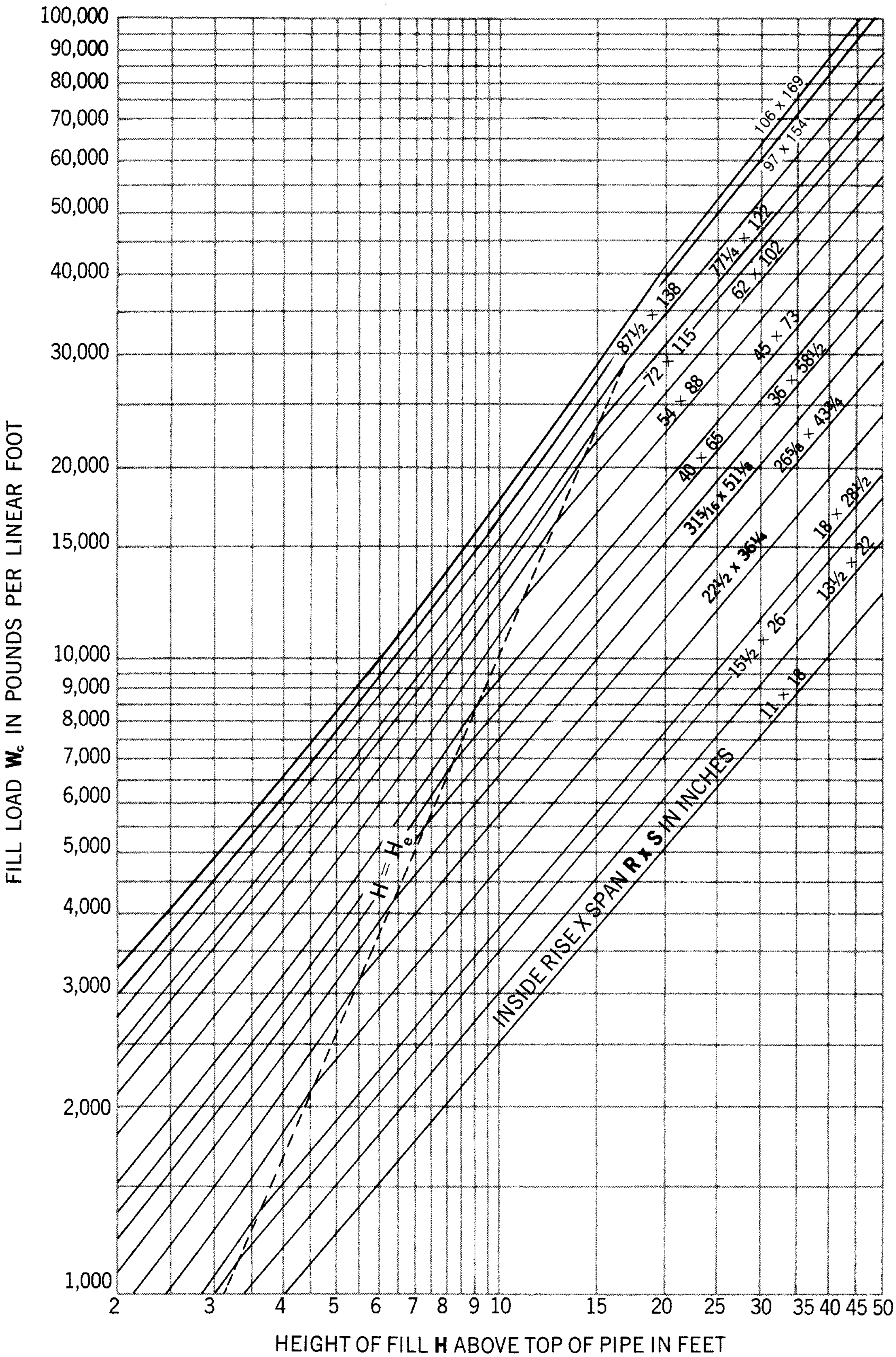


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 191

EMBANKMENT FILL LOADS ON ARCH PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.3$ **100** POUNDS PER CUBIC FOOT FILL

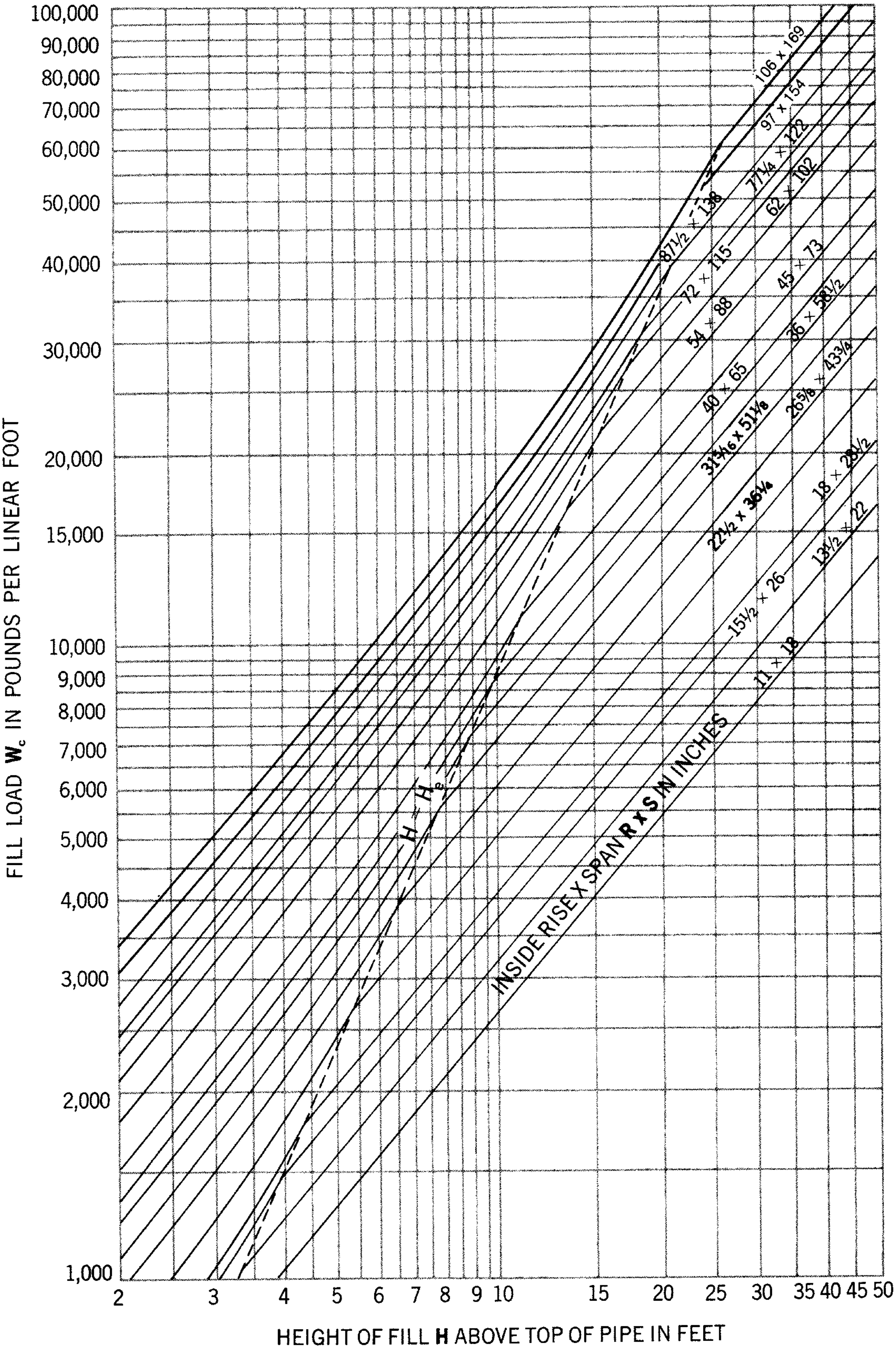


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 192

EMBANKMENT FILL LOADS ON ARCH PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.5$ **100** POUNDS PER CUBIC FOOT FILL

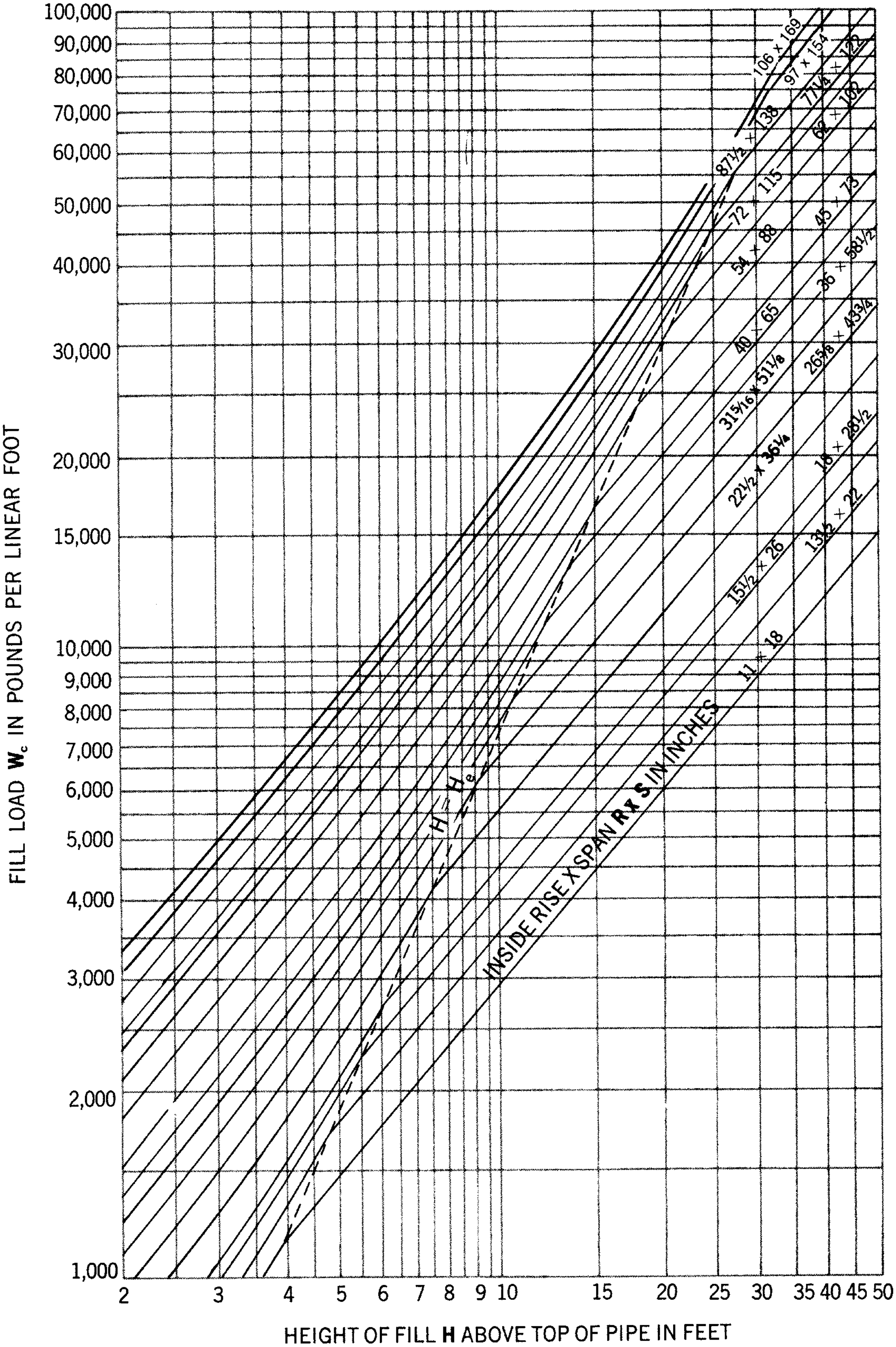


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 193

EMBANKMENT FILL LOADS ON ARCH PIPE

POSITIVE PROJECTING $r_{sd}p = 1.0$ **100** POUNDS PER CUBIC FOOT FILL

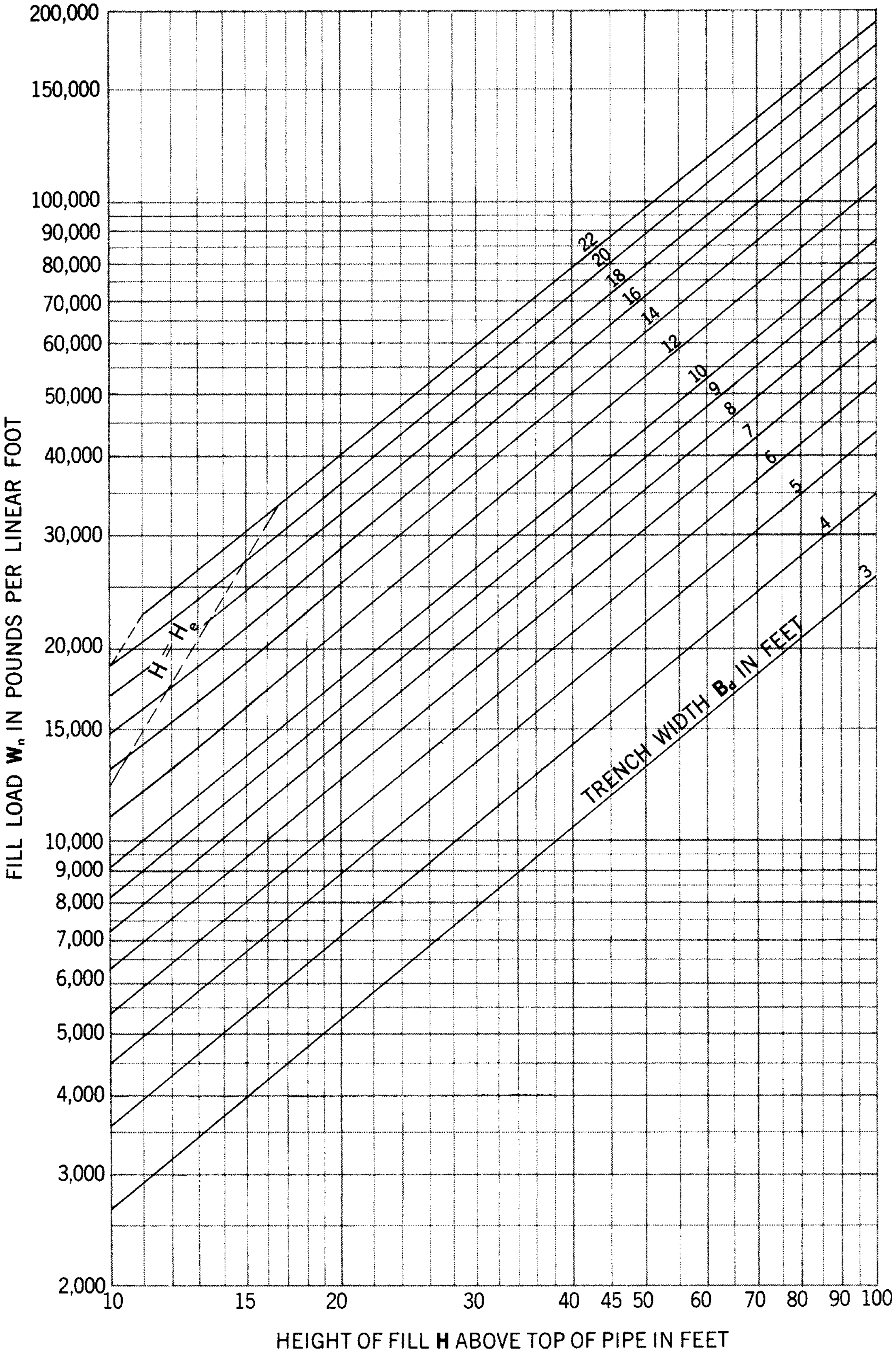


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure 194

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 0.5$ $r_{sd} = 0$ **100** POUNDS PER CUBIC FOOT FILL

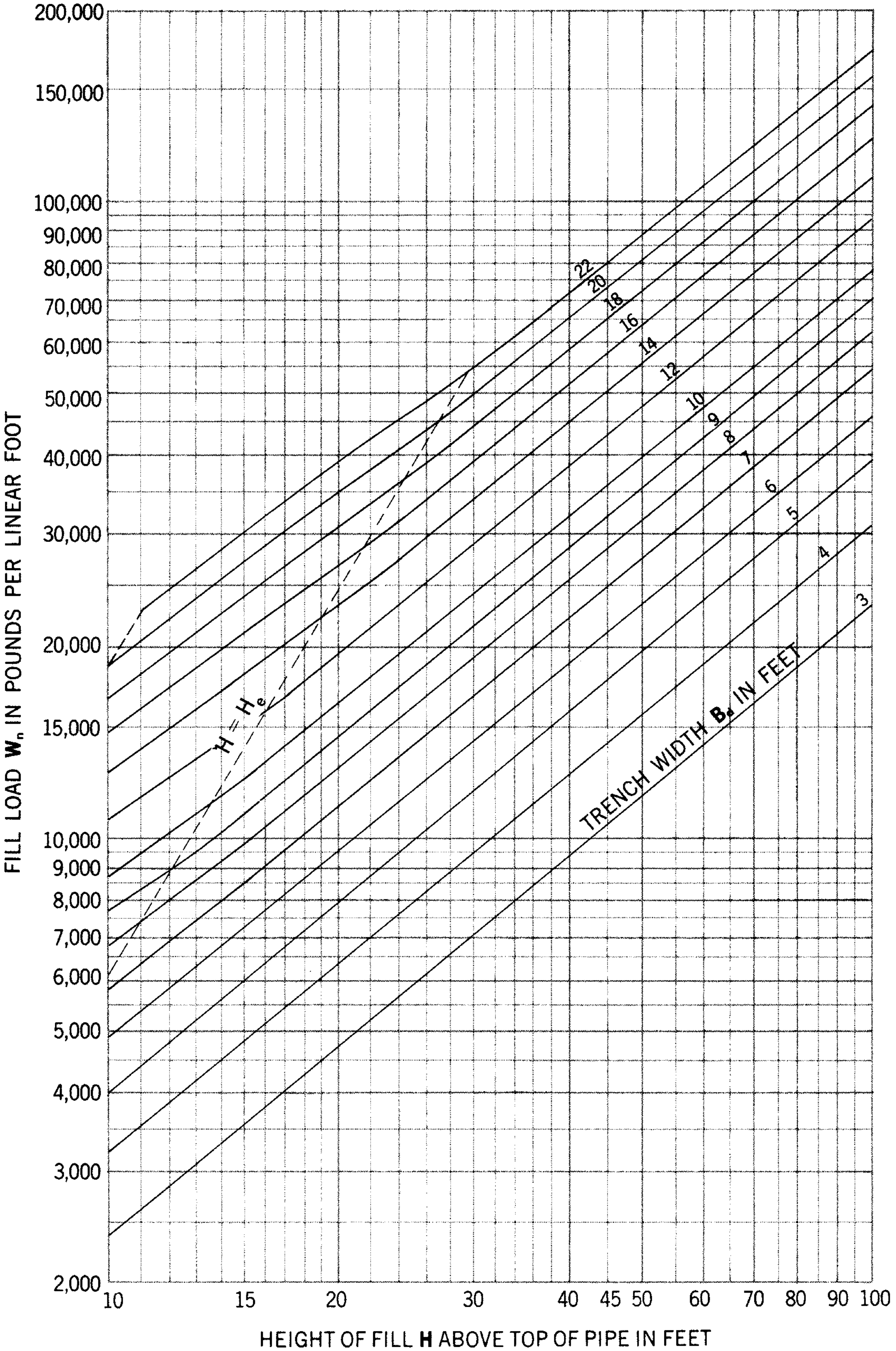


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 195

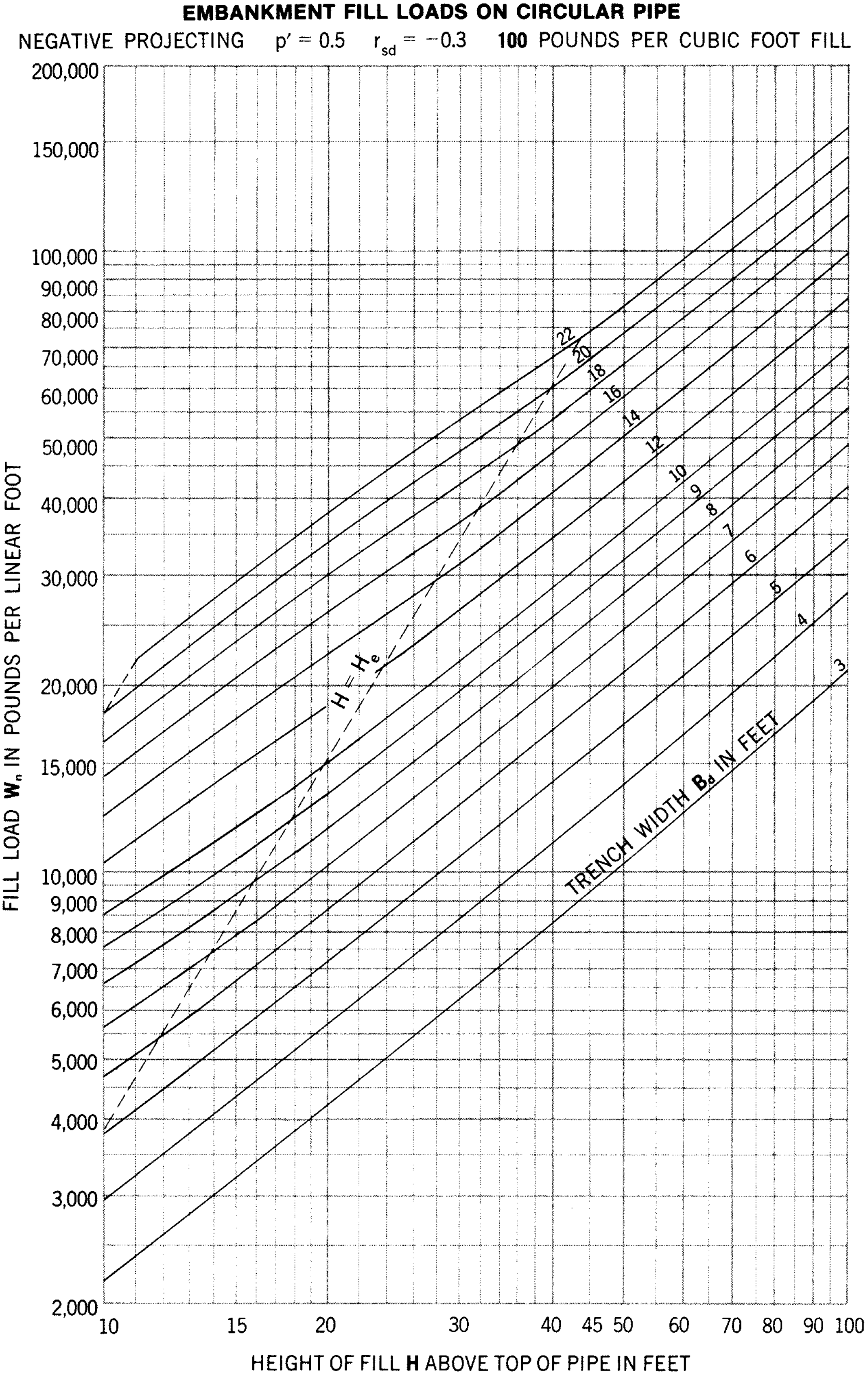
EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 0.5$ $r_{sd} = -0.1$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 196

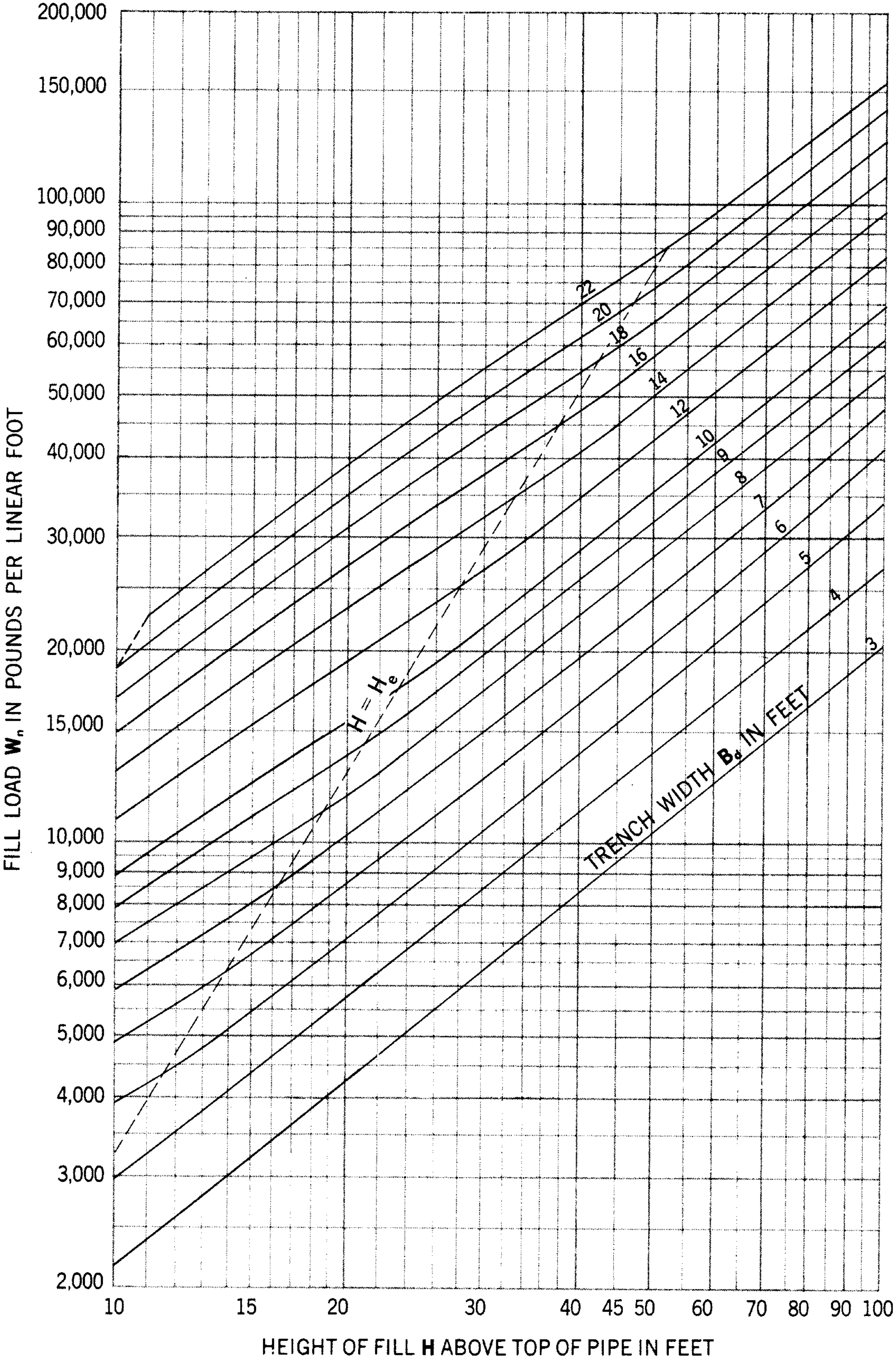


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 197

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 0.5$ $r_{sd} = -0.5$ **100** POUNDS PER CUBIC FOOT FILL

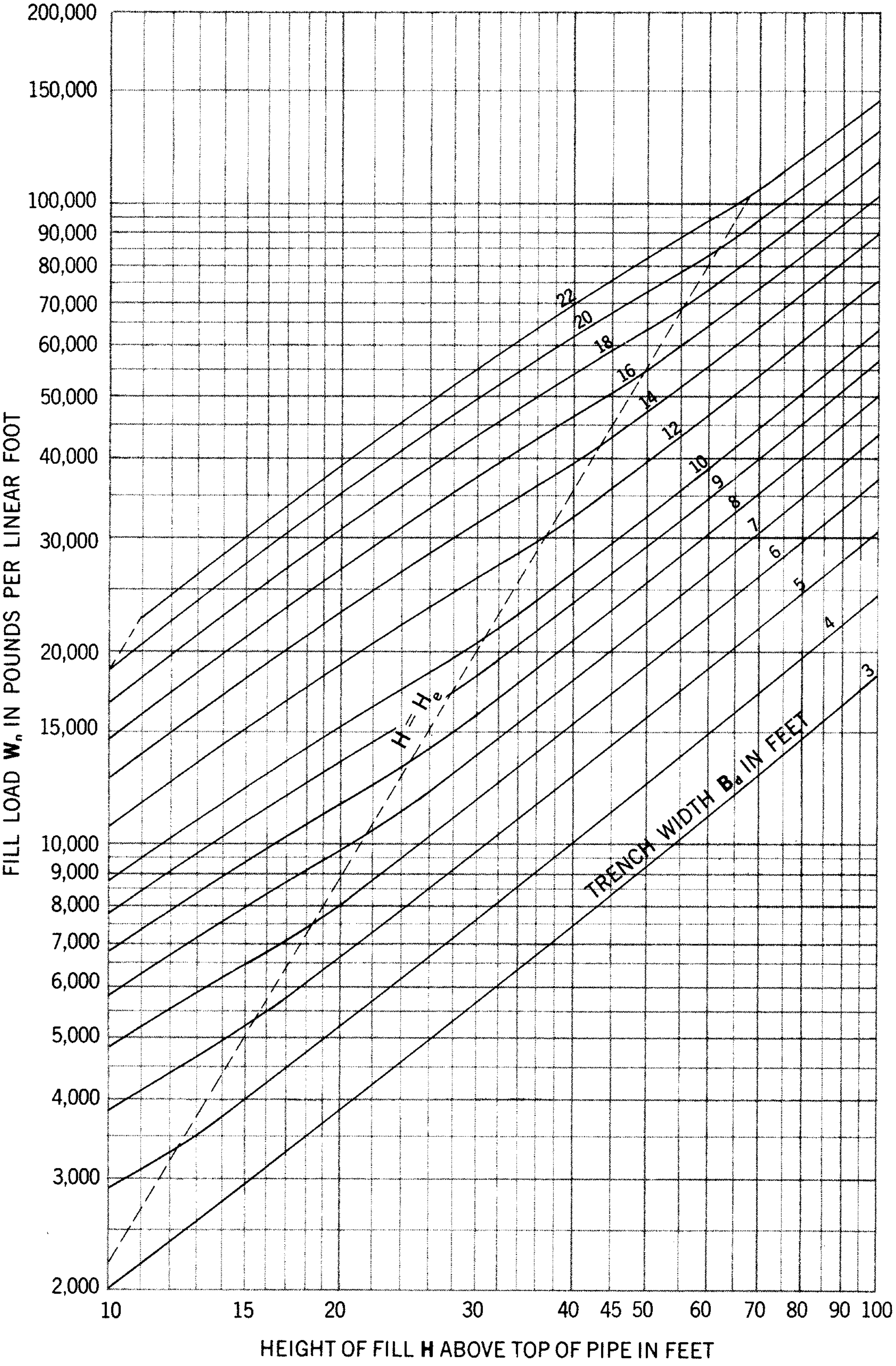


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 198

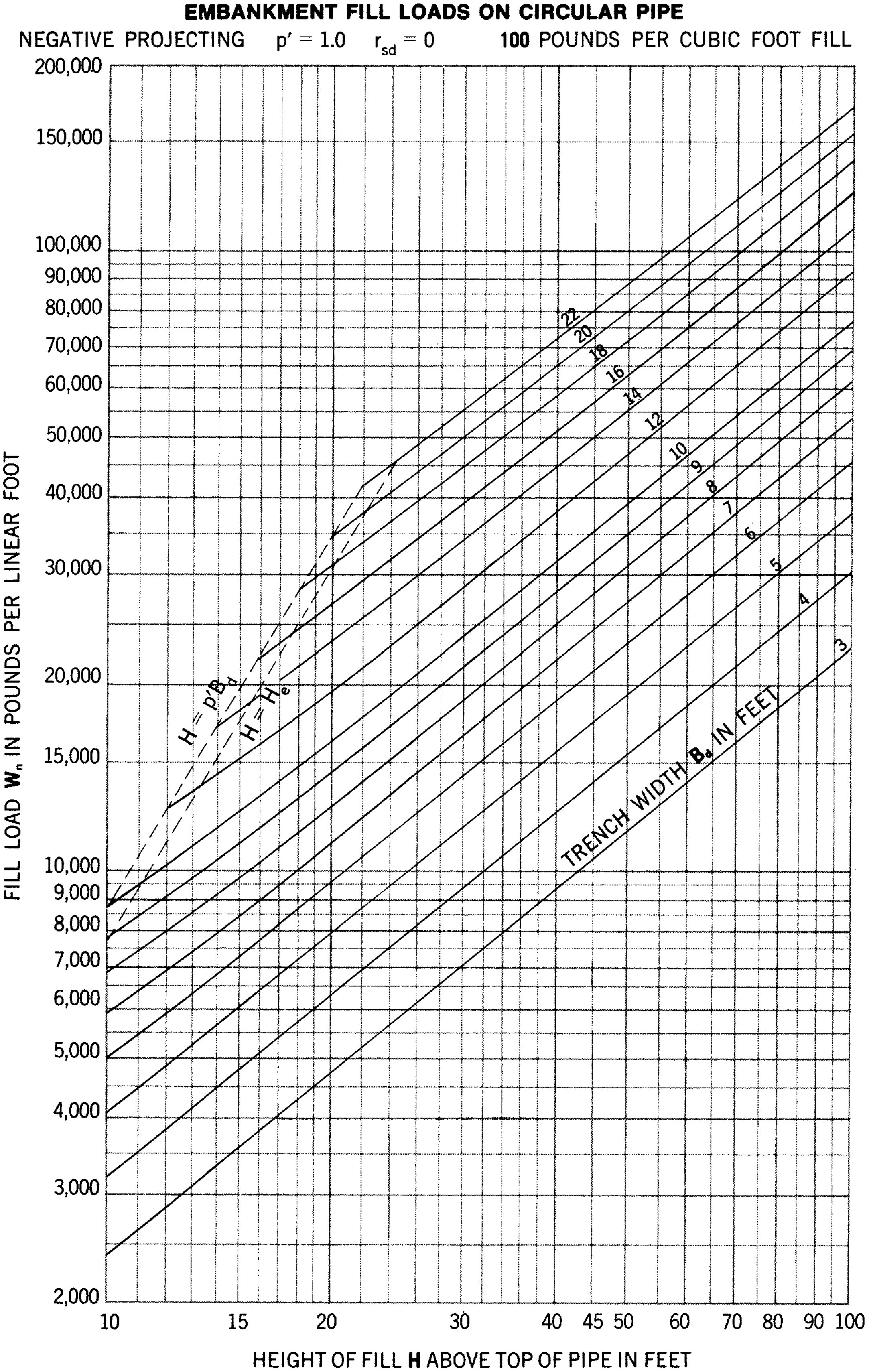
EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 0.5$ $r_{sd} = -1.0$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 199

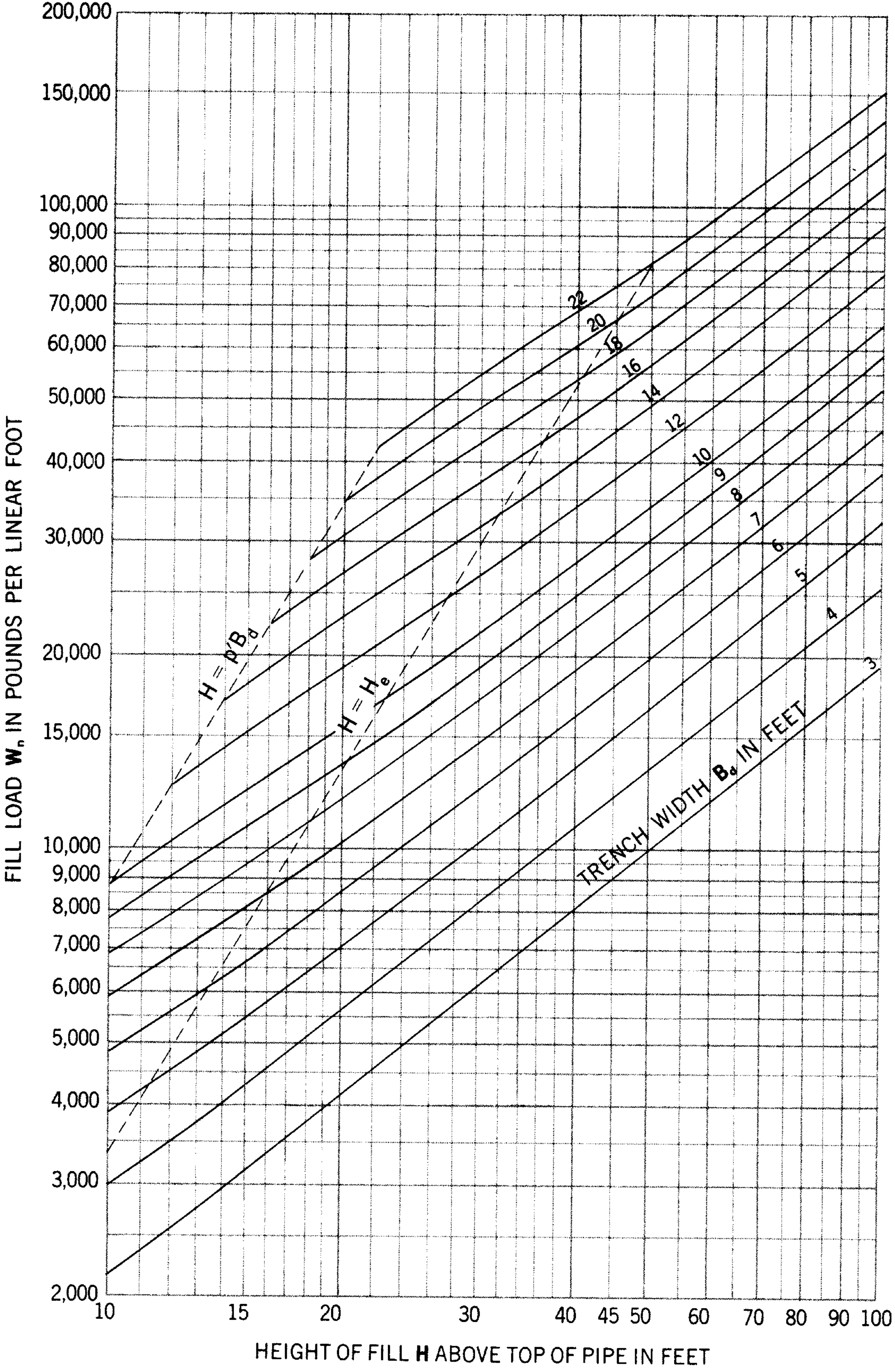


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 200

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.0$ $r_{sd} = -0.1$ **100** POUNDS PER CUBIC FOOT FILL

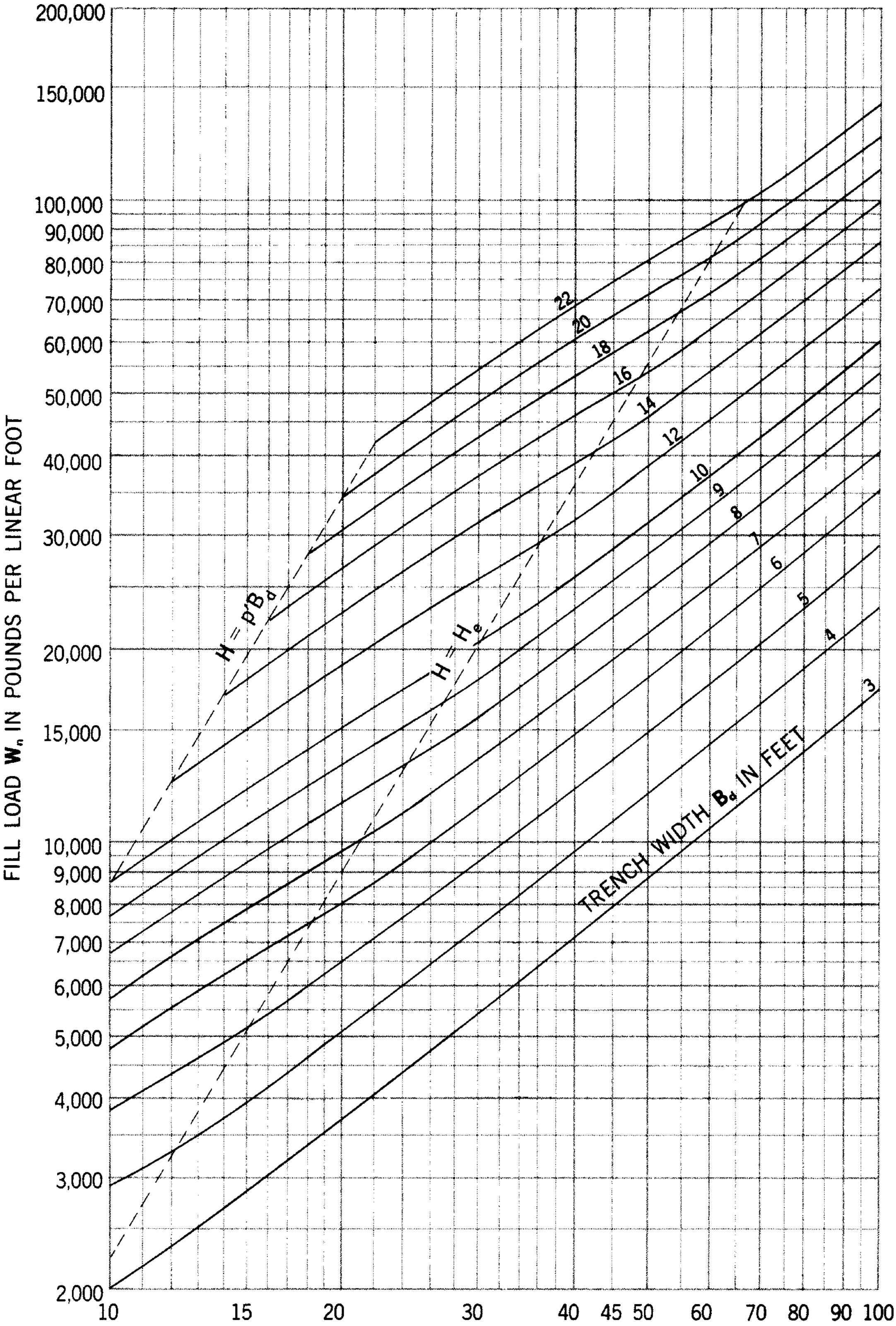


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 201

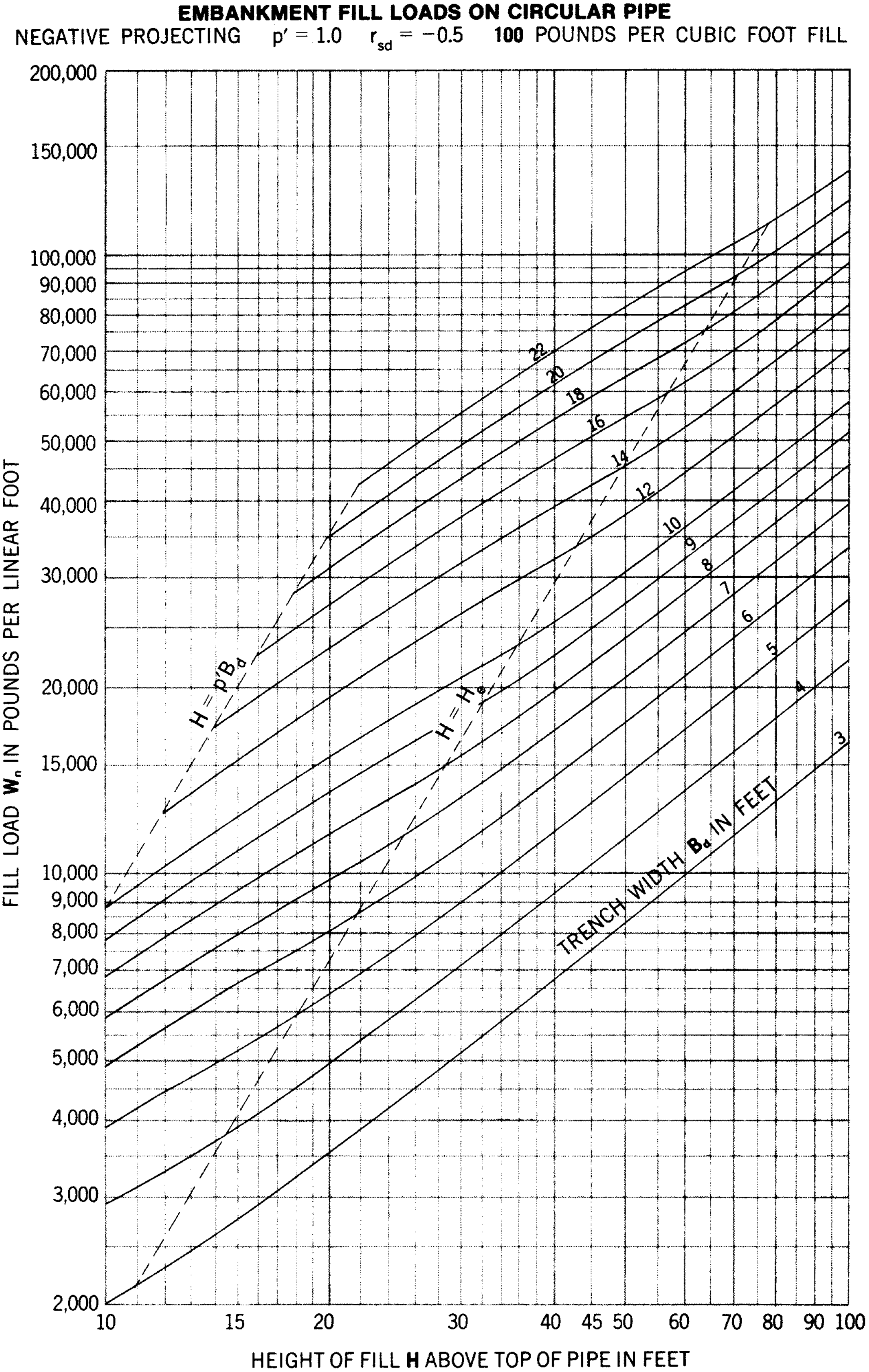
EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.0$ $r_{sd} = -0.3$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 202

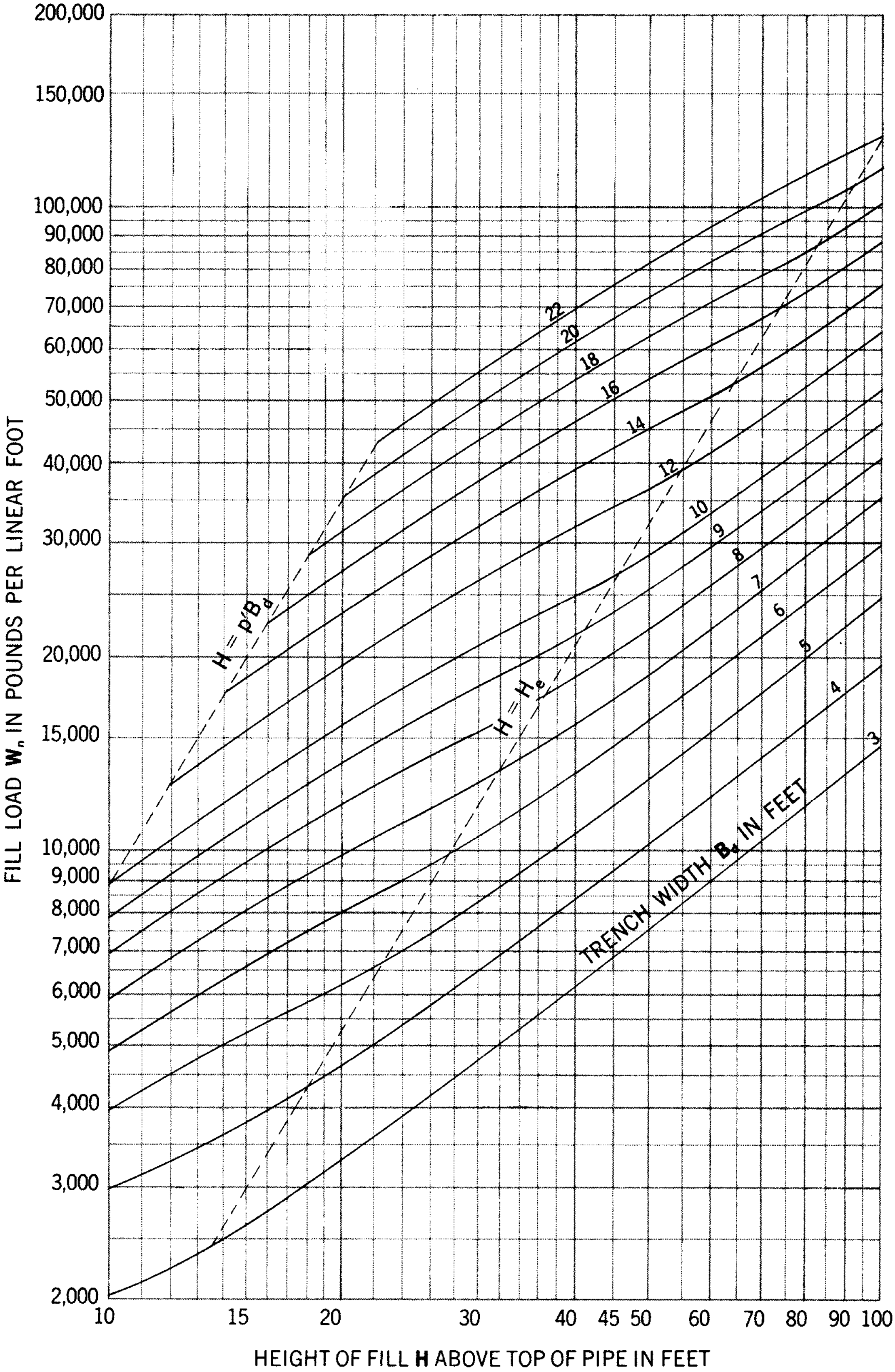


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 203

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.0$ $r_{sd} = -1.0$ **100** POUNDS PER CUBIC FOOT FILL

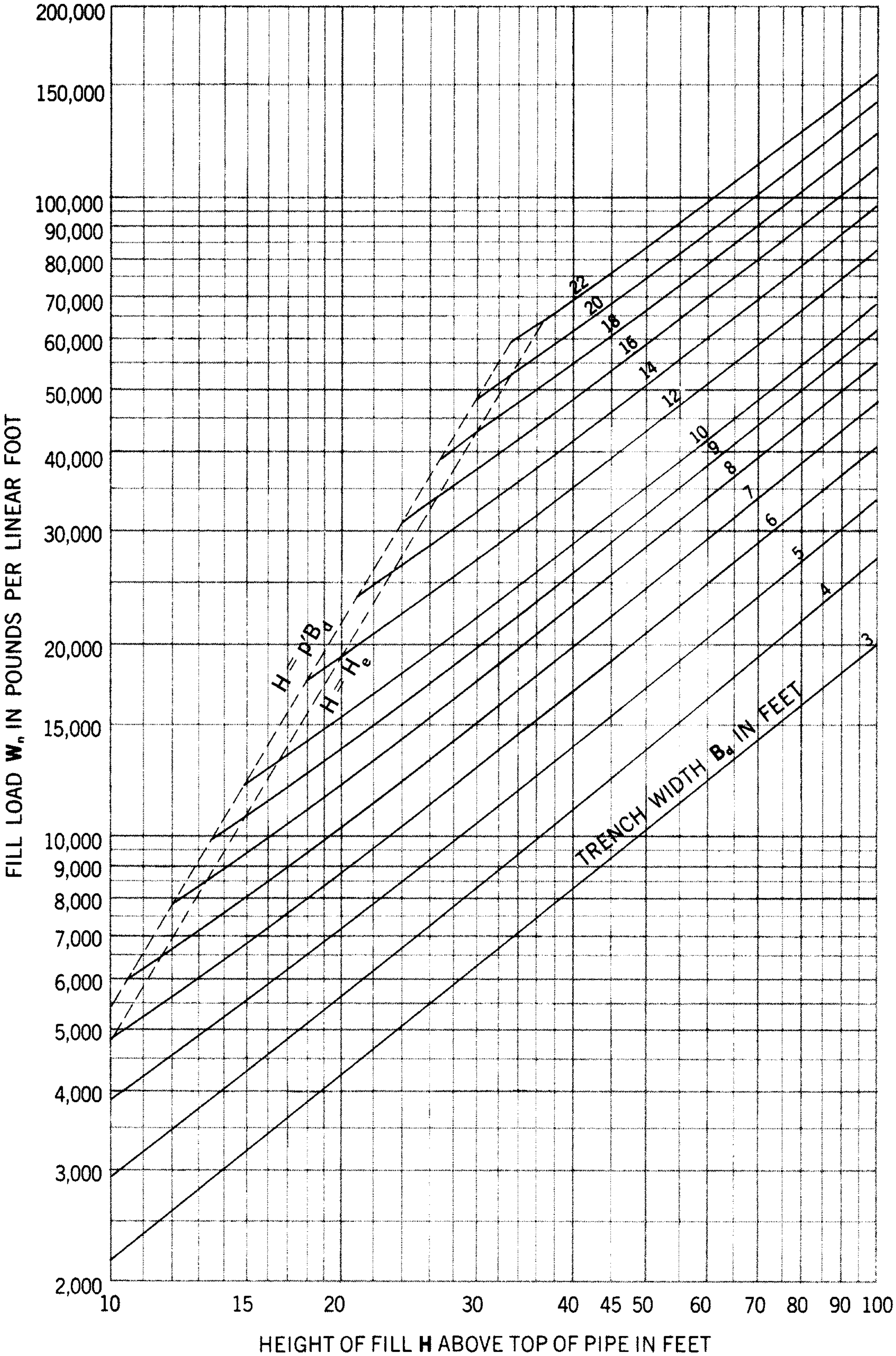


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 204

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.5$ $r_{sd} = 0$ **100** POUNDS PER CUBIC FOOT FILL

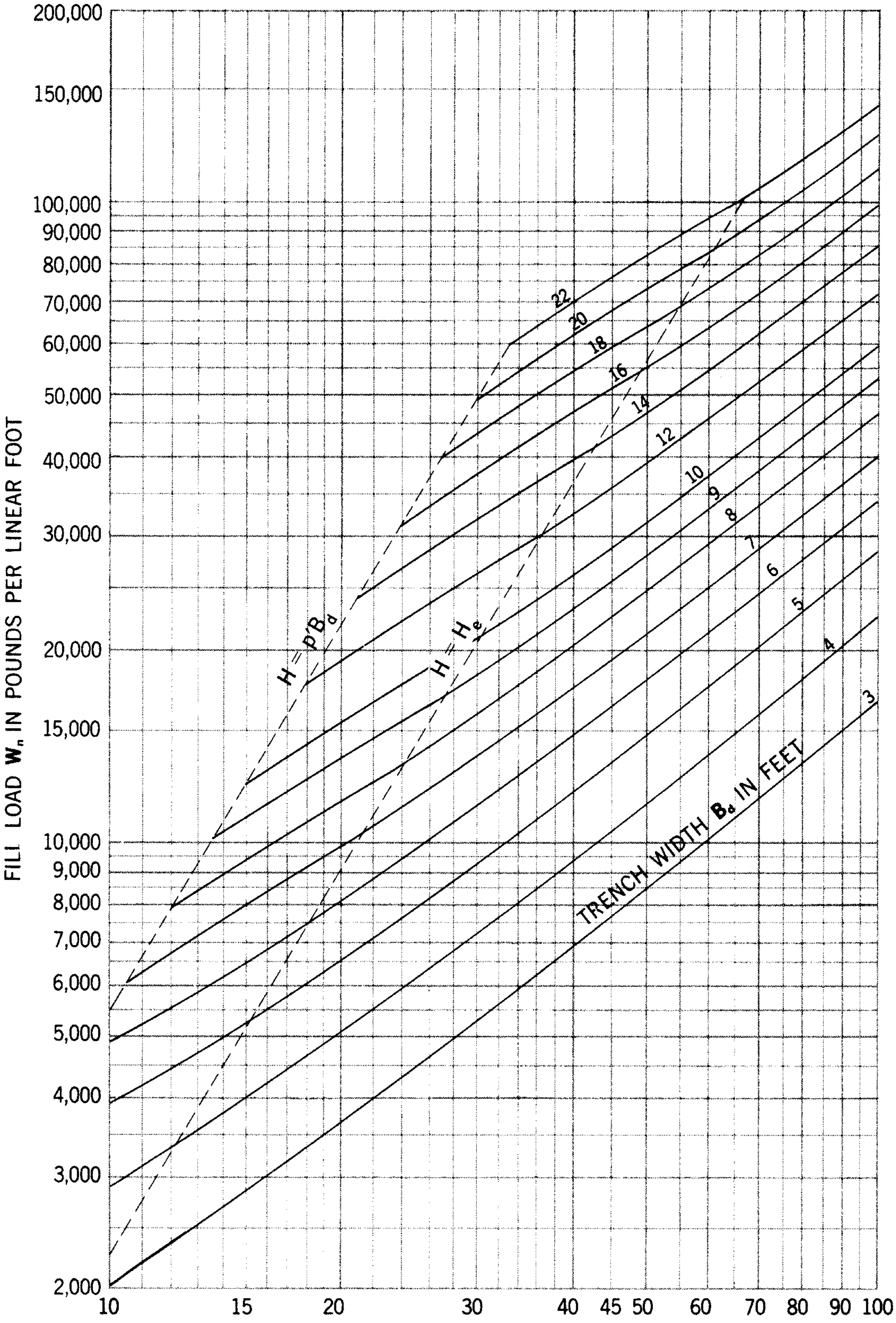


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 205

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.5$ $r_{sd} = -0.1$ **100** POUNDS PER CUBIC FOOT FILL

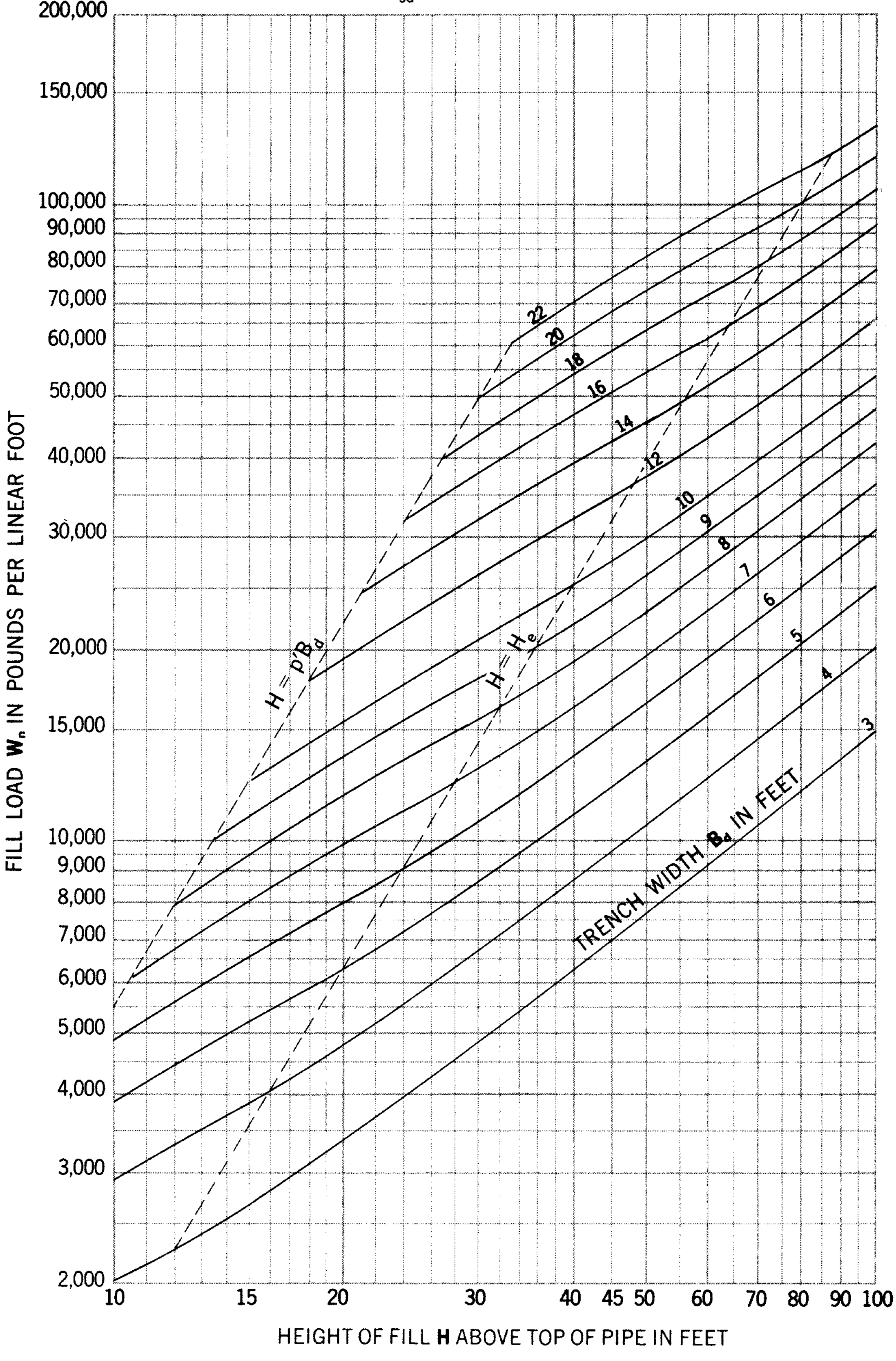


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 206

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.5$ $r_{sd} = -0.3$ **100** POUNDS PER CUBIC FOOT FILL

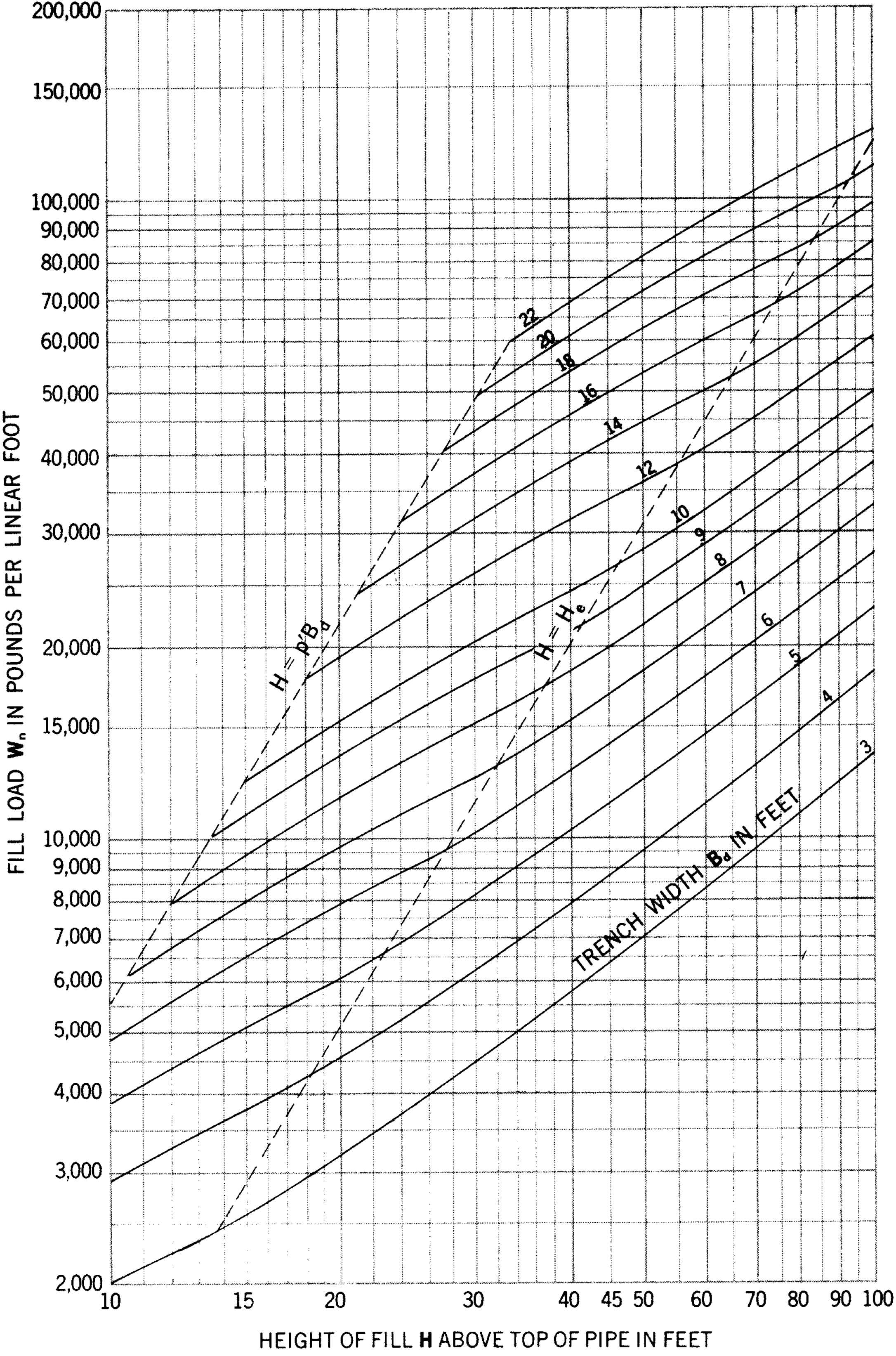


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 207

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.5$ $r_{sd} = -0.5$ **100** POUNDS PER CUBIC FOOT FILL

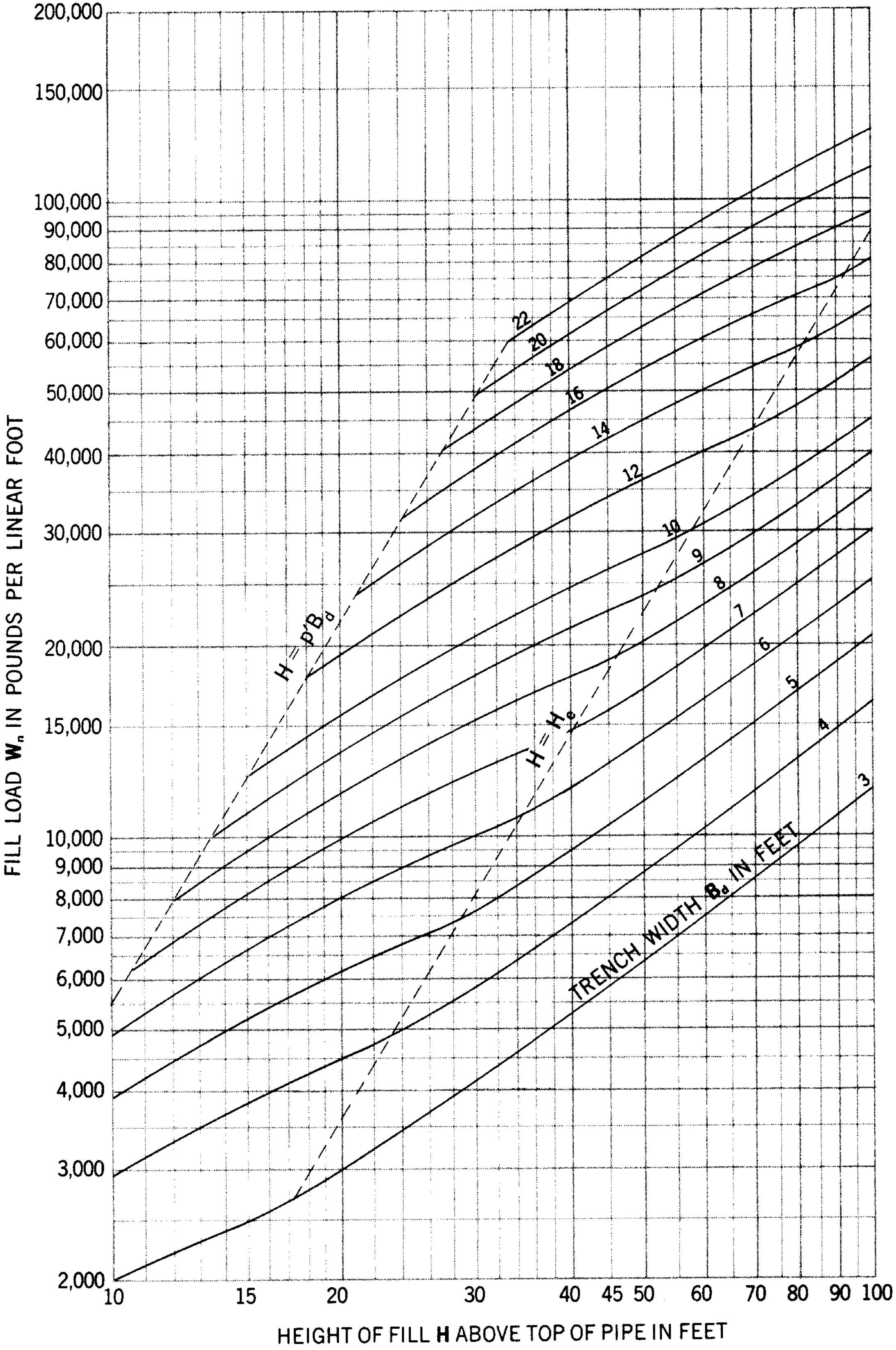


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 208

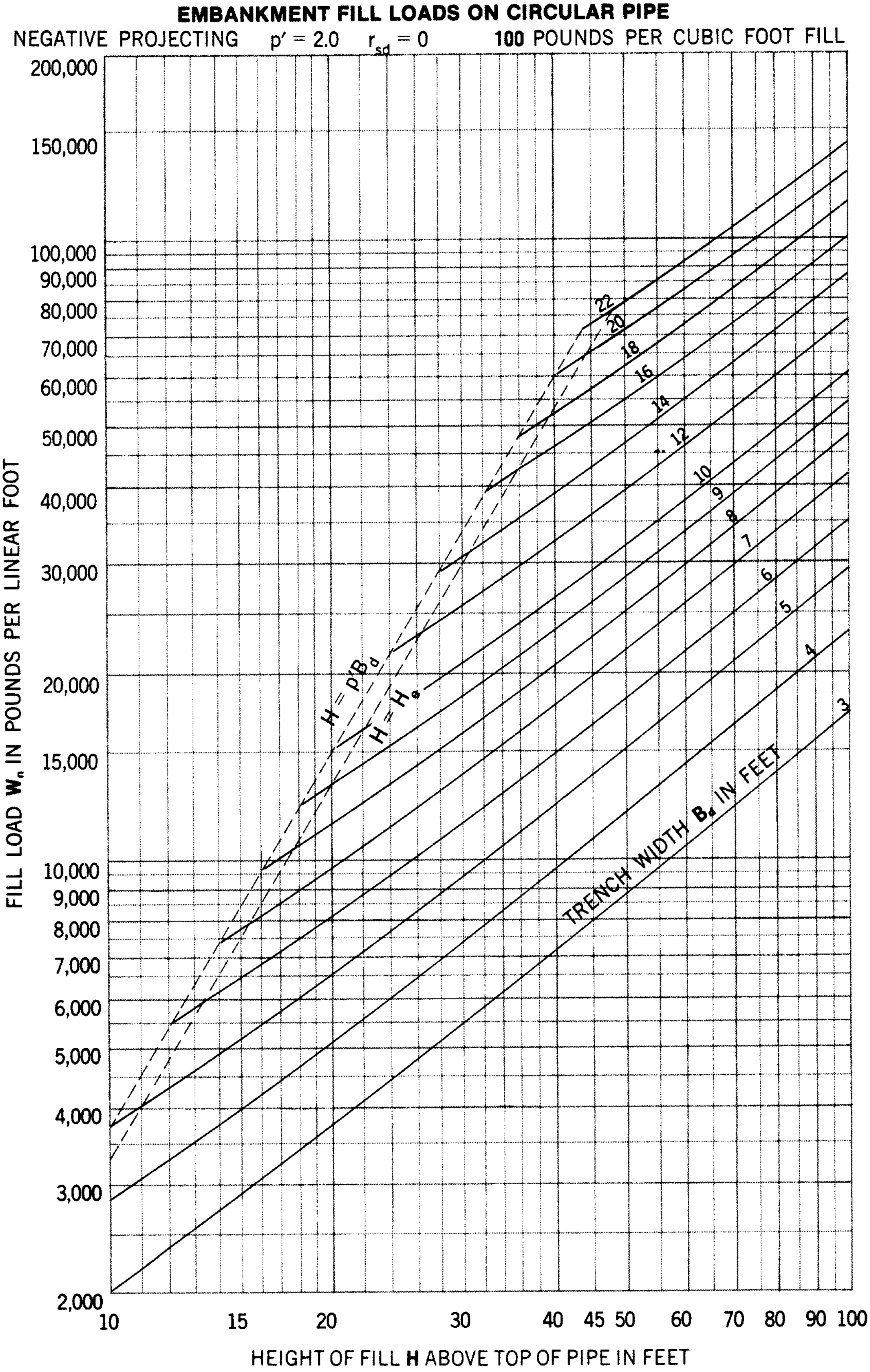
EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 1.5$ $r_{sd} = -1.0$ **100** POUNDS PER CUBIC FOOT FILL



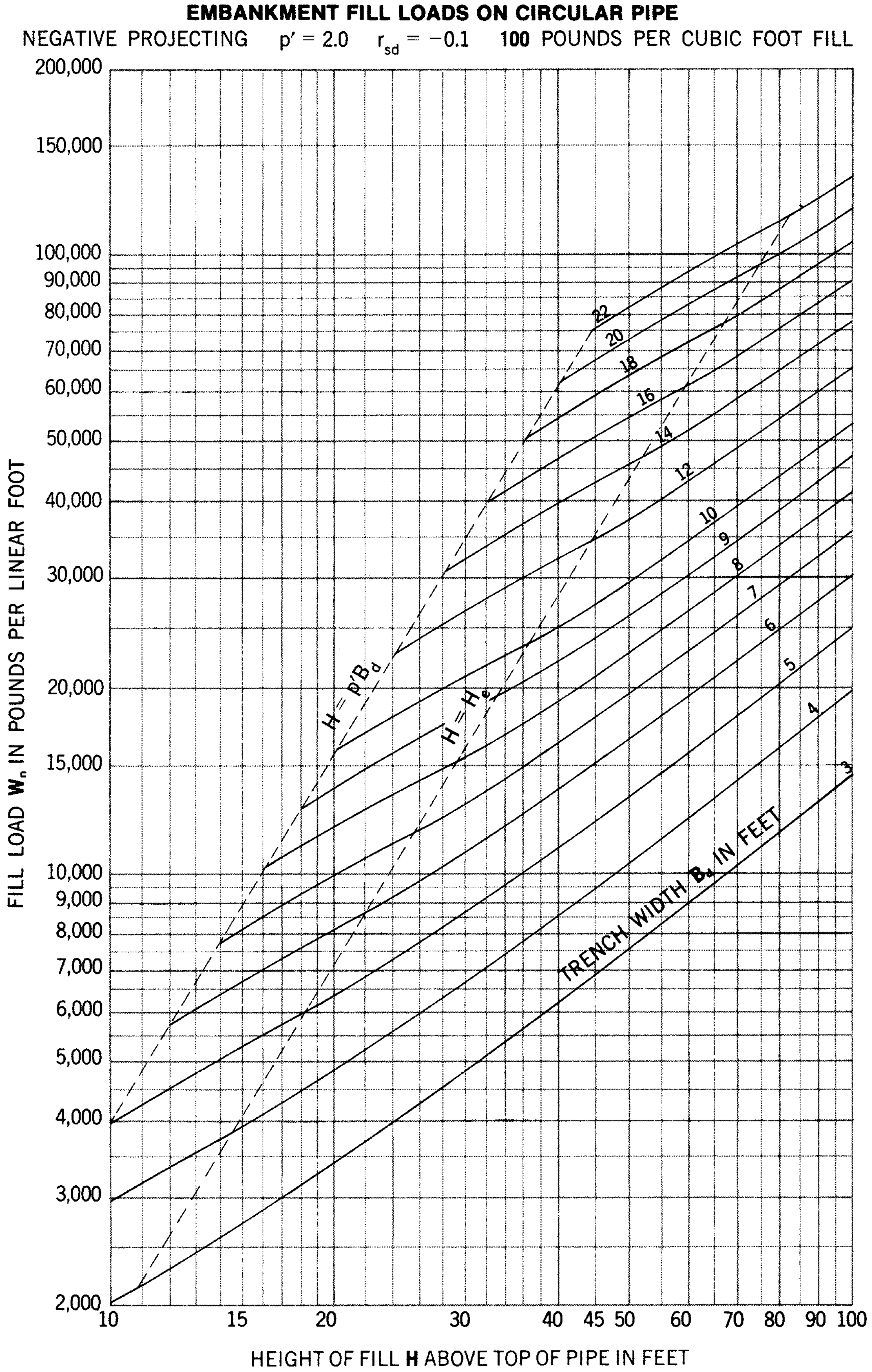
For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 209



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 210

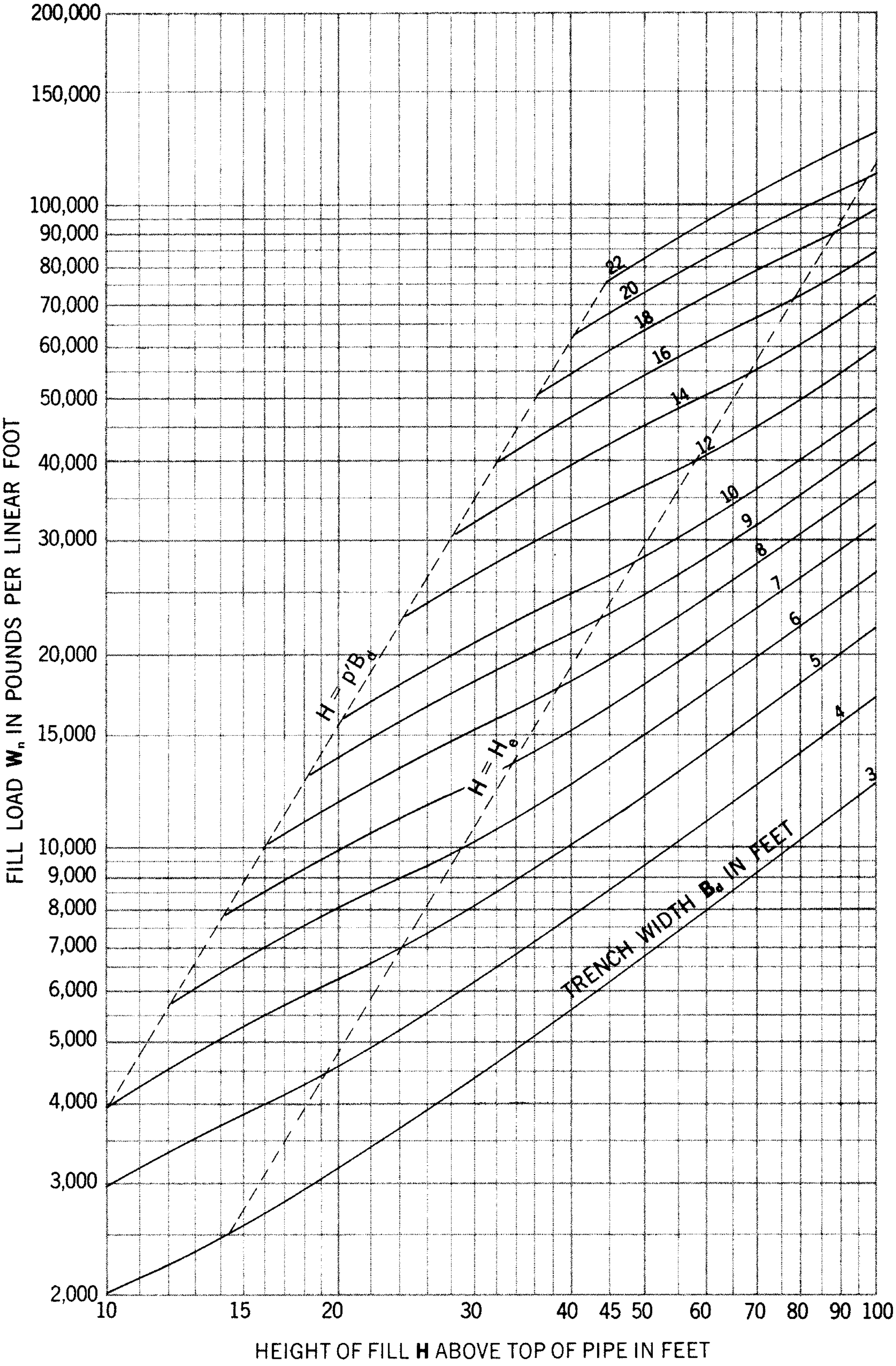


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 211

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 2.0$ $r_{sd} = -0.3$ **100** POUNDS PER CUBIC FOOT FILL

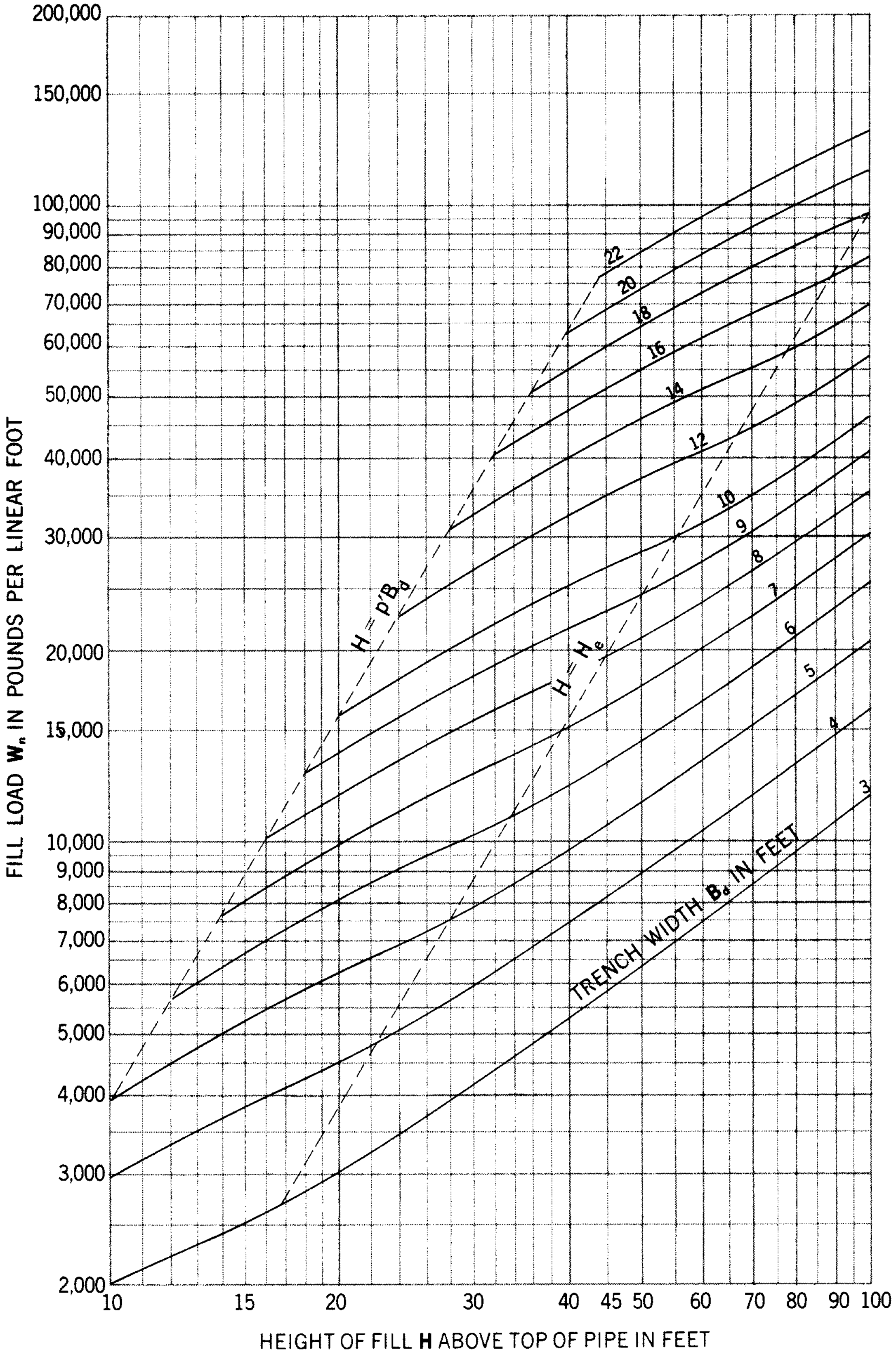


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 212

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 2.0$ $r_{sd} = -0.5$ **100** POUNDS PER CUBIC FOOT FILL

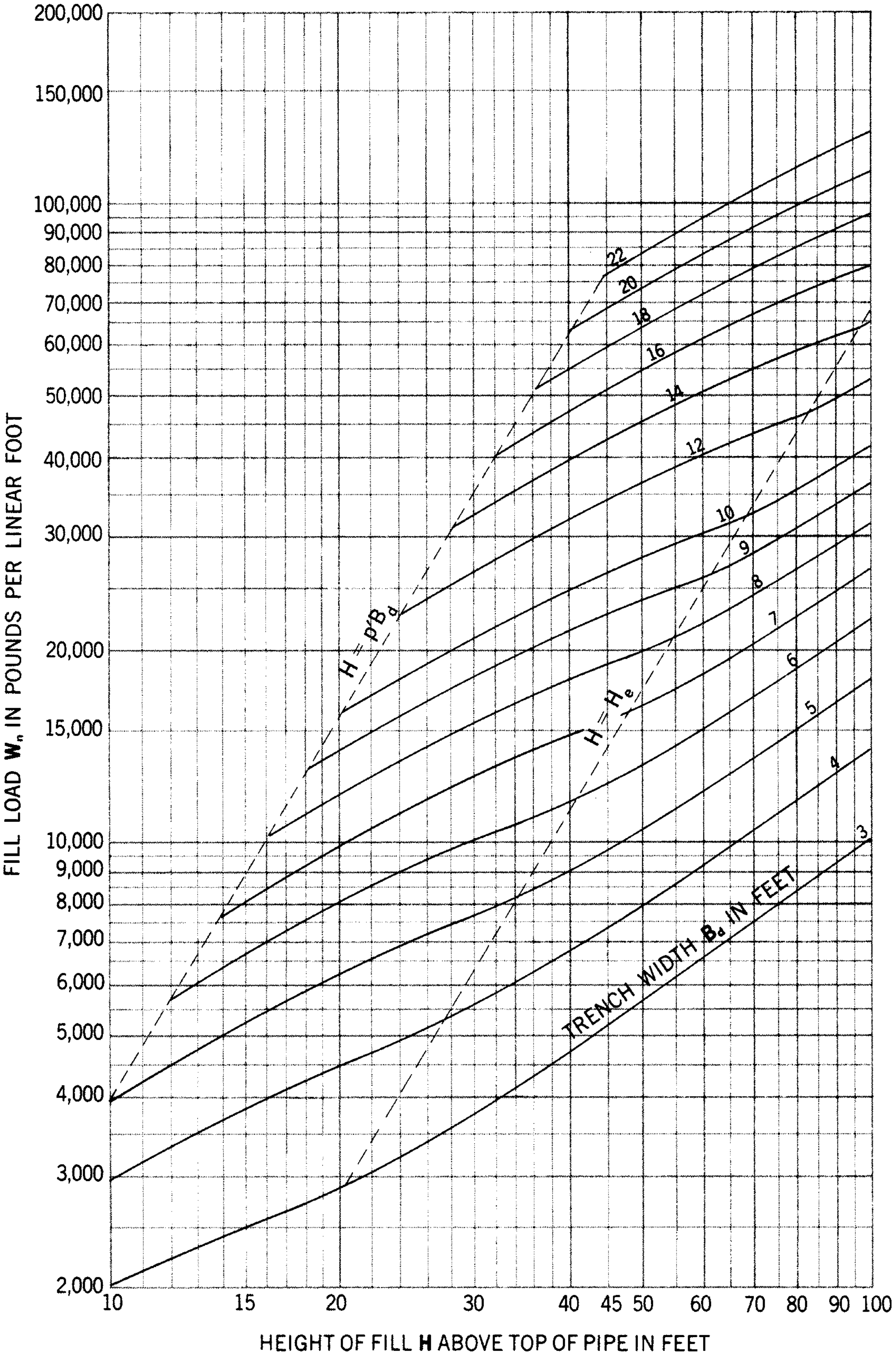


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 213

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

NEGATIVE PROJECTING $p' = 2.0$ $r_{sd} = -1.0$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate trench widths.

Figure 214

LOAD COEFFICIENT DIAGRAM FOR TRENCH INSTALLATIONS

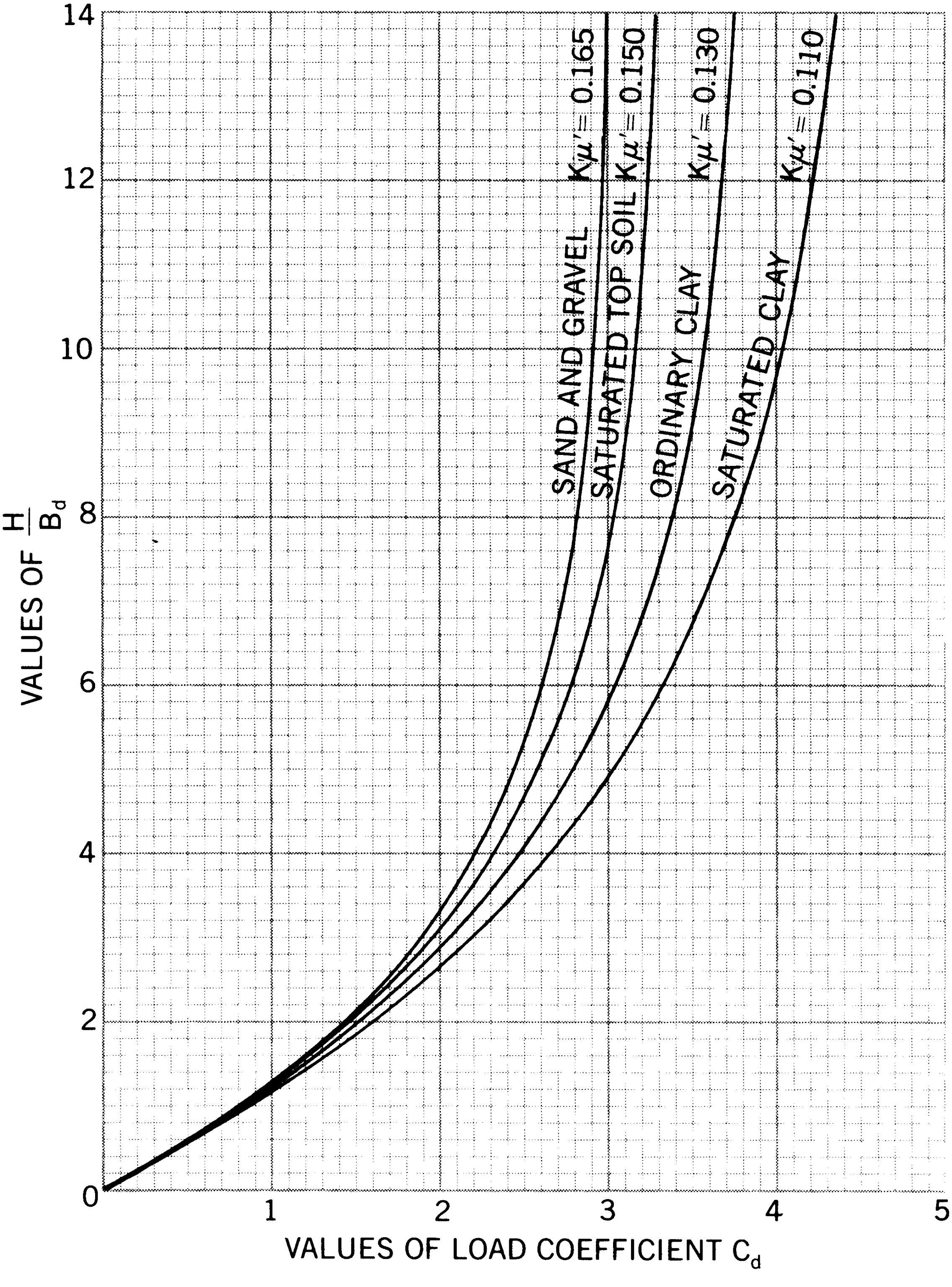
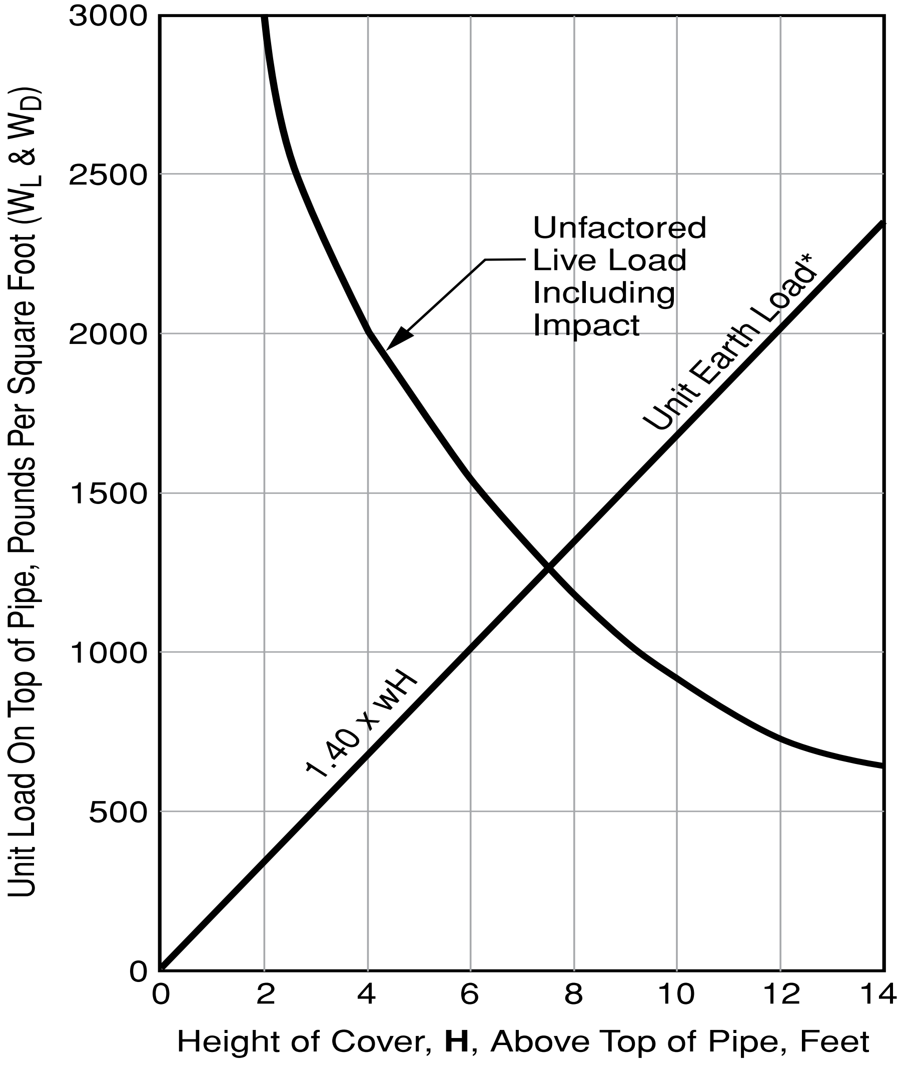


Figure 215 Loads on Concrete Pipe Installed Under Railways



*Fill for embankment installations
DL/Bc = 1.40wH with w = 18.85kN/m3
1.40 = Vertical Arching Factor

* Fill for embankment installations DL/B_c = 1.40wH with w = 120pcf 1.40 = Vertical Arching Factor

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"Part 10 Reinforced Concrete Culvert Pipe, Chapter 8, Concrete Structures and Foundations, AREMA Manual of Railway Engineering", American Railway Engineering and Maintenance-of-Way Association, 1999.

Appendix A

Table A-1

SQUARE ROOTS OF DECIMAL NUMBER($S^{1/2}$ IN MANNING'S FORMULA)

No.	.–0	.–1	.–2	.–3	.–4	.–5	.–6	.–7	.–8	.–9
.00001	.003162	.003317	.003464	.003606	.003742	.003873	.004000	.004123	.004243	.004359
.00002	.004472	.004583	.004690	.004796	.004899	.005000	.005099	.005196	.005292	.005385
.00003	.005477	.005568	.005657	.005745	.005831	.005916	.006000	.006083	.006164	.006245
.00004	.006325	.006403	.006481	.006557	.006633	.006708	.006782	.006856	.006928	.007000
.00005	.007071	.007141	.007211	.007280	.007348	.007416	.007483	.007550	.007616	.007681
.00006	.007746	.007810	.007874	.007937	.008000	.008062	.008124	.008185	.008246	.008307
.00007	.008367	.008426	.008485	.008544	.008602	.008660	.008718	.008775	.008832	.008888
.00008	.008944	.009000	.009055	.009110	.009165	.009220	.009274	.009327	.009381	.009434
.00009	.009487	.009539	.009592	.009644	.009695	.009747	.009798	.009849	.009899	.009950
.00010	.010000	.010050	.010100	.010149	.010198	.010247	.010296	.010344	.010392	.010440
.0001	.01000	.01049	.01095	.01140	.01183	.01225	.01265	.01304	.01342	.01378
.0002	.01414	.01449	.01483	.01517	.01549	.01581	.01612	.01643	.01673	.01703
.0003	.01732	.01761	.01789	.01817	.01844	.01871	.01897	.01924	.01949	.01975
.0004	.02000	.02025	.02049	.02074	.02098	.02121	.02145	.02168	.02191	.02214
.0005	.02236	.02258	.02280	.02302	.02324	.02345	.02366	.02387	.02408	.02429
.0006	.02449	.02470	.02490	.02510	.02530	.02550	.02569	.02588	.02608	.02627
.0007	.02646	.02665	.02683	.02702	.02720	.02739	.02757	.02775	.02793	.02811
.0008	.02828	.02846	.02864	.02881	.02898	.02915	.02933	.02950	.02966	.02983
.0009	.03000	.03017	.03033	.03050	.03066	.03082	.03098	.03114	.03130	.03146
.0010	.03162	.03178	.03194	.03209	.03225	.03240	.03256	.03271	.03286	.03302
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05099	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07746	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302

Table A-2

THREE-EIGHTHS POWERS OF NUMBERS

No.	0	2	4	6	8	No.	0	2	4	6	8
0	.00	.55	.71	.83	.92	50	4.34	4.40	4.46	4.52	4.58
1	1.00	1.07	1.13	1.19	1.25	60	4.64	4.70	4.76	4.81	4.87
2	1.30	1.34	1.39	1.43	1.47	70	4.92	4.97	5.02	5.07	5.12
3	1.51	1.55	1.58	1.62	1.65	80	5.17	5.22	5.27	5.31	5.36
4	1.68	1.71	1.74	1.77	1.80	90	5.41	5.45	5.49	5.54	5.58
5	1.83	1.86	1.88	1.91	1.93	100	5.62	5.67	5.71	5.75	5.79
6	1.96	1.98	2.01	2.03	2.05	110	5.83	5.87	5.91	5.95	5.98
7	2.07	2.10	2.12	2.14	2.16	120	6.02	6.06	6.10	6.13	6.17
8	2.18	2.20	2.22	2.24	2.26	130	6.20	6.24	6.28	6.31	6.35
9	2.28	2.30	2.32	2.34	2.35	140	6.38	6.41	6.45	6.48	6.51
10	2.37	2.39	2.41	2.42	2.44	150	6.55	6.58	6.61	6.64	6.68
11	2.46	2.47	2.49	2.51	2.52	160	6.71	6.74	6.77	6.80	6.83
12	2.54	2.56	2.57	2.59	2.60	170	6.86	6.89	6.92	6.95	6.98
13	2.62	2.63	2.65	2.66	2.68	180	7.01	7.04	7.07	7.10	7.12
14	2.69	2.71	2.72	2.73	2.75	190	7.15	7.18	7.21	7.24	7.27
15	2.76	2.77	2.79	2.80	2.81	200	7.29	7.32	7.35	7.37	7.40
16	2.83	2.84	2.86	2.87	2.88	210	7.43	7.46	7.48	7.51	7.54
17	2.89	2.91	2.92	2.93	2.94	220	7.56	7.58	7.61	7.63	7.66
18	2.96	2.97	2.98	2.99	3.00	230	7.69	7.71	7.73	7.76	7.78
19	3.02	3.03	3.04	3.05	3.06	240	7.81	7.83	7.86	7.88	7.91
20	3.08	3.09	3.10	3.11	3.12	250	7.93	7.95	7.98	8.00	8.02
21	3.13	3.14	3.15	3.17	3.18	260	8.05	8.07	8.09	8.12	8.14
22	3.19	3.20	3.21	3.22	3.23	270	8.16	8.18	8.21	8.23	8.25
23	3.24	3.25	3.26	3.27	3.28	280	8.27	8.30	8.32	8.34	8.36
24	3.29	3.30	3.31	3.32	3.33	290	8.38	8.40	8.43	8.45	8.47
25	3.34	3.35	3.36	3.37	3.38	300	8.49	8.51	8.53	8.55	8.57
26	3.39	3.40	3.41	3.42	3.43	310	8.60	8.62	8.64	8.66	8.68
27	3.44	3.45	3.46	3.47	3.48	320	8.70	8.72	8.74	8.76	8.78
28	3.49	3.50	3.51	3.52	3.53	330	8.80	8.82	8.84	8.86	8.88
29	3.54	3.54	3.55	3.56	3.57	340	8.90	8.92	8.94	8.96	8.98
30	3.58	3.59	3.60	3.61	3.62	350	9.00	9.01	9.03	9.05	9.07
31	3.62	3.63	3.64	3.65	3.66	360	9.09	9.11	9.13	9.15	9.17
32	3.67	3.68	3.69	3.69	3.70	370	9.18	9.20	9.22	9.24	9.26
33	3.71	3.72	3.73	3.74	3.74	380	9.28	9.30	9.31	9.33	9.35
34	3.75	3.76	3.77	3.78	3.79	390	9.37	9.39	9.40	9.42	9.44
35	3.79	3.80	3.81	3.82	3.83	400	9.46	9.48	9.49	9.51	9.53
36	3.83	3.84	3.85	3.86	3.87	410	9.55	9.56	9.58	9.60	9.61
37	3.87	3.88	3.89	3.90	3.91	420	9.63	9.65	9.67	9.68	9.70
38	3.91	3.92	3.93	3.94	3.94	430	9.72	9.73	9.75	9.77	9.78
39	3.95	3.96	3.97	3.97	3.98	440	9.80	9.82	9.83	9.85	9.87
40	3.99	4.00	4.00	4.01	4.02	450	9.88	9.90	9.92	9.93	9.95
41	4.03	4.03	4.04	4.05	4.05	460	9.97	9.98	10.00	10.01	10.03
42	4.06	4.07	4.08	4.08	4.09	470	10.05	10.06	10.08	10.09	10.11
43	4.10	4.10	4.11	4.12	4.13	480	10.13	10.14	10.16	10.17	10.19
44	4.13	4.14	4.15	4.15	4.16	490	10.21	10.22	10.24	10.25	10.27
45	4.17	4.18	4.18	4.19	4.20	500	10.28	10.30	10.31	10.33	10.34
46	4.20	4.21	4.22	4.22	4.23	510	10.36	10.37	10.39	10.41	10.42
47	4.24	4.24	4.25	4.26	4.26	520	10.44	10.45	10.47	10.48	10.50
48	4.27	4.28	4.28	4.29	4.30	530	10.51	10.52	10.54	10.55	10.57
49	4.30	4.31	4.32	4.32	4.33	540	10.58	10.60	10.61	10.63	10.64

Table A-3

TWO-THIRDS POWERS OF NUMBERS

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.046	.074	.097	.117	.136	.153	.170	.186	.201
.1	.215	.229	.243	.256	.269	.282	.295	.307	.319	.331
.2	.342	.353	.364	.375	.386	.397	.407	.418	.428	.438
.3	.448	.458	.468	.477	.487	.497	.506	.515	.525	.534
.4	.543	.552	.561	.570	.578	.587	.596	.604	.613	.622
.5	.630	.638	.647	.655	.663	.671	.679	.687	.695	.703
.6	.711	.719	.727	.735	.743	.750	.758	.765	.773	.781
.7	.788	.796	.803	.811	.818	.825	.832	.840	.847	.855
.8	.862	.869	.876	.883	.890	.897	.904	.911	.918	.925
.9	.932	.939	.946	.953	.960	.966	.973	.980	.987	.993
1.0	1.000	1.007	1.013	1.020	1.027	1.033	1.040	1.046	1.053	1.059
1.1	1.065	1.072	1.078	1.085	1.091	1.097	1.104	1.110	1.117	1.123
1.2	1.129	1.136	1.142	1.148	1.154	1.160	1.167	1.173	1.179	1.185
1.3	1.191	1.197	1.203	1.209	1.215	1.221	1.227	1.233	1.239	1.245
1.4	1.251	1.257	1.263	1.269	1.275	1.281	1.287	1.293	1.299	1.305
1.5	1.310	1.316	1.322	1.328	1.334	1.339	1.345	1.351	1.357	1.362
1.6	1.368	1.374	1.379	1.385	1.391	1.396	1.402	1.408	1.413	1.419
1.7	1.424	1.430	1.436	1.441	1.447	1.452	1.458	1.463	1.469	1.474
1.8	1.480	1.485	1.491	1.496	1.502	1.507	1.513	1.518	1.523	1.529
1.9	1.534	1.539	1.545	1.550	1.556	1.561	1.566	1.571	1.577	1.582
2.0	1.587	1.593	1.598	1.603	1.608	1.613	1.619	1.624	1.629	1.634
2.1	1.639	1.645	1.650	1.655	1.660	1.665	1.671	1.676	1.681	1.686
2.2	1.691	1.697	1.702	1.707	1.712	1.717	1.722	1.727	1.732	1.737
2.3	1.742	1.747	1.752	1.757	1.762	1.767	1.772	1.777	1.782	1.787
2.4	1.792	1.797	1.802	1.807	1.812	1.817	1.822	1.827	1.832	1.837
2.5	1.842	1.847	1.852	1.857	1.862	1.867	1.871	1.876	1.881	1.886
2.6	1.891	1.896	1.900	1.905	1.910	1.915	1.920	1.925	1.929	1.934
2.7	1.939	1.944	1.949	1.953	1.958	1.963	1.968	1.972	1.977	1.982
2.8	1.987	1.992	1.996	2.001	2.006	2.010	2.015	2.020	2.024	2.029
2.9	2.034	2.038	2.043	2.048	2.052	2.057	2.062	2.066	2.071	2.075
3.0	2.080	2.085	2.089	2.094	2.099	2.103	2.108	2.112	2.117	2.122
3.1	2.126	2.131	2.135	2.140	2.144	2.149	2.153	2.158	2.163	2.167
3.2	2.172	2.176	2.180	2.185	2.190	2.194	2.199	2.203	2.208	2.212
3.3	2.217	2.221	2.226	2.230	2.234	2.239	2.243	2.248	2.252	2.257
3.4	2.261	2.265	2.270	2.274	2.279	2.283	2.288	2.292	2.296	2.301
3.5	2.305	2.310	2.314	2.318	2.323	2.327	2.331	2.336	2.340	2.345
3.6	2.349	2.353	2.358	2.362	2.366	2.371	2.375	2.379	2.384	2.388
3.7	2.392	2.397	2.401	2.405	2.409	2.414	2.418	2.422	2.427	2.431
3.8	2.435	2.439	2.444	2.448	2.452	2.457	2.461	2.465	2.469	2.474
3.9	2.478	2.482	2.486	1.490	2.495	2.499	2.503	2.507	2.511	2.516
4.0	2.520	2.524	2.528	2.532	2.537	2.541	2.545	2.549	2.553	2.558
4.1	2.562	2.566	2.570	2.574	2.579	2.583	2.587	2.591	2.595	2.599
4.2	2.603	2.607	2.611	2.616	2.620	2.624	2.628	2.632	2.636	2.640
4.3	2.644	2.648	2.653	2.657	2.661	2.665	2.669	2.673	2.677	2.681
4.4	2.685	2.689	2.693	2.698	2.702	2.706	2.710	2.714	2.718	2.722
4.5	2.726	2.730	2.734	2.738	2.742	2.746	2.750	2.754	2.758	2.762
4.6	2.766	2.770	2.774	2.778	2.782	2.786	2.790	2.794	2.798	2.802
4.7	2.806	2.810	2.814	2.818	2.822	2.826	2.830	2.834	2.838	2.842
4.8	2.846	2.850	2.854	2.858	2.862	2.865	2.869	2.873	2.877	2.881
4.9	2.885	2.889	2.893	2.897	2.901	2.904	2.908	2.912	2.916	2.920

Table A-4

EIGHT-THIRDS POWERS OF NUMBERS

No.	.00	.02	.04	.06	.08	No.	.00	.02	.04	.06	.08
0.1	.002	.004	.005	.008	.010	5.1	77.1	77.9	78.7	79.5	80.3
0.2	.014	.018	.022	.028	.034	5.2	81.2	82.0	82.8	83.7	84.5
0.3	.040	.048	.056	.066	.076	5.3	85.4	86.3	87.1	88.0	88.9
0.4	.087	.099	.112	.126	.141	5.4	89.8	90.6	91.5	92.4	93.3
0.5	.157	.175	.193	.213	.234	5.5	94.3	95.2	96.1	97.0	98.0
0.6	.256	.279	.304	.330	.358	5.6	98.9	99.8	101	102	103
0.7	.386	.416	.448	.481	.516	5.7	104	105	106	107	108
0.8	.552	.589	.628	.669	.711	5.8	109	110	111	112	113
0.9	.755	.801	.848	.897	.948	5.9	114	115	116	117	118
1.0	1.000	1.054	1.110	1.168	1.228	6.0	119	120	121	122	123
1.1	1.29	1.35	1.42	1.49	1.55	6.1	124	125	126	128	129
1.2	1.63	1.70	1.77	1.85	1.93	6.2	130	131	132	133	134
1.3	2.01	2.10	2.18	2.27	2.36	6.3	135	137	138	139	140
1.4	2.45	2.55	2.64	2.74	2.84	6.4	141	142	144	145	146
1.5	2.95	3.05	3.16	3.27	3.39	6.5	147	148	150	151	152
1.6	3.50	3.62	3.74	3.86	3.99	6.6	153	155	156	157	158
1.7	4.12	4.25	4.38	4.51	4.65	6.7	160	161	162	163	165
1.8	4.79	4.94	5.08	5.23	5.39	6.8	166	167	169	170	171
1.9	5.54	5.69	5.85	6.02	6.18	6.9	173	174	175	177	178
2.0	6.35	6.52	6.69	6.87	7.05	7.0	179	181	182	183	185
2.1	7.23	7.42	7.60	7.80	7.99	7.1	186	188	189	190	192
2.2	8.19	8.39	8.59	8.80	9.00	7.2	193	195	196	198	199
2.3	9.22	9.43	9.65	9.87	10.10	7.3	201	202	203	205	206
2.4	10.33	10.56	10.79	11.03	11.27	7.4	208	209	211	212	214
2.5	11.51	11.76	12.01	12.26	12.52	7.5	216	217	219	220	222
2.6	12.8	13.0	13.3	13.6	13.9	7.6	223	225	226	228	230
2.7	14.1	14.4	14.7	15.0	15.3	7.7	231	233	234	236	238
2.8	15.6	15.9	16.2	16.5	16.8	7.8	239	241	243	244	246
2.9	17.1	17.4	17.7	18.1	18.4	7.9	248	249	251	253	254
3.0	18.7	19.1	19.4	19.7	20.1	8.0	256	258	259	261	263
3.1	20.4	20.8	21.1	21.5	21.9	8.1	265	266	268	270	272
3.2	22.2	22.6	23.0	23.4	23.7	8.2	273	275	277	279	281
3.3	24.1	24.5	24.9	25.3	25.7	8.3	282	284	286	288	290
3.4	26.1	26.6	27.0	27.4	27.8	8.4	292	293	295	297	299
3.5	28.2	28.7	29.1	29.5	30.0	8.5	301	303	305	307	309
3.6	30.4	30.9	31.4	31.8	32.3	8.6	310	312	314	316	318
3.7	32.7	33.2	33.7	34.2	34.7	8.7	320	322	324	326	328
3.8	35.2	35.7	36.2	36.7	37.2	8.8	330	332	334	336	338
3.9	37.7	38.2	38.7	39.3	39.8	8.9	340	342	344	346	348
4.0	40.3	40.9	41.4	42.0	42.5	9.0	350	353	355	357	359
4.1	43.1	43.6	44.2	44.8	45.3	9.1	361	363	365	367	369
4.2	45.9	46.5	47.1	47.7	48.3	9.2	372	374	376	378	380
4.3	48.9	49.5	50.1	50.7	51.4	9.3	382	385	387	390	391
4.4	52.0	52.6	53.3	53.9	54.5	9.4	394	396	398	400	403
4.5	55.2	55.9	56.5	57.2	57.9	9.5	405	407	409	412	414
4.6	58.5	59.2	59.9	60.6	61.3	9.6	416	419	421	423	426
4.7	62.0	62.7	63.4	64.1	64.8	9.7	428	429	433	435	437
4.8	65.6	66.3	67.0	67.8	68.5	9.8	440	442	445	447	449
4.9	69.3	70.0	70.8	71.6	72.3	9.9	452	454	457	459	462
5.0	73.1	73.9	74.7	75.5	76.3	10.0	464	467	469	472	474

Table A-5

SQUARE ROOTS AND CUBE ROOTS OF NUMBERS

No.	Square Root	Cube Root	No.	Square Root	Cube Root	No.	Square Root	Cube Root	No	Square Root	Cube Root
1	1.000	1.000	26	5.099	2.963	51	7.141	3.708	76	8.718	4.236
2	1.414	1.260	27	5.196	3.000	52	7.211	3.733	77	8.775	4.254
3	1.732	1.442	28	5.292	3.037	53	7.280	3.756	78	8.832	4.273
4	2.000	1.587	29	5.385	3.072	54	7.348	3.780	79	8.888	4.291
5	2.236	1.710	30	5.477	3.107	55	7.416	3.803	80	8.944	4.309
6	2.449	1.817	31	5.568	3.141	56	7.483	3.826	81	9.000	4.327
7	2.646	1.913	32	5.657	3.175	57	7.550	3.849	82	9.055	4.345
8	2.828	2.000	33	5.745	3.208	58	7.616	3.871	83	9.110	4.362
9	3.000	2.080	34	5.831	3.240	59	7.681	3.893	84	9.165	4.380
10	3.162	2.154	35	5.916	3.271	60	7.746	3.915	85	9.220	4.397
11	3.317	2.224	36	6.000	3.302	61	7.810	3.937	86	9.274	4.414
12	3.464	2.289	37	6.083	3.332	62	7.874	3.958	87	9.327	4.431
13	3.606	2.351	38	6.164	3.362	63	7.937	3.979	88	9.381	4.448
14	3.742	2.410	39	6.245	3.391	64	8.000	4.000	89	9.434	4.465
15	3.873	2.466	40	6.325	3.420	65	8.062	4.021	90	9.487	4.481
16	4.000	2.520	41	6.403	3.448	66	8.124	4.041	91	9.539	4.498
17	4.123	2.571	42	6.481	3.476	67	8.185	4.062	92	9.592	4.514
18	4.243	2.621	43	6.557	3.503	68	8.246	4.082	93	9.644	4.531
19	4.359	2.668	44	6.633	3.530	69	8.307	4.102	94	9.695	4.547
20	4.472	2.714	45	6.708	3.557	70	8.367	4.121	95	9.747	4.563
21	4.583	2.759	46	6.782	3.583	71	8.426	4.141	96	9.798	4.579
22	4.690	2.802	47	6.856	3.609	72	8.485	4.160	97	9.849	4.595
23	4.796	2.844	48	6.928	3.634	73	8.544	4.179	98	9.900	4.610
24	4.899	2.885	49	7.000	3.659	74	8.602	4.198	99	9.950	4.626
25	5.000	2.924	50	7.071	3.684	75	8.660	4.217	100	10.000	4.642

For Square Roots — moving the decimal point 2 places in the number requires a change of 1 place in the square root.
For Cube Roots — moving the decimal point 3 places in the number requires a change of 1 place in the cube root.

Table A-6

DECIMAL EQUIVALENTS OF INCHES AND FEET

Fractions of		Inch Equivalents to Foot Fractions	Fractions of		Inch Equivalents to Foot Fractions	Fractions of		Inch Equivalents to Foot Fractions	Fractions of		Inch Equivalents to Foot Fractions
Inch	Foot		Inch	Foot		Inch	Foot		Inch	Foot	
	.005208	1/16		.255208	3 1/16		.505208	6 1/16		.755208	9 1/16
	.010417	⅛		.260417	3⅛		.510417	6⅛		.760417	9⅛
1/64	.015625	3/16	17/64	.265625	3 3/16	33/64	.515625	6 3/16	49/64	.765625	9 3/16
	.020833	¼		.270833	3¼		.520833	6¼		.770833	9¼
	.026042	5/16		.276042	3 5/16		.526042	6 5/16		.776042	9 5/16
1/32	.031250	⅜	9/32	.281250	3⅜	17/32	.531250	6⅜	25/32	.781250	9⅜
	.036458	7/16		.286458	3 7/16		.536458	6 7/16		.786458	9 7/16
	.041667	½		.291667	3½		.541667	6½		.791667	9½
3/64	.046875	9/16	19/64	.296875	3 9/16	35/64	.546875	6 9/64	51/64	.796875	9 9/16
	.052083	⅝		.302083	3⅝		.552083	6⅝		.802083	9⅝
	.057292	11/16		.307292	3 11/16		.557292	6 11/16		.807292	9 11/16
1/16	.062500	¾	5/16	.312500	3¾	9/16	.562500	6¾	13/16	.812500	9¾
	.067708	13/16		.317708	3 13/16		.567708	6 13/16		.817708	9 13/16
	.072917	⅞		.322917	3⅞		.572917	6⅞		.822917	9⅞
5/64	.078125	15/16	21/64	.328125	3 15/16	37/64	.578125	6 15/16	53/64	.828125	9 15/16
	.083333	1		.333333	4		.583333	7		.833333	10
	.088542	1 1/16		.338542	4 1/16		.588542	7 1/16		.838542	10 1/16
3/32	.093750	1⅛	11/32	.343750	4⅛	19/32	.593750	7⅛	27/32	.843750	10⅛
	.098958	1 3/16		.348958	4 3/16		.598958	7 3/16		.848958	10 3/16
	.104167	1¼		.354167	4¼		.604167	7¼		.854167	10¼
7/64	.109375	1 5/16	23/64	.359375	4 5/16	39/64	.609375	7 5/16	55/64	.859375	10 5/16
	.114583	1⅜		.364583	4⅜		.614583	7⅜		.864583	10⅜
	.119792	1 7/16		.369792	4 7/16		.619792	7 7/16		.869792	10 7/16
⅛	.125000	1½	⅜	.375000	4½	⅝	.625000	7½	⅞	.875000	10½
	.130208	1 9/16		.380208	4 9/16		.630208	7 9/16		.880208	10 9/16
	.135417	1⅝		.385417	4⅝		.635417	7⅝		.885417	10⅝
9/64	.140625	1 11/16	25/64	.390625	4 11/16	41/64	.640625	7 11/16	57/64	.890625	10 11/16
	.145833	1¾		.395833	4¾		.645833	7¾		.895833	10¾
	.151042	1 13/16		.401042	4 13/16		.651042	7 13/16		.901042	10 13/16
5/32	.156250	1⅞	13/32	.406250	4⅞	21/32	.656250	7⅞	29/32	.906250	10⅞
	.161458	1 15/16		.411458	4 15/16		.661458	7 15/16		.911458	10 15/16
	.166667	2		.416667	5		.666667	8		.916667	11
11/64	.171875	2 1/16	27/64	.421875	5 1/16	43/64	.671875	8 1/16	59/64	.921875	11 1/16
	.177083	2⅛		.427083	5⅛		.677083	8⅛		.927083	11⅛
	.182292	2 3/16		.432292	5 3/16		.682292	8 3/16		.932292	11 3/16
3/16	.187500	2¼	7/16	.437500	5¼	11/16	.687500	8¼	15/16	.937500	11¼
	.192708	2 5/16		.442708	5 5/16		.692708	8 5/16		.942708	11 5/16
	.197917	2⅜		.447917	5⅜		.697917	8⅜		.947917	11⅜
13/64	.203125	2 7/16	29/64	.453125	5 7/16	45/64	.703125	8 7/16	61/64	.953125	11 7/16
	.208333	2½		.458333	5½		.708333	8½		.958333	11½
	.213542	2 9/16		.463542	5 9/16		.713542	8 9/16		.963542	11 9/16
7/32	.218750	2⅝	15/32	.468750	5⅝	23/32	.718750	8⅝	31/32	.968750	11⅝
	.223958	2 11/16		.473958	5 11/16		.723958	8 11/16		.973958	11 11/16
	.229167	2¾		.479167	5¾		.729167	8¾		.979167	11¾
15/64	.234375	2 13/16	31/64	.484375	5 13/16	47/64	.734375	8 13/16	63/64	.984375	11 13/16
	.229583	2⅞		.489583	5⅞		.739583	8⅞		.989583	11⅞
	.244792	2 15/16		.494792	5 15/16		.744792	8 15/16		.994792	11 15/16
¼	.2500	3	½	.5000	6	¾	.7500	9	1	1.0000	12

Table A-7

VARIOUS POWERS OF PIPE DIAMETERS

Pipe Diameter								
In.	Ft.(D)	$D^{1/3}$	$D^{2/3}$	$D^{4/3}$	$D^{8/3}$	$D^{5/2}$	$D^{16/3}$	D^{4}
6	0.50	0.794	0.630	0.397	0.157	0.177	0.025	0.063
8	0.67	0.874	0.763	0.582	0.339	0.363	0.115	0.198
9	0.75	0.909	0.825	0.681	0.464	0.487	0.216	0.316
10	0.83	0.941	0.886	0.784	0.615	0.634	0.378	0.482
12	1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000
15	1.25	1.077	1.160	1.347	1.813	1.747	3.287	2.441
16	1.33	1.101	1.211	1.468	2.154	2.053	4.638	3.160
18	1.50	1.145	1.310	1.717	2.948	2.756	8.693	5.063
21	1.75	1.205	1.452	2.109	4.447	4.051	19.78	9.379
24	2.00	1.260	1.587	2.520	6.35	5.657	40.32	16.00
27	2.25	1.310	1.717	2.948	8.69	7.594	75.56	25.63
30	2.50	1.357	1.842	3.393	11.51	9.882	132.5	39.06
33	2.75	1.401	1.963	3.853	14.84	12.54	220.3	57.19
36	3.00	1.442	2.080	4.327	18.72	15.59	350.4	81.0
39	3.25	1.481	2.194	4.814	23.17	19.04	537.1	111.6
42	3.50	1.518	2.305	5.314	28.24	22.92	797.5	150.1
45	3.75	1.554	2.414	5.826	33.94	27.23	1152.	197.8
48	4.0	1.587	2.520	6.35	40.32	32.00	1626.	256.0
54	4.5	1.651	2.726	7.43	55.20	42.96	3047.	410.1
60	5.0	1.710	2.924	8.55	73.10	55.90	5344.	625.0
66	5.5	1.765	3.116	9.71	94.25	70.94	8883.	915.1
72	6.0	1.817	3.302	10.90	118.8	88.2	14130	1296
78	6.5	1.866	3.483	12.13	147.1	107.7	21654	1785
84	7.0	1.913	3.659	13.39	179.3	129.6	32148	2401
90	7.5	1.957	3.832	14.68	215.5	154.0	46451	3164
96	8.0	2.000	4.00	16.00	256	181.0	65536	4096
102	8.5	2.041	4.17	17.35	301	210.6	90552	5220
108	9.0	2.080	4.33	18.72	350	243.0	122827	6561
114	9.5	2.118	4.49	20.12	405	278.2	163879	8145
120	10.0	2.154	4.64	21.54	464	316	215443	10000
132	11.0	2.224	4.95	24.46	598	401	358173	14641
144	12.0	2.289	5.24	27.47	755	499	569680	20736
156	13.0	2.351	5.53	30.57	934	609	873031	28561
168	14.0	2.410	5.81	33.74	1140	733	1296200	38416
180	15.0	2.466	6.08	36.99	1370	871	1872800	50625

Table A-8

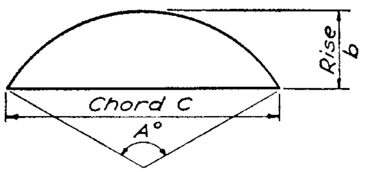
AREAS OF CIRCULAR SECTIONS (Square Feet)

Diameter		0	⅛	¼	⅜	½	⅝	¾	⅞
Inches	Feet and inches								
0	0-0		.0001	.0003	.0008	.0014	.0021	.0031	.0042
1	0-1	.0055	.0069	.0085	.0103	.0123	.0144	.0167	.0192
2	0-2	.0218	.0246	.0276	.0308	.0341	.0376	.0413	.0451
3	0-3	.0491	.0533	.0576	.0621	.0668	.0717	.0767	.0819
4	0-4	.0873	.0928	.0985	.1044	.1104	.1167	.1231	.1296
5	0-5	.1364	.1433	.1503	.1576	.1650	.1726	.1803	.1883
6	0-6	.1963	.2046	.2131	.2217	.2304	.2394	.2485	.2578
7	0-7	.2673	.2769	.2867	.2967	.3068	.3171	.3276	.3382
8	0-8	.3491	.3601	.3712	.3826	.3941	.4057	.4176	.4296
9	0-9	.4418	.4541	.4667	.4794	.4922	.5053	.5185	.5319
10	0-10	.5454	.5591	.5730	.5871	.6013	.6157	.6303	.6450
11	0-11	.6600	.6750	.6903	.7057	.7213	.7371	.7530	.7691
12	1-0	.7854	.8018	.8185	.8353	.8522	.8693	.8866	.9041
13	1-1	.9218	.9396	.9575	.9757	.9940	1.013	1.031	1.050
14	1-2	1.069	1.088	1.108	1.127	1.147	1.167	1.187	1.207
15	1-3	1.227	1.248	1.268	1.289	1.310	1.332	1.353	1.375
16	1-4	1.396	1.418	1.440	1.462	1.485	1.507	1.530	1.553
17	1-5	1.576	1.600	1.623	1.647	1.670	1.694	1.718	1.743
18	1-6	1.767	1.792	1.817	1.842	1.867	1.892	1.917	1.943
19	1-7	1.969	1.995	2.021	2.047	2.074	2.101	2.127	2.154
20	1-8	2.182	2.209	2.237	2.264	2.292	2.320	2.348	2.377
21	1-9	2.405	2.434	2.463	2.492	2.521	2.551	2.580	2.610
22	1-10	2.640	2.670	2.700	2.731	2.761	2.792	2.823	2.854
23	1-11	2.885	2.917	2.948	2.980	3.012	3.044	3.076	3.109
24	2-0	3.142	3.174	3.207	3.241	3.274	3.307	3.341	3.375
25	2-1	3.409	3.443	3.477	3.512	3.547	3.581	3.616	3.652
26	2-2	3.687	3.723	3.758	3.794	3.830	3.866	3.903	3.939
27	2-3	3.976	4.013	4.050	4.087	4.125	4.162	4.200	4.238
28	2-4	4.276	4.314	4.353	4.391	4.430	4.469	4.508	4.547
29	2-5	4.587	4.627	4.666	4.706	4.746	4.787	4.827	4.868
30	2-6	4.909	4.950	4.991	5.032	5.074	5.115	5.157	5.199
31	2-7	5.241	5.284	5.326	5.369	5.412	5.455	5.498	5.541
32	2-8	5.585	5.629	5.673	5.717	5.761	5.805	5.850	5.895
33	2-9	5.940	5.985	6.030	6.075	6.121	6.167	6.213	6.259
34	2-10	6.305	6.351	6.398	6.445	6.492	6.539	6.586	6.634
35	2-11	6.681	6.729	6.777	6.825	6.874	6.922	6.971	7.020
36	3-0	7.069	7.118	7.167	7.217	7.266	7.316	7.366	7.416
37	3-1	7.467	7.517	7.568	7.619	7.670	7.721	7.773	7.824
38	3-2	7.876	7.928	7.980	8.032	8.084	8.137	8.190	8.243
39	3-3	8.296	8.349	8.402	8.456	8.510	8.564	8.618	8.672
40	3-4	8.727	8.781	8.836	8.891	8.946	9.001	9.057	9.113
41	3-5	9.168	9.224	9.281	9.337	9.393	9.450	9.507	9.564
42	3-6	9.621	9.678	9.736	9.794	9.852	9.910	9.968	10.03
43	3-7	10.08	10.14	10.20	10.26	10.32	10.38	10.44	10.50
44	3-8	10.56	10.62	10.68	10.74	10.80	10.86	10.92	10.98
45	3-9	11.04	11.11	11.17	11.23	11.29	11.35	11.42	11.48
46	3-10	11.54	11.60	11.67	11.73	11.79	11.86	11.92	11.98
47	3-11	12.05	12.11	12.18	12.24	12.31	12.37	12.44	12.50
48	4-0	12.57	12.63	12.70	12.76	12.83	12.90	12.96	13.03
49	4-1	13.10	13.16	13.23	13.30	13.36	13.43	13.50	13.57

Table A-9

AREAS OF CIRCULAR SEGMENTS

For Ratios of Rise and Chord



Area = b x C x coefficient

A°	Coefficient	b/C	A°	Coefficient	b/C	A°	Coefficient	b/C	A°	Coefficient	b/C
1	.6667	.0022	46	.6722	.1017	91	.6895	.2097	136	.7239	.3373
2	.6667	.0044	47	.6724	.1040	92	.6901	.2122	137	.7249	.3404
3	.6667	.0066	48	.6727	.1063	93	.6906	.2148	138	.7260	.3436
4	.6667	.0087	49	.6729	.1086	94	.6912	.2174	139	.7270	.3469
5	.6667	.0109	50	.6732	.1109	95	.6918	.2200	140	.7281	.3501
6	.6667	.0131	51	.6734	.1131	96	.6924	.2226	141	.7292	.3534
7	.6668	.0153	52	.6737	.1154	97	.6930	.2252	142	.7303	.3567
8	.6668	.0175	53	.6740	.1177	98	.6936	.2279	143	.7314	.3600
9	.6669	.0197	54	.6743	.1200	99	.6942	.2305	144	.7325	.3633
10	.6670	.0218	55	.6746	.1224	100	.6948	.2332	145	.7336	.3666
11	.6670	.0240	56	.6749	.1247	101	.6954	.2358	146	.7348	.3700
12	.6671	.0262	57	.6752	.1270	102	.6961	.2385	147	.7360	.3734
13	.6672	.0284	58	.6755	.1293	103	.6967	.2412	148	.7372	.3768
14	.6672	.0306	59	.6758	.1316	104	.6974	.2439	149	.7384	.3802
15	.6673	.0328	60	.6761	.1340	105	.6980	.2466	150	.7396	.3837
16	.6674	.0350	61	.6764	.1363	106	.6987	.2493	151	.7408	.3871
17	.6674	.0372	62	.6768	.1387	107	.6994	.2520	152	.7421	.3906
18	.6675	.0394	63	.6771	.1410	108	.7001	.2548	153	.7434	.3942
19	.6676	.0416	64	.6775	.1434	109	.7008	.2575	154	.7447	.3977
20	.6677	.0437	65	.6779	.1457	110	.7015	.2603	155	.7460	.4013
21	.6678	.0459	66	.6782	.1481	111	.7022	.2631	156	.7473	.4049
22	.6679	.0481	67	.6786	.1505	112	.7030	.2659	157	.7486	.4085
23	.6680	.0504	68	.6790	.1529	113	.7037	.2687	158	.7500	.4122
24	.6681	.0526	69	.6794	.1553	114	.7045	.2715	159	.7514	.4159
25	.6682	.0548	70	.6797	.1577	115	.7052	.2743	160	.7528	.4196
26	.6684	.0570	71	.6801	.1601	116	.7060	.2772	161	.7542	.4233
27	.6685	.0592	72	.6805	.1625	117	.7068	.2800	162	.7557	.4270
28	.6687	.0614	73	.6809	.1649	118	.7076	.2829	163	.7571	.4308
29	.6688	.0636	74	.6814	.1673	119	.7084	.2858	164	.7586	.4346
30	.6690	.0658	75	.6818	.1697	120	.7092	.2887	165	.7601	.4385
31	.6691	.0681	76	.6822	.1722	121	.7100	.2916	166	.7616	.4424
32	.6693	.0703	77	.6826	.1746	122	.7109	.2945	167	.7632	.4463
33	.6694	.0725	78	.6831	.1771	123	.7117	.2975	168	.7648	.4502
34	.6696	.0747	79	.6835	.1795	124	.7126	.3004	169	.7664	.4542
35	.6698	.0770	80	.6840	.1820	125	.7134	.3034	170	.7680	.4582
36	.6700	.0792	81	.6844	.1845	126	.7143	.3064	171	.7696	.4622
37	.6702	.0814	82	.6849	.1869	127	.7152	.3094	172	.7712	.4663
38	.6704	.0837	83	.6854	.1894	128	.7161	.3124	173	.7729	.4704
39	.6706	.0859	84	.6859	.1919	129	.7170	.3155	174	.7746	.4745
40	.6708	.0882	85	.6864	.1944	130	.7180	.3185	175	.7763	.4787
41	.6710	.0904	86	.6869	.1970	131	.7189	.3216	176	.7781	.4828
42	.6712	.0927	87	.6874	.1995	132	.7199	.3247	177	.7799	.4871
43	.6714	.0949	88	.6879	.2020	133	.7209	.3278	178	.7817	.4914
44	.6717	.0972	89	.6884	.2046	134	.7219	.3309	179	.7835	.4957
45	.6719	.0995	90	.6890	.2071	135	.7229	.3341	180	.7854	.5000

COURTESY OF CONCRETE REINFORCING STEEL INSTITUTE

Table A-10

AREA, WETTED PERIMETER AND HYDRAULIC RADIUS OF PARTIALLY FILLED CIRCULAR PIPE

$\frac{d}{D}$	$\frac{\text{area}}{D^2}$	$\frac{\text{wet. per.}}{D}$	$\frac{\text{hyd. rad.}}{D}$	$\frac{d}{D}$	$\frac{\text{area}}{D^2}$	$\frac{\text{wet. per.}}{D}$	$\frac{\text{hyd. rad.}}{D}$
0.01	0.0013	0.2003	0.0066	0.51	0.4027	1.5908	0.2531
0.02	0.0037	0.2838	0.0132	0.52	0.4127	1.6108	0.2561
0.03	0.0069	0.3482	0.0197	0.53	0.4227	1.6308	0.2591
0.04	0.0105	0.4027	0.0262	0.54	0.4327	1.6509	0.2620
0.05	0.0147	0.4510	0.0326	0.55	0.4426	1.6710	0.2649
0.06	0.0192	0.4949	0.0389	0.56	0.4526	1.6911	0.2676
0.07	0.0242	0.5355	0.0451	0.57	0.4625	1.7113	0.2703
0.08	0.0294	0.5735	0.0513	0.58	0.4723	1.7315	0.2728
0.09	0.0350	0.6094	0.0574	0.59	0.4822	1.7518	0.2753
0.10	0.0409	0.6435	0.0635	0.60	0.4920	1.7722	0.2776
0.11	0.0470	0.6761	0.0695	0.61	0.5018	1.7926	0.2799
0.12	0.0534	0.7075	0.0754	0.62	0.5115	1.8132	0.2821
0.13	0.0600	0.7377	0.0813	0.63	0.5212	1.8338	0.2842
0.14	0.0668	0.7670	0.0871	0.64	0.5308	1.8546	0.2862
0.15	0.0739	0.7954	0.0929	0.65	0.5404	1.8755	0.2881
0.16	0.0811	0.8230	0.0986	0.66	0.5499	1.8965	0.2899
0.17	0.0885	0.8500	0.1042	0.67	0.5594	1.9177	0.2917
0.18	0.0961	0.8763	0.1097	0.68	0.5687	1.9391	0.2933
0.19	0.1039	0.9020	0.1152	0.69	0.5780	1.9606	0.2948
0.20	0.1118	0.9273	0.1206	0.70	0.5872	1.9823	0.2962
0.21	0.1199	0.9521	0.1259	0.71	0.5964	2.0042	0.2975
0.22	0.1281	0.9764	0.1312	0.72	0.6054	2.0264	0.2987
0.23	0.1365	1.0003	0.1364	0.73	0.6143	2.0488	0.2998
0.24	0.1449	1.0239	0.1416	0.74	0.6231	2.0714	0.3008
0.25	0.1535	1.0472	0.1466	0.75	0.6318	2.0944	0.3017
0.26	0.1623	1.0701	0.1516	0.76	0.6404	2.1176	0.3025
0.27	0.1711	1.0928	0.1566	0.77	0.6489	2.1412	0.3032
0.28	0.1800	1.1152	0.1614	0.78	0.6573	2.1652	0.3037
0.29	0.1890	1.1373	0.1662	0.79	0.6655	2.1895	0.3040
0.30	0.1982	1.1593	0.1709	0.80	0.6736	2.2143	0.3042
0.31	0.2074	1.1810	0.1755	0.81	0.6815	2.2395	0.3044
0.32	0.2167	1.2025	0.1801	0.82	0.6893	2.2653	0.3043
0.33	0.2260	1.2239	0.1848	0.83	0.6969	2.2916	0.3041
0.34	0.2355	1.2451	0.1891	0.84	0.7043	2.3186	0.3038
0.35	0.2450	1.2661	0.1935	0.85	0.7115	2.3462	0.3033
0.36	0.2546	1.2870	0.1978	0.86	0.7186	2.3746	0.3026
0.37	0.2642	1.3078	0.2020	0.87	0.7254	2.4038	0.3017
0.38	0.2739	1.3284	0.2061	0.88	0.7320	2.4341	0.3008
0.39	0.2836	1.3490	0.2102	0.89	0.7384	2.4655	0.2996
0.40	0.2934	1.3694	0.2142	0.90	0.7445	2.4981	0.2980
0.41	0.3032	1.3898	0.2181	0.91	0.7504	2.5322	0.2963
0.42	0.3130	1.4101	0.2220	0.92	0.7560	2.5681	0.2944
0.43	0.3229	1.4303	0.2257	0.93	0.7612	2.6061	0.2922
0.44	0.3328	1.4505	0.2294	0.94	0.7662	2.6467	0.2896
0.45	0.3428	1.4706	0.2331	0.95	0.7707	2.6906	0.2864
0.46	0.3527	1.4907	0.2366	0.96	0.7749	2.7389	0.2830
0.47	0.3627	1.5108	0.2400	0.97	0.7785	2.7934	0.2787
0.48	0.3727	1.5308	0.2434	0.98	0.7816	2.8578	0.2735
0.49	0.3827	1.5508	0.2467	0.99	0.7841	2.9412	0.2665
0.50	0.3927	1.5708	0.2500	1.00	0.7854	3.1416	0.2500

Table A-11

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH INLET CONTROL

END SECTION WITH CLOSED TAPER

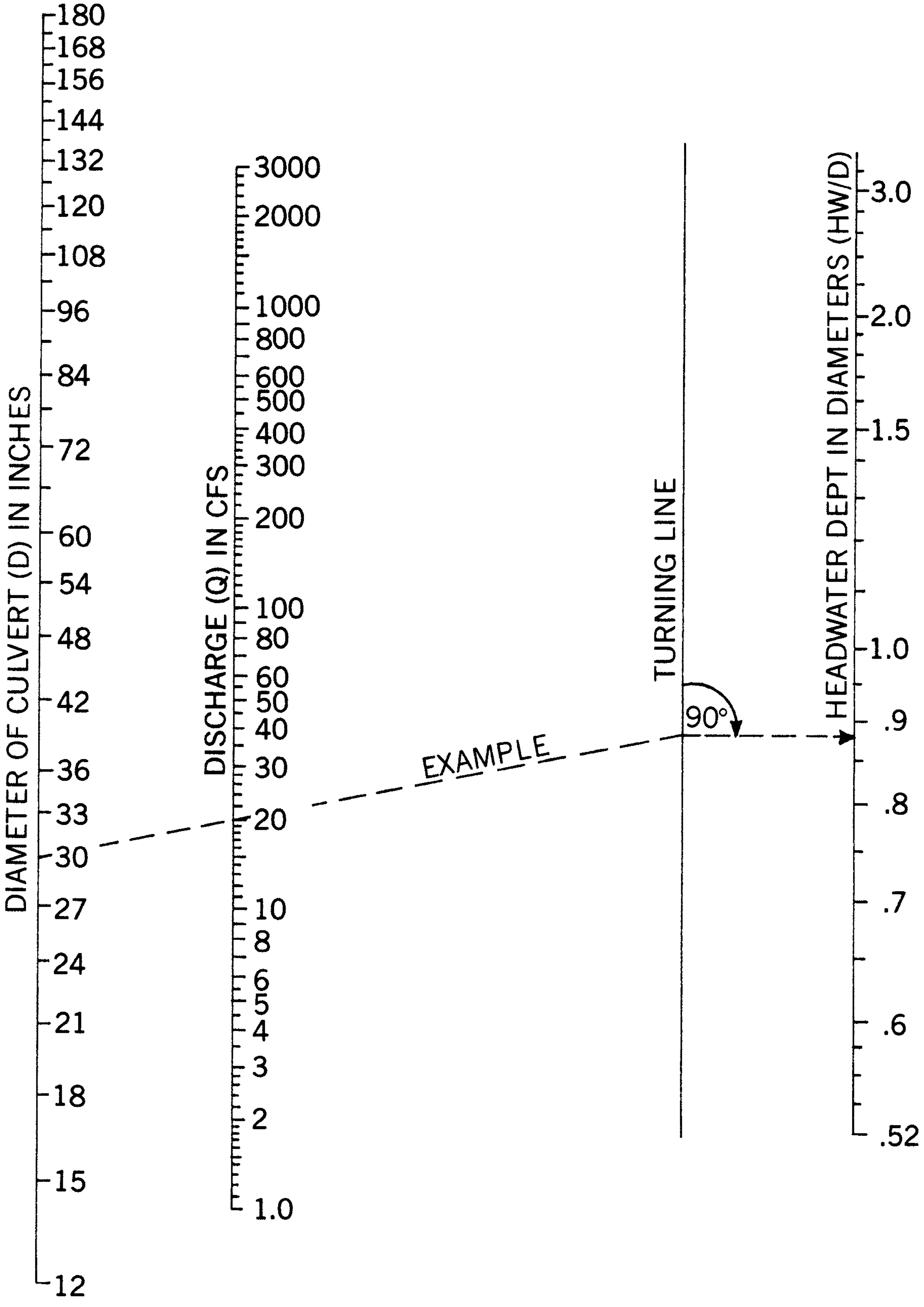
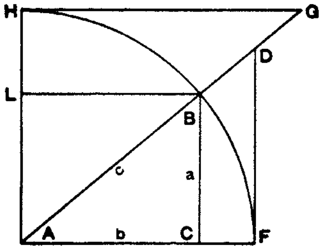


Table A-12

TRIGONOMETRIC FORMULAS

TRIGONOMETRIC FUNCTIONS



Radius AF $= 1$

$= \sin^2 A + \cos^2 A = \sin A \operatorname{cosec} A$

$= \cos A \sec A = \tan A \cot A$

Sine A $= \dfrac{\cos A}{\cot A} = \dfrac{1}{\operatorname{cosec} A} = \cos A \tan A = \sqrt{1-\cos^2 A} = BC$

Cosine A $= \dfrac{\sin A}{\tan A} = \dfrac{1}{\sec A} = \sin A \cot A = \sqrt{1-\sin^2 A} = AC$

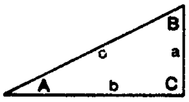
Tangent A $= \dfrac{\sin A}{\cos A} = \dfrac{1}{\cot A} = \sin A \sec A = FD$

Cotangent A $= \dfrac{\cos A}{\sin A} = \dfrac{1}{\tan A} = \cos A \operatorname{cosec} A = HG$

Secant A $= \dfrac{\tan A}{\sin A} = \dfrac{1}{\cos A} = AD$

Cosecant A $= \dfrac{\cot A}{\cos A} = \dfrac{1}{\sin A} = AG$

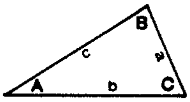
RIGHT ANGLED TRIANGLES



$$a^2 = c^2 - b^2$$
$$b^2 = c^2 - a^2$$
$$c^2 = a^2 + b^2$$

Known	Required					
	A	B	a	b	c	Area
a, b	$\tan A = \frac{a}{b}$	$\tan B = \frac{b}{a}$			$\sqrt{a^2+b^2}$	$\frac{ab}{2}$
a, c	$\sin A = \frac{a}{c}$	$\cos B = \frac{a}{c}$		$\sqrt{c^2-a^2}$		$\frac{a\sqrt{c^2-a^2}}{2}$
A, a		$90° - A$		$a \cot A$	$\frac{a}{\sin A}$	$\frac{a^2 \cot A}{2}$
A, b		$90° - A$	$b \tan A$		$\frac{b}{\cos A}$	$\frac{b^2 \tan A}{2}$
A, c		$90° - A$	$c \sin A$	$c \cos A$		$\frac{c^2 \sin 2A}{4}$

OBLIQUE ANGLED TRIANGLES



$$s = \frac{a+b+c}{2}$$

$$K = \sqrt{\frac{(s-a)(s-b)(s-c)}{s}}$$

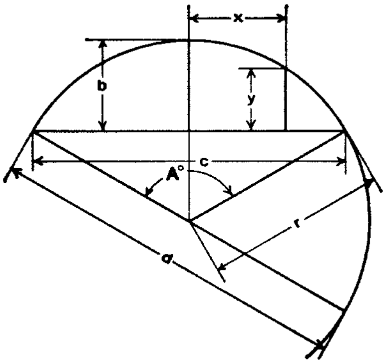
$$a^2 = b^2 + c^2 - 2\,bc \cos A$$
$$b^2 = a^2 + c^2 - 2\,ac \cos B$$
$$c^2 = a^2 + b^2 - 2\,ab \cos C$$

Known	Required					
	A	B	C	b	c	Area
a, b, c	$\tan \frac{1}{2} A = \frac{K}{s-a}$	$\tan \frac{1}{2} B = \frac{K}{s-b}$	$\tan \frac{1}{2} C = \frac{K}{s-c}$			$\sqrt{s(s-a)(s-b)(s-c)}$
a, A, B			$180° - (A+B)$	$\frac{a \sin B}{\sin A}$	$\frac{a \sin C}{\sin A}$	
a, b, A		$\sin B = \frac{b \sin A}{a}$			$\frac{b \sin C}{\sin B}$	
a, b, C	$\tan A = \frac{a \sin C}{b - a \cos C}$				$\sqrt{a^2+b^2-2ab\cos C}$	$\frac{ab \sin C}{2}$

COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-13

PROPERTIES OF THE CIRCLE



Circumference $= 6.28318\ r = 3.14159\ d$

Diameter $= 0.31831$ circumference

Area $= 3.14159\ r^2$

Arc $a = \frac{\pi r\ A°}{180°} = 0.017453\ r\ A°$

Angle $A° = \frac{180°\ a}{\pi r} = 57.29578\ \frac{a}{r}$

Radius $r = \frac{4\ b^2 + c^2}{8\ b}$

Chord $c = 2\sqrt{2\ br - b^2} = 2\ r \sin\frac{A}{2}$

Rise $b = r - \frac{1}{2}\sqrt{4\ r^2 - c^2} = \frac{c}{2}\tan\frac{A}{4}$

$= 2\ r \sin^2\frac{A}{4} = r + y - \sqrt{r^2 - x^2}$

$y = b - r + \sqrt{r^2 - x^2}$

$x = \sqrt{r^2 - (r + y - b)^2}$

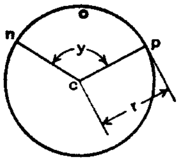
Diameter of circle of equal periphery as square = 1.27324 side of square

Side of square of equal periphery as circle = 0.78540 diameter of circle

Diameter of circle circumscribed about square = 1.41421 side of square

Side of square inscribed in circle = 0.70711 diameter of circle

CIRCULAR SECTOR



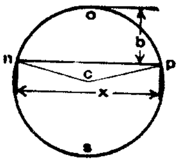
r = radius of circle   y = angle ncp in degrees

Area of Sector ncpo = ½ (length of arc nop × r)

$= \text{Area of Circle} \times \frac{y}{360}$

$= 0.0087266 \times r^2 \times y$

CIRCULAR SEGMENT



r = radius of circle   x = chord   b = rise

Area of Segment nop = Area of Sector ncpo — Area of triangle ncp

$= \frac{(\text{Length of arc nop} \times r) - x\ (r - b)}{2}$

Area of Segment nsp = Area of Circle — Area of Segment nop

VALUES FOR FUNCTIONS OF π

$\pi = 3.14159265359$, log = 0.4971499

$\pi^2 = 9.8696044$, log = 0.9942997	$\frac{1}{\pi} = 0.3183099$, log = $\bar{1}.5028501$	$\sqrt{\frac{1}{\pi}} = 0.5641896$, log = $\bar{1}.7514251$
$\pi^3 = 31.0062767$, log = 1.4914496	$\frac{1}{\pi^2} = 0.1013212$, log = $\bar{1}.0057003$	$\frac{\pi}{180} = 0.0174533$, log = $\bar{2}.2418774$
$\sqrt{\pi} = 1.7724539$, log = 0.2485749	$\frac{1}{\pi^3} = 0.0322515$, log = $\bar{2}.5085500$	$\frac{180}{\pi} = 57.2957795$, log = 1.7581226

Note: Logs of fractions such as $\bar{1}$:5028501 and $\bar{2}$.5085500 may also be written 9.5028501 − 10 and 8.5085500 − 10 respectively.

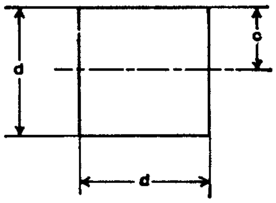
COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14a

PROPERTIES OF GEOMETRIC SECTIONS

SQUARE

Axis of moments through center



$A = d^2$

$c = \frac{d}{2}$

$I = \frac{d^4}{12}$

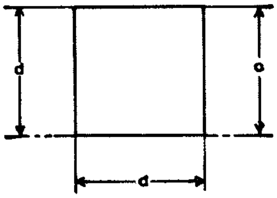
$S = \frac{d^3}{6}$

$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{d^3}{4}$

SQUARE

Axis of moments on base



$A = d^2$

$c = d$

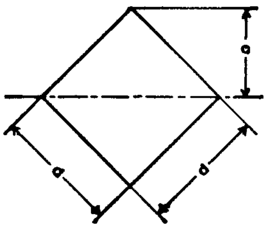
$I = \frac{d^4}{3}$

$S = \frac{d^3}{3}$

$r = \frac{d}{\sqrt{3}} = .577350\ d$

SQUARE

Axis of moments on diagonal



$A = d^2$

$c = \frac{d}{\sqrt{2}} = .707107\ d$

$I = \frac{d^4}{12}$

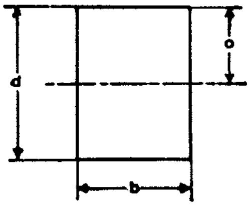
$S = \frac{d^3}{6\sqrt{2}} = .117851\ d^3$

$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{2c^3}{3} = \frac{d^3}{3\sqrt{2}} = .235702d^3$

RECTANGLE

Axis of moments through center



$A = bd$

$c = \frac{d}{2}$

$I = \frac{bd^3}{12}$

$S = \frac{bd^2}{6}$

$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{bd^2}{4}$

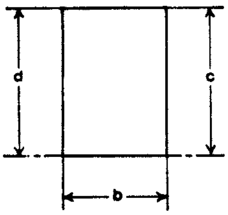
COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14b

PROPERTIES OF GEOMETRIC SECTIONS

RECTANGLE

Axis of moments on base



$A = bd$

$c = d$

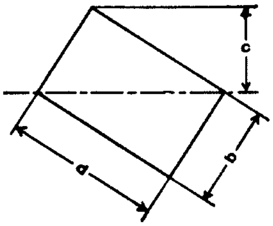
$I = \frac{bd^3}{3}$

$S = \frac{bd^2}{3}$

$r = \frac{d}{\sqrt{3}} = .577350\ d$

RECTANGLE

Axis of moments on diagonal



$A = bd$

$c = \frac{bd}{\sqrt{b^2 + d^2}}$

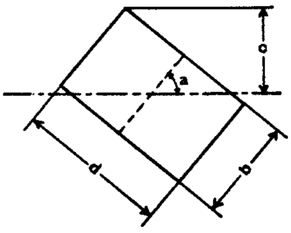
$I = \frac{b^3d^3}{6\,(b^2 + d^2)}$

$S = \frac{b^2d^2}{6\sqrt{b^2 + d^2}}$

$r = \frac{bd}{\sqrt{6\,(b^2 + d^2)}}$

RECTANGLE

Axis of moments any line through center of gravity



$A = bd$

$c = \frac{b \sin a + d \cos a}{2}$

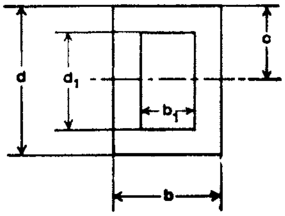
$I = \frac{bd\,(b^2 \sin^2 a + d^2 \cos^2 a)}{12}$

$S = \frac{bd\,(b^2 \sin^2 a + d^2 \cos^2 a)}{6\,(b \sin a + d \cos a)}$

$r = \sqrt{\frac{b^2 \sin^2 a + d^2 \cos^2 a}{12}}$

HOLLOW RECTANGLE

Axis of moments through center



$A = bd - b_1d_1$

$c = \frac{d}{2}$

$I = \frac{bd^3 - b_1d_1^3}{12}$

$S = \frac{bd^3 - b_1d_1^3}{6d}$

$r = \sqrt{\frac{bd^3 - b_1d_1^3}{12\ A}}$

$Z = \frac{bd^2}{4} - \frac{b_1d_1^2}{4}$

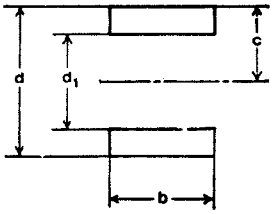
COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14c

PROPERTIES OF GEOMETRIC SECTIONS

EQUAL RECTANGLES

Axis of moments through center of gravity



$$A = b(d - d_1)$$

$$c = \frac{d}{2}$$

$$I = \frac{b(d^3 - d_1^3)}{12}$$

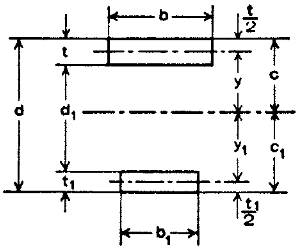
$$S = \frac{b(d^3 - d_1^3)}{6d}$$

$$r = \sqrt{\frac{d^3 - d_1^3}{12(d - d_1)}}$$

$$Z = \frac{b}{4}(d^2 - d_1^2)$$

UNEQUAL RECTANGLES

Axis of moments through center of gravity



$$A = bt + b_1t_1$$

$$c = \frac{\frac{1}{2}bt^2 + b_1t_1(d - \frac{1}{2}t_1)}{A}$$

$$I = \frac{bt^3}{12} + bty^2 + \frac{b_1t_1^3}{12} + b_1t_1y_1^2$$

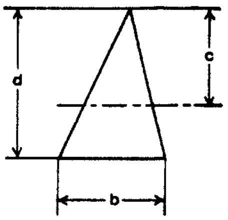
$$S = \frac{I}{c} \qquad S_1 = \frac{I}{c_1}$$

$$= \sqrt{\frac{I}{A}}$$

$$Z = \frac{A}{2}\left[d - \left(\frac{t + t_1}{2}\right)\right]$$

TRIANGLE

Axis of moments through center of gravity



$$A = \frac{bd}{2}$$

$$c = \frac{2d}{3}$$

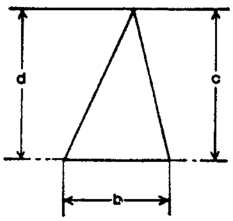
$$I = \frac{bd^3}{36}$$

$$S = \frac{bd^2}{24}$$

$$r = \frac{d}{\sqrt{18}} = .235702\,d$$

TRIANGLE

Axis of moments on base



$$A = \frac{bd}{2}$$

$$c = d$$

$$I = \frac{bd^3}{12}$$

$$S = \frac{bd^2}{12}$$

$$r = \frac{d}{\sqrt{6}} = .408248\,d$$

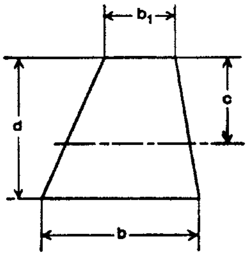
COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14d

PROPERTIES OF GEOMETRIC SECTIONS

TRAPEZOID

Axis of moments through center of gravity



$$A = \frac{d(b + b_1)}{2}$$

$$c = \frac{d(2b + b_1)}{3(b + b_1)}$$

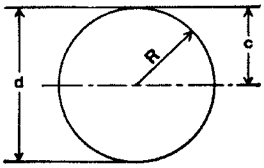
$$I = \frac{d^3\,(b^2 + 4\,bb_1 + b_1^2)}{36\,(b + b_1)}$$

$$S = \frac{d^2\,(b^2 + 4\,bb_1 + b_1^2)}{12\,(2b + b_1)}$$

$$r = \frac{d}{6(b + b_1)}\sqrt{2\,(b^2 + 4\,bb_1 + b_1^2)}$$

CIRCLE

Axis of moments through center



$$A = \frac{\pi d^2}{4} = \pi R^2 = .785398\,d^2 = 3.141593\,R^2$$

$$c = \frac{d}{2} = R$$

$$I = \frac{\pi d^4}{64} = \frac{\pi R^4}{4} = .049087\,d^4 = .785398\,R^4$$

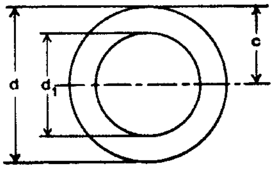
$$S = \frac{\pi d^3}{32} = \frac{\pi R^3}{4} = .098175\,d^3 = .785398\,R^3$$

$$r = \frac{d}{4} = \frac{R}{2}$$

$$Z = \frac{d^3}{6}$$

HOLLOW CIRCLE

Axis of moments through center



$$A = \frac{\pi(d^2 - d_1^2)}{4} = .785398\,(d^2 - d_1^2)$$

$$c = \frac{d}{2}$$

$$I = \frac{\pi(d^4 - d_1^4)}{64} = .049087\,(d^4 - d_1^4)$$

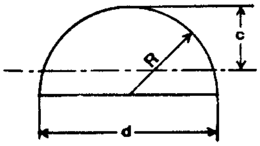
$$S = \frac{\pi(d^4 - d_1^4)}{32d} = .098175\,\frac{d^4 - d_1^4}{d}$$

$$r = \frac{\sqrt{d^2 + d_1^2}}{4}$$

$$Z = \frac{d^3}{6} - \frac{d_1^3}{6}$$

HALF CIRCLE

Axis of moments through center of gravity



$$A = \frac{\pi R^2}{2} = 1.570796\,R^2$$

$$c = R\left(1 - \frac{4}{3\pi}\right) = .575587\,R$$

$$I = R^4\left(\frac{\pi}{8} - \frac{8}{9\pi}\right) = .109757\,R^4$$

$$S = \frac{R^3}{24}\,\frac{(9\pi^2 - 64)}{(3\pi - 4)} = .190687\,R^3$$

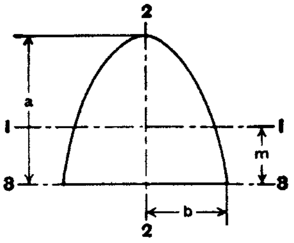
$$r = R\,\frac{\sqrt{9\pi^2 - 64}}{6\pi} = .264336\,R$$

COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14e

PROPERTIES OF GEOMETRIC SECTIONS

PARABOLA



$$A = \frac{4}{3}ab$$

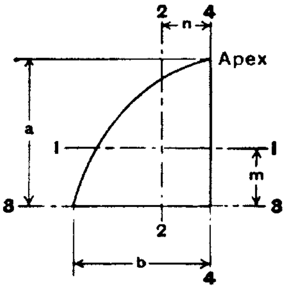
$$m = \frac{2}{5}a$$

$$I_1 = \frac{16}{175}a^3b$$

$$I_2 = \frac{4}{15}ab^3$$

$$I_3 = \frac{32}{105}a^3b$$

HALF PARABOLA



$$A = \frac{2}{3}ab$$

$$m = \frac{2}{5}a$$

$$n = \frac{3}{8}b$$

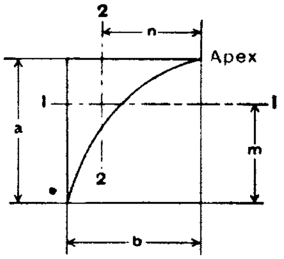
$$I_1 = \frac{8}{175}a^3b$$

$$I_2 = \frac{19}{480}ab^3$$

$$I_3 = \frac{16}{105}a^3b$$

$$I_4 = \frac{2}{15}ab^3$$

COMPLEMENT OF HALF PARABOLA



$$A = \frac{1}{3}ab$$

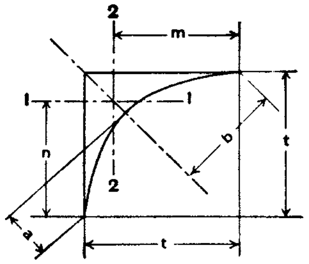
$$m = \frac{7}{10}a$$

$$n = \frac{3}{4}b$$

$$I_1 = \frac{37}{2100}a^3b$$

$$I_2 = \frac{1}{80}ab^3$$

PARABOLIC FILLET IN RIGHT ANGLE



$$a = \frac{t}{2\sqrt{2}}$$

$$b = \frac{t}{\sqrt{2}}$$

$$A = \frac{1}{6}t^2$$

$$m = n = \frac{4}{5}t$$

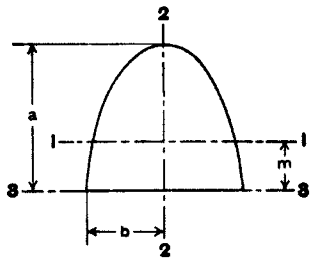
$$I_1 = I_2 = \frac{11}{2100}t^4$$

COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-14f

PROPERTIES OF GEOMETRIC SECTIONS

*** HALF ELLIPSE**



$$A = \frac{1}{2}\pi ab$$

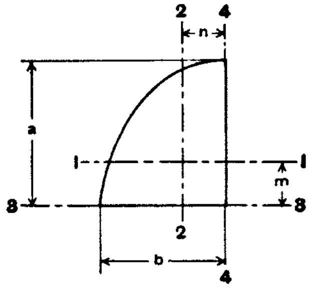
$$m = \frac{4a}{3\pi}$$

$$I_1 = a^3b\left(\frac{\pi}{8} - \frac{8}{9\pi}\right)$$

$$I_2 = \frac{1}{8}\pi ab^3$$

$$I_3 = \frac{1}{8}\pi a^3b$$

*** QUARTER ELLIPSE**



$$A = \frac{1}{4}\pi ab$$

$$m = \frac{4a}{3\pi}$$

$$n = \frac{4b}{3\pi}$$

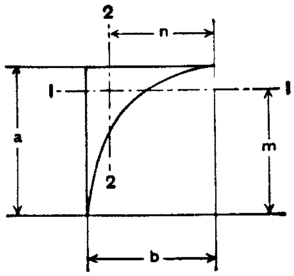
$$I_1 = a^3b\left(\frac{\pi}{16} - \frac{4}{9\pi}\right)$$

$$I_2 = ab^3\left(\frac{\pi}{16} - \frac{4}{9\pi}\right)$$

$$I_3 = \frac{1}{16}\pi a^3b$$

$$I_4 = \frac{1}{16}\pi ab^3$$

*** ELLIPTIC COMPLEMENT**



$$A = ab\left(1 - \frac{\pi}{4}\right)$$

$$m = \frac{a}{6\left(1 - \frac{\pi}{4}\right)}$$

$$n = \frac{b}{6\left(1 - \frac{\pi}{4}\right)}$$

$$I_1 = a^3b\left(\frac{1}{3} - \frac{\pi}{16} - \frac{1}{36\left(1 - \frac{\pi}{4}\right)}\right)$$

$$I_2 = ab^3\left(\frac{1}{3} - \frac{\pi}{16} - \frac{1}{36\left(1 - \frac{\pi}{4}\right)}\right)$$

* To obtain properties of half circle, quarter circle and circular complement substitute a = b = R.

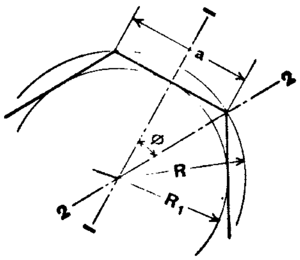
COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-15

PROPERTIES OF GEOMETRIC SECTIONS AND STRUCTURAL SHAPES

REGULAR POLYGON

Axis of moments through center



n = Number of sides

$$\phi = \frac{180^\circ}{n}$$

$$a = 2\sqrt{R^2 - R_1^2}$$

$$R = \frac{a}{2\sin\phi}$$

$$R_1 = \frac{a}{2\tan\phi}$$

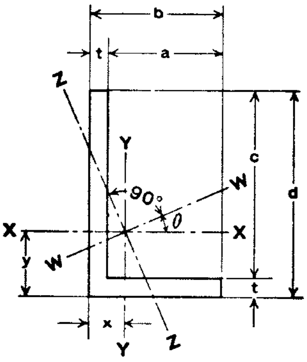
$$A = \frac{1}{4}na^2\cot\phi = \frac{1}{2}nR^2\sin 2\phi = nR_1^2\tan\phi$$

$$I_1 = I_2 = \frac{A(6R^2 - a^2)}{24} = \frac{A(12R_1^2 + a^2)}{48}$$

$$r_1 = r_2 = \sqrt{\frac{6R^2 - a^2}{24}} = \sqrt{\frac{12R_1^2 + a^2}{48}}$$

ANGLE

Axis of moments through center of gravity



Z-Z is axis of minimum I

$$\tan 2\theta = \frac{2K}{I_Y - I_X}$$

$$A = t(b + c) \quad x = \frac{b^2 + ct}{2(b + c)} \quad y = \frac{d^2 + at}{2(b + c)}$$

K = Product of Inertia about X-X & Y-Y

$$= \mp \frac{abcdt}{4(b + c)}$$

$$I_X = \frac{1}{3}\left(t(d - y)^3 + by^3 - a(y - t)^3\right)$$

$$I_Y = \frac{1}{3}\left(t(b - x)^3 + dx^3 - c(x - t)^3\right)$$

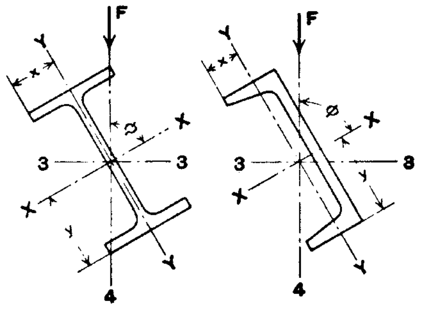
$$I_Z = I_X\sin^2\theta + I_Y\cos^2\theta + K\sin 2\theta$$

$$I_W = I_X\cos^2\theta + I_Y\sin^2\theta - K\sin 2\theta$$

K is negative when heel of angle, with respect to c. g., is in 1st or 3rd quadrant, positive when in 2nd or 4th quadrant.

BEAMS AND CHANNELS

Transverse force oblique through center of gravity



$$I_3 = I_X\sin^2\phi + I_Y\cos^2\phi$$

$$I_4 = I_X\cos^2\phi + I_Y\sin^2\phi$$

$$f_b = M\left(\frac{y}{I_X}\sin\phi + \frac{x}{I_Y}\cos\phi\right)$$

where M is bending moment due to force F.

COURTESY OF AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Table A-16

FOUR PLACE LOGARITHM TABLES

No.	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5498	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

Table A-17a

FREQUENTLY USED CONVERSION FACTORS

TO CONVERT	INTO	MULTIPLY BY
	A	
acres	sq feet	43,560.0
acres	sq meters	4,047
acres	sq miles	1.562×10^{-3}
acres	sq yards	4,840.
acre-feet	cu feet	43,560.0
acre-feet	gallons	3.259×10^{5}
atmospheres	cms of mercury	76.0
atmospheres	ft of water (at 4°C)	33.90
atmospheres	in. of mercury (at 0°C)	29.92
atmospheres	kgs/sq cm	1.0333
atmospheres	kgs/sq meter	10,332.
atmospheres	pounds/sq in	14.70
	C	
Centigrade	Fahrenheit	(C°x9/5)+32
centiliters	liters	0.01
centimeters	feet	3.281×10^{-2}
centimeters	inches	0.3937
centimeters	kilometers	10^{-5}
centimeters	meters	0.01
centimeters	miles	6.214×10^{-6}
centimeters	millimeters	10.0
centimeters	yards	1.094×10^{-2}
centimeters of mercury	atmospheres	0.01316
centimeters of mercury	feet of water	0.4461
centimeters of mercury	kgs/sq meter	136.0
centimeters of mercury	pounds/sq ft	27.85
centimeters of mercury	pounds/sq in	0.1934
centimeters/sec	feet/min	1.1969
centimeters/sec	feet/sec	0.03281
centimeters/sec	kilometers/hr	0.036
centimeters/sec	meters/min	0.6
centimeters/sec	miles/hr	0.02237
centimeters/sec	miles/min	3.728×10^{-4}
centimeters/sec/sec	feet/sec/sec	0.03281
centimeters/sec/sec	kms/hr/sec	0.036
centimeters/sec/sec	meters/sec/sec	0.01
centimeters/sec/sec	miles/hr/sec	0.02237
Chain	Inches	792.00
Chain	meters	20.12
Chains (suveyors' or Gunter's)	yards	22.00
Circumference	Radians	6.283
cubic centimeters	cu feet	3.531×10^{-5}
cubic centimeters	cu inches	0.06102
cubic centimeters	cu meters	10^{-6}
cubic centimeters	cu yards	1.308×10^{-6}
cubic centimeters	gallons (U.S. liq.)	2.642×10^{-4}
cubic centimeters	liters	0.001
cubic centimeters	pints (U.S. liq.)	2.113×10^{-3}
cubic centimeters	quarts (U.S. liq.)	1.057×10^{-3}
cubic feet	cu cms	28,320.0
cubic feet	cu inches	1,728.0
cubic feet	cu meters	0.02832
cubic feet	cu yards	0.03704
cubic feet	gallons (U.S. liq.)	7.48052
cubic feet	liters	28.32
cubic feet	pints (U.S. liq.)	59.84
cubic feet	quarts (U.S. liq.)	29.92
cubic feet/min	cu cms/sec	472.0
cubic feet/min	gallons/sec	0.1247
cubic feet/min	liters/sec	0.4720
cubic feet/min	pounds of water/min	62.43
cubic feet/sec	gallons/min	448.831
cubic inches	cu cms	16.39
cubic inches	cu feet	5.787×10^{-4}
cubic inches	cu meters	1.639×10^{-5}
cubic inches	cu yards	2.143×10^{-5}
cubic inches	gallons	4.329×10^{-3}
cubic inches	liters	0.01639
cubic inches	pints (U.S. liq.)	0.03463
cubic inches	quarts (U.S. liq.)	0.01732
cubic meters	cu cms	10^{6}
cubic meters	cu feet	35.31
cubic meters	cu incnes	61,023.0
cubic meters	cu yards	1.308
cubic meters	gallons (U.S. liq.)	264.2
cubic meters	liters	1,000.0
cubic meters	pints (U.S. liq.)	2,113.0
cubic meters	quarts (U.S. liq.)	1,057.
cubic yards	cu cms	7.646×10^{5}
cubic yards	cu feet	27.0
cubic yards	cu inches	46,656.0
cubic yards	cu meters	0.7646
cubic yards	gallons (U.S. liq.)	202.0
cubic yards	liters	764.6
cubic yards	pints (U.S. liq.)	1,615.9
cubic yards	quarts (U.S. liq.)	807.9
cubic yards/min	cubic ft/sec	0.45
cubic yards/min	gallons/sec	3.367
cubic yards/min	liters/sec	12.74
	D	
days	seconds	86,400.0
decigrams	grams	0.1
deciliters	liters	0.1
decimeters	meters	0.1
degrees (angle)	quadrants	0.01111
degrees (angle)	radians	0.01745
degrees (angle)	seconds	3,600.0
dekagrams	grams	10.0
dekaliters	liters	10.0
dekameters	meters	10.0
	F	
feet	centimeters	30.48
feet	kilometers	3.048×10^{-4}
feet	meters	0.3048
feet	miles (naut.)	1.645×10^{-4}
feet	miles (stat.)	1.894×10^{-4}
feet	millimeters	304.8
feet	mils	1.2×10^{4}
feet of water	atmospheres	0.02950
feet of water	in. of mercury	0.8826
feet of water	kgs/sq cm	0.03048
feet of water	kgs/sq meter	304.8
feet of water	pounds/sq ft	62.43
feet of water	pounds/sq in	0.4335
feet/min	cms/sec	0.5080
feet/min	feet/sec	0.01667
feet/min	kms/hr	0.01829
feet/min	meters/min	0.3048
feet/min	miles/hr	0.01136
feet/sec	cms/sec	30.48
feet/sec	kms/hr	1.097
feet/sec	knots	0.5921
feet/sec	meters/min	18.29
feet/sec	miles/hr	0.6818
feet/sec	miles/min	0.01136
feet/sec/sec	cms/sec/sec	30.48
feet/sec/sec	kms/hr/sec	1.097
feet/sec/sec	meters/sec/sec	0.3048
feet/sec/sec	miles/hr/sec	0.6818
furlongs	miles (U.S.)	0.125
furlongs	feet	660.0
	G	
gallons	cu cms	3,785.0
gallons	cu feet	0.1337
gallons	cu inches	231.0
gallons	cu meters	3.785×10^{-3}
gallons	cu yards	4.951×10^{-3}
gallons	liters	3.785
gallons (liq. Br. Imp.)	gallons (U.S. liq.)	1.20095
gallons (U.S.)	gallons (Imp.)	0.83267
gallons of water	pounds of water	8.3453
gallons/min	cu ft/sec	2.228×10^{-3}

Table A-17b

FREQUENTLY USED CONVERSION FACTORS

TO CONVERT	INTO	MULTIPLY BY
gallons/min	cu ft/hr	8.0208
gallons/day	cu ft/sec	1.5472 x 10^{-6}
grains (troy)	grams	0.06480
grains (troy)	ounces (avdp)	2.0833 x 10^{-3}
grams	grains	15.43
grams	kilograms	0.001
grams	milligrams	1,000.
grams	ounces (avdp)	0.03527
grams	ounces (troy)	0.03215
grams	pounds	2.205 x 10^{-3}
grams/cm	pounds/inch	5.600 x 10^{-3}
grams/cu cm	pounds/cu ft	62.43
grams/cu cm	pounds/cu in	0.03613
grams/liter	pounds/cu ft	0.062427
grams/sq cm	pounds/sq ft	2.0481
	H	
hectograms	grams	100.0
hectoliters	liters	100.0
hectometers	meters	100.0
hours	days	4.167 x 10^{-2}
hours	weeks	5.952 x 10^{-3}
	I	
inches	centimeters	2.540
inches	meters	2.540 x 10^{-2}
inches	miles	1.578 x 10^{-5}
inches	millimeters	25.40
inches	mils	1,000.0
inches	yards	2.778 x 10^{-2}
inches of mercury	atmospheres	0.03342
inches of mercury	feet of water	1.133
inches of mercury	kgs/sq cm	0.03453
inches of mercury	kgs/sq meter	345.3
inches of mercury	pounds/sq ft	70.73
inches of mercury	pounds/sq in	0.4912
inches of water (at 4°C)	atmospheres	2.458 x 10^{-3}
inches of water (at 4°C)	inches of mercury	0.07355
inches of water (at 4°C)	kgs/sq cm	2.540 x 10^{-3}
inches of water (at 4°C)	ounces/sq in	0.5781
inches of water (at 4°C)	pounds/sq ft	5.204
inches of water (at 4°C)	pounds/sq in	0.03613
	K	
kilograms	dynes	980,665.
kilograms	grams	1,000.0
kilograms	pounds	2.205
kilograms	tons (long)	9.842 x 10^{-4}
kilograms	tons (short)	1.102 x 10^{-3}
kilograms/cu meter	grams/cu cm	0.001
kilograms/cu meter	pounds/cu ft	0.06243
kilograms/cu meter	pounds/cu in.	3.613 x 10^{-5}
kilograms/cu meter	pounds/mil-foot	3.405 x 10^{-10}
kilograms/meter	pounds/ft	0.6720
kilograms/sq cm	atmospheres	0.9678
kilograms/sq cm	feet of water	32.81
kilograms/sq cm	inches of mercury	28.96
kilograms/sq cm	pounds/sq ft	2,048.
kilograms/sq cm	pounds/sq in	14.22
kilograms/sq meter	atmospheres	9.678 x 10^{-5}
kilograms/sq meter	feet of water	3.281 x 10^{-3}
kilograms/sq meter	inches of mercury	2.896 x 10^{-5}
kilograms/sq meter	pounds/sq ft	0.2048
kilograms/sq meter	pounds/sq in	1.422 x 10^{-3}
kilograms/sq mm	kgs/sq meter	10^{6}
kiloliters	liters	1,000.0
kilometers	centimeters	10^{5}
kilometers	feet	3,281.
kilometers	inches	3.937 x 10^{4}
kilometers	meters	1,000.0
kilometers	miles	0.6214
kilometers	millimeters	10^{6}
kilometers	yards	1,094.
kilometers/hr	cms/sec	27.78
kilometers/hr	feet/min	54.68
kilometers/hr	feet/sec	0.9113
kilometers/hr	knots	0.5396
kilometers/hr	meters/min	16.67
kilometers/hr	miles/hr	0.6214
knots	feet/hr	6,080.
knots	kilometers/hr	1.8532
knots	nautical miles/hr	1.0
knots	statute miles/hr	1.151
knots	yards/hr	2,027.
knots	feet/sec	1.689
	L	
links (engineer's)	inches	12.0
links (surveyor's)	inches	7.92
liters	bushels (U. S. dry)	0.02838
liters	cu cm	1,000.0
liters	cu feet	0.03531
liters	cu inches	61.02
liters	cu meters	0.001
liters	cu yards	1.308 x 10^{-3}
liters	gallons (U. S. liq.)	0.2642
liters	pints (U. S. liq.)	2.113
liters	quarts (U. S. liq.)	1.057
liters/min	cu ft/sec	5.886 x 10^{-4}
liters/min	gals/sec	4.403 x 10^{-3}
	M	
meters	centimeters	100.0
meters	feet	3.281
meters	inches	39.37
meters	kilometers	0.001
meters	miles (naut.)	5.396 x 10^{-4}
meters	miles (stat.)	6.214 x 10^{-4}
meters	millimeters	1,000.0
meters	yards	1.094
meters/min	cms/sec	1.667
meters/min	feet/min	3.281
meters/min	feet/sec	0.05468
meters/min	knots	0.03238
meters/min	miles/hr	0.03728
meters/sec	feet/min	196.8
meters/sec	feet/sec	3.281
meters/sec	kilometers/hr	3.6
meters/sec	kilometers/min	0.06
meters/sec	miles/hr	2.237
meters/sec	miles/min	0.03728
micrograms	grams	10^{-6}
microliters	liters	10^{-6}
microns	meters	1 x 10^{-6}
miles (naut.)	feet	6,080.27
miles (naut.)	kilometers	1.853
miles (naut.)	meters	1,853.
miles (naut.)	miles (statute)	1.1516
miles (naut.)	yards	2,027.
miles (statute)	centimeters	1.609 x 10^{5}
miles (statute)	feet	5,280.
miles (statute)	inches	6.336 x 10^{4}
miles (statute)	kilometers	1.609
miles (statute)	meters	1,609.
miles (statute)	miles (naut.)	0.8684
miles (statute)	yards	1,760.
miles/hr	cms/sec	44.70
miles/hr	feet/min	88.
miles/hr	feet/sec	1.467
miles/hr	kms/hr	1.609
miles/hr	kms/min	0.02682
miles/hr	knots	0.8684
miles/hr	meters/min	26.82
miles/hr	miles/min	0.1667
miles/min	cms/sec	2,682.
miles/min	feet/sec	88.
miles/min	kms/min	1.609
miles/min	knots/min	0.8684
miles/min	miles/hr	60.0
mil-feet	cu inches	9.425 x 10^{-6}

Table A-17c

FREQUENTLY USED CONVERSION FACTORS

TO CONVERT	INTO	MULTIPLY BY
milliers	kilograms	1,000.
Millimicrons	meters	1×10^{-9}
milligrams	grams	0.001
milliliters	liters	0.001
millimeters	centimeters	0.1
millimeters	feet	3.281×10^{-3}
millimeters	inches	0.03937
millimeters	kilometers	10^{-6}
millimeters	meters	0.001
millimeters	miles	6.214×10^{-7}
millimeters	yards	1.094×10^{-3}
million gals/day	cu ft/sec	1.54723
mils	centimeters	2.540×10^{-3}
mils	feet	8.333×10^{-5}
mils	inches	0.001
mils	kilometers	2.540×10^{-8}
mils	yards	2.778×10^{-5}
minutes (angles)	degrees	0.01667
myriagrams	kilograms	10.0
myriameters	kilometers	10.0
myriawatts	kilowatts	10.0
	O	
ounces	drams	16.0
ounces	grains	437.5
ounces	grams	28.349527
ounces	pounds	0.0625
ounces	ounces (troy)	0.9115
ounces	tons (long)	2.790×10^{-5}
ounces	tons (metric)	2.835×10^{-5}
ounces (fluid)	cu inches	1.805
ounces (fluid)	liters	0.02957
ounces (troy)	grains	480.0
ounces (troy)	grams	31.103481
ounces (troy)	ounces (avdp.)	1.09714
ounces (troy)	pounds (troy)	0.08333
ounces/sq in.	pounds/sq in.	0.0625
	P	
pints (dry)	cu inches	33.60
pints (liq.)	cu cms	473.2
pints (liq.)	cu feet	0.01671
pints (liq.)	cu inches	28.87
pints (liq.)	cu meters	4.732×10^{-4}
pints (liq.)	cu yards	6.189×10^{-4}
pints (liq.)	gallons	0.125
pints (liq.)	liters	0.4732
pints (liq.)	quarts (liq.)	0.5
Pounds (advp)	ounces (troy)	14.5833
pounds	drams	256.
pounds	grams	453.5924
pounds	kilograms	0.4536
pounds	ounces	16.0
pounds	ounces (troy)	14.5833
pounds	pounds (troy)	1.21528
pounds	tons (short)	0.0005
pounds (troy)	ounces (avdp.)	13.1657
pounds (troy)	ounces (troy)	12.0
pounds (troy)	pounds (avdp.)	0.822857
pounds (troy)	tons (long)	3.6735×10^{-4}
pounds (troy)	tons (metric)	3.7324×10^{-4}
pounds (troy)	tons (short)	4.1143×10^{-4}
pounds of water	cu feet	0.01602
pounds of water	cu inches	27.68
pounds of water	gallons	0.1198
pounds/cu ft	grams/cu cm	0.01602
pounds/cu ft	kgs/cu meter	16.02
pounds/cu ft	pounds/cu in.	5.787×10^{-4}
pounds/cu in	gms/cu cm	27.68
pounds/cu in	kgs/cu meter	2.768×10^{4}
pounds/cu in	pounds/cu ft	1,728.
pounds/ft	kgs/meter	1.488
pounds/in.	gms/cm	178.6

TO CONVERT	INTO	MULTIPLY BY
pounds/sq ft	atmospheres	4.725×10^{-4}
pounds/sq ft	feet of water	0.01602
pounds/sq ft	inches of mercury	0.01414
pounds/sq ft	kgs/sq meter	4.882
pounds/sq in.	atmospheres	0.06804
pounds/sq in.	feet of water	2.307
pounds/sq in.	inches of mercury	2.036
pounds/sq in.	kgs/sq meter	703.1
pounds/sq in	pounds/sq ft	144.0
	Q	
quadrants (angle)	degrees	90.0
quadrants (angle)	minutes	5,400.0
quadrants (angle)	radians	1.571
quadrants (angle)	seconds	3.24×10^{5}
	R	
radians	degrees	57.30
radians	minutes	3,438.
radians	quadrants	0.6366
radians	seconds	2.063×10^{5}
rods	chain (Gunters)	.25
rods	meters	5.029
rods (Surveyors' meas.)	yards	5.5
rods	feet	16.5
	S	
square centimeters	sq feet	1.076×10^{-3}
square centimeters	sq inches	0.1550
square centimeters	sq meters	0.0001
square centimeters	sq miles	3.861×10^{-11}
square centimeters	sq millimeters	100.0
square centimeters	sq yards	1.196×10^{-4}
square feet	acres	2.296×10^{-5}
square feet	sq cms	929.0
square feet	sq inches	144.0
square feet	sq meters	0.09290
square feet	sq miles	3.587×10^{-8}
square feet	sq millimeters	9.290×10^{4}
square feet	sq yards	0.1111
square inches	sq cms	6.452
square inches	sq feet	6.944×10^{-3}
square inches	sq millimeters	645.2
square inches	sq yards	7.716×10^{-4}
square kilometers	acres	247.1
square kilometers	sq cms	10^{10}
square kilometers	sq ft	10.76×10^{6}
square kilometers	sq inches	1.550×10^{9}
square kilometers	sq meters	10^{6}
square kilometers	sq miles	0.3861
square kilometers	sq yards	1.196×10^{6}
square meters	acres	2.471×10^{-4}
square meters	sq cms	10^{4}
square meters	sq feet	10.76
square meters	sq inches	1,550.
square meters	sq miles	3.861×10^{-7}
square meters	sq millimeters	10^{6}
square meters	sq yards	1.196
square miles	acres	640.0
square miles	sq feet	27.88×10^{6}
square miles	sq kms	2.590
square miles	sq meters	2.590×10^{6}
square miles	sq yards	3.098×10^{6}
square millimeters	sq cms	0.01
square millimeters	sq feet	1.076×10^{-5}
square millimeters	sq inches	1.550×10^{-3}
square mils	sq cms	6.452×10^{-6}
square mils	sq inches	10^{-6}
square yards	acres	2.066×10^{-4}
square yards	sq cms	8,361.
square yards	sq feet	9.0
square yards	sq inches	1,296.
square yards	sq meters	0.8361

Table A-17d

FREQUENTLY USED CONVERSION FACTORS

TO CONVERT	INTO	MULTIPLY BY
square yards	sq miles	3.288 x 10^{-7}
square yards	sq millimeters	8.361 x 10^{5}
	T	
temperature (°C)+273	absolute temperature (°C)	1.0
temperature (°C)+17.78	temperature (°F)	1.8
temperature (°F)+460	absolute temperature (°F)	1.0
temperature (°F)−32	temperature (°C)	5/9
tons (long)	kilograms	1,016.
tons (long)	pounds	2,240.
tons (long)	tons (short)	1.120
tons (metric)	kilograms	1,000.
tons (metric)	pounds	2,205.
tons (short)	kilograms	907.1848
tons (short)	ounces	32,000.
tons (short)	ounces (troy)	29,166.66
tons (short)	pounds	2,000.
tons (short)	pounds (troy)	2,430.56
tons (short)	tons (long)	0.89287
tons (short)	tons (metric)	0.9078
tons (short)/sq ft	kgs/sq meter	9,765.
tons (short)/sq ft	pounds/sq in.	2,000.
tons of water/24 hrs	pounds of water/hr	83.333
tons of water/24 hrs	gallons/min	0.16643
tons of water/24 hrs	cu ft/hr	1.3349
	Y	
yards	centimeters	91.44
yards	kilometers	9.144 x 10^{-4}
yards	meters	0.9144
yards	miles (naut.)	4.934 x 10^{-4}
yards	miles (stat.)	5.682 x 10^{-4}
yards	millimeters	914.4

TABLE A-18

METRIC CONVERSION OF DIAMETER

in	mm	in	mm	in	mm	in	mm
6	150	30	750	57	1425	96	2400
8	200	33	825	60	1500	102	2550
10	250	36	900	63	1575	108	2700
12	300	39	975	66	1650	114	2850
15	375	42	1050	69	1725	120	3000
18	450	45	1125	72	1800	132	3300
21	525	48	1200	78	1950	144	3600
24	600	51	1275	84	2100	156	3900
27	675	54	1350	90	2250	168	4200

TABLE A-19

METRIC CONVERSION OF WALL THICKNESS

in	mm	in	mm	in	mm	in	mm
1	25	3-1/8	79	5	125	8	200
1-1/2	38	3-1/4	82	5-1/4	131	8-1/2	213
2	50	3-1/2	88	5-1/2	138	9	225
2-1/4	56	3-3/4	94	5-3/4	144	9-1/2	238
2-3/8	59	3-7/8	98	6	150	10	250
2-1/2	63	4	100	6-1/4	156	10-1/2	263
2-5/8	66	4-1/8	103	6-1/2	163	11	275
2-3/4	69	4-1/4	106	6-3/4	169	11-1/2	288
2-7/8	72	4-1/2	113	7	175	12	300
3	75	4-3/4	119	7-1/2	188	12-1/2	313

APPENDIX B

LOADS AND SUPPORTING STRENGTHS

Based on Marston/Spangler Design Procedure

The design procedure for the selection of pipe strength requires:

I . Determination of Earth Load
2. Determination of Live Load
3. Selection of Bedding
4. Determination of Bedding Factor
5. Application of Factor of Safety
6. Selection of Pipe Strength

TYPES OF INSTALLATIONS

The earth load transmitted to a pipe is largely dependent on the type of installation, and the three common types are Trench, Positive Projecting Embankment, and Negative Projecting Embankment. Pipe are also installed by jacking or tunneling methods where deep installations are necessary or where conventional open excavation and backfill methods may not be feasible. The essential features of each of these installations are shown in Figure 146.

Trench. This type of installation is normally used in the construction of sewers, drains and water mains. The pipe is installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill extending to the ground surface.

$$W_d = C_d w B_d^2 \qquad \text{B1}$$

Cd is further defined as:

$$C_d = \frac{1 - e^{-2K\mu' \frac{H}{B_d}}}{2K\mu'} \qquad \text{B2}$$

Note: *In 1996 AASHTO adopted the Standard Installations as presented in Chapter 4 of this manual, and eliminated the use of the Marston/Spangler beddings and design procedure for circular concrete pipe. The Standard Installations and the design criteria in Chapter 4 are the preferred method of ACPA. The older and less quantitative Marston/Spangler beddings and the design method associated with them are presented in this Appendix for those agencies and individuals still using this method.*

Tables B1 through B30 are based on equation (B1) and list backfill loads in pounds per linear foot for various heights of backfill and trench widths. There are four tables for each circular pipe size based on Kμ' = 0.165, 0.150, 0.130 and 0.110. The “Transition Width” column gives the trench width at which the backfill load on the pipe is a maximum and remains constant regardless of any increase in the width of the trench. For any given height of backfill, the maximum load at the transition width is shown by **bold type**.

Figures B1 through B8 also present backfill loads for circular pipe installed in a trench condition. For elliptical and arch pipe, Figures 155 through 178 in the main body of the manual may be used. The solid lines represent trench widths and the dashed lines represent pipe size for the evaluation of transition widths and maximum backfill loads. If, when entering the figures from the horizontal axis, the dashed line representing pipe size is interesected before the solid line representing trench width, the actual trench width is wider than the transition width and the maximum backfill load should be read at the intersection of the height of backfill and the dashed line representing pipe size.

Positive Projecting Embankment. This type of installation is normally used when the culvert is installed in a relatively flat stream bed or drainage path. The pipe is installed on the original ground or compacted fill and then covered by an earth fill or embankment. The fill load on a pipe installed in a positive projecting embankment condition is computed by the equation:

$$W_c = C_c w B_c^2 \qquad \text{B3}$$

C, is further defined as:

$$C_c = \frac{e^{2K\mu \frac{H}{B_c}} - 1}{2K\mu} \quad \text{when } H \leq H_e \qquad \text{B4}$$

and

$$C_c = \frac{e^{2K\mu \frac{H_e}{B_c}} - 1}{2K\mu'} + \left(\frac{H}{B_c} - \frac{H_e}{B_c}\right) e^{2K\mu \frac{H_e}{B_c}} \quad \text{when } H > H_e \qquad \text{B5}$$

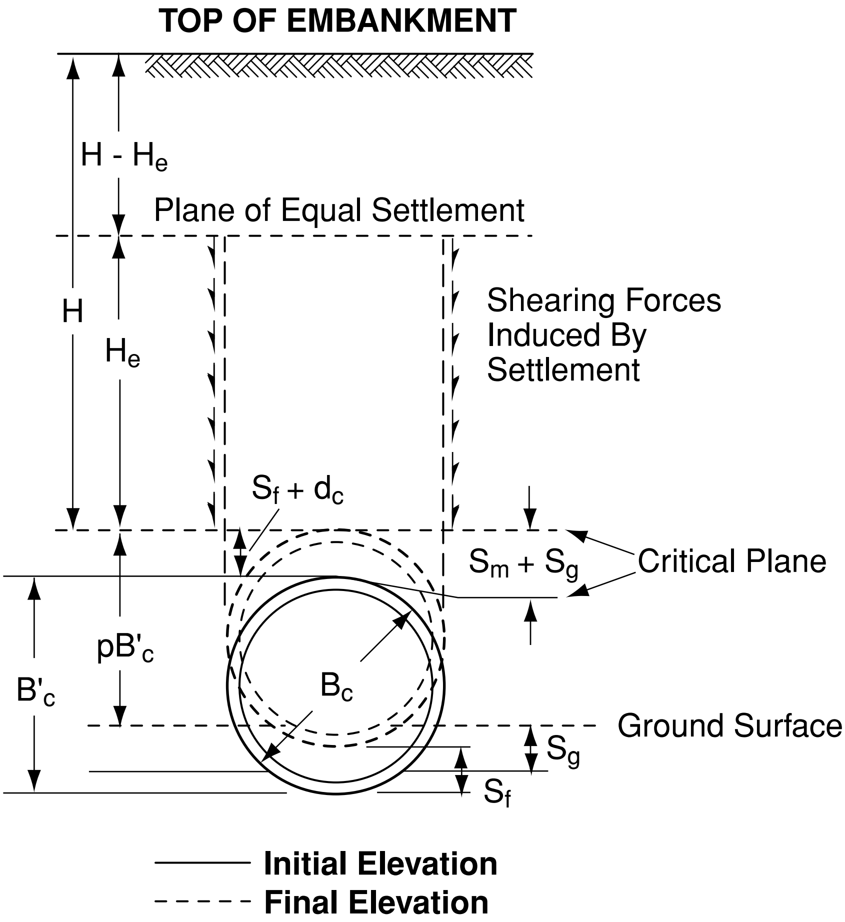
The settlements which influence loads on positive projecting embankment installations are shown in Illustration B1. To evaluate the H_e term in equation (B5), it is necessary to determine numerically the relationship between the pipe deflection and the relative settlement between the prism of fill directly above the pipe and the adjacent soil. This relationship is defined as a settlement ratio, expressed as:

$$r_{sd} = \frac{(S_m + S_g) - (S_f + d_c)}{S_m} \qquad \text{B6}$$

---

1. Pipe widths are based on a wall thickness equivalent to thicknesses indicated for Wall B in ASTM C 76 and designated thicknesses in other applicable ASTM Standards. Loads corresponding to these wall thicknesses are sufficiently accurate for the normal range of pipe widths for any particular pipe size. For extra heavy wall thicknesses, resulting in a pipe width considerably in excess of the normal range, interpolation within the Tables and Figures may be necessary.

Illustration B.1 Settlements Which Influence Loads
Positive Projecting Embankment Installation



The fill load on a pipe installed in a positive projecting embankment condition is influenced by the product of the settlement ratio (r_{sd}) and the projection ratio (p). The projection ratio (p) is the vertical distance the pipe projects above the original ground divided by the outside vertical height of the pipe (B'_c). Recommended settlement ratio design values are listed in Table B-31.

Figures B-9 through B-13 include fill loads in pounds per linear foot for circular pipe under various fill heights and pipe sizes based on $r_{sd}p$ values of 0, 0.1, 0.3, 0.5 and 1.0. For elliptical pipe, Figures 179 through 193 in the main body of the manual may be used. The dashed $H = H_e$ line represents the condition where the height of the plane of equal settlement (H_e) is equal to the height of fill (H).

Negative Projecting Embankment. This type of installation is normally used when the culvert is installed in a relatively narrow and deep stream bed or drainage path. The pipe is installed in a shallow trench of such depth that the top of the pipe is below the natural ground surface or compacted fill and then covered with an earth fill or embankment which extends above the original ground level. The fill load on a pipe installed in a negative projecting embankment condition is computed by the equation:

$$W_n = C_n w B_d^2 \qquad \text{B7}$$

Cn is further defined as:

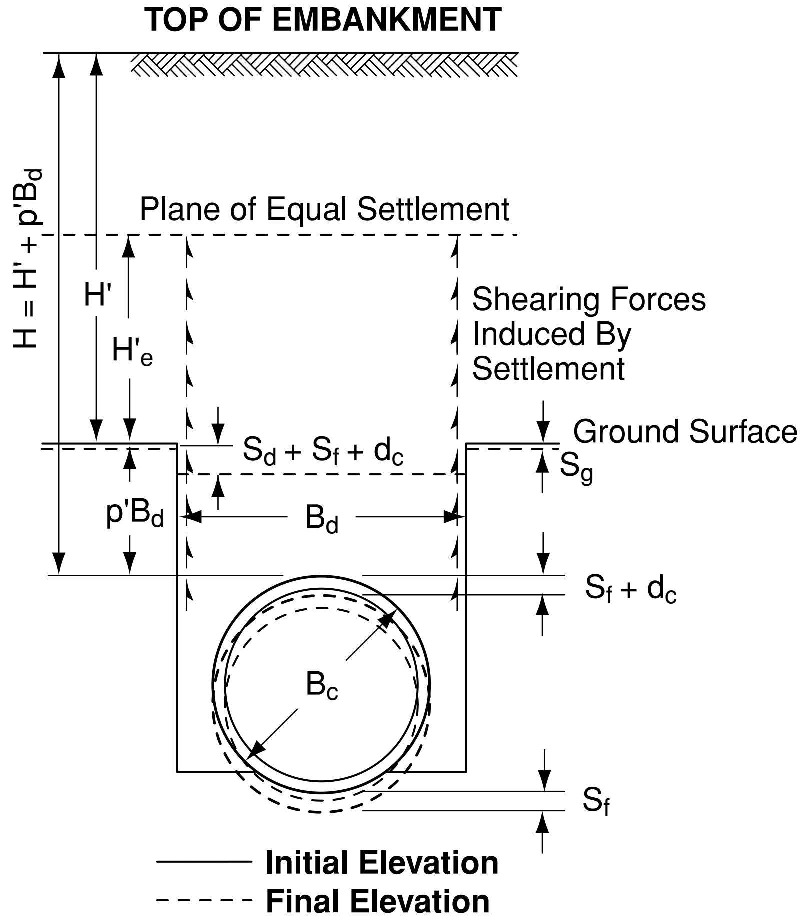
$$C_n = \frac{e^{-2K\mu\frac{H}{B_d}} - 1}{-2K\mu} \quad \text{when } H \leq H_e \qquad \text{B8}$$

and

$$C_n = \frac{e^{-2K\mu\frac{H_e}{B_d}} - 1}{-2K\mu'} + \left(\frac{H}{B_d} - \frac{H_e}{B_d}\right) e^{-2K\mu\frac{H_e}{B_d}} \quad \text{when } H > H_e \qquad \text{B9}$$

When the material within the subtrench is densely compacted, equation (B7) can be expressed as $W_n = C_n w B_d B'_d$ where B'_d is the average of the trench width and the outside diameter of the pipe.

Illustration B.2 Settlements Which Influence Loads
Negative Projecting Embankment Installation



The settlements which influence loads on negative projecting embankment installations are shown in Illustration B2. As in the case of the positive projecting embankment installation, it is necessary to define the settlement ratio. Equating the deflection of the pipe and the total settlement of the prism of fill above the pipe to the settlement of the adjacent soil:

$$r_{sd} = \frac{S_g - (S_d + S_f + d_c)}{S_d} \qquad \text{B10}$$

Recommended settlement ratio design values are listed in Table B-31. The projection ratio (p') for this type of installation is the distance from the top of the pipe to the surface of the natural ground or compacted fill at the time of installation divided by the width of the trench. Where the ground surface is sloping, the average vertical distance from the top of the pipe to the original ground should be used in determining the projection ratio (p'). Figures 194 through 213 present fill loads in pounds per linear foot for circular pipe based on projection ratios of 0.5, 1.0, 1.5, 2.0 and settlement ratios of 0, -0.1, -0.3, -0.5 and -1.0. The dashed $H = p'B_d$ line represents the limiting condition where the height of fill is at the same elevation as the natural ground surface. The dashed $H = H_e$, line represents the condition where the height of the plane of equal settlement (H_e) is equal to the height of fill (H).

SELECTION OF BEDDING

A bedding is provided to distribute the vertical reaction around the lower exterior surface of the pipe and reduce stress concentrations within the pipe wall. The load that a concrete pipe will support depends on the width of the bedding contact area and the quality of the contact between the pipe and bedding. An important consideration in selecting a material for bedding is to be sure that positive contact can be obtained between the bed and the pipe. Since most granular materials will shift to attain positive contact as the pipe settles an ideal load distribution can be attained through the use of clean coarse sand, well-rounded pea gravel or well-graded crushed rock.

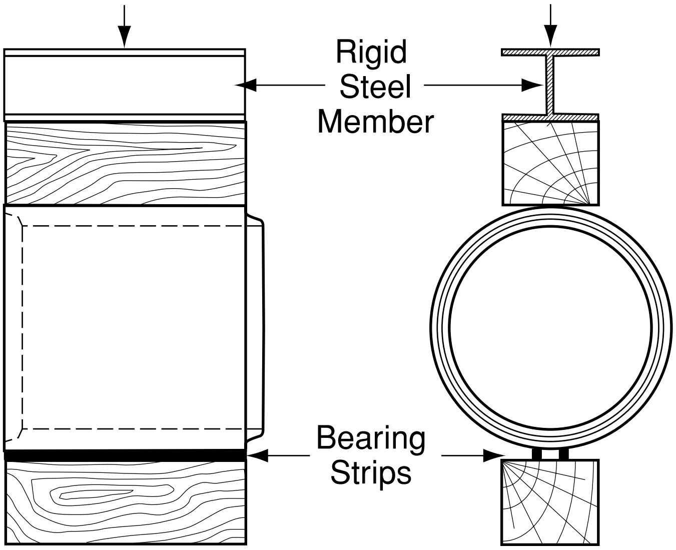
Trench Beddings. Four general classes of bedding for the installation of circular pipe in a trench condition are illustrated in Figure B-14. Trench bedding for horizontal elliptical, arch and vertical elliptical pipe are shown in Figure B-15.

Embankment Beddings. Four general classes of bedding for the installation of circular pipe in an embankment condition are shown in Figure B-16. Embankment beddings for horizontal elliptical, arch and vertical elliptical pipe are shown in Figure B-17. Class A through D bedding classifications are presented as a guideline which should be reasonably attainable under field conditions. To assure that the in-place supporting strength of the pipe is adequate, the width of the band of contact between the pipe and the bedding material should be in accordance with the specified class of bedding. With the development of mechanical methods for subgrade preparation, pipe installation, backfilling and compaction, the flat bottom trench with granular foundation is generally the more practical method of bedding. If the pipe is installed in a flat bottom trench, it is essential that the bedding material be uniformly compacted under the haunches of the pipe.

DETERMINATION OF BEDDING FACTOR

Under installed conditions the vertical load on a pipe is distributed over its width and the reaction is distributed in accordance with the type of bedding. When the pipe strength used in design has been determined by plant testing, bedding factors must be developed to relate the in-place supporting strength to the more severe plant test strength. The bedding factor is the ratio of the strength of the pipe under the installed condition of loading and bedding to the strength of the pipe in the plant test. This same ratio was defined originally by Spangler as the load factor. This latter term, however, was subsequently defined in the ultimate strength method of reinforced concrete design with an entirely different meaning. To avoid confusion, therefore, Spangler's term was renamed the bedding factor. The three-edge bearing test as shown in Illustration B.3 is the normally accepted plant test so that all bedding factors described below relate the in-place supporting strength to the three-edge bearing strength.

Illustration B.3 Three-Edge Bearing Test



The bedding factor for a particular pipeline, and consequently the supporting strength of the buried pipe, depends upon two characteristics of the installation:

- Width and quality of contact between the bedding and the pipe
- Magnitude of the lateral pressure and the portion of the vertical area of the pipe over which it is effective

Since the sidefill material can be more readily compacted for pipe installed in a positive projection embankment condition, the effect of lateral pressure is considered in evaluating the bedding factor. For trench installations, the effect of lateral pressure was neglected in development of bedding factors. Instead of a general theory as for the embankment condition, Spangler, from analysis of test installations, established conservative fixed bedding factors for each of the standard classes of bedding used for trench installations.

Trench Bedding Factors. Conservative fixed bedding factors for pipe installed in a narrow trench condition are listed below the particular classes of beddings shown in Figures B-14 and B-15.

Both Spangler and Schlick, in early Iowa Engineering Experiment Stations publications, postulate that some active lateral pressure is developed in trench installations before the transition width is reached. Experience indicates that the active lateral pressure increases as the trench width increases from a very narrow width to the transition width, provided the sidefill is compacted. Defining the narrow trench width as a trench having a width at the top of the pipe equal to or less than the outside horizontal span plus one foot, and assuming a conservative linear variation, the variable trench bedding factor can be determined by:

$$B_{fv} = (B_{fe} - B_{ft})\left[\frac{B_d - (B_c + 1.0)}{B_{dt} - (B_c + 1.0)}\right] + B_{ft} \qquad \text{B11}$$

Where:

B_c = outside horizontal span of pipe, feet
B_d = trench width at top of pipe, feet
B_{dt} = transition width at top of pipe, feet
B_{fe} = bedding factor, embankment
B_{ft} = fixed bedding factor, trench
B_{fv} = variable bedding factor, trench

A six-step design procedure for determining the trench variable bedding factor is:

- Determine the trench fixed bedding factor, B_{ft}
- Determine the trench width, B_d
- Determine the transition width for the installation conditions, B_{dt}
- Determine H/B_c ratio, settlement ratio, r_{sd}, projection ratio, p, and the product of the settlement and projection ratios, $r_{sd}p$
- Determine positive projecting embankment bedding factor, B_{fe}
- Calculate the trench variable bedding factor, B_{fv}

Positive Projecting Embankment Bedding Factors. For pipe installed in a positive projecting embankment condition, active lateral pressure is exerted against the sides of the pipe. Bedding factors for this type of installation are computed by the equation:

$$B_f = \frac{A}{N - xq} \qquad \text{B12}$$

For circular pipe q is further defined as:

$$q = \frac{pK}{C_c}\left(\frac{H}{B_c} + \frac{p}{2}\right) \leq 0.33 \qquad \text{B13}$$

For elliptical and arch pipe q is further defined as:

$$q = \frac{pB'_cK}{C_cB_c^2}\left(H + \frac{pB'_c}{2}\right) \leq 0.33 \qquad \text{B14}$$

The value of q, as determined by equations B13 and B 14, shall not exceed 0.33.

Tables B32 and B33 list bedding factors for circular pipe. For elliptical and arch pipe bedding factors may be found in Tables 59 through 61 in the main body of the manual.

Negative Projecting Embankment Bedding Factors. The methods described for determining trench bedding factors should be used for negative projecting embankment installations.

APPLICATION OF FACTOR OF SAFETY

The total earth and live load on a buried concrete pipe is computed and multiplied by a factor of safety to determine the pipe supporting strength required. The safety factor is defined as the relationship between the ultimate strength D-load and the 0.01-inch crack D-load. This relationship is specified in the ASTM standards on reinforced concrete pipe. Therefore, for reinforced concrete pipe a factor of safety of 1.0 should be applied if the 0.01-inch crack strength is used as the design criterion. For nonreinforced concrete pipe a factor of safety of 1.25 to 1.5 is normally used.

SELECTION OF PIPE STRENGTH

Since numerous reinforced concrete pipe sizes are available, three-edge bearing test strengths are classified by D-loads. The D-load concept provides strength classification of pipe independent of pipe diameter. For reinforced circular pipe the three-edge bearing test load in pounds per linear foot equals D-load X inside diameter in feet. For arch, horizontal elliptical and vertical elliptical pipe the three-edge bearing test load in pounds per linear foot equals D-load X nominal inside span in feet.

The required three-edge bearing strength of non-reinforced concrete pipe is expressed in pounds per linear foot, not as a D-load, and is computed by the equation:

$$\text{T.E.B.} = \frac{W_L + W_E}{B_f} \text{ X F.S.} \qquad \text{B15}$$

The required three-edge bearing strength of circular reinforced concrete pipe is expressed as D-load and is computed by the equation:

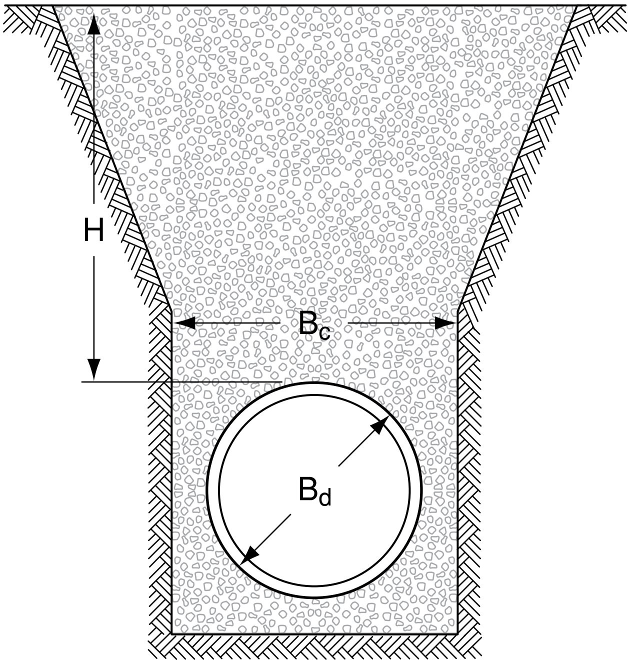
$$\text{D-load} = \frac{W_L + W_E}{B_f \times D} \times \text{F.S.} \qquad \text{B16}$$

The determination of required strength of elliptical and arch concrete pipe is computed by the equation:

$$\text{D-load} = \frac{W_L + W_E}{B_f \times S} \times \text{F.S.} \qquad \text{B17}$$

EXAMPLE PROBLEMS

EXAMPLE B-1
Trench Installation



Given: A 48 inch circular pipe is to be installed in a 7 foot wide trench with 35 feet of cover over the top of the pipe. The pipe will be backfilled with sand and gravel weighing 110 pounds per cubic foot.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

Solution: 1. Determination of Earth Load (W_E)
From Table B-14A, Sand and Gravel, the backfill load based on 100 pounds per cubic foot backfill is 12,000 pounds per linear foot. Increase the load 10 percent for 110 pound backfill material.

W_d = 1.10 X 12,000
W_d = 13,200 pounds per linear foot

2. Determination of Live Load (W_L)
From Table 42, live load is negligible at a depth of 35 feet.

3. Selection of Bedding
A Class B bedding will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical overall installation.

4. Determination of Bedding Factor (B_f)
The trench variable bedding factor, B_{fv} is given by Equation B11:

$$B_{fv} = (B_{fe} - B_{ft})\left[\frac{B_d - (B_c + 1.0)}{B_{dt} - (B_c + 1.0)}\right] + B_{ft}$$

Step 1. From Figure B-14, for circular pipe installed on a Class B bedding, the trench fixed bedding factor, B_{ft}, is 1.9.

Step 2. A trench width, B_d, of 7 feet is specified.

Step 3. The transition width, B_{dt}, determined from Table B-14A is 11.4 feet.

Step 4. $H/B_c = 35/4.8 = 7.3$
From Table B-31, the r_{sd} design range of values for ordinary soil is +0.5 to +0.8. Assume an r_{sd} value of +0.5. For a granular Class B bedding p = 0.5, then $r_{sd}p = 0.5 \times 0.5 = 0.25$.

Step 5. From Table B-32 for $H/B_c = 7.3$, p = 0. 5, $r_{sd}p = 0.25$ and a Class B bedding, $B_{fe} = 2.19$.

Step 6. The trench variable bedding factor is:

$$B_{fv} = (2.19 - 1.9)\left[\frac{7 - (4.8 + 1.0)}{11.4 - (4.8 + 1.0)}\right] + 1.9$$

$$B_{fv} = 1.96$$

Use a variable bedding factor, B_{fv} of 1.96 to determine the required D-load pipe strength.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01-inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by Equation B16:

$$D_{0.01} = \frac{W_L + W_E}{B_f \times D} \times \text{F.S.}$$

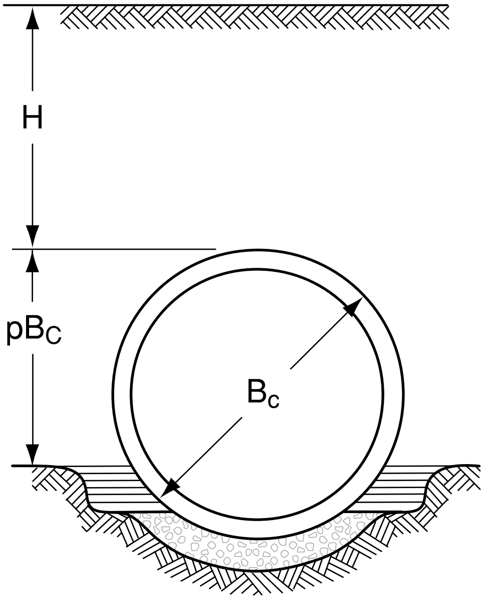
$$W_{L\,+}\ W_E = W_d = 13{,}200 \text{ pounds per linear foot}$$

$$D_{0.01} = \frac{13{,}200}{1.96 \times 4.0} \times 1.0$$

$D_{0.01}$ = 1684 pounds per linear foot per foot of inside diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 1684 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE B-2
Positive Projecting Embankment Installation



Given: A 48 inch circular pipe is to be installed in a positive projecting embankment condition in ordinary soil. The pipe will be covered with 35 feet of 110 pounds per cubic foot overfill.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

Solution:

1. Determination of Earth Load (W_E)
   A settlement ratio must first be assumed. In Table B-31 values of settlement ratio from +0.5 to +0.8 are given for positive projecting installations on a foundation of ordinary soil. A conservative value of 0.7 will be used with an assumed projection ratio of 0.7. The product of the settlement ratio and the projection ratio will be 0.49 ($r_{sd}p = 0.5$).

   Enter Figure B-12 on the horizontal scale at H = 35 feet. Proceed vertically until the line representing D = 48 inches is intersected. At this point the vertical scale shows the fill load to be 25,300 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 10 percent for 110 pound material.

   $W_c = 1.10 \text{ X } 25{,}300$
   $W_c = 27{,}800$ pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, live load is negligible at a depth of 35 feet.

3. Selection of Bedding
   A Class B bedding will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical overall installation.

4. Determination of Bedding Factor (B_f)
   The outside diameter for a 48 inch diameter pipe is 58 inches = 4.83 feet. From Table B-32, from an H/B_c ratio of 7.25, $r_{sd}p$ value of 0.5, p value of 0.7 and Class B bedding, a bedding factor of 2.34 is obtained.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by equation B16:

$$D_{0.01} = \frac{W_L + W_E}{B_f \times D} \times F.S.$$

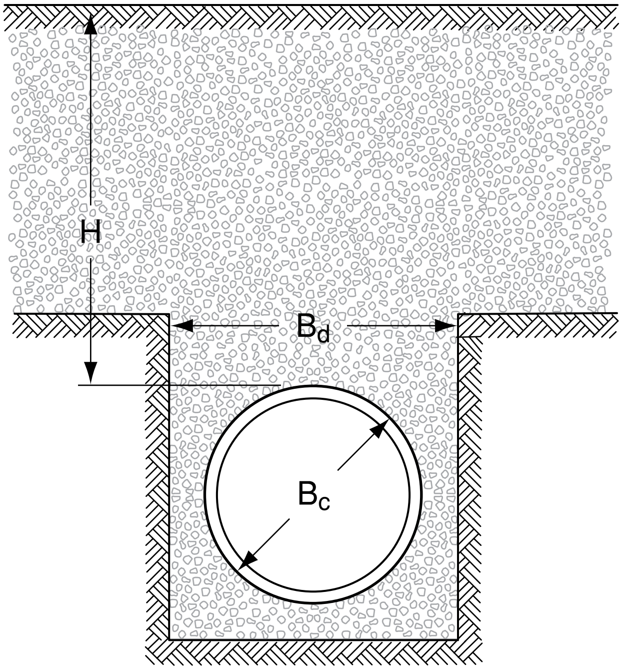
$$W_{L\,+}\ W_E = W_c = 27{,}800 \text{ pounds per linear foot}$$

$$D_{0.01} = \frac{27{,}800}{2.34 \times 4.0} \times 1.0$$

$$D_{0.01} = 2970 \text{ pounds per linear foot per foot of inside diameter}$$

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 2970 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE B-3
Negative Projecting Embankment Installation



Given: A 48 inch circular pipe is to be installed in a negative projecting embankment condition in ordinary soil. The pipe will be covered with 35 feet of 110 pounds per cubic foot overfill. A 7 foot trench width will be constructed with a 7 foot depth from the top of the pipe to the natural ground surface.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

Solution: 1. Determination of Earth Load (W_E)

A settlement ratio must first be assumed. In Table B-31, for a negative projection ratio, p' = 1.0, the design value of the settlement ratio is -0.3.

Enter Figure 201 on the horizontal scale at H = 35 feet. Proceed vertically until the line representing B_d = 7 feet is intersected. At this point the vertical scale shows the fill load to be 15,800 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 10 percent for 110 pound material.

W_n = 1.10 X 15,800
W_n = 17,380 pounds per linear foot

2. Determination of Live Load (W_L)

From Table 42, live load is negligible at a depth of 35 feet.

3. Selection of Bedding

A Class B bedding will be assumed for this example. In actual design, it may be desirable to consider other types of bedding in order to arrive at the most economical overall installation.

4. Determination of Bedding Factor (B_f)

The trench variable bedding factor, B_f, is given by Equation B11:

$$B_{fv} = (\ B_{fe}\ - B_{ft})\left[\frac{B_d - (B_c + 1.0)}{B_{dt} - (B_c + 1.0)}\right] + B_{ft}$$

Step 1. From Figure B-14, for circular pipe installed on a Class B bedding, the trench fixed bedding factor, B_{ft}, is 1.9.

Step 2. A trench width, B_d, of 7 feet is specified.

Step 3. The transition width, B_{dt}, determined from Table B-14 is 11.4 feet.

Step 4. H/B_c = 35/4.8 = 7.3
From Table B-31, the r_{sd} design range of values for ordinary soil is +0.5 to +0.8. Assume an r_{sd} value of +0.5. For a granular Class B bedding p = 0.5, then $r_{sd}p$ = 0.5 x 0.5 = 0.25.

Step 5. From Table B-32, for H/B_c = 7.3, p = 0.5, $r_{sd}p$ = 0.25 and a Class B bedding, B_{fe} = 2.19.

Step 6. The trench variable bedding factor is:

$$B_{fv} = (2.19\ - 1.9)\left[\frac{7 - (4.8 + 1.0)}{11.4 - (4.8 + 1.0)}\right] + 1.9$$

$$B_{fv} = 1.96$$

Use a variable bedding factor, B_{fv}, of 1.96 to determine the required D-load pipe strength.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by equation B16:

$$D_{0.01} = \frac{W_L + W_E}{B_f \text{ x } D} \text{ x F.S.}$$

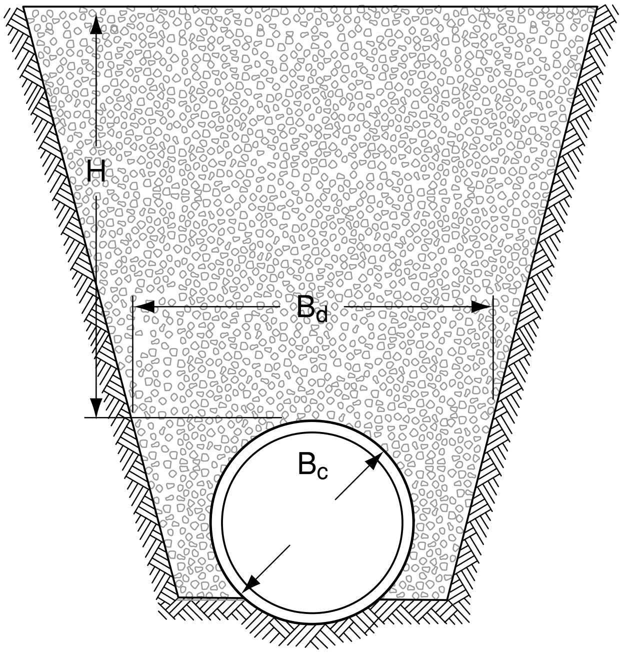
$W_{L\,+}\ W_E = W_n$ = 17,380 pounds per linear foot

$$D_{0.01} = \frac{17{,}380}{1.96 \text{ x } 4.0} \text{ x } 1.0$$

$D_{0.01}$ = 2217 pounds per linear foot per foot of inside diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 2217 pounds per linear foot per foot of inside diameter would be required.

EXAMPLE B-4
Wide Trench Installation



Given: A 24 inch circular pipe is to be installed in a 5 foot wide trench with 9 feet of cover over the top of the pipe. The pipe will be backfilled with ordinary clay weighing 120 pounds per cubic foot.

Find: The required three-edge bearing test strength for nonreinforced pipe and the ultimate D-load for reinforced pipe.

Solution:

1. Determination of Earth Load (W_E)
   From Table B-8C, the transition width for H = 9 feet is 4'-8". Since the actual 5 foot trench width exceeds the transition width, the backfill load based on 100 pounds per cubic foot backfill is 3,331 pounds per linear foot as given by the bold type. Increase the load 20 percent for 120 pound backfill material.

   W_d = 1.20 X 3,331
   W_d = 3,997 pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 42, the live load is 240 pounds per linear foot.

3. Selection of Bedding
   A Class C bedding will be assumed for this example.

4. Determination of Bedding Factor (B_f)
   Since the trench is beyond transition width, a bedding factor for an embankment condition is required.

   The outside diameter for a 24 inch diameter pipe is 30 inches = 2.5 feet. H/B_c = 3.6. From Table B-31, the r_{sd} design range of values for ordinary soil is +0.5 to +0.8. Assume an r_{sd} value of +0.5. For shaped Class C bedding p = 0.9, then $r_{sd}p$ = 0.5 x 0.9 = 0.45. From Table B-33, a bedding factor of 2.07 is obtained.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.5 based on the three-edge bearing strength for nonreinforced pipe and ultimate D-load for reinforced pipe will be applied.

6. Selection of Pipe Strength The three-edge bearing strength for nonreinforced pipe is given by equation B15:

$$\text{T.E.B.} = \frac{W_L + W_E}{B_f} \text{ X F.S.}$$

$W_L + W_E = W_d = 4{,}237$ pounds per linear foot

$$\text{T.E.B.} = \frac{4{,}237}{2.07} \text{ X } 1.5$$

T.E.B. = 3,070 pounds per linear foot

The D-load for reinforced pipe is given by equation B16:

$$D_{ult.} = \frac{W_L + W_E}{B_f \text{ x } D} \text{ x F.S.}$$

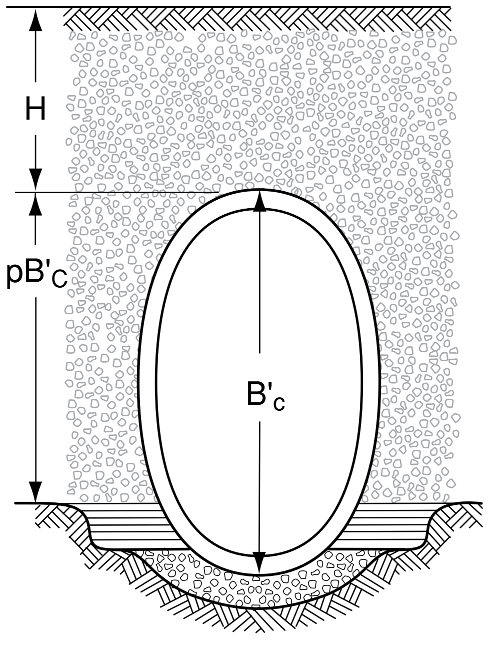
$$D_{ult.} = \frac{4{,}237}{2.07 \text{ x } 2.0} \text{ x } 1.5$$

$D_{ult.}$ = 1,535 pounds per linear foot per foot of inside diameter

Answer: A nonreinforced pipe which would withstand a minimum three edge bearing test load of 3,070 pounds per linear foot would be required.

A reinforced pipe which would withstand a minimum three-edge bearing test load for the ultimate load of 1,535 pounds per linear foot per foot inside diameter would be required.

EXAMPLE B-5
Positive Projecting Embankment Installation
Vertical Elliptical Pipe



Given: A 76 inch X 48 inch vertical elliptical pipe is to be installed in a positive projecting embankment condition in ordinary soil. The pipe will be covered with 50 feet of 120 pounds per cubic foot overfill.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

Solution:

1. Determination of Earth Load (W_E)
   A settlement ratio must first be assumed. In Table B-31 values of settlement ratio from +0.5 to +0.8 are given for positive projecting installations on a foundation of ordinary soil. A value of 0.5 will be used. The product of the settlement ratio and the projection ratio will be 0.35 ($r_{sd}p = 0.3$).

   Enter Figure 181 on the horizontal scale at H = 50 feet. Proceed vertically until the line representing R X S = 76" X 48" is intersected. At this point the vertical scale shows the fill load to be 37,100 pounds per linear foot for 100 pounds per cubic foot fill material. Increase the load 20 percent for 120 pound material.

   $W_c = 1.20 \text{ X } 37{,}100$
   $W_c = 44{,}520$ pounds per linear foot

2. Determination of Live Load (W_L)
   From Table 44, live load is negligible at a depth of 50 feet.

3. Selection of Bedding
   A Class B bedding will be assumed for this example.

4. Determination of Bedding Factor (B_f)
   From Table 59, for an H/B_c, ratio of 9.84, $r_{sd}p$ value of 0.3, p value of 0.7 and a Class B bedding, a bedding factor of 2.80 is obtained.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength
   The D-load is given by equation B17:

$$D_{0.01} = \frac{W_L + W_E}{B_f \text{ x } S} \text{ x F.S.}$$

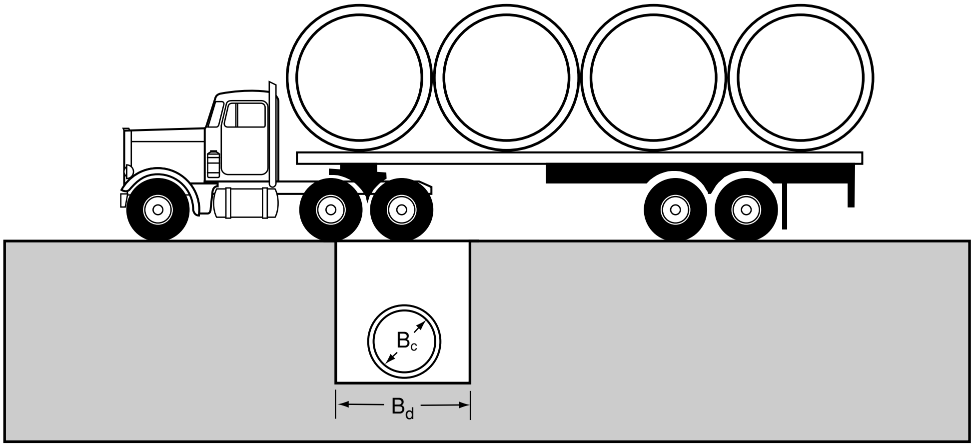
$W_{L\,+}\ W_E = W_c$ = 44,520 pounds per linear foot

$$D_{0.01} = \frac{44{,}520}{2.80 \text{ x } 4.0} \text{ x } 1.0$$

$D_{0.01}$ = 3,975 pounds per linear foot per foot of inside horizonal span

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01 inch crack of 3,975 pounds per linear foot per foot of inside horizontal span would be required.

EXAMPLE B-6
Highway Live Load



Given: A 12 inch circular pipe is to be installed in a narrow trench $B_d \leq (B_c + 1.0)$, under an unsurfaced roadway and covered with 1.0 foot of 120 pounds per cubic foot backfill material.

Find: The required pipe strength in terms of 0.01 inch crack D-load.

Solution: 1. Determination of Earth Load (W_E)
For pipe installed with less than 3 feet of cover, it is sufficiently accurate to calculate the backfill or fill load as being equal to the weight of the prism of earth on top of the pipe.

$W_d = wHB_c$
$W_d = 120 \text{ X } 1.0 \text{ X } 1.33$
W_d = 160 pounds per linear foot

2. Determination of Live Load (W_L)
   Since the pipe is being installed under an unsurfaced roadway with shallow cover, a truck loading based on legal load limitations should be evaluated. From Table 42, for D = 12 inches, H = 1.0 foot and AASHTO loading, a live load of 2,080 pounds per linear foot is obtained. This live load value includes impact.

3. Selection of Bedding
   A Class C bedding will be assumed for this example.

4. Determination of Bedding Factor (B_f)
   From Figure B-14, for circular pipe installed on a Class C bedding, a bedding factor of 1.5 is obtained.

5. Application of Factor of Safety (F.S.)
   A factor of safety of 1.0 based on the 0.01 inch crack will be applied.

6. Selection of Pipe Strength The D-load is given by equation B16:

$$D_{0.01} = \frac{W_L + W_E}{B_f \text{ x } D} \text{ x F.S.}$$

$$D_{0.01} = \frac{2{,}080 + 160}{1.5 \text{ x } 1.0} \text{ x } 1.0$$

$D_{0.01}$ = 1,493 pounds per linear foot per foot of inside diameter

Answer: A pipe which would withstand a minimum three-edge bearing test load for the 0.01-inch crack of 1,443 pounds per linear foot per foot of inside diameter would be required.

Appendix B
Tables
&
Figures

Table B-1

6" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 6"

* 100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-3"	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	
5	347	**470**									1'- 6"
6	376	499	**564**								1'- 8"
7	398	535	**658**								1'- 9"
8	416	564	722	**753**							1'-10"
9	429	587	758	**848**							1'-11"
10	439	606	787	**942**							1'-11"
11	447	621	811	**1037**							2'- 0"
12	453	633	831	1044	**1132**						2'- 1"
13	458	642	848	1070	**1227**						2'- 2"
14	461	650	861	1091	**1320**						2'- 3"
15	464	656	873	1110	1364	**1416**					2'- 4"
16	466	661	882	1125	1387	**1512**					2'- 4"
17	468	665	890	1138	1407	**1602**					2'- 5"
18	469	668	896	1149	1424	**1701**					2'- 6"
19	470	671	902	1159	1439	**1797**					2'- 6"
20	471	673	906	1167	1452	1758	**1887**				2'- 7"
21	471	675	910	1174	1463	1775	**1983**				2'- 8"
22	472	676	913	1179	1473	1790	**2074**				2'- 8"
23	472	677	915	1184	1481	1802	**2173**				2'- 9"
24	472	678	917	1189	1488	1814	2163	**2269**			2'-10"
25	472	679	919	1192	1494	1824	2177	**2362**			2'-11"
26	472	679	921	1195	1500	1832	2190	**2451**			2'-11"
27	473	680	922	1198	1504	1840	2201	**2553**			3'- 0"
28	473	680	923	1200	1508	1846	2212	**2652**			3'- 0"
29	473	680	924	1201	1512	1852	2221	2614	**2749**		3'- 1"
30	473	680	924	1203	1515	1857	2229	2626	**2843**		3'- 2"
31	473	681	925	1204	1517	1862	2236	2637	**2935**		3'- 2"
32	473	681	925	1205	1520	1866	2242	2646	**3024**		3'- 3"
33	473	681	926	1206	1521	1869	2247	2654	**3109**		3'- 3"
34	473	681	926	1207	1523	1872	2252	2662	3099	**3217**	3'- 4"
35	473	681	926	1208	1525	1875	2257	2669	3109	**3296**	3'- 4"
36	473	681	926	1208	1526	1877	2261	2675	3118	**3400**	3'- 5"
37	473	681	927	1209	1527	1879	2264	2680	3126	**3503**	3'- 5"
38	473	681	927	1209	1528	1881	2267	2685	3133	**3605**	3'- 6"
39	473	681	927	1210	1529	1882	2270	2689	3139	**3671**	3'- 6"
40	473	681	927	1210	1529	1884	2272	2693	3145	**3768**	3'- 7"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
1'-3"	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"		
363	**470**									1'- 6"	5
397	524	**564**								1'- 7"	6
423	565	**658**								1'- 8"	7
444	598	**753**								1'- 9"	8
460	626	802	**848**							1'-10"	9
473	648	836	**942**							1'-11"	10
483	666	865	**1037**							1'-11"	11
491	681	890	**1132**							2'- 0"	12
497	694	910	1143	**1227**						2'- 1"	13
502	704	928	1170	**1320**						2'- 2"	14
506	712	942	1192	**1416**						2'- 2"	15
509	719	955	1212	**1512**						2'- 3"	16
512	724	965	1229	1512	**1602**					2'- 4"	17
513	729	974	1243	1534	**1701**					2'- 5"	18
515	733	981	1256	1553	**1797**					2'- 5"	19
516	736	987	1266	1570	**1887**					2'- 6"	20
517	738	992	1276	1584	1915	**1983**				2'- 7"	21
518	740	997	1284	1597	1934	**2074**				2'- 7"	22
518	742	1001	1291	1608	1951	**2173**				2'- 8"	23
519	743	1004	1296	1618	1966	**2269**				2'- 8"	24
519	744	1006	1301	1627	1979	**2362**				2'- 9"	25
519	745	1008	1306	1634	1991	2373	**2451**			2'-10"	26
520	746	1010	1310	1641	2001	2388	**2553**			2'-10"	27
520	747	1012	1313	1647	2010	2401	**2652**			2'-11"	28
520	747	1013	1316	1652	2019	2414	**2749**			2'-11"	29
520	748	1014	1318	1656	2026	2425	**2843**			3'- 0"	30
520	748	1015	1320	1660	2032	2435	**2935**			3'- 0"	31
520	748	1016	1322	1663	2038	2444	2877	**3024**		3'- 1"	32
520	748	1017	1323	1666	2043	2451	2889	**3109**		3'- 1"	33
520	749	1017	1325	1669	2048	2459	2899	**3217**		3'- 2"	34
520	749	1018	1326	1671	2052	2465	2909	**3296**		3'- 2"	35
520	749	1018	1327	1673	2055	2471	2918	**3400**		3'- 3"	36
520	749	1019	1328	1675	2058	2476	2925	3405	**3503**	3'- 4"	37
520	749	1019	1328	1676	2061	2480	2932	3415	**3605**	3'- 4"	38
520	749	1019	1329	1678	2064	2485	2939	3424	**3671**	3'- 4"	39
520	749	1019	1330	1679	2066	2488	2945	3433	**3768**	3'- 5"	40

Table B-1 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-3"	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	
5	388	**470**									1'- 5"
6	428	**564**									1'- 6"
7	460	608	**658**								1'- 7"
8	487	649	**753**								1'- 8"
9	508	683	**848**								1'- 9"
10	525	712	**942**								1'- 9"
11	539	736	948	**1037**							1'-10"
12	551	757	979	**1132**							1'-11"
13	560	774	1007	**1227**							2'- 0"
14	568	788	1030	**1320**							2'- 0"
15	574	801	1051	1319	**1416**						2'- 1"
16	579	811	1068	1346	**1512**						2'- 2"
17	583	819	1083	1369	**1602**						2'- 2"
18	586	827	1096	1390	**1701**						2'- 3"
19	589	833	1107	1408	1730	**1797**					2'- 4"
20	591	838	1117	1424	1754	**1887**					2'- 4"
21	593	842	1125	1438	1775	**1983**					2'- 5"
22	594	846	1133	1450	1793	**2074**					2'- 5"
23	595	849	1139	1461	1810	**2173**					2'- 6"
24	596	851	1144	1470	1825	**2269**					2'- 6"
25	597	854	1149	1478	1838	2225	**2362**				2'- 7"
26	598	855	1153	1486	1850	2242	**2451**				2'- 8"
27	598	857	1156	1492	1861	2258	**2553**				2'- 8"
28	599	858	1159	1498	1870	2273	**2652**				2'- 9"
29	599	859	1162	1502	1878	2286	**2749**				2'- 9"
30	599	860	1164	1507	1886	2297	2738	**2843**			2'-10"
31	600	861	1166	1511	1892	2308	2753	**2935**			2'-10"
32	600	862	1167	1514	1898	2317	2767	**3024**			2'-11"
33	600	862	1169	1517	1904	2326	2780	**3109**			2'-11"
34	600	862	1170	1519	1908	2333	2791	**3217**			3'- 0"
35	600	863	1171	1522	1913	2340	2802	**3296**			3'- 0"
36	600	863	1172	1524	1916	2346	2811	3308	**3400**		3'- 1"
37	600	863	1173	1525	1920	2352	2820	3321	**3503**		3'- 1"
38	600	864	1173	1527	1922	2357	2828	3333	**3605**		3'- 2"
39	600	864	1174	1528	1925	2362	2835	3343	**3671**		3'- 2"
40	600	864	1174	1529	1927	2366	2842	3353	**3768**		3'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
1'-3"	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"		
415	**470**									1'- 4"	5
463	**564**									1'- 5"	6
503	**658**									1'- 6"	7
536	706	**753**								1'- 7"	8
564	749	**848**								1'- 7"	9
588	786	**942**								1'- 8"	10
607	818	**1037**								1'- 9"	11
624	846	1084	**1132**							1'-10"	12
638	870	1120	**1227**							1'-10"	13
649	891	1152	**1320**							1'-11"	14
659	909	1180	**1416**							1'-11"	15
667	924	1205	**1512**							2'- 0"	16
674	938	1227	1537	**1602**						2'- 1"	17
680	949	1247	1567	**1701**						2'- 1"	18
685	959	1264	1593	**1797**						2'- 2"	19
689	968	1279	1616	**1887**						2'- 2"	20
692	975	1292	1637	**1983**						2'- 3"	21
695	982	1304	1656	**2074**						2'- 3"	22
697	987	1314	1673	2058	**2173**					2'- 4"	23
699	992	1323	1688	2080	**2269**					2'- 4"	24
701	996	1331	1701	2101	**2362**					2'- 5"	25
702	1000	1339	1714	2120	**2451**					2'- 5"	26
704	1003	1345	1724	2136	**2553**					2'- 6"	27
705	1005	1350	1734	2152	**2652**					2'- 6"	28
705	1008	1355	1743	2166	2619	**2749**				2'- 7"	29
706	1010	1360	1751	2178	2638	**2843**				2'- 7"	30
707	1011	1363	1758	2190	2655	**2935**				2'- 8"	31
707	1013	1367	1764	2200	2670	**3024**				2'- 8"	32
708	1014	1370	1769	2209	2685	**3109**				2'- 8"	33
708	1015	1372	1774	2218	2698	**3217**				2'- 9"	34
708	1016	1374	1779	2226	2710	**3296**				2'- 9"	35
708	1017	1376	1783	2233	2721	3244	**3400**			2'-10"	36
709	1018	1378	1787	2239	2731	3259	**3503**			2'-10"	37
709	1018	1380	1790	2245	2740	3273	**3605**			2'-11"	38
709	1019	1381	1793	2250	2749	3285	**3671**			2'-11"	39
709	1019	1382	1795	2255	2756	3297	**3768**			3'- 0"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-2

8" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 8"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL   LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	
5	454	566	**603**								1'-10"
6	499	628	**724**								1'-11"
7	535	680	**847**								2'- 0"
8	564	722	888	**969**							2'- 1"
9	587	758	937	**1088**							2'- 2"
10	606	787	979	**1213**							2'- 3"
11	621	811	1014	1228	**1332**						2'- 4"
12	633	831	1044	1270	**1458**						2'- 5"
13	642	848	1070	1306	**1575**						2'- 6"
14	650	861	1091	1337	1595	**1698**					2'- 7"
15	656	873	1110	1364	1632	**1818**					2'- 8"
16	661	882	1125	1387	1664	**1942**					2'- 9"
17	665	890	1138	1407	1693	1993	**2065**				2'-10"
18	668	896	1149	1424	1717	2027	**2182**				2'-10"
19	671	902	1159	1439	1739	2057	**2308**				2'-11"
20	673	906	1167	1452	1758	2083	**2429**				3'- 0"
21	675	910	1174	1463	1775	2107	2456	**2553**			3'- 1"
22	676	913	1179	1473	1790	2128	2484	**2673**			3'- 2"
23	677	915	1184	1481	1802	2146	2510	**2788**			3'- 2"
24	678	917	1189	1488	1814	2163	2532	**2910**			3'- 3"
25	679	919	1192	1494	1824	2177	2552	2947	**3041**		3'- 4"
26	679	921	1195	1500	1832	2190	2571	2972	**3154**		3'- 4"
27	680	922	1198	1504	1840	2201	2587	2994	**3278**		3'- 5"
28	680	923	1200	1508	1846	2212	2601	3014	**3398**		3'- 6"
29	680	924	1201	1512	1852	2221	2614	3032	**3514**		3'- 6"
30	680	924	1203	1515	1857	2229	2626	3048	3492	**3646**	3'- 7"
31	681	925	1204	1517	1862	2236	2637	3063	3512	**3776**	3'- 8"
32	681	925	1205	1520	1866	2242	2646	3076	3530	**3880**	3'- 8"
33	681	926	1206	1521	1869	2247	2654	3088	3546	**4004**	3'- 9"
34	681	926	1207	1523	1872	2252	2662	3099	3561	**4124**	3'- 9"
35	681	926	1208	1525	1875	2257	2669	3109	3575	**4241**	3'-10"
36	681	926	1208	1526	1877	2261	2675	3118	3587	**4384**	3'-11"
37	681	927	1209	1527	1879	2264	2680	3126	3598	**4495**	3'-11"
38	681	927	1209	1528	1881	2267	2685	3133	3608	**4603**	4'- 0"
39	681	927	1210	1529	1882	2270	2689	3139	3618	**4740**	4'- 0"
40	681	927	1210	1529	1884	2272	2693	3142	3626	**4877**	4'- 1"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"		
474	**603**									1'- 9"	5
524	655	**724**								1'-11"	6
565	713	**847**								2'- 0"	7
598	761	931	**969**							2'- 1"	8
626	802	987	**1088**							2'- 2"	9
648	836	1035	**1213**							2'- 3"	10
666	865	1077	**1332**							2'- 3"	11
681	890	1112	1346	**1458**						2'- 4"	12
694	910	1143	1389	**1575**						2'- 5"	13
704	928	1170	1426	**1698**						2'- 6"	14
712	942	1192	1459	1738	**1818**					2'- 7"	15
719	955	1212	1487	1777	**1942**					2'- 8"	16
724	965	1229	1512	1812	**2065**					2'- 8"	17
729	974	1243	1534	1843	**2182**					2'- 9"	18
733	981	1256	1553	1870	2203	**2308**				2'-10"	19
736	987	1266	1570	1894	2236	**2429**				2'-11"	20
738	992	1276	1584	1915	2265	**2553**				2'-11"	21
740	997	1284	1597	1934	2292	**2673**				3'- 0"	22
742	1001	1291	1608	1951	2315	2699	**2788**			3'- 1"	23
743	1004	1296	1618	1966	2336	2727	**2910**			3'- 1"	24
744	1006	1301	1627	1979	2355	2753	**3041**			3'- 2"	25
745	1008	1306	1634	1991	2373	2777	**3154**			3' 3"	26
746	1010	1310	1641	2001	2388	2798	**3278**			3'- 3"	27
747	1012	1313	1647	2010	2401	2817	3255	**3398**		3'- 4"	28
747	1013	1316	1652	2019	2414	2834	3278	**3514**		3'- 5"	29
748	1014	1318	1656	2026	2425	2850	3300	**3646**		3'- 5"	30
748	1015	1320	1660	2032	2435	2864	3319	**3776**		3'- 6"	31
748	1016	1322	1663	2038	2444	2877	3337	**3880**		3'- 6"	32
748	1017	1323	1666	2043	2451	2889	3353	3842	**4004**	3'- 7"	33
749	1017	1325	1669	2048	2459	2899	3368	3861	**4124**	3'- 8"	34
749	1018	1326	1671	2052	2465	2909	3381	3880	**4241**	3'- 8"	35
749	1018	1327	1673	2055	2471	2918	3393	3896	**4384**	3'- 9"	36
749	1019	1328	1675	2058	2476	2925	3405	3912	**4495**	3'- 9"	37
749	1019	1328	1676	2061	2480	2932	3415	3926	**4603**	3'-10"	38
749	1019	1329	1678	2064	2485	2939	3424	3939	**4740**	3'-10"	39
749	1019	1330	1679	2066	2488	2945	3433	3950	**4877**	3'-11"	40

Table B-2 Continued

C ORDINARY CLAY $K\mu'$—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	
5	501	**603**									1'- 9"
6	559	694	**724**								1'-10"
7	608	761	**847**								1'-11"
8	649	819	**969**								2'- 0"
9	683	868	**1088**								2'- 0"
10	712	911	1119	**1213**							2'- 1"
11	736	948	1170	**1332**							2'- 2"
12	757	979	1215	**1458**							2'- 3"
13	774	1007	1254	1513	**1575**						2'- 4"
14	788	1030	1289	1560	**1698**						2'- 4"
15	801	1051	1319	1603	**1818**						2'- 5"
16	811	1068	1346	1640	**1942**						2'- 6"
17	819	1083	1369	1674	1993	**2065**					2'- 7"
18	827	1096	1390	1703	2034	**2182**					2'- 7"
19	833	1107	1408	1730	2070	**2308**					2'- 8"
20	838	1117	1424	1754	2103	**2429**					2'- 9"
21	842	1125	1438	1775	2133	**2553**					2'- 9"
22	846	1133	1450	1793	2159	2545	**2673**				2'-10"
23	849	1139	1461	1810	2184	2578	**2788**				2'-11"
24	851	1144	1470	1825	2205	2607	**2910**				2'-11"
25	854	1149	1478	1838	2225	2635	**3041**				3'- 0"
26	855	1153	1486	1850	2242	2659	**3154**				3'- 0"
27	857	1156	1492	1861	2258	2682	3128	**3278**			3'- 1"
28	858	1159	1498	1870	2273	2702	3155	**3398**			3'- 2"
29	859	1162	1502	1878	2286	2721	3181	**3514**			3'- 2"
30	860	1164	1507	1886	2297	2738	3204	**3646**			3'- 3"
31	861	1166	1511	1892	2308	2753	3225	**3776**			3'- 3"
32	862	1167	1514	1898	2317	2767	3245	3748	**3880**		3'- 4"
33	862	1169	1517	1904	2326	2780	3263	3772	**4004**		3'- 4"
34	862	1170	1519	1908	2333	2791	3279	3794	**4124**		3'- 5"
35	863	1171	1522	1913	2340	2802	3294	3815	**4241**		3'- 5"
36	863	1172	1524	1916	2346	2811	3308	3834	**4384**		3'- 6"
37	863	1173	1525	1920	2352	2820	3321	3851	**4495**		3'- 6"
38	864	1173	1527	1922	2357	2828	3333	3868	4431	**4603**	3'- 7"
39	864	1174	1528	1925	2362	2835	3343	3883	4451	**4740**	3'- 7"
40	864	1174	1529	1927	2366	2842	3353	3896	4470	**4877**	3'- 8"

D SATURATED CLAY $K\mu'$—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
1'-6"	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"		
531	**603**									1'- 8"	5
598	**724**									1'- 9"	6
656	814	**847**								1'-10"	7
706	882	**969**								1'-10"	8
749	943	**1088**								1'-11"	9
786	996	**1213**								2'- 0"	10
818	1042	1276	**1332**							2'- 1"	11
846	1084	1332	**1458**							2'- 1"	12
870	1120	1383	**1575**							2'- 2"	13
891	1152	1428	**1698**							2'- 3"	14
909	1180	1469	**1818**							2'- 3"	15
924	1205	1505	1819	**1942**						2'- 4"	16
938	1227	1537	1864	**2065**						2'- 5"	17
949	1247	1567	1905	**2182**						2'- 5"	18
959	1264	1593	1942	**2308**						2'- 6"	19
968	1279	1616	1975	2352	**2429**					2'- 7"	20
975	1292	1637	2005	2393	**2553**					2'- 7"	21
982	1304	1656	2033	2431	**2673**					2'- 8"	22
987	1314	1673	2058	2465	**2788**					2'- 8"	23
992	1323	1688	2080	2497	**2910**					2'- 9"	24
996	1331	1701	2101	2526	**3041**					2'- 9"	25
1000	1339	1714	2120	2552	3008	**3154**				2'-10"	26
1003	1345	1724	2136	2576	3041	**3278**				2'-10"	27
1005	1350	1734	2152	2599	3071	**3398**				2'-11"	28
1008	1355	1743	2166	2619	3099	**3514**				3'- 0"	29
1010	1360	1751	2178	2638	3125	**3646**				3'- 0"	30
1011	1363	1758	2190	2655	3149	3669	**3776**			3'- 1"	31
1013	1367	1764	2200	2670	3171	3699	**3880**			3'- 1"	32
1014	1370	1769	2209	2685	3192	3727	**4004**			3'- 2"	33
1015	1372	1774	2218	2698	3211	3752	**4124**			3'- 2"	34
1016	1374	1779	2226	2710	3228	3776	**4241**			3'- 2"	35
1017	1376	1783	2233	2721	3244	3798	**4384**			3'- 3"	36
1018	1378	1787	2239	2731	3259	3819	**4495**			3'- 3"	37
1018	1380	1790	2245	2740	3273	3838	4434	**4603**		3'- 4"	38
1019	1381	1793	2250	2749	3285	3856	4458	**4740**		3'- 4"	39
1019	1382	1795	2255	2756	3297	3873	4480	**4877**		3'- 5"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on $K\mu$—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-3

10" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 10"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	
5	566	680	**743**								2'- 2"
6	628	761	**893**								2'- 3"
7	680	830	984	**1043**							2'- 4"
8	722	888	1059	**1193**							2'- 5"
9	758	937	1124	**1344**							2'- 6'
10	787	979	1180	1388	**1495**						2'- 8"
11	811	1014	1228	1450	**1645**						2'- 8"
12	831	1044	1270	1505	1748	**1795**					2'-10"
13	848	1070	1306	1553	1810	**1946**					2'-11"
14	861	1091	1337	1595	1864	**2094**					3'- 0"
15	873	1110	1364	1632	1912	**2241**					3'- 0"
16	882	1125	1387	1664	1955	2258	**2395**				3'- 1"
17	890	1138	1407	1693	1993	2306	**2547**				3'- 2"
18	896	1149	1424	1717	2027	2350	**2698**				3'- 3"
19	902	1159	1439	1739	2057	2389	2735	**2842**			3'- 4"
20	906	1167	1452	1758	2083	2425	2780	**2994**			3'- 5"
21	910	1174	1463	1775	2107	2456	2821	**3150**			3'- 6"
22	913	1179	1473	1790	2128	2484	2857	**3301**			3'- 6"
23	915	1184	1481	1802	2146	2510	2891	3287	**3445**		3'- 7"
24	917	1189	1488	1814	2163	2532	2920	3325	**3595**		3'- 8"
25	919	1192	1494	1824	2177	2552	2947	3360	**3739**		3'- 9"
26	921	1195	1500	1832	2190	2571	2972	3392	**3892**		3'- 9"
27	922	1198	1504	1840	2201	2587	2994	3421	**4041**		3'-10"
28	923	1200	1508	1846	2212	2601	3014	3447	**4201**		3'-11"
29	924	1201	1512	1852	2221	2614	3032	3471	**4340**		4'- 0"
30	924	1203	1515	1857	2229	2626	3048	3492	**4493**		4'- 0"
31	925	1204	1517	1862	2236	2637	3063	3512	4472	**4642**	4'- 1"
32	925	1205	1520	1866	2242	2646	3076	3530	4502	**4786**	4'- 2"
33	926	1206	1521	1869	2247	2654	3088	3546	4529	**4950**	4'- 2"
34	926	1207	1523	1872	2252	2662	3099	3561	4555	**5085**	4'- 3"
35	926	1208	1525	1875	2257	2669	3109	3575	4578	**5243**	4'- 4"
36	926	1208	1526	1877	2261	2675	3118	3587	4599	**5397**	4'- 4"
37	927	1209	1527	1879	2264	2680	3126	3598	4619	**5549**	4'- 5"
38	927	1209	1528	1881	2267	2685	3133	3608	4637	**5697**	4'- 6"
39	927	1210	1529	1882	2270	2689	3139	3618	4654	**5842**	4'- 6"
40	927	1210	1529	1884	2272	2693	3145	3626	4669	**5983**	4'- 7"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"		
587	703	**743**								2'- 1"	5
655	791	**893**								2'- 2"	6
713	866	**1043**								2'- 3"	7
761	931	1106	**1193**							2'- 4"	8
802	987	1179	**1344**							2'- 5"	9
836	1035	1242	1455	**1495**						2'- 7"	10
865	1077	1298	1526	**1645**						2'- 8"	11
890	1112	1346	1589	**1795**						2'- 9"	12
910	1143	1389	1645	**1946**						2'- 9"	13
928	1170	1426	1695	1973	**2094**					2'-10"	14
942	1192	1459	1738	2030	**2241**					2'-11"	15
955	1212	1487	1777	2080	**2395**					3'- 0"	16
965	1229	1512	1812	2126	2451	**2547**				3'- 1"	17
974	1243	1534	1843	2167	2504	**2698**				3'- 2"	18
981	1256	1553	1870	2203	2551	**2842**				3'- 2"	19
987	1266	1570	1894	2236	2593	**2994**				3'- 3"	20
992	1276	1584	1915	2265	2632	3014	**3150**			3'- 4"	21
997	1284	1597	1934	2292	2667	3058	**3301**			3'- 5"	22
1001	1291	1608	1951	2315	2699	3099	**3445**			3'- 5"	23
1004	1296	1618	1966	2336	2727	3136	**3595**			3'- 6"	24
1006	1301	1627	1979	2355	2753	3170	3604	**3739**		3'- 7"	25
1008	1306	1634	1991	2373	2777	3201	3643	**3892**		3'- 8"	26
1010	1310	1641	2001	2388	2798	3229	3679	**4041**		3'- 8"	27
1012	1313	1647	2010	2401	2817	3255	3712	**4201**		3'- 9"	28
1013	1316	1652	2019	2414	2834	3278	3743	**4340**		3'-10"	29
1014	1318	1656	2026	2425	2850	3300	3771	**4493**		3'-10"	30
1015	1320	1660	2032	2435	2864	3319	3796	**4642**		3'-11"	31
1016	1322	1663	2038	2444	2877	3337	3820	**4786**		4'- 0"	32
1017	1323	1666	2043	2451	2889	3353	3842	**4950**		4'- 0"	33
1017	1325	1669	2048	2459	2899	3368	3861	4916	**5085**	4'- 1"	34
1018	1326	1671	2052	2465	2909	3381	3380	4946	**5243**	4'- 2"	35
1018	1327	1673	2055	2471	2918	3393	3896	4974	**5397**	4'- 2"	36
1019	1328	1675	2058	2476	2925	3405	3912	5000	**5549**	4'- 3"	37
1019	1328	1676	2061	2480	2932	3415	3926	5024	**5697**	4'- 3"	38
1019	1329	1678	2064	2485	2939	3424	3939	5047	**5842**	4'- 4"	39
1019	1330	1679	2066	2488	2945	3433	3950	5067	**5983**	4'- 5"	40

Table B-3 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	
5	617	**743**									2'- 0"
6	694	833	**893**								2'- 1"
7	761	919	**1043**								2'- 2"
8	819	994	**1193**								2'- 3"
9	868	1060	1258	**1344**							2'- 4"
10	911	1119	1334	**1495**							2'- 5"
11	948	1170	1400	**1645**							2'- 6"
12	979	1215	1460	1713	**1795**						2'- 7"
13	1007	1254	1513	1781	**1946**						2'- 8"
14	1030	1289	1560	1843	**2094**						2'- 8"
15	1051	1319	1603	1898	**2241**						2'- 9"
16	1068	1346	1640	1948	2267	**2395**					2'-10"
17	1083	1369	1674	1993	2325	**2547**					2'-11"
18	1096	1390	1703	2034	2378	**2698**					3'- 0"
19	1107	1408	1730	2070	2426	**2842**					3'- 0"
20	1117	1424	1754	2103	2469	2849	**2994**				3'- 1"
21	1125	1438	1775	2133	2509	2900	**3150**				3'- 2"
22	1133	1450	1793	2159	2545	2947	**3301**				3'- 2"
23	1139	1461	1810	2184	2578	2989	**3445**				3'- 3"
24	1144	1470	1825	2205	2607	3029	3466	**3595**			3'- 4"
25	1149	1478	1838	2225	2635	3064	3512	**3739**			3'- 5"
26	1153	1486	1850	2242	2659	3097	3554	**3892**			3'- 5"
27	1156	1492	1861	2258	2682	3128	3593	**4041**			3'- 6"
28	1159	1498	1870	2273	2702	3155	3630	**4201**			3'- 6"
29	1162	1502	1878	2286	2721	3181	3663	4165	**4340**		3'- 7"
30	1164	1507	1886	2297	2738	3204	3693	4204	**4493**		3'- 8"
31	1166	1511	1892	2308	2753	3225	3722	4240	**4642**		3'- 8"
32	1167	1514	1898	2317	2767	3245	3748	4274	**4786**		3'- 9"
33	1169	1517	1904	2326	2780	3263	3772	4305	**4950**		3'- 9"
34	1170	1519	1908	2333	2791	3279	3794	4334	**5085**		3'-10"
35	1171	1522	1913	2340	2802	3294	3815	4361	**5243**		3'-11"
36	1172	1524	1916	2346	2811	3308	3834	4386	**5397**		3'-11"
37	1173	1525	1920	2352	2820	3321	3851	4409	**5549**		4'- 0"
38	1173	1527	1922	2357	2828	3333	3868	4431	**5697**		4'- 0"
39	1174	1528	1925	2362	2835	3343	3883	4451	5666	**5842**	4'- 1"
40	1174	1529	1927	2366	2842	3353	3896	4470	5696	**5983**	4'- 1"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
1'-9"	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"		
649	**743**									1'-11"	5
737	**893**									2'- 0"	6
814	976	**1043**								2'- 1"	7
882	1064	**1193**								2'- 2"	8
943	1142	**1344**								2'- 3"	9
996	1212	1435	**1495**							2'- 4"	10
1042	1276	1516	**1645**							2'- 5"	11
1084	1332	1589	**1795**							2'- 5"	12
1120	1383	1655	**1946**							2'- 6"	13
1152	1428	1715	2012	**2094**						2'- 7"	14
1180	1469	1770	2082	**2241**						2'- 8"	15
1205	1505	1819	2145	**2395**						2'- 8"	16
1227	1537	1864	2204	**2547**						2'- 9"	17
1247	1567	1905	2258	2623	**2698**					2'-10"	18
1264	1593	1942	2307	2685	**2842**					2'-10"	19
1279	1616	1975	2352	2743	**2994**					2'-11"	20
1292	1637	2005	2393	2796	**3150**					3'- 0"	21
1304	1656	2033	2431	2846	**3301**					3'- 0"	22
1314	1673	2058	2465	2891	3333	**3445**				3'- 1"	23
1323	1688	2080	2497	2933	3387	**3595**				3'- 1"	24
1331	1701	2101	2526	2972	3436	**3739**				3'- 2"	25
1339	1714	2120	2552	3008	3483	**3892**				3'- 2"	26
1345	1724	2136	2576	3041	3526	**4041**				3'- 3"	27
1350	1734	2152	2599	3071	3566	4079	**4201**			3'- 4"	28
1355	1743	2166	2619	3099	3603	4126	**4340**			3'- 4"	29
1360	1751	2178	2638	3125	3637	4171	**4493**			3'- 5"	30
1363	1758	2190	2655	3149	3669	4212	**4642**			3'- 5"	31
1367	1764	2200	2670	3171	3699	4250	**4786**			3'- 6"	32
1370	1769	2209	2685	3192	3727	4286	**4950**			3'- 6"	33
1372	1774	2218	2698	3211	3752	4320	4911	**5085**		3'- 7"	34
1374	1779	2226	2710	3228	3776	4351	4951	**5243**		3'- 7"	35
1376	1783	2233	2721	3244	3798	4381	4988	**5397**		3'- 8"	36
1378	1787	2239	2731	3259	3819	4408	5024	**5549**		3'- 8"	37
1380	1790	2245	2740	3273	3838	4434	5057	**5697**		3'- 9"	38
1381	1793	2250	2749	3285	3856	4458	5088	**5842**		3'- 9"	39
1382	1795	2255	2756	3297	3873	4480	5117	**5983**		3'-10"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-4

12" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 12"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	
5	680	797	915	**985**							2'- 8"
6	761	897	1036	**1185**							2'- 9"
7	830	984	1142	1302	**1385**						2'-11"
8	888	1059	1235	1414	**1585**						3'- 0"
9	937	1124	1316	1513	1713	**1786**					3'- 1"
10	979	1180	1388	1601	1819	**1982**					3'- 2"
11	1014	1228	1450	1679	1914	**2182**					3'- 3"
12	1044	1270	1505	1748	1998	2254	**2385**				3'- 5"
13	1070	1306	1553	1810	2074	2345	**2581**				3'- 6"
14	1091	1337	1595	1864	2142	2428	2720	**2785**			3'- 7"
15	1110	1364	1632	1912	2203	2502	2809	**2986**			3'- 8"
16	1125	1387	1664	1955	2258	2570	2890	**3186**			3'- 9"
17	1138	1407	1693	1993	2306	2631	2964	**3385**			3'-10"
18	1149	1424	1717	2027	2350	2686	3032	**3588**			3'-11"
19	1159	1439	1739	2057	2389	2735	3093	**3780**			4'- 0"
20	1167	1452	1758	2083	2425	2780	3148	**3979**			4'- 0"
21	1174	1463	1775	2107	2456	2821	3199	3991	**4177**		4'- 1"
22	1179	1473	1790	2128	2484	2857	3245	4058	**4377**		4'- 2"
23	1184	1481	1802	2146	2510	2891	3287	4121	**4581**		4'- 3"
24	1189	1488	1814	2163	2532	2920	3325	4179	**4777**		4'- 4"
25	1192	1494	1824	2177	2552	2947	3360	4232	**4979**		4'- 5"
26	1195	1500	1832	2190	2571	2972	3392	4280	**5174**		4'- 6"
27	1198	1504	1840	2201	2587	2994	3421	4325	5289	**5377**	4'- 7"
28	1200	1508	1846	2212	2601	3014	3447	4367	5349	**5575**	4'- 7"
29	1201	1512	1852	2221	2614	3032	3471	4405	5404	**5784**	4'- 8"
30	1203	1515	1857	2229	2626	3048	3492	4440	5456	**5969**	4'- 9"
31	1204	1517	1862	2236	2637	3063	3512	4472	5504	**6188**	4'-10"
32	1205	1520	1866	2242	2646	3076	3530	4502	5549	**6381**	4'-10"
33	1206	1521	1869	2247	2654	3088	3546	4529	5590	**6569**	4'-11"
34	1207	1523	1872	2252	2662	3099	3561	4555	5629	**6774**	5'- 0"
35	1208	1525	1875	2257	2669	3109	3575	4578	5665	**6976**	5'- 1"
36	1208	1526	1877	2261	2675	3118	3587	4599	5698	**7173**	5'- 1"
37	1209	1527	1879	2264	2680	3126	3598	4619	5729	**7365**	5'- 2"
38	1209	1528	1881	2267	2685	3133	3608	4637	5758	**7583**	5'- 3"
39	1210	1529	1882	2270	2689	3139	3618	4654	5784	**7765**	5'- 4"
40	1210	1529	1884	2272	2693	3145	3626	4669	5809	**7976**	5'- 4"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"		
703	821	939	**985**							2'- 7"	5
791	929	1069	**1185**							2'- 8"	6
866	1023	1183	1346	**1385**						2'-10"	7
931	1106	1285	1467	**1585**						2'-11"	8
987	1179	1375	1576	**1786**						3'- 0"	9
1035	1242	1455	1674	1896	**1982**					3'- 1"	10
1077	1298	1526	1761	2001	**2182**					3'- 2"	11
1112	1346	1589	1840	2096	**2385**					3'- 3"	12
1143	1389	1645	1910	2182	2460	**2581**				3'- 4"	13
1170	1426	1695	1973	2260	2553	**2785**				3'- 5"	14
1192	1459	1738	2030	2330	2639	**2986**				3'- 6"	15
1212	1487	1777	2080	2394	2716	3047	**3186**			3'- 7"	16
1229	1512	1812	2126	2451	2787	3132	**3385**			3'- 8"	17
1243	1534	1843	2167	2504	2852	3210	**3588**			3'- 9"	18
1256	1553	1870	2203	2551	2911	3282	**3780**			3'-10"	19
1266	1570	1894	2236	2593	2965	3347	**3979**			3'-11"	20
1276	1584	1915	2265	2632	3014	3408	**4177**			4'- 0"	21
1284	1597	1934	2292	2667	3058	3463	**4377**			4'- 0"	22
1291	1608	1951	2315	2699	3099	3514	4383	**4581**		4'- 1"	23
1296	1618	1966	2336	2727	3136	3561	4451	**4777**		4'- 2"	24
1301	1627	1979	2355	2753	3170	3604	4515	**4979**		4'- 3"	25
1306	1634	1991	2373	2777	3201	3643	4574	**5174**		4'- 4"	26
1310	1641	2001	2388	2798	3229	3679	4629	**5377**		4'- 5"	27
1313	1647	2010	2401	2817	3255	3712	4680	**5575**		4'- 5"	28
1316	1652	2019	2414	2834	3278	3743	4727	**5784**		4'- 6"	29
1318	1656	2026	2425	2850	3300	3771	4771	5836	**5969**	4'- 7"	30
1320	1660	2032	2435	2864	3319	3796	4811	5895	**6188**	4'- 8"	31
1322	1663	2038	2444	2877	3337	3820	4849	5950	**6381**	4'- 8"	32
1323	1666	2043	2451	2889	3353	3842	4884	6002	**6569**	4'- 9"	33
1325	1669	2048	2459	2899	3368	3861	4916	6050	**6774**	4'-10"	34
1326	1671	2052	2465	2909	3381	3880	4946	6095	**6976**	4'-10"	35
1327	1673	2055	2471	2918	3393	3896	4974	6137	**7173**	4'-11"	36
1328	1675	2058	2476	2925	3405	3912	5000	6177	**7365**	5'- 0"	37
1328	1676	2061	2480	2932	3415	3926	5024	6214	**7583**	5'- 0"	38
1329	1678	2064	2485	2939	3424	3939	5047	6248	**7765**	5'- 1"	39
1330	1679	2066	2488	2945	3433	3950	5067	6280	**7976**	5'- 2"	40

Table B-4 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	
5	735	854	**985**								2'- 6"
6	833	973	1115	**1185**							2'- 7"
7	919	1079	1243	**1385**							2'- 9"
8	994	1174	1357	1543	**1585**						2'-10"
9	1060	1258	1461	1666	**1786**						2'-11"
10	1119	1334	1554	1778	**1982**						3'- 0"
11	1170	1400	1638	1880	2127	**2182**					3'- 1"
12	1215	1460	1713	1973	2238	**2385**					3'- 2"
13	1254	1513	1781	2057	2339	**2581**					3'- 2"
14	1289	1560	1843	2134	2432	**2785**					3'- 3"
15	1319	1603	1898	2204	2518	2838	**2986**				3'- 4"
16	1346	1640	1948	2267	2596	2932	**3186**				3'- 5"
17	1369	1674	1993	2325	2668	3019	**3385**				3'- 6"
18	1390	1703	2034	2378	2734	3099	3474	**3588**			3'- 7"
19	1408	1730	2070	2426	2794	3173	3562	**3780**			3'- 8"
20	1424	1754	2103	2469	2849	3242	3645	**3979**			3'- 8"
21	1438	1775	2133	2509	2900	3305	3721	**4177**			3'- 9"
22	1450	1793	2159	2545	2947	3363	3792	**4377**			3'-10"
23	1461	1810	2184	2578	2989	3417	3858	**4581**			3'-11"
24	1470	1825	2205	2607	3029	3466	3919	**4777**			3'-11"
25	1478	1838	2225	2635	3064	3512	3975	**4979**			4'- 0"
26	1486	1850	2242	2659	3097	3554	4028	5018	**5174**		4'- 1"
27	1492	1861	2258	2682	3128	3593	4077	5089	**5377**		4'- 2"
28	1498	1870	2273	2702	3155	3630	4122	5156	**5575**		4'- 2"
29	1502	1878	2286	2721	3181	3663	4165	5219	**5784**		4'- 3"
30	1507	1886	2297	2738	3204	3693	4204	5278	**5969**		4'- 4"
31	1511	1892	2308	2753	3225	3722	4240	5333	**6188**		4'- 5"
32	1514	1898	2317	2767	3245	3748	4274	5385	**6381**		4'- 5"
33	1517	1904	2326	2780	3263	3772	4305	5433	**6569**		4'- 6"
34	1519	1908	2333	2791	3279	3794	4334	5478	**6774**		4'- 6"
35	1522	1913	2340	2802	3294	3815	4361	5521	6757	**6976**	4'- 7"
36	1524	1916	2346	2811	3308	3834	4386	5561	6815	**7173**	4'- 8"
37	1525	1920	2352	2820	3321	3851	4409	5598	6870	**7365**	4'- 8"
38	1527	1922	2357	2828	3333	3868	4431	5633	6921	**7583**	4'- 9"
39	1528	1925	2362	2835	3343	3883	4451	5666	6970	**7765**	4'- 9"
40	1529	1927	2366	2842	3353	3896	4470	5696	7016	**7976**	4'-10"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
2'-0"	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"		
769	889	**985**								2'- 5"	5
878	1021	**1185**								2'- 6"	6
976	1140	1306	**1385**							2'- 7"	7
1064	1248	1435	**1585**							2'- 8"	8
1142	1346	1554	**1786**							2'- 9"	9
1212	1435	1662	1892	**1982**						2'-10"	10
1276	1516	1761	2011	**2182**						2'-11"	11
1332	1589	1852	2121	**2385**						3'- 0"	12
1383	1655	1935	2222	2514	**2581**					3'- 1"	13
1428	1715	2012	2315	2625	**2785**					3'- 2"	14
1469	1770	2082	2402	2729	**2986**					3'- 2"	15
1505	1819	2145	2481	2825	**3186**					3'- 3"	16
1537	1864	2204	2555	2914	3282	**3385**				3'- 4"	17
1567	1905	2258	2623	2998	3381	**3588**				3'- 5"	18
1593	1942	2307	2685	3075	3474	**3780**				3'- 5"	19
1616	1975	2352	2743	3147	3561	**3979**				3'- 6"	20
1637	2005	2393	2796	3213	3642	4080	**4177**			3'- 7"	21
1656	2033	2431	2846	3275	3718	4171	**4377**			3'- 7"	22
1673	2058	2465	2891	3333	3789	4256	**4581**			3'- 8"	23
1688	2080	2497	2933	3387	3855	4336	**4777**			3'- 9"	24
1701	2101	2526	2972	3436	3917	4411	**4979**			3'- 9"	25
1714	2120	2552	3008	3483	3975	4481	**5174**			3'-10"	26
1724	2136	2576	3041	3526	4029	4548	**5377**			3'-11"	27
1734	2152	2599	3071	3566	4079	4610	**5575**			3'-11"	28
1743	2166	2619	3099	3603	4126	4668	**5784**			4'- 0"	29
1751	2178	2638	3125	3637	4171	4723	**5969**			4'- 0"	30
1758	2190	2655	3149	3669	4212	4774	5950	**6188**		4'- 1"	31
1764	2200	2670	3171	3699	4250	4823	6021	**6381**		4'- 2"	32
1769	2209	2685	3192	3727	4286	4868	6088	**6569**		4'- 2"	33
1774	2218	2698	3211	3752	4320	4911	6151	**6774**		4'- 3"	34
1779	2226	2710	3228	3776	4351	4951	6211	**6976**		4'- 3"	35
1783	2233	2721	3244	3798	4381	4988	6268	**7173**		4'- 4"	36
1787	2239	2731	3259	3819	4408	5024	6322	**7365**		4'- 5"	37
1790	2245	2740	3273	3838	4434	5057	6373	**7583**		4'- 5"	38
1793	2250	2749	3285	3856	4458	5088	6421	**7765**		4'- 6"	39
1795	2255	2756	3297	3873	4480	5117	6466	**7976**		4'- 6"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads ***(bold type)*** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-5

15" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 15"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	
5	797	915	1033	1153	**1203**						3'- 1"
6	897	1036	1176	1317	**1448**						3'- 3"
7	984	1142	1302	1464	1628	**1692**					3'- 4"
8	1059	1235	1414	1596	1780	**1938**					3'- 5"
9	1124	1316	1513	1713	1917	2123	**2183**				3'- 7"
10	1180	1388	1601	1819	2041	2266	**2429**				3'- 8"
11	1228	1450	1679	1914	2153	2396	**2672**				3'- 9"
12	1270	1505	1748	1998	2254	2514	**2920**				3'-11"
13	1306	1553	1810	2074	2345	2622	**3162**				4'- 0"
14	1337	1595	1864	2142	2428	2720	3320	**3408**			4'- 1"
15	1364	1632	1912	2203	2502	2809	3441	**3647**			4'- 2"
16	1387	1664	1955	2258	2570	2890	3553	**3900**			4'- 3"
17	1407	1693	1993	2306	2631	2964	3655	**4142**			4'- 4"
18	1424	1717	2027	2350	2686	3032	3750	**4382**			4'- 5"
19	1439	1739	2057	2389	2735	3093	3837	**4624**			4'- 6"
20	1452	1758	2083	2425	2780	3148	3917	4720	**4870**		4'- 7"
21	1463	1775	2107	2456	2821	3199	3991	4820	**5123**		4'- 8"
22	1473	1790	2128	2484	2857	3245	4058	4913	**5368**		4'- 9"
23	1481	1802	2146	2510	2891	3287	4121	5000	**5603**		4'-10"
24	1488	1814	2163	2532	2920	3325	4179	5080	**5851**		4'-11"
25	1494	1824	2177	2552	2947	3360	4232	5155	**6091**		5'- 0"
26	1500	1832	2190	2571	2972	3392	4280	5224	6213	**6350**	5'- 1"
27	1504	1840	2201	2587	2994	3421	4325	5289	6300	**6588**	5'- 2"
28	1508	1846	2212	2601	3014	3447	4367	5349	6382	**6833**	5'- 3"
29	1512	1852	2221	2614	3032	3471	4405	5404	6458	**7070**	5'- 3"
30	1515	1857	2229	2626	3048	3492	4440	5456	6529	**7319**	5'- 4"
31	1517	1862	2236	2637	3063	3512	4472	5504	6596	**7561**	5'- 5"
32	1520	1866	2242	2646	3076	3530	4502	5549	6659	**7818**	5'- 6"
33	1521	1869	2247	2654	3088	3546	4529	5590	6717	**8046**	5'- 7"
34	1523	1872	2252	2662	3099	3561	4555	5629	6772	**8290**	5'- 8"
35	1525	1875	2257	2669	3109	3575	4578	5665	6823	**8556**	5'- 8"
36	1526	1877	2261	2675	3118	3587	4599	5698	6871	**8789**	5'- 9"
37	1527	1879	2264	2680	3126	3598	4619	5729	6916	**9045**	5'-10"
38	1528	1881	2267	2685	3133	3608	4637	5758	6958	**9265**	5'-11"
39	1529	1882	2270	2689	3139	3618	4654	5784	6998	**9510**	6'- 0"
40	1529	1884	2272	2693	3145	3626	4669	5809	7035	**9785**	6'- 0"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"		
821	939	1059	1180	**1203**						3'- 1"	5
929	1069	1210	1353	**1448**						3'- 2"	6
1023	1183	1346	1510	**1692**						3'- 3"	7
1106	1285	1467	1652	1838	**1938**					3'- 5"	8
1179	1375	1576	1780	1986	**2183**					3'- 6"	9
1242	1455	1674	1896	2122	2350	**2429**				3'- 7"	10
1298	1526	1761	2001	2245	2492	**2672**				3'- 8"	11
1346	1589	1840	2096	2357	2623	**2920**				3'- 9"	12
1389	1645	1910	2182	2460	2743	**3162**				3'-10"	13
1426	1695	1973	2260	2553	2853	**3408**				3'-11"	14
1459	1738	2030	2330	2639	2954	**3647**				4'- 0"	15
1487	1777	2080	2394	2716	3047	3726	**3900**			4'- 2"	16
1512	1812	2126	2451	2787	3132	3843	**4142**			4'- 2"	17
1534	1843	2167	2504	2852	3210	3950	**4382**			4'- 3"	18
1553	1870	2203	2551	2911	3282	4050	**4624**			4'- 4"	19
1570	1894	2236	2593	2965	3347	4143	**4870**			4'- 5"	20
1584	1915	2265	2632	3014	3408	4229	**5123**			4'- 6"	21
1597	1934	2292	2667	3058	3463	4309	5192	**5368**		4'- 7"	22
1608	1951	2315	2699	3099	3514	4383	5293	**5603**		4'- 8"	23
1618	1966	2336	2727	3136	3561	4451	5387	**5851**		4'- 9"	24
1627	1979	2355	2753	3170	3604	4515	5475	**6091**		4'-10"	25
1634	1991	2373	2777	3201	3643	4574	5557	**6350**		4'-11"	26
1641	2001	2388	2798	3229	3679	4629	5634	**6588**		4'-11"	27
1647	2010	2401	2817	3255	3712	4680	5706	**6833**		5'- 0"	28
1652	2019	2414	2834	3278	3743	4727	5773	6870	**7070**	5'- 1"	29
1656	2026	2425	2850	3300	3771	4771	5836	6955	**7319**	5'- 2"	30
1660	2032	2435	2864	3319	3796	4811	5895	7036	7561	5'- 3"	31
1663	2038	2444	2877	3337	3820	4849	5950	7111	7818	5'- 3"	32
1666	2043	2451	2889	3353	3842	4884	6002	7182	8046	5'- 4"	33
1669	2048	2459	2899	3368	3861	4916	6050	7249	**8290**	5'- 5"	34
1671	2052	2465	2909	3381	3880	4946	6095	7312	**8556**	5'- 6"	35
1673	2055	2471	2918	3393	3896	4974	6137	7372	**8789**	5'- 7"	36
1675	2058	2476	2925	3405	3912	5000	6177	7428	**9045**	5'- 7"	37
1676	2061	2480	2932	3415	3926	5024	6214	7480	**9265**	5'- 8"	38
1678	2064	2485	2939	3424	3939	5047	6248	7530	**9510**	5'- 9"	39
1679	2066	2488	2945	3433	3950	5067	6280	7577	**9785**	5'-10"	40

Table B-5 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	
5	854	974	1095	**1203**							3'- 0"
6	973	1115	1259	1403	**1448**						3'- 1"
7	1079	1243	1408	1574	**1692**						3'- 2"
8	1174	1357	1543	1731	**1938**						3'- 3"
9	1258	1461	1666	1874	2085	**2183**					3'- 4"
10	1334	1554	1778	2006	2237	**2429**					3'- 5"
11	1400	1638	1880	2127	2377	**2672**					3'- 6"
12	1460	1713	1973	2238	2506	2779	**2920**				3'- 8"
13	1513	1781	2057	2339	2626	2917	**3162**				3'- 8"
14	1560	1843	2134	2432	2736	3046	**3408**				3'- 9"
15	1603	1898	2204	2518	2838	3165	**3647**				3'-10"
16	1640	1948	2267	2596	2932	3276	**3900**				3'-11"
17	1674	1993	2325	2668	3019	3378	**4142**				4'- 0"
18	1703	2034	2378	2734	3099	3474	4243	**4382**			4'- 1"
19	1730	2070	2426	2794	3173	3562	4364	**4624**			4'- 2"
20	1754	2103	2469	2849	3242	3645	4476	**4870**			4'- 3"
21	1775	2133	2509	2900	3305	3721	4582	**5123**			4'- 4"
22	1793	2159	2545	2947	3363	3792	4681	**5368**			4'- 5"
23	1810	2184	2578	2989	3417	3858	4773	**5603**			4'- 5"
24	1825	2205	2607	3029	3466	3919	4860	**5851**			4'- 6"
25	1838	2225	2635	3064	3512	3975	4942	5951	**6091**		4'- 7"
26	1850	2242	2659	3097	3554	4028	5018	6054	**6350**		4'- 8"
27	1861	2258	2682	3128	3593	4077	5089	6151	**6588**		4'- 8"
28	1870	2273	2702	3155	3630	4122	5156	6243	**6833**		4'- 9"
29	1878	2286	2721	3181	3663	4165	5219	6330	**7070**		4'-10"
30	1886	2297	2738	3204	3693	4204	5278	6412	**7319**		4'-11"
31	1892	2308	2753	3225	3722	4240	5333	6489	**7561**		4'-11"
32	1898	2317	2767	3245	3748	4274	5385	6562	**7818**		5'- 0"
33	1904	2326	2780	3263	3772	4305	5433	6631	7886	**8046**	5'- 1"
34	1908	2333	2791	3279	3794	4334	5478	6696	7974	**8290**	5'- 1"
35	1913	2340	2802	3294	3815	4361	5521	6757	8057	**8556**	5'- 2"
36	1916	2346	2811	3308	3834	4386	5561	6815	8136	**8789**	5'- 3"
37	1920	2352	2820	3321	3851	4409	5598	6870	8211	**9045**	5'- 4"
38	1922	2357	2828	3333	3868	4431	5633	6921	8282	**9265**	5'- 4"
39	1925	2362	2835	3343	3883	4451	5666	6970	8350	**9510**	5'- 5"
40	1927	2366	2842	3353	3896	4470	5696	7016	8414	**9785**	5'- 6"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"		
889	1011	1133	**1203**							2'-11"	5
1021	1165	1310	**1448**							3'- 0"	6
1140	1306	1473	1642	**1692**						3'- 1"	7
1248	1435	1624	1815	**1938**						3'- 2"	8
1346	1554	1764	1976	**2183**						3'- 3"	9
1435	1662	1892	2126	2361	**2429**					3'- 4"	10
1516	1761	2011	2264	2520	**2672**					3'- 5"	11
1589	1852	2121	2394	2670	**2920**					3'- 6"	12
1655	1935	2222	2514	2809	**3162**					3'- 6"	13
1715	2012	2315	2625	2940	3258	**3408**				3'- 7"	14
1770	2082	2402	2729	3061	3399	**3647**				3'- 8"	15
1819	2145	2481	2825	3175	3531	**3900**				3'- 9"	16
1864	2204	2555	2914	3282	3655	**4142**				3'-10"	17
1905	2258	2623	2998	3381	3772	**4382**				3'-11"	18
1942	2307	2685	3075	3474	3881	**4624**				3'-11"	19
1975	2352	2743	3147	3561	3984	**4870**				4'- 0"	20
2005	2393	2796	3213	3642	4080	4981	**5123**			4'- 1"	21
2033	2431	2846	3275	3718	4171	5104	**5368**			4'- 2"	22
2058	2465	2891	3333	3789	4256	5220	**5603**			4'- 2"	23
2080	2497	2933	3387	3855	4336	5329	**5851**			4'- 3"	24
2101	2526	2972	3436	3917	4411	5433	**6091**			4'- 4"	25
2120	2552	3008	3483	3975	4481	5532	**6350**			4'- 5"	26
2136	2576	3041	3526	4029	4548	5625	**6588**			4'- 5"	27
2152	2599	3071	3566	4079	4610	5713	**6833**			4'- 6"	28
2166	2619	3099	3603	4126	4668	5797	**7070**			4'- 6"	29
2178	2638	3125	3637	4171	4723	5876	7081	**7319**		4'- 7"	30
2190	2655	3149	3669	4212	4774	5950	7182	**7561**		4'- 8"	31
2200	2670	3171	3699	4250	4823	6021	7278	**7818**		4'- 8"	32
2209	2685	3192	3727	4286	4868	6088	7370	**8046**		4'- 9"	33
2218	2698	3211	3752	4320	4911	6151	7458	**8290**		4'-10"	34
2226	2710	3228	3776	4351	4951	6211	7541	**8556**		4'-10"	35
2233	2721	3244	3798	4381	4988	6268	7620	**8789**		4'-11"	36
2239	2731	3259	3819	4408	5024	6322	7696	**9045**		5'- 0"	37
2245	2740	3273	3838	4434	5057	6373	7768	**9265**		5'- 0"	38
2250	2749	3285	3856	4458	5088	6421	7836	9320	**9510**	5'- 1"	39
2255	2756	3297	3873	4480	5117	6466	7902	9408	**9785**	5'- 2"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads (**bold type**) and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-6

18" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 18"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	7'-0"	
5	915	1033	1153	1274	**1411**						3'- 6"
6	1036	1176	1317	1460	1603	**1700**					3'- 8"
7	1142	1302	1464	1628	1793	**1989**					3'-10"
8	1235	1414	1596	1780	1966	**2277**					3'-11"
9	1316	1513	1713	1917	2123	**2566**					4'- 0"
10	1388	1601	1819	2041	2266	2723	**2855**				4'- 2"
11	1450	1679	1914	2153	2396	2891	**3145**				4'- 3"
12	1505	1748	1998	2254	2514	3046	**3431**				4'- 4"
13	1553	1810	2074	2345	2622	3189	**3718**				4'- 5"
14	1595	1864	2142	2428	2720	3320	3938	**4012**			4'- 7"
15	1632	1912	2203	2502	2809	3441	4093	**4298**			4'- 8"
16	1664	1955	2258	2570	2890	3553	4238	**4584**			4'- 9"
17	1693	1993	2306	2631	2964	3655	4372	**4877**			4'-10"
18	1717	2027	2350	2686	3032	3750	4497	**5168**			4'-11"
19	1739	2057	2389	2735	3093	3837	4613	**5444**			5'- 0"
20	1758	2083	2425	2780	3148	3917	4720	5552	**5737**		5'- 1"
21	1775	2107	2456	2821	3199	3991	4820	5681	**6035**		5'- 2"
22	1790	2128	2484	2857	3245	4058	4913	5802	**6324**		5'- 3"
23	1802	2146	2510	2891	3287	4121	5000	5915	**6600**		5'- 4"
24	1814	2163	2532	2920	3325	4179	5080	6021	**6887**		5'- 5"
25	1824	2177	2552	2947	3360	4232	5155	6120	**7189**		5'- 6"
26	1832	2190	2571	2972	3392	4280	5224	6213	**7455**		5'- 7"
27	1840	2201	2587	2994	3421	4325	5289	6300	**7768**		5'- 8"
28	1846	2212	2601	3014	3447	4367	5349	6382	**8044**		5'- 9"
29	1852	2221	2614	3032	3471	4405	5404	6458	**8344**		5'-10"
30	1857	2229	2626	3048	3492	4440	5456	6529	**8636**		5'-11"
31	1862	2236	2637	3063	3512	4472	5504	6596	**8901**		6'- 0"
32	1866	2242	2646	3076	3530	4502	5549	6659	9032	**9198**	6'- 1"
33	1869	2247	2654	3088	3546	4529	5590	6717	9132	**9488**	6'- 2"
34	1872	2252	2662	3099	3561	4555	5629	6772	9227	**9771**	6'- 2"
35	1875	2257	2669	3109	3575	4578	5665	6823	9317	**10070**	6'- 3"
36	1877	2261	2675	3118	3587	4599	5698	6871	9402	**10340**	6'- 4"
37	1879	2264	2680	3126	3598	4619	5729	6916	9483	**10630**	6'- 5"
38	1881	2267	2685	3133	3608	4637	5758	6958	9559	**10940**	6'- 6"
39	1882	2270	2689	3139	3618	4654	5784	6998	9631	**11220**	6'- 7"
40	1884	2272	2693	3145	3626	4669	5809	7035	9700	**11520**	6'- 8"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	7'-0"		
939	1059	1180	1301	**1411**						3'- 6"	5
1069	1210	1353	1497	1641	**1700**					3'- 7"	6
1183	1346	1510	1675	1842	**1989**					3'- 9"	7
1285	1467	1652	1838	2026	**2277**					3'-10"	8
1375	1576	1780	1986	2195	**2566**					3'-11"	9
1455	1674	1896	2122	2350	2814	**2855**				4'- 1"	10
1526	1761	2001	2245	2492	2996	**3145**				4'- 2"	11
1589	1840	2096	2357	2623	3164	**3431**				4'- 3"	12
1645	1910	2182	2460	2743	3321	**3718**				4'- 4"	13
1695	1973	2260	2553	2853	3466	**4012** *				4'- 5"	14
1738	2030	2330	2639	2954	3601	**4298**				4'- 6"	15
1777	2080	2394	2716	3047	3726	4426	**4584**			4'- 7"	16
1812	2126	2451	2787	3132	3843	4576	**4877**			4'- 8"	17
1843	2167	2504	2852	3210	3950	4716	**5168**			4'- 9"	18
1870	2203	2551	2911	3282	4050	4848	**5444**			4'-10"	19
1894	2236	2593	2965	3347	4143	4970	**5737**			4'-11"	20
1915	2265	2632	3014	3408	4229	5085	**6035**			5'- 0"	21
1934	2292	2667	3058	3463	4309	5192	6107	**6324**		5'- 1"	22
1951	2315	2699	3099	3514	4383	5293	6236	**6600**		5'- 2"	23
1966	2336	2727	3136	3561	4451	5387	6358	**6887**		5'- 3"	24
1979	2355	2753	3170	3604	4515	5475	6473	**7189**		5'- 4"	25
1991	2373	2777	3201	3643	4574	5557	6582	**7455**		5'- 5"	26
2001	2388	2798	3229	3679	4629	5634	6684	**7768**		5'- 6"	27
2010	2401	2817	3255	3712	4680	5706	6780	**8044**		5'- 7"	28
2019	2414	2834	3278	3743	4727	5773	6870	**8344**		5'- 8"	29
2026	2425	2850	3300	3771	4771	5836	6955	**8636**		5'- 9"	30
2032	2435	2864	3319	3796	4811	5895	7036	**8901**		5'- 9"	31
2038	2444	2877	3337	3820	4849	5950	7111	**9198**		5'-10"	32
2043	2451	2889	3353	3842	4884	6002	7182	**9488**		5'-11"	33
2048	2459	2899	3368	3861	4916	6050	7249	**9771**		6'- 0"	34
2052	2465	2909	3381	3880	4946	6095	7312	9914	**10070**	6'- 1"	35
2055	2471	2918	3393	3896	4974	6137	7372	10020	**10340**	6'- 1"	36
2058	2476	2925	3405	3912	5000	6177	7428	10110	**10630**	6'- 2"	37
2061	2480	2932	3415	3926	5024	6214	7480	10200	**10940**	6'- 3"	38
2064	2485	2939	3424	3939	5047	6248	7530	10290	**11220**	6'- 4"	39
2066	2488	2945	3433	3950	5067	6280	7577	10380	**11520**	6'- 5"	40

Table B-6 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	7'-0"	
5	974	1095	1217	1339	**1411**						3'- 5"
6	1115	1259	1403	1548	**1700**						3'- 6"
7	1243	1408	1574	1741	1910	**1989**					3'- 7"
8	1357	1543	1731	1920	2110	**2277**					3'- 9"
9	1461	1666	1874	2085	2297	**2566**					3'-10"
10	1554	1778	2006	2237	2470	**2855**					3'-11"
11	1638	1880	2127	2377	2630	**3145**					4'- 0"
12	1713	1973	2238	2506	2779	3332	**3431**				4'- 1"
13	1781	2057	2339	2626	2917	3510	**3718**				4'- 2"
14	1843	2134	2432	2736	3046	3676	**4012**				4'- 3"
15	1898	2204	2518	2838	3165	3832	**4298**				4'- 4"
16	1948	2267	2596	2932	3276	3978	**4584**				4'- 5"
17	1993	2325	2668	3019	3378	4115	**4877**				4'- 6"
18	2034	2378	2734	3099	3474	4243	5035	**5168**			4'- 7"
19	2070	2426	2794	3173	3562	4364	5190	**5444**			4'- 8"
20	2103	2469	2849	3242	3645	4476	5336	**5737**			4'- 9"
21	2133	2509	2900	3305	3721	4582	5473	**6035**			4'-10"
22	2159	2545	2947	3363	3792	4681	5603	**6324**			4'-11"
23	2184	2578	2989	3417	3858	4773	5726	**6600**			4'-11"
24	2205	2607	3029	3466	3919	4860	5842	**6887**			5'- 0"
25	2225	2635	3064	3512	3975	4942	5951	6994	**7189**		5'- 1"
26	2242	2659	3097	3554	4028	5018	6054	7127	**7455**		5'- 2"
27	2258	2682	3128	3593	4077	5089	6151	7253	**7768**		5'- 3"
28	2273	2702	3155	3630	4122	5156	6243	7373	**8044**		5'- 3"
29	2286	2721	3181	3663	4165	5219	6330	7486	**8344**		5'- 4"
30	2297	2738	3204	3693	4204	5278	6412	7594	**8636**		5'- 5"
31	2308	2753	3225	3722	4240	5333	6489	7697	**8901**		5'- 6"
32	2317	2767	3245	3748	4274	5385	6562	7794	**9198**		5'- 7"
33	2326	2780	3263	3772	4305	5433	6631	7886	**9488**		5'- 7"
34	2333	2791	3279	3794	4334	5478	6696	7974	**9771**		5'- 8"
35	2340	2802	3294	3815	4361	5521	6757	8057	**10070**		5'- 9"
36	2346	2811	3308	3834	4386	5561	6815	8136	**10340**		5'-10"
37	2352	2820	3321	3851	4409	5598	6870	8211	**10630**		5'-10"
38	2357	2828	3333	3868	4431	5633	6921	8282	**10940**		5'-11"
39	2362	2835	3343	3883	4451	5666	6970	8350	**11220**		6'- 0"
40	2366	2842	3353	3896	4470	5696	7016	8414	**11520**		6'- 0"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
2'-6"	2'-9"	3'-0"	3'-3"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"	7'-0"		
1011	1133	1255	1378	**1411**						3'- 4"	5
1165	1310	1456	1602	**1700**						3'- 5"	6
1306	1473	1642	1811	**1989**						3'- 6"	7
1435	1624	1815	2007	2200	**2277**					3'- 7"	8
1554	1764	1976	2190	2405	**2566**					3'- 8"	9
1662	1892	2126	2361	2598	**2855**					3'- 9"	10
1761	2011	2264	2520	2779	**3145**					3'-10"	11
1852	2121	2394	2670	2949	**3431**					3'-11"	12
1935	2222	2514	2809	3108	**3718**					4'- 0"	13
2012	2315	2625	2940	3258	3905	**4012**				4'- 1"	14
2082	2402	2729	3061	3399	4085	**4298**				4'- 2"	15
2145	2481	2825	3175	3531	4256	**4584**				4'- 3"	16
2204	2555	2914	3282	3655	4417	**4877**				4'- 4"	17
2258	2623	2998	3381	3772	4570	**5168**				4'- 4"	18
2307	2685	3075	3474	3881	4714	**5444**				4'- 5"	19
2352	2743	3147	3561	3984	4851	**5737**				4'- 6"	20
2393	2796	3213	3642	4080	4981	5907	**6035**			4'- 7"	21
2431	2846	3275	3718	4171	5104	6064	**6324**			4'- 8"	22
2465	2891	3333	3789	4256	5220	6214	**6600**			4'- 8"	23
2497	2933	3387	3855	4336	5329	6357	**6887**			4'- 9"	24
2526	2972	3436	3917	4411	5433	6493	**7189**			4'-10"	25
2552	3008	3483	3975	4481	5532	6622	**7455**			4'-11"	26
2576	3041	3526	4029	4548	5625	6745	**7768**			4'-11"	27
2599	3071	3566	4079	4610	5713	6863	**8044**			5'- 0"	28
2619	3099	3603	4126	4668	5797	6974	8191	**8344**		5'- 1"	29
2638	3125	3637	4171	4723	5876	7081	8328	**8636**		5'- 2"	30
2655	3149	3669	4212	4774	5950	7182	8458	**8901**		5'- 2"	31
2670	3171	3699	4250	4823	6021	7278	8583	**9198**		5'- 3"	32
2685	3192	3727	4286	4868	6088	7370	8703	**9488**		5'- 3"	33
2698	3211	3752	4320	4911	6151	7458	8817	**9771**		5'- 4"	34
2710	3228	3776	4351	4951	6211	7541	8927	**10070**		5'- 5"	35
2721	3244	3798	4381	4988	6268	7620	9032	**10340**		5'- 5"	36
2731	3259	3819	4408	5024	6322	7696	9132	**10630**		5'- 6"	37
2740	3273	3838	4434	5057	6373	7768	9228	**10940**		5'- 7"	38
2749	3285	3856	4458	5088	6421	7836	9320	**11220**		5'- 7"	39
2756	3297	3873	4480	5117	6466	7902	9408	**11520**		5'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-7

21" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 21"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	3'-0"	3'-3"	3'-6"	3'-9"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	7'-0"	
5	1153	1274	1395	1516	**1617**						4'- 0"
6	1317	1460	1603	1748	1892	**1951**					4'- 1"
7	1464	1628	1793	1959	2127	**2284**					4'- 3"
8	1596	1780	1966	2153	2342	**2617**					4'- 4"
9	1713	1917	2123	2331	2540	**2950**					4'- 6"
10	1819	2041	2266	2493	2723	3189	**3282**				4'- 7"
11	1914	2153	2396	2642	2891	3397	**3612**				4'- 8"
12	1998	2254	2514	2779	3046	3591	**3947**				4'-10"
13	2074	2345	2622	2903	3189	3771	**4280**				4'-11"
14	2142	2428	2720	3018	3320	3938	**4610**				5'- 0"
15	2203	2502	2809	3123	3441	4093	4760	**4942**			5'- 2"
16	2258	2570	2890	3218	3553	4238	4940	**5273**			5'- 3"
17	2306	2631	2964	3306	3655	4372	5108	**5606**			5'- 4"
18	2350	2686	3032	3387	3750	4497	5266	**5934**			5'- 5"
19	2389	2735	3093	3460	3837	4613	5413	**6274**			5'- 6"
20	2425	2780	3148	3528	3917	4720	5552	6405	**6598**		5'- 7"
21	2456	2821	3199	3589	3991	4820	5681	6566	**6942**		5'- 8"
22	2484	2857	3245	3646	4058	4913	5802	6717	**7273**		5'- 9"
23	2510	2891	3287	3698	4121	5000	5915	6860	**7591**		5'-10"
24	2532	2920	3325	3745	4179	5080	6021	6994	**7916**		6'- 0"
25	2552	2947	3360	3789	4232	5155	6120	7121	**8255**		6'- 0"
26	2571	2972	3392	3828	4280	5224	6213	7240	8298	**8582**	6'- 1"
27	2587	2994	3421	3865	4325	5289	6300	7352	8438	**8928**	6'- 3"
28	2601	3014	3447	3898	4367	5349	6382	7458	8570	**9266**	6'- 4"
29	2614	3032	3471	3929	4405	5404	6458	7557	8695	**9593**	6'- 5"
30	2626	3048	3492	3957	4440	5456	6529	7651	8814	**9910**	6'- 5"
31	2637	3063	3512	3982	4472	5504	6596	7739	8926	**10260**	6'- 6"
32	2646	3076	3530	4006	4502	5549	6659	7822	9032	**10590**	6'- 7"
33	2654	3088	3546	4027	4529	5590	6717	7901	9132	**10920**	6'- 8"
34	2662	3099	3561	4047	4555	5629	6772	7974	9227	**11250**	6'- 9"
35	2669	3109	3575	4065	4578	5665	6823	8044	9317	**11580**	6'-10"
36	2675	3118	3587	4082	4599	5698	6871	8109	9402	**11910**	6'-11"
37	2680	3126	3598	4097	4619	5729	6916	8171	9483	**12230**	7'- 0"
38	2685	3133	3608	4110	4637	5758	6958	8229	9551	**12580**	7'- 1"
39	2689	3139	3618	4123	4654	5784	6998	8283	9631	**12920**	7'- 2"
40	2693	3145	3626	4135	4669	5809	7035	8335	9700	**13250**	7'- 3"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
3'-0"	3'-3"	3'-6"	3'-9"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	7'-0"		
1180	1301	1423	1545	**1617**						3'-11"	5
1353	1497	1641	1786	**1951**						4'- 0"	6
1510	1675	1842	2009	2178	**2284**					4'- 2"	7
1652	1838	2026	2215	2406	**2617**					4'- 3"	8
1780	1986	2195	2405	2617	**2950**					4'- 5"	9
1896	2122	2350	2581	2814	**3282**					4'- 6"	10
2001	2245	2492	2743	2996	3507	**3612**				4'- 7"	11
2096	2357	2623	2892	3164	3717	**3947**				4'- 8"	12
2182	2460	2743	3030	3321	3912	**4280**				4'-10"	13
2260	2553	2853	3158	3466	4095	**4610**				4'-11"	14
2330	2639	2954	3275	3601	4266	**4942**				5'- 0"	15
2394	2716	3047	3384	3726	4426	5142	**5273**			5'- 1"	16
2451	2787	3132	3484	3843	4576	5328	**5606**			5'- 2"	17
2504	2852	3210	3576	3950	4716	5503	**5934**			5'- 3"	18
2551	2911	3282	3662	4050	4848	5668	**6274**			5'- 4"	19
2593	2965	3347	3741	4143	4970	5823	**6598**			5'- 5"	20
2632	3014	3408	3813	4229	5085	5969	**6942**			5'- 6"	21
2667	3058	3463	3881	4309	5192	6107	7046	**7273**		5'- 7"	22
2699	3099	3514	3943	4383	5293	6236	7207	**7591**		5'- 8"	23
2727	3136	3561	4000	4451	5387	6358	7360	**7916**		5'- 9"	24
2753	3170	3604	4053	4515	5475	6473	7504	**8255**		5'-10"	25
2777	3201	3643	4101	4574	5557	6582	7641	**8582**		5'-11"	26
2798	3229	3679	4146	4629	5634	6684	7771	**8928**		6'- 0"	27
2817	3255	3712	4188	4680	5706	6780	7893	9040	**9266**	6'- 1"	28
2834	3278	3743	4226	4727	5773	6870	8010	9185	**9593**	6'- 2"	29
2850	3300	3771	4262	4771	5836	6955	8120	9322	**9910**	6'- 3"	30
2864	3319	3796	4294	4811	5895	7036	8224	9453	**10260**	6'- 4"	31
2887	3337	3820	4325	4849	5950	7111	8323	9577	**10590**	6'- 5"	32
2889	3353	3842	4352	4884	6002	7182	8416	9695	**10920**	6'- 6"	33
2899	3368	3861	4378	4916	6050	7249	8505	9807	**11250**	6'- 6"	34
2909	3381	3880	4402	4946	6095	7312	8588	9914	**11580**	6'- 7"	35
2918	3393	3896	4424	4974	6137	7372	8668	10020	**11910**	6'- 8"	36
2925	3405	3912	4444	5000	6177	7428	8743	10110	**12230**	6'- 9"	37
2932	3415	3926	4463	5024	6214	7480	8814	10200	**12580**	6'-10"	38
2939	3424	3939	4480	5047	6248	7530	8881	10290	**12920**	6'-11"	39
2945	3433	3950	4496	5067	6280	7577	8945	10380	**13250**	6'-11"	40

Table B-7 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE 3'-0"	3'-3"	3'-6"	3'-9"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	7'-0"	▲TRANSITION WIDTH
5	1217	1339	1461	1584	**1617**						3'-10"
6	1403	1548	1694	1840	**1951**						3'-11"
7	1574	1741	1910	2079	2249	**2284**					4'-1"
8	1731	1920	2110	2302	2495	**2617**					4'-2"
9	1874	2085	2297	2510	2725	**2950**					4'-3"
10	2006	2237	2470	2704	2941	**3282**					4'-4"
11	2127	2377	2630	2885	3143	**3612**					4'-5"
12	2238	2506	2779	3054	3332	3894	**3947**				4'-7"
13	2339	2626	2917	3212	3510	4113	**4280**				4'-8"
14	2432	2736	3046	3359	3676	4319	**4610**				4'-9"
15	2518	2838	3165	3496	3832	4514	**4942**				4'-10"
16	2596	2932	3276	3624	3978	4698	**5273**				4'-11"
17	2668	3019	3378	3744	4115	4871	**5606**				5'-0"
18	2734	3099	3474	3855	4243	5035	5844	**5934**			5'-1"
19	2794	3173	3562	3959	4364	5190	6035	**6274**			5'-2"
20	2849	3242	3645	4056	4476	5336	6216	**6598**			5'-3"
21	2900	3305	3721	4147	4582	5473	6388	**6942**			5'-4"
22	2947	3363	3792	4232	4681	5603	6552	**7273**			5'-5"
23	2989	3417	3858	4310	4773	5726	6707	**7591**			5'-5"
24	3029	3466	3919	4384	4860	5842	6855	**7916**			5'-6"
25	3064	3512	3975	4452	4942	5951	6994	8066	**8255**		5'-7"
26	3097	3554	4028	4516	5018	6054	7127	8230	**8582**		5'-8"
27	3128	3593	4077	4576	5089	6151	7253	8387	**8928**		5'-9"
28	3155	3630	4122	4632	5156	6243	7373	8537	**9266**		5'-10"
29	3181	3663	4165	4684	5219	6330	7486	8680	**9593**		5'-10"
30	3204	3693	4204	4732	5278	6412	7594	8817	**9910**		5'-11"
31	3225	3722	4240	4778	5333	6489	7697	8947	**10260**		6'-0"
32	3245	3748	4274	4820	5385	6562	7794	9071	10380	**10590**	6'-1"
33	3263	3772	4305	4859	5433	6631	7886	9189	10530	**10920**	6'-2"
34	3279	3794	4334	4896	5478	6696	7974	9302	10670	**11250**	6'-2"
35	3294	3815	4361	4930	5521	6757	8057	9410	10810	**11580**	6'-3"
36	3308	3834	4386	4962	5561	6815	8136	9513	10940	**11910**	6'-4"
37	3321	3851	4409	4992	5598	6870	8211	9610	11060	**12230**	6'-5"
38	3333	3868	4431	5020	5633	6921	8282	9704	11180	**12580**	6'-5"
39	3343	3883	4451	5046	5666	6970	8350	9793	11290	**12920**	6'-6"
40	3353	3896	4470	5070	5696	7016	8414	9878	11400	**13250**	6'-7"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE 3'-0"	3'-3"	3'-6"	3'-9"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	7'-0"	▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
1255	1378	1501	**1617**							3'-9"	5
1456	1602	1749	1896	**1951**						3'-10"	6
1642	1811	1982	2152	**2284**						3'-11"	7
1815	2007	2200	2394	**2617**						4'-0"	8
1976	2190	2405	2622	2839	**2950**					4'-1"	9
2126	2361	2598	2836	3076	**3282**					4'-3"	10
2264	2520	2779	3039	3301	**3612**					4'-3"	11
2394	2670	2949	3230	3513	**3947**					4'-4"	12
2514	2809	3108	3410	3714	**4280**					4'-5"	13
2625	2940	3258	3580	3905	**4610**					4'-6"	14
2729	3061	3399	3740	4085	4783	**4942**				4'-7"	15
2825	3175	3531	3891	4256	4994	**5273**				4'-8"	16
2914	3282	3655	4034	4417	5195	**5606**				4'-9"	17
2998	3381	3772	4168	4570	5386	**5934**				4'-10"	18
3075	3474	3881	4295	4714	5568	**6274**				4'-11"	19
3147	3561	3984	4414	4851	5742	**6598**				5'-0"	20
3213	3642	4080	4527	4981	5907	**6942**				5'-0"	21
3275	3718	4171	4633	5104	6064	7047	**7273**			5'-1"	22
3333	3789	4256	4733	5220	6214	7233	**7591**			5'-2"	23
3387	3855	4336	4828	5329	6357	7410	**7916**			5'-3"	24
3436	3917	4411	4917	5433	6493	7581	**8255**			5'-4"	25
3483	3975	4481	5001	5532	6622	7743	**8582**			5'-4"	26
3526	4029	4548	5080	5625	6745	7899	**8928**			5'-5"	27
3566	4079	4610	5155	5713	6863	8048	**9266**			5'-6"	28
3603	4126	4668	5225	5797	6974	8191	9439	**9593**		5'-7"	29
3637	4171	4723	5292	5876	7081	8328	9608	**9910**		5'-7"	30
3669	4212	4774	5354	5950	7182	8458	9770	**10260**		5'-8"	31
3699	4250	4823	5414	6021	7278	8583	9926	**10590**		5'-9"	32
3727	4286	4868	5469	6088	7370	8703	10080	**10920**		5'-10"	33
3752	4320	4911	5522	6151	7458	8817	10220	**11250**		5'-10"	34
3776	4351	4951	5571	6211	7541	8927	10360	**11580**		5'-11"	35
3798	4381	4988	5618	6268	7620	9032	10490	**11910**		6'-0"	36
3819	4408	5024	5662	6322	7696	9132	10620	**12230**		6'-0"	37
3838	4434	5057	5704	6373	7768	9228	10740	12300	**12580**	6'-1"	38
3856	4458	5088	5743	6421	7836	9320	10860	12450	**12920**	6'-2"	39
3873	4480	5117	5780	6466	7902	9408	10970	12590	**13250**	6'-2"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on $K\mu$—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-8

24" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 24"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE 3'-6"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	▲TRANSITION WIDTH
5	1395	1638	**1819**								4'- 4"
6	1603	1892	**2199**								4'- 6"
7	1793	2127	2463	**2576**							4'- 8"
8	1966	2342	2723	**2954**							4'-10"
9	2123	2540	2964	**3331**							4'-11"
10	2266	2723	3189	**3705**							5'- 0"
11	2396	2891	3397	3910	**4081**						5'- 2"
12	2514	3046	3591	4144	**4456**						5'- 3"
13	2622	3189	3771	4363	**4836**						5'- 5"
14	2720	3320	3938	4568	**5209**						5'- 6"
15	2809	3441	4093	4760	5439	**5580**					5'- 7"
16	2890	3553	4238	4940	5656	**5955**					5'- 8"
17	2964	3655	4372	5108	5861	**6330**					5'-10"
18	3032	3750	4497	5266	6053	**6708**					5'-11"
19	3093	3837	4613	5413	6234	**7082**					6'- 0"
20	3148	3917	4720	5552	6405	7277	**7454**				6'- 1"
21	3199	3991	4820	5681	6566	7472	**7842**				6'- 2"
22	3245	4058	4913	5802	6717	7656	**8217**				6'- 4"
23	3287	4121	5000	5915	6860	7830	**8598**				6'- 5"
24	3325	4179	5080	6021	6994	7994	**8965**				6'- 6"
25	3360	4232	5155	6120	7121	8150	9204	**9341**			6'- 7"
26	3392	4280	5224	6213	7240	8298	9382	**9704**			6'- 8"
27	3421	4325	5289	6300	7352	8438	9552	**10080**			6'- 9"
28	3447	4367	5349	6382	7458	8570	7913	**10450**			6'-10"
29	3471	4405	5404	6458	7557	8695	9866	**10840**			6'-11"
30	3492	4440	5456	6529	7651	8814	10010	**11220**			7'- 0"
31	3512	4472	5504	6596	7739	8926	10150	11400	**11580**		7'- 1"
32	3530	4502	5549	6659	7822	9032	10280	11560	**11990**		7'- 2"
33	3546	4529	5590	6717	7901	9132	10400	11710	**12330**		7'- 3"
34	3561	4555	5629	6772	7974	9227	10520	11860	**12720**		7'- 4"
35	3575	4578	5665	6823	8044	9317	10640	12000	**13090**		7'- 5"
36	3587	4599	5698	6871	8109	9402	10740	12130	**13450**		7'- 6"
37	3598	4619	5729	6916	8181	9483	10850	12250	13700	**13860**	7'- 7"
38	3608	4637	5758	6958	8229	9559	10940	12370	13840	**14210**	7'- 8"
39	3618	4654	5784	6998	8283	9631	11040	12490	13980	**14610**	7'- 8"
40	3626	4669	5809	7035	8335	9700	11120	12600	14110	**14970**	7'- 9"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE 3'-6"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
1423	1667	**1819**								4'- 4"	5
1641	1932	**2199**								4'- 5"	6
1842	2178	2517	**2576**							4'- 7"	7
2026	2406	2790	**2954**							4'- 8"	8
2195	2617	3045	**3331**							4'-10"	9
2350	2814	3284	**3705**							4'-11"	10
2492	2996	3507	4026	**4081**						5'- 1"	11
2623	3164	3717	4277	**4456**						5'- 2"	12
2743	3321	3912	4513	**4836**						5'- 3"	13
2853	3466	4095	4735	**5209**						5'- 4"	14
2954	3601	4266	4945	**5580**						5'- 6"	15
3047	3726	4426	5142	5870	**5955**					5'- 7"	16
3132	3843	4576	5328	6094	**6330**					5'- 8"	17
3210	3950	4716	5503	6305	**6708**					5'- 9"	18
3282	4050	4848	5668	6506	**7082**					5'-10"	19
3347	4143	4970	5823	6696	**7454**					5'-11"	20
3408	4229	5085	5969	6876	**7842**					6'- 0"	21
3463	4309	5192	6107	7046	8005	**8217**				6'- 1"	22
3514	4383	5293	6236	7207	8200	**8598**				6'- 2"	23
3561	4451	5387	6358	7360	8385	**8965**				6'- 3"	24
3604	4515	5475	6473	7504	8561	**9341**				6'- 4"	25
3643	4574	5557	6582	7641	8729	**9704**				6'- 5"	26
3679	4629	5634	6684	7771	8889	**10080**				6'- 6"	27
3712	4680	5706	6780	7893	9040	10220	**10450**			6'- 7"	28
3743	4727	5773	6870	8010	9185	10390	**10840**			6'- 8"	29
3771	4771	5836	6955	8120	9322	10560	**11220**			6'- 9"	30
3796	4811	5895	7036	8224	9453	10720	**11580**			6'-10"	31
3820	4849	5950	7111	8323	9577	10870	**11990**			6'-11"	32
3842	4884	6002	7182	8416	9695	11010	**12330**			7'- 0"	33
3861	4916	6050	7249	8505	9807	11150	12530	**12720**		7'- 1"	34
3880	4946	6095	7312	8588	9914	11280	12690	**13090**		7'- 2"	35
3896	4974	6137	7372	8668	10020	11410	12840	**13450**		7'- 3"	36
3912	5000	6177	7428	8743	10110	11530	12990	**13860**		7'- 3"	37
3926	5024	6214	7480	8814	10200	11640	13130	**14210**		7'- 4"	38
3939	5047	6248	7530	8881	10290	11760	13260	**14610**		7'- 5"	39
3950	5067	6280	7577	8945	10380	11860	13390	**14970**		7'- 6"	40

Table B-8 Continued

C ORDINARY CLAY $K\mu'$—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	3'-6"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	
5	1461	1707	**1819**								4'- 3"
6	1694	1987	**2199**								4'- 4"
7	1910	2249	**2576**								4'- 6"
8	2110	2495	2882	**2954**							4'- 7"
9	2297	2725	3158	**3331**							4'- 8"
10	2470	2941	3418	**3705**							4'-10"
11	2630	3143	3663	**4081**							4'-11"
12	2779	3332	3894	**4456**							5'- 0"
13	2917	3510	4113	4724	**4836**						5'- 1"
14	3046	3676	4319	4972	**5209**						5'- 2"
15	3165	3832	4514	5207	**5580**						5'- 3"
16	3276	3978	4698	5430	**5955**						5'- 4"
17	3378	4115	4871	5643	**6330**						5'- 5"
18	3474	4243	5035	5844	**6708**						5'- 6"
19	3562	4364	5190	6035	6895	**7082**					5'- 7"
20	3645	4476	5336	6216	7114	**7455**					5'- 8"
21	3721	4582	5473	6388	7323	**7842**					5'- 9"
22	3792	4681	5603	6552	7522	**8217**					5'-10"
23	3858	4773	5726	6707	7712	**8598**					5'-11"
24	3919	4860	5842	6855	7893	**8965**					6'- 0"
25	3975	4942	5951	6994	8066	9159	**9341**				6'- 1"
26	4028	5018	6054	7127	8230	9358	**9704**				6'- 2"
27	4077	5089	6151	7253	8387	9548	**10080**				6'- 3"
28	4122	5156	6243	7373	8537	9731	**10450**				6'- 4"
29	4165	5219	6330	7486	8680	9905	**10840**				6'- 4"
30	4204	5278	6412	7594	8817	10070	**11220**				6'- 5"
31	4240	5333	6489	7697	8947	10230	**11580**				6'- 6"
32	4274	5385	6562	7794	9071	10380	11730	**11990**			6'- 7"
33	4305	5433	6631	7886	9189	10530	11910	**12330**			6'- 8"
34	4334	5478	6696	7974	9302	10670	12080	**12720**			6'- 9"
35	4361	5521	6757	8057	9410	10810	12240	**13090**			6'- 9"
36	4386	5561	6815	8136	9513	10940	12400	**13450**			6'-10"
37	4409	5598	6870	8211	9610	11060	12550	**13860**			6'-11"
38	4431	5633	6921	8282	9704	11180	12700	**14210**			7'- 0"
39	4451	5666	6970	8350	9793	11290	12840	14420	**14610**		7'- 1"
40	4470	5696	7016	8414	9878	11400	12970	14580	**14970**		7'- 2"

D SATURATED CLAY $K\mu'$—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
3'-6"	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"		
1501	1748	**1819**								4'- 2"	5
1749	2044	**2199**								4'- 3"	6
1982	2323	**2576**								4'- 4"	7
2200	2588	**2954**								4'- 5"	8
2405	2839	**3331**								4'- 7"	9
2598	3076	3559	**3705**							4'- 8"	10
2779	3301	3828	**4081**							4'- 9"	11
2949	3513	4085	**4456**							4'-10"	12
3108	3714	4329	**4836**							4'-11"	13
3258	3905	4562	**5209**							5'- 0"	14
3399	4085	4783	5490	**5580**						5'- 1"	15
3531	4256	4994	5743	**5955**						5'- 2"	16
3655	4417	5195	5985	**6330**						5'- 3"	17
3772	4570	5386	6216	**6708**						5'- 3"	18
3881	4714	5568	6438	**7082**						5'- 4"	19
3984	4851	5742	6650	**7454**						5'- 5"	20
4080	4981	5907	6853	**7842**						5'- 6"	21
4171	5104	6064	7047	8046	**8217**					5'- 7"	22
4256	5220	6214	7233	8270	**8598**					5'- 8"	23
4336	5329	6357	7410	8485	**8965**					5'- 9"	24
4411	5433	6493	7581	8691	**9341**					5'- 9"	25
4481	5532	6622	7743	8889	**9704**					5'-10"	26
4548	5625	6745	7899	9080	**10080**					5'-11"	27
4610	5713	6863	8048	9263	**10450**					6'- 0"	28
4668	5797	6974	8191	9439	10710	**10840**				6'- 1"	29
4723	5876	7081	8328	9608	10920	**11220**				6'- 1"	30
4774	5950	7182	8458	9770	11110	**11580**				6'- 2"	31
4823	6021	7278	8583	9926	11300	**11990**				6'- 3"	32
4868	6088	7370	8703	10080	11480	**12330**				6'- 4"	33
4911	6151	7458	8817	10220	11660	**12720**				6'- 4"	34
4951	6211	7541	8927	10360	11830	**13090**				6'- 5"	35
4988	6268	7620	9032	10490	11990	**13450**				6'- 6"	36
5024	6322	7696	9132	10620	12150	13720	**13860**			6'- 7"	37
5057	6373	7768	9228	10740	12300	13900	**14210**			6'- 7"	38
5088	6421	7836	9320	10860	12450	14070	**14610**			6'- 8"	39
5117	6466	7902	9408	10970	12590	14240	**14970**			6'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on $K\mu$—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-9

30" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 30"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	
5	1638	1883	**2119**								5'- 0"
6	1892	2184	2477	**2686**							5'- 4"
7	2127	2463	2802	**3155**							5'- 6"
8	2342	2723	3107	3494	**3620**						5'- 8"
9	2540	2964	3393	3824	**4085**						5'-10"
10	2723	3189	3660	4135	**4551**						5'-11"
11	2891	3397	3910	4428	4951	**5015**					6'- 1"
12	3046	3591	4144	4704	5270	**5478**					6'- 2"
13	3189	3771	4363	4964	5572	**5938**					6'- 4"
14	3320	3938	4568	5209	5858	**6401**					6'- 5"
15	3441	4093	4760	5439	6128	**6862**					6'- 6"
16	3553	4238	4940	5656	6384	7120	**7330**				6'- 8"
17	3655	4372	5108	5861	6626	7401	**7791**				6'- 9"
18	3750	4497	5266	6053	6855	7669	**8250**				6'-10"
19	3837	4613	5413	6234	7072	7923	**8711**				7'- 0"
20	3917	4720	5552	6405	7277	8164	9064	**9179**			7'- 1"
21	3991	4820	5681	6566	7472	8394	9331	**9643**			7'- 2"
22	4058	4913	5802	6717	7656	8612	9585	**10110**			7'- 3"
23	4121	5000	5915	6860	7830	8820	9827	**10570**			7'- 4"
24	4179	5080	6021	6994	7994	9017	10060	**11020**			7'- 5"
25	4232	5155	6120	7121	8150	9204	10280	11370	**11500**		7'- 7"
26	4280	5224	6213	7240	8298	9382	10490	11620	**11960**		7'- 8"
27	4325	5289	6300	7352	8438	9552	10690	11850	**12400**		7'- 9"
28	4367	5349	6382	7458	8570	9713	10880	12070	**12860**		7'-10"
29	4405	5404	6458	7557	8695	9866	11060	12290	**13340**		7'-11"
30	4440	5456	6529	7651	8814	10010	11240	12490	**13810**		8'- 0"
31	4472	5504	6596	7739	8926	10150	11400	12690	13990	**14270**	8'- 1"
32	4502	5549	6659	7822	9032	10280	11560	12880	14210	**14710**	8'- 2"
33	4529	5590	6717	7901	9132	10400	11710	13060	14420	**15180**	8'- 3"
34	4555	5629	6772	7974	9227	10520	11860	13230	14620	**15640**	8'- 4"
35	4578	5665	6823	8044	9317	10640	12000	13390	14820	**16140**	8'- 5"
36	4599	5698	6871	8109	9402	10740	12130	13550	15000	**16570**	8'- 6"
37	4619	5729	6916	8171	9483	10850	12250	13700	15180	**17050**	8'- 7"
38	4637	5758	6958	8229	9559	10940	12370	13840	15350	**17520**	8'- 9"
39	4654	5784	6998	8283	9631	11040	12490	13980	15510	**17980**	8'- 9"
40	4669	5809	7035	8335	9700	11120	12600	14110	15670	**18430**	8'-10"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"		
1667	1913	**2119**								4'-11"	5
1932	2225	2519	**2686**							5'- 3"	6
2178	2517	2857	**3155**							5'- 5"	7
2406	2790	3176	3565	**3620**						5'- 7"	8
2617	3045	3477	3911	**4085**						5'- 8"	9
2814	3284	3759	4239	**4551**						5'-10"	10
2996	3507	4026	4549	**5015**						5'-11"	11
3164	3717	4277	4843	5414	**5478**					6'- 1"	12
3321	3912	4513	5121	5735	**5938**					6'- 2"	13
3466	4095	4735	5384	6040	**6401**					6'- 3"	14
3601	4266	4945	5634	6331	**6862**					6'- 5"	15
3726	4426	5142	5870	6608	**7330**					6'- 6"	16
3843	4576	5328	6094	6871	7657	**7791**				6'- 7"	17
3950	4716	5503	6305	7121	7947	**8250**				6'- 8"	18
4050	4848	5668	6506	7359	8223	**8711**				6'- 9"	19
4143	4970	5823	6696	7585	8488	**9179**				6'-10"	20
4229	5085	5969	6876	7800	8740	**9643**				7'- 0"	21
4309	5192	6107	7046	8005	8981	9971	**10110**			7'- 1"	22
4383	5293	6236	7207	8200	9211	10240	**10570**			7'- 2"	23
4451	5387	6358	7360	8385	9431	10490	**11020**			7'- 3"	24
4515	5475	6473	7504	8561	9641	10740	**11500**			7'- 4"	25
4574	5557	6582	7641	8729	9841	10970	**11960**			7'- 5"	26
4629	5634	6684	7771	8889	10030	11200	**12400**			7'- 6"	27
4680	5706	6780	7893	9040	10220	11410	12630	**12860**		7'- 7"	28
4727	5773	6870	8010	9185	10390	11620	12870	**13340**		7'- 8"	29
4771	5836	6955	8120	9322	10560	11820	13100	**13810**		7'- 9"	30
4811	5895	7036	8224	9453	10720	12010	13320	**14270**		7'-10"	31
4849	5950	7111	8323	9577	10870	12190	13540	**14710**		7'-11"	32
4884	6002	7182	8416	9695	11010	12360	13740	**15180**		8'- 0"	33
4916	6050	7249	8505	9807	11150	12530	13940	15370	**15640**	8'- 1"	34
4946	6095	7312	8588	9914	11280	12690	14130	15590	**16140**	8'- 2"	35
4974	6137	7372	8668	10020	11410	12840	14310	15800	**16570**	8'- 3"	36
5000	6177	7428	8743	10110	11530	12990	14480	16010	**17050**	8'- 4"	37
5024	6214	7480	8814	10200	11640	13130	14650	16200	**17520**	8'- 5"	38
5047	6248	7530	8881	10290	11760	13260	14810	16390	**17980**	8'- 6"	39
5067	6280	7577	8945	10380	11860	13390	14960	16570	**18430**	8'- 7"	40

Table B-9 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE 4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	▲TRANSITION WIDTH
5	1707	1954	**2119**								4'-10"
6	1987	2281	2577	**2686**							5'- 2"
7	2249	2590	2933	**3155**							5'- 4"
8	2495	2882	3272	**3620**							5'- 5"
9	2725	3158	3593	4031	**4085**						5'- 7"
10	2941	3418	3898	4382	**4551**						5'- 8"
11	3143	3663	4188	4717	**5015**						5'-10"
12	3332	3894	4463	5036	**5478**						5'-10"
13	3510	4113	4724	5341	**5938**						6'- 0"
14	3676	4319	4972	5632	6297	**6401**					6'- 1"
15	3832	4514	5207	5909	6617	**6862**					6'- 2"
16	3978	4698	5430	6173	6924	**7330**					6'- 3"
17	4115	4871	5643	6425	7217	**7791**					6'- 4"
18	4243	5035	5844	6666	7498	**8250**					6'- 5"
19	4364	5190	6035	6895	7768	**8711**					6'- 6"
20	4476	5336	6216	7114	8025	8948	**9179**				6'- 8"
21	4582	5473	6388	7323	8272	9234	**9643**				6'- 9"
22	4681	5603	6552	7522	8509	9509	**10110**				6'-10"
23	4773	5726	6707	7712	8735	9774	**10570**				6'-10"
24	4860	5842	6855	7893	8952	10030	**11020**				7'- 0"
25	4942	5951	6994	8066	9159	10270	11400	**11500**			7'- 1"
26	5018	6054	7127	8230	9358	10510	11670	**11960**			7'- 1"
27	5089	6151	7253	8387	9548	10730	11930	**12400**			7'- 2"
28	5156	6243	7373	8537	9731	10950	12180	**12860**			7'- 3"
29	5219	6330	7486	8680	9905	11160	12430	**13340**			7'- 4"
30	5278	6412	7594	8817	10070	11360	12660	**13810**			7'- 5"
31	5333	6489	7697	8947	10230	11550	12890	**14270**			7'- 6"
32	5385	6562	7794	9071	10380	11730	13100	14500	**14710**		7'- 7"
33	5433	6631	7886	9189	10530	11910	13310	14740	**15180**		7'- 8"
34	5478	6696	7974	9302	10670	12080	13520	14980	**15640**		7'- 8"
35	5521	6757	8057	9410	10810	12240	13710	15200	**16140**		7'-10"
36	5561	6815	8136	9513	10940	12400	13900	15420	**16570**		7'-10"
37	5598	6870	8211	9610	11060	12550	14080	15640	**17050**		7'-11"
38	5633	6921	8282	9704	11180	12700	14250	15840	**17520**		8'- 0"
39	5666	6970	8350	9793	11290	12840	14420	16040	17680	**17980**	8'- 1"
40	5696	7016	8414	9878	11400	12970	14580	16230	17910	**18430**	8'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE 4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
1748	1996	**2119**								4'- 9"	5
2044	2340	2636	**2686**							5'- 1"	6
2323	2667	3012	**3155**							5'- 2"	7
2588	2979	3371	**3620**							5'- 4"	8
2839	3276	3715	**4085**							5'- 5"	9
3076	3559	4045	**4551**							5'- 6"	10
3301	3828	4360	4894	**5015**						5'- 7"	11
3513	4085	4661	5241	**5478**						5'- 8"	12
3714	4329	4950	5575	**5938**						5'- 9"	13
3905	4562	5226	5895	**6401**						5'-10"	14
4085	4783	5490	6203	**6862**						6'- 0"	15
4256	4994	5743	6499	7262	**7330**					6'- 1"	16
4417	5195	5985	6784	7590	**7791**					6'- 1"	17
4570	5386	6216	7057	7906	**8250**					6'- 2"	18
4714	5568	6438	7319	8210	**8711**					6'- 3"	19
4851	5742	6650	7571	8504	**9179**					6'- 4"	20
4981	5907	6853	7813	8787	**9643**					6'- 5"	21
5104	6064	7047	8046	9059	**10110**					6'- 6"	22
5220	6214	7233	8270	9322	10390	**10570**				6'- 7"	23
5329	6357	7410	8485	9576	10680	**11020**				6'- 8"	24
5433	6493	7581	8691	9820	10960	**11500**				6'- 9"	25
5532	6622	7743	8889	10060	11240	**11960**				6'-10"	26
5625	6745	7899	9080	10280	11500	**12400**				6'-10"	27
5713	6863	8048	9263	10500	11760	**12860**				6'-11"	28
5797	6974	8191	9439	10710	12010	**13340**				7'- 0"	29
5876	7081	8328	9608	10920	12250	13600	**13810**			7'- 1"	30
5950	7182	8458	9770	11110	12480	13860	**14270**			7'- 2"	31
6021	7278	8583	9926	11300	12700	14120	**14710**			7'- 2"	32
6088	7370	8703	10080	11480	12920	14380	**15180**			7'- 3"	33
6151	7458	8817	10220	11660	13130	14620	**15640**			7'- 4"	34
6211	7541	8927	10360	11830	13330	14860	**16140**			7'- 5"	35
6268	7620	9032	10490	11990	13530	15090	**16570**			7'- 6"	36
6322	7696	9132	10620	12150	13720	15310	**17050**			7'- 6"	37
6373	7768	9228	10740	12300	13900	15520	17180	**17520**		7'- 7"	38
6421	7836	9320	10860	12450	14070	15730	17420	**17980**		7'- 8"	39
6466	7902	9408	10970	12590	14240	15940	17660	**18430**		7'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*
*▲Transition loads (**bold type**) and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*
Interpolate for intermediate heights of backfill and/or trench widths

Table B-10

33" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 33"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"	
5	1883	2129	**2258**								5'- 3"
6	2184	2477	2771	**2880**							5'- 8"
7	2463	2802	3143	**3450**							5'-11"
8	2723	3107	3494	3883	**3963**						6'- 1"
9	2964	3393	3824	4259	**4474**						6'- 3"
10	3189	3660	4135	4615	**4983**						6'- 4"
11	3397	3910	4428	4951	**5492**						6'- 6"
12	3591	4144	4704	5270	5841	**6003**					6'- 8"
13	3771	4363	4964	5572	6185	**6512**					6'- 9"
14	3938	4568	5209	5858	6513	**7019**					6'-11"
15	4093	4760	5439	6128	6824	**7526**					7'- 0"
16	4238	4940	5656	6384	7120	7864	**8034**				7'- 1"
17	4372	5108	5861	6626	7401	8186	**8542**				7'- 3"
18	4497	5266	6053	6855	7669	8492	**9045**				7'- 4"
19	4613	5413	6234	7072	7923	8785	**9559**				7'- 5"
20	4720	5552	6405	7277	8164	9064	**10060**				7'- 6"
21	4820	5681	6566	7472	8394	9331	10280	**10580**			7'- 8"
22	4913	5802	6717	7656	8612	9585	10570	**11070**			7'- 9"
23	5000	5915	6860	7830	8820	9827	10850	**11580**			7'-10"
24	5080	6021	6994	7994	9017	10060	11120	**12090**			8'- 0"
25	5155	6120	7121	8150	9204	10280	11370	12480	**12610**		8'- 1"
26	5224	6213	7240	8298	9382	10490	11620	12760	**13110**		8'- 2"
27	5289	6300	7352	8438	9552	10690	11850	13030	**13630**		8'- 3"
28	5349	6382	7458	8570	9713	10880	12070	13280	**14120**		8'- 4"
29	5404	6458	7557	8695	9866	11060	12290	13530	**14630**		8'- 5"
30	5456	6529	7651	8814	10010	11240	12490	13770	**15130**		8'- 6"
31	5504	6596	7739	8926	10150	11420	12690	13990	**15650**		8'- 7"
32	5549	6659	7822	9032	10280	11560	12880	14210	**16150**		8'- 9"
33	5590	6717	7901	9132	10400	11710	13060	14420	**16640**		8'-10"
34	5629	6772	7974	9227	10520	11860	13230	14620	**17170**		8'-11"
35	5665	6823	8044	9317	10640	11200	13390	14820	**17680**		9'- 0"
36	5698	6871	8109	9402	10740	12130	13550	15000	17990	**18180**	9'- 1"
37	5729	6916	8171	9483	10850	12250	13700	15180	18220	**18670**	9'- 2"
38	5758	6958	8229	9559	10940	12370	13840	15350	18450	**19200**	9'- 3"
39	5784	6998	8283	9631	11040	12490	13980	15510	18670	**19730**	9'- 4"
40	5809	7035	8335	9700	11120	12600	14110	15670	18880	**20240**	9'- 5"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"		
1913	2159	**2258**								5'- 3"	5
2225	2519	2814	**2880**							5'- 7"	6
2517	2857	3200	**3450**							5'-10"	7
2790	3176	3565	**3963**							6'- 0"	8
3045	3477	3911	4348	**4474**						6'- 2"	9
3284	3759	4239	4721	**4983**						6'- 3"	10
3507	4026	4549	5076	**5492**						6'- 5"	11
3717	4277	4843	5414	**6003**						6'- 6"	12
3912	4513	5121	5735	6354	**6512**					6'- 7"	13
4095	4735	5384	6040	6702	**7019**					6'- 9"	14
4266	4945	5634	6331	7035	**7526**					6'-10"	15
4426	5142	5870	6608	7353	**8034**					7'- 0"	16
4576	5328	6094	6871	7657	8450	**8542**				7'- 1"	17
4716	5503	6305	7121	7947	8781	**9045**				7'- 2"	18
4848	5668	6506	7359	8223	9098	**9559**				7'- 3"	19
4970	5823	6696	7585	8488	9401	**10060**				7'- 4"	20
5085	5969	6876	7800	8740	9692	**10580**				7'- 6"	21
5192	6107	7046	8005	8981	9971	**10970**				7'- 6"	22
5293	6236	7207	8200	9211	10240	11280	**11580**			7'- 8"	23
5387	6358	7360	8385	9431	10490	11570	**12090**			7'- 9"	24
5475	6473	7504	8561	9641	10740	11850	**12610**			7'-10"	25
5557	6582	7641	8729	9841	10970	12120	**13110**			7'-11"	26
5634	6684	7771	8889	10030	11200	12380	**13630**			8'- 0"	27
5706	6780	7893	9040	10220	11410	12630	13870	**14120**		8'- 1"	28
5773	6870	8010	9185	10390	11620	12870	14140	**14630**		8'- 2"	29
5836	6955	8120	9322	10560	11820	13100	14410	**15130**		8'- 3"	30
5895	7036	8224	9453	10720	12010	13320	14660	**15650**		8'- 4"	31
5950	7111	8323	9577	10870	12190	13540	14910	**16150**		8'- 5"	32
6002	7182	8416	9695	11010	12360	13740	15140	**16640**		8'- 6"	33
6050	7249	8505	9807	11150	12530	13940	15370	**17170**		8'- 7"	34
6095	7312	8588	9914	11280	12690	14130	15590	**17680**		8'- 8"	35
6137	7372	8668	10020	11410	12840	14310	15800	**18180**		8'- 9"	36
6177	7428	8743	10110	11530	12990	14480	16010	**18670**		8'-10"	37
6214	7480	8814	10200	11640	13130	14650	16200	**19200**		8'-11"	38
6248	7530	8881	10290	11760	13260	14810	16390	**19730**		9'- 0"	39
6280	7577	8945	10380	11860	13390	14960	16570	19880	**20240**	9'- 1"	40

Table B-10 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	
5	1707	1954	**2119**								4'-10"
6	1987	2281	2577	**2686**							5'- 2"
7	2249	2590	2933	**3155**							5'- 4"
8	2495	2882	3272	**3620**							5'- 5"
9	2725	3158	3593	4031	**4085**						5'- 7"
10	2941	3418	3898	4382	**4551**						5'- 8"
11	3143	3663	4188	4717	**5015**						5'-10"
12	3332	3894	4463	5036	**5478**						5'-10"
13	3510	4113	4724	5341	**5938**						6'- 0"
14	3676	4319	4972	5632	6297	**6401**					6'- 1"
15	3832	4514	5207	5909	6617	**6862**					6'- 2"
16	3978	4698	5430	6173	6924	**7330**					6'- 3"
17	4115	4871	5643	6425	7217	**7791**					6'- 4"
18	4243	5035	5844	6666	7498	**8250**					6'- 5"
19	4364	5190	6035	6895	7768	**8711**					6'- 6"
20	4476	5336	6216	7114	8025	8948	**9179**				6'- 8"
21	4582	5473	6388	7323	8272	9234	**9643**				6'- 9"
22	4681	5603	6552	7522	8509	9509	**10110**				6'-10"
23	4773	5726	6707	7712	8735	9774	**10570**				6'-10"
24	4860	5842	6855	7893	8952	10030	**11020**				7'- 0"
25	4942	5951	6994	8066	9159	10270	11400	**11500**			7'- 1"
26	5018	6054	7127	8230	9358	10510	11670	**11960**			7'- 1"
27	5089	6151	7253	8387	9548	10730	11930	**12400**			7'- 2"
28	5156	6243	7373	8537	9731	10950	12180	**12860**			7'- 3"
29	5219	6330	7486	8680	9905	11160	12430	**13340**			7'- 4"
30	5278	6412	7594	8817	10070	11360	12660	**13810**			7'- 5"
31	5333	6489	7697	8947	10230	11550	12890	**14270**			7'- 6"
32	5385	6562	7794	9071	10380	11730	13100	14500	**14710**		7'- 7"
33	5433	6631	7886	9189	10530	11910	13310	14740	**15180**		7'- 8"
34	5478	6696	7974	9302	10670	12080	13520	14980	**15640**		7'- 8"
35	5521	6757	8057	9410	10810	12240	13710	15200	**16140**		7'-10"
36	5561	6815	8136	9513	10940	12400	13900	15420	**16570**		7'-10"
37	5598	6870	8211	9610	11060	12550	14080	15640	**17050**		7'-11"
38	5633	6921	8282	9704	11180	12700	14250	15840	**17520**		8'- 0"
39	5666	6970	8350	9793	11290	12840	14420	16040	17680	**17980**	8'- 1"
40	5696	7016	8414	9878	11400	12970	14580	16230	17910	**18430**	8'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
4'-0"	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"		
1748	1996	**2119**								4'- 9"	5
2044	2340	2636	**2686**							5'- 1"	6
2323	2667	3012	**3155**							5'- 2"	7
2588	2979	3371	**3620**							5'- 4"	8
2839	3276	3715	**4085**							5'- 5"	9
3076	3559	4045	**4551**							5'- 6"	10
3301	3828	4360	4894	**5015**						5'- 7"	11
3513	4085	4661	5241	**5478**						5'- 8"	12
3714	4329	4950	5575	**5938**						5'- 9"	13
3905	4562	5226	5895	**6401**						5'-10"	14
4085	4783	5490	6203	**6862**						6'- 0"	15
4256	4994	5743	6499	7262	**7330**					6'- 1"	16
4417	5195	5985	6784	7590	**7791**					6'- 1"	17
4570	5386	6216	7057	7906	**8250**					6'- 2"	18
4714	5568	6438	7319	8210	**8711**					6'- 3"	19
4851	5742	6650	7571	8504	**9179**					6'- 4"	20
4981	5907	6853	7813	8787	**9643**					6'- 5"	21
5104	6064	7047	8046	9059	**10110**					6'- 6"	22
5220	6214	7233	8270	9322	10390	**10570**				6'- 7"	23
5329	6357	7410	8485	9576	10680	**11020**				6'- 8"	24
5433	6493	7581	8691	9820	10960	**11500**				6'- 9"	25
5532	6622	7743	8889	10060	11240	**11960**				6'-10"	26
5625	6745	7899	9080	10280	11500	**12400**				6'-10"	27
5713	6863	8048	9263	10500	11760	**12860**				6'-11"	28
5797	6974	8191	9439	10710	12010	**13340**				7'- 0"	29
5876	7081	8328	9608	10920	12250	13600	**13810**			7'- 1"	30
5950	7182	8458	9770	11110	12480	13860	**14270**			7'- 2"	31
6021	7278	8583	9926	11300	12700	14120	**14710**			7'- 2"	32
6088	7370	8703	10080	11480	12920	14380	**15180**			7'- 3"	33
6151	7458	8817	10220	11660	13130	14620	**15640**			7'- 4"	34
6211	7541	8927	10360	11830	13330	14860	**16140**			7'- 5"	35
6268	7620	9032	10490	11990	13530	15090	**16570**			7'- 6"	36
6322	7696	9132	10620	12150	13720	15310	**17050**			7'- 6"	37
6373	7768	9228	10740	12300	13900	15520	17180	**17520**		7'- 7"	38
6421	7836	9320	10860	12450	14070	15730	17420	**17980**		7'- 8"	39
6466	7902	9408	10970	12590	14240	15940	17660	**18430**		7'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-11

33" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 33"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"	
5	1883	2129	**2258**								**5'- 3"**
6	2184	2477	2771	**2880**							**5'- 8"**
7	2463	2802	3143	**3450**							**5'-11"**
8	2723	3107	3494	3883	**3963**						**6'- 1"**
9	2964	3393	3824	4259	**4474**						**6'- 3"**
10	3189	3660	4135	4615	**4983**						**6'- 4"**
11	3397	3910	4428	4951	**5492**						**6'- 6"**
12	3591	4144	4704	5270	5841	**6003**					**6'- 8"**
13	3771	4363	4964	5572	6185	**6512**					**6'- 9"**
14	3938	4568	5209	5858	6513	**7019**					**6'-11"**
15	4093	4760	5439	6128	6824	**7526**					**7'- 0"**
16	4238	4940	5656	6384	7120	7864	**8034**				**7'- 1"**
17	4372	5108	5861	6626	7401	8186	**8542**				**7'- 3"**
18	4497	5266	6053	6855	7669	8492	**9045**				**7'- 4"**
19	4613	5413	6234	7072	7923	8785	**9559**				**7'- 5"**
20	4720	5552	6405	7277	8164	9064	**10060**				**7'- 6"**
21	4820	5681	6566	7472	8394	9331	10280	**10580**			**7'- 8"**
22	4913	5802	6717	7656	8612	9585	10570	**11070**			**7'- 9"**
23	5000	5915	6860	7830	8820	9827	10850	**11580**			**7'-10"**
24	5080	6021	6994	7994	9017	10060	11120	**12090**			**8'- 0"**
25	5155	6120	7121	8150	9204	10280	11370	12480	**12610**		**8'- 1"**
26	5224	6213	7240	8298	9382	10490	11620	12760	**13110**		**8'- 2"**
27	5289	6300	7352	8438	9552	10690	11850	13030	**13630**		**8'- 3"**
28	5349	6382	7458	8570	9713	10880	12070	13280	**14120**		**8'- 4"**
29	5404	6458	7557	8695	9866	11060	12290	13530	**14630**		**8'- 5"**
30	5456	6529	7651	8814	10010	11240	12490	13770	**15130**		**8'- 6"**
31	5504	6596	7739	8926	10150	11420	12690	13990	**15650**		**8'- 7"**
32	5549	6659	7822	9032	10280	11560	12880	14210	**16150**		**8'- 9"**
33	5590	6717	7901	9132	10400	11710	13060	14420	**16640**		**8'-10"**
34	5629	6772	7974	9227	10520	11860	13230	14620	**17170**		**8'-11"**
35	5665	6823	8044	9317	10640	11200	13390	14820	**17680**		**9'- 0"**
36	5698	6871	8109	9402	10740	12130	13550	15000	17990	**18180**	**9'- 1"**
37	5729	6916	8171	9483	10850	12250	13700	15180	18220	**18670**	**9'- 2"**
38	5758	6958	8229	9559	10940	12370	13840	15350	18450	**19200**	**9'- 3"**
39	5784	6998	8283	9631	11040	12490	13980	15510	18670	**19730**	**9'- 4"**
40	5809	7035	8335	9700	11120	12600	14110	15670	18880	**20240**	**9'- 5"**

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"		
1913	2159	**2258**								5'- 3"	5
2225	2519	2814	**2880**							5'- 7"	6
2517	2857	3200	**3450**							5'-10"	7
2790	3176	3565	**3963**							6'- 0"	8
3045	3477	3911	4348	**4474**						6'- 2"	9
3284	3759	4239	4721	**4983**						6'- 3"	10
3507	4026	4549	5076	**5492**						6'- 5"	11
3717	4277	4843	5414	**6003**						6'- 6"	12
3912	4513	5121	5735	6354	**6512**					6'- 7"	13
4095	4735	5384	6040	6702	**7019**					6'- 9"	14
4266	4945	5634	6331	7035	**7526**					6'-10"	15
4426	5142	5870	6608	7353	**8034**					7'- 0"	16
4576	5328	6094	6871	7657	8450	**8542**				7'- 1"	17
4716	5503	6305	7121	7947	8781	**9045**				7'- 2"	18
4848	5668	6506	7359	8223	9098	**9559**				7'- 3"	19
4970	5823	6696	7585	8488	9401	**10060**				7'- 4"	20
5085	5969	6876	7800	8740	9692	**10580**				7'- 6"	21
5192	6107	7046	8005	8981	9971	**10970**				7'- 6"	22
5293	6236	7207	8200	9211	10240	11280	**11580**			7'- 8"	23
5387	6358	7360	8385	9431	10490	11570	**12090**			7'- 9"	24
5475	6473	7504	8561	9641	10740	11850	**12610**			7'-10"	25
5557	6582	7641	8729	9841	10970	12120	**13110**			7'-11"	26
5634	6684	7771	8889	10030	11200	12380	**13630**			8'- 0"	27
5706	6780	7893	9040	10220	11410	12630	13870	**14120**		8'- 1"	28
5773	6870	8010	9185	10390	11620	12870	14140	**14630**		8'- 2"	29
5836	6955	8120	9322	10560	11820	13100	14410	**15130**		8'- 3"	30
5895	7036	8224	9453	10720	12010	13320	14660	**15650**		8'- 4"	31
5950	7111	8323	9577	10870	12190	13540	14910	**16150**		8'- 5"	32
6002	7182	8416	9695	11010	12360	13740	15140	**16640**		8'- 6"	33
6050	7249	8505	9807	11150	12530	13940	15370	**17170**		8'- 7"	34
6095	7312	8588	9914	11280	12690	14130	15590	**17680**		8'- 8"	35
6137	7372	8668	10020	11410	12840	14310	15800	**18180**		8'- 9"	36
6177	7428	8743	10110	11530	12990	14480	16010	**18670**		8'-10"	37
6214	7480	8814	10200	11640	13130	14650	16200	**19200**		8'-11"	38
6248	7530	8881	10290	11760	13260	14810	16390	**19730**		9'- 0"	39
6280	7577	8945	10380	11860	13390	14960	16570	19880	**20240**	9'- 1"	40

Table B-11 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"	
5	1954	2201	**2258**								5'- 1"
6	2281	2577	**2880**								5'- 6"
7	2590	2933	3277	**3450**							5'- 9"
8	2882	3272	3663	**3963**							5'-11"
9	3158	3593	4031	**4474**							6'- 0"
10	3418	3898	4382	4869	**4983**						6'- 1"
11	3663	4188	4717	5249	**5492**						6'- 3"
12	3894	4463	5036	5614	**6003**						6'- 4"
13	4113	4724	5341	5963	**6512**						6'- 5"
14	4319	4972	5632	6297	**7019**						6'- 6"
15	4514	5207	5909	6617	7331	**7526**					6'- 8"
16	4698	5430	6173	6924	7681	**8034**					6'- 9"
17	4871	5643	6425	7217	8017	**8542**					6'-10"
18	5035	5844	6666	7498	8340	**9045**					6'-11"
19	5190	6035	6895	7768	8650	**9559**					7'- 0"
20	5336	6216	7114	8025	8948	9880	**10060**				7'- 1"
21	5473	6388	7323	8272	9234	10210	**10580**				7'- 2"
22	5603	6552	7522	8509	9509	10520	**11070**				7'- 3"
23	5726	6707	7712	8735	9774	10820	**11580**				7'- 4"
24	5842	6855	7893	8952	10030	11120	**12090**				7'- 5"
25	5951	6994	8066	9159	10270	11400	**12610**				7'- 6"
26	6054	7127	8230	9358	10510	11670	12850	**13110**			7'- 7"
27	6151	7253	8387	9548	10730	11930	13150	**13630**			7'- 8"
28	6243	7373	8537	9731	10950	12180	13440	**14120**			7'- 9"
29	6330	7486	8680	9905	11160	12430	13720	**14630**			7'-10"
30	6412	7594	8817	10070	11360	12660	13990	**15130**			7'-11"
31	6489	7697	8947	10230	11550	12890	14250	**15650**			8'- 0"
32	6562	7794	9071	10380	11730	13100	14500	15910	**16150**		8'- 1"
33	6631	7886	9189	10530	11910	13310	14740	16190	**16640**		8'- 2"
34	6696	7974	9302	10670	12080	13520	14980	16460	**17170**		8'- 3"
35	6757	8057	9410	10810	12240	13710	15200	16720	**17680**		8'- 4"
36	6815	8136	9513	10940	12400	13900	15420	16980	**18180**		8'- 5"
37	6870	8211	9610	11060	12550	14080	15640	17220	**18670**		8'- 5"
38	6921	8282	9704	11180	12700	14250	15840	17460	**19200**		8'- 6"
39	6970	8350	9793	11290	12840	14420	16040	17680	**19730**		8'- 7"
40	7016	8414	9878	11400	12970	14580	16230	17910	**20240**		8'- 8"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
4'-6"	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	9'-0"	10'-0"		
1996	2244	**2258**								5'- 0"	5
2340	2636	**2880**								5'- 5"	6
2667	3012	3357	**3450**							5'- 8"	7
2979	3371	3765	**3963**							5'- 9"	8
3276	3715	4156	**4474**							5'-10"	9
3559	4045	4533	**4983**							6'- 0"	10
3828	4360	4894	5431	**5492**						6'- 1"	11
4085	4661	5241	5824	**6003**						6'- 2"	12
4329	4950	5575	6204	**6512**						6'- 3"	13
4562	5226	5895	6570	**7019**						6'- 4"	14
4783	5490	6203	6922	**7526**						6'- 5"	15
4994	5743	6499	7262	**8034**						6'- 6"	16
5195	5985	6784	7590	8402	**8542**					6'- 7"	17
5386	6216	7057	7906	8761	**9045**					6'- 8"	18
5568	6438	7319	8210	9109	**9559**					6'- 9"	19
5742	6650	7571	8504	9445	**10060**					6'-10"	20
5907	6853	7813	8787	9770	**10580**					6'- 1"	21
6064	7047	8046	9059	10080	**11070**					7'- 0"	22
6214	7233	8270	9322	10390	11460	**11580**				7'- 1"	23
6357	7410	8485	9576	10680	11800	**12090**				7'- [illegible]"	24
6493	7581	8691	9820	10960	12120	**12610**				7'- 2"	25
6622	7743	8889	10060	11240	12440	**13110**				7'- 3"	26
6745	7899	9080	10280	11500	12740	**13630**				7'- 4"	27
6863	8048	9263	10500	11760	13030	**14120**				7'- 5"	28
6974	8191	9439	10710	12010	13320	**14630**				7'- 6"	29
7081	8328	9608	10920	12250	13600	14960	**15130**			7'- 7"	30
7182	8458	9770	11110	12480	13860	15270	**15650**			7'- 8"	31
7278	8583	9926	11300	12700	14120	15570	**16150**			7'- 8"	32
7370	8703	10080	11480	12920	14380	15860	**16640**			7'- 9"	33
7458	8817	10220	11660	13130	14620	16140	**17170**			7'-10"	34
7541	8927	10360	11830	13330	14860	16410	**17680**			7'-11"	35
7620	9032	10490	11990	13530	15090	16670	**18180**			8'- 0"	36
7696	9132	10620	12150	13720	15310	16930	**18670**			8'- 0"	37
7768	9228	10740	12300	13900	15520	17180	18860	**19200**		8'- 1"	38
7836	9320	10860	12450	14070	15730	17420	19140	**19730**		8'- 2"	39
7902	9408	10970	12590	14240	15940	17660	19410	**20240**		8'- 3"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-12

36" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 36"

* **100** POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	10'-0"	
5	2129	2375	**2394**								5'- 7"
6	2477	2771	**3038**								5'-11"
7	2802	3143	3485	**3730**							6'- 4"
8	3107	3494	3883	**4289**							6'- 6"
9	3393	3824	4259	4695	**4846**						6'- 8"
10	3660	4135	4615	5097	**5401**						6'-10"
11	3910	4428	4951	5478	**5952**						6'-11"
12	4144	4704	5270	5841	6415	**6508**					7'- 1"
13	4363	4964	5572	6185	6803	**7060**					7'- 3"
14	4568	5209	5858	6513	7174	**7609**					7'- 4"
15	4760	5439	6128	6824	7527	**8160**					7'- 5"
16	4940	5656	6384	7120	7864	8614	**8717**				7'- 7"
17	5108	5861	6626	7401	8186	8977	**9261**				7'- 8"
18	5266	6053	6855	7669	8492	9324	**9817**				7'- 9"
19	5413	6234	7072	7923	8785	9657	**10370**				7'-11"
20	5552	6405	7277	8164	9064	9975	**10930**				8'- 0"
21	5681	6566	7472	8394	9331	10280	11240	**11470**			8'- 1"
22	5802	6717	7656	8612	9585	10570	11570	**12030**			8'- 3"
23	5915	6860	7830	8820	9827	10850	11880	**12580**			8'- 4"
24	6021	6994	7994	9017	10060	11120	12190	**13120**			8'- 5"
25	6120	7121	8150	9204	10280	11370	12480	**13670**			8'- 6"
26	6213	7240	8298	9382	10490	11620	12760	13920	**14240**		8'- 8"
27	6300	7352	8438	9552	10690	11850	13030	14220	**14790**		8'- 9"
28	6382	7458	8570	9713	10880	12070	13280	14510	**15350**		8'-10"
29	6458	7557	8695	9866	11060	12290	13530	14790	**15890**		8'-11"
30	6529	7651	8814	10010	11240	12490	13770	15060	**16450**		9'- 0"
31	6596	7739	8926	10150	11400	12690	13990	15320	16670	**16990**	9'- 1"
32	6659	7822	9032	10280	11560	12880	14210	15570	16950	**17520**	9'- 2"
33	6717	7901	9132	10400	11710	13060	14420	15810	17230	**18080**	9'- 4"
34	6772	7974	9227	10520	11860	13230	14620	16040	17490	**18620**	9'- 5"
35	6823	8044	9317	10640	12000	13390	14820	16270	17740	**19190**	9'- 6"
36	6871	8109	9402	10740	12130	13550	15000	16480	17990	**19750**	9'- 7"
37	6916	8171	9483	10850	12250	13700	15180	16690	18220	**20300**	9'- 8"
38	6958	8229	9559	10940	12370	13840	15350	16890	18450	**20840**	9'- 9"
39	6998	8283	9631	11040	12490	13980	15510	17080	18670	**21370**	9'-10"
40	7035	8335	9700	11120	12600	14110	15670	17260	18880	**21940**	9'-11"

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	10'-0"		
2159	**2394**									5'- 6"	5
2519	2814	**3038**								5'-11"	6
2857	3200	3543	**3730**							6'- 3"	7
3176	3565	3956	**4289**							6'- 5"	8
3477	3911	4348	4787	**4846**						6'- 7"	9
3759	4239	4721	5206	**5401**						6'- 8"	10
4026	4549	5076	5606	**5952**						6'-10"	11
4277	4843	5414	5989	**6508**						6'-11"	12
4513	5121	5735	6354	6976	**7060**					7'- 1"	13
4735	5384	6040	6702	7369	**7609**					7'- 2"	14
4945	5634	6331	7035	7745	**8160**					7'- 3"	15
5142	5870	6608	7353	8105	**8717**					7'- 5"	16
5328	6094	6871	7657	8450	**9261**					7'- 6"	17
5503	6305	7121	7947	8781	9623	**9817**				7'- 7"	18
5668	6506	7359	8223	9098	9981	**10370**				7'- 8"	19
5823	6696	7585	8488	9401	10320	**10930**				7'-10"	20
5969	6876	7800	8740	9692	10660	**11470**				7'-11"	21
6107	7046	8005	8981	9971	10970	**12030**				8'- 0"	22
6236	7207	8200	9211	10240	11280	12330	**12580**			8'- 1"	23
6358	7360	8385	9431	10490	11570	12660	**13120**			8'- 3"	24
6473	7504	8561	9641	10740	11850	12980	**13670**			8'- 3"	25
6582	7641	8729	9841	10970	12120	13290	**14240**			8'- 5"	26
6684	7771	8889	10030	11200	12380	13580	**14790**			8'- 6"	27
6780	7893	9040	10220	11410	12630	13870	15120	**15350**		8'- 7"	28
6870	8010	9185	10390	11620	12870	14140	15430	**15890**		8'- 8"	29
6955	8120	9322	10560	11820	13100	14410	15730	**16450**		8'- 9"	30
7036	8224	9453	10720	12010	13320	14660	16020	**16990**		8'-10"	31
7111	8323	9577	10870	12190	13540	14910	16300	**17520**		8'-11"	32
7182	8416	9695	11010	12360	13740	15140	16570	**18080**		9'- 0"	33
7249	8505	9807	11150	12530	13940	15370	16830	18310	**18620**	9'- 1"	34
7312	8588	9914	11280	12690	14130	15590	17080	18590	**19190**	9'- 2"	35
7372	8668	10020	11410	12840	14310	15800	17320	18870	**19750**	9'- 3"	36
7428	8743	10110	11530	12990	14480	16010	17560	19130	**20300**	9'- 5"	37
7480	8814	10200	11640	13130	14650	16210	17780	19390	**20840**	9'- 5"	38
7530	8881	10290	11760	13260	14810	16390	18000	19640	**21370**	9'- 6"	39
7577	8945	10380	11860	13390	14960	16570	18210	19880	**21940**	9'- 7"	40

Table B-12 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	10'-0"	
5	2201	**2394**									5'- 5"
6	2577	2873	**3038**								5'- 9"
7	2933	3277	3622	**3730**							6'- 2"
8	3272	3663	4056	**4289**							6'- 3"
9	3593	4031	4471	**4846**							6'- 5"
10	3898	4382	4869	5357	**5401**						6'- 7"
11	4188	4717	5249	5784	**5952**						6'- 8"
12	4463	5036	5614	6194	**6508**						6'- 9"
13	4724	5341	5963	6589	**7060**						6'-10"
14	4972	5632	6297	6967	**7609**						7'- 0"
15	5207	5909	6617	7331	8050	**8160**					7'- 1"
16	5430	6173	6924	7681	8443	**8717**					7'- 2"
17	5643	6425	7217	8017	8823	**9261**					7'- 3"
18	5844	6666	7498	8340	9188	**9817**					7'- 4"
19	6035	6895	7768	8650	9540	**10370**					7'- 6"
20	6216	7114	8025	8948	9880	10820	**10930**				7'- 7"
21	6388	7323	8272	9234	10210	11190	**11470**				7'- 8"
22	6552	7522	8509	9509	10520	11540	**12030**				7'- 9"
23	6707	7712	8735	9774	10820	11890	**12580**				7'-10"
24	6855	7893	8952	10030	11120	12220	**13120**				7'-11"
25	6994	8066	9159	10270	11400	12540	**13670**				8'- 0"
26	7127	8230	9358	10510	11670	12850	14040	**14240**			8'- 1"
27	7253	8387	9548	10730	11930	13150	14380	**14790**			8'- 2"
28	7373	8537	9731	10950	12180	13440	14710	**15350**			8'- 3"
29	7486	8680	9905	11160	12430	13720	15020	**15890**			8'- 4"
30	7594	8817	10070	11360	12660	13990	15330	**16450**			8'- 5"
31	7697	8947	10230	11550	12890	14250	15630	**16990**			8'- 6"
32	7794	9071	10380	11730	13100	14500	15910	17350	**17520**		8'- 7"
33	7886	9189	10530	11910	13310	14740	16190	17660	**18080**		8'- 8"
34	7974	9302	10670	12080	13520	14980	16460	17970	**18620**		8'- 9"
35	8057	9410	10810	12240	13710	15200	16720	18260	**19190**		8'-10"
36	8136	9513	10940	12400	13900	15420	16980	18550	**19750**		8'-11"
37	8211	9610	11060	12550	14080	15640	17220	18830	**20300**		8'-11"
38	8282	9704	11180	12700	14250	15840	17460	19100	**20840**		9'- 0"
39	8350	9793	11290	12840	14420	16040	17680	19360	21060	**21370**	9'- 1"
40	8414	9878	11400	12970	14580	16230	17910	19610	21340	**21940**	9'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	10'-0"		
2244	**2394**									5'- 4"	5
2636	2933	**3038**								5'- 8"	6
3012	3357	3704	**3730**							6'- 1"	7
3371	3765	4160	**4289**							6'- 2"	8
3715	4156	4599	**4846**							6'- 3"	9
4045	4533	5022	**5401**							6'- 5"	10
4360	4894	5431	**5952**							6'- 6"	11
4661	5241	5824	6410	**6508**						6'- 7"	12
4950	5575	6204	6836	**7060**						6'- 8"	13
5226	5895	6570	7247	**7609**						6'- 9"	14
5490	6203	6922	7645	**8160**						6'-10"	15
5743	6499	7262	8030	**8717**						6'-11"	16
5985	6784	7590	8402	**9261**						7'- 0"	17
6216	7057	7906	8761	9622	**9817**					7'- 1"	18
6438	7319	8210	9109	10010	**10370**					7'- 2"	19
6650	7571	8504	9445	10390	**10930**					7'- 3"	20
6853	7813	8787	9770	10760	**11470**					7'- 4"	21
7047	8046	9059	10080	11120	**12030**					7'- 5"	22
7233	8270	9322	10390	11460	**12580**					7'- 6"	23
7410	8485	9576	10680	11800	12920	**13120**				7'- 7"	24
7581	8691	9820	10960	12120	13290	**13670**				7'- 8"	25
7743	8889	10060	11240	12440	13640	**14240**				7'- 9"	26
7899	9080	10280	11500	12740	13990	**14790**				7'-10"	27
8048	9263	10500	11760	13030	14320	**15350**				7'-11"	28
8191	9439	10710	12010	13320	14650	**15890**				7'-11"	29
8328	9608	10920	12250	13600	14960	**16450**				8'- 0"	30
8458	9770	11110	12480	13860	15270	16690	**16990**			8'- 1"	31
8583	9926	11300	12700	14120	15570	17020	**17520**			8'- 2"	32
8703	10080	11480	12920	14380	15860	17350	**18080**			8'- 3"	33
8817	10220	11660	13130	14620	16140	17670	**18620**			8'- 3"	34
8927	10360	11830	13330	14860	16410	17980	**19190**			8'- 4"	35
9032	10490	11990	13530	15090	16670	18280	**19750**			8'- 5"	36
9132	10620	12150	13720	15310	16930	18570	**20300**			8'- 6"	37
9228	10740	12300	13900	15520	17180	18860	20560	**20840**		8'- 7"	38
9320	10860	12450	14070	15730	17420	19140	20870	**21370**		8'- 8"	39
9408	10970	12590	14240	15940	17660	19410	21180	**21940**		8'- 9"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads ***(bold type)*** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-13

42" 42"

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	
5	2622	**2671**									6'- 1"
6	3066	**3361**									6'- 6"
7	3485	3829	**4114**								6'-11"
8	3883	4273	4665	**4932**							7'- 4"
9	4259	4695	5134	**5582**							7'- 6"
10	4615	5097	5581	6067	**6227**						7'- 8"
11	4951	5478	6008	6540	**6869**						7'-10"
12	5270	5841	6415	6992	**7510**						7'-11"
13	5572	6185	6803	7425	8049	**8150**					8'- 1"
14	5858	6513	7174	7839	8508	**8789**					8'- 2"
15	6128	6824	7527	8235	8948	**9434**					8'- 4"
16	6384	7120	7864	8614	9370	**10070**					8'- 6"
17	6626	7401	8186	8977	9775	10580	**10710**				8'- 7"
18	6855	7669	8492	9324	10160	11010	**11350**				8'- 8"
19	7072	7923	8785	9657	10540	11420	**11980**				8'-10"
20	7277	8164	9064	9975	10890	11820	**12630**				8'-11"
21	7472	8394	9331	10280	11240	12200	13180	**13270**			9'- 1"
22	7656	8612	9585	10570	11570	12570	13590	**13900**			9'- 2"
23	7830	8820	9827	10850	11880	12930	13980	**14550**			9'- 3"
24	7994	9017	10060	11120	12190	13270	14360	**15190**			9'- 4"
25	8150	9204	10280	11370	12480	13600	14730	**15830**			9'- 6"
26	8298	9382	10490	11620	12760	13920	15080	16260	**16470**		9'- 7"
27	8438	9552	10690	11850	13030	14220	15420	16640	**17090**		9'- 8"
28	8570	9713	10880	12070	13280	14510	15750	17010	**17740**		9'- 9"
29	8695	9866	11060	12290	13530	14790	16070	17360	**18380**		9'-11"
30	8814	10010	11240	12490	13770	15060	16370	17700	**19000**		10'- 0"
31	8926	10150	11400	12690	13990	15320	16670	18030	19410	**19670**	10'- 1"
32	9032	10280	11560	12880	14210	15570	16950	18350	19760	**20280**	10'- 2"
33	9132	10400	11710	13060	14420	15810	17230	18660	20100	**20920**	10'- 3"
34	9227	10520	11860	13230	14620	16040	17490	18950	20440	**21540**	10'- 4"
35	9317	10640	12000	13390	14820	16270	17740	19240	20760	**22190**	10'- 5"
36	9402	10740	12130	13550	15000	16480	17990	19520	21060	**22830**	10'- 7"
37	9483	10850	12250	13700	15180	16690	18220	19780	21360	**23500**	10'- 8"
38	9559	10940	12370	13840	15350	16890	18450	20040	21660	**24110**	10'- 9"
39	9631	11040	12490	13980	15510	17080	18670	20290	21940	**24760**	10'-10"
40	9700	11120	12600	14110	15670	17260	18880	20530	22210	**25400**	10'-11"

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"		
2671										6'- 0"	5
3110	**3361**									6'- 5"	6
3543	3888	**4114**								6'-10"	7
3956	4348	4740	**4932**							7'- 3"	8
4348	4787	5227	**5582**							7'- 5"	9
4721	5206	5693	6181	**6227**						7'- 7"	10
5076	5606	6139	6674	**6869**						7'- 8"	11
5414	5989	6567	7147	**7510**						7'-10"	12
5735	6354	6976	7602	**8150**						7'-11"	13
6040	6702	7369	8039	**8789**						8'- 0"	14
6331	7035	7745	8459	9177	**9434**					8'- 2"	15
6608	7353	8105	8863	9625	**10070**					8'- 3"	16
6871	7657	8450	9250	10060	**10710**					8'- 5"	17
7121	7947	8781	9623	10470	**11350**					8'- 6"	18
7359	8223	9098	9981	10870	11770	**11980**				8'- 8"	19
7585	8488	9401	10320	11260	12190	**12630**				8'- 9"	20
7800	8740	9692	10660	11630	12610	**13270**				8'-10"	21
8005	8981	9971	10970	11980	13000	**13900**				8'-11"	22
8200	9211	10240	11280	12330	13390	14460	**14550**			9'- 1"	23
8385	9431	10490	11570	12660	13760	14870	**15190**			9'- 2"	24
8561	9641	10740	11850	12980	14120	15260	**15830**			9'- 3"	25
8729	9841	10970	12120	13290	14460	15650	**16470**			9'- 4"	26
8889	10030	11200	12380	13580	14800	16020	**17090**			9'- 5"	27
9040	10220	11410	12630	13870	15120	16380	**17740**			9'- 6"	28
9185	10390	11620	12870	14140	15430	16730	18040	**18380**		9'- 8"	29
9322	10560	11820	13100	14410	15730	17070	18420	**19000**		9'- 9"	30
9453	10720	12010	13320	14660	16020	17390	18780	**19670**		9'-10"	31
9577	10870	12190	13540	14910	16300	17710	19130	**20280**		9'-11"	32
9695	11010	12360	13740	15140	16570	18010	19470	**20920**		10'- 0"	33
9807	11150	12530	13940	15370	16830	18310	19800	21310	**21540**	10'- 1"	34
9914	11280	12690	14130	15590	17080	18590	20120	21670	**22190**	10'- 2"	35
10020	11410	12840	14310	15800	17320	18870	20430	22010	**22830**	10'- 3"	36
10110	11530	12990	14480	16010	17560	19130	20730	22350	**23500**	10'- 4"	37
10200	11640	13130	14650	16200	17780	19390	21020	22670	**24110**	10'- 5"	38
10290	11760	13260	14810	16390	18000	19640	21300	22990	**24760**	10'- 6"	39
10380	11860	13390	14960	16570	18210	19880	21580	23290	**25400**	10'- 7"	40

Table B-13 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	
5	**2671**										5'-11"
6	3170	**3361**									6'- 4"
7	3622	3968	**4114**								6'- 8"
8	4056	4450	4844	**4932**							7'- 1"
9	4471	4912	5355	**5582**							7'- 3"
10	4869	5357	5847	**6227**							7'- 5"
11	5249	5784	6321	**6869**							7'- 6"
12	5614	6194	6777	7362	**7510**						7'- 7"
13	5963	6589	7217	7848	**8150**						7'- 9"
14	6297	6967	7641	8318	**8789**						7'-10"
15	6617	7331	8050	8772	**9434**						7'-11"
16	6924	7681	8443	9210	**10070**						8'- 0"
17	7217	8017	8823	9633	10450	**10710**					8'- 2"
18	7498	8340	9188	10040	10900	**11350**					8'- 3"
19	7768	8650	9540	10440	11340	**11980**					8'- 4"
20	8025	8948	9880	10820	11760	**12630**					8'- 5"
21	8272	9234	10210	11190	12180	13170	**13270**				8'- 7"
22	8509	9509	10520	11540	12570	13610	**13900**				8'- 8"
23	8735	9774	10820	11890	12960	14040	**14550**				8'- 9"
24	8952	10030	11120	12220	13330	14450	**15190**				8'-10"
25	9159	10270	11400	12540	13690	14850	**15830**				8'-11"
26	9358	10510	11670	12850	14040	15240	**16470**				9'- 0"
27	9548	10730	11930	13150	14380	15620	16870	**17090**			9'- 1"
28	9731	10950	12180	13440	14710	15990	17280	**17740**			9'- 2"
29	9905	11160	12430	13720	15020	16340	17670	**18380**			9'- 3"
30	10070	11360	12660	13990	15330	16690	18060	**19000**			9'- 4"
31	10230	11550	12890	14250	15630	17020	18430	**19670**			9'- 5"
32	10380	11730	13100	14500	15910	17350	18790	**20280**			9'- 6"
33	10530	11910	13310	14740	16190	17660	19140	20640	**20920**		9'- 7"
34	10670	12080	13520	14980	16460	17970	19490	21020	**21540**		9'- 8"
35	10810	12240	13710	15200	16720	18260	19820	21390	**22190**		9'- 9"
36	10940	12400	13900	15420	16980	18550	20140	21750	**22830**		9'-10"
37	11060	12550	14080	15640	17220	18830	20460	22100	**23500**		9'-11"
38	11180	12700	14250	15840	17460	19100	20760	22440	**24110**		10'- 0"
39	11290	12840	14420	16040	17680	19360	21060	22770	24510	**24760**	10'- 1"
40	11400	12970	14580	16230	17910	19610	21340	23100	24870	**25400**	10'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"		
2671										5'-10"	5
3231	**3361**									6'- 3"	6
3704	4051	**4114**								6'- 7"	7
4160	4555	**4932**								7'- 0"	8
4599	5042	5487	**5582**							7'- 1"	9
5022	5514	6006	**6227**							7'- 3"	10
5431	5969	6509	**6869**							7'- 4"	11
5824	6410	6997	**7510**							7'- 5"	12
6204	6836	7470	**8150**							7'- 6"	13
6570	7247	7928	8611	**8789**						7'- 7"	14
6922	7645	8372	9101	**9434**						7'- 9"	15
7262	8030	8802	9577	**10070**						7'-10"	16
7590	8402	9218	10040	**10710**						7'-11"	17
7906	8761	9622	10490	**11350**						8'- 0"	18
8210	9109	10010	10920	11840	**11980**					8'- 1"	19
8504	9445	10390	11350	12310	**12630**					8'- 2"	20
8787	9770	10760	11760	12760	**13270**					8'- 3"	21
9059	10080	11120	12160	13200	**13900**					8'- 4"	22
9322	10390	11460	12540	13640	**14550**					8'- 5"	23
9576	10680	11800	12920	14060	**15190**					8'- 6"	24
9820	10960	12120	13290	14460	15640	**15830**				8'- 7"	25
10060	11240	12440	13640	14860	16080	**16470**				8'- 8"	26
10280	11500	12740	13990	15240	16510	**17090**				8'- 9"	27
10500	11760	13030	14320	15620	16930	**17740**				8'-10"	28
10710	12010	13320	14650	15990	17340	**18380**				8'-10"	29
10920	12250	13600	14960	16340	17730	**19000**				9'- 0"	30
11110	12480	13860	15270	16690	18120	**19670**				9'- 0"	31
11300	12700	14120	15570	17020	18500	19980	**20280**			9'- 1"	32
11480	12920	14380	15860	17350	18860	20380	**20920**			9'- 2"	33
11660	13130	14620	16140	17670	19220	20780	**21540**			9'- 3"	34
11830	13330	14860	16410	17980	19570	21170	**22190**			9'- 4"	35
11990	13530	15090	16670	18280	19910	21550	**22830**			9'- 5"	36
12150	13720	15310	16930	18570	20240	21920	**23500**			9'- 6"	37
12300	13900	15520	17180	18860	20560	22280	**24110**			9'- 6"	38
12450	14070	15730	17420	19140	20870	22630	24400	**24760**		9'- 7"	39
12590	14240	15940	17660	19410	21180	22970	24780	**25400**		9'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads ***(bold type)*** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-14

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

48"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE 6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10-0"	11'-0"	12'-0"	▲TRANSITION WIDTH
5	2870	**2950**									6'- 8"
6	3361	3658	**3691**								7'- 1"
7	3829	4173	**4490**								7'- 6"
8	4273	4665	5057	**5354**							7'-11"
9	4695	5134	5573	6014	**6287**						8'- 4"
10	5097	5581	6067	6555	**7041**						8'- 6"
11	5478	6008	6540	7074	7609	**7776**					8'- 8"
12	5841	6415	6992	7571	8153	**8508**					8'- 9"
13	6185	6803	7425	8049	8676	**9235**					8'-11"
14	6513	7174	7839	8508	9180	9855	**9966**				9'- 1"
15	6824	7527	8235	8948	9664	10380	**10690**				9'- 2"
16	7120	7864	8614	9370	10130	10890	**11420**				9'- 4"
17	7401	8186	8977	9775	10580	11380	**12150**				9'- 5"
18	7669	8492	9324	10160	11010	11860	12710	**12870**			9'- 7"
19	7923	8785	9657	10540	11420	12320	13210	**13600**			9'- 9"
20	8164	9064	9975	10890	11820	12760	13700	**14330**			9'-10"
21	8394	9331	10280	11240	12200	13180	14160	**15060**			9'-11"
22	8612	9585	10570	11570	12570	13590	14610	15640	**15770**		10'- 1"
23	8820	9827	10850	11880	12930	13980	15050	16120	**16510**		10'- 2"
24	9017	10060	11120	12190	13270	14360	15470	16580	**17230**		10'- 3"
25	9204	10280	11370	12480	13600	14730	15870	17020	**17960**		10'- 5"
26	9382	10490	11620	12760	13920	15080	16260	17450	**18680**		10'- 6"
27	9552	10690	11850	13030	14220	15420	16640	17870	**19400**		10'- 7"
28	9713	10880	12070	13280	14510	15750	17010	18270	**20120**		10'- 8"
29	9866	11060	12290	13530	14790	16070	17360	18660	**20850**		10'-10"
30	10010	11240	12490	13770	15060	16370	17700	19040	**21590**		10'-11"
31	10150	11400	12690	13990	15320	16670	18030	19410	22200	**22320**	11'- 1"
32	10280	11560	12880	14210	15570	16950	18350	19760	22630	**23020**	11'- 1"
33	10400	11710	13060	14420	15810	17230	18660	20100	23040	**23740**	11'- 3"
34	10520	11860	13230	14620	16040	17490	18950	20440	23440	**24490**	11'- 4"
35	10640	12000	13390	14820	16270	17740	19240	20760	23840	**25220**	11'- 5"
36	10740	12130	13550	15000	16480	17990	19520	21060	24210	**25930**	11'- 6"
37	10850	12250	13700	15180	16690	18220	19780	21360	24580	**26680**	11'- 8"
38	10940	12370	13840	15350	16890	18450	20040	21660	24940	**27410**	11'- 9"
39	11040	12490	13980	15510	17080	18670	20290	21940	25290	**28130**	11'-10"
40	11120	12600	14110	15670	17260	18880	20530	22210	25620	**28820**	11'-11"

48"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE 6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
2902	**2950**									6'- 7"	5
3406	**3691**									7'- 0"	6
3888	4233	**4490**								7'- 4"	7
4348	4740	5134	**5354**							7'- 9"	8
4787	5227	5668	6110	**6287**						8'- 2"	9
5206	5693	6181	6671	**7041**						8'- 5"	10
5606	6139	6674	7210	**7776**						8'- 6"	11
5989	6567	7147	7730	8315	**8508**					8'- 8"	12
6354	6976	7602	8231	8862	**9235**					8'- 9"	13
6702	7369	8039	8713	9389	**9966**					8'-11"	14
7035	7745	8459	9177	9899	**10690**					9'- 0"	15
7353	8105	8863	9625	10390	11160	**11420**				9'- 2"	16
7657	8450	9250	10060	10870	11680	**12150**				9'- 3"	17
7947	8781	9623	10470	11320	12180	**12870**				9'- 5"	18
8223	9098	9981	10870	11770	12670	**13600**				9'- 6"	19
8488	9401	10320	11260	12190	13140	14090	**14330**			9'- 8"	20
8740	9692	10660	11630	12610	13590	14580	**15060**			9'- 9"	21
8981	9971	10970	11980	13000	14030	15060	**15770**			9'-10"	22
9211	10240	11280	12330	13390	14460	15530	**16510**			9'-11"	23
9431	10490	11570	12660	13760	14870	15980	17110	**17230**		10'- 1"	24
9641	10740	11850	12980	14120	15260	16420	17590	**17960**		10'- 2"	25
9841	10970	12120	13290	14460	15650	16850	18050	**18680**		10'- 3"	26
10030	11200	12380	13580	14800	16020	17260	18500	**19400**		10'- 4"	27
10220	11410	12630	13870	15120	16380	17660	18940	**20120**		10'- 5"	28
10390	11620	12870	14140	15430	16730	18040	19370	**20850**		10'- 7"	29
10560	11820	13100	14410	15730	17070	18420	19780	**21590**		10'- 8"	30
10720	12010	13320	14660	16020	17390	18780	20180	**22320**		10'- 9"	31
10870	12190	13540	14910	16300	17710	19130	20570	**23020**		10'-10"	32
11010	12360	13740	15140	16570	18010	19470	20950	**23740**		10'-11"	33
11150	12530	13940	15370	16830	18310	19800	21310	**24490**		11'- 0"	34
11280	12690	14130	15590	17080	18590	20120	21670	24800	**25220**	11'- 1"	35
11410	12840	14310	15800	17320	18870	20430	22010	25220	**25930**	11'- 3"	36
11530	12990	14480	16010	17560	19130	20730	22350	25630	**26680**	11'- 4"	37
11640	13130	14650	16200	17780	19390	21020	22670	26020	**27410**	11'- 5"	38
11760	13260	14810	16390	18000	19640	21300	22990	26410	**28130**	11'- 6"	39
11860	13390	14960	16570	18210	19880	21580	23290	26780	**28820**	11'- 7"	40

Table B-14 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	
5	**2950**										6'- 6"
6	3467	**3691**									6'-11"
7	3968	4314	**4490**								7'- 3"
8	4450	4844	5239	**5354**							7'- 8"
9	4912	5355	5798	6242	**6287**						8'- 1"
10	5357	5847	6338	6830	**7041**						8'- 2"
11	5784	6321	6859	7398	**7776**						8'- 4"
12	6194	6777	7362	7949	**8508**						8'- 6"
13	6589	7217	7848	8482	9117	**9235**					8'- 7"
14	6967	7641	8318	8998	9679	**9966**					8'- 9"
15	7331	8050	8772	9497	10220	**10690**					8'-10"
16	7681	8443	9210	9981	10750	**11420**					8'-11"
17	8017	8823	9633	10450	11270	**12150**					9'- 0"
18	8340	9188	10040	10900	11760	12630	**12870**				9'- 2"
19	8650	9540	10440	11340	12250	13160	**13600**				9'- 3"
20	8948	9880	10820	11760	12720	13670	**14330**				9'- 4"
21	9234	10210	11190	12180	13170	14170	**15060**				9'- 5"
22	9509	10520	11540	12570	13610	14650	**15770**				9'- 6"
23	9774	10820	11890	12960	14040	15120	16210	**16510**			9'- 8"
24	10030	11120	12220	13330	14450	15580	16710	**17230**			9'- 9"
25	10270	11400	12540	13690	14850	16020	17200	**17960**			9'-10"
26	10510	11670	12850	14040	15240	16450	17670	**18680**			9'-11"
27	10730	11930	13150	14380	15620	16870	18130	**19400**			10'- 0"
28	10950	12180	13440	14710	15990	17280	18580	19890	**20120**		10'- 1"
29	11160	12430	13720	15020	16340	17670	19020	20370	**20850**		10'- 2"
30	11360	12660	13990	15330	16690	18060	19440	20830	**21590**		10'- 3"
31	11550	12890	14250	15630	17020	18430	19850	21280	**22320**		10'- 4"
32	11730	13100	14500	15910	17350	18790	20250	21720	**23020**		10'- 5"
33	11910	13310	14740	16190	17660	19140	20640	22150	**23740**		10'- 6"
34	12080	13520	14980	16460	17970	19490	21020	22570	**24490**		10'- 7"
35	12240	13710	15200	16720	18260	19820	21390	22980	**25220**		10'- 8"
36	12400	13900	15420	16980	18550	20140	21750	23380	**25930**		10'- 9"
37	12550	14080	15640	17220	18830	20460	22100	23760	**26680**		10'-11"
38	12700	14250	15840	17460	19100	20760	22440	24140	**27410**		10'-11"
39	12840	14420	16040	17680	19360	21060	22770	24510	**28130**		11'- 0"
40	12970	14580	16230	17910	19610	21340	23100	24870	28460	**28820**	11'- 1"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"		
2950										6'- 5"	5
3529	**3691**									6'- 9"	6
4051	4398	**4490**								7'- 2"	7
4555	4951	**5354**								7'- 6"	8
5042	5487	5932	**6287**							7'-11"	9
5514	6006	6500	6994	**7041**						8'- 1"	10
5969	6509	7051	7593	**7776**						8'- 2"	11
6410	6997	7586	8176	**8508**						8'- 3"	12
6836	7470	8106	8744	**9235**						8'- 5"	13
7247	7928	8611	9295	**9966**						8'- 6"	14
7645	8372	9101	9832	10570	**10690**					8'- 7"	15
8030	8802	9577	10360	11140	**11420**					8'- 8"	16
8402	9218	10040	10860	11690	**12150**					8'- 9"	17
8761	9622	10490	11360	12230	**12870**					8'-10"	18
9109	10010	10920	11840	12760	**13600**					9'- 0"	19
9445	10390	11350	12310	13270	**14330**					9'- 0"	20
9770	10760	11760	12760	13770	14780	**15060**				9'- 2"	21
10080	11120	12160	13200	14260	15310	**15770**				9'- 3"	22
10390	11460	12540	13640	14730	15830	**16510**				9'- 4"	23
10680	11800	12920	14060	15200	16340	**17230**				9'- 5"	24
10960	12120	13290	14460	15640	16840	**17960**				9'- 6"	25
11240	12440	13640	14860	16080	17320	18560	**18680**			9'- 7"	26
11500	12740	13990	15240	16510	17790	19070	**19400**			9'- 8"	27
11760	13030	14320	15620	16930	18250	19570	**20120**			9'- 8"	28
12010	13320	14650	15990	17340	18700	20060	**20850**			9'-10"	29
12250	13600	14960	16340	17730	19130	20540	**21590**			9'-10"	30
12480	13860	15270	16690	18120	19560	21010	**22320**			9'-11"	31
12700	14120	15570	17020	18500	19980	21470	**23020**			10'- 0"	32
12920	14380	15860	17350	18860	20380	21920	23460	**23740**		10'- 1"	33
13130	14620	16140	17670	19220	20780	22360	23940	**24490**		10'- 2"	34
13330	14860	16410	17980	19570	21170	22780	24410	**25220**		10'- 3"	35
13530	15090	16670	18280	19910	21550	23200	24870	**25930**		10'- 4"	36
13720	15310	16930	18570	20240	21920	23610	25310	**26680**		10'- 5"	37
13900	15520	17180	18860	20560	22280	24010	25750	**27410**		10'- 6"	38
14070	15730	17420	19140	20870	22630	24400	26180	**28130**		10'- 6"	39
14240	15940	17660	19410	21180	22970	24780	26600	**28820**		10'- 7"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-15

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

54" 54"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	13'-0"	
5	3118	**3238**									7'- 3"
6	3658	3954	**4030**								7'- 7"
7	4173	4518	**4880**								8'- 0"
8	4665	5057	5451	**5790**							8'- 5"
9	5134	5573	6014	6456	**6765**						8'-10"
10	5581	6067	6555	7044	7534	**7809**					9'- 3"
11	6008	6540	7074	7609	8146	**8683**					9'- 6"
12	6415	6992	7571	8153	8737	9322	**9507**				9'- 8"
13	6803	7425	8049	8676	9306	9937	**10330**				9'- 9"
14	7114	7839	8508	9180	9855	10530	**11150**				9'-11"
15	7527	8235	8948	9664	10380	11110	11830	**11970**			10'- 1"
16	7864	8614	9370	10130	10890	11660	12430	**12780**			10'- 3"
17	8186	8977	9775	10580	11380	12200	13010	**13600**			10'- 5"
18	8492	9324	10160	11010	11860	12710	13570	**14420**			10'- 6"
19	8785	9657	10540	11420	12320	13210	14120	**15230**			10'- 7"
20	9064	9975	10890	11820	12760	13700	14640	**16050**			10'- 9"
21	9331	10280	11240	12200	13180	14160	15150	**16860**			10"-10"
22	9585	10570	11570	12570	13590	14610	15640	**17680**			11'- 0"
23	9827	10850	11880	12930	13980	15050	16120	18280	**18490**		11'- 1"
24	10060	11120	12190	13270	14360	15470	16580	18820	**19310**		11'- 3"
25	10280	11370	12480	13600	14730	15870	17020	19350	**20120**		11'- 4"
26	10490	11620	12760	13920	15080	16260	17450	19860	**20930**		11'- 5"
27	10690	11850	13030	14220	15420	16640	17870	20360	**21750**		11'- 7"
28	10880	12070	13280	14510	15750	17010	18270	20840	**22580**		11'- 8"
29	11060	12290	13530	14790	16070	17360	18660	21300	**23380**		11'- 9"
30	11240	12490	13770	15060	16370	17700	19040	21760	**24190**		11'-11"
31	11400	12690	13990	15320	16670	18030	19410	22200	**25010**		12'- 0"
32	11560	12880	14210	15570	16950	18350	19760	22630	25540	**25840**	12'- 1"
33	11710	13060	14420	15810	17230	18660	20100	23040	26030	**26650**	12'- 3"
34	11860	13230	14620	16040	17490	18950	20440	23440	26500	**27440**	12'- 3"
35	12000	13390	14820	16270	17740	19240	20760	23840	26970	**28250**	12'- 5"
36	12130	13550	15000	16480	17990	19520	21060	24210	27420	**29090**	12'- 6"
37	12250	13700	15180	16690	18220	19780	21360	24580	27860	**29910**	12'- 7"
38	12370	13840	15350	16890	18450	20040	21660	24940	28290	**30720**	12'- 9"
39	12490	13980	15510	17080	18670	20290	21940	25290	28710	**31500**	12'-10"
40	12600	14110	15670	17260	18880	20530	22210	25620	29110	**32330**	12'-11"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	13'-0"		
3150	**3238**									7'- 2"	5
3703	4000	**4030**								7'- 7"	6
4233	4579	**4880**								7'-11"	7
4740	5134	5529	**5790**							8'- 4"	8
5227	5668	6110	6554	**6765**						8'- 9"	9
5693	6181	6671	7161	7653	**7809**					9'- 2"	10
6139	6674	7210	7748	8287	**8683**					9'- 4"	11
6567	7147	7730	8315	8901	**9507**					9'- 6"	12
6976	7602	8231	8862	9494	10130	**10330**				9'- 8"	13
7369	8039	8713	9389	10070	10750	**11150**				9'- 9"	14
7745	8459	9177	9899	10620	11350	**11970**				9'-11"	15
8105	8863	9625	10390	11160	11930	12710	**12780**			10'- 1"	16
8450	9250	10060	10870	11680	12500	13320	**13600**			10'- 2"	17
8781	9623	10470	11320	12180	13040	13910	**14420**			10'- 4"	18
9098	9981	10870	11770	12670	13570	14480	**15230**			10'- 5"	19
9401	10320	11260	12190	13140	14090	15040	**16050**			10'- 6"	20
9692	10660	11630	12610	13590	14580	15580	**16860**			10'- 8"	21
9971	10970	11980	13000	14030	15060	16100	**17680**			10'- 9"	22
10240	11280	12330	13390	14460	15530	16610	**18490**			10'-10"	23
10490	11570	12660	13760	14870	15980	17110	**19310**			11'- 0"	24
10740	11850	12980	14120	15260	16420	17590	19940	**20120**		11'- 1"	25
10970	12120	13290	14460	15650	16850	18050	20480	**20930**		11'- 2"	26
11200	12380	13580	14800	16020	17260	18500	21020	**21750**		11'- 3"	27
11410	12630	13870	15120	16380	17660	18940	21540	**22580**		11'- 5"	28
11620	12870	14140	15430	16730	18040	19370	22040	**23380**		11'- 6"	29
11820	13100	14410	15730	17070	18420	19780	22540	**24190**		11'- 7"	30
12010	13320	14660	16020	17390	18780	20180	23020	**25010**		11'- 8"	31
12190	13540	14910	16300	17710	19130	20570	23480	**25840**		11'- 9"	32
12360	13740	15140	16570	18010	19470	20950	23940	**26650**		11'-11"	33
12530	13940	15370	16830	18310	19800	21310	24380	**27440**		12'- 0"	34
12690	14130	15590	17080	18590	20120	21670	24800	27990	**28250**	12'- 1"	35
12840	14310	15800	17320	18870	20430	22010	25220	28480	**29090**	12'- 2"	36
12990	14480	16010	17560	19130	20730	22350	25630	28970	**29910**	12'- 3"	37
13130	14650	16200	17780	19390	21020	22670	26020	29440	**30720**	12'- 4"	38
13260	14810	16390	18000	19640	21300	22990	26410	29890	**31500**	12'- 5"	39
13390	14960	16570	18210	19880	21580	23290	26780	30340	**32330**	12'- 7"	40

Table B-15 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	13'-0"	
5	3194	**3238**									7'- 1"
6	3764	**4030**									7'- 5"
7	4314	4661	**4880**								7'-10"
8	4844	5239	5635	**5790**							8'- 2"
9	5355	5798	6242	6687	**6765**						8'- 7"
10	5847	6338	6830	7323	**7809**						9'- 0"
11	6321	6859	7398	7939	8481	**8683**					9'- 3"
12	6777	7362	7949	8537	9126	**9507**					9'- 4"
13	7217	7848	8482	9117	9754	**10330**					9'- 5"
14	7641	8318	8998	9679	10360	11050	**11150**				9'- 7"
15	8050	8772	9497	10220	10960	11690	**11970**				9'- 8"
16	8443	9210	9981	10750	11530	12310	**12780**				9'- 9"
17	8823	9633	10450	11270	12090	12910	**13600**				9'-11"
18	9188	10040	10900	11760	12630	13500	**14420**				10'- 0"
19	9540	10440	11340	12250	13160	14070	14990	**15230**			10'- 2"
20	9880	10820	11760	12720	13670	14630	15600	**16050**			10'- 3"
21	10210	11190	12180	13170	14170	15170	16180	**16860**			10'- 4"
22	10520	11540	12570	13610	14650	15700	16750	**17680**			10'- 5"
23	10820	11890	12960	14040	15120	16210	17310	**18490**			10'- 6"
24	11120	12220	13330	14450	15580	16710	17850	**19310**			10'- 8"
25	11400	12540	13690	14850	16020	17200	18380	**20120**			10'- 9"
26	11670	12850	14040	15240	16450	17670	18900	**20930**			10'-10"
27	11930	13150	14380	15620	16870	18130	19400	**21750**			10'-11"
28	12180	13440	14710	15990	17280	18580	19890	**22580**			11'- 0"
29	12430	13720	15020	16340	17670	19020	20370	23090	**23380**		11'- 1"
30	12660	13990	15330	16690	18060	19440	20830	23640	**24190**		11'- 2"
31	12890	14250	15630	17020	18430	19850	21280	24170	**25010**		11'- 3"
32	13100	14500	15910	17350	18790	20250	21720	24690	**25840**		11'- 5"
33	13310	14740	16190	17660	19140	20640	22150	25200	**26650**		11'- 6"
34	13520	14980	16460	17970	19490	21020	22570	25700	**27440**		11'- 7"
35	13710	15200	16720	18260	19820	21390	22980	26190	**28250**		11'- 7"
36	13900	15420	16980	18550	20140	21750	23380	26660	**29090**		11'- 9"
37	14080	15640	17220	18830	20460	22100	23760	27130	**29910**		11'-10"
38	14250	15840	17460	19100	20760	22440	24140	27580	**30720**		11'-11"
39	14420	16040	17680	19360	21060	22770	24510	28020	**31500**		12'- 0"
40	14580	16230	17910	19610	21340	23100	24870	28460	32100	**32330**	12'- 1"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	13'-0"		
3238										7'- 0"	5
3827	**4030**									7'- 4"	6
4398	4746	**4880**								7'- 8"	7
4951	5347	5744	**5790**							8'- 1"	8
5487	5932	6378	**6765**							8'- 5"	9
6006	6500	6994	7489	**7809**						8'-10"	10
6509	7051	7593	8136	**8683**						9'- 0"	11
6997	7586	8176	8768	9360	**9507**					9'- 2"	12
7470	8106	8744	9383	10020	**10330**					9'- 3"	13
7928	8611	9295	9982	10670	**11150**					9'- 4"	14
8372	9101	9832	10570	11300	**11970**					9'- 5"	15
8802	9577	10360	11140	11920	12700	**12780**				9'- 7"	16
9218	10040	10860	11690	12520	13350	**13600**				9'- 8"	17
9622	10490	11360	12230	13100	13980	**14420**				9'- 9"	18
10010	10920	11840	12760	13680	14600	**15230**				9'-10"	19
10390	11350	12310	13270	14240	15210	**16050**				9'-11"	20
10760	11760	12760	13770	14780	15800	**16860**				10'- 0"	21
11120	12160	13200	14260	15310	16380	17440	**17680**			10'- 1"	22
11460	12540	13640	14730	15830	16940	18050	**18490**			10'- 2"	23
11800	12920	14060	15200	16340	17490	18650	**19310**			10'- 4"	24
12120	13290	14460	15640	16840	18030	19230	**20120**			10'- 5"	25
12440	13640	14860	16080	17320	18560	19800	**20930**			10'- 5"	26
12740	13990	15240	16510	17790	19070	20360	**21750**			10'- 6"	27
13030	14320	15620	16930	18250	19570	20900	**22580**			10'- 7"	28
13320	14650	15990	17340	18700	20060	21440	**23380**			10'- 8"	29
13600	14960	16340	17730	19130	20540	21960	**24190**			10'- 9"	30
13860	15270	16690	18120	19560	21010	22470	**25010**			10'-10"	31
14120	15570	17020	18500	19980	21470	22970	**25840**			11'- 0"	32
14380	15860	17350	18860	20380	21920	23460	**26650**			11'- 0"	33
14620	16140	17670	19220	20780	22360	23940	27140	**27440**		11'- 1"	34
14860	16410	17980	19570	21170	22780	24410	27690	**28250**		11'- 2"	35
15090	16670	18280	19910	21550	23200	24870	28230	**29090**		11'- 3"	36
15310	16930	18570	20240	21920	23610	25310	28760	**29910**		11'- 4"	37
15520	17180	18860	20560	22280	24010	25750	29280	**30720**		11'- 5"	38
15730	17420	19140	20870	22630	24400	26180	29790	**31500**		11'- 6"	39
15940	17660	19410	21180	22970	24780	26600	30290	**32330**		11'- 7"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-16

60" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 60"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	12'-0"	13'-0"	14'-0"	
5	**3522**										**7'-10"**
6	4252	**4368**									**8'- 2"**
7	4864	5210	**5268**								**8'- 7"**
8	5451	5845	**6226**								**9'- 0"**
9	6014	6456	6899	**7246**							**9'- 5"**
10	6555	7044	7534	8025	**8331**						**9'-10"**
11	7074	7609	8146	8685	9224	**9486**					**10'- 3"**
12	7571	8153	8737	9322	9908	**10480**					**10'- 6"**
13	8049	8676	9306	9937	10570	11200	**11390**				**10'- 8"**
14	8508	9180	9855	10530	11210	11890	**12300**				**10'-10"**
15	8948	9664	10380	11110	11830	12560	**13210**				**11'- 0"**
16	9370	10130	10890	11660	12430	13200	13980	**14120**			**11'- 1"**
17	9775	10580	11380	12200	13010	13830	14650	**15020**			**11'- 3"**
18	10160	11010	11860	12710	13570	14430	15300	**15930**			**11'- 4"**
19	10540	11420	12320	13210	14120	15020	15930	**16830**			**11'- 6"**
20	10890	11820	12760	13700	14640	15590	16540	**17740**			**11'- 7"**
21	11240	12200	13180	14160	15150	16140	17140	**18640**			**11'- 9"**
22	11570	12570	13590	14610	15640	16680	17720	**19540**			**11'-11"**
23	11880	12930	13980	15050	16120	17190	18280	**20440**			**12'- 0"**
24	12190	13270	14360	15470	16580	17700	18820	21080	**21340**		**12'- 1"**
25	12480	13600	14730	15870	17020	18180	19350	21690	**22240**		**12'- 3"**
26	12760	13920	15080	16260	17450	18650	19860	22290	**23150**		**12'- 4"**
27	13030	14220	15420	16640	17870	19110	20360	22870	**24060**		**12'- 6"**
28	13280	14510	15750	17010	18270	19550	20840	23430	**24960**		**12'- 7"**
29	13530	14790	16070	17360	18660	19980	21300	23980	**25860**		**12'- 8"**
30	13770	15060	16370	17700	19040	20400	21760	24510	**26760**		**12'-10"**
31	13990	15320	16670	18030	19410	20800	22200	25030	**27680**		**12'-11"**
32	14210	15570	16950	18350	19760	21190	22630	25540	**28560**		**13'- 0"**
33	14420	15810	17230	18660	20100	21570	23040	26030	29050	**29460**	**13'- 2"**
34	14620	16040	17490	18950	20440	21930	23440	26500	29610	**30380**	**13'- 3"**
35	14820	16270	17740	19240	20760	22290	23840	26970	30150	**31270**	**13'- 4"**
36	15000	16480	17990	19520	21060	22630	24210	27420	30680	**32140**	**13'- 5"**
37	15180	16690	18220	19780	21360	22960	24580	27860	31190	**33090**	**13'- 7"**
38	15350	16890	18450	20040	21660	23290	24940	28290	31690	**33970**	**13'- 8"**
39	15510	17080	18670	20290	21940	23600	25290	28710	32180	**34880**	**13'- 9"**
40	15670	17260	18880	20530	22210	23900	25620	29110	32660	**35770**	**13'-10"**

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	12'-0"	13'-0"	14'-0"		
3522										**7'- 9"**	5
4298	**4368**									**8'- 1"**	6
4925	**5268**									**8'- 6"**	7
5529	5924	**6226**								**8'-11"**	8
6110	6554	6997	**7246**							**9'- 3"**	9
6671	7161	7653	8146	**8331**						**9'- 8"**	10
7210	7748	8287	8828	9369	**9486**					**10'- 1"**	11
7730	8315	8901	9488	10080	**10480**					**10'- 4"**	12
8231	8862	9494	10130	10760	**11390**					**10'- 6"**	13
8713	9389	10070	10750	11430	12120	**12300**				**10'- 7"**	14
9177	9899	10620	11350	12080	12810	**13210**				**10'-10"**	15
9625	10390	11160	11930	12710	13480	**14120**				**10'-11"**	16
10060	10870	11680	12500	13320	14140	14960	**15020**			**11'- 1"**	17
10470	11320	12180	13040	13910	14780	15650	**15930**			**11'- 2"**	18
10870	11770	12670	13570	14480	15400	16310	**16830**			**11'- 3"**	19
11260	12190	13140	14090	15040	16000	16960	**17740**			**11'- 5"**	20
11630	12610	13590	14580	15580	16580	17580	**18640**			**11'- 6"**	21
11980	13000	14030	15060	16100	17150	18200	**19540**			**11'- 8"**	22
12330	13390	14460	15530	16610	17700	18790	**20440**			**11'- 9"**	23
12660	13760	14870	15980	17110	18240	19370	**21340**			**11'-11"**	24
12980	14120	15260	16420	17590	18760	19940	**22240**			**12'- 0"**	25
13290	14460	15650	16850	18050	19270	20480	22940	**23150**		**12'- 1"**	26
13580	14800	16020	17260	18500	19760	21020	23560	**24060**		**12'- 2"**	27
13870	15120	16380	17660	18940	20240	21540	24160	**24960**		**12'- 4"**	28
14140	15430	16730	18040	19370	20700	22040	24750	**25860**		**12'- 5"**	29
14410	15730	17070	18420	19780	21150	22540	25330	**26760**		**12'- 6"**	30
14660	16020	17390	18780	20180	21590	23020	25890	**27680**		**12'- 7"**	31
14910	16300	17710	19130	20570	22020	23480	26430	**28560**		**12'- 8"**	32
15140	16570	18010	19470	20950	22440	23940	26960	**29460**		**12'-10"**	33
15370	16830	18310	19800	21310	22840	24380	27480	**30380**		**12'-11"**	34
15590	17080	18590	20120	21670	23230	24800	27990	**31270**		**13'- 0"**	35
15800	17320	18870	20430	22010	23610	25220	28480	31790	**32140**	**13'- 2"**	36
16010	17560	19130	20730	22350	23980	25630	28970	32350	**33090**	**13'- 3"**	37
16200	17780	19390	21020	22670	24340	26020	29440	32900	**33970**	**13'- 4"**	38
16390	18000	19640	21300	22990	24690	26410	29890	33430	**34880**	**13'- 5"**	39
16570	18210	19880	21580	23290	25030	26780	30340	33950	**35770**	**13'- 6"**	40

Table B-16 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	12'-0"	13'-0"	14'-0"	
5	**3522**										7'- 8"
6	**4368**										8'- 0"
7	5008	**5268**									8'- 5"
8	5635	6031	**6226**								8'- 9"
9	6242	6687	7132	**7246**							9'- 1"
10	6830	7323	7816	**8331**							9'- 6"
11	7398	7939	8481	9023	**9486**						9'-11"
12	7949	8537	9126	9717	10310	**10480**					10'- 2"
13	8482	9117	9754	10390	11030	**11390**					10'- 3"
14	8998	9679	10360	11050	11730	**12300**					10'- 5"
15	9497	10220	10960	11690	12420	**13210**					10'- 6"
16	9981	10750	11530	12310	13090	13870	**14120**				10'- 8"
17	10450	11270	12090	12910	13740	14570	**15020**				10'-10"
18	10900	11760	12630	13500	14370	15250	**15930**				10'-11"
19	11340	12250	13160	14070	14990	15910	**16830**				11'- 0"
20	11760	12720	13670	14630	15600	16560	17530	**17740**			11'- 1"
21	12180	13170	14170	15170	16180	17190	18210	**18640**			11'- 3"
22	12570	13610	14650	15700	16750	17810	18870	**19540**			11'- 4"
23	12960	14040	15120	16210	17310	18410	19520	**20440**			11'- 5"
24	13330	14450	15580	16710	17850	19000	20150	**21340**			11'- 6"
25	13690	14850	16020	17200	18380	19570	20760	**22240**			11'- 7"
26	14040	15240	16450	17670	18900	20130	21370	**23150**			11'- 8"
27	14380	15620	16870	18130	19400	20670	21950	**24060**			11'-10"
28	14710	15990	17280	18580	19890	21200	22530	**24960**			11'-11"
29	15020	16340	17670	19020	20370	21720	23090	**25860**			12'- 0"
30	15330	16690	18060	19440	20830	22230	23640	26470	**26760**		12'- 1"
31	15630	17020	18430	19850	21280	22720	24170	27090	**27680**		12'- 2"
32	15910	17350	18790	20250	21720	23200	24690	27700	**28560**		12'- 4"
33	16190	17660	19140	20640	22150	23670	25200	28290	**29460**		12'- 5"
34	16460	17970	19490	21020	22570	24130	25700	28870	**30380**		12'- 6"
35	16720	18260	19820	21390	22980	24580	26190	29440	**31270**		12'- 7"
36	16980	18550	20140	21750	23380	25020	26660	30000	**32140**		12'- 8"
37	17220	18830	20460	22100	23760	25440	27130	30540	**33090**		12'- 9"
38	17460	19100	20760	22440	24140	25860	27580	31070	**33970**		12'-10"
39	17680	19360	21060	22770	24510	26260	28020	31590	**34880**		12'-11"
40	17910	19610	21340	23100	24870	26660	28460	32100	**35770**		13'- 0"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	12'-0"	13'-0"	14'-0"		
3522										7'- 7"	5
4368										7'-11"	6
5093	**5268**									8'- 3"	7
5744	6142	**6226**								8'- 7"	8
6378	6824	**7246**								9'- 0"	9
6994	7489	7984	**8331**							9'- 4"	10
7593	8136	8680	9225	**9486**						9'- 9"	11
8176	8768	9360	9953	**10480**						9'-11"	12
8744	9383	10020	10660	11310	**11390**					10'- 1"	13
9295	9982	10670	11360	12050	**12300**					10'- 2"	14
9832	10570	11300	12040	12780	**13210**					10'- 3"	15
10360	11140	11920	12700	13490	**14120**					10'- 5"	16
10860	11690	12520	13350	14180	**15020**					10'- 6"	17
11360	12230	13100	13980	14860	15740	**15930**				10'- 7"	18
11840	12760	13680	14600	15530	16460	**16830**				10'- 8"	19
12310	13270	14240	15210	16180	17160	**17740**				10'-10"	20
12760	13770	14780	15800	16820	17840	**18640**				10'-11"	21
13200	14260	15310	16380	17440	18510	**19540**				11'- 0"	22
13640	14730	15830	16940	18050	19160	20280	**20440**			11'- 1"	23
14060	15200	16340	17490	18650	19800	20970	**21340**			11'- 2"	24
14460	15640	16840	18030	19230	20430	21640	**22240**			11'- 3"	25
14860	16080	17320	18560	19800	21050	22300	**23150**			11'- 4"	26
15240	16510	17790	19070	20360	21650	22950	**24060**			11'- 5"	27
15620	16930	18250	19570	20900	22240	23580	**24960**			11'- 6"	28
15990	17340	18700	20060	21440	22820	24200	**25860**			11'- 7"	29
16340	17730	19130	20540	21960	23380	24820	**26760**			11'- 8"	30
16690	18120	19560	21010	22470	23940	25410	**27680**			11'- 9"	31
17020	18500	19980	21470	22970	24480	26000	**28560**			11'-10"	32
17350	18860	20380	21920	23460	25010	26570	**29460**			11'-11"	33
17670	19220	20780	22360	23940	25530	27140	**30380**			12'- 0"	34
17980	19570	21170	22780	24410	26040	27690	31000	**31270**		12'- 1"	35
18280	19910	21550	23200	24870	26540	28230	31620	**32140**		12'- 2"	36
18570	20240	21920	23610	25310	27030	28760	32240	**33090**		12'- 3"	37
18860	20560	22280	24010	25750	27510	29280	32840	**33970**		12'- 4"	38
19140	20870	22630	24400	26180	27980	29790	33430	**34880**		12'- 5"	39
19410	21180	22970	24780	26600	28440	30290	34020	**35770**		12'- 6"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-17

66" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 66"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	
5	**3807**										**8'- 5"**
6	**4707**										**8'- 9"**
7	5556	**5660**									**9'- 2"**
8	6240	**6668**									**9'- 6"**
9	6899	7342	**7735**								**9'-11"**
10	7534	8025	8517	**8865**							**10'- 4"**
11	8146	8685	9224	9764	**10061**						**10'-10"**
12	8737	9322	9908	10500	11080	**11330**					**11'- 3"**
13	9306	9937	10570	11200	11840	**12440**					**11'- 6"**
14	9855	10530	11210	11890	12570	13260	**13440**				**11'- 8"**
15	10380	11110	11830	12560	13290	14020	**14450**				**11'- 9"**
16	10890	11660	12430	13200	13980	14750	**15440**				**11'-11"**
17	11380	12200	13010	13830	14650	15470	16300	**16440**			**12'- 1"**
18	11860	12710	13570	14430	15300	16170	17040	**17430**			**12'- 3"**
19	12320	13210	14120	15020	15930	16840	17760	**18420**			**12'- 4"**
20	12760	13700	14640	15590	16540	17500	18460	**19410**			**12'- 6"**
21	13180	14160	15150	16140	17140	18140	19140	**20410**			**12'- 8"**
22	13590	14610	15640	16680	17720	18760	19810	**21390**			**12'- 9"**
23	13980	15050	16120	17190	18280	19360	20450	**22380**			**12'-11"**
24	14360	15470	16580	17700	18820	19950	21080	**23370**			**13'- 0"**
25	14730	15870	17020	18180	19350	20520	21690	24060	**24360**		**13'- 1"**
26	15080	16260	17450	18650	19860	21070	22290	24740	**25360**		**13'- 3"**
27	15420	16640	17870	19110	20360	21610	22870	25410	**26350**		**13'- 4"**
28	15750	17010	18270	19550	20840	22130	23430	26050	**27330**		**13'- 6"**
29	16070	17360	18660	19980	21300	22640	23980	26680	**28340**		**13'- 7"**
30	16370	17700	19040	20400	21760	23130	24510	27300	**29310**		**13'- 9"**
31	16670	18030	19410	20800	22200	23610	25030	27900	**30320**		**13'-10"**
32	16950	18350	19760	21190	22630	24080	25540	28480	**31300**		**13'-11"**
33	17230	18660	20100	21570	23040	24530	26030	29050	32110	**32280**	**14'- 1"**
34	17490	18950	20440	21930	23440	24970	26500	29610	32740	**33290**	**14'- 2"**
35	17740	19240	20760	22290	23840	25400	26970	30150	33360	**34270**	**14'- 4"**
36	17990	19520	21060	22630	24210	25810	27420	30680	33970	**35270**	**14'- 5"**
37	18220	19780	21360	22970	24580	26220	27860	31190	34560	**36240**	**14'- 6"**
38	18450	20040	21660	23290	24940	26610	28290	31690	35140	**37250**	**14'- 7"**
39	18670	20290	21940	23600	25290	26990	28710	32180	35710	**38230**	**14'- 9"**
40	18880	20530	22210	23900	25620	27360	29110	32660	36260	**39190**	**14'-10"**

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"		
3807										**8'- 4"**	5
4707										**8'- 8"**	6
5618	**5660**									**9'- 1"**	7
6319	**6668**									**9'- 5"**	8
6997	7442	**7735**								**9'-10"**	9
7653	8146	8639	**8865**							**10'- 3"**	10
8287	8828	9369	9911	**10060**						**10'- 8"**	11
8901	9488	10080	10670	11260	**11330**					**11'- 1"**	12
9494	10130	10760	11400	12040	**12440**					**11'- 4"**	13
10070	10750	11430	12120	12800	**13440**					**11'- 5"**	14
10620	11350	12080	12810	13540	14280	**14450**				**11'- 7"**	15
11160	11930	12710	13480	14260	15040	**15440**				**11'- 9"**	16
11680	12500	13320	14140	14960	15790	**16440**				**11'-11"**	17
12180	13040	13910	14780	15650	16520	**17430**				**12'- 0"**	18
12670	13570	14480	15400	16310	17230	18150	**18420**			**12'- 1"**	19
13140	14090	15040	16000	16960	17920	18890	**19410**			**12'- 3"**	20
13590	14580	15580	16580	17580	18590	19600	**20410**			**12'- 5"**	21
14030	15060	16100	17150	18200	19250	20310	**21390**			**12'- 6"**	22
14460	15530	16610	17700	18790	19890	20990	**22380**			**12'- 8"**	23
14870	15980	17110	18240	19370	20510	21660	**23370**			**12'- 9"**	24
15260	16420	17590	18760	19940	21120	22310	**24360**			**12'-11"**	25
15650	16850	18050	19270	20480	21710	22940	**25360**			**13'- 0"**	26
16020	17260	18500	19760	21020	22290	23560	26120	**26350**		**13'- 1"**	27
16380	17660	18940	20240	21540	22850	24160	26810	**27330**		**13'- 3"**	28
16730	18040	19370	20700	22040	23400	24750	27480	**28340**		**13'- 4"**	29
17070	18420	19780	21150	22540	23930	25330	28140	**29310**		**13'- 5"**	30
17390	18780	20180	21590	23020	24450	25890	28790	**30320**		**13'- 6"**	31
17710	19130	20570	22020	23480	24950	26430	29410	**31300**		**13'- 8"**	32
18010	19470	20950	22440	23940	25440	26960	30030	**32280**		**13'- 9"**	33
18310	19800	21310	22840	24380	25920	27480	30630	**33290**		**13'-10"**	34
18590	20120	21670	23230	24800	26390	27990	31220	**34270**		**13'-11"**	35
18870	20430	22010	23610	25220	26850	28480	31790	35130	**35270**	**14'- 1"**	36
19130	20730	22350	23980	25630	27290	28970	32350	35770	**36240**	**14'- 2"**	37
19390	21020	22670	24340	26020	27720	29440	32900	36390	**37250**	**14'- 3"**	38
19640	21300	22990	24690	26410	28140	29890	33430	37010	**38230**	**14'- 4"**	39
19880	21580	23290	25030	26780	28560	30340	33950	37610	**39190**	**14'- 5"**	40

Table B-17 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	
5	**3807**										8'- 3"
6	**4707**										8'- 7"
7	**5660**										8'-11"
8	6428	**6668**									9'- 4"
9	7132	7578	**7735**								9'- 8"
10	7816	8310	**8865**								10'- 0"
11	8481	9023	9566	**10060**							10'- 6"
12	9126	9717	10310	10900	**11330**						10'-10"
13	9754	10390	11030	11670	12310	**12440**					11'- 1"
14	10360	11050	11730	12420	13110	**13440**					11'- 3"
15	10960	11690	12420	13160	13890	**14450**					11'- 4"
16	11530	12310	13090	13870	14650	**15440**					11'- 6"
17	12090	12910	13740	14570	15400	16230	**16440**				11'- 7"
18	12630	13500	14370	15250	16130	17000	**17430**				11'- 9"
19	13160	14070	14990	15910	16840	17760	**18420**				11'-10"
20	13670	14630	15600	16560	17530	18500	**19410**				12'- 0"
21	14170	15170	16180	17190	18210	19230	20240	**20410**			12'- 1"
22	14650	15700	16750	17810	18870	19930	21000	**21390**			12'- 2"
23	15120	16210	17310	18410	19520	20620	21740	**22380**			12'- 3"
24	15580	16710	17850	19000	20150	21300	22460	**23370**			12'- 5"
25	16020	17200	18380	19570	20760	21960	23160	**24360**			12'- 6"
26	16450	17670	18900	20130	21370	22610	23850	**25360**			12'- 7"
27	16870	18130	19400	20670	21950	23240	24530	**26350**			12'- 8"
28	17280	18580	19890	21200	22530	23860	25190	**27330**			12'- 9"
29	17670	19020	20370	21720	23090	24460	25840	**28340**			12'-11"
30	18060	19440	20830	22230	23640	25050	26470	**29310**			13'- 0"
31	18430	19850	21280	22720	24170	25630	27090	30030	**30320**		13'- 1"
32	18790	20250	21720	23200	24690	26190	27700	30720	**31300**		13'- 2"
33	19140	20640	22150	23670	25200	26740	28290	31400	**32280**		13'- 3"
34	19490	21020	22570	24130	25700	27280	28870	32070	**33290**		13'- 5"
35	19820	21390	22980	24580	26190	27810	29440	32720	**34270**		13'- 5"
36	20140	21750	23380	25020	26660	28320	30000	33360	**35270**		13'- 6"
37	20460	22100	23760	25440	27130	28830	30540	33990	**36240**		13'- 8"
38	20760	22440	24140	25860	27580	29320	31070	34600	**37250**		13'- 9"
39	21060	22770	24510	26260	28020	29800	31590	35200	**38230**		13'-10"
40	21340	23100	24870	26660	28460	30270	32100	35790	**39190**		13'-11"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"		
3807										8'- 2"	5
4707										8'- 6"	6
5660										8'-10"	7
6539	**6668**									9'- 2"	8
7270	**7735**									9'- 6"	9
7984	8480	**8865**								9'-11"	10
8680	9225	9770	**10060**							10'- 3"	11
9360	9953	10550	11140	**11330**						10'- 8"	12
10020	10660	11310	11950	**12440**						10'-11"	13
10670	11360	12050	12740	**13440**						11'- 0"	14
11300	12040	12780	13520	14250	**14450**					11'- 2"	15
11920	12700	13490	14270	15060	**15440**					11'- 3"	16
12520	13350	14180	15020	15850	**16440**					11'- 4"	17
13100	13980	14860	15740	16630	**17430**					11'- 6"	18
13680	14600	15530	16460	17390	18320	**18420**				11'- 7"	19
14240	15210	16180	17160	18130	19110	**19410**				11'- 8"	20
14780	15800	16820	17840	18860	19890	**20410**				11'- 9"	21
15310	16380	17440	18510	19580	20650	**21390**				11'-10"	22
15830	16940	18050	19160	20280	21400	**22380**				11'-11"	23
16340	17490	18650	19800	20970	22130	**23370**				12'- 0"	24
16840	18030	19230	20430	21640	22850	24060	**24360**			12'- 1"	25
17320	18560	19800	21050	22300	23560	24820	**25360**			12'- 3"	26
17790	19070	20360	21650	22950	24250	25560	**26350**			12'- 4"	27
18250	19570	20900	22240	23580	24930	26280	**27330**			12'- 5"	28
18700	20060	21440	22820	24200	25600	26990	**28340**			12'- 6"	29
19130	20540	21960	23380	24820	26250	27690	**29310**			12'- 7"	30
19560	21010	22470	23940	25410	26890	28380	**30320**			12'- 8"	31
19980	21470	22970	24480	26000	27520	29050	**31300**			12'- 9"	32
20380	21920	23460	25010	26570	28140	29710	**32280**			12'-10"	33
20780	22360	23940	25530	27140	28740	30360	**33290**			12'-11"	34
21170	22780	24410	26040	27690	29340	31000	**34270**			13'- 0"	35
21550	23200	24870	26540	28230	29920	31620	35050	**35270**		13'- 1"	36
21920	23610	25310	27030	28760	30490	32240	35750	**36240**		13'- 1"	37
22280	24010	25750	27510	29280	31060	32840	36440	**37250**		13'- 3"	38
22630	24400	26180	27980	29790	31610	33430	37110	**38230**		13'- 4"	39
22970	24780	26600	28440	30290	32150	34020	37780	**39190**		13'- 4"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on* $K\mu$—0.19, $r_{sd}p$—0.5 *in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-18

72" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 72"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	
5	**4097**										**9'- 0"**
6	**5053**										**9'- 4"**
7	5903	**6060**									**9'- 9"**
8	6635	7031	**7121**								**10'- 1"**
9	7342	7786	**8239**								**10'- 6"**
10	8025	8517	9010	**9417**							**10'-11"**
11	8685	9224	9764	10310	**10660**						**11'- 4"**
12	9322	9908	10500	11080	11670	**11960**					**11'- 9"**
13	9937	10570	11200	11840	12480	13120	**13340**				**12'- 2"**
14	10530	11210	11890	12570	13260	13940	**14590**				**12'- 6"**
15	11110	11830	12560	13290	14020	14750	**15690**				**12'- 8"**
16	11660	12430	13200	13980	14750	15530	**16780**				**12'-10"**
17	12200	13010	13830	14650	15470	16300	**17860**				**12'-11"**
18	12710	13570	14430	15300	16170	17040	18780	**18950**			**13'- 1"**
19	13210	14120	15020	15930	16840	17760	19600	**20030**			**13'- 3"**
20	13700	14640	15590	16540	17500	18460	20390	**21110**			**13'- 4"**
21	14160	15150	16140	17140	18140	19140	21160	**22200**			**13'- 6"**
22	14610	15640	16680	17720	18760	19810	21910	**23270**			**13'- 7"**
23	15050	16120	17190	18280	19360	20450	22650	**24360**			**13'- 9"**
24	15470	16580	17700	18820	19950	21080	23360	**25420**			**13'-11"**
25	15870	17020	18180	19350	20520	21690	24060	**26520**			**14'- 0"**
26	16260	17450	18650	19860	21070	22290	24740	27210	**27590**		**14'- 2"**
27	16640	17870	19110	20360	21610	22870	25410	27960	**28670**		**14'- 3"**
28	17010	18270	19550	20840	22130	23430	26050	28700	**29760**		**14'- 5"**
29	17360	18660	19980	21300	22640	23980	26680	29410	**30840**		**14'- 6"**
30	17700	19040	20400	21760	23130	24510	27300	30110	**31910**		**14'- 8"**
31	18030	19410	20800	22200	23610	25030	27900	30790	**32990**		**14'- 9"**
32	18350	19760	21190	22630	24080	25540	28480	31460	**34060**		**14'-10"**
33	18660	20100	21570	23040	24530	26030	29050	32110	**35150**		**15'- 0"**
34	18950	20440	21930	23440	24970	26500	29610	32740	35910	**36200**	**15'- 1"**
35	19240	20760	22290	23840	25400	26970	30150	33360	36610	**37310**	**15'- 3"**
36	19520	21060	22630	24210	25810	27420	30680	33970	37300	**38350**	**15'- 4"**
37	19780	21360	22960	24580	26220	27860	31190	34560	37970	**39450**	**15'- 5"**
38	20040	21660	23290	24940	26610	28290	31690	35140	38630	**40540**	**15'- 6"**
39	20290	21940	23600	25290	26990	28710	32180	35710	39270	**41590**	**15'- 8"**
40	20530	22210	23900	25620	27360	29110	32660	36260	39900	**42680**	**15'- 9"**

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"		
4097										**8'-11"**	5
5053										**9'- 3"**	6
5966	**6060**									**9'- 8"**	7
6715	**7121**									**10'- 0"**	8
7442	7887	**8239**								**10'- 5"**	9
8146	8639	9133	**9417**							**10'- 9"**	10
8828	9369	9911	10450	**10660**						**11'- 2"**	11
9488	10080	10670	11260	11850	**11960**					**11'- 7"**	12
10130	10760	11400	12040	12680	**13340**					**12'- 0"**	13
10750	11430	12120	12800	13490	14170	**14590**				**12'- 3"**	14
11350	12080	12810	13540	14280	15010	**15690**				**12'- 5"**	15
11930	12710	13480	14260	15040	15820	**16780**				**12'- 7"**	16
12500	13320	14140	14960	15790	16620	**17860**				**12'- 9"**	17
13040	13910	14780	15650	16520	17390	**18950**				**12'-11"**	18
13570	14480	15400	16310	17230	18150	**20030**				**13'- 0"**	19
14090	15040	16000	16960	17920	18890	20820	**21110**			**13'- 2"**	20
14580	15580	16580	17580	18590	19600	21640	**22200**			**13'- 3"**	21
15060	16100	17150	18200	19250	20310	22430	**23270**			**13'- 5"**	22
15530	16610	17700	18790	19890	20990	23200	**24360**			**13'- 6"**	23
15980	17110	18240	19370	20510	21660	23960	**25420**			**13'- 7"**	24
16420	17590	18760	19940	21120	22310	24700	**26520**			**13'- 9"**	25
16850	18050	19270	20480	21710	22940	25420	**27590**			**13'-11"**	26
17260	18500	19760	21020	22290	23560	26120	**28670**			**14'- 0"**	27
17660	18940	20240	21540	22850	24160	26810	29480	**29760**		**14'- 1"**	28
18040	19370	20700	22040	23400	24750	27480	30240	**30840**		**14'- 2"**	29
18420	19780	21150	22540	23930	25330	28140	30980	**31910**		**14'- 4"**	30
18780	20180	21590	23020	24450	25890	28790	31710	**32990**		**14'- 5"**	31
19130	20570	22020	23480	24950	26430	29410	32420	**34060**		**14'- 7"**	32
19470	20950	22440	23940	25440	26960	30030	33120	**35150**		**14'- 8"**	33
19800	21310	22840	24380	25920	27480	30630	33800	**36200**		**14'- 9"**	34
20120	21670	23230	24800	26390	27990	31220	34470	**37310**		**14'-10"**	35
20430	22010	23610	25220	26850	28480	31790	35130	**38350**		**15'- 0"**	36
20730	22350	23980	25630	27290	28970	32350	35770	39220	**39450**	**15'- 1"**	37
21020	22670	24340	26020	27720	29440	32900	36390	39920	**40540**	**15'- 2"**	38
21300	22990	24690	26410	28140	29890	33430	37010	40620	**41590**	**15'- 3"**	39
21580	23290	25030	26780	28560	30340	33950	37610	41300	**42680**	**15'- 5"**	40

Table B-18 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	
5	**4097**										8'-10"
6	**5053**										9'- 2"
7	**6060**										9'- 6"
8	6825	**7121**									9'-11"
9	7578	8024	**8239**								10'- 3"
10	8310	8805	9300	**9417**							10'- 8"
11	9023	9566	10110	**10660**							11'- 0"
12	9717	10310	10900	11490	**11960**						11'- 5"
13	10390	11030	11670	12310	12950	**13340**					11'-10"
14	11050	11730	12420	13110	13800	14490	**14590**				12'- 1"
15	11690	12420	13160	13890	14630	15370	**15690**				12'- 3"
16	12310	13090	13870	14650	15440	16220	**16780**				12'- 4"
17	12910	13740	14570	15400	16230	17060	**17860**				12'- 6"
18	13500	14370	15250	16130	17000	17890	**18950**				12'- 7"
19	14070	14990	15910	16840	17760	18690	**20030**				12'- 9"
20	14630	15600	16560	17530	18500	19480	**21110**				12'-10"
21	15170	16180	17190	18210	19230	20240	**22200**				12'-11"
22	15700	16750	17810	18870	19930	21000	23140	**23270**			13'- 1"
23	16210	17310	18410	19520	20620	21740	23970	**24360**			13'- 2"
24	16710	17850	19000	20150	21300	22460	24780	**25420**			13'- 3"
25	17200	18380	19570	20760	21960	23160	25580	**26520**			13'- 4"
26	17670	18900	20130	21370	22610	23850	26360	**27590**			13'- 6"
27	18130	19400	20670	21950	23240	24530	27120	**28670**			13'- 7"
28	18580	19890	21200	22530	23860	25190	27870	**29760**			13'- 8"
29	19020	20370	21720	23090	24460	25840	28610	**30840**			13'- 9"
30	19440	20830	22230	23640	25050	26470	27900	**31910**			13'-11"
31	19850	21280	22720	24170	25630	27090	28560	**32990**			14'- 0"
32	20250	21720	23200	24690	26190	27700	30720	33780	**34060**		14'- 1"
33	20640	22150	23670	25200	26740	28290	31400	34540	**35150**		14'- 2"
34	21020	22570	24130	25700	27280	28870	32070	35290	**36200**		14'- 3"
35	21390	22980	24580	26190	27810	29440	32720	36030	**37310**		14'- 5"
36	21750	23380	25020	26660	28320	30000	33360	36750	**38350**		14'- 5"
37	22100	23760	25440	27130	28830	30540	33990	37460	**39450**		14'- 7"
38	22440	24140	25860	27580	29320	31070	34600	38160	**40540**		14'- 8"
39	22770	24510	26260	28020	29800	31590	35200	38850	**41590**		14'- 9"
40	23100	24870	26660	28460	30270	32100	35790	39520	**42680**		14'-10"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
9'-6"	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"		
4097										8'- 9"	5
5053										9'- 1"	6
6060										9'- 5"	7
6937	**7121**									9'- 9"	8
7717	8165	**8239**								10'- 1"	9
8480	8976	**9417**								10'- 5"	10
9225	9770	10320	**10660**							10'-10"	11
9953	10550	11140	11740	**11960**						11'- 2"	12
10660	11310	11950	12590	13240	**13340**					11'- 7"	13
11360	12050	12740	13430	14124	**14590**					11'-10"	14
12040	12780	13520	14250	15000	**15690**					12'- 0"	15
12700	13490	14270	15060	15850	16640	**16780**				12'- 1"	16
13350	14180	15020	15850	16690	17530	**17860**				12'- 2"	17
13980	14860	15740	16630	17510	18400	**18950**				12'- 4"	18
14600	15530	16460	17390	18320	19250	**20030**				12'- 5"	19
15210	16180	17160	18130	19110	20090	**21110**				12'- 6"	20
15800	16820	17840	18860	19890	20920	**22200**				12'- 8"	21
16380	17440	18510	19580	20650	21720	**23270**				12'- 8"	22
16940	18050	19160	20280	21400	22520	**24360**				12'-10"	23
17490	18650	19800	20970	22130	23300	**25420**				12'-11"	24
18030	19230	20430	21640	22850	24060	**26520**				13'- 0"	25
18560	19800	21050	22300	23560	24820	27340	**27590**			13'- 1"	26
19070	20360	21650	22950	24250	25560	28170	**28670**			13'- 3"	27
19570	20900	22240	23580	24930	26280	28990	**29760**			13'- 3"	28
20060	21440	22820	24200	25600	26990	29790	**30840**			13'- 4"	29
20540	21960	23380	24820	26250	27690	30580	**31910**			13'- 6"	30
21010	22470	23940	25410	26890	28380	31360	**32990**			13'- 6"	31
21470	22970	24480	26000	27520	29050	32120	**34060**			13'- 7"	32
21920	23460	25010	26570	28140	29710	32870	**35150**			13'- 9"	33
22360	23940	25530	27140	28740	30360	33610	**36200**			13'- 9"	34
22780	24410	26040	27690	29340	31000	34330	**37310**			13'-11"	35
23200	24870	26540	28230	29920	31620	35050	**38350**			13'-11"	36
23610	25310	27030	28760	30490	32240	35750	**39450**			14'- 0"	37
24010	25750	27510	29280	31060	32840	36440	40060	**40540**		14'- 2"	38
24400	26180	27980	29790	31610	33430	37110	40820	**41590**		14'- 2"	39
24780	26600	28440	30290	32150	34020	37780	41570	**42680**		14'- 3"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-19

78" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 78"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	
5	**4384**										9'- 6"
6	**5395**										9'-11"
7	6250	**6457**									10'- 3"
8	7031	7427	**7570**								10'- 8"
9	7786	8231	8676	**8739**							11'- 1"
10	8517	9010	9503	**9966**							11'- 6"
11	9224	9764	10310	10850	**11250**						11'-11"
12	9908	10500	11080	11670	12260	**12600**					12'- 3"
13	10570	11200	11840	12480	13120	**14020**					12'- 9"
14	11210	11890	12570	13260	13940	15320	**15510**				13'- 2"
15	11830	12560	13290	14020	14750	16220	**16890**				13'- 5"
16	12430	13200	13980	14750	15530	17090	**18080**				13'- 7"
17	13010	13830	14650	15470	16300	17950	**19250**				13'- 9"
18	13570	14430	15300	16170	17040	18780	**20430**				13'-11"
19	14120	15020	15930	16840	17760	19600	21440	**21600**			14'- 1"
20	14640	15590	16540	17500	18460	20390	22320	**22780**			14'- 3"
21	15150	16140	17140	18140	19140	21160	23190	**23940**			14'- 5"
22	15640	16680	17720	18760	19810	21910	24030	**25110**			14'- 6"
23	16120	17190	18280	19360	20450	22650	24860	**26280**			14'- 8"
24	16580	17700	18820	19950	21080	23360	25660	**27450**			14'- 9"
25	17020	18180	19350	20520	21690	24060	26450	**28610**			14'-11"
26	17450	18650	19860	21070	22290	24740	27210	**29780**			15'- 0"
27	17870	19110	20360	21610	22870	25410	27960	30540	**30940**		15'- 2"
28	18270	19550	20840	22130	23430	26050	28700	31360	**32120**		15'- 3"
29	18660	19980	21300	22640	23980	26680	29410	32160	**33280**		15'- 5"
30	19040	20400	21760	23130	24510	27300	30110	32940	**34460**		15'- 6"
31	19410	20800	22200	23610	25030	27900	30790	33710	**35600**		15'- 7"
32	19760	21190	22630	24080	25540	28480	31460	34460	**36770**		15'- 9"
33	20100	21570	23040	24530	26030	29050	32110	35190	**37950**		15'-11"
34	20440	21930	23440	24970	26500	29610	32740	35910	**39100**		16'- 0"
35	20760	22290	23840	25400	26970	30150	33360	36610	39890	**40290**	16'- 1"
36	21060	22630	24210	25810	27420	30680	33970	37300	40660	**41460**	16'- 3"
37	21360	22960	24580	26220	27860	31190	34560	37970	41410	**42600**	16'- 4"
38	21660	23290	24940	26610	28290	31690	35140	38630	42150	**43760**	16'- 5"
39	21940	23600	25290	26990	28710	32180	35710	39270	42870	**44940**	16'- 7"
40	22210	23900	25620	27360	29110	32660	36260	39900	43580	**46100**	16'- 8"

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"		
4384										9'- 6"	5
5395										9'-10"	6
6313	**6457**									10'- 3"	7
7112	7509	**7570**								10'- 7"	8
7887	8332	**8739**								11'- 0"	9
8639	9133	9627	**9966**							11'- 4"	10
9369	9911	10450	11000	**11250**						11'- 9"	11
10080	10670	11260	11850	12440	**12600**					12'- 2"	12
10760	11400	12040	12680	13320	**14020**					12'- 7"	13
11430	12120	12800	13490	14170	**15510**					13'- 0"	14
12080	12810	13540	14280	15010	16480	**16890**				13'- 3"	15
12710	13480	14260	15040	15820	17390	**18080**				13'- 5"	16
13320	14140	14960	15790	16620	18280	**19250**				13'- 7"	17
13910	14780	15650	16520	17390	19150	**20430**				13'- 9"	18
14480	15400	16310	17230	18150	20000	**21600**				13'-11"	19
15040	16000	16960	17920	18890	20820	**22780**				14'- 0"	20
15580	16580	17580	18590	19600	21640	23670	**23940**			14'- 1"	21
16100	17150	18200	19250	20310	22430	24560	**25110**			14'- 3"	22
16610	17700	18790	19890	20990	23200	25420	**26280**			14'- 5"	23
17110	18240	19370	20510	21660	23960	26270	**27450**			14'- 6"	24
17590	18760	19940	21120	22310	24700	27100	**28610**			14'- 7"	25
18050	19270	20480	21710	22940	25420	27910	**29780**			14'- 9"	26
18500	19760	21020	22290	23560	26120	28700	**30940**			14'-11"	27
18940	20240	21540	22850	24160	26810	29480	**32120**			15'- 0"	28
19370	20700	22040	23400	24750	27480	30240	33010	**33280**		15'- 1"	29
19780	21150	22540	23930	25330	28140	30980	33840	**34460**		15'- 3"	30
20180	21590	23020	24450	25890	28790	31710	34650	**35600**		15'- 4"	31
20570	22020	23480	24950	26430	29410	32420	35450	**36770**		15'- 5"	32
20950	22440	23940	25440	26960	30030	33120	36240	**37950**		15'- 7"	33
21310	22840	24380	25920	27480	30630	33800	37000	**39100**		15'- 8"	34
21670	23230	24800	26390	27990	31220	34470	37760	**40290**		15'- 9"	35
22010	23610	25220	26850	28480	31790	35130	38490	**41460**		15'-11"	36
22350	23980	25630	27290	28970	32350	35770	39220	**42600**		15'-11"	37
22670	24340	26020	27720	29440	32900	36390	39920	43480	**43760**	16'- 1"	38
22990	24690	26410	28140	29890	33430	37010	40620	44260	**44940**	16'- 2"	39
23290	25030	26780	28560	30340	33950	37610	41300	45020	**46100**	16'- 3"	40

Table B-19 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	
5	**4384**										9'- 5"
6	**5395**										9'- 9"
7	6399	**6457**									10'- 1"
8	7222	**7570**									10'- 5"
9	8024	8471	**8739**								10'- 9"
10	8805	9300	9796	**9966**							11'- 2"
11	9566	10110	10650	**11250**							11'- 6"
12	10310	10900	11490	12090	**12600**						11'-11"
13	11030	11670	12310	12950	13600	**14020**					12'- 4"
14	11730	12420	13110	13800	14490	**15510**					12'- 9"
15	12420	13160	13890	14630	15370	16850	**16890**				13'- 1"
16	13090	13870	14650	15440	16220	17800	**18080**				13'- 2"
17	13740	14570	15400	16230	17060	18730	**19250**				13'- 4"
18	14370	15250	16130	17000	17890	19650	**20430**				13'- 5"
19	14990	15910	16840	17760	18690	20550	**21600**				13'- 7"
20	15600	16560	17530	18500	19480	21430	**22780**				13'- 8"
21	16180	17190	18210	19230	20240	22290	**23940**				13'-10"
22	16750	17810	18870	19930	21000	23140	**25110**				13'-11"
23	17310	18410	19520	20620	21740	23970	26200	**26280**			14'- 1"
24	17850	19000	20150	21300	22460	24780	27110	**27450**			14'- 2"
25	18380	19570	20760	21960	23160	25580	28000	**28610**			14'- 3"
26	18900	20130	21370	22610	23850	26360	28870	**29780**			14'- 4"
27	19400	20670	21950	23240	24530	27120	29730	**30940**			14'- 5"
28	19890	21200	22530	23860	25190	27870	30570	**32120**			14'- 7"
29	20370	21720	23090	24460	25840	28610	31390	**33280**			14'- 8"
30	20830	22230	23640	25050	26470	29330	32200	**34460**			14'- 9"
31	21280	22720	24170	25630	27090	30030	33000	**35600**			14'-11"
32	21720	23200	24690	26190	27700	30720	33780	**36770**			15'- 0"
33	22150	23670	25200	26740	28290	31400	34540	37700	**37950**		15'- 1"
34	22570	24130	25700	27280	28870	32070	35290	38540	**39100**		15'- 2"
35	22980	24580	26190	27810	29440	32720	36030	39360	**40290**		15'- 3"
36	23380	25020	26660	28320	30000	33360	36750	40170	**41460**		15'- 5"
37	23760	25440	27130	28830	30540	33990	37460	40970	**42600**		15'- 5"
38	24140	25860	27580	29320	31070	34600	38160	41750	**43760**		15'- 7"
39	24510	26260	28020	29800	31590	35200	38850	42520	**44940**		15'- 8"
40	24870	26660	28460	30270	32100	35790	39520	43280	**46100**		15'- 9"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
10'-0"	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"		
4384										9'- 3"	5
5395										9'- 7"	6
6457										9'-11"	7
7335	**7570**									10'- 3"	8
8165	8612	**8739**								10'- 8"	9
8976	9472	**9966**								11'- 0"	10
9770	10320	10860	**11250**							11'- 5"	11
10550	11140	11740	12330	**12600**						11'- 9"	12
11310	11950	12590	13240	13880	**14020**					12'- 1"	13
12050	12740	13430	14120	14820	**15510**					12'- 6"	14
12780	13520	14250	15000	15740	**16890**					12'- 9"	15
13490	14270	15060	15850	16640	**18080**					12'-11"	16
14180	15020	15850	16690	17530	19200	**19250**				13'- 1"	17
14860	15740	16630	17510	18400	20170	**20430**				13'- 2"	18
15530	16460	17390	18320	19250	21120	**21600**				13'- 3"	19
16180	17160	18130	19110	20090	22060	**22780**				13'- 5"	20
16820	17840	18860	19890	20920	22980	**23940**				13'- 5"	21
17440	18510	19580	20650	21720	23880	**25110**				13'- 7"	22
18050	19160	20280	21400	22520	24770	**26280**				13'- 8"	23
18650	19800	20970	22130	23300	25640	**27450**				13'- 9"	24
19230	20430	21640	22850	24060	26500	**28610**				13'-11"	25
19800	21050	22300	23560	24820	27340	**29780**				13'-11"	26
20360	21650	22950	24250	25560	28170	30800	**30940**			14'- 1"	27
20900	22240	23580	24930	26280	28990	31710	**32120**			14'- 2"	28
21440	22820	24200	25600	26990	29790	32610	**33280**			14'- 3"	29
21960	23380	24820	26250	27690	30580	33490	**34460**			14'- 4"	30
22470	23940	25410	26890	28380	31360	34360	**35600**			14'- 5"	31
22970	24480	26000	27520	29050	32120	35210	**36770**			14'- 6"	32
23460	25010	26570	28140	29710	32870	36050	**37950**			14'- 7"	33
23940	25530	27140	28740	30360	33610	36880	**39100**			14'- 8"	34
24410	26040	27690	29340	31000	34330	37690	**40290**			14'- 9"	35
24870	26540	28230	29920	31620	35050	38490	**41460**			14'-10"	36
25310	27030	28760	30490	32240	35750	39280	**42600**			14'-11"	37
25750	27510	29280	31060	32840	36440	40060	**43760**			15'- 0"	38
26180	27980	29790	31610	33430	37110	40820	44550	**44940**		15'- 1"	39
26600	28440	30290	32150	34020	37780	41570	45390	**46100**		15'- 2"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on* $K\mu$*—0.19,* $r_{sd}p$*—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-20

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

84"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	
5	**4671**										10'- 2"
6	**5738**										10'- 6"
7	6597	**6854**									10'-11"
8	7427	7823	**8021**								11'- 3"
9	8231	8676	9121	**9242**							11'- 8
10	9010	9503	9997	**10520**							12'- 0"
11	9764	10310	10850	11390	**11860**						12'- 5"
12	10500	11080	11670	12260	**13250**						12'-10"
13	11200	11840	12480	13120	14390	**14710**					13'- 3"
14	11890	12570	13260	13940	15320	**16240**					13'- 8"
15	12560	13290	14020	14750	16220	17690	**17840**				14'- 1"
16	13200	13980	14750	15530	17090	18660	**19360**				14'- 5"
17	13830	14650	15470	16300	17950	19610	**20630**				14'- 8"
18	14430	15300	16170	17040	18780	20540	**21900**				14'- 9"
19	15020	15930	16840	17760	19600	21440	**23160**				14'-11"
20	15590	16540	17500	18460	20390	22320	24270	**24420**			15'- 1"
21	16140	17140	18140	19140	21160	23190	25220	**25680**			15'- 3"
22	16680	17720	18760	19810	21910	24030	26160	**26940**			15'- 4"
23	17190	18280	19360	20450	22650	24860	27070	**28200**			15'- 6"
24	17700	18820	19950	21080	23360	25660	27970	**29460**			15'- 8"
25	18180	19350	20520	21690	24060	26450	28840	**30720**			15'- 9"
26	18650	19860	21070	22290	24740	27210	29700	**31970**			15'-11"
27	19110	20360	21610	22870	25410	27960	30540	33120	**33230**		16'- 1"
28	19550	20840	22130	23430	26050	28700	31360	34030	**34470**		16'- 2"
29	19980	21300	22640	23980	26680	29410	32160	34920	**35740**		16'- 4"
30	20400	21760	23130	24510	27300	30110	32940	35790	**36970**		16'- 5"
31	20800	22200	23610	25030	27900	30790	33710	36640	**38250**		16'- 7"
32	21190	22630	24080	25540	28480	31460	34460	37480	**39490**		16'- 8"
33	21570	23040	24530	26030	29050	32110	35190	38300	**40720**		16'- 9"
34	21930	23440	24970	26500	29610	32740	35910	39100	**42000**		16'-11"
35	22290	23840	25400	26970	30150	33360	36610	39890	**43240**		17'- 0"
36	22630	24210	25810	27420	30680	33970	37300	40660	44040	**44500**	17'- 2"
37	22960	24580	26220	27860	31190	34560	37970	41410	44870	**45770**	17'- 3"
38	23290	24940	26610	28290	31690	35140	38630	42150	45690	**47010**	17'- 5"
39	23600	25290	26990	28710	32180	35710	39270	42870	46500	**48270**	17'- 6"
40	23900	25620	27360	29110	32660	36260	39900	43580	47290	**49500**	17'- 7"

B SATURATED TOP SOIL Kµ'—0.150

84"

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"		
4671										10'- 1"	5
5738										10'- 5"	6
6661	**6854**									10'- 9"	7
7509	7906	**8021**								11'- 2"	8
8332	8778	**9242**								11'- 6"	9
9133	9627	10120	**10520**							11'-11"	10
9911	10450	11000	11540	**11860**						12'- 3"	11
10670	11260	11850	12440	**13250**						12'- 9"	12
11400	12040	12680	13320	14600	**14710**					13'- 1"	13
12120	12800	13490	14170	15550	**16240**					13'- 6"	14
12810	13540	14280	15010	16480	**17840**					13'-11"	15
13480	14260	15040	15820	17390	18960	**19360**				14'- 3"	16
14140	14960	15790	16620	18280	19950	**20630**				14'- 5"	17
14780	15650	16520	17390	19150	20910	**21900**				14'- 7"	18
15400	16310	17230	18150	20000	21850	**23160**				14'- 8"	19
16000	16960	17920	18890	20820	22770	**24420**				14'-10"	20
16580	17580	18590	19600	21640	23670	**25680**				15'- 0"	21
17150	18200	19250	20310	22430	24560	26700	**26940**			15'- 1"	22
17700	18790	19890	20990	23200	25420	27650	**28200**			15'- 3"	23
18240	19370	20510	21660	23960	26270	28590	**29460**			15'- 4"	24
18760	19940	21120	22310	24700	27100	29510	**30720**			15'- 6"	25
19270	20480	21710	22940	25420	27910	30410	**31970**			15'- 8"	26
19760	21020	22290	23560	26120	28700	31290	**33230**			15'- 9"	27
20240	21540	22850	24160	26810	29480	32160	**34470**			15'-11"	28
20700	22040	23400	24750	27480	30240	33010	**35740**			16'- 0"	29
21150	22540	23930	25330	28140	30980	33840	36710	**36970**		16'- 1"	30
21590	23020	24450	25890	28790	31710	34650	37620	**38250**		16'- 2"	31
22020	23480	24950	26430	29410	32420	35450	38500	**39490**		16'- 4"	32
22440	23940	25440	26960	30030	33120	36240	39370	**40720**		16'- 5"	33
22840	24380	25920	27480	30630	33800	37000	40220	**42000**		16'- 7"	34
23230	24800	26390	27990	31220	34470	37760	41060	**43240**		16'- 8"	35
23610	25220	26850	28480	31790	35130	38490	41880	**44500**		16'- 9"	36
23980	25630	27290	28970	32350	35770	39220	42690	**45770**		16'-11"	37
24340	26020	27720	29440	32900	36390	39920	43480	**47010**		17'- 0"	38
24690	26410	28140	29890	33430	37010	40620	44260	47930	**48270**	17'- 1"	39
25030	26780	28560	30340	33950	37610	41300	45020	48780	**49500**	17'- 3"	40

Table B-20 Continued

C ORDINARY CLAY Kµ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	
5	**4671**										**10'- 0"**
6	**5738**										**10'- 4"**
7	6748	**6854**									**10'- 8"**
8	7620	**8021**									**11'- 0"**
9	8471	8917	**9242**								**11'- 4"**
10	9300	9796	10290	**10520**							**11'- 9"**
11	10110	10650	11200	11740	**11860**						**12'- 1"**
12	10900	11490	12090	12680	**13250**						**12'- 6"**
13	11670	12310	12950	13600	**14710**						**12'-11"**
14	12420	13110	13800	14490	15870	**16240**					**13'- 3"**
15	13160	13890	14630	15370	16850	**17840**					**13'- 8"**
16	13870	14650	15440	16220	17800	**19360**					**14'- 0"**
17	14570	15400	16230	17060	18730	20410	**20630**				**14'- 2"**
18	15250	16130	17000	17890	19650	21420	**21900**				**14'- 3"**
19	15910	16840	17760	18690	20550	22410	**23160**				**14'- 5"**
20	16560	17530	18500	19480	21430	23390	**24420**				**14'- 6"**
21	17190	18210	19230	20240	22290	24340	**25680**				**14'- 8"**
22	17810	18870	19930	21000	23140	25280	**26940**				**14'- 9"**
23	18410	19520	20620	21740	23970	26200	**28200**				**14'-10"**
24	19000	20150	21300	22460	24780	27110	**29460**				**15'- 0"**
25	19570	20760	21960	23160	25580	28000	30430	**30720**			**15'- 1"**
26	20130	21370	22610	23850	26360	28870	31400	**31970**			**15'- 3"**
27	20670	21950	23240	24530	27120	29730	32340	**33230**			**15'- 4"**
28	21200	22530	23860	25190	27870	30570	33270	**34470**			**15'- 6"**
29	21720	23090	24460	25840	28610	31390	34190	**35740**			**15'- 6"**
30	22230	23640	25050	26470	29330	32200	35090	**36970**			**15'- 8"**
31	22720	24170	25630	27090	30030	33000	35970	**38250**			**15'- 9"**
32	23200	24690	26190	27700	30720	33780	36840	**39490**			**15'-11"**
33	23670	25200	26740	28290	31400	34540	37700	**40720**			**15'-11"**
34	24130	25700	27280	28870	32070	35290	28540	41800	**42000**		**16'- 1"**
35	24580	26190	27810	29440	32720	36030	39360	42710	**43240**		**16'- 2"**
36	25020	26660	28320	30000	33360	36750	40170	43610	**44500**		**16'- 3"**
37	25440	27130	28830	30540	33990	37460	40970	44490	**45770**		**16'- 4"**
38	25860	27580	29320	31070	34600	38160	41750	45360	**47010**		**16'- 5"**
39	26260	28020	29800	31590	35200	38850	42520	46220	**48270**		**16'- 7"**
40	26660	28460	30270	32100	35790	39520	43280	47060	**49500**		**16'- 8"**

D SATURATED CLAY Kµ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
10'-6"	11'-0"	11'-6"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"		
4671										**9'-10"**	5
5738										**10'- 2"**	6
6854										**10'- 6"**	7
7733	**8021**									**10'-10"**	8
8612	9060	**9242**								**11'- 3"**	9
9472	9969	**10520**								**11'- 6"**	10
10320	10860	11410	**11860**							**11'-11"**	11
11140	11740	12330	12930	**13250**						**12'- 3"**	12
11950	12590	13240	13880	**14710**						**12'- 8"**	13
12740	13430	14120	14820	**16240**						**13'- 0"**	14
13520	14250	15000	15740	17220	**17840**					**13'- 5"**	15
14270	15060	15850	16640	18220	**19360**					**13'- 9"**	16
15020	15850	16690	17530	19200	**20630**					**13'-10"**	17
15740	16630	17510	18400	20170	**21900**					**14'- 0"**	18
16460	17390	18320	19250	21120	23000	**23160**				**14'- 1"**	19
17160	18130	19110	20090	22060	24030	**24420**				**14'- 3"**	20
17840	18860	19890	20920	22980	25040	**25680**				**14'- 4"**	21
18510	19580	20650	21720	23880	26040	**26940**				**14'- 5"**	22
19160	20280	21400	22520	24770	27020	**28200**				**14'- 6"**	23
19800	20970	22130	23300	25640	27990	**29460**				**14'- 8"**	24
20430	21640	22850	24060	26500	28940	**30720**				**14'- 9"**	25
21050	22300	23560	24820	27340	29880	**31970**				**14'-10"**	26
21650	22950	24250	25560	28170	30800	**33230**				**14'-11"**	27
22240	23580	24930	26280	28990	31710	**34470**				**15'- 0"**	28
22820	24200	25600	26990	29790	32610	35430	**35740**			**15'- 1"**	29
23380	24820	26250	27690	30580	33490	36400	**36970**			**15'- 2"**	30
23940	25410	26890	28380	31360	34360	37360	**38250**			**15'- 3"**	31
24480	26000	27520	29050	32120	35210	38310	**39490**			**15'- 5"**	32
25010	26570	28140	29710	32870	36050	39240	**40720**			**15'- 6"**	33
25530	27140	28740	30360	33610	36880	40160	**42000**			**15'- 7"**	34
26040	27690	29340	31000	34330	37690	41060	**43240**			**15'- 8"**	35
26540	28230	29920	31620	35050	38490	41950	**44500**			**15'- 9"**	36
27030	28760	30490	32240	35750	39280	42830	**45770**			**15'-10"**	37
27510	29280	31060	32840	36440	40060	43700	**47010**			**15'-11"**	38
27980	29790	31610	33430	37110	40820	44550	**48270**			**16'- 0"**	39
28440	30290	32150	34020	37780	41570	45390	49230	**49500**		**16'- 1"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*
*▲Transition loads **(bold type)** and widths based on Kµ—0.19, $r_{sd}p$—0.5 in the embankment equation*
Interpolate for intermediate heights of backfill and/or trench widths

Table B-21

90" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 90"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	11'-0"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"		
5	**4963**										**10'- 9"**
6	6040	**6087**									**11'- 1"**
7	6945	**7260**									**11'- 5"**
8	7823	**8482**									**11'-10"**
9	8676	9567	**9757**								**12'- 3"**
10	9503	10490	**11090**								**12'- 7"**
11	10310	11390	**12470**								**13'- 0"**
12	11080	12260	13450	**13920**							**13'- 5"**
13	11840	13120	14390	**15430**							**13'-10"**
14	12570	13940	15320	16690	**17000**						**14'- 3"**
15	13290	14750	16220	17690	**18640**						**14'- 8"**
16	13980	15530	17090	18660	20230	**20340**					**15'- 1"**
17	14650	16300	17950	19610	21270	**22010**					**15'- 6"**
18	15300	17040	18780	20540	22290	**23380**					**15'- 7"**
19	15930	17760	19600	21440	23290	**24740**					**15'- 9"**
20	16540	18460	20390	22320	24270	**26090**					**15'-11"**
21	17140	19140	21160	23190	25220	27270	**27440**				**16'- 1"**
22	17720	19810	21910	24030	26160	28300	**28790**				**16'- 3"**
23	18280	20450	22650	24860	27070	29300	**30150**				**16'- 4"**
24	18820	21080	23360	25660	27970	30290	**31500**				**16'- 6"**
25	19350	21690	24060	26450	28840	31250	**32840**				**16'- 8"**
26	19860	22290	24740	27210	29700	32200	**34180**				**16'-10"**
27	20360	22870	25410	27960	30540	33120	**35520**				**16'-11"**
28	20840	23430	26050	28700	31360	34030	36720	**36860**			**17'- 1"**
29	21300	23980	26680	29410	32160	34920	37700	**38220**			**17'- 2"**
30	21760	24510	27300	30110	32940	35790	38660	**39560**			**17'- 4"**
31	22200	25030	27900	30790	33710	36640	39600	**40880**			**17'- 5"**
32	22630	25540	28480	31460	34460	37480	40520	**42230**			**17'- 7"**
33	23040	26030	29050	32110	35190	38300	41420	**43560**			**17'- 8"**
34	23440	26500	29610	32740	35910	39100	42310	**44940**			**17'- 9"**
35	23840	26970	30150	33360	36610	39890	43180	**46280**			**17'-11"**
36	24210	27420	30680	33970	37300	40660	44040	**47620**			**18'- 0"**
37	24580	27860	31190	34560	37970	41410	44870	48360	**48940**		**18'- 2"**
38	24940	28290	31690	35140	38630	42150	45690	49260	**50310**		**18'- 4"**
39	25290	28710	32180	35710	39270	42870	46500	50150	**51650**		**18'- 5"**
40	25620	29110	32660	36260	39900	43580	47290	51020	**52960**		**18'- 6"**

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
11'-0"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"			
4963										**10'- 8"**	5
6087										**11'- 0"**	6
7009	**7260**									**11'- 4"**	7
7906	**8482**									**11'- 8"**	8
8778	9671	**9757**								**12'- 1"**	9
9627	10620	**11090**								**12'- 6"**	10
10450	11540	**12470**								**12'-10"**	11
11260	12440	13630	**13920**							**13'- 3"**	12
12040	13320	14600	**15430**							**13'- 8"**	13
12800	14170	15550	16930	**17000**						**14'- 1"**	14
13540	15010	16480	17960	**18640**						**14'- 5"**	15
14260	15820	17390	18960	**20340**						**14'-11"**	16
14960	16620	18280	19950	21620	**22010**					**15'- 3"**	17
15650	17390	19150	20910	22670	**23380**					**15'- 5"**	18
16310	18150	20000	21850	23710	**24740**					**15'- 6'**	19
16960	18890	20820	22770	24720	**26090**					**15'- 9"**	20
17580	19600	21640	23670	25720	**27440**					**15'-10"**	21
18200	20310	22430	24560	26700	**28790**					**16'- 0"**	22
18790	20990	23200	25420	27650	29890	**30150**				**16'- 1"**	23
19370	21660	23960	26270	28590	30920	**31500**				**16'- 3"**	24
19940	22310	24700	27100	29510	31930	**32840**				**16'- 4"**	25
20480	22940	25420	27910	30410	32920	**34180**				**16'- 6"**	26
21020	23560	26120	28700	31290	33900	**35520**				**16'- 8"**	27
21540	24160	26810	29480	32160	34850	**36860**				**16'- 9"**	28
22040	24750	27480	30240	33010	35790	**38220**				**16'-11"**	29
22540	25330	28140	30980	33840	36710	**39560**				**17'- 0"**	30
23020	25890	28790	31710	34650	37620	40590	**40880**			**17'- 1"**	31
23480	26430	29410	32420	35450	38500	41560	**42230**			**17'- 2"**	32
23940	26960	30030	33120	36240	39370	42520	**43560**			**17'- 4"**	33
24380	27480	30630	33800	37000	40220	43460	**44940**			**17'- 5"**	34
24800	27990	31220	34470	37760	41060	44390	**46280**			**17'- 7"**	35
25220	28480	31790	35130	38490	41880	45300	**47620**			**17'- 8'**	36
25630	28970	32350	35770	39220	42690	46190	**48940**			**17'- 9"**	37
26020	29440	32900	36390	39920	43480	47070	**50310**			**17'-11"**	38
26410	29890	33430	37010	40620	44260	47930	**51650**			**18'- 0"**	39
26780	30340	33950	37610	41300	45020	48780	52550	**52960**		**18'- 1"**	40

Table B-21 Continued

C ORDINARY CLAY Kµ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRAN-SITION WIDTH
	11'-0"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"		
5	**4963**										**10'- 7"**
6	**6087**										**10'-11"**
7	7096	**7260**									**11'- 3"**
8	8018	**8482**									**11'- 7"**
9	8917	**9757**									**11'-11"**
10	9796	10790	**11090**								**12'- 3"**
11	10650	11740	**12470**								**12'- 8"**
12	11490	12680	**13920**								**13'- 0"**
13	12310	13600	14880	**15430**							**13'- 5"**
14	13110	14490	15870	**17000**							**13'-10"**
15	13890	15370	16850	18330	**18640**						**14'- 2"**
16	14650	16220	17800	19380	**20340**						**14'- 8"**
17	15400	17060	18730	20410	**22010**						**15'- 0"**
18	16130	17890	19650	21420	23190	**23380**					**15'- 1"**
19	16840	18690	20550	22410	24280	**24740**					**15'- 3"**
20	17530	19480	21430	23390	25350	**26090**					**15'- 5"**
21	18210	20240	22290	24340	26400	**27440**					**15'- 6"**
22	18870	21000	23140	25280	27440	**28790**					**15'- 7"**
23	19520	21740	23970	26200	28450	**30250**					**15'- 9"**
24	20150	22460	24780	27110	29450	**31500**					**15'-10"**
25	20760	23160	25580	28000	30430	**32840**					**16'- 0"**
26	21370	23850	26360	28870	31400	33930	**34180**				**16'- 1"**
27	21950	24530	27120	29730	32340	34970	**35520**				**16'- 3"**
28	22530	25190	27870	30570	33270	35990	**36860**				**16'- 4"**
29	23090	25840	28610	31390	34190	37000	**38220**				**16'- 5"**
30	23640	26470	29330	32200	35090	37990	**39560**				**16'- 7"**
31	24170	27090	30030	33000	35970	38960	**40880**				**16'- 8"**
32	24690	27700	30720	33780	36840	39920	**42230**				**16'- 9"**
33	25200	28290	31400	34540	37700	40870	**43560**				**16'-10"**
34	25700	28870	32070	35290	38540	41800	**44940**				**16'-11"**
35	26190	29440	32720	36030	39360	42710	46070	**46280**			**17'- 1"**
36	26660	30000	33360	36750	40170	43610	47060	**47620**			**17'- 2"**
37	27130	30540	33990	37460	40970	44490	48030	**48940**			**17'- 3"**
38	27580	31070	34600	38160	41750	45360	48990	**50310**			**17'- 4"**
39	28020	31590	35200	38850	42520	46220	49940	**51650**			**17'- 5"**
40	28460	32100	35790	39520	43280	47060	50860	**52960**			**17'- 6"**

D SATURATED CLAY Kµ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRAN-SITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
11'-0"	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"			
4963										**10'- 5"**	5
6087										**10'- 9"**	6
7185	**7260**									**11'- 1"**	7
8132	**8482**									**11'- 5"**	8
9060	**9757**									**11'- 9"**	9
9969	10960	**11090**								**12'- 2"**	10
10860	11950	**12470**								**12'- 6"**	11
11740	12930	**13920**								**12'-10"**	12
12590	13880	15170	**15430**							**13'- 3"**	13
13430	14820	16200	**17000**							**13'- 6"**	14
14250	15740	17220	**18640**							**13'-11"**	15
15060	16640	18220	19800	**20340**						**14'- 4"**	16
15850	17530	19200	20890	**22010**						**14'- 8"**	17
16630	18400	20170	21950	**23380**						**14'-10"**	18
17390	19250	21120	23000	**24740**						**15'- 0"**	19
18130	20090	22060	24030	**26090**						**15'- 0"**	20
18860	20920	22980	25040	27110	**27440**					**15'- 2"**	21
19580	21720	23880	26040	28200	**28790**					**15'- 3"**	22
20280	22520	24770	27020	29280	**30150**					**15'- 5"**	23
20970	23300	25640	27990	30350	**31500**					**15'- 6"**	24
21640	24060	26500	28940	31390	**32840**					**15'- 7"**	25
22300	24820	27340	29880	32420	**34180**					**15'- 8"**	26
22950	25560	28170	30800	33440	**35520**					**15'- 9"**	27
23580	26280	28990	31710	34440	**36860**					**15'-10"**	28
24200	26990	29790	32610	35430	**38220**					**16'- 0"**	29
24820	27690	30580	33490	36400	39330	**39560**				**16'- 1"**	30
25410	28380	31360	34360	37360	40380	**40880**				**16'- 2"**	31
26000	29050	32120	35210	38310	41420	**42230**				**16'- 3"**	32
26570	29710	32870	36050	39240	42440	**43560**				**16'- 4"**	33
27140	30360	33610	36880	40160	43450	**44940**				**16'- 5"**	34
27690	31000	34330	37690	41060	44450	**46280**				**16'- 7"**	35
28230	31620	35050	38490	41950	45430	**47620**				**16'- 8"**	36
28760	32240	35750	39280	42830	46400	**48940**				**16'- 8"**	37
29280	32840	36440	40060	43700	47360	**50310**				**16'-10"**	38
29790	33430	37110	40820	44550	48300	**51650**				**16'-11"**	39
30290	34020	37780	41570	45390	49230	**52960**				**16'-11"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on Kµ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-22

96" 96"

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"		
5	**5251**										**11'- 3"**
6	**6432**										**11'- 8"**
7	**7659**										**12'- 0"**
8	8617	**8937**									**12'- 5"**
9	9567	**10260**									**12'- 9"**
10	10490	11480	**11650**								**13'- 2"**
11	11390	12480	**13080**								**13'- 7"**
12	12260	13450	**14580**								**13'-11"**
13	13120	14390	15680	**16130**							**14'- 4"**
14	13940	15320	16690	**17750**							**14'- 9"**
15	14750	16220	17690	19160	**19430**						**15'- 2"**
16	15530	17090	18660	20230	**21180**						**15'- 7"**
17	16300	17950	19610	21270	22940	**23000**					**16'- 1"**
18	17040	18780	20540	22290	24060	**24820**					**16'- 5"**
19	17760	19600	21440	23290	25150	**26270**					**16'- 7"**
20	18460	20390	22320	24270	26220	**27720**					**16'- 9"**
21	19140	21160	23190	25220	27270	**29160**					**17'- 0"**
22	19810	21910	24030	26160	28300	30440	**30600**				**17'- 1"**
23	20450	22650	24860	27070	29300	31540	**32040**				**17'- 3"**
24	21080	23360	25660	27970	30290	32610	**33470**				**17'- 4"**
25	21690	24060	26450	28840	31250	33670	**34910**				**17'- 6"**
26	22290	24740	27210	29700	32200	34710	**36340**				**17'- 8"**
27	22870	25410	27960	30540	33120	35720	**37790**				**17'- 9"**
28	23430	26050	28700	31360	34030	36720	**39200**				**17'-11"**
29	23980	26680	29410	32160	34920	37700	40490	**40650**			**18'- 1"**
30	24510	27300	30110	32940	35790	38660	41540	**42080**			**18'- 2"**
31	25030	27900	30790	33710	36640	39600	42560	**43520**			**18'- 4"**
32	25540	28480	31460	34460	37480	40520	43580	**44940**			**18'- 5"**
33	26030	29050	32110	35190	38300	41420	44570	**46380**			**18'- 7"**
34	26500	29610	32740	35910	39100	42310	45540	**47810**			**18'- 9"**
35	26970	30150	33360	36610	39890	43180	46500	**49210**			**18'-10"**
36	27420	30680	33970	37300	40660	44040	47440	**50640**			**18'-11"**
37	27860	31190	34560	37970	41410	44870	48360	51860	**52090**		**19'- 1"**
38	28290	31690	35140	38630	42150	45690	49260	52850	**53490**		**19'- 2"**
39	28710	32180	35710	39270	42870	46500	50150	53830	**54920**		**19'- 3"**
40	29110	32660	36260	39900	43580	47290	51020	54780	**56360**		**19'- 5"**

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"			
5251										**11'- 3"**	5
6432										**11'- 7"**	6
7659										**11'-11"**	7
8700	**8937**									**12'- 4"**	8
9671	**10260**									**12'- 8"**	9
10620	**11650**									**13'- 0"**	10
11540	12630	**13080**								**13'- 5"**	11
12440	13630	**14580**								**13'-10"**	12
13320	14600	15880	**16130**							**14'- 3"**	13
14170	15550	16930	**17750**							**14'- 7"**	14
15010	16480	17960	**19430**							**15'- 0"**	15
15820	17390	18960	20540	**21180**						**15'- 5"**	16
16620	18280	19950	21620	**23000**						**15'-10"**	17
17390	19150	20910	22670	24440	**24820**					**16'- 2"**	18
18150	20000	21850	23710	25570	**26270**					**16'- 4"**	19
18890	20820	22770	24720	26680	**27720**					**16'- 7"**	20
19600	21640	23670	25720	27770	**29160**					**16'- 8"**	21
20310	22430	24560	26700	28840	**30600**					**16'-10"**	22
20990	23200	25420	27650	19890	**32040**					**17'- 0"**	23
21660	23960	26270	28590	30920	33260	**33470**				**17'- 1"**	24
22310	24700	27100	29510	31930	34360	**34910**				**17'- 3"**	25
22940	25420	27910	30410	32920	35450	**36340**				**17'- 4"**	26
23560	26120	28700	31290	33900	36510	**37790**				**17'- 6"**	27
24160	26810	29480	32160	34850	37560	**39200**				**17'- 8"**	28
24750	27480	30240	33010	35790	38590	**40650**				**17'- 9"**	29
25330	28140	30980	33840	36710	39600	**42080**				**17'-10"**	30
25890	28790	31710	34650	37620	40590	**43520**				**18'- 0"**	31
26430	29410	32420	35450	38500	41560	44640	**44940**			**18'- 1"**	32
26960	30030	33120	36240	39370	42520	45690	**46380**			**18'- 2"**	33
27480	30630	33800	37000	40220	43460	46720	**47810**			**18'- 4"**	34
27990	31220	34470	37760	41060	44390	47730	**49210**			**18'- 5"**	35
28480	31790	35130	38490	41880	45300	48730	**50640**			**18'- 6"**	36
28970	32350	35770	39220	42690	46190	49710	**52090**			**18'- 8"**	37
29440	32900	36390	39920	43480	47070	50670	**53490**			**18'-10"**	38
29890	33430	37010	40620	44260	47930	51620	**54920**			**18'-10"**	39
30340	33950	37610	41300	45020	48780	52550	**56360**			**19'- 0"**	40

Table B-22 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"		
5	**5251**										**11'- 2"**
6	**6432**										**11'- 5"**
7	**7659**										**11'- 9"**
8	8814	**8937**									**12'- 2"**
9	9812	**10260**									**12'- 6"**
10	10790	**11650**									**12'-10"**
11	11740	12840	**13080**								**13'- 3"**
12	12680	13870	**14580**								**13'- 7"**
13	13600	14880	**16130**								**13'-11"**
14	14490	15870	17260	**17750**							**14'- 4"**
15	15370	16850	18330	**19430**							**14'- 9"**
16	16220	17800	19380	20960	**21180**						**15'- 1"**
17	17060	18730	20410	22090	**23000**						**15'- 6"**
18	17890	19650	21420	23190	**24820**						**15'-11"**
19	18690	20550	22410	24280	26150	**26270**					**16'- 1"**
20	19480	21430	23390	25350	27320	**27720**					**16'- 2"**
21	20240	22290	24340	26400	28470	**29160**					**16'- 4"**
22	21000	23140	25280	27440	29600	**30600**					**16'- 6"**
23	21740	23970	26200	28450	30700	**32040**					**16'- 7"**
24	22460	24780	27110	29450	31800	**33470**					**16'- 8"**
25	23160	25580	28000	30430	32870	**34910**					**16'-10"**
26	23850	26360	28870	31400	33930	**36340**					**17'- 0"**
27	24530	27120	29730	32340	34970	37600	**37790**				**17'- 1"**
28	25190	27870	30570	33270	35990	38720	**39200**				**17'- 2"**
29	25840	28610	31390	34190	37000	39820	**40650**				**17'- 4"**
30	26470	29330	32200	35090	37990	40900	**42080**				**17'- 5"**
31	27090	30030	33000	35970	38960	41970	**43520**				**17'- 6"**
32	27700	30720	33780	36840	39920	43020	**44940**				**17'- 8"**
33	28290	31400	34540	37700	40870	44050	**46380**				**17'- 9"**
34	28870	32070	35290	38540	41800	45070	**47810**				**17'-10"**
35	29440	32720	36030	39360	42710	46070	**49210**				**17'-11"**
36	30000	33360	36750	40170	43610	47060	50530	**50640**			**18'- 1"**
37	30540	33990	37460	40970	44490	48030	51590	**52090**			**18'- 1"**
38	31070	34600	38160	41750	45360	48990	52640	**53490**			**18'- 3"**
39	31590	35200	38850	42520	46220	49940	53670	**54920**			**18'- 4"**
40	32100	35790	39520	43280	47060	50860	54690	**56360**			**18'- 5"**

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"			
5251										**11'- 0"**	5
6432										**11'- 4"**	6
7659										**11'- 8"**	7
8937										**12'- 0"**	8
9956	**10260**									**12'- 4"**	9
10960	**11650**									**12'- 8"**	10
11950	**13080**									**13'- 0"**	11
12930	14120	**14580**								**13'- 5"**	12
13880	15170	**16130**								**13'- 9"**	13
14820	16200	17590	**17750**							**14'- 1"**	14
15740	17220	18710	**19430**							**14'- 6"**	15
16640	18220	19800	**21180**							**14'-10"**	16
17530	19200	20890	22570	**23000**						**15'- 3"**	17
18400	20170	21950	23730	**24820**						**15'- 7"**	18
19250	21120	23000	24870	**26270**						**15'- 9"**	19
20090	22060	24030	26000	**27720**						**15'-10"**	20
20920	22980	25040	27110	**29160**						**16'- 0"**	21
21720	23880	26040	28200	30370	**30600**					**16'- 2"**	22
22520	24770	27020	29280	31550	**32040**					**16'- 2"**	23
23300	25640	27990	30350	32710	**33470**					**16'- 4"**	24
24060	26500	28940	31390	33850	**34910**					**16'- 5"**	25
24820	27340	29880	32420	34980	**36340**					**16'- 7"**	26
25560	28170	30800	33440	36090	**37790**					**16'- 7"**	27
26280	28990	31710	34440	37180	**39200**					**16'- 9"**	28
26990	29790	32610	35430	38260	**40650**					**16'-10"**	29
27690	30580	33490	36400	39330	**42080**					**17'- 0"**	30
28380	31360	34360	37360	40380	**43520**					**17'- 0"**	31
29050	32120	35210	38310	41420	44540	**44940**				**17'- 1"**	32
29710	32870	36050	39240	42440	45660	**46380**				**17'- 3"**	33
30360	33610	36880	40160	43450	46760	**47810**				**17'- 4"**	34
31000	34330	37690	41060	44450	47850	**49210**				**17'- 4"**	35
31620	35050	38490	41950	45430	48920	**50640**				**17'- 6"**	36
32240	35750	39280	42830	46400	49980	**52090**				**17'- 7"**	37
32840	36440	40060	43700	47360	51030	**53490**				**17'- 8"**	38
33430	37110	40820	44550	48300	52060	**54920**				**17'- 9"**	39
34020	37780	41570	45390	49230	53080	**56360**				**17'-10"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-23

102" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 102"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	22'-0"	
5	**5539**										11'-10"
6	6637	**6776**									12'- 3"
7	7640	**8060**									12'- 7"
8	8617	**9392**									13'- 0"
9	9567	10460	**10780**								13'- 4"
10	10490	11480	**12210**								13'- 9"
11	11390	12480	13560	**13700**							14'- 1"
12	12260	13450	14630	**15240**							14'- 6"
13	13120	14390	15680	**16850**							14'-11"
14	13940	15320	16690	18070	**18510**						15'- 4"
15	14750	16220	17690	19160	**20240**						15'- 9"
16	15530	17090	18660	20230	21800	**22030**					16'- 2"
17	16300	17950	19610	21270	22940	**23890**					16'- 6"
18	17040	18780	20540	22290	24060	**25820**					17'- 0"
19	17760	19600	21440	23290	25150	27010	**27780**				17'- 5"
20	18460	20390	22320	24270	26220	28180	**29330**				17'- 7"
21	19140	21160	23190	25220	27270	29320	**30870**				17'- 9"
22	19810	21910	24030	26160	28300	30440	**32400**				17'-11"
23	20450	22650	24860	27070	29300	31540	33780	**33940**			18'- 1"
24	21080	23360	25660	27970	30290	32610	34950	**35460**			18'- 3"
25	21690	24060	26450	28840	31250	33670	36100	**36980**			18'- 4"
26	22290	24740	27210	29700	32200	34710	37220	**38500**			18'- 6"
27	22870	25410	27960	30540	33120	35720	38330	**40020**			18'- 8"
28	23430	26050	28700	31360	34030	36720	39420	**41540**			18'- 9"
29	23980	26680	29410	32160	34920	37700	40490	**43070**			18'-11"
30	24510	27300	30110	32940	35790	38660	41540	44420	**44590**		19'- 1"
31	25030	27900	30790	33710	36640	39600	42560	45540	**46110**		19'- 3"
32	25540	28480	31460	34460	37480	40520	43580	46640	**47640**		19'- 4"
33	26030	29050	32110	35190	38300	41420	44570	47720	**49150**		19'- 5"
34	26500	29610	32740	35910	39100	42310	45540	48780	**50650**		19'- 7"
35	26970	30150	33360	36610	39890	43180	46500	49830	**52180**		19'- 9"
36	27420	30680	33970	37300	40660	44040	47440	50850	**53710**		19'-10"
37	27860	31190	34560	37970	41410	44870	48360	51860	**55200**		19'-11"
38	28290	31690	35140	38630	42150	45690	49260	52850	56460	**56740**	20'- 1"
39	28710	32180	35710	39270	42870	46500	50150	53830	57520	**58250**	20'- 2"
40	29110	32660	36260	39900	43580	47290	51020	54780	58560	**59770**	20'- 4"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	22'-0"		
5539										11'- 9"	5
6686	**6776**									12'- 2"	6
7706	**8060**									12'- 6"	7
8700	**9392**									12'-10"	8
9671	10560	**10780**								13'- 3"	9
10620	11610	**12210**								13'- 7"	10
11540	12630	**13700**								14'- 0"	11
12440	13630	14810	**15240**							14'- 4"	12
13320	14600	15880	**16850**							14'- 9"	13
14170	15550	16930	18320	**18510**						15'- 2"	14
15010	16480	17960	19440	**20240**						15'- 6"	15
15820	17390	18960	20540	**22030**						16'- 0"	16
16620	18280	19950	21620	23290	**23890**					16'- 5"	17
17390	19150	20910	22670	24440	**25820**					16'- 9"	18
18150	20000	21850	23710	25570	27440	**27780**				17'- 2"	19
18890	20820	22770	24720	26680	28650	**29330**				17'- 4"	20
19600	21640	23670	25720	27770	29830	**30870**				17'- 6"	21
20310	22430	24560	26700	28840	30990	**32400**				17'- 8"	22
20990	23200	25420	27650	29890	32140	**33940**				17'- 9"	23
21660	23960	26270	28590	30920	33260	**35460**				17'-11"	24
22310	24700	27100	29510	31930	34360	36800	**36980**			18'- 1"	25
22940	25420	27910	30410	32920	35450	37980	**38500**			18'- 3"	26
23560	26120	28700	31290	33900	36510	39140	**40020**			18'- 4"	27
24160	26810	29480	32160	34850	37560	40270	**41540**			18'- 6"	28
24750	27480	30240	33010	35790	38590	41390	**43070**			18'- 7"	29
25330	28140	30980	33840	36710	39600	42490	**44590**			18'- 9"	30
25890	28790	31710	34650	37620	40590	43580	**46110**			18'-10"	31
26430	29410	32420	35450	38500	41560	44640	**47640**			18'-11"	32
26960	30030	33120	36240	39370	42520	45690	48870	**49150**		19'- 1"	33
27480	30630	33800	37000	40220	43460	46720	49990	**50650**		19'- 3"	34
27990	31220	34470	37760	41060	44390	47730	51090	**52180**		19'- 4"	35
28480	31790	35130	38490	41880	45300	48730	52170	**53710**		19'- 5"	36
28970	32350	35770	39220	42690	46190	49710	53240	**55200**		19'- 7"	37
29440	32900	36390	39920	43480	47070	50670	54290	**56740**		19'- 8"	38
29890	33430	37010	40620	44260	47930	51620	55330	**58250**		19'-10"	39
30340	33950	37610	41300	45020	48780	52550	56340	**59770**		19'-11"	40

Table B-23 Continued

C ORDINARY CLAY Kµ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	22'-0"	
5	**5539**										11'- 9"
6	**6776**										12'- 0"
7	7794	**8060**									12'- 4"
8	8814	**9392**									12'- 9"
9	9812	10710	**10780**								13'- 1"
10	10790	11780	**12210**								13'- 5"
11	11740	12840	**13700**								13'- 9"
12	12680	13870	15060	**15240**							14'- 2"
13	13600	14880	16170	**16850**							14'- 6"
14	14490	15870	17260	**18510**							14'-10"
15	15370	16850	18330	19810	**20240**						15'- 4"
16	16220	17800	19380	20960	**22030**						15'- 8"
17	17060	18730	20410	22090	23770	**23890**					16'- 1"
18	17890	19650	21420	23190	24970	**25820**					16'- 6"
19	18690	20550	22410	24280	26150	**27780**					16'-11"
20	19480	21430	23390	25350	27320	29290	**29330**				17'- 1"
21	20240	22290	24340	26400	28470	30530	**30870**				17'- 2"
22	21000	23140	25280	27440	29600	31760	**32400**				17'- 3"
23	21740	23970	26200	28450	30700	32960	**33940**				17'- 5"
24	22460	24780	27110	29450	31800	34150	**35460**				17'- 7"
25	23160	25580	28000	30430	32870	35320	**36980**				17'- 8"
26	23850	26360	28870	31400	33930	36470	**38500**				17'- 9"
27	24530	27120	29730	32340	34970	37600	**40020**				17'-11"
28	25190	27870	30570	33270	35990	38720	41450	**41540**			18'- 1"
29	25840	28610	31390	34190	37000	39820	42650	**43070**			18'- 2"
30	26470	29330	32200	35090	37990	40900	43820	**44590**			18'- 3"
31	27090	30030	33000	35970	38960	41970	44980	**46110**			18'- 4"
32	27700	30720	33780	36840	39920	43020	46120	**47640**			18'- 6"
33	28290	31400	34540	37700	40870	44050	47250	**49150**			18'- 7"
34	28870	32070	35290	38540	41800	45070	48360	**50650**			18'- 9"
35	29440	32720	36030	39360	42710	46070	49450	**52180**			18'- 9"
36	30000	33360	36750	40170	43610	47060	50530	**53710**			18'-11"
37	30540	33990	37460	40970	44490	48030	51590	**55200**			19'- 0"
38	31070	34600	38160	41750	45360	48990	52640	56300	**56740**		19'- 2"
39	31590	35200	38850	42520	46220	49940	53670	57420	**58250**		19'- 3"
40	32100	35790	39520	43280	47060	50860	54690	58530	**59770**		19'- 4"

D SATURATED CLAY Kµ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
12'-0"	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	22'-0"		
5539										11'- 7"	5
6776										11'-11"	6
7883	**8060**									12'- 3"	7
8929	**9392**									12'- 7"	8
9956	**10780**									12'-11"	9
10960	11960	**12210**								13'- 3"	10
11950	13050	**13700**								13'- 7"	11
12930	14120	**15240**								13'-11"	12
13880	15170	16460	**16850**							14'- 3"	13
14820	16200	17590	**18510**							14'- 8"	14
15740	17220	18710	**20240**							15'- 0"	15
16640	18220	19800	21390	**22030**						15'- 5"	16
17530	19200	20890	22570	**23890**						15'-10"	17
18400	20170	21950	23730	25510	**25820**					16'- 2"	18
19250	21120	23000	24870	26750	**27780**					16'- 6"	19
20090	22060	24030	26000	27980	**29330**					16'- 8"	20
20920	22980	25040	27110	29180	**30870**					16'-10"	21
21720	23880	26040	28200	30370	**32400**					16'-11"	22
22520	24770	27020	29280	31550	33820	**33940**				17'- 1"	23
23300	25640	27990	30350	32710	35070	**35460**				17'- 2"	24
24060	26500	28940	31390	33850	36310	**36980**				17'- 3"	25
24820	27340	29880	32420	34980	37530	**38500**				17'- 5"	26
25560	28170	30800	33440	36090	38740	**40020**				17'- 6"	27
26280	28990	31710	34440	37180	39930	**41540**				17'- 7"	28
26990	29790	32610	35430	38260	41100	**43070**				17'- 8"	29
27690	30580	33490	36400	39330	42260	**44590**				17'- 9"	30
28380	31360	34360	37360	40380	43410	**46110**				17'-11"	31
29050	32120	35210	38310	41420	44540	**47640**				18'- 0"	32
29710	32870	36050	39240	42440	45660	48880	**49150**			18'- 1"	33
30360	33610	36880	40160	43450	46760	50080	**50650**			18'- 3"	34
31000	34330	37690	41060	44450	47850	51260	**52180**			18'- 3"	35
31620	35050	38490	41950	45430	48920	52420	**53710**			18'- 4"	36
32240	35750	39280	42830	46400	49980	53580	**55200**			18'- 5"	37
32840	36440	40060	43700	47360	51030	54710	**56740**			18'- 7"	38
33430	37110	40820	44550	48300	52060	55840	**58250**			18'- 8"	39
34020	37780	41570	45390	49230	53080	56950	**59770**			18'- 9"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on Kµ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-24

108" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 108"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	
5	**5833**										12'- 5"
6	**7127**										12'-10"
7	8337	**8468**									13'- 3"
8	9411	**9857**									13'- 7"
9	10460	**11300**									13'-11"
10	11480	12470	**12780**								14'- 4"
11	12480	13560	**14330**								14'- 8"
12	13450	14630	15820	**15920**							15'- 1"
13	14390	15680	16960	**17580**							15'- 6"
14	15320	16690	18070	**19290**							15'-11"
15	16220	17690	19160	20640	**21070**						16'- 3"
16	17090	18660	20230	21800	**22910**						16'- 8"
17	17950	19610	21270	22940	24620	**24810**					17'- 1"
18	18780	20540	22290	24060	25820	**26780**					17'- 6"
19	19600	21440	23290	25150	27010	**28820**					18'- 0"
20	20390	22320	24270	26220	28180	30140	**30940**				18'- 5"
21	21160	23190	25220	27270	29320	31370	**32580**				18'- 7"
22	21910	24030	26160	28300	30440	32590	**34220**				18'- 9"
23	22650	24860	27070	29300	31540	33780	**35840**				18'-11"
24	23360	25660	27970	30290	32610	34950	**37460**				19'- 0"
25	24060	26450	28840	31250	33670	36100	38530	**39080**			19'- 2"
26	24740	27210	29700	32200	34710	37220	39750	**40690**			19'- 4"
27	25410	27960	30540	33120	35720	38330	40950	**42310**			19'- 6"
28	26050	28700	31360	34030	36720	39420	42130	**43920**			19'- 8"
29	26680	29410	32160	34920	37700	40490	43290	**45530**			19'-10"
30	27300	30110	32940	35790	38660	41540	44420	**47130**			20'- 0"
31	27900	30790	33710	36640	39600	42560	45540	48530	**48740**		20'- 1"
32	28480	31460	34460	37480	40520	43580	46640	49720	**50350**		20'- 2"
33	29050	32110	35190	38300	41420	44570	47720	50890	**51950**		20'- 4"
34	29610	32740	35910	39100	43210	45540	48780	52040	**53550**		20'- 5"
35	30150	33360	36610	39890	43180	46500	49830	53180	**55190**		20'- 7"
36	30680	33970	37300	40660	44040	47440	50850	54290	**56780**		20'- 9"
37	31190	34560	37970	41410	44870	48360	51860	55380	**58400**		20'-11"
38	31690	35140	38630	42150	45690	49260	52850	56460	**59990**		21'- 0"
39	32180	35710	39270	42870	46500	50150	53830	57520	61230	**61590**	21'- 1"
40	32660	36260	39900	43580	47290	51020	54780	58560	62360	**63190**	21'- 2"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"		
5833										12'- 5"	5
7127										12'- 9"	6
8403	**8468**									13'- 1"	7
9496	**9857**									13'- 5"	8
10560	**11300**									13'-10"	9
11610	12600	**12780**								14'- 2"	10
12630	13720	**14330**								14'- 7"	11
13630	14810	**15920**								14'-11"	12
14600	15880	17170	**17580**							15'- 4"	13
15550	16930	18320	**19290**							15'- 9"	14
16480	17960	19440	20920	**21070**						16'- 1"	15
17390	18960	20540	22120	**22910**						16'- 6"	16
18280	19950	21620	23290	**24810**						16'-11"	17
19150	20910	22670	24440	26220	**26780**					17'- 4"	18
20000	21850	23710	25570	27440	**28820**					17'- 9"	19
20820	22770	24720	26680	28650	30610	**30940**				18'- 2"	20
21640	23670	25720	27770	29830	31890	**32580**				18'- 4"	21
22430	24560	26700	28840	30990	33150	**34220**				18'- 6"	22
23200	25420	27650	29890	32140	34390	**35840**				18'- 8"	23
23960	26270	28590	30920	33260	35600	**37460**				18'-10"	24
24700	27100	29510	31930	34360	36800	**39080**				19'- 0"	25
25420	27910	30410	32920	35450	37980	40520	**40690**			19'- 1"	26
26120	28700	31290	33900	36510	39140	41770	**42310**			19'- 2"	27
26810	29480	32160	34850	37560	40270	43000	**43920**			19'- 4"	28
27480	30240	33010	35790	38590	41390	44210	**45530**			19'- 6"	29
28140	30980	33840	36710	39600	42490	45400	**47130**			19'- 7"	30
28790	31710	34650	37620	40590	43580	46580	**48740**			19'- 9"	31
29410	32420	35450	38500	41560	44640	47730	**50350**			19'-10"	32
30030	33120	36240	39370	42520	45690	48870	**51950**			20'- 0"	33
30630	33800	37000	40220	43460	46720	49990	53270	**53550**		20'- 1"	34
31220	34470	37760	41060	44390	47730	51090	54460	**55190**		20'- 2"	35
31790	35130	38490	41880	45300	48730	52170	55630	**56780**		20'- 4"	36
32350	35770	39220	42690	46190	49710	53240	56790	**58400**		20'- 5"	37
32900	36390	39920	43480	47070	50670	54290	57930	**59990**		20'- 7"	38
33430	37010	40620	44260	47930	51620	55330	59050	**61590**		20'- 8"	39
33950	37610	41300	45020	48780	52550	56340	60160	**63190**		20'-10"	40

Table B-24 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	
5	**5833**										**12'- 3"**
6	**7127**										**12'- 8"**
7	**8468**										**13'- 0"**
8	9610	**9857**									**13'- 4"**
9	10710	**11300**									**13'- 8"**
10	11780	**12780**									**14'- 0"**
11	12840	13930	**14330**								**14'- 4"**
12	13870	15060	**15920**								**14'- 9"**
13	14880	16170	17460	**17580**							**15'- 1"**
14	15870	17260	18650	**19290**							**15'- 6"**
15	16850	18330	19810	**21070**							**15'-10"**
16	17800	19380	20960	22540	**22910**						**16'- 2"**
17	18730	20410	22090	23770	**24810**						**16'- 7"**
18	19650	21420	23190	24970	26750	**26780**					**17'- 1"**
19	20550	22410	24280	26150	28030	**28820**					**17'- 5"**
20	21430	23390	25350	27320	29290	**30940**					**17'-10"**
21	22290	24340	26400	28470	30530	**32580**					**18'- 0"**
22	23140	25280	27440	29600	31760	33920	**34220**				**18'- 1"**
23	23970	26200	28450	30700	32960	35220	**35840**				**18'- 3"**
24	24780	27110	29450	31800	34150	36510	**37460**				**18'- 5"**
25	25580	28000	30430	32870	35320	37770	**39080**				**18'- 6"**
26	26360	28870	31400	33930	36470	39020	**40690**				**18'- 8"**
27	27120	29730	32340	34970	37600	40240	**42310**				**18'-10"**
28	27870	30570	33270	35990	38780	41450	**43920**				**18'-11"**
29	28610	31390	34190	37000	38720	41450	**43920**				**19'- 0"**
30	29330	32200	35090	37990	40900	43820	46750	**47130**			**19'- 1"**
31	30030	33000	35970	38960	41970	44980	48000	**48740**			**19'- 3"**
32	30720	33780	36840	39920	43020	46120	49240	**50350**			**19'- 4"**
33	31400	34540	37700	40870	44050	47250	50450	**51950**			**19'- 5"**
34	32070	35290	38540	41800	45070	48360	51650	**53550**			**19'- 7"**
35	32720	36030	39360	42710	46070	49450	52840	**55190**			**19'- 8"**
36	33360	36750	40170	43610	47060	50530	54010	**56780**			**19'-10"**
37	33990	37460	40970	44490	48030	51590	55160	**58400**			**19'-11"**
38	34600	38160	41750	45360	48990	52640	56300	**59990**			**20'- 0"**
39	35200	38850	42520	46220	49940	53670	57420	61180	**61590**		**20'- 1"**
40	35790	39520	43280	47060	50860	54690	58530	62380	**63190**		**20'- 2"**

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
13'-0"	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"		
5833										**12'- 3"**	5
7127										**12'- 6"**	6
8468										**12'-10"**	7
9726	**9857**									**13'- 2"**	8
10850	**11300**									**13'- 6"**	9
11960	**12780**									**13'-10"**	10
13050	14140	**14330**								**14'- 2"**	11
14120	15310	**15920**								**14'- 6"**	12
15170	16460	**17580**								**14'-10"**	13
16200	17590	18980	**19290**							**15'- 3"**	14
17220	18710	20200	**21070**							**15'- 7"**	15
18220	19800	21390	**22910**							**16'- 0"**	16
19200	20890	22570	24250	**24810**						**16'- 4"**	17
20170	21950	23730	25510	**26780**						**16'- 9"**	18
21120	23000	24870	26750	28640	**28820**					**17'- 1"**	19
22060	24030	26000	27980	29960	**30940**					**17'- 6"**	20
22980	25040	27110	29180	31260	**32580**					**17'- 8"**	21
23880	26040	28200	30370	32550	**34220**					**17'- 9"**	22
24770	27020	29280	31550	33820	**35840**					**17'-11"**	23
25640	27990	30350	32710	35070	37440	**37460**				**18'- 1"**	24
26500	28940	31390	33850	36310	38770	**39080**				**18'- 1"**	25
27340	29880	32420	34980	37530	40090	**40690**				**18'- 2"**	26
28170	30800	33440	36090	38740	41390	**42310**				**18'- 4"**	27
28990	31710	34440	37180	33930	42680	**43920**				**18'- 5"**	28
29790	32610	35430	38260	41100	43950	**45530**				**18'- 7"**	29
30580	33490	36400	39330	42260	45210	**47130**				**18'- 8"**	30
31360	34360	37360	40380	43410	46450	**48740**				**18'- 9"**	31
32120	35210	38310	41420	44540	47670	**50350**				**18'-11"**	32
32870	36050	39240	42440	45660	48880	**51950**				**19'- 0"**	33
33610	36880	40160	43450	46760	50080	53400	**53550**			**19'- 1"**	34
34330	37690	41060	44450	47850	51260	54670	**55190**			**19'- 1"**	35
35050	38490	41950	45430	48920	52420	55930	**56780**			**19'- 3"**	36
35750	39280	42830	46400	49980	53580	57180	**58400**			**19'- 4"**	37
36440	40060	43700	47360	51030	54710	58410	**59990**			**19'- 5"**	38
37110	40820	44550	48300	52060	55840	59630	**61590**			**19'- 6"**	39
37780	41570	45390	49230	53080	56950	60830	**63190**			**19'- 7"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-25

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

114″ 114″

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	
5	**6121**										13'- 0"
6	**7472**										13'- 5"
7	**8870**										13'- 9"
8	10210	**10310**									14'- 2"
9	11350	**11810**									14'- 6"
10	12470	**13350**									14'-11"
11	13560	14660	**14950**								15'- 3"
12	14630	15820	**16600**								15'- 8"
13	15680	16960	**18300**								16'- 0"
14	16690	18070	19460	**20070**							16'- 5"
15	17690	19160	20640	**21890**							16'-10"
16	18660	20230	21800	23380	**23770**						17'- 3"
17	19610	21270	22940	24620	**25720**						17'- 8"
18	20540	22290	24060	25820	27600	**27740**					18'- 1"
19	21440	23290	25150	27010	28880	**29820**					18'- 6"
20	22320	24270	26220	28180	30140	**31970**					18'-11"
21	23190	25220	27270	29320	31370	33430	**34190**				19'- 4"
22	24030	26160	28300	30440	32590	34740	**35980**				19'- 7"
23	24860	27070	29300	31540	33780	36030	**37700**				19'- 9"
24	25660	27970	30290	32610	34950	37290	**39410**				19'-11"
25	26450	28840	31250	33670	36100	38530	40970	**41120**			20'- 1"
26	27210	29700	32200	34710	37220	39750	42280	**42820**			20'- 3"
27	27960	30540	33120	35720	38330	40950	43580	**44540**			20'- 5"
28	28700	31360	34030	36720	39420	42130	44840	**46240**			20'- 6"
29	29410	32160	34920	37700	40490	43290	46100	**47940**			20'- 8"
30	30110	32940	35790	38660	41540	44430	47320	**49640**			20'-10"
31	30790	33710	36640	39600	42560	45540	48530	**51320**			21'- 0"
32	31460	34460	37480	40520	43580	46640	49720	52810	**53030**		21'- 1"
33	32110	35190	38300	41420	44570	47720	50890	54070	**54730**		21'- 3"
34	32740	35910	39100	42310	45540	48780	52040	55310	**56420**		21'- 4"
35	33360	36610	39890	43180	46500	49830	53180	56530	**58120**		21'- 5"
36	33970	37300	40660	44040	47440	50850	54290	57740	**59810**		21'- 7"
37	34560	37970	41410	44870	48360	51860	55380	58920	**61490**		21'- 8"
38	35140	38630	42150	45690	49260	52850	56460	60080	**63220**		21'-10"
39	35710	39270	42870	46500	50150	53830	57520	61230	**64900**		22'- 0"
40	36260	39900	43580	47290	51020	54780	58560	62360	66170	**66590**	22'- 1"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"		
6121										12'-11"	5
7472										13'- 4"	6
8870										13'- 8"	7
10310										14'- 0"	8
11460	**11810**									14'- 4"	9
12600	**13350**									14'- 9"	10
13720	14810	**14950**								15'- 2"	11
14810	16000	**16600**								15'- 6"	12
15880	17170	**18300**								15'-11"	13
16930	18320	19700	**20070**							16'- 3"	14
17960	19440	20920	**21890**							16'- 8"	15
18960	20540	22120	23700	**23770**						17'- 1"	16
19950	21620	23290	24970	**25720**						17'- 6"	17
20910	22670	24440	26220	**27740**						17'-11"	18
21850	23710	25570	27440	29310	**29820**					18'- 4"	19
22770	24720	26680	28650	30610	**31970**					18'- 8"	20
23670	25720	27770	29830	31890	33960	**34190**				19'- 1"	21
24560	26700	28840	30990	33150	35310	**35980**				19'- 3"	22
25420	27650	29890	32140	34390	36640	**37700**				19'- 5"	23
26270	28590	30920	33260	35600	37960	**39410**				19'- 7"	24
27100	29510	31930	34360	36800	39240	**41120**				19'- 9"	25
27910	30410	32920	35450	37930	40520	**42820**				19'-11"	26
28700	31290	33900	36510	39140	41770	44400	**44540**			20'- 1"	27
29480	32160	34850	37560	40270	43000	45730	**46240**			20'- 2"	28
30240	33010	35790	38590	41390	44210	47030	**47940**			20'- 4"	29
30980	33840	36710	39600	42490	45400	48320	**49640**			20'- 6"	30
31710	34650	37620	40590	43530	46580	49580	**51320**			20'- 7"	31
32420	35450	38500	41560	44610	47730	50830	**53030**			20'- 9"	32
33120	36240	39370	42520	45690	48870	52060	**54730**			20'-10"	33
33800	37000	40220	43460	46720	49990	53270	**56420**			21'- 0"	34
34470	37760	41060	44390	47730	51090	54460	57840	**58120**		21'- 1"	35
35130	38490	41880	45300	48730	52170	55630	59100	**59810**		21'- 3"	36
35770	39220	42690	46190	49710	53240	56790	60350	**61490**		21'- 3"	37
36390	39920	43480	47070	50670	54290	57930	61580	**63220**		21'- 5"	38
37010	40620	44260	47930	51620	55330	59050	62790	**64900**		21'- 6"	39
37610	41300	45020	48780	52550	56340	60160	63990	**66590**		21'- 8"	40

Table B-25 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	
5	**6121**										12'-10"
6	**7472**										13'- 2"
7	**8870**										13'- 7"
8	**10310**										13'-11"
9	11600	**11810**									14'- 3"
10	12780	**13350**									14'- 7"
11	13930	**14950**									14'-11"
12	15060	16250	**16600**								15'- 4"
13	16170	17460	**18300**								15'- 8"
14	17260	18650	**20070**								16'- 0"
15	18330	19810	21300	**21890**							16'- 5"
16	19380	20960	22540	**23770**							16'- 9"
17	20410	22090	23770	25450	**25720**						17'- 2"
18	21420	23190	24970	26750	**27740**						17'- 7"
19	22410	24280	26150	28030	**29820**						18'- 0"
20	23390	25350	27320	29290	31270	**31970**					18'- 5"
21	24340	26400	28470	30530	32600	**34190**					18'- 9"
22	25280	27440	29600	31760	33920	**35980**					18'-11"
23	26200	28450	30700	32960	35220	37490	**37700**				19'- 1"
24	27110	29450	31800	34150	36510	38870	**39410**				19'- 3"
25	28000	30430	32870	35320	37770	40230	**41120**				19'- 4"
26	28870	31400	33930	36470	39020	41570	**42820**				19'- 6"
27	29730	32340	34970	37600	40240	42890	**44540**				19'- 7"
28	30570	33270	35990	38720	41450	44190	**46240**				19'- 9"
29	31390	34190	37000	39820	42650	45480	**47940**				19'-10"
30	32200	35090	37990	40900	43820	46750	**49640**				20'- 0"
31	33000	35970	38960	41970	44980	48000	51030	**51320**			20'- 1"
32	33780	36840	39920	43020	46120	49240	52360	**53030**			20'- 3"
33	34540	37700	40870	44050	47250	50450	53670	**54730**			20'- 4"
34	35290	38540	41800	45070	48360	51650	54960	**56420**			20'- 5"
35	36030	39360	42710	46070	49450	52840	56240	**58120**			20'- 7"
36	36750	40170	43610	47060	50530	54010	57500	**59810**			20'- 8"
37	37460	40970	44490	48030	51590	55160	58740	**61490**			20'- 9"
38	38160	41750	45360	48990	52640	56300	59970	**63220**			20'-11"
39	38850	42520	46220	49940	53670	57420	61180	**64900**			21'- 0"
40	39520	43280	47060	50860	54690	58530	62380	66250	**66590**		21'- 1"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"		
6121										12'- 9"	5
7472										13'- 1"	6
8870										13'- 5"	7
10310										13'- 9"	8
11810										14'- 0"	9
12960	**13350**									14'- 5"	10
14140	**14950**									14'- 9"	11
15310	16500	**16600**								15'- 1"	12
16460	17750	**18300**								15'- 5"	13
17590	18980	**20070**								15'- 9"	14
18710	20200	21690	**21890**							16'- 2"	15
19800	21390	22980	**23770**							16'- 6"	16
20890	22570	24250	**25720**							16'-10"	17
21950	23730	25510	27300	**27740**						17'- 3"	18
23000	24870	26750	28640	**29820**						17'- 8"	19
24030	26000	27980	29960	31940	**31970**					18'- 1"	20
25040	27110	29180	31260	33340	**34190**					18'- 5"	21
26040	28200	30370	32550	34720	**35980**					18'- 6"	22
27020	29280	31550	33820	36090	**37700**					18'- 8"	23
27990	30350	32710	35070	37440	**39410**					18'-10"	24
28940	31390	33850	36310	38770	**41120**					18'-11"	25
29880	32420	34980	37530	40090	**42820**					19'- 0"	26
30800	33440	36090	38740	41390	44060	**44540**				19'- 2"	27
31710	34440	37180	39930	42680	45440	**46240**				19'- 3"	28
32610	35430	38260	41100	43950	46800	**47940**				19'- 5"	29
33490	36400	39330	42260	45210	48150	**49640**				19'- 6"	30
34360	37360	40380	43410	46450	49490	**51320**				19'- 7"	31
35210	38310	41420	44540	47670	50810	**53030**				19'- 8"	32
36050	39240	42440	45660	48880	52110	**54730**				19'-10"	33
36880	40160	43450	46760	50080	53400	**56420**				19'-11"	34
37690	41060	44450	47850	51260	54670	**58120**				20'- 0"	35
38490	41950	45430	48920	52420	55930	59450	**59810**			20'- 1"	36
39280	42830	46400	49980	53580	57180	60790	**61490**			20'- 2"	37
40060	43700	47360	51030	54710	58410	62120	**63220**			20'- 4"	38
40820	44550	48300	52060	55840	59630	63420	**64900**			20'- 5"	39
41570	45390	49230	53080	56950	60830	64720	**66590**			20'- 6"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-26

120" 120"

BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	
5	**6330**										**13'- 5"**
6	**7723**										**13'-10"**
7	9034	**9161**									**14'- 2"**
8	10210	**10650**									**14'- 7"**
9	11350	**12180**									**14'-11"**
10	12470	13460	**13760**								**15'- 3"**
11	13560	14660	**15400**								**15'- 8"**
12	14630	15820	17010	**17090**							**16'- 1"**
13	15680	16960	18240	**18830**							**16'- 5"**
14	16690	18070	19460	**20630**							**16'-10"**
15	17690	19160	20640	22120	**22490**						**17'- 3"**
16	18660	20230	21800	23380	**24410**						**17'- 8"**
17	19610	21270	22940	24620	26290	**26390**					**18'- 1"**
18	20540	22290	24060	25820	27600	**28430**					**18'- 6"**
19	21440	23290	25150	27010	28880	**30540**					**18'-11"**
20	22320	24270	26220	28180	30140	32100	**32730**				**19'- 4"**
21	23190	25220	27270	29320	31370	33430	**34980**				**19'- 9"**
22	24030	26160	28300	30440	32590	34740	36900	**37240**			**20'- 2"**
23	24860	27070	29300	31540	33780	36030	38280	**39040**			**20'- 4"**
24	25660	27970	30290	32610	34950	37290	39640	**40820**			**20'- 6"**
25	26450	28840	31250	33670	36100	38530	40970	**42600**			**20'- 8"**
26	27210	29700	32200	34710	37220	39750	42280	**44370**			**20'-10"**
27	27960	30540	33120	35720	38330	40950	43580	**46140**			**21'- 0"**
28	28700	31360	34030	36720	39420	42130	44840	47570	**47900**		**21'- 1"**
29	29410	32160	34920	37700	40490	43290	46100	48910	**49660**		**21'- 3"**
30	30110	32940	35790	38660	41540	44420	47320	50230	**51430**		**21'- 5"**
31	30790	33710	36640	39600	42560	45540	48530	51530	**53200**		**21'- 7"**
32	31460	34460	37480	40520	43580	46640	49720	52810	**54960**		**21'- 8"**
33	32110	35190	38300	41420	44570	47720	50890	54070	**56710**		**21'-10"**
34	32740	35910	39100	42310	45540	48780	52040	55310	**58470**		**21'-11"**
35	33360	36610	39890	43180	46500	49830	53180	56530	59900	**60240**	**22'- 1"**
36	33970	37300	40660	44040	47440	50850	54290	57740	61200	**61990**	**22'- 3"**
37	34560	37970	41410	44870	48360	51860	55380	58920	62470	**63740**	**22'- 4"**
38	35140	38630	42150	45690	49260	52850	56460	60080	63720	**65510**	**22'- 6"**
39	35710	39270	42870	46500	50150	53830	57520	61230	64960	**67250**	**22'- 7"**
40	36260	39900	43580	47290	51020	54780	58560	62360	66170	**69040**	**22'- 9"**

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"		
6330										**13'- 5"**	5
7723										**13'- 9"**	6
9100	**9161**									**14'- 1"**	7
10290	**10650**									**14'- 5"**	8
11460	**12180**									**14'-10"**	9
12600	13600	**13760**								**15'- 2"**	10
13720	14810	**15400**								**15'- 6"**	11
14810	16000	**17090**								**15'-11"**	12
15880	17170	18460	**18830**							**16'- 3"**	13
16930	18320	19700	**20630**							**16'- 8"**	14
17960	19440	20920	22400	**22490**						**17'- 1"**	15
18960	20540	22120	23700	**24410**						**17'- 6"**	16
19950	21620	23290	24970	**26390**						**17'-10"**	17
20910	22670	24440	26220	27990	**28430**					**18'- 3"**	18
21850	23710	25570	27440	29310	**30540**					**18'- 8"**	19
22770	24720	26680	28650	30610	32580	**32730**				**19'- 1"**	20
23670	25720	27770	29830	31890	33960	**34980**				**19'- 6"**	21
24560	26700	28840	30990	33150	35310	**37240**				**19'-11"**	22
25420	27650	29890	32140	34390	36640	38900	**39040**			**20'- 1"**	23
26270	28590	30920	33260	35600	37960	40310	**40820**			**20'- 3"**	24
27100	29510	31930	34360	36800	39240	41690	**42600**			**20'- 5"**	25
27910	30410	32920	35450	37980	40520	43060	**44370**			**20'- 6"**	26
28700	31290	33900	36510	39140	41770	44400	**46140**			**20'- 8"**	27
29480	32160	34850	37560	40270	43000	45730	**47900**			**20'-10"**	28
30240	33010	35790	38590	41390	44210	47030	**49660**			**20'-11"**	29
30980	33840	36710	39690	42490	45400	48320	51240	**51430**		**21'- 1"**	30
31710	34650	37620	40590	43580	46580	49580	52600	**53200**		**21'- 2"**	31
32420	35450	38500	41560	44640	47730	50830	53940	**54960**		**21'- 4"**	32
33120	36240	39370	42520	45690	48870	52060	55260	**56710**		**21'- 5"**	33
33800	37000	40220	43460	46720	49990	53270	56560	**58470**		**21'- 7"**	34
34470	37760	41060	44390	47730	51090	54460	57840	**60240**		**21'- 8"**	35
35130	38490	41880	45300	48730	52170	55630	59100	**61990**		**21'-10"**	36
35770	39220	42690	46190	49710	53240	56790	60350	**63740**		**21'-11"**	37
36390	39920	43480	47070	50670	54290	57930	61580	65240	**65510**	**22'- 1"**	38
37010	40620	44260	47930	51620	55330	59050	62790	66540	**67250**	**22'- 2"**	39
37610	41300	45020	48780	52550	56340	60160	63990	67830	**69040**	**22'- 4"**	40

Table B-26 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRAN-SITION WIDTH
	14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	
5	**6330**										**13'- 4"**
6	**7723**										**13'- 7"**
7	**9161**										**13'-11"**
8	10410	**10650**									**14'- 4"**
9	11600	**12180**									**14'- 8"**
10	12780	**13760**									**15'- 0"**
11	13930	15020	**15400**								**15'- 4"**
12	15060	16250	**17090**								**15'- 8"**
13	16170	17460	18750	**18830**							**16'- 1"**
14	17260	18650	20030	**20630**							**16'- 5"**
15	18330	19810	21300	**22490**							**16'-10"**
16	19380	20960	22540	24130	**24400**						**17'- 3"**
17	20410	22090	23770	25450	**26390**						**17'- 7"**
18	21420	23190	24970	26750	**28430**						**18'- 0"**
19	22410	24280	26150	28030	29910	**30540**					**18'- 4"**
20	23390	25350	27320	29290	31270	**32730**					**18'- 9"**
21	24340	26400	28470	30530	32600	34680	**34980**				**19'- 2"**
22	25280	27440	29600	31760	33920	36090	**37240**				**19'- 7"**
23	26200	28450	30700	32960	35220	37490	**39040**				**19'- 8"**
24	27110	29450	31800	34150	36510	38870	**40820**				**19'-10"**
25	28000	30430	32870	35320	37770	40230	**42600**				**20'- 0"**
26	28870	31400	33930	36470	39020	41570	44120	**44370**			**20'- 1"**
27	29730	32340	34970	37600	40240	42890	45540	**46140**			**20'- 3"**
28	30570	33270	35990	38720	41450	44190	46940	**47900**			**20'- 4"**
29	31390	34190	37000	39820	42650	45480	48320	**49660**			**20'- 6"**
30	32200	35090	37990	40900	43820	46750	49680	**51430**			**20'- 7"**
31	33000	35970	38960	41970	44980	48000	51030	**53200**			**20'- 9"**
32	33780	36840	39920	43020	46120	49240	52360	**54960**			**20'-10"**
33	34540	37700	40870	44050	47250	50450	53670	**56710**			**20'-11"**
34	35290	38540	41800	45070	48360	51650	54960	58280	**58470**		**21'- 1"**
35	36030	39360	42710	46070	49450	52840	56240	59650	**60240**		**21'- 2"**
36	36750	40170	43610	47060	50530	54010	57500	61000	**61990**		**21'- 3"**
37	37460	40970	44490	48030	51590	55160	58740	62340	**63740**		**21'- 5"**
38	38160	41750	45360	48990	52640	56300	59970	63660	**65510**		**21'- 6"**
39	38850	42520	46220	49940	53670	57420	61180	64960	**67250**		**21'- 7"**
40	39520	43280	47060	50860	54690	58530	62380	66250	**69040**		**21'- 9"**

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRAN-SITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
14'-0"	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"		
6330										**13'- 2"**	5
7723										**13'- 6"**	6
9161										**13'-10"**	7
10520	**10650**									**14'- 2"**	8
11750	**12180**									**14'- 6"**	9
12960	**13760**									**14'-10"**	10
14140	15240	**15400**								**15'- 2"**	11
15310	16500	**17090**								**15'- 6"**	12
16460	17750	**18830**								**15'-10"**	13
17590	18990	20380	**20630**							**16'- 2"**	14
18710	20200	21690	**22490**							**16'- 6"**	15
19800	21390	22980	**24410**							**16'-11"**	16
20890	22570	24250	25940	**26390**						**17'- 4"**	17
21950	23730	25510	27300	**28430**						**17'- 8"**	18
23000	24870	26750	28640	**30540**						**18'- 0"**	19
24030	26000	27980	29960	31940	**32730**					**18'- 5"**	20
25040	27110	29180	31260	33340	**34980**					**18'-10"**	21
26040	28200	30370	32550	34720	36900	**37240**				**19'- 2"**	22
27020	29280	31550	33820	36090	38360	**39040**				**19'- 4"**	23
27990	30350	32710	35070	37440	39810	**40820**				**19'- 5"**	24
28940	31390	33850	36310	38770	41240	**42600**				**19'- 7"**	25
29880	32420	34980	37530	40090	42660	**44370**				**19'- 8"**	26
30800	33440	36090	38740	41390	44060	**46140**				**19'-10"**	27
31710	34440	37180	39930	42680	45440	**47900**				**19'-11"**	28
32610	35430	38260	41100	43950	46800	**49660**				**20'- 0"**	29
33490	36400	39330	42260	45210	48150	51100	**51430**			**20'- 1"**	30
34360	37360	40380	43410	46450	49490	52530	**53200**			**20'- 3"**	31
35210	38310	41420	44540	47670	50810	53950	**54960**			**20'- 4"**	32
36050	39240	42440	45660	48880	52110	55350	**56710**			**20'- 5"**	33
36880	40160	43450	46760	50080	53400	56730	**58470**			**20'- 6"**	34
37690	41060	44450	47850	51260	54670	58100	**60240**			**20'- 8"**	35
38490	41950	45430	48920	52420	55930	59450	**61990**			**20'- 9"**	36
39280	42830	46400	49980	53580	57180	60790	**63740**			**20'-10"**	37
40060	43700	47360	51030	54710	58410	62120	**65510**			**20'-11"**	38
40820	44550	48300	52060	55840	59630	63420	**67250**			**21'- 0"**	39
41570	45390	49230	53080	56950	60830	64720	68620	**69040**		**21'- 1"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-27

126" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 126"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kµ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	
5	**6619**										14'- 0"
6	**8068**										14'- 5"
7	**9563**										14'- 9"
8	11000	**11100**									15'- 1"
9	12250	**12690**									15'- 6"
10	13460	**14330**									15'-10"
11	14660	15750	**16020**								16'- 3"
12	15820	17010	**17760**								16'- 7"
13	16960	18240	**19560**								17'- 0"
14	18070	19460	20840	**21410**							17'- 5"
15	19160	20640	22120	**23320**							17'-10"
16	20230	21800	23380	24960	**25280**						18'- 3"
17	21270	22940	24620	26290	**27310**						18'- 7"
18	22290	24060	25820	27600	29370	**29400**					19'- 1"
19	23290	25150	27010	28880	30750	**31560**					19'- 5"
20	24270	26220	28180	30140	32100	**33780**					19'-10"
21	25220	27270	29320	31370	33430	35500	**36070**				20'- 3"
22	26160	28300	30440	32590	34740	36900	**38440**				20'- 9"
23	27070	29300	31540	33780	36030	38280	40530	**40860**			21'- 2"
24	27970	30290	32610	34950	37290	39640	41990	**42740**			21'- 4"
25	28840	31250	33670	36100	38530	40970	43420	**44620**			21'- 6"
26	29700	32200	34710	37220	39750	42280	44820	**46490**			21'- 8"
27	30540	33120	35720	38330	40950	43580	46210	**48340**			21'- 9"
28	31360	34030	36720	39420	42130	44840	47570	**50210**			21'-11"
29	32160	34920	37700	40490	43290	46100	48910	51730	**52060**		22'- 2"
30	32940	35790	38660	41540	44420	47320	50230	53150	**53910**		22'- 4"
31	33710	36640	39600	42560	45540	48530	51530	54540	**55770**		22'- 5"
32	34460	37480	40520	43580	46640	49720	52810	55910	**57630**		22'- 7"
33	35190	38300	41420	44570	47720	50890	54070	57260	**59470**		22'- 8"
34	35910	39100	42310	45540	48780	52040	55310	58590	**61320**		22'-10"
35	36610	39890	43180	46500	49830	53180	56530	59900	**63160**		22'-11"
36	37300	40600	44040	47440	50850	54290	57740	61200	64670	**64990**	23'- 1"
37	37970	41410	44870	48360	51860	55380	58920	62470	66030	**66840**	23'- 2"
38	38630	42150	45690	49260	52850	56460	60080	63720	67370	**68710**	23'- 4"
39	39270	42870	46500	50150	53830	57520	61230	64960	68700	**70540**	23'- 5"
40	39900	43580	47290	51020	54780	58560	62360	66170	70000	**72370**	23'- 8"

B SATURATED TOP SOIL Kµ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"		
6619										14'- 0"	5
8068										14'- 4"	6
9563										14'- 8"	7
11100										15'- 0"	8
12350	**12690**									15'- 5"	9
13600	**14330**									15'- 9"	10
14810	15900	**16020**								16'- 1"	11
16000	17190	**17760**								16'- 6"	12
17170	18460	**19560**								16'-10"	13
18320	19700	21090	**21410**							17'- 3"	14
19440	20920	22400	**23320**							17'- 8"	15
20540	22120	23700	**25280**							18'- 0"	16
21620	23290	24970	26650	**27310**						18'- 5"	17
22670	24440	26220	27990	**29400**						18'- 9"	18
23710	25570	27440	29310	31190	**31560**					19'- 3"	19
24720	26680	28650	30610	32580	**33780**					19'- 7"	20
25720	27770	29830	31890	33960	**36070**					20'- 0"	21
26700	28840	30990	33150	35310	37480	**38440**				20'- 5"	22
27650	29890	32140	34390	36640	38900	**40860**				20'-11"	23
28590	30920	33260	35600	37960	40310	42670	**42740**			21'- 1"	24
29510	31930	34360	36800	39240	41690	44150	**44620**			21'- 2"	25
30410	32920	35450	37980	40520	43060	45610	**46490**			21'- 4"	26
31290	33900	36510	39140	41770	44400	47040	**48340**			21'- 6"	27
32160	34850	37560	40270	43000	45730	48460	**50210**			21'- 7"	28
33010	35790	38590	41390	44210	47030	49860	**52060**			21'- 9"	29
33840	36710	39600	42490	45400	48320	51240	**53910**			21'-11"	30
34650	37620	40590	43580	46580	49580	52600	**55770**			22'- 0"	31
35450	38500	41560	44640	47730	50830	53940	57050	**57630**		22'- 3"	32
36240	39370	42520	45690	48870	52060	55260	58460	**59470**		22'- 4"	33
37000	40220	43460	46720	49990	53270	56560	59860	**61320**		22'- 6"	34
37760	41060	44390	47730	51090	54460	57840	61230	**63160**		22'- 7"	35
38490	41880	45300	48730	52710	55630	59100	62590	**64990**		22'- 8"	36
39220	42690	46190	49710	53240	56790	60350	63920	**66840**		22'-10"	37
39920	43480	47070	50670	54290	57930	61580	65240	**68710**		22'-11"	38
40620	44260	47930	51620	55330	59050	62790	66540	70310	**70540**	23'- 1"	39
41300	45020	48780	52550	56340	60160	63990	67830	71680	**72370**	23'- 2"	40

Table B-27 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	
5	**6619**										**13'-11"**
6	**8068**										**14'- 2"**
7	**9563**										**14'- 6"**
8	**11100**										**14'-10"**
9	12500	**12690**									**15'- 2"**
10	13770	**14330**									**15'- 7"**
11	15020	**16020**									**15'-11"**
12	16250	17440	**17760**								**16'- 3"**
13	17460	18750	**19560**								**16'- 7"**
14	18650	20030	**21410**								**17'- 0"**
15	19810	21300	22790	**23320**							**17'- 4"**
16	20960	22540	24130	**25280**							**17'- 9"**
17	22090	23770	25450	27130	**27310**						**18'- 1"**
18	23190	24970	26750	28530	**29400**						**18'- 6"**
19	24280	26150	28030	29910	**31560**						**18'-10"**
20	25350	27320	29290	31270	33240	**33780**					**19'- 4"**
21	26400	28470	30530	32600	34680	**36070**					**19'- 8"**
22	27440	29600	31760	33920	36090	38270	**38440**				**20'- 1"**
23	28450	30700	32960	35220	37490	39760	**40860**				**20'- 5"**
24	29450	31800	34150	36510	38870	41230	**42740**				**20'- 8"**
25	30430	32870	35320	37770	40230	42690	**44620**				**20'-10"**
26	31400	33930	36470	39020	41570	44120	**46490**				**20'-11"**
27	32340	34970	37600	40240	42890	45540	48200	**48340**			**21'- 1"**
28	33270	35990	38720	41450	44190	46940	49690	**50210**			**21'- 2"**
29	34190	37000	39820	42650	45480	48320	51160	**52060**			**21'- 4"**
30	35090	37990	40900	43820	46750	49680	52620	**53910**			**21'- 5"**
31	35970	38960	41970	44980	48000	51030	54060	**55770**			**21'- 7"**
32	36840	39920	43020	46120	49240	52360	55480	**57630**			**21'- 8"**
33	37700	40870	44050	47250	50450	53670	56890	**59470**			**21'- 9"**
34	38540	41800	45070	48360	51650	54960	58280	**61320**			**21'-11"**
35	39360	42710	46070	49450	52840	56240	59650	**63160**			**22'- 0"**
36	40170	43610	47060	50530	54010	57500	61000	64510	**64990**		**22'- 2"**
37	40970	44490	48030	51590	55160	58740	62340	65940	**66840**		**22'- 3"**
38	41750	45360	48990	52640	56300	59970	63660	67350	**68710**		**22'- 5"**
39	42520	46220	49940	53670	57420	61180	64960	68740	**70540**		**22'- 6"**
40	43280	47060	50860	54690	58530	62380	66250	70120	**72370**		**22'- 7"**

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"		
6619										**13'- 9"**	5
8068										**14'- 1"**	6
9563										**14'- 5"**	7
11100										**14'- 9"**	8
12650	**12690**									**15'- 1"**	9
13950	**14330**									**15'- 5"**	10
15240	**16020**									**15'- 9"**	11
16500	**17760**									**16'- 0"**	12
17750	19050	**19560**								**16'- 5"**	13
18980	20380	**21410**								**16'- 9"**	14
20200	21690	23180	**23320**							**17'- 1"**	15
21390	22980	24570	**25280**							**17'- 5"**	16
22570	24250	25940	**27310**							**17'-10"**	17
23730	25510	27300	29080	**29400**						**18'- 2"**	18
24870	26750	28640	30520	**31560**						**18'- 6"**	19
26000	27980	29960	31940	**33780**						**18'-11"**	20
27110	29180	31260	83340	35420	**36070**					**19'- 4"**	21
28200	30370	32550	34720	36900	**38440**					**19'- 9"**	22
29280	31550	33820	36090	38360	40640	**40860**				**20'- 1"**	23
30350	32710	35070	37440	39810	42190	**42740**				**20'- 3"**	24
31390	33850	36310	38770	41240	43710	**44620**				**20'- 4"**	25
32420	34980	37530	40090	42660	45220	**46490**				**20'- 5"**	26
33440	36090	38740	41390	44060	46720	**48340**				**20'- 8"**	27
34440	37180	39930	42680	45440	48200	**50210**				**20'- 9"**	28
35430	38260	41100	43950	46800	49660	**52060**				**20'-10"**	29
36400	39330	42260	45210	48150	51100	**53910**				**21'- 0"**	30
37360	40380	43410	46450	49490	52530	55590	**55770**			**21'- 1"**	31
38310	41420	44540	47670	50810	53950	57100	**57630**			**21'- 2"**	32
39240	42440	45660	48880	52110	55350	58590	**59470**			**21'- 3"**	33
40160	43450	46760	50080	53400	56730	60070	**61320**			**21'- 4"**	34
41060	44450	47850	51260	54670	58100	61530	**63160**			**21'- 6"**	35
41950	45430	48920	52420	55930	59450	62980	**64990**			**21'- 7"**	36
42830	46400	49980	53580	57180	60790	64410	**66840**			**21'- 8"**	37
43700	47360	51030	54710	58410	62120	65830	**68710**			**21'- 9"**	38
44550	48300	52060	55840	59630	63420	67230	**70540**			**21'-10"**	39
45390	49230	53080	56950	60830	64720	68620	**72370**			**21'-11"**	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-28

132" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 132"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	25'-0"	
5	**6908**										14'- 8"
6	**8414**										14'-11"
7	9731	**9966**									15'- 4"
8	11000	**11560**									15'- 8"
9	12250	13140	**13210**								16'- 1"
10	13460	14460	**14900**								16'- 5"
11	14660	15750	**16640**								16'-10"
12	15820	17010	18200	**18400**							17'- 3"
13	16960	18240	19530	**20290**							17'- 7"
14	18070	19460	20840	**22190**							18'- 0"
15	19160	20640	22120	23600	**24150**						18'- 4"
16	20230	21800	23380	24960	**26170**						18'- 9"
17	21270	22940	24620	26290	27970	**28240**					19'- 2"
18	22290	24060	25820	27600	29370	**30380**					19'- 7"
19	23290	25150	27010	28880	30750	**32580**					19'-11"
20	24270	26220	28180	30140	32100	34070	**34850**				20'- 5"
21	25220	27270	29320	31370	33430	35500	**37180**				20'- 9"
22	26160	28300	30440	32590	34740	36900	39060	**39580**			21'- 3"
23	27070	29300	31540	33780	36030	38280	40530	**42060**			21'- 8"
24	27970	30290	32610	34950	37290	39640	41990	44340	**44600**		22'- 1"
25	28840	31250	33670	36100	38530	40970	43420	45860	**46620**		22'- 4"
26	29700	32200	34710	37220	39750	42280	44820	47360	**48580**		22'- 5"
27	30540	33120	35720	38330	40950	43580	46210	48840	**50540**		22'- 7"
28	31360	34030	36720	39420	42130	44840	47570	50300	**52490**		22'-10"
29	32160	34920	37700	40490	43290	46100	48910	51730	**54440**		23'- 0"
30	32940	35790	38660	41540	44420	47320	50230	53150	56070	**56390**	23'- 1"
31	33710	36640	39600	42560	45540	48530	51530	54540	57550	**58320**	23'- 3"
32	34460	37480	40520	43580	46640	49720	52810	55910	59020	**60260**	23'- 4"
33	35190	38300	41420	44570	47720	50890	54070	57260	60460	**62210**	23'- 7"
34	35910	39100	42310	45540	48780	52040	55310	58590	61880	**64150**	23'- 9"
35	36610	39890	43180	46500	49830	53180	56530	59900	63280	**66080**	23'-10"
36	37300	40660	44040	47440	50850	54290	57740	61200	64670	**68020**	24'- 0"
37	37970	41410	44870	48360	51860	55380	58920	62470	66030	**69930**	24'- 1"
38	38630	42150	45690	49260	52850	56460	60080	63720	67370	**71870**	24'- 2"
39	39270	42870	46500	50150	53830	57520	61230	64960	68700	**73800**	24'- 5"
40	39900	43580	47290	51020	54780	58560	62360	66170	70000	**75770**	24'- 6"

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	25'-0"		
6908										14'- 6"	5
8414										14'-11"	6
9798	**9966**									15'- 3"	7
11090	**11560**									15'- 7"	8
12350	**13210**									16'- 0"	9
13600	14590	**14900**								16'- 3"	10
14810	15900	**16640**								16'- 8"	11
16000	17190	**18440**								17'- 0"	12
17170	18460	19750	**20290**							17'- 5"	13
18320	19700	21090	**22190**							17'- 9"	14
19440	20920	22400	23890	**24150**						18'- 2"	15
20540	22120	23700	25280	**26170**						18'- 7"	16
21620	23290	24970	26650	**28240**						18'-11"	17
22670	24440	26220	27990	29770	**30380**					19'- 5"	18
23710	25570	27440	29310	31190	**32580**					19'- 9"	19
24720	26680	28650	30610	32580	34560	**34850**				20'- 2"	20
25720	27770	29830	31890	33960	36030	**37180**				20'- 7"	21
26700	28840	30990	33150	35310	37480	**39580**				21'- 0"	22
27650	29890	32140	34390	36640	38900	41170	**42060**			21'- 5"	23
28590	30920	33260	35600	37960	40310	42670	**44600**			21'- 9"	24
29510	31930	34360	36800	39240	41690	44150	**46620**			22'- 0"	25
30410	32920	35450	37980	40520	43060	45610	48160	**48580**		22'- 2"	26
31290	33900	36510	39140	41770	44400	47040	49690	**50540**		22'- 4"	27
32160	34850	37560	40270	43000	45730	48460	51200	**52490**		22'- 5"	28
33010	35790	38590	41390	44210	47030	49860	52700	**54440**		22'- 7"	29
33840	36710	39600	42490	45400	48320	51240	54170	**56390**		22'- 9"	30
34650	37620	40590	43580	46580	49580	52600	55620	**58320**		22'-11"	31
35450	38500	41560	44640	47730	50830	53940	57050	**60260**		23'- 0"	32
36240	39370	42520	45690	48870	52060	55260	58460	61680	**62210**	23'- 2"	33
37000	40220	43460	46720	49990	53270	56560	59860	63160	**64150**	23'- 3"	34
37760	41060	44390	47730	51090	54460	57840	61230	64630	**66080**	23'- 5"	35
38490	41880	45300	48730	52170	55630	59100	62590	66080	**68020**	23'- 7"	36
39220	42690	46190	49710	53240	56790	60350	63920	67500	**69930**	23'- 8"	37
39920	43480	47070	50670	54290	57930	61580	65240	68920	**71870**	23'-10"	38
40620	44260	47930	51620	55330	59050	62790	66540	70310	**73800**	23'-11"	39
41300	45020	48780	52550	56340	60160	63990	67830	71680	**75770**	24'- 1"	40

Table B-28 Continued

C ORDINARY CLAY Kµ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	25'-0"	
5	**6908**										14'- 5"
6	**8414**										14'- 9"
7	9887	**9966**									15'- 1"
8	11200	**11560**									15'- 5"
9	12500	**13210**									15'- 9"
10	13770	14770	**14900**								16'- 2"
11	15020	16120	**16640**								16'- 6"
12	16250	17440	**18440**								16'-10"
13	17460	18750	20040	**20290**							17'- 2"
14	18650	20030	21420	**22190**							17'- 6"
15	19810	21300	22790	**24150**							17'-11"
16	20960	22540	24130	25710	**26170**						18'- 3"
17	22090	23770	25450	27130	**28240**						18'- 8"
18	23190	24970	26750	28530	**30380**						19'- 0"
19	24280	26150	28030	29910	31790	**32580**					19'- 5"
20	25350	27320	29290	31270	33240	**34850**					19'-10"
21	26400	28470	30530	32600	34680	36750	**37180**				20'- 3"
22	27440	29600	31760	33920	36090	38270	**39580**				20'- 7"
23	28450	30700	32960	35200	37490	39760	42030	**42060**			21'- 1"
24	29450	31800	34150	36510	38870	41230	43600	**44600**			21'- 5"
25	30430	32870	35320	37770	40230	42690	45150	**46620**			21'- 7"
26	31400	33930	36470	39020	41570	44120	46680	**48580**			21'- 8"
27	32340	34970	37600	40240	42890	45540	48200	**50540**			21'-11"
28	33270	35990	38720	41450	44190	46940	49690	**52490**			22'- 0"
29	34190	37000	39820	42650	45480	48320	51160	54020	**54440**		22'- 2"
30	35090	37990	40900	43820	46750	49680	52620	55570	**56390**		22'- 3"
31	35970	38960	41970	44980	48000	51030	54060	57100	**58320**		22'- 5"
32	36840	39920	43020	46120	49240	52360	55480	58620	**60260**		22'- 6"
33	37700	40870	44050	47250	50450	53670	56890	60120	**62210**		22'- 7"
34	38540	41800	45070	48360	51650	54960	58280	61600	**64150**		22'-10"
35	39360	42710	46070	49450	52840	56240	59650	63060	**66080**		22'-11"
36	40170	43610	47060	50530	54010	57500	61000	64510	**68020**		23'- 0"
37	40970	44490	48030	51590	55160	58740	62340	65940	69540	**69930**	23'- 1"
38	41750	45360	48990	52640	56300	59970	63660	67350	71050	**71870**	23'- 2"
39	42520	46220	49940	53670	57420	61180	64960	68740	72540	**73800**	23'- 4"
40	43280	47060	50860	54690	58530	62380	66250	70120	74010	**75770**	23'- 5"

D SATURATED CLAY Kµ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
15'-0"	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	25'-0"		
6908										14'- 4"	5
8414										14'- 8"	6
9966										15'- 0"	7
11320	**11560**									15'- 4"	8
12650	**13210**									15'- 8"	9
13950	**14900**									16'- 0"	10
15240	16330	**16640**								16'- 3"	11
16500	17700	**18440**								16'- 7"	12
17750	19050	**20290**								16'-11"	13
18980	20380	21770	**22190**							17'- 4"	14
20200	21690	23180	**24150**							17'- 8"	15
21390	22980	24570	**26170**							18'- 0"	16
22570	24250	25940	27630	**28240**						18'- 4"	17
23730	25510	27300	29080	**30380**						18'- 9"	18
24870	26750	28640	30520	32400	**32580**					19'- 1"	19
26000	27980	29960	31940	33920	**34850**					19'- 6"	20
27110	29180	31260	33340	35420	**37180**					19'-10"	21
28200	30370	32550	34720	36900	39080	**39580**				20'- 3"	22
29280	31550	33820	36090	38360	40640	**42060**				20'- 7"	23
30350	32710	35070	37440	39810	42190	44560	**44600**			21'- 1"	24
31390	33850	36310	38770	41240	43710	46190	**46620**			21'- 2"	25
32420	34980	37530	40090	42660	45220	47800	**48580**			21'- 4"	26
33440	36090	38740	41390	44060	46720	49390	**50540**			21'- 5"	27
34440	37180	39930	42680	45440	48200	50960	**52490**			21'- 6"	28
35430	38260	41100	43950	46800	49660	52520	**54440**			21'- 8"	29
36400	39330	42260	45210	48150	51100	54060	**56390**			21'- 9"	30
37360	40380	43410	46450	49490	52530	55590	**58320**			21'-11"	31
38310	41420	44540	47670	50810	53950	57100	**60260**			22'- 0"	32
39240	42440	45660	48880	52110	55350	58590	61840	**62210**		22'- 2"	33
40160	43450	46760	50080	53400	56730	60070	63410	**64150**		22'- 3"	34
41060	44450	47850	51260	54670	58100	61530	64970	**66080**		22'- 4"	35
41950	45430	48920	52420	55930	59450	62980	66510	**68020**		22'- 5"	36
42830	46400	49980	53580	57180	60790	64410	68040	**69930**		22'- 6"	37
43700	47360	51030	54710	58410	62120	65830	69550	**71870**		22'- 7"	38
44550	48300	52060	55840	59630	63420	67230	71050	**73800**		22'- 8"	39
45390	49230	53080	56950	60830	64720	68620	72530	**75770**		22'-10"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲*Transition loads* **(bold type)** *and widths based on Kµ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-29

138" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 138"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL   LOADS IN POUNDS PER LINEAR FOOT

A   SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	26'-0"	
5	**7202**										**15'- 3"**
6	**8767**										**15'- 7"**
7	**10380**										**15'-11"**
8	11800	**12031**									**16'- 3"**
9	13140	**13730**									**16'- 8"**
10	14460	15450	**15480**								**17'- 1"**
11	15750	16840	**17280**								**17'- 5"**
12	17010	18200	**19130**								**17'- 9"**
13	18240	19530	20820	**21030**							**18'- 2"**
14	19460	20840	22220	**22990**							**18'- 6"**
15	20640	22120	23600	**25000**							**18'-11"**
16	21800	23380	24960	26540	**27070**						**19'- 4"**
17	22940	24620	26290	27970	**29200**						**19'- 8"**
18	24060	25820	27600	29370	31150	**31380**					**20'- 1"**
19	25150	27010	28880	30750	32620	**33630**					**20'- 7"**
20	26220	28180	30140	32100	34070	**35940**					**21'- 0"**
21	27270	29320	31370	33430	35500	37560	**38320**				**21'- 4"**
22	28300	30440	32590	34740	36900	39060	**40770**				**21'-10"**
23	29300	31540	33780	36030	38280	40530	42790	**43280**			**22'- 3"**
24	30290	32610	34950	37290	39640	41990	44340	**45860**			**22'- 7"**
25	31250	33670	36100	38530	40970	43420	45860	48320	**48520**		**23'- 1"**
26	32200	34710	37220	39750	42280	44820	47360	49910	**50700**		**23'- 3"**
27	33120	35720	38330	40950	43580	46210	48840	51480	**52750**		**23'- 6"**
28	34030	36720	39420	42130	44840	47570	50300	53040	**54800**		**23'- 8"**
29	34920	37700	40490	43290	46100	48910	51730	54560	**56850**		**23'- 9"**
30	35790	38660	41540	44420	47320	50230	53150	56070	**58890**		**23'-11"**
31	36640	39600	42560	45540	48530	51530	54540	57550	60580	**60920**	**24'- 2"**
32	37480	40520	43580	44640	49720	52810	55910	59020	62130	**62940**	**24'- 3"**
33	38300	41420	44570	47720	50890	54070	57260	60460	63670	**64970**	**24'- 5"**
34	39100	42310	45540	48780	52040	55310	58590	61880	65180	**67010**	**24'- 6"**
35	39890	43180	46500	49830	53180	56530	59900	63280	66670	**69040**	**24'- 9"**
36	40660	44040	47440	50850	54290	57740	61200	64670	68150	**71060**	**24'-10"**
37	41410	44870	48360	51860	55380	58920	62470	66030	69600	**73090**	**25'- 0"**
38	42150	45690	49260	52850	56460	60080	63720	67370	71030	**75100**	**25'- 1"**
39	42870	46500	50150	53830	57520	61230	64960	68700	72450	**77130**	**25'- 3"**
40	43580	47290	51020	54780	58560	62360	66170	70000	73840	**79150**	**25'- 5"**

B   SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	26'-0"		
7202										**15'- 1"**	5
8767										**15'- 6"**	6
10380										**15'-10"**	7
11890	**12030**									**16'- 2"**	8
13250	**13730**									**16'- 7"**	9
14590	**15480**									**16'-11"**	10
15900	17000	**17280**								**17'- 3"**	11
17190	18380	**19130**								**17'- 7"**	12
18460	19750	**21030**								**18'- 0"**	13
19700	21090	22480	**22990**							**18'- 4"**	14
20920	22400	23890	**25000**							**18'- 9"**	15
22120	23700	25280	26860	**27070**						**19'- 1"**	16
23290	24970	26650	28330	**29200**						**19'- 6"**	17
24440	26220	27990	29770	**31380**						**19'-11"**	18
25570	27440	29310	31190	33060	**33630**					**20'- 3"**	19
26680	28650	30610	32580	34560	**35940**					**20'- 8"**	20
27770	29830	31890	33960	36030	38100	**38320**				**21'- 2"**	21
28840	30990	33150	35310	37480	39640	**40770**				**21'- 6"**	22
29890	32140	34390	36640	38900	41170	**43280**				**21'-11"**	23
30920	33260	35600	37960	40310	42670	45030	**45860**			**22'- 4"**	24
31930	34360	36800	39240	41690	44150	46600	**48520**			**22'- 9"**	25
32920	35450	37980	40520	43060	45610	48160	**50700**			**23'- 0"**	26
33900	36510	39140	41770	44400	47040	49690	52340	**52750**		**23'- 2"**	27
34850	37560	40270	43000	45730	48460	51200	53950	**54800**		**23'- 3"**	28
35790	38590	41390	44210	47030	49860	52700	55540	**56850**		**23'- 6"**	29
36710	39600	42490	45400	48320	51240	54170	57100	**58890**		**23'- 7"**	30
37620	40590	43580	46580	49580	52600	55620	58650	**60920**		**23'- 9"**	31
38500	41560	44640	47730	50830	53940	57050	60170	**62940**		**23'-10"**	32
39370	42520	45690	48870	52060	55260	58460	61680	64900	**64970**	**24'- 1"**	33
40220	43460	46720	49990	53270	56560	59860	63160	66480	**67010**	**24'- 2"**	34
41060	44390	47730	51090	54460	57840	61230	64630	68040	**69040**	**24'- 4"**	35
41880	45300	48730	52170	55630	59100	62590	66080	69580	**71060**	**24'- 5"**	36
42690	46190	49710	53240	56790	60350	63920	67500	71100	**73090**	**24'- 6"**	37
43480	47070	50670	54290	57930	61580	65240	68920	72600	**75100**	**24'- 9"**	38
44260	47930	51620	55330	59050	62790	66540	70310	74080	**77130**	**24'-10"**	39
45020	48780	52550	56340	60160	63990	67830	71680	75550	**79150**	**24'-11"**	40

Table B-29 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	26'-0"	
5	**7202**										15'- 0"
6	**8767**										15'- 4"
7	**10380**										15'- 8"
8	**12030**										16'- 0"
9	13400	**13730**									16'- 4"
10	14770	**15480**									16'- 9"
11	16120	**17280**									17'- 0"
12	17440	18640	**19130**								17'- 5"
13	18750	20040	**21030**								17'- 9"
14	20030	21420	22820	**22990**							18'- 1"
15	21300	22790	24280	**25000**							18'- 6"
16	22540	24130	25710	**27070**							18'-10"
17	23770	25450	27130	28820	**29200**						19'- 3"
18	24970	26750	28530	80310	**31380**						19'- 7"
19	26150	28030	29910	31790	**33630**						20'- 0"
20	27320	29290	31270	33240	35220	**35940**					20'- 5"
21	28470	30530	32600	34680	36750	**38320**					20'- 9"
22	29600	31760	33920	36090	38270	40440	**40770**				21'- 2"
23	30700	32960	35220	37490	39760	42030	**43280**				21'- 6"
24	31800	34150	36510	38870	41230	43600	**45860**				21'-11"
25	32870	35320	37770	40230	42690	45150	47620	**48520**			22'- 5"
26	33930	36470	39020	41570	14120	46680	49250	**50700**			22'- 7"
27	34970	37600	40240	42890	45540	48200	50860	**52750**			22'- 8"
28	35990	38720	41450	44190	46940	49690	52440	**54800**			22'-11"
29	37000	39820	42650	45480	48320	51160	54020	**56850**			23'- 0"
30	37990	40900	43820	46750	49680	52620	55570	58520	**58890**		23'- 1"
31	38960	41970	44980	48000	51030	54060	57100	60150	**60920**		23'- 3"
32	39920	43020	46120	49240	52360	55480	58620	61760	**62940**		23'- 4"
33	40870	44050	47250	50450	53670	56890	60120	63350	**64970**		23'- 6"
34	41800	45070	48360	51650	54960	58280	61600	64920	**67010**		23'- 8"
35	42710	46070	49450	52840	56240	59650	63060	66480	**69040**		23'- 9"
36	43610	47060	50530	54010	57500	61000	64510	68020	**71060**		23'-10"
37	44490	48030	51590	55160	58740	62340	65940	69540	**73090**		23'-11"
38	45360	48990	52640	56300	59970	63660	67350	71050	74760	**75100**	24'- 1"
39	46220	49940	53670	57420	61180	64980	68740	72540	76340	**77130**	24'- 3"
40	47060	50860	54690	58530	62380	66250	70120	74010	77900	**79150**	24'- 4"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
16'-0"	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	26'-0"		
7202										14'-11"	5
8767										15'- 3"	6
10380										15'- 7"	7
12030										15'-11"	8
13540	**13730**									16'- 3"	9
14950	**15480**									16'- 6"	10
16330	**17280**									16'-10"	11
17700	18890	**19130**								17'- 2"	12
19050	20340	**21030**								17'- 6"	13
20380	21770	**22990**								17'-10"	14
21690	23180	24670	**25000**							18'- 2"	15
22980	24570	26160	**27070**							18'- 7"	16
24250	25940	27630	**29200**							18'-11"	17
25510	27300	29080	30870	**31380**						19'- 3"	18
26750	28640	30520	32400	**33630**						19'- 7"	19
27980	29960	31940	33920	**35940**						20'- 0"	20
29180	31260	33340	35420	37500	**38320**					20'- 5"	21
30370	32550	34720	36900	39080	**40770**					20'- 9"	22
31550	33820	36090	38360	40640	42920	**43280**				21'- 2"	23
32710	35070	37440	39810	42190	44560	**45860**				21'- 6"	24
33850	36310	38770	41240	43710	46190	**48520**				21'-11"	25
34980	37530	40090	42660	45220	47800	50370	**50700**			22'- 1"	26
36090	38740	41390	44060	46720	49390	52060	**52750**			22'- 3"	27
37180	39930	42680	45440	48200	50960	53730	**54800**			22'- 5"	28
38260	41100	43950	46800	49660	52520	55380	**56850**			22'- 6"	29
39330	42260	45210	48150	51100	54060	57020	**58890**			22'- 7"	30
40380	43410	46450	49490	52530	55590	58640	**60920**			22'- 8"	31
41420	44540	47670	50810	53950	57100	60250	**62940**			22'-11"	32
42440	45660	48880	52110	55350	58590	61840	**64970**			23'- 0"	33
43450	46760	50080	53400	56730	60070	63410	66760	**67010**		23'- 1"	34
44450	47850	51260	54670	58100	61530	64970	68410	**69040**		23'- 2"	35
45430	48920	52420	55930	59450	62980	66510	70050	**71060**		23'- 3"	36
46400	49980	53580	57180	60790	64410	68040	71670	**73090**		23'- 4"	37
47360	51030	54710	58410	62120	65830	69550	73280	**75100**		23'- 6"	38
48300	52060	55840	59630	63420	67230	71050	74870	**77130**		23'- 7"	39
49230	53080	56950	60830	64720	68620	72530	76440	**79150**		23'- 8"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

▲Transition loads **(bold type)** *and widths based on $K\mu—0.19$, $r_{sd}p—0.5$ in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-30

144" BACKFILL LOADS ON CIRCULAR PIPE IN TRENCH INSTALLATION 144"

*100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL LOADS IN POUNDS PER LINEAR FOOT

A SAND AND GRAVEL Kμ'—0.165

HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH
	17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	25'-0"	26'-0"	
5	**7491**										**15'- 9"**
6	**9113**										**16'- 1"**
7	**10780**										**16'- 6"**
8	**12490**										**16'-10"**
9	14040	**14250**									**17'- 3"**
10	15450	**16050**									**17'- 8"**
11	16840	**17910**									**18'- 0"**
12	18200	19390	**19810**								**18'- 4"**
13	19530	20820	**21770**								**18'- 9"**
14	20840	22220	23610	**23780**							**19'- 2"**
15	22120	23600	25090	**25840**							**19'- 6"**
16	23380	24960	26540	**27960**							**19'-11"**
17	24620	26290	27970	29650	**30140**						**20'- 4"**
18	25820	27600	29370	31150	**32370**						**20'- 8"**
19	27010	28880	30750	32620	34490	**34670**					**21'- 1"**
20	28180	30140	32100	34070	36040	**37030**					**21'- 5"**
21	29320	31370	33430	35500	37560	**39450**					**22'- 0"**
22	30440	32590	34740	36900	39060	41220	**41940**				**22'- 4"**
23	31540	33780	36030	38280	40530	42790	**44490**				**22'- 9"**
24	32610	34950	37290	39640	41990	44340	46700	**47120**			**23'- 2"**
25	33670	36100	38530	40970	43420	45860	48320	**49810**			**23'- 7"**
26	34710	37220	39750	42280	44820	47360	49910	52460	**52580**		**24'- 1"**
27	35720	38330	40950	43580	46210	48840	51480	54130	**54910**		**24'- 3"**
28	36720	39420	42130	44840	47570	50300	53040	55780	**57050**		**24'- 6"**
29	37700	40490	43290	46100	48910	51730	54560	57400	**59190**		**24'- 7"**
30	38660	41540	44420	47320	50120	53150	56070	59000	**61320**		**24'- 9"**
31	39600	42560	45540	48530	51530	54540	57550	60580	**63440**		**25'- 0"**
32	40520	43580	46640	49720	52810	55910	59020	62130	65250	**65580**	**25'- 1"**
33	41420	44570	47720	50890	54070	57260	60460	63670	66880	**67690**	**25'- 3"**
34	42310	45540	48780	52040	55310	58590	61880	65180	68490	**69810**	**25'- 5"**
35	43180	46500	49830	53180	56530	59900	63280	66670	70070	**71930**	**25'- 7"**
36	44040	47440	50850	54290	55740	61200	64670	68150	71640	**74050**	**25'- 8"**
37	44870	48360	51860	55380	58920	62470	66030	69600	73180	**76160**	**25'- 9"**
38	45690	49260	52850	56460	60080	63720	67370	71030	74700	**78280**	**26'- 0"**
39	46500	50150	53830	57520	61230	64960	68700	72450	76210	**80380**	**26'- 1"**
40	47290	51020	54780	58560	62360	66170	70000	73840	77690	**82500**	**26'- 2"**

B SATURATED TOP SOIL Kμ'—0.150

TRENCH WIDTH AT TOP OF PIPE										▲TRANSITION WIDTH	HEIGHT OF BACKFILL **H** ABOVE TOP OF PIPE, FEET
17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	25'-0"	26'-0"		
7491										**15'- 9"**	5
9113										**16'- 1"**	6
10780										**16'- 5"**	7
12490										**16'- 9"**	8
14150	**14250**									**17'- 1"**	9
15580	**16050**									**17'- 6"**	10
17000	**17910**									**17'-10"**	11
18380	19580	**19810**								**18'- 2"**	12
19750	21040	**21770**								**18'- 7"**	13
21090	22480	**23780**								**18'-11"**	14
22400	23890	25380	**25840**							**19'- 3"**	15
23700	25280	26860	**27960**							**19'- 8"**	16
24970	26650	28330	30010	**30140**						**20'- 1"**	17
26220	27990	29770	31550	**32370**						**20'- 5"**	18
27440	29310	31190	33060	**34670**						**20'-10"**	19
28650	30610	32580	34560	36530	**37030**					**21'- 3"**	20
29830	31890	33960	36030	38100	**39450**					**21'- 8"**	21
30990	33150	35310	37480	39640	41810	**41940**				**22'- 1"**	22
32140	34390	36640	38900	41170	43430	**44490**				**22'- 6"**	23
33260	35600	37960	40310	42670	45030	**47120**				**22'-10"**	24
34360	36800	39240	41690	44150	46600	49070	**49810**			**23'- 3"**	25
35450	37980	40520	43060	45610	48160	50720	**52580**			**23'- 9"**	26
36510	39140	41770	44400	47040	49690	52340	**54910**			**24'- 0"**	27
37560	40270	43000	45730	48460	51200	53950	56700	**57050**		**24'- 1"**	28
38590	41390	44210	47030	49860	52700	55540	58380	**59190**		**24'- 3"**	29
39600	42490	45400	48320	51240	54170	57100	60040	**61320**		**24'- 6"**	30
40590	43580	46580	49580	52600	55620	58650	61680	**63440**		**24'- 7"**	31
41560	44640	47730	50830	53940	57050	60170	63300	**65580**		**24'- 8"**	32
42520	45690	48870	52060	52260	58460	61680	64900	**67690**		**24'-11"**	33
43460	46720	49990	53270	56560	59860	63160	66480	**69810**		**25'- 0"**	34
44390	47730	51090	54460	57840	61230	64630	68040	71450	**71930**	**25'- 2"**	35
45300	48730	52170	55630	59100	62590	66080	69580	73080	**74050**	**25'- 3"**	36
46190	49710	53240	56790	60350	63920	67500	71100	74690	**76160**	**25'- 5"**	37
47070	50670	54290	57930	61580	65240	68920	72600	76290	**78280**	**25'- 6"**	38
47930	51620	55330	59050	62790	66540	70310	74080	77860	**80380**	**25'- 8"**	39
48780	52550	56340	60160	63990	67830	71680	75550	79420	**82500**	**25'- 9"**	40

Table B-30 Continued

C ORDINARY CLAY Kμ'—0.130

HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET	TRENCH WIDTH AT TOP OF PIPE 17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0'	25'-0"	26'-0"	▲TRANSITION WIDTH
5	**7491**										15'- 7"
6	**9113**										16'- 0"
7	**10780**										16'- 3"
8	**12490**										16'- 7"
9	**14250**										17'- 0"
10	15760	**16050**									17'- 3"
11	17210	**17910**									17'- 8"
12	18640	**19810**									18'- 0"
13	20040	21330	**21770**								18'- 4"
14	21420	22820	**23780**								18'- 8"
15	22790	24280	25760	**25840**							19'- 1"
16	24130	25710	27300	**27960**							19'- 5"
17	25450	27130	28820	**30140**							19'-10"
18	26750	28530	30310	32100	**32370**						20'- 2"
19	28030	29910	31790	33670	**34670**						20'- 7"
20	29290	31270	33240	35220	**37030**						21'- 0"
21	30530	32600	34680	36750	38830	**39450**					21'- 3"
22	31760	33920	36090	38270	40440	**41940**					21'- 8"
23	32960	35220	37490	39760	42030	44300	**44490**				22'- 1
24	34150	36510	38870	41230	43600	45970	**47120**				22'- 6"
25	35320	37770	40230	42690	45150	47620	**49810**				22'-10"
26	36470	39020	41570	44120	46680	49250	51810	**52580**			23'- 3"
27	37600	40240	42890	45540	48200	50860	53520	**54910**			23'- 6"
28	38720	41450	44190	46940	49690	52440	55200	**57050**			23'- 8"
29	39820	42650	45480	48320	51160	54020	56870	**59190**			23'- 9"
30	40900	43820	46750	49680	52620	55570	58520	**61320**			24'- 0"
31	41970	44980	48000	51030	54060	57100	60150	63200	**63440**		24'- 1"
32	43020	46120	49240	52360	55480	58620	61760	64900	**65580**		24'- 2"
33	44050	47250	50450	53670	56890	60120	63350	66590	**67690**		24'- 5"
34	45070	48360	51650	54960	58280	61600	64920	68260	**69810**		24'- 6"
35	46070	49450	52840	56240	59650	63060	66480	69910	**71930**		24'- 7"
36	47060	50530	54010	57500	61000	64510	68020	71540	**74050**		24'- 8"
37	48030	51590	55160	58740	62340	65940	69540	73160	**76160**		24'- 9"
38	48990	52640	56300	59970	63660	67350	71050	74760	**78280**		25'- 0"
39	49940	53670	57420	61180	64960	68740	72540	76340	80150	**80380**	25'- 1"
40	50860	54690	58530	62380	66250	70120	74010	77900	81810	**82500**	25'- 2"

D SATURATED CLAY Kμ'—0.110

TRENCH WIDTH AT TOP OF PIPE 17'-0"	18'-0"	19'-0"	20'-0"	21'-0"	22'-0"	23'-0"	24'-0"	25'-0"	26'-0"	▲TRANSITION WIDTH	HEIGHT OF BACKFILL H ABOVE TOP OF PIPE, FEET
7491										15'- 6"	5
9113										15'-10"	6
10780										16'- 2"	7
12490										16'- 6"	8
14250										16'- 9"	9
15940	**16050**									17'- 1"	10
17430	**17910**									17'- 5"	11
18890	**19810**									17'- 9"	12
20340	21640	**21770**								18'- 1"	13
21770	23160	**23780**								18'- 5"	14
23180	24670	**25840**								18'- 9"	15
24570	26160	27750	**27960**							19'- 2"	16
25940	27630	29320	**30140**							19'- 6"	17
27300	29080	30870	**32370**							19'-10"	18
28640	30520	32400	34290	**34670**						20'- 2"	19
29960	31940	33920	35900	**37030**						20'- 7"	20
31260	33340	35420	37500	**39450**						21'- 0"	21
32550	34720	36900	39080	41260	**41940**					21'- 4"	22
33820	36090	38360	40640	42920	**44490**					21'- 8"	23
35070	37440	39810	42190	44560	46940	**47120**				22'- 1"	24
36310	38770	41240	43710	46190	48660	**49810**				22'- 6"	25
37530	40090	42660	45220	47800	50370	**52580**				22'-10"	26
38740	41390	44060	46720	49390	52060	54730	**54910**			23'- 1"	27
39930	42680	45440	48200	50960	53730	56500	**57050**			23'- 2"	28
41100	43950	46800	49660	52520	55380	58250	**59190**			23'- 4"	29
42260	45210	48150	51100	54060	57020	59980	**61320**			23'- 6"	30
43410	46450	49490	52530	55590	58640	61700	**63440**			23'- 7"	31
44540	47670	50810	53950	57100	60250	63400	**65580**			23'- 8"	32
45660	48880	52110	55350	58590	61840	65090	**67690**			23'- 9"	33
46760	50080	53400	56730	60070	63410	66760	**69810**			23'-11"	34
47850	51260	54670	58100	61530	64970	68410	**71930**			24'- 0"	35
48920	52420	55930	59450	62980	66510	70050	73590	**74050**		24'- 1"	36
49980	53580	57180	60790	64410	68040	71670	75310	**76160**		24'- 3"	37
51030	54710	58410	62120	65830	69550	73280	77010	**78280**		24'- 5"	38
52060	55840	59630	63420	67230	71050	74870	78700	**80380**		24'- 6"	39
53080	56950	60830	64720	68620	72530	76440	80370	**82500**		24'- 7"	40

** For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.*

*▲Transition loads **(bold type)** and widths based on Kμ—0.19, $r_{sd}p$—0.5 in the embankment equation*

Interpolate for intermediate heights of backfill and/or trench widths

Table B-31

DESIGN VALUES OF SETTLEMENT RATIO

Installation and Foundation Condition	Settlement Ratio r_{sd}	
	Usual Range	Design Value
Positive Projecting	0.0 to +1.0	
Rock or Unyielding Soil	+1.0	+1.0
*Ordinary Soil	+0.5 to +0.8	+0.7
Yielding Soil	0.0 to +0.5	+0.3
Zero Projecting		0.0
Negative Projecting	−1.0 to 0.0	
$p' = 0.5$		−0.1
$p' = 1.0$		−0.3
$p' = 1.5$		−0.5
$p' = 2.0$		−1.0
Induced Trench	−2.0 to 0.0	
$p' = 0.5$		−0.5
$p' = 1.0$		−0.7
$p' = 1.5$		−1.0
$p' = 2.0$		−2.0

**The value of the settlement ratio depends on the degree of compaction of the fill material adjacent to the sides of the pipe. With good construction methods resulting in proper compaction of bedding and sidefill materials, a settlement ratio design value of +0.5 is recommended.*

Table B-32

BEDDING FACTORS FOR CIRCULAR PIPE
POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS A BEDDING					CLASS B BEDDING				
	p = 0.9									
	r_{sd} p = 0	0.1	0.3	0.5	1.0	r_{sd} p = 0	0.1	0.3	0.5	1.0
0.5	5.09	5.09	5.09	5.09	5.09	2.92	2.92	2.92	2.92	2.92
1.0	5.09	5.09	5.09	5.09	5.09	2.92	2.92	2.92	2.92	2.92
1.5	5.09	4.83	4.47	4.47	4.47	2.92	2.83	2.71	2.71	2.71
2.0	5.09	4.49	4.35	4.19	4.19	2.92	2.77	2.67	2.61	2.61
3.0	5.09	4.50	4.21	4.06	3.88	2.92	2.72	2.62	2.56	2.50
5.0	4.97	4.37	4.11	3.97	3.81	2.88	2.67	2.58	2.52	2.46
10.0	4.82	4.28	4.04	3.90	3.76	2.83	2.64	2.55	2.50	2.44
15.0	4.77	4.25	4.01	3.88	3.74	2.81	2.63	2.54	2.49	2.43
	p = 0.7									
	r_{sd} p = 0	0.1	0.3	0.5	1.0	r_{sd} p = 0	0.1	0.3	0.5	1.0
0.5	6.03	6.03	6.03	6.03	6.03	2.80	2.80	2.80	2.80	2.87
1.0	5.61	4.79	4.79	4.79	4.79	2.73	2.58	2.58	2.58	2.58
1.5	5.17	4.46	4.19	4.19	4.19	2.65	2.50	2.44	2.44	2.44
2.0	4.98	4.35	4.11	3.99	3.98	2.61	2.48	2.42	2.39	2.39
3.0	4.80	4.25	4.02	3.90	3.75	2.58	2.45	2.40	2.36	2.32
5.0	4.66	4.18	3.95	3.84	3.70	2.55	2.43	2.38	2.35	2.31
10.0	4.57	4.12	3.91	3.79	3.66	2.53	2.42	2.36	2.33	2.30
15.0	4.53	4.09	3.89	3.77	3.65	2.52	2.41	2.36	2.33	2.29
	p = 0.5									
	r_{sd} p = 0	0.1	0.3	0.5	1.0	r_{sd} p = 0	0.1	0.3	0.5	1.0
0.5	4.84	4.54	4.55	4.55	4.55	2.37	2.33	2.33	2.33	2.33
1.0	4.33	3.97	3.97	3.97	3.97	2.31	2.25	2.25	2.25	2.25
1.5	4.18	3.83	3.68	3.68	3.68	2.28	2.23	2.20	2.20	2.20
2.0	4.11	3.79	3.65	3.58	3.58	2.27	2.22	2.20	2.19	2.18
3.0	4.04	3.75	3.62	3.54	3.45	2.26	2.22	2.19	2.18	2.16
5.0	3.99	3.72	3.58	3.51	3.43	2.26	2.21	2.19	2.17	2.16
10.0	3.95	3.69	3.56	3.49	3.41	2.25	2.20	2.18	2.17	2.15
15.0	3.94	3.68	3.56	3.48	3.40	2.25	2.20	2.18	2.17	2.15
	p = 0.3									
	r_{sd} p = 0	0.1	0.3	0.5	1.0	r_{sd} p = 0	0.1	0.3	0.5	1.0
0.5	3.49	3.41	3.41	3.41	3.41	2.11	2.10	2.10	2.10	2.10
1.0	3.40	3.28	3.28	3.28	3.28	2.10	2.08	2.08	2.08	2.08
1.5	3.37	3.25	3.20	3.20	3.20	2.09	2.08	2.07	2.07	2.07
2.0	3.35	3.24	3.20	3.16	3.16	2.09	2.08	2.07	2.07	2.07
3.0	3.34	3.23	3.18	3.15	3.11	2.09	2.08	2.07	2.07	2.06
5.0	3.33	3.22	3.17	3.14	3.11	2.09	2.08	2.07	2.07	2.06
10.0	3.32	3.22	3.17	3.14	3.10	2.09	2.08	2.07	2.07	2.06
15.0	3.32	3.22	3.17	3.14	3.10	2.09	2.08	2.07	2.07	2.06
	ZERO PROJECTING									
	2.83					2.02				

Table B-33

BEDDING FACTORS FOR CIRCULAR PIPE
POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

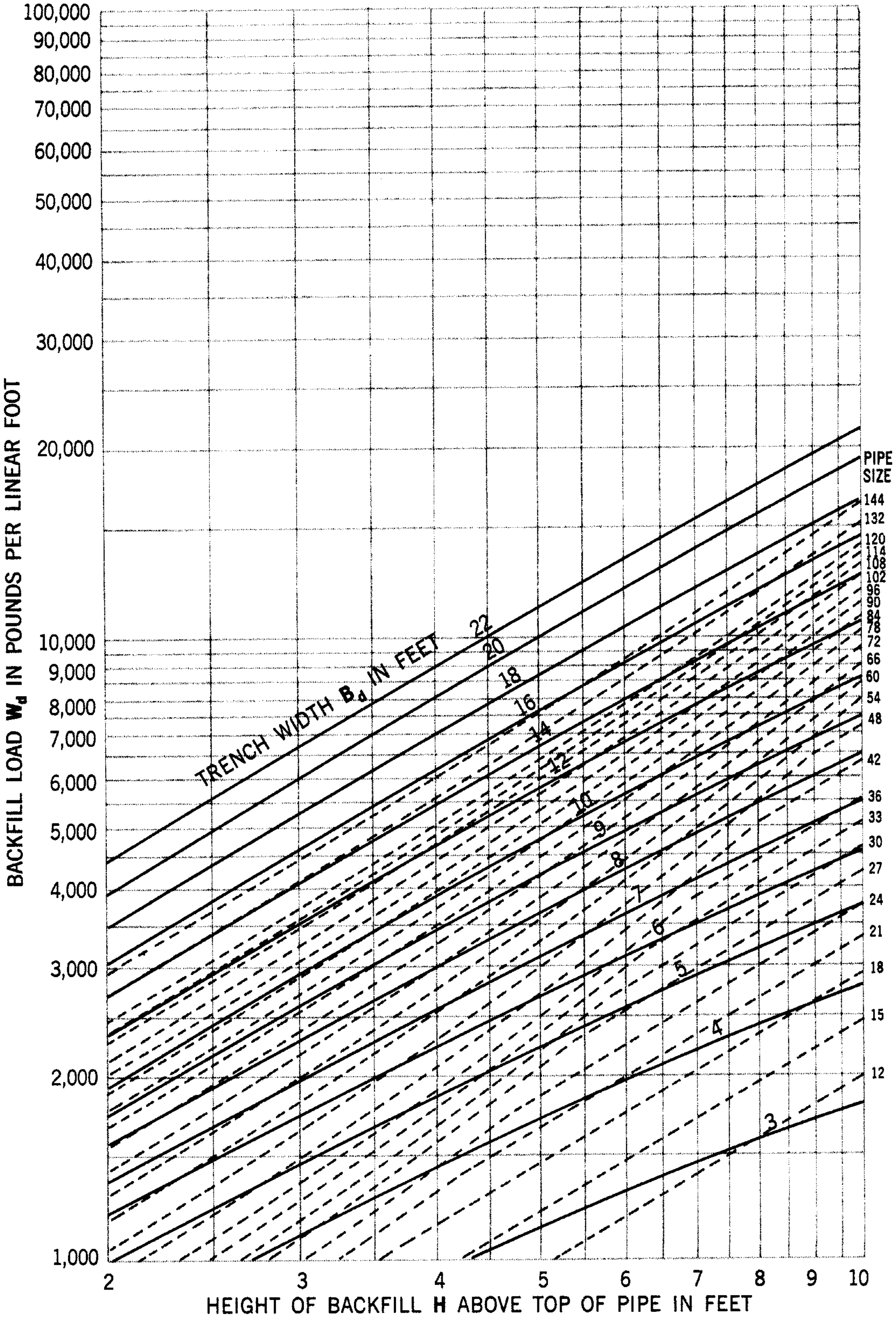
$\frac{H}{B_c}$	CLASS C BEDDING					CLASS D BEDDING				
					p = 0.9					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	2.29	2.29	2.29	2.29	2.29	1.31	1.31	1.31	1.31	1.31
1.0	2.29	2.29	2.29	2.29	2.29	1.31	1.31	1.31	1.31	1.31
1.5	2.29	2.26	2.16	2.16	2.16	1.31	1.29	1.27	1.27	1.27
2.0	2.29	2.20	2.14	2.10	2.10	1.31	1.28	1.26	1.24	1.24
3.0	2.29	2.17	2.10	2.07	2.02	1.31	1.27	1.24	1.23	1.22
5.0	2.27	2.14	2.08	2.04	2.00	1.30	1.26	1.24	1.22	1.21
10.0	2.24	2.12	2.06	2.03	1.99	1.29	1.25	1.23	1.22	1.20
15.0	2.23	2.10	2.05	2.02	1.98	1.29	1.25	1.23	1.21	1.20
					p = 0.7					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	2.22	2.22	2.22	2.22	2.22	1.28	1.28	1.28	1.28	1.28
1.0	2.18	2.08	2.08	2.08	2.08	1.27	1.24	1.24	1.24	1.24
1.5	2.13	2.03	1.99	1.99	1.99	1.25	1.22	1.20	1.20	1.20
2.0	2.10	2.01	1.97	1.95	1.95	1.24	1.21	1.20	1.19	1.19
3.0	2.08	2.00	1.96	1.94	1.91	1.24	1.21	1.19	1.18	1.17
5.0	2.06	1.98	1.95	1.93	1.90	1.23	1.20	1.19	1.18	1.17
10.0	2.05	1.98	1.94	1.92	1.89	1.22	1.20	1.18	1.18	1.17
15.0	2.04	1.97	1.94	1.91	1.89	1.22	1.20	1.18	1.18	1.17
					p = 0.5					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.94	1.92	1.92	1.92	1.92	1.19	1.18	1.18	1.18	1.18
1.0	1.90	1.86	1.86	1.86	1.86	1.17	1.16	1.16	1.16	1.16
1.5	1.88	1.85	1.83	1.83	1.83	1.16	1.15	1.14	1.14	1.14
2.0	1.88	1.84	1.83	1.82	1.82	1.16	1.15	1.14	1.14	1.14
3.0	1.87	1.84	1.82	1.81	1.80	1.16	1.15	1.14	1.14	1.13
5.0	1.86	1.83	1.82	1.81	1.80	1.16	1.14	1.14	1.13	1.13
10.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
15.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
					p = 0.3					
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.76	1.76	1.76	1.76	1.76	1.12	1.11	1.11	1.11	1.11
1.0	1.76	1.75	1.75	1.75	1.75	1.11	1.11	1.11	1.11	1.11
1.5	1.75	1.74	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11
2.0	1.75	1.74	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11
3.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
5.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
10.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.10	1.10
15.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.10	1.10
					ZERO PROJECTING					
	1.70					1.10				

Figure B-1

TRENCH BACKFILL LOADS ON CIRCULAR PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SAND AND GRAVEL $K\mu' = 0.165$

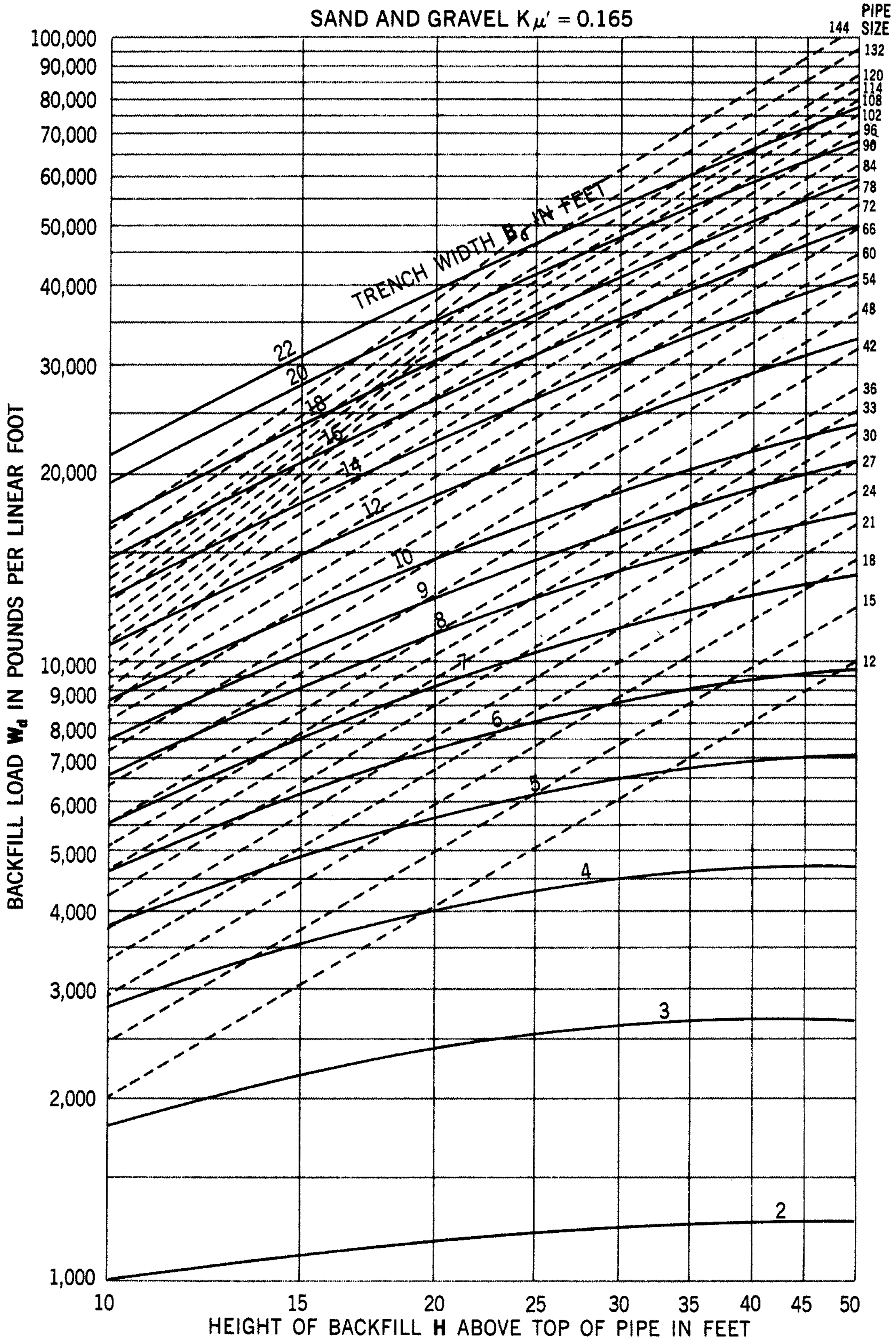


For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure B-2

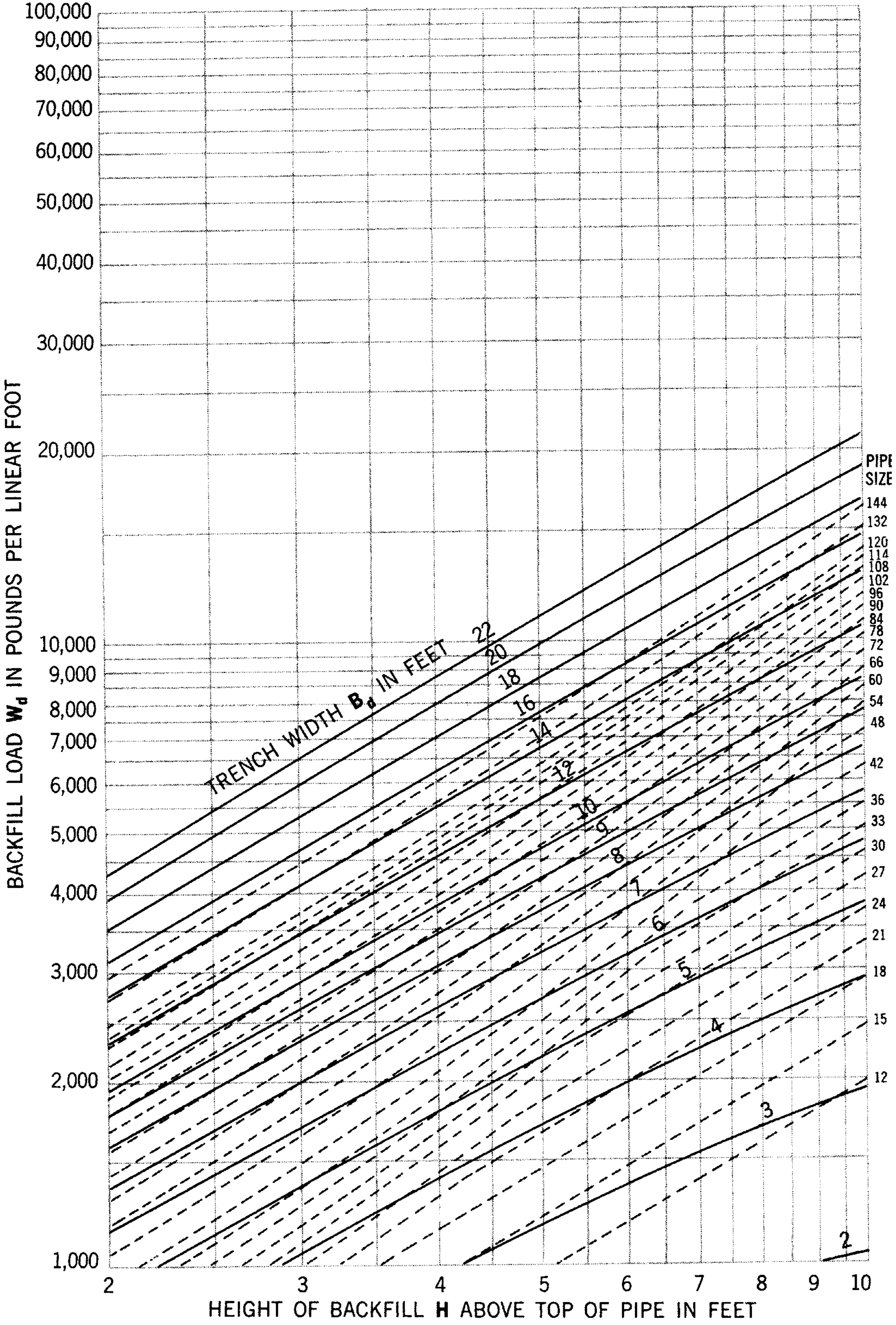
TRENCH BACKFILL LOADS ON CIRCULAR PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SAND AND GRAVEL $K\mu' = 0.165$



For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure B-3

TRENCH BACKFILL LOADS ON CIRCULAR PIPE
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL
SATURATED TOP SOIL $K\mu' = 0.150$



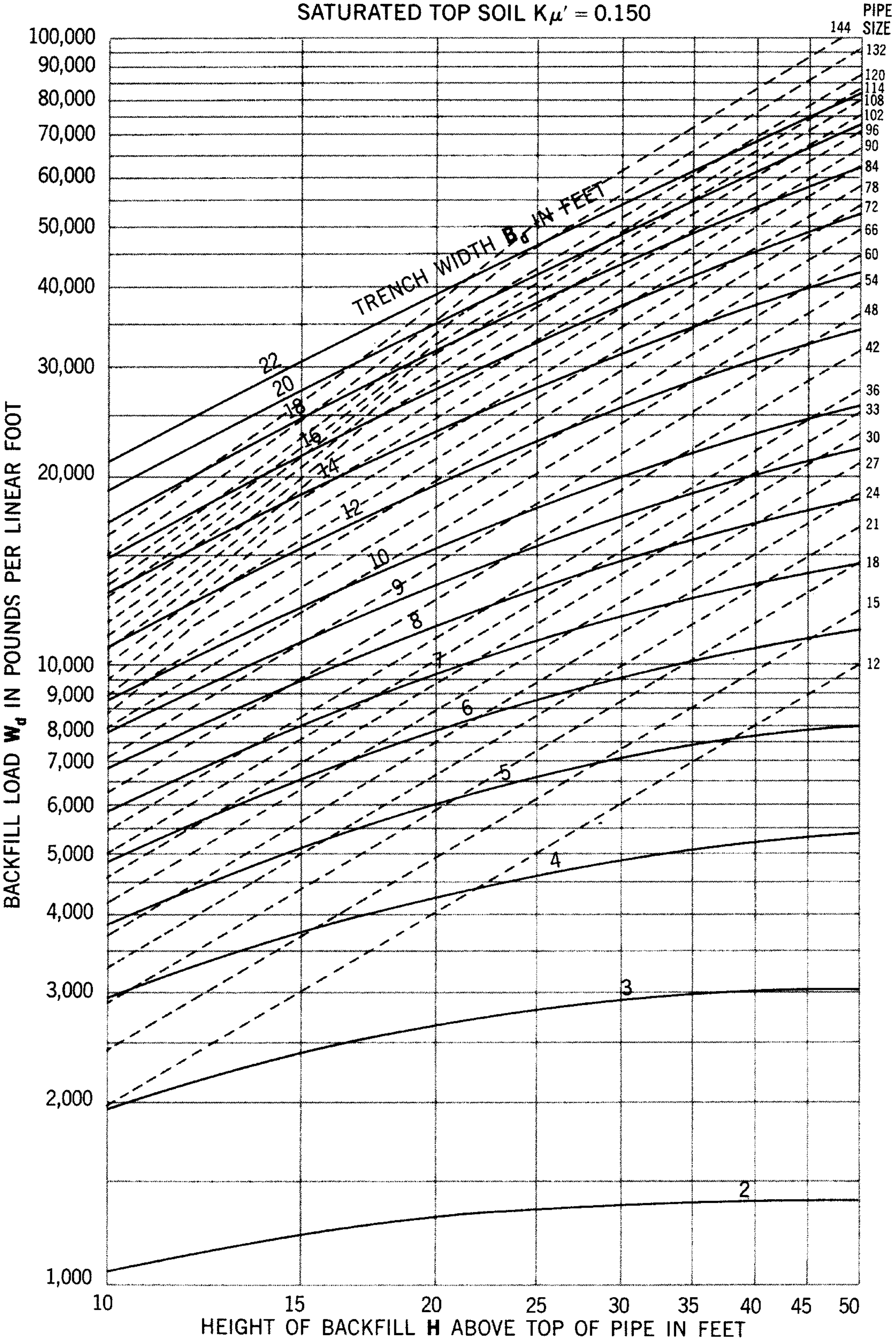
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure B-4

TRENCH BACKFILL LOADS ON CIRCULAR PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

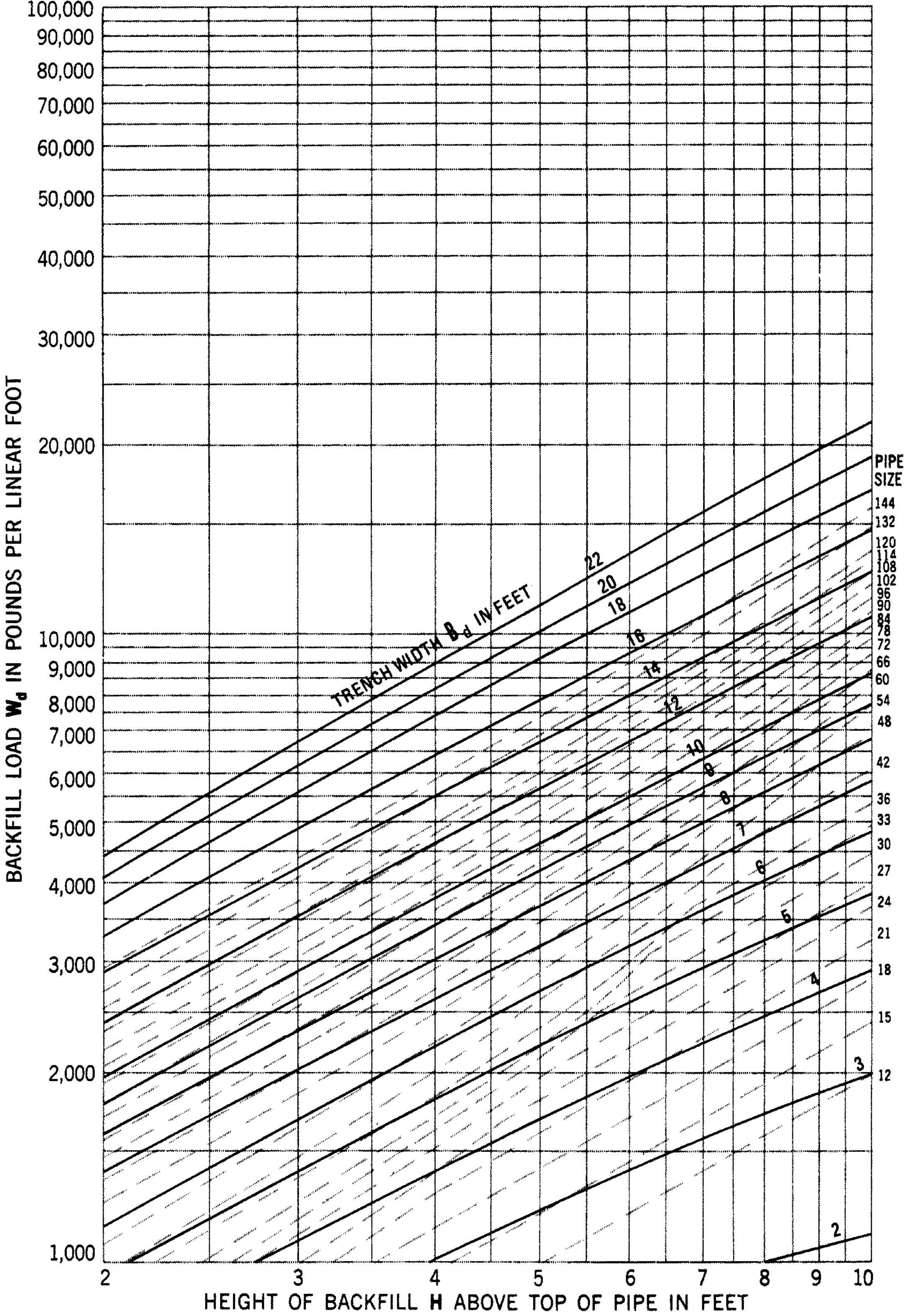
SATURATED TOP SOIL $K\mu' = 0.150$



For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure B-5



TRENCH BACKFILL LOADS ON CIRCULAR PIPE

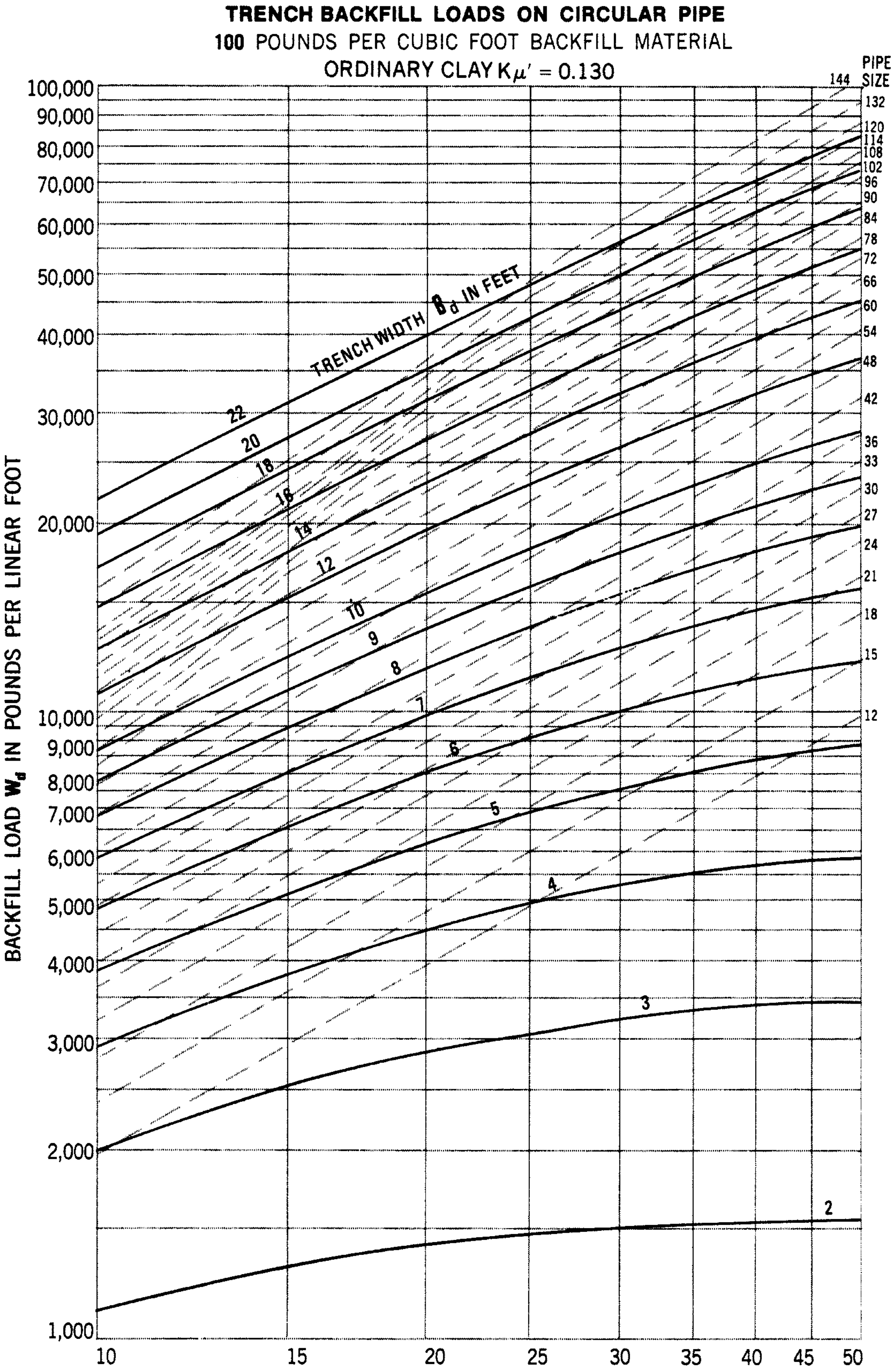
100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure B-6



TRENCH BACKFILL LOADS ON CIRCULAR PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

ORDINARY CLAY $K\mu' = 0.130$

For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

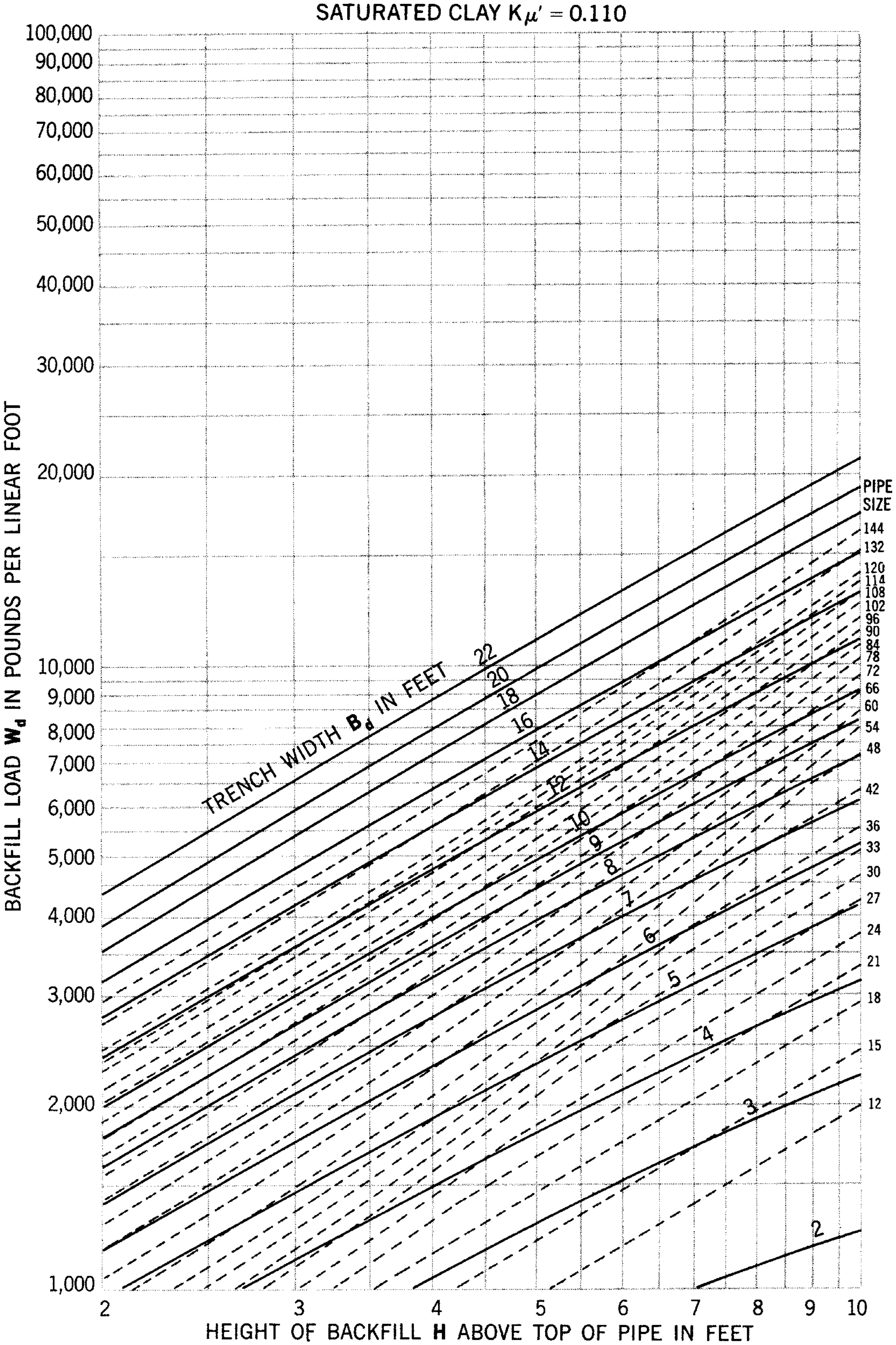
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and p = 0.7 in the embankment equation

Figure B-7

TRENCH BACKFILL LOADS ON CIRCULAR PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED CLAY $K\mu' = 0.110$



For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

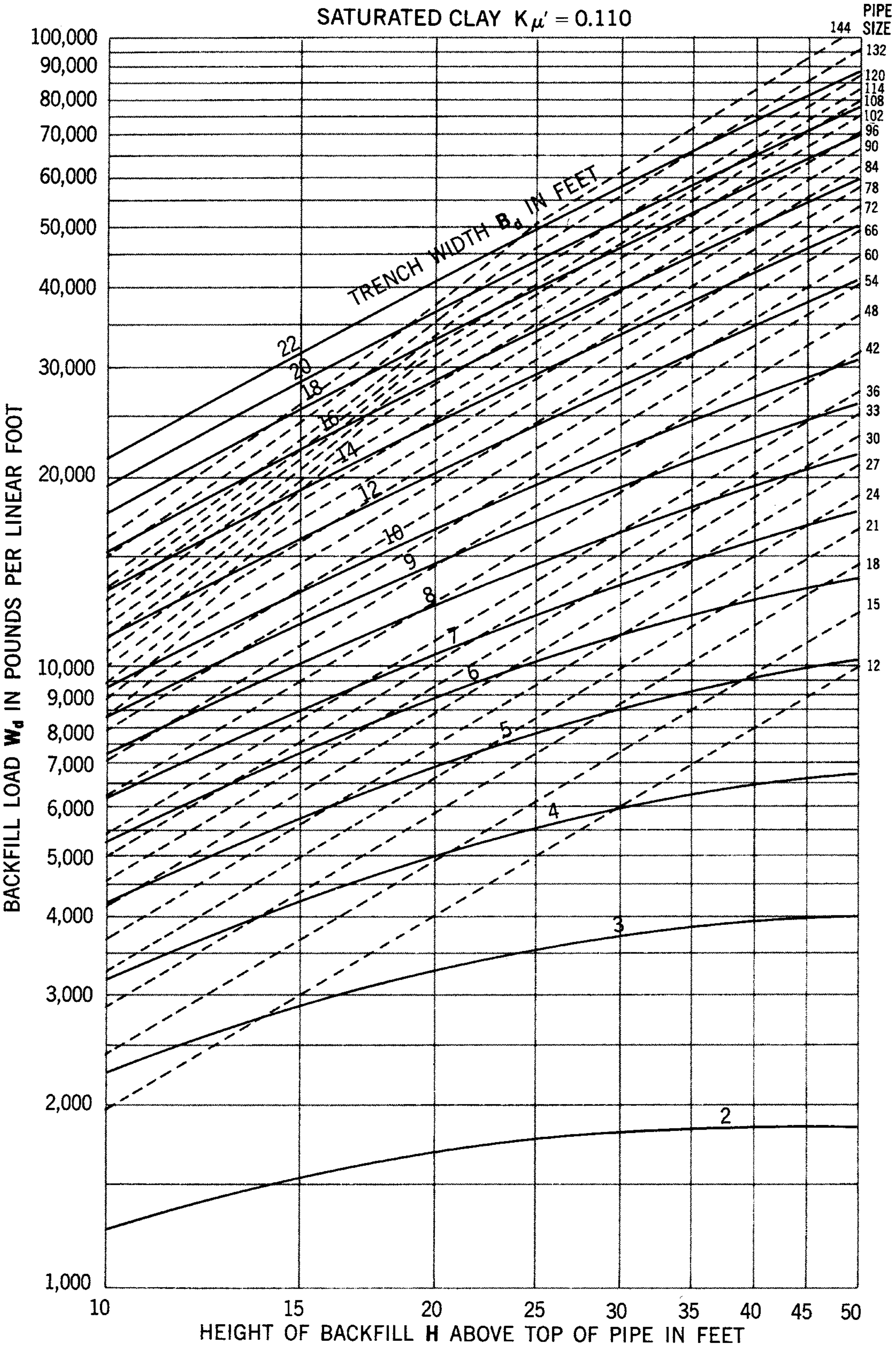
Transition loads and widths based on $K\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure B-8

TRENCH BACKFILL LOADS ON CIRCULAR PIPE

100 POUNDS PER CUBIC FOOT BACKFILL MATERIAL

SATURATED CLAY $K\mu' = 0.110$



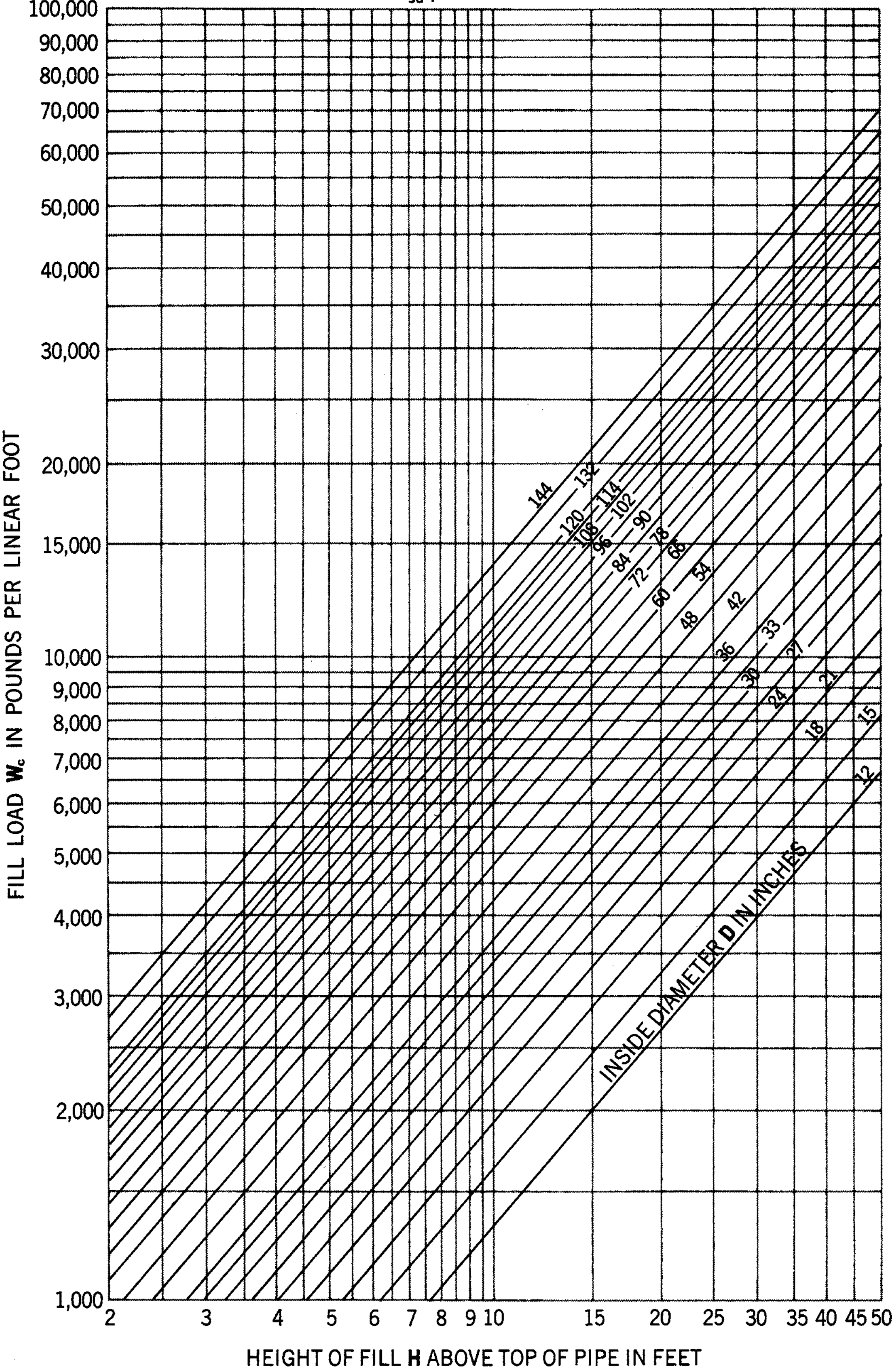
For backfill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds per cubic foot, increase 20%; etc.

Transition loads and widths based on $K_\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$ in the embankment equation

Figure B-9

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0$ **100** POUNDS PER CUBIC FOOT FILL

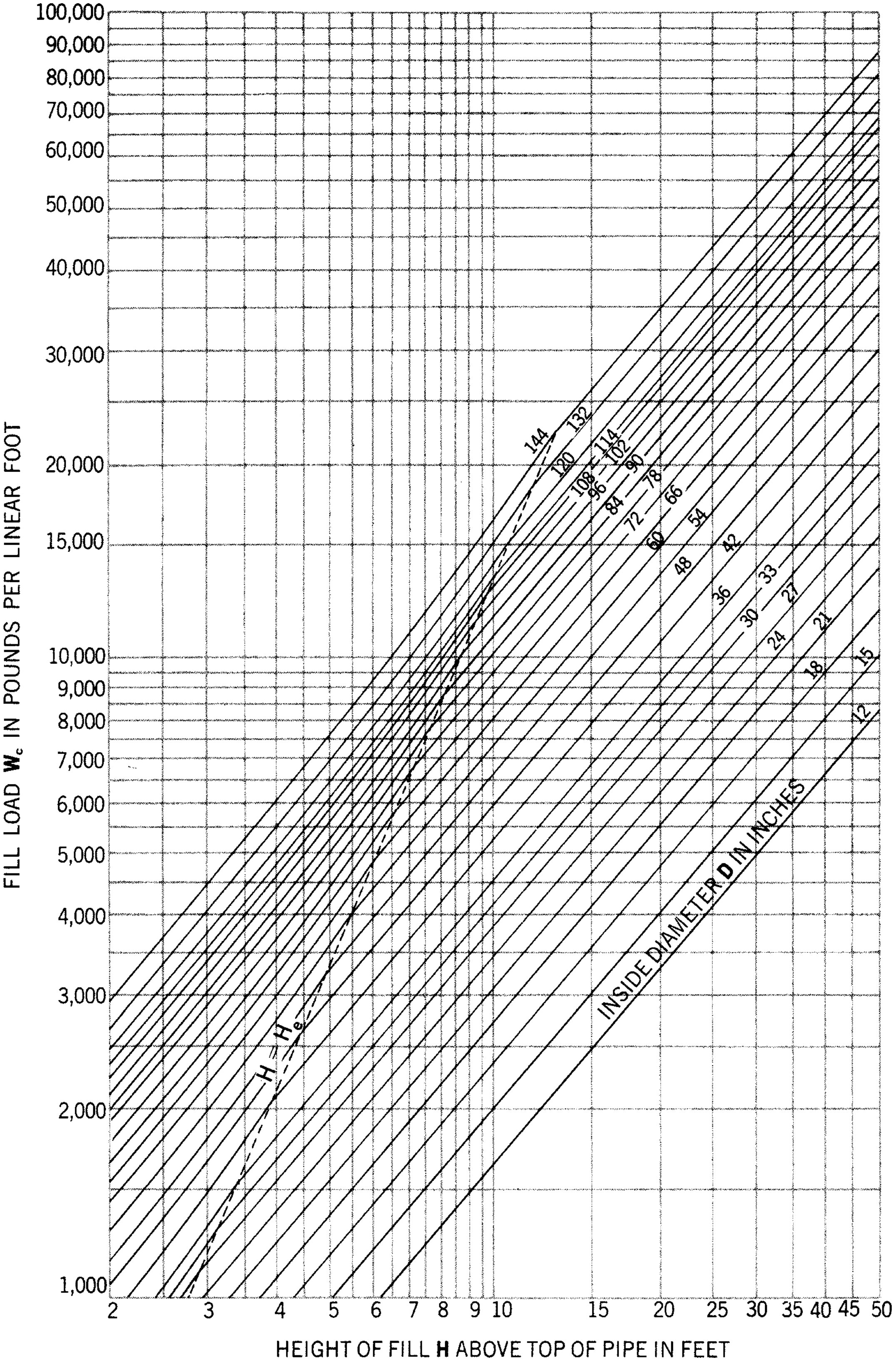


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure B-10

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.1$ **100** POUNDS PER CUBIC FOOT FILL

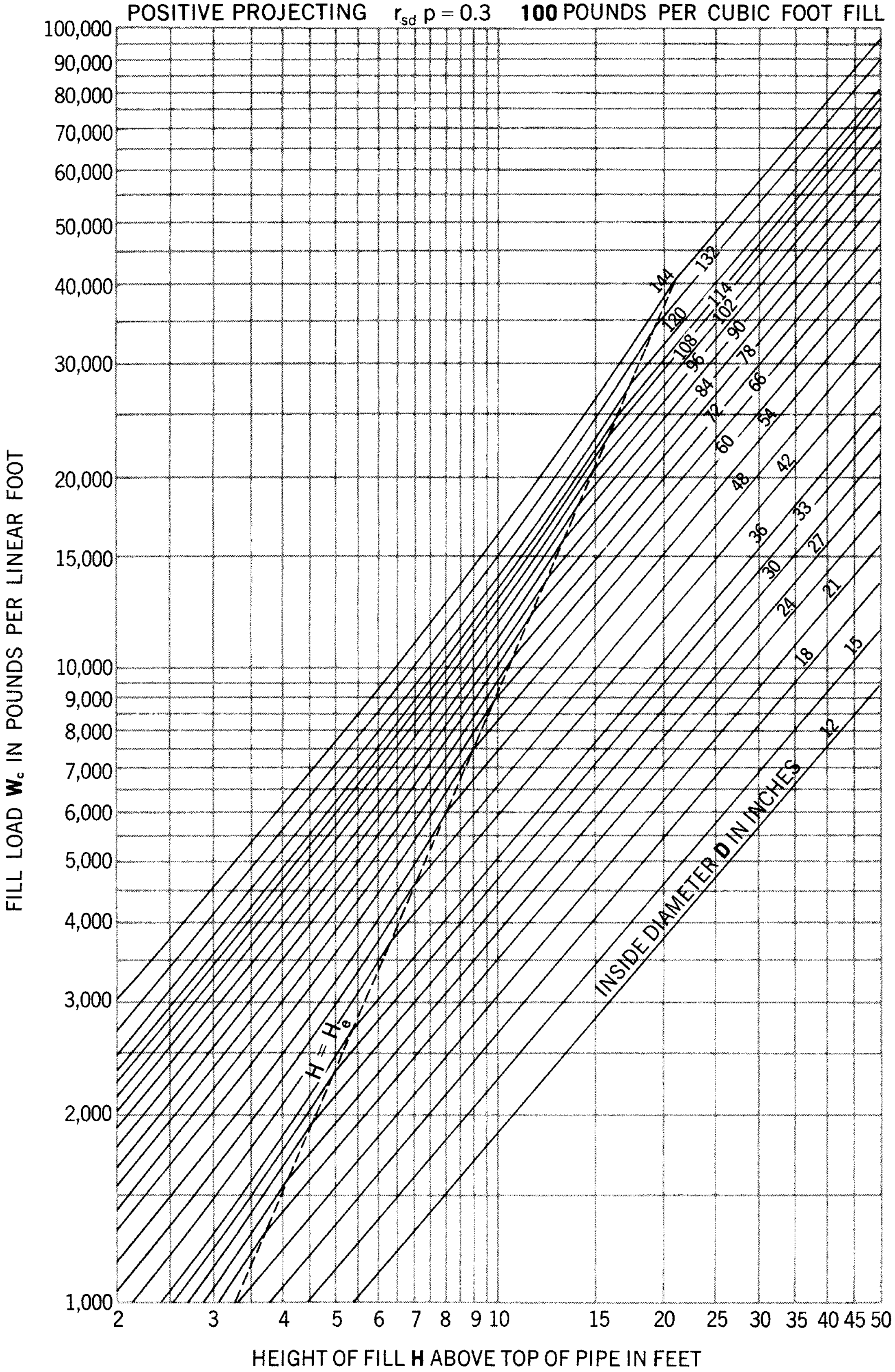


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure B-11

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.3$ **100** POUNDS PER CUBIC FOOT FILL

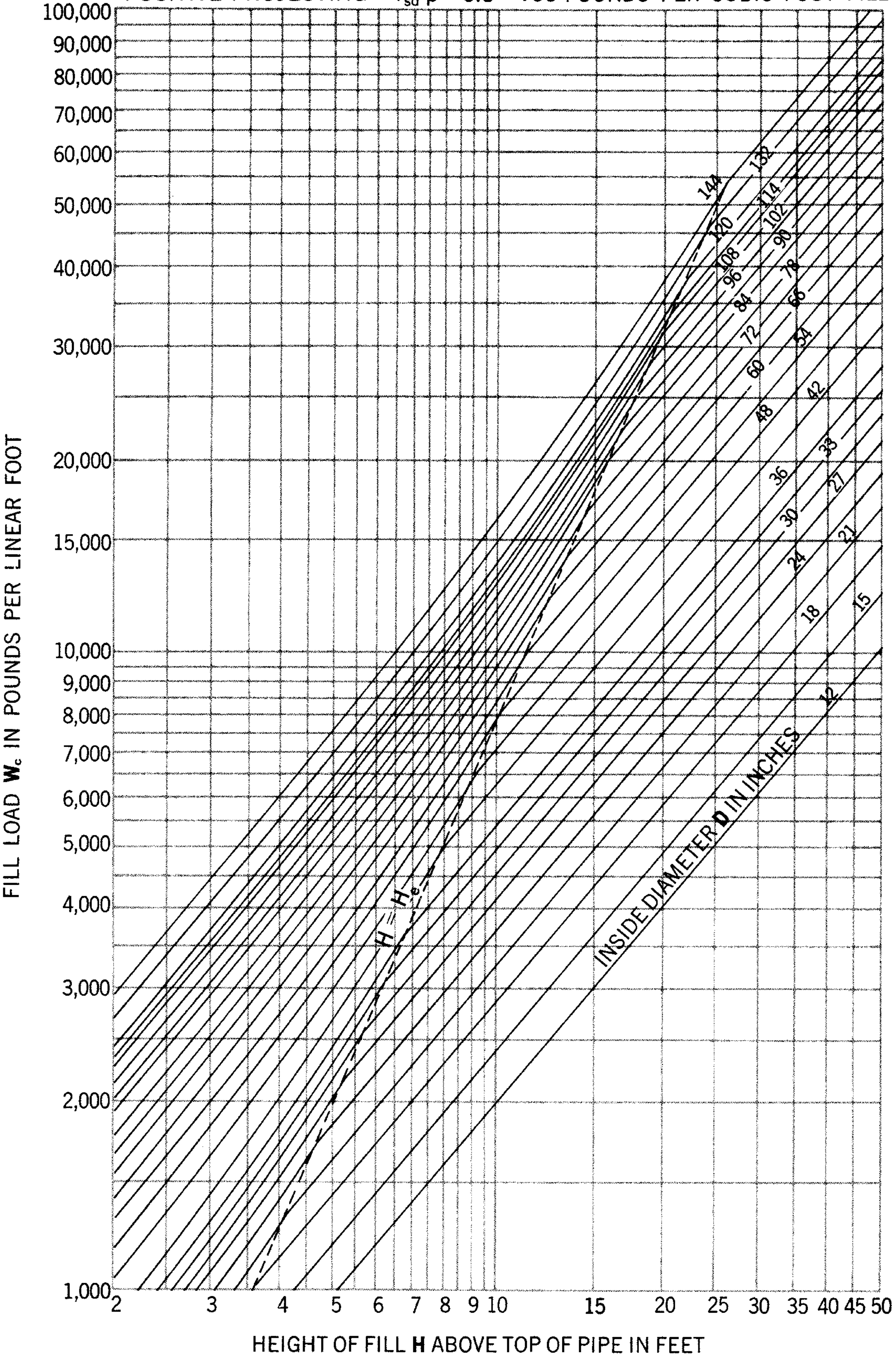


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure B-12

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

POSITIVE PROJECTING $r_{sd}\,p = 0.5$ **100** POUNDS PER CUBIC FOOT FILL

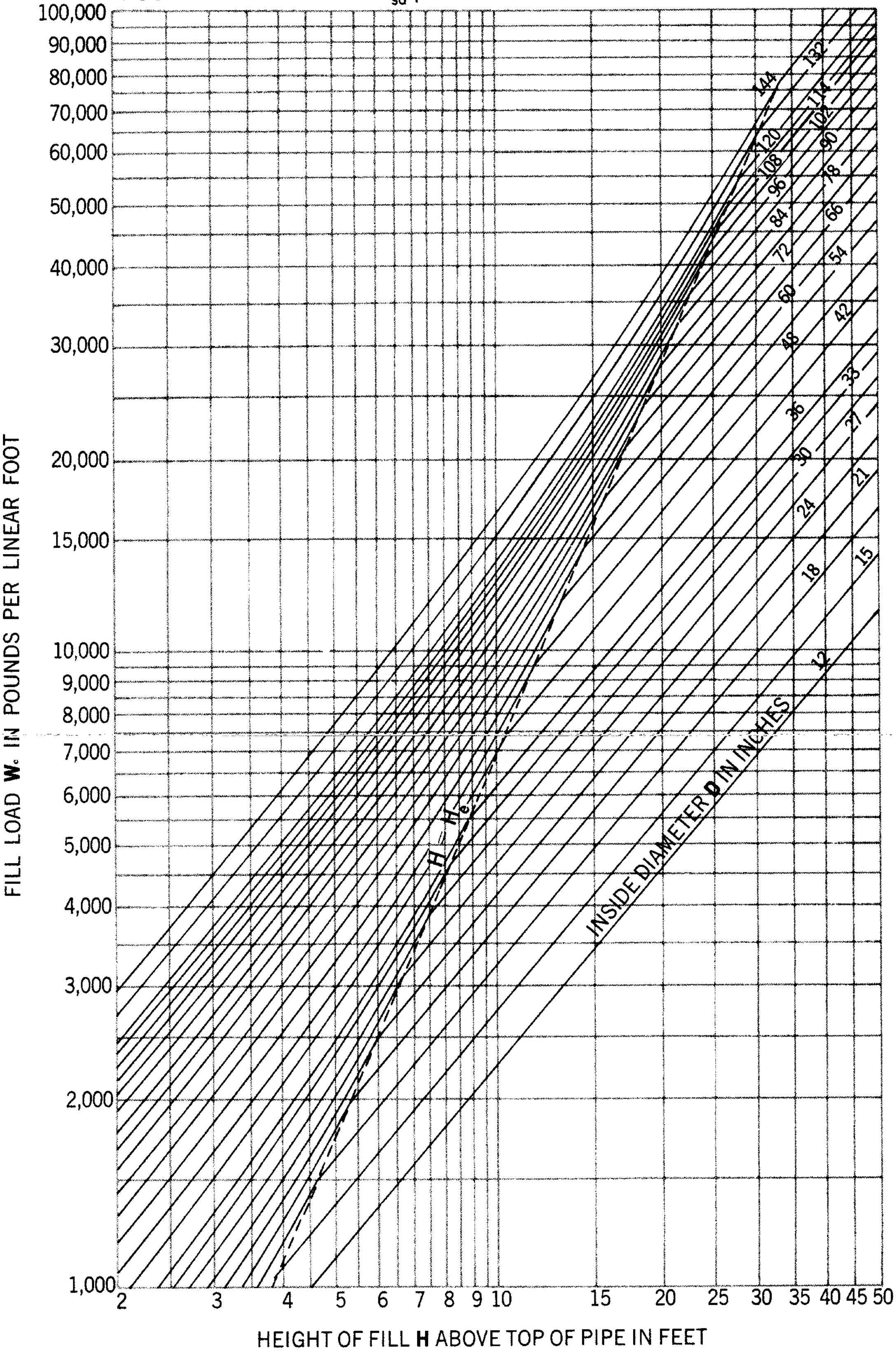


For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure B-13

EMBANKMENT FILL LOADS ON CIRCULAR PIPE

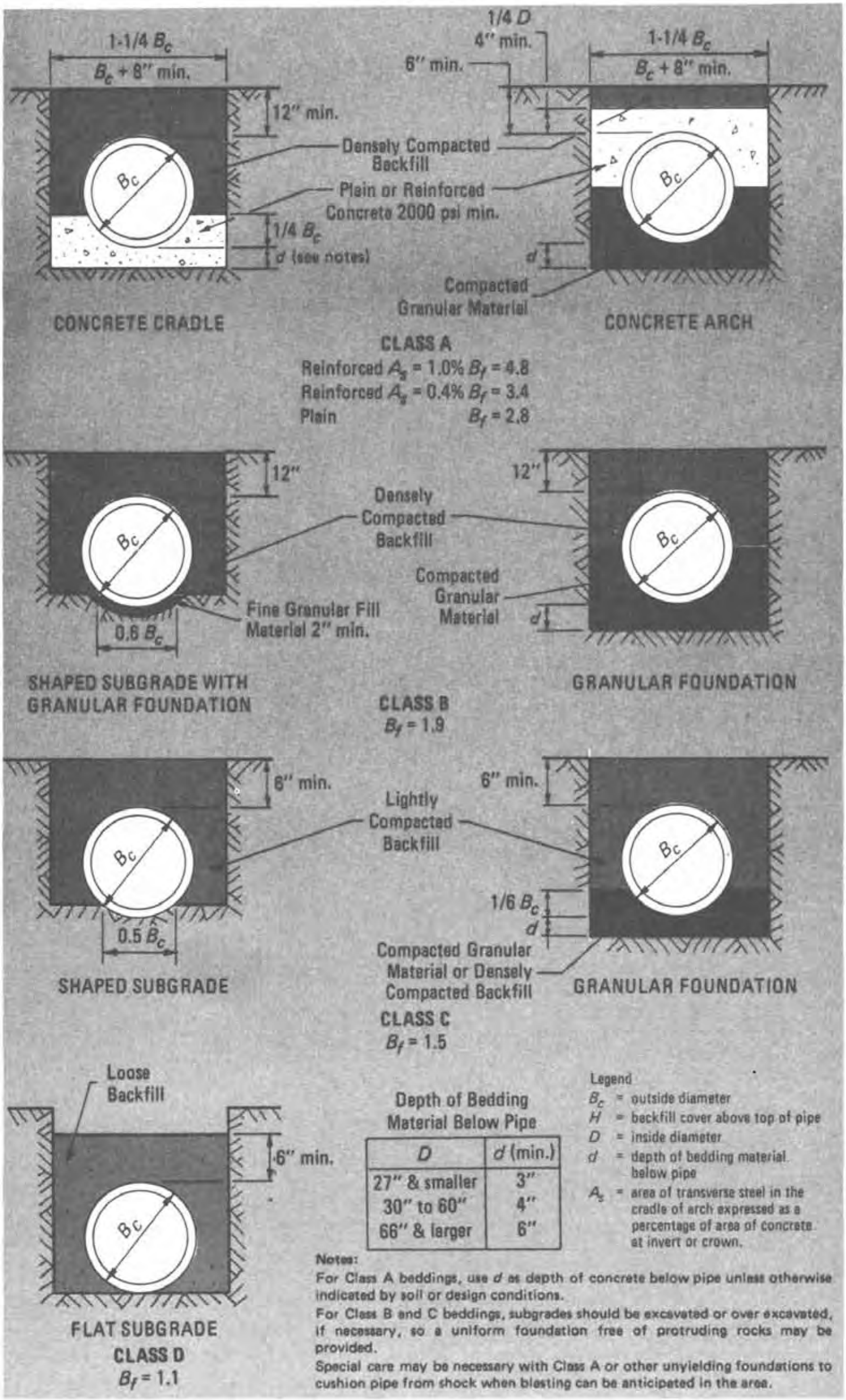
POSITIVE PROJECTING $r_{sd}\,p = 1.0$ **100** POUNDS PER CUBIC FOOT FILL



For fill weighing 110 pounds per cubic foot, increase loads 10%; for 120 pounds increase 20%, etc. Interpolate for intermediate pipe sizes.

Figure B-14

TRENCH BEDDINGS
CIRCULAR PIPE



Depth of Bedding Material Below Pipe

D	d (min.)
27" & smaller	3"
30" to 60"	4"
66" & larger	6"

Legend

B_c = outside diameter

H = backfill cover above top of pipe

D = inside diameter

d = depth of bedding material below pipe

A_s = area of transverse steel in the cradle of arch expressed as a percentage of area of concrete at invert or crown.

Notes:

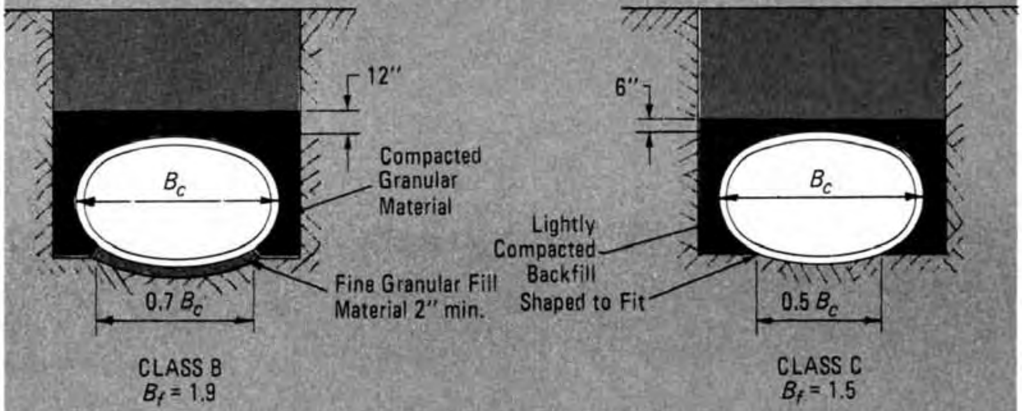
For Class A beddings, use *d* as depth of concrete below pipe unless otherwise indicated by soil or design conditions.

For Class B and C beddings, subgrades should be excavated or over excavated, if necessary, so a uniform foundation free of protruding rocks may be provided.

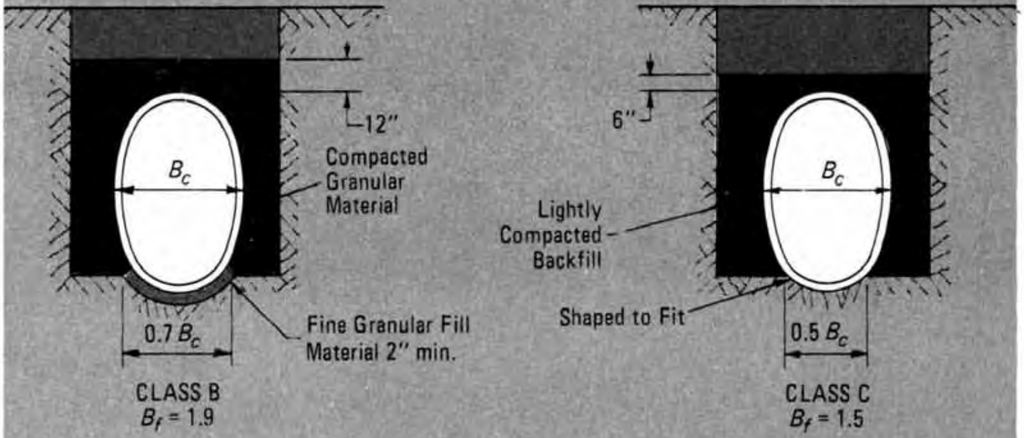
Special care may be necessary with Class A or other unyielding foundations to cushion pipe from shock when blasting can be anticipated in the area.

Figure B-15

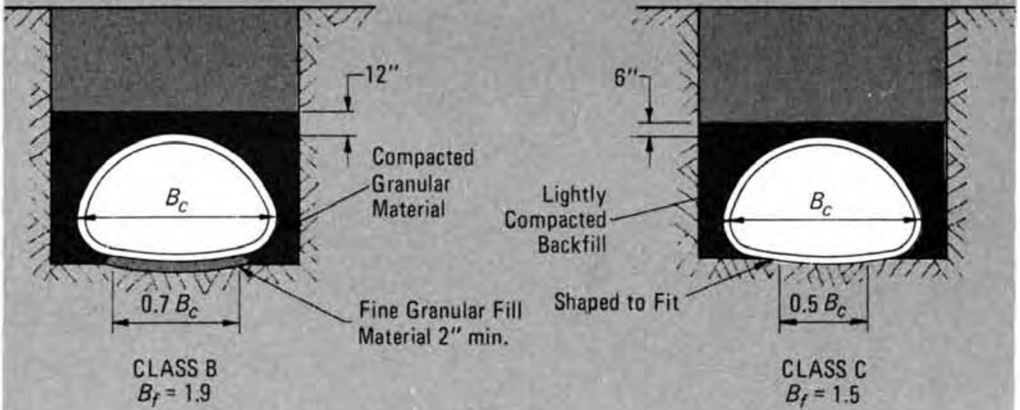
TRENCH BEDDINGS



HORIZONTAL ELLIPTICAL PIPE



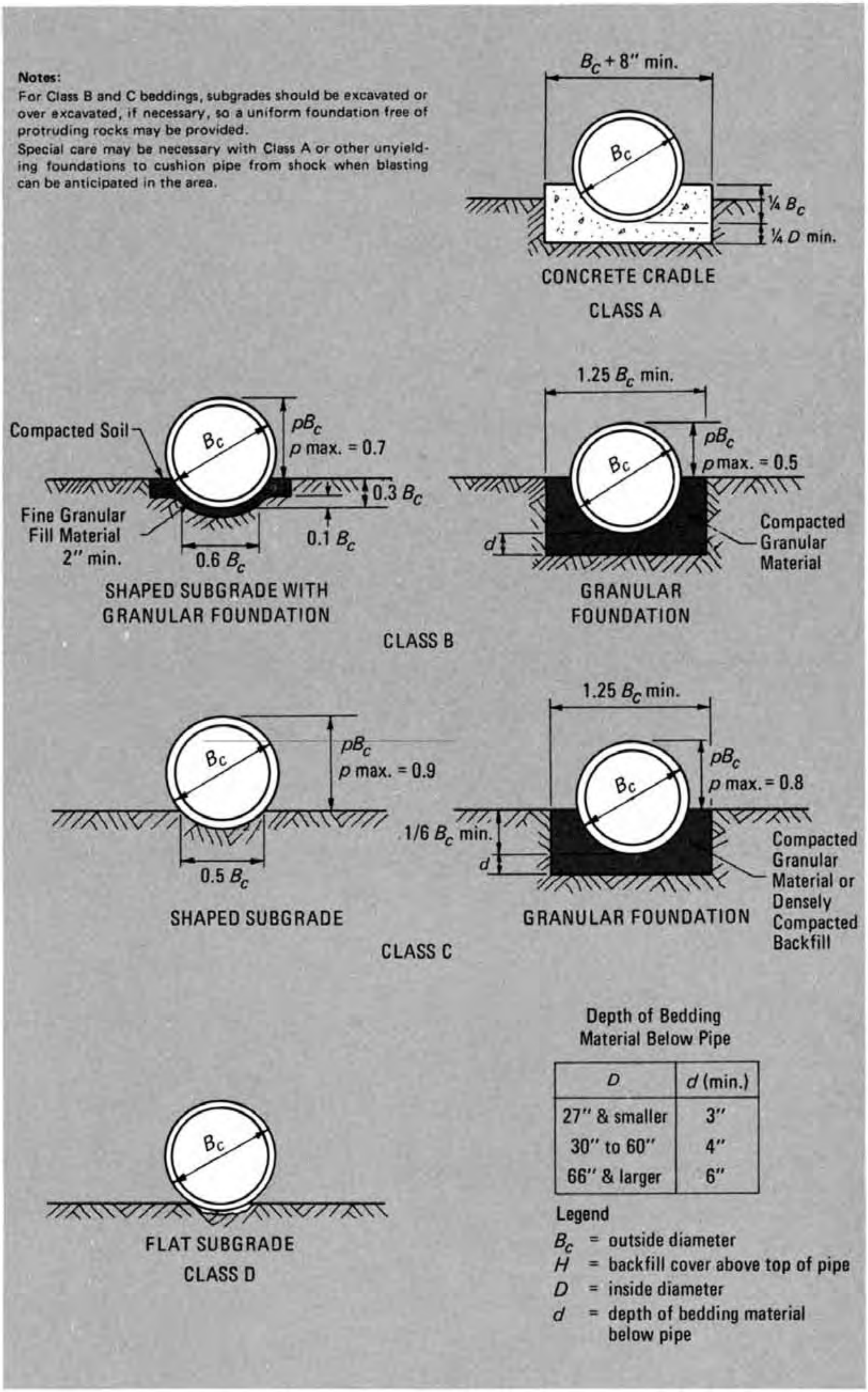
VERTICAL ELLIPTICAL PIPE



ARCH PIPE

Figure B-16

EMBANKMENT BEDDINGS
CIRCULAR PIPE



Notes:

For Class B and C beddings, subgrades should be excavated or over excavated, if necessary, so a uniform foundation free of protruding rocks may be provided.

Special care may be necessary with Class A or other unyielding foundations to cushion pipe from shock when blasting can be anticipated in the area.

Depth of Bedding
Material Below Pipe

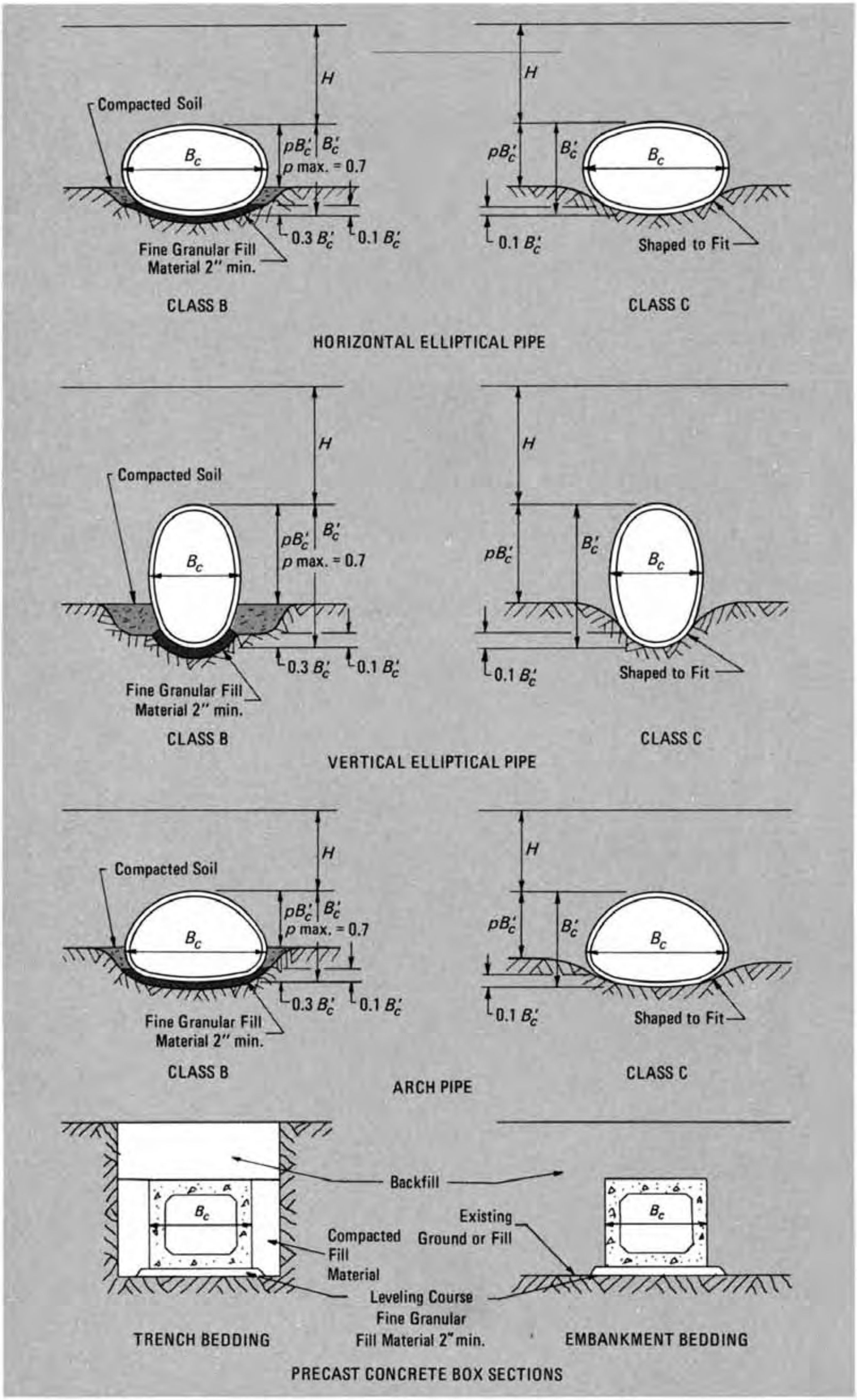
D	d (min.)
27" & smaller	3"
30" to 60"	4"
66" & larger	6"

Legend

B_c = outside diameter
H = backfill cover above top of pipe
D = inside diameter
d = depth of bedding material below pipe

Figure B-17

EMBANKMENT BEDDINGS



Glossary of Terms

GLOSSARY OF HYDRAULIC TERMS
(Chapters 2 and 3)

A............cross-sectional area of flow, square feet

A ....drainage area, acres

AHW.......allowable headwater depth at culvert entrance, feet

C............coefficient of runoff which is a function of the characteristics of the drainage area

C_1 ....constant in Manning's Formula for full flow

D ....height of culvert opening or diameter of pipe, inches or feet

d_c............critical depth, feet

H............head loss, feet (the difference between the elevation of the entrance pool surface and the outlet tailwater surface)

HW.........headwater depth at culvert inlet measured from invert of pipe, feet

h_o............vertical distance between the culvert invert at the outlet and the hydraulic grade line, feet

k_e............entrance head loss coefficient

i..............rainfall intensity, inches per hour

L.............length of culvert, feet

n.............Manning's coefficient of roughness

Q............flow in sewer or culvert discharge, cubic feet per second

R............hydraulic radius, equals area of flow divided by wetted perimeter, feet

R............inside vertical rise of elliptical, arch pipe, or boxes, feet or inches

S............inside horizontal span of elliptical, arch pipe, or boxes, feet or inches

S............slope of sewer, feet per foot

S_o...........slope of culvert, feet per foot

TW.........tailwater depth at culvert outlet measured from invert of pipe, feet

V............velocity, feet per second

GLOSSARY OF LOAD TERMS
(Chapter 4 and Appendix B)

A............a constant corresponding to the shape of the pipe

A_{LL}..........distributed live load area on subsoil plane at outside top of pipe, square feet

A_s............area of transverse steel in a cradle expressed as a percentage of the area of concrete in the cradle at the invert

B_c............outside horizontal span of the pipe, feet

B'_c...........outside vertical height of the pipe, feet

B_d............width of trench at top of pipe, feet

B_{dt}...........transition width at top of pipe, feet

B_f............bedding factor

B_{fe}...........bedding factor, embankment

B_{fLL}..........bedding factor for live load

B_{fo}...........minimum bedding factor, trench

B_{fv}............variable bedding factor, trench

B_t............maximum width of excavation ahead of pipe or tunnel, feet

C	pressure coefficient for live loads
C_c	load coefficient for positive projecting embankment installations
C_d	load coefficient for trench installations
C_n	load coefficient for negative projecting embankment installations
C_t	load coefficient for jacked or tunneled installations
c	thickness of concrete cover over the inner reinforcement, inches
c	coefficient of cohesion of undisturbed soil, pounds per square foot
D_i	inside diameter of pipe, inches
D_o	outside diameter of pipe, inches
D	inside diameter of circular pipe, feet or inches
D-load	the supporting strength of a pipe loaded under three-edge-bearing test conditions expressed in pounds per linear foot per foot of inside diameter or horizontal span
$D_{0.01}$	the maximum three-edge-bearing test load supported by a concrete pipe before a crack occurs having a width of 0.01 inch measured at close intervals throughout a length of at least 1 foot, expressed as D-Load.
$D_{ult.}$	The maximum three-edge-bearing test load supported by a pipe, expressed as D-load.
d	depth of bedding material below pipe, inches
d_c	deflection of the vertical height of the pipe
E	modulus of elasticity of concrete, pounds per square inch (4,000,000 psi)
e	base of natural logarithms (2.718)
F.S.	factor of safety
H	height of backfill or fill material above top of pipe, feet
HAF	horizontal arching factor, dimensionless
H_e	height of the plane of equal settlement above top of pipe, feet
h	thickness of rigid pavement
I_f	impact factor for live loads
K	ratio of active lateral unit pressure to vertical unit pressure
k	modulus of subgrade reaction, pounds per cubic inch
L	length of ALL parallel to longitudinal axis of pipe, feet
L_e	effective live load supporting length of pipe, feet
M_{FI}	moment at the invert under field loading, inch-pounds/ft
M_{FIELD}	maximum moment in pipe wall under field loads, inch-pounds/ft
M_{TEST}	maximum moment in pipe wall under three-edge bearing test load, inch-pounds/ft
μ	coefficient of internal friction of fill material
μ'	coefficient of sliding friction between the backfill material and the trench walls
N	a parameter which is a function of the distribution of the vertical load and vertical reaction
N_{FI}	axial thrust at the invert under field loads, pounds per foot
N_{FS}	axial thrust at the springline under a three-edge bearing test load, pounds per foot
N'	a parameter which is a function of the distribution of the vertical load and the vertical reaction for the concrete cradle method of bedding

PL	prism load, weight of the column of earth cover over the pipe outside diameter, pounds per linear foot
p	wheel load, pounds
p	projection ratio for positive projecting embankment installation; equals vertical distance between the top of the pipe and the natural ground surface divided by the outside vertical height of the pipe
p'	projection ratio for negative projecting installations; equals vertical distance between the top of the pipe and the top of the trench divided by the trench width
p_o	live load pressure at the surface, pounds per square inch or pounds per square foot
$P_{(H,X)}$	pressure intensity at any vertical distance, H, and horizontal distance, X, pounds per square inch or pounds per square foot
ϖ	3.1416
q	the ratio of total lateral pressure to the total vertical load
R	inside vertical rise of elliptical, arch pipe, or boxes feet or inches
R_s	radius of stiffness of the concrete pavement, inches or feet
r	radius of the circle of pressure at the surface, inches
r_{sd}	settlement ratio
S	inside horizontal span of elliptical, arch pipe, or boxes feet or inches
S_L	outside horizontal span of pipe (B_C) or width of A_{LL} transverse to longitudinal axis of pipe, whichever is less, feet
s_d	compression of the fill material in the trench within the height $p'B_d$ for negative projecting embankment installations
s_f	settlement of the pipe into its bedding foundation
s_g	settlement of the natural ground or compacted fill surface adjacent to the pipe
$T.E.B.$	three-edge bearing strength, pounds per linear foot
t	pipe wall thickness, inches
u	Poisson's ratio of concrete (0.15)
VAF	vertical arching factor, dimensionless
W_c	fill load for positive projecting embankment installations, pounds per linear foot
W_d	backfill load for trench installations, pounds per linear foot
W_E	earth load, pounds per linear foot
W_L	live load on pipe, pounds per linear foot
W_n	fill load for negative projecting embankment installations, pounds per linear foot
W_p	weight of pavement, pounds per linear foot
W_T	total live load on pipe, pounds
W_t	earth load for jacked or tunneled installations, pounds per linear foot
w	unit weight of backfill or fill material, pounds per cubic foot
w_L	average pressure intensity of live load on subsoil plane at outside top of pipe, pounds per square foot
x	a parameter which is a function of the area of the vertical projection of the pipe over which active lateral pressure is effective
x'	a parameter which is a function of the effective lateral support provided by the concrete cradle method of bedding

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