CHAPTER 4

CULVERT DESIGN

4-1 **PURPOSE**. This chapter discusses the hydraulic design of culverts. Though it is fairly easy to perform culvert design using the charts and nomographs from this chapter, it is still highly recommended that the designer obtain a copy of the FHWA's HY-8 culvert analysis software from the FHWA Web site. The HY-8 program is easy and quick to use and provides accurate answers using the equations shown on the charts and nomographs.

A drainage culvert is defined as any structure under a pavement with a clear opening of 20 feet or less measured along the center of the pavement. Culverts are used to convey flow through an embankment or past some other type of flow obstruction. Culverts are constructed from a variety of materials and are available in many different shapes and configurations. Culvert hydraulics and diagrams, charts, coefficients, and related information useful in the design of culverts are shown later in this chapter.

4-1.1 Culverts are generally of circular, oval, elliptical, arch, or box cross section and may be of single or multiple construction, the choice depending on available headroom and economy. Culvert materials for permanent-type installations include plain concrete, reinforced concrete, corrugated metal, and plastic. Concrete culverts may be either precast or cast in place, and corrugated metal culverts may have either annular or helical corrugations and be constructed of steel or aluminum. For the metal culverts, different kinds of coatings and linings are available for improvement of durability and hydraulic characteristics. The design of economical culverts involves consideration of many factors relating to requirements of hydrology, hydraulics, physical environment, imposed exterior loads, construction, and maintenance. With the design discharge and general layout determined, the design requires detailed consideration of such hydraulic factors as shape and slope of approach and exit channels, allowable head at entrance (and ponding capacity, if appreciable), tailwater levels, hydraulic and energy grade lines, and erosion potential. A selection from possible alternative designs may depend on practical considerations such as minimum acceptable size, available materials, local experience concerning corrosion and erosion, and construction and maintenance aspects. If two or more alternative designs involving competitive materials of equivalent merit appear to be about equal in estimated cost, plans will be developed to permit contractor’s options or alternate bids, so that the least construction cost will result.

4-1.2 Culvert pipe is available in many sizes depending on the material type and configuration. Pipe manufacturers provide pipe and culvert manuals and handbooks that describe their products. See Chapter 9 of this UFC for allowable pipe sizes and fill heights. Designs for extra large sizes or for special shapes or structural requirements may be submitted by manufacturers for approval and fabrication. Short culverts under sidewalks (not entrances or driveways) may be as small as 8 in. in diameter if placed to be comparatively free from accumulation of debris or ice. In general, pipe diameters or pipe-arch rises should be not less than 18 inches. A diameter or pipe-arch of not less than 24 in. should be used in areas where windblown materials such as weeds and sand may tend to block the waterway. Within these ranges of sizes, structural requirements may limit the maximum size that can be used for a specific installation.

4-1.3 The capacity of a culvert is determined by its ability to admit, convey, and discharge water under specified conditions of potential and kinetic energy upstream and downstream. The hydraulic design of a culvert for a specified design discharge involves selection of a type and size, determination of the position of hydraulic control, and hydraulic computations to determine whether acceptable headwater depths (HW/D) and outfall conditions will result. In considering what degree of detailed refinement is appropriate in selecting culvert sizes, the relative accuracy of the estimated design discharge should be taken into account. Hydraulic computations will be carried out by standard methods based on pressure, energy, momentum, and loss considerations. Appropriate formulas, coefficients, and charts for culvert design are provided later in this chapter. The FHWA’s Hydraulic Design Series No. 5 (HDS-5) should be consulted for detailed information regarding culvert design practice.

4-1.4 Rounding or beveling the entrance in any way will increase the capacity of a culvert for every design condition. Some degree of entrance improvement should always be considered for incorporation in design. A headwall will improve entrance flow over that of a projecting culvert. A headwall is particularly desirable as a cutoff to prevent saturation, sloughing, and/or erosion of the embankment. Provisions for drainage should be made over the center of the headwall to prevent scouring along the sides of the walls. A mitered entrance conforming to the fill slope produces a little improvement in efficiency over that of the straight, sharp-edged, projecting inlet, but may be structurally unsafe due to uplift forces. Both types of inlets tend to inhibit the culvert from flowing full when the inlet is submerged. The most efficient entrances incorporate such geometric features as elliptical arcs, circular arcs, tapers, and parabolic drop-down curves. In general, elaborate inlet designs for culverts are justifiable only in unusual circumstances.

4-1.5 Outlets and endwalls must be protected against undermining, bottom scour, damaging lateral erosion, and degradation of the downstream channel. The presence of tailwater higher than the culvert crown will affect culvert performance and may require protection of the adjacent embankment against wave or eddy scour. Endwalls (outfall headwalls) and wingwalls should be used where practical, and wingwalls should flare 1 on 8 from 1 diameter width to that required for the formation of a hydraulic jump and the establishment of a Froude number in the exit channel that will ensure stability. Two general types of channel instability can develop downstream of a culvert: gully scour or a localized erosion referred to as a scour hole. Gully scour is to be expected when the Froude number of flow in the channel exceeds that required for stability. Erosion of this type may be considerable depending upon the location of the stable channel section relative to that of the outlet in both the vertical and downstream directions. A scour hole can be expected downstream of an outlet even if the downstream channel is stable. The severity of damage depends upon the conditions existing or created at the outlet. More information on erosion protection is provided at the end of this chapter. In addition, the FHWA's HEC-14 is highly recommended for this topic.

4-1.6 In the design and construction of any drainage system it is necessary to consider the minimum and maximum earth cover allowable in the underground conduits to be placed under both flexible and rigid pavements. Minimum-maximum cover requirements for various pipe and culverts is provided in Chapter 9 of this UFC. The cover depths recommended are valid for average bedding and backfill conditions. Deviations from these conditions may result in significant minimum cover requirements.

4-1.7 Infiltration of fine-grained soils into drainage pipelines through joint openings is one of the major causes of ineffective drainage facilities. This is particularly a problem along pipes on relatively steep slopes such as those encountered with broken-back culverts. Infiltration of backfill and subgrade material can be controlled by watertight flexible joint materials in rigid pipe and with watertight coupling bands in flexible pipe. The results of laboratory research concerning soil infiltration through pipe joints and the effectiveness of gasketing tapes for waterproofing joints and seams are available. More information on watertight joints can be found in Chapter 9.

4-2 **FISH PASSAGE CONSIDERATIONS.** While the need for fish passage rarely occurs on DOD projects, this section provides some general fish passage guidance.

4-2.1 **General.** When it is determined that fish are present and fish passage must be accommodated, several design items must be considered. Consult a local fisheries biologist prior to making any of the design accommodations noted in paragraphs 4-2.2 through 4-2.8.

4-2.2 **High Inverts**. Fish passage is impossible when the culvert outlet is set too high, exceeding jumping ability of the fish and creating a spill velocity exceeding the swimming capability of the fish. Causes can be survey or design error, improper installation, or unexpected degradation of the downstream channel after culvert installation.

4-2.3 **High Velocities in Culverts**. These prevent fish from swimming upstream. Factors affecting velocity include the culvert's area, shape, slope, and internal roughness, and inlet and outlet conditions. Some increases in velocity result from the increased slope due to the culvert alignment being straight in lieu of the natural stream's meander, reduced surface roughness of the pipe, and a reduction in the cross-sectional area due to the pipe. Tailwater elevation, the water level in the downstream channel at the culvert outlet, should be based on the type of fish present. This minimum should be set with due consideration to recommendations of local fishery biologists.

Countersinking or partially burying a culvert will allow the natural stream material to be sustained throughout the length of the culvert. Enlarged, countersunk pipes have been effective for passing fish through a culvert.

4-2.4 **Undersized or Failed Culverts.** These can cause overtopping and washout of an embankment and destroy a fish resource by release of large amounts of sediment and debris.

4-2.5 **Erosion Along Drainageways or at Outlets**. Additional sediment from uncontrolled erosion can adversely affect fish. Causes can be high velocities, high inverts, undersized culverts, inadequate bank protection, and lack of suitable culvert endwalls.

4-2.6 **Channel Filling**. Covering an extensive reach of stream bottom decreases the area most suitable for spawning, depleting renewal of stocks. Proper biological input in siting and designing drainageways will avoid this problem.

4-2.7 **Culvert Installation**. Scheduling culvert excavation, channel diversion, and channel crossings by equipment should avoid times of the year that are critical to the fish cycle.

4-2.8 **Control of Icing**. Thawing devices such as electrical cables or steam lines, essential to any design where there is ice buildup, should be in operation to assure freedom from ice blockages during the spring migration period.

4-3 DESIGN STORM

4-3.1 The design of culverts will be based on the design storm frequencies defined in Chapter 2, section 2-2.5. The headwater depth for the design storm shall not exceed 1.25 or the local requirement. Examples of conditions where greater than the design storm frequency may be used are areas of steep slope in which overflows would cause severe erosion damage; high road fills that impound large quantities of water; and primary diversion structures, important bridges, and critical facilities where uninterrupted operation is imperative.

4-3.2 Protection of facilities against flood flows originating from areas exterior to the facility will normally be based on local design requirements but not less than the 10-yr event. Operational requirements, cost-benefit considerations, and the nature and consequences of flood damage resulting from the failure of protective works shall also be considered. Justification for the selected design storm will be presented, and, if appropriate, comparative costs and damages for alternative designs should be included.

4-4 **DESIGN.** Improper design and careless construction of various drainage structures may render facilities ineffective and unsafe. Consequently, the necessity of applying basic hydraulic principles to the design of all drainage structures must be emphasized. Care should be give to both preliminary field surveys that establish control elevations and to the construction of the various hydraulic structures in strict accordance with proper and approved design procedures. A successful drainage system requires the coordination of both the field and design engineers.

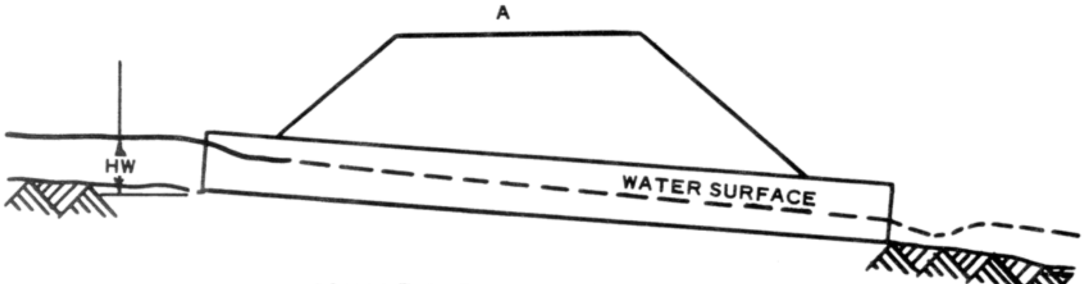
4-4.1 Hydraulic Design Data for Culverts

4-4.1.1 **General**. This section presents diagrams, charts, coefficients, and related information useful in the design of culverts. The information has been obtained largely from the U.S. Department of Transportation (USDOT), Federal Highway Administration (FHWA), and supplemented or modified as appropriate by information from various other sources and as required for consistency with design practice of the U.S. Army Corps of Engineers.

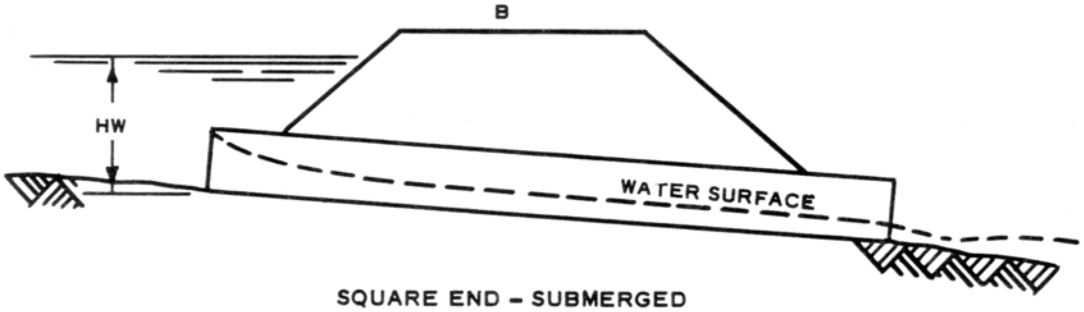
4-4.1.2 **Culvert Flow.** Laboratory tests and field observations show two major types of culvert flow: flow with inlet control and flow with outlet control. Under inlet control, the cross-sectional area of the culvert barrel, the inlet geometry, and the amount of headwater (HW) or ponding at the entrance are of primary importance. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the slope, roughness, and length of the culvert barrel. The type of flow or the location of the control is dependent on the quantity of flow, roughness of the culvert barrel, type of inlet, flow pattern in the approach channel, and other factors. In some instances, the flow control changes with varying discharges, and occasionally the control fluctuates from inlet control to outlet control and vice versa for the same discharge. Thus, the design of culverts should consider both types of flow and should be based on the more adverse flow condition anticipated.

4-4.1.3 **Inlet Control**. The discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater and the entrance geometry, including the area, slope, and type of inlet edge. Types of inlet-controlled flow for unsubmerged and submerged entrances are shown at A and B in Figure 4-1. A mitered entrance (C, Figure 4-1) produces little improvement in efficiency over that of the straight, sharp-edged, projecting inlet. Both types of inlets tend to inhibit the culvert from flowing full when the inlet is submerged. With inlet control, the roughness and length of the culvert barrel and outlet conditions (including depths of tailwater) are not factors in determining culvert capacity. The effect of the barrel slope on inlet-control flow in conventional culverts is negligible. Nomographs for determining culvert capacity for inlet control were developed by the Division of Hydraulic Research, Bureau of Public Roads (see the FHWA's HDS-1). These nomographs (Figures 4-2 through 4-9) give headwater-discharge relations for most conventional culverts flowing with inlet control. Nomographs for other culvert shapes are provided in HDS-5.

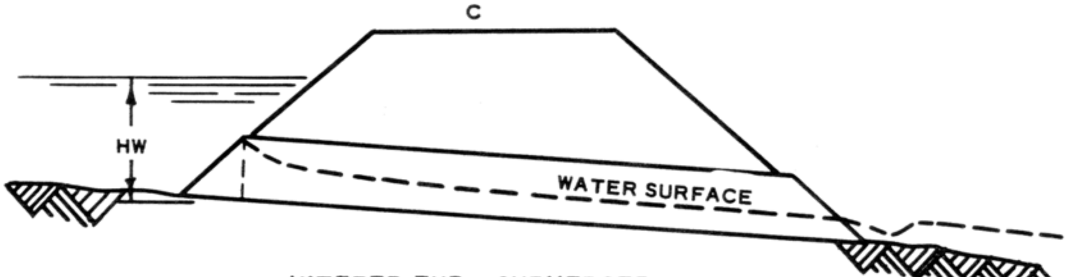
Figure 4-1. Inlet Control



SQUARE END – UNSUBMERGED



SQUARE END – SUBMERGED



MITERED END – SUBMERGED

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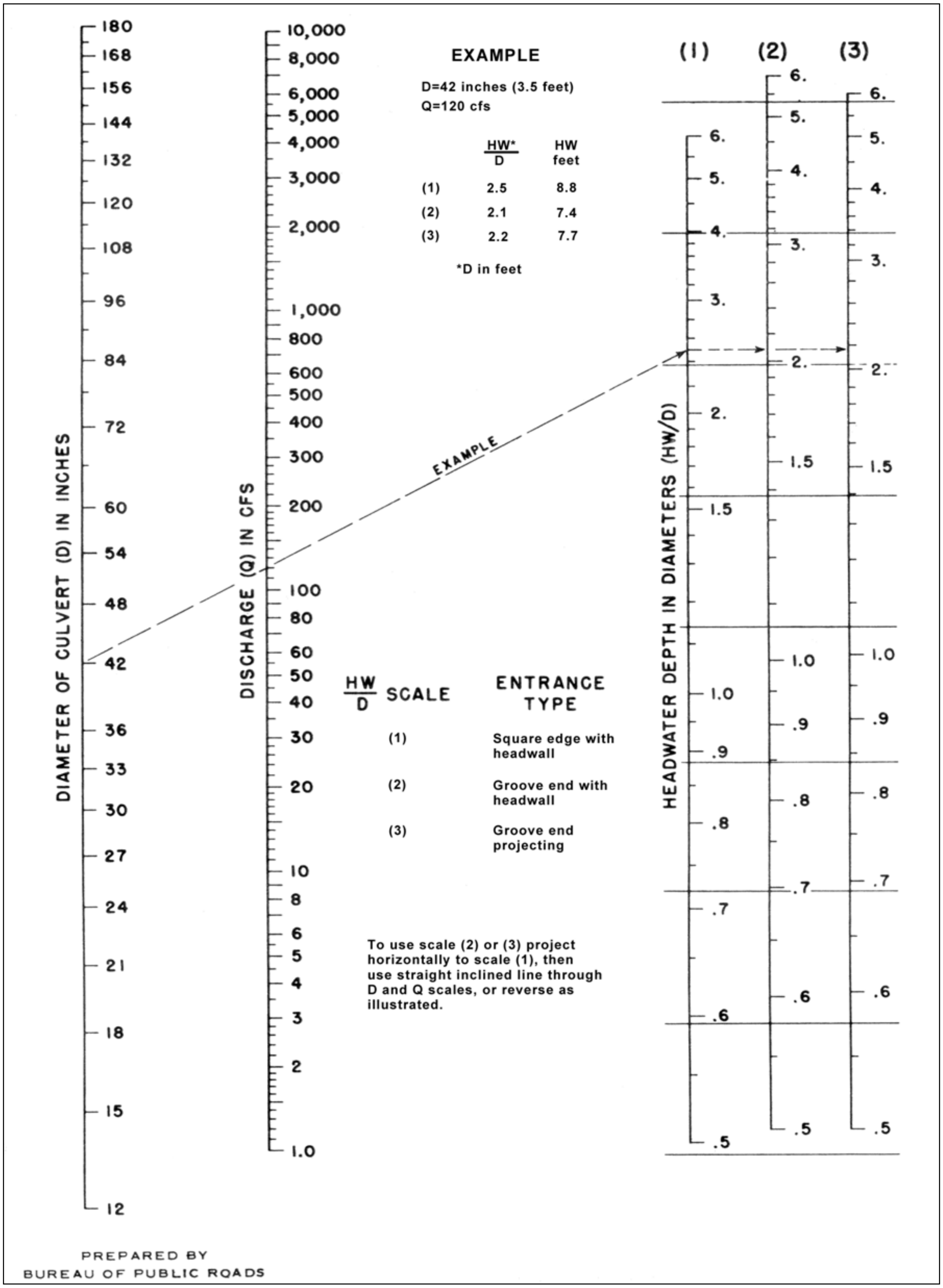
Figure 4-2. Headwater Depth for Concrete Pipe Culverts with Inlet Control



EXAMPLE

D=42 inches (3.5 feet)
Q=120 cfs

	HW*/D	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

HW/D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

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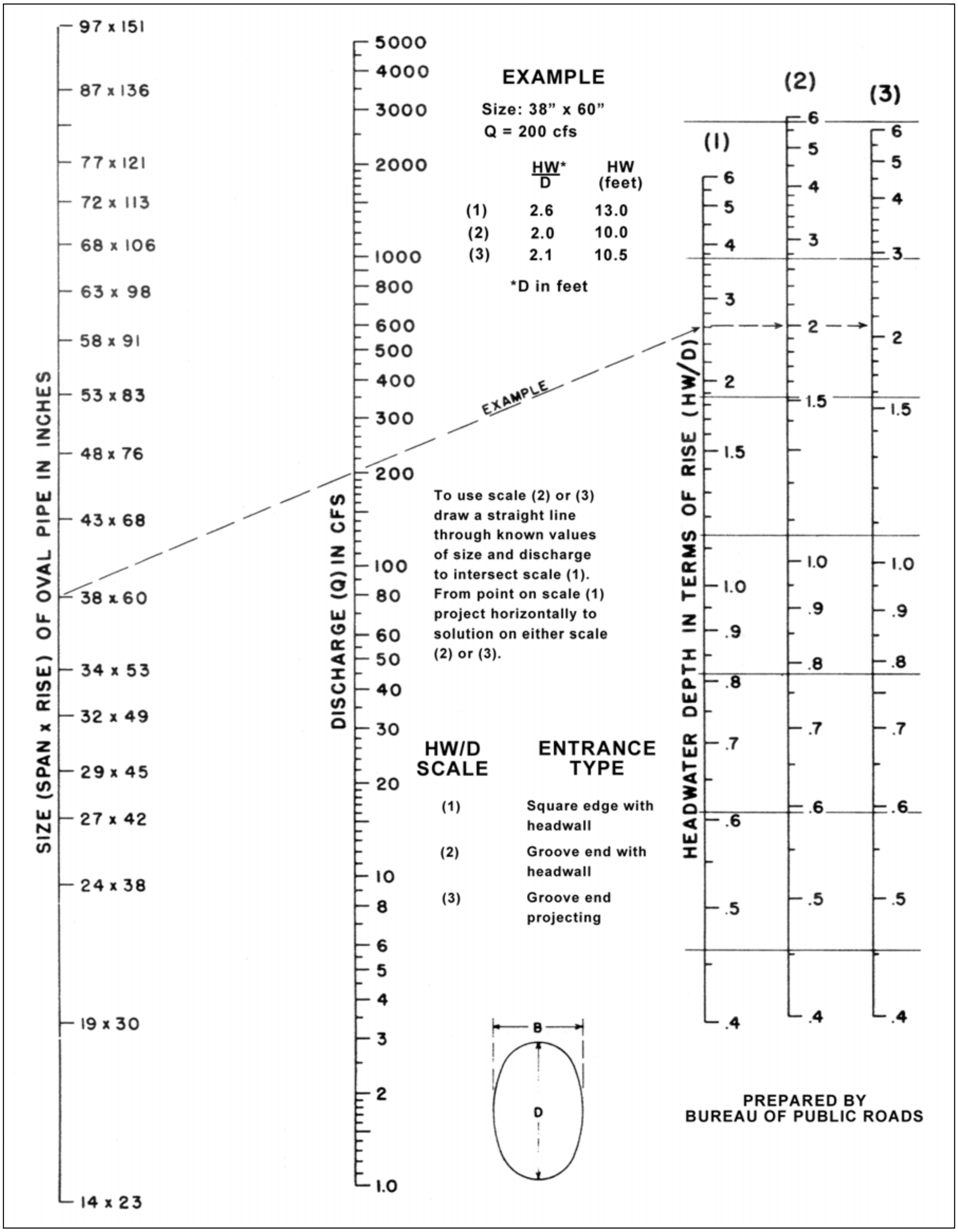
Figure 4-3. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Vertical with Inlet Control



EXAMPLE

Size: 38" x 60"
Q = 200 cfs

	$\frac{HW^*}{D}$	HW (feet)
(1)	2.6	13.0
(2)	2.0	10.0
(3)	2.1	10.5

*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 with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

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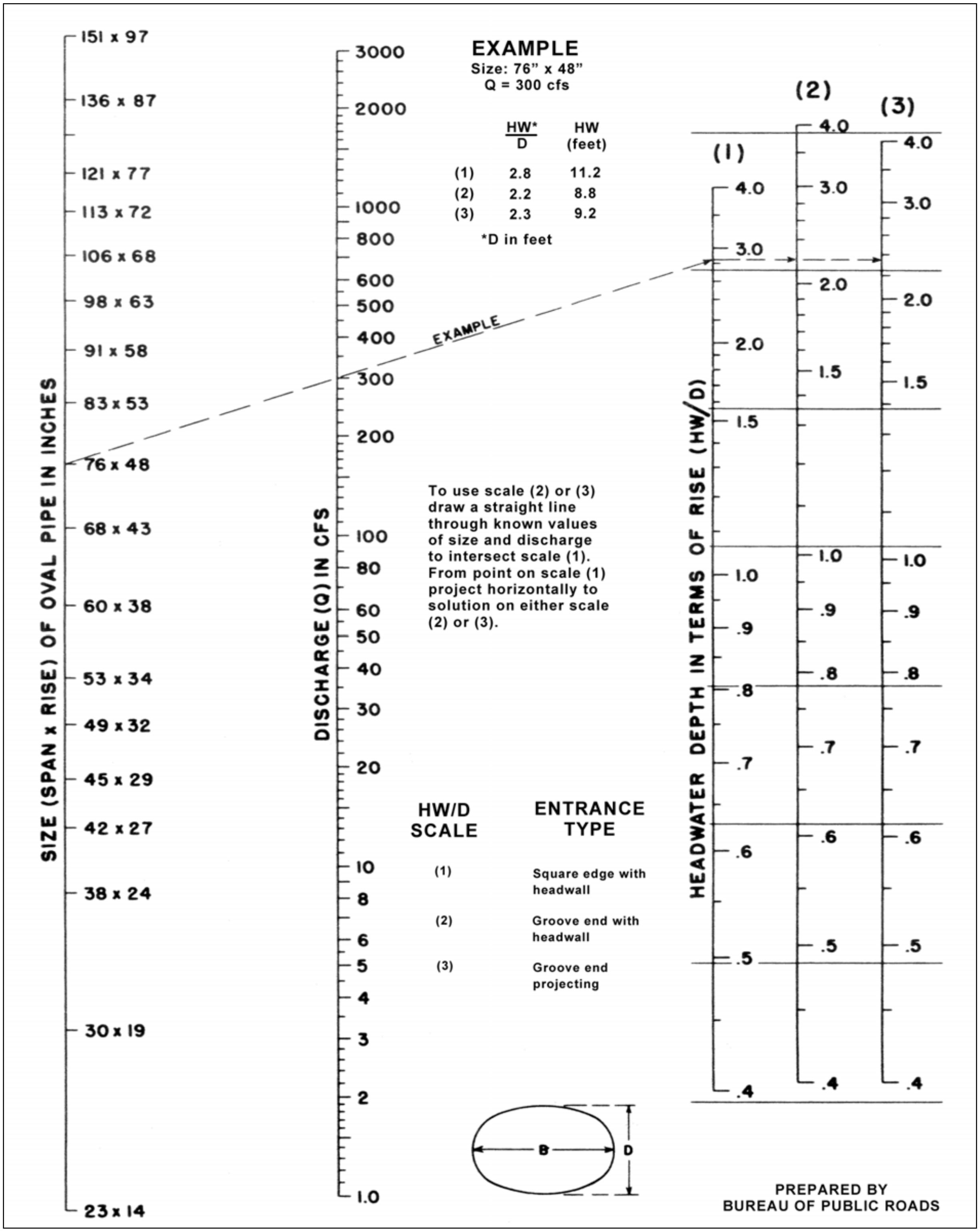
Figure 4-4. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Horizontal with Inlet Control



EXAMPLE
Size: 76" x 48"
Q = 300 cfs

	HW*/D	HW (feet)
(1)	2.8	11.2
(2)	2.2	8.8
(3)	2.3	9.2

*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 with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

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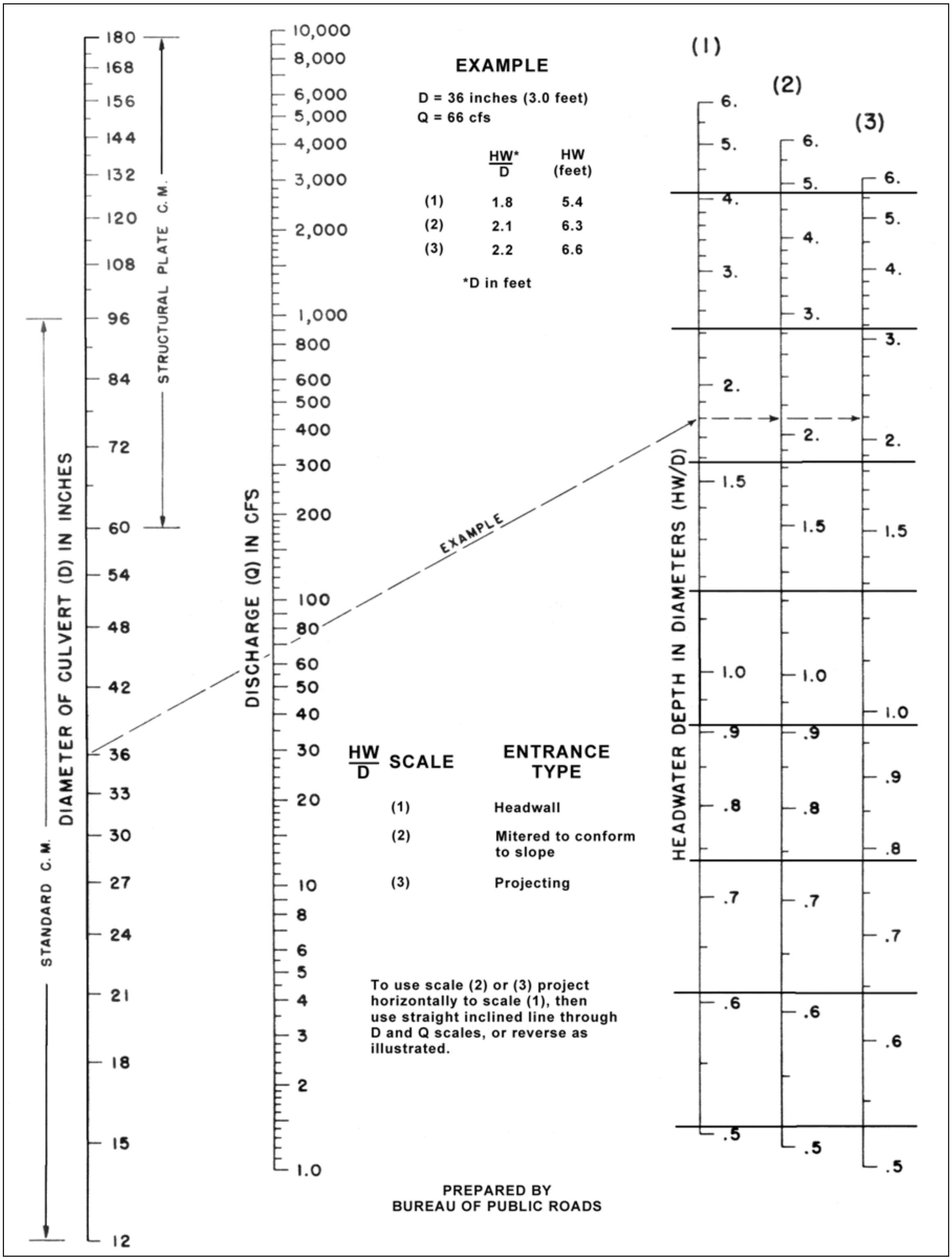
Figure 4-5. Headwater Depth for Corrugated Metal Pipe Culverts with Inlet Control



EXAMPLE

D = 36 inches (3.0 feet)
Q = 66 cfs

	$\frac{HW}{D}$*	HW (feet)
(1)	1.8	5.4
(2)	2.1	6.3
(3)	2.2	6.6

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

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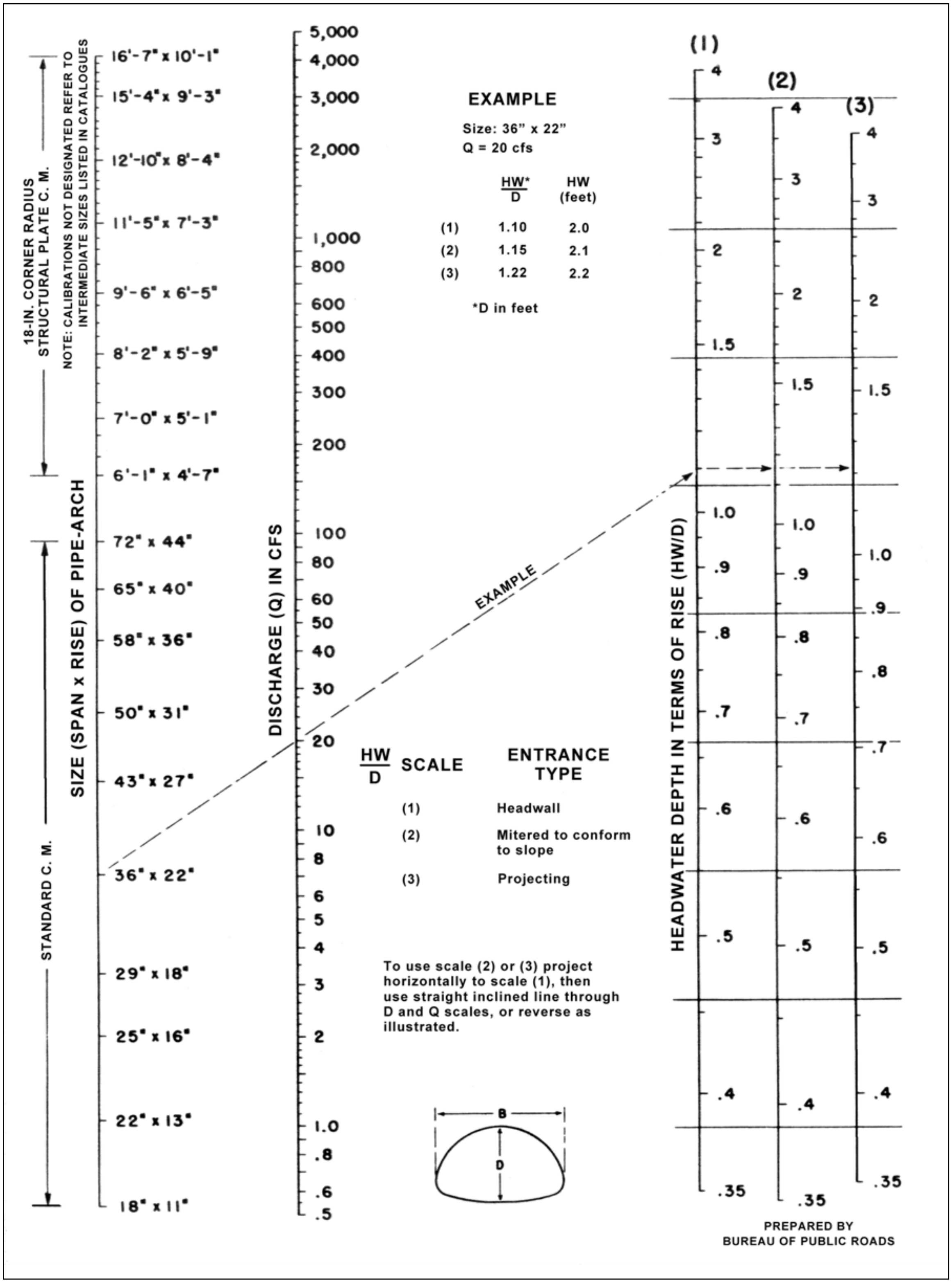
Figure 4-6. Headwater Depth for Structural Plate and Standard Corrugated Metal Pipe-Arch Culverts with Inlet Control



EXAMPLE

Size: 36" x 22"
Q = 20 cfs

	HW*/D	HW (feet)
(1)	1.10	2.0
(2)	1.15	2.1
(3)	1.22	2.2

*D in feet

HW/D SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

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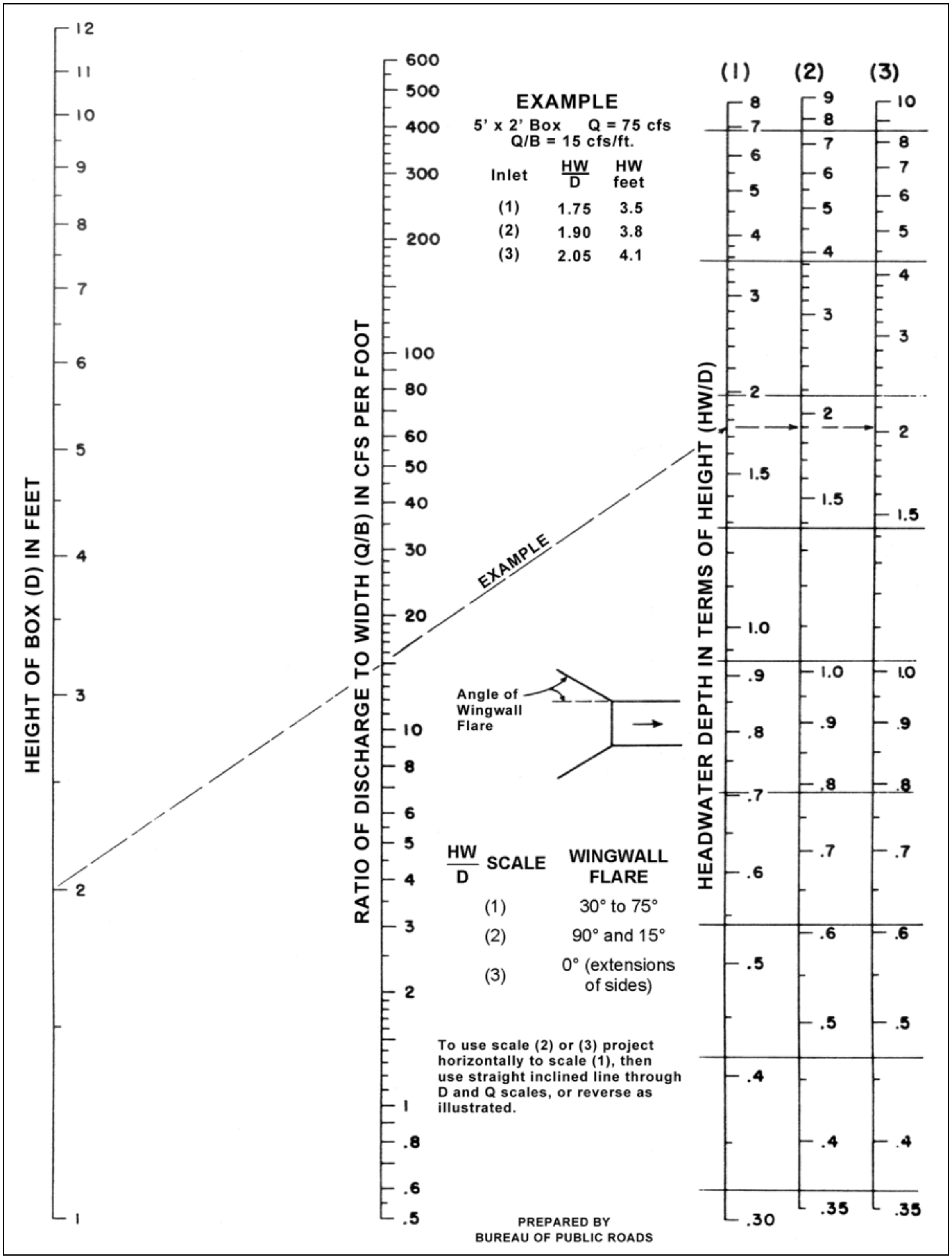
Figure 4-7. Headwater Depth for Box Culverts with Inlet Control



EXAMPLE

5' x 2' Box Q = 75 cfs
Q/B = 15 cfs/ft.

Inlet	$\frac{HW}{D}$	HW feet
(1)	1.75	3.5
(2)	1.90	3.8
(3)	2.05	4.1

$\frac{HW}{D}$ SCALE	WINGWALL 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 D and Q scales, or reverse as illustrated.

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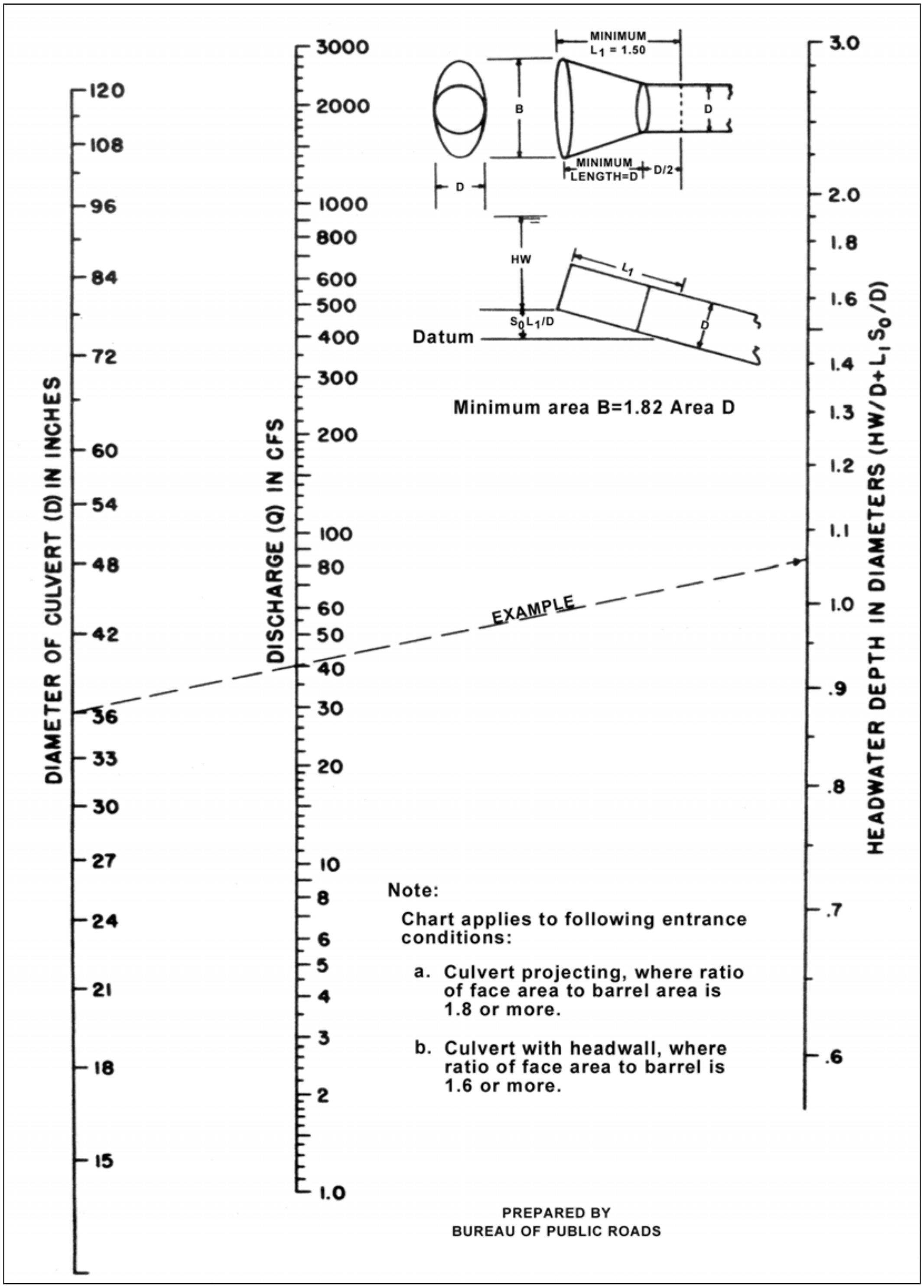
Figure 4-8. Headwater Depth for Corrugated Metal Pipe Culverts with Tapered Inlet Inlet Control



Minimum area B=1.82 Area D

Note:

Chart applies to following entrance conditions:

a. Culvert projecting, where ratio of face area to barrel area is 1.8 or more.

b. Culvert with headwall, where ratio of face area to barrel is 1.6 or more.

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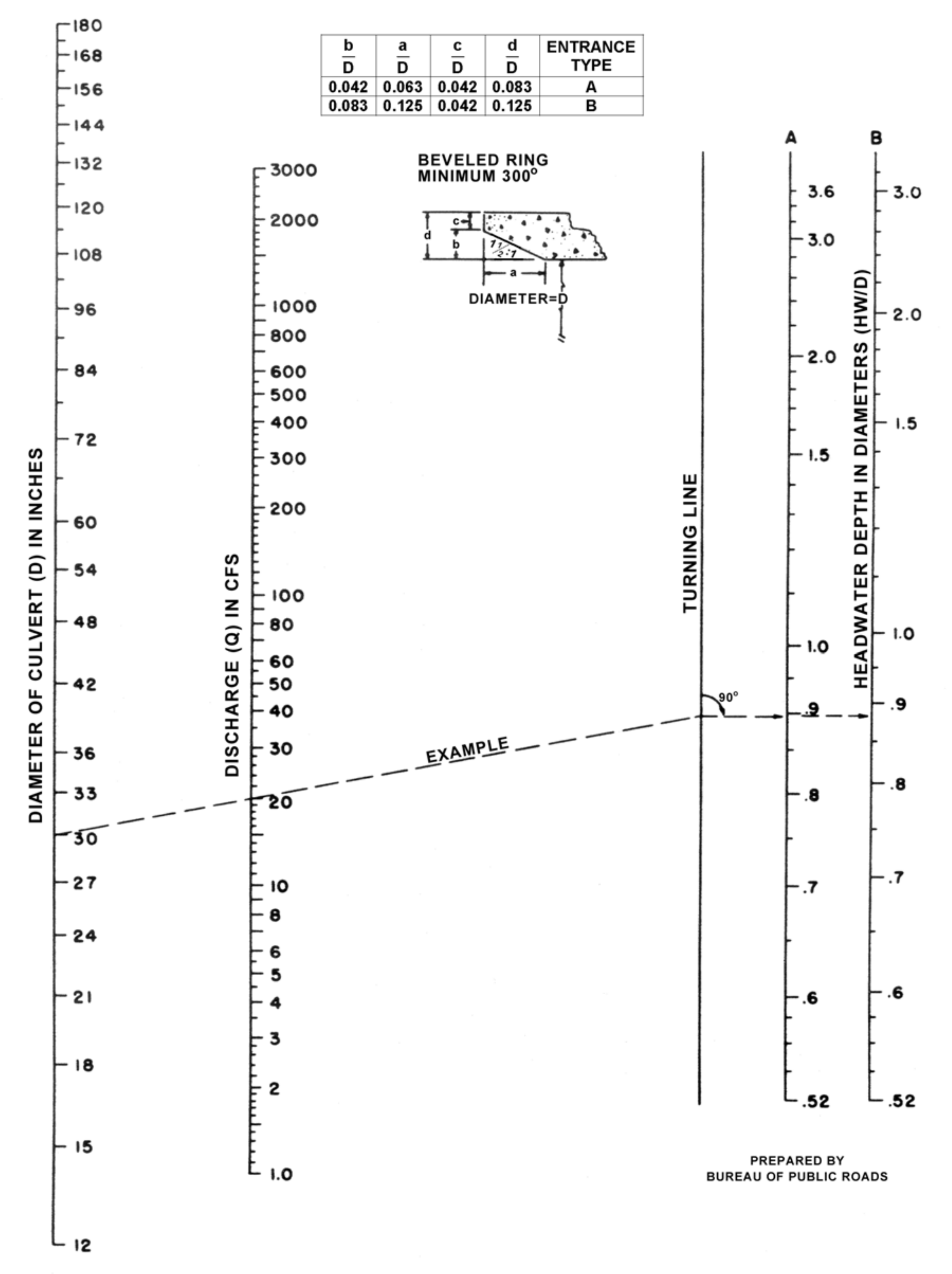
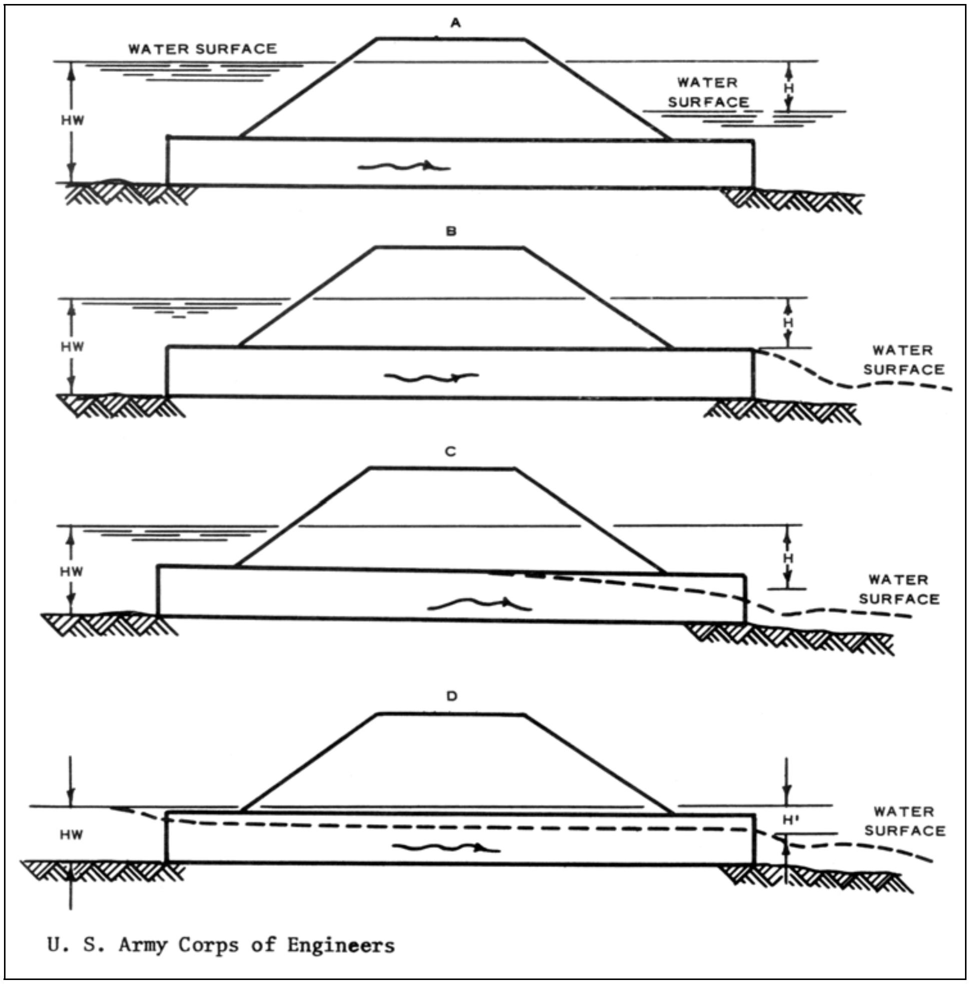
Figure 4-9. Headwater Depth for Circular Pipe Culverts with Beveled Ring Inlet Control



b/D	a/D	c/D	d/D	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

4-4.1.4 **Outlet Control.** Culverts flowing with outlet control can flow with the culvert barrel full or partially full for part of the barrel length or for all of it (Figure 4-10). If the entire barrel is filled (both cross section and length) with water, the culvert is said to be in full flow or flowing full (Figure 4-10, A and B). The other two common types of outlet-control flow are shown in Figure 4-10, C and D. The procedure given for outlet-control flow does not give an exact solution for a free-water-surface condition throughout the barrel length shown in Figure 4-10, D. An approximate solution is given for this case when the headwater, *HW*, is equal to or greater than 0.75*D*, where *D* is the height of the culvert barrel. The head, *H*, required to pass a given quantity of water through a culvert flowing full with control at the outlet is made up of three major parts.

Figure 4-10. Outlet Control



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4-4.1.4.1 These three parts are usually expressed in feet of water and include a velocity head, an entrance loss, and a friction loss. The velocity head (the kinetic energy of the water in the culvert barrel) equals $\frac{V^2}{2g}$. The entrance loss varies with the type or design of the culvert inlet and is expressed as a coefficient times the velocity head, or $K_e \frac{V^2}{2g}$. Values of K_e for various types of culvert entrances are given in Table 4-1. The friction loss, H_f, is the energy required to overcome the roughness of the culvert barrel and is usually expressed in terms of Manning's *n* (Table 6-1) and Equation 4-1:

$$H_f = \left(\frac{29n^2L}{R^{1.333}} \right) \left(\frac{V^2}{2g} \right) \tag{4-1}$$

Table 4-1. Entrance Loss Coefficients, Outlet Control, Full or Partly Full Entrance Head Loss, $H_e = K_e \frac{V^2}{2g}$ *

Type of Structure and Design of Entrance	Coefficient, K_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, square-cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 0.083 barrel dimension)	0.2
Mitered to conform to fill slope	0.7
**End section conforming to fill slope	0.5
Beveled edges, 33.7-degree or 45-degree bevels	0.2
Side- or sloped-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls, square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
**End section conforming to fill slope	0.5
Beveled edges, 33.7-degree or 45-degree bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 0.083 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30 degrees to 75 degrees to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 0.083 barrel dimension, or beveled top edge	0.2

Type of Structure and Design of Entrance	**Coefficient, K_e**
Wingwalls at 10 degrees to 25 degrees to barrel	
Square-edged at crown	0.7
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

* Table developed by the U.S. Army Corps of Engineers

** ***NOTE:*** Made of either metal or concrete, these end sections are 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. These latter sections can be designed using the information given for the beveled inlet.

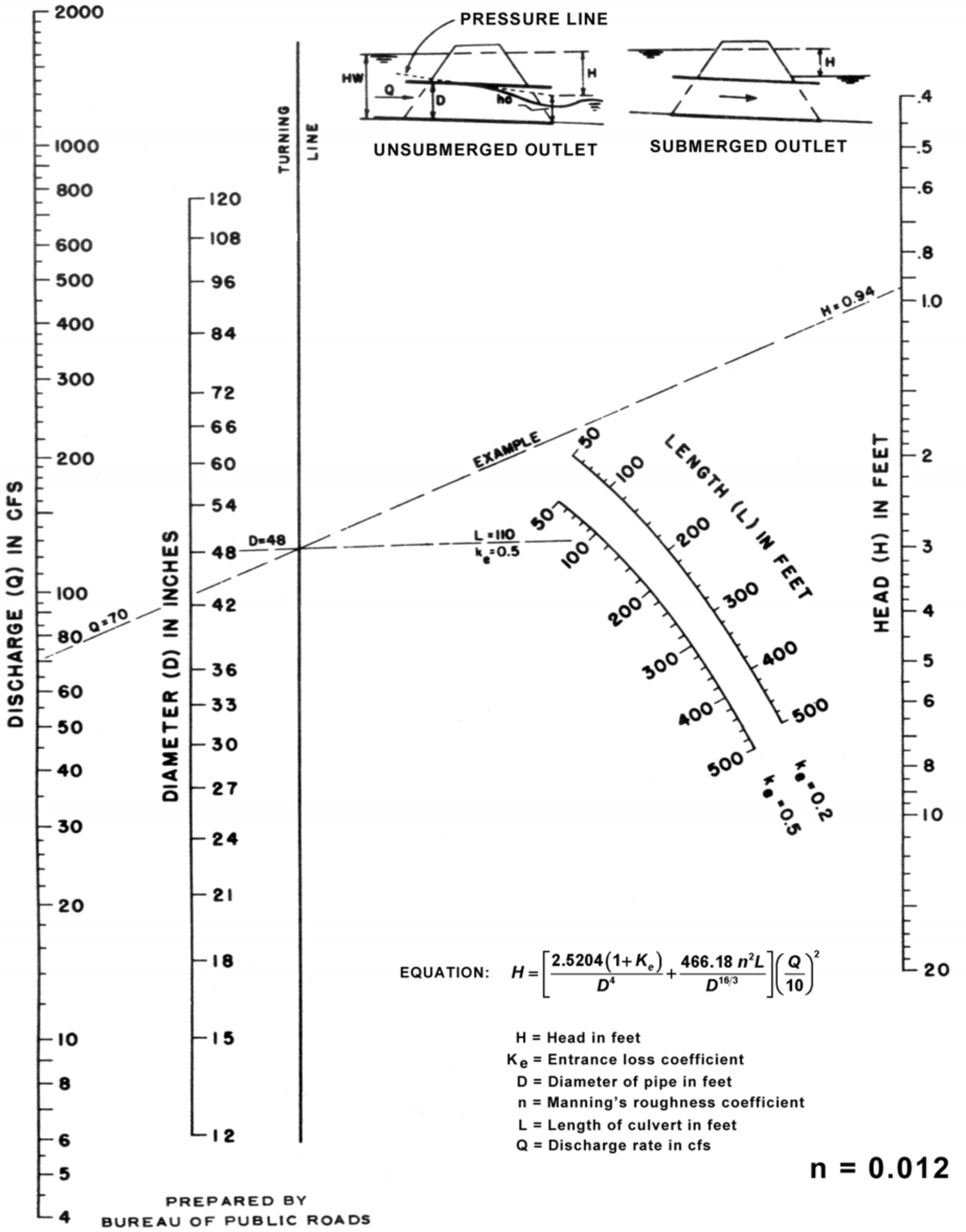
4-4.1.4.2 Adding the three terms and simplifying, yields for full pipe, outlet control flow Equation 4-2:

$$H = \left(1 + K_e + \frac{29n^2L}{R^{1.333}}\right)\left(\frac{V^2}{2g}\right) \tag{4-2}$$

This equation can be solved readily by the use of the full-flow nomographs, Figures 4-11 through 4-17. The equations shown on these nomographs are the same as Equation 4-1 but expressed in a different form. Each nomograph is drawn for a single value of n as noted in the respective figure. These nomographs may be used for other values of n by modifying the culvert length as explained later in this chapter in the section describing the use of the outlet-control nomographs. The value of H (head, ft) must be measured from some “control” elevation at the outlet that is dependent on the rate of discharge or the elevation of the water surface of the tailwater. For simplicity, a value h_o is used as the distance in feet from the culvert invert (flow line) at the outlet to the control elevation. Equation 4-3 is used to compute headwater in reference to the inlet invert:

$$HW = h_o + H - LS_o \tag{4-3}$$

Figure 4-11. Head for Circular Pipe Culverts Flowing Full, *n* = 0.012

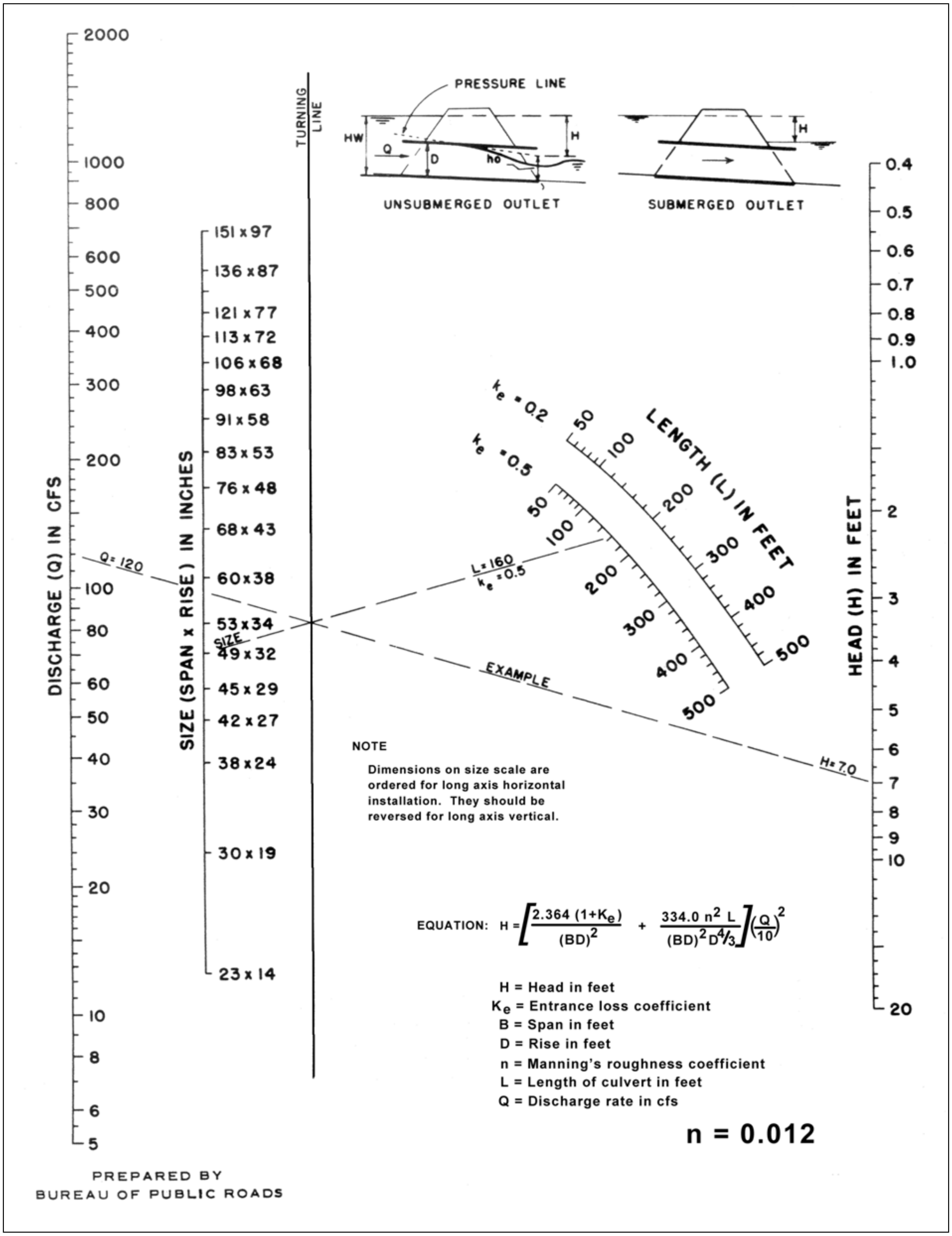


EQUATION: $H = \left[\frac{2.5204(1+K_e)}{D^4} + \frac{466.18\, n^2 L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$

H = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

n = 0.012

Figure 4-12. Head for Oval Circular Pipe Culverts Long Axis Horizontal or Vertical Flowing Full, *n* = 0.012



NOTE

Dimensions on size scale are ordered for long axis horizontal installation. They should be reversed for long axis vertical.

EQUATION: $$H = \left[\frac{2.364\,(1+K_e)}{(BD)^2} + \frac{334.0\,n^2\,L}{(BD)^2 D^{4/3}}\right]\left(\frac{Q}{10}\right)^2$$

H = Head in feet
K_e = Entrance loss coefficient
B = Span in feet
D = Rise in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

n = 0.012

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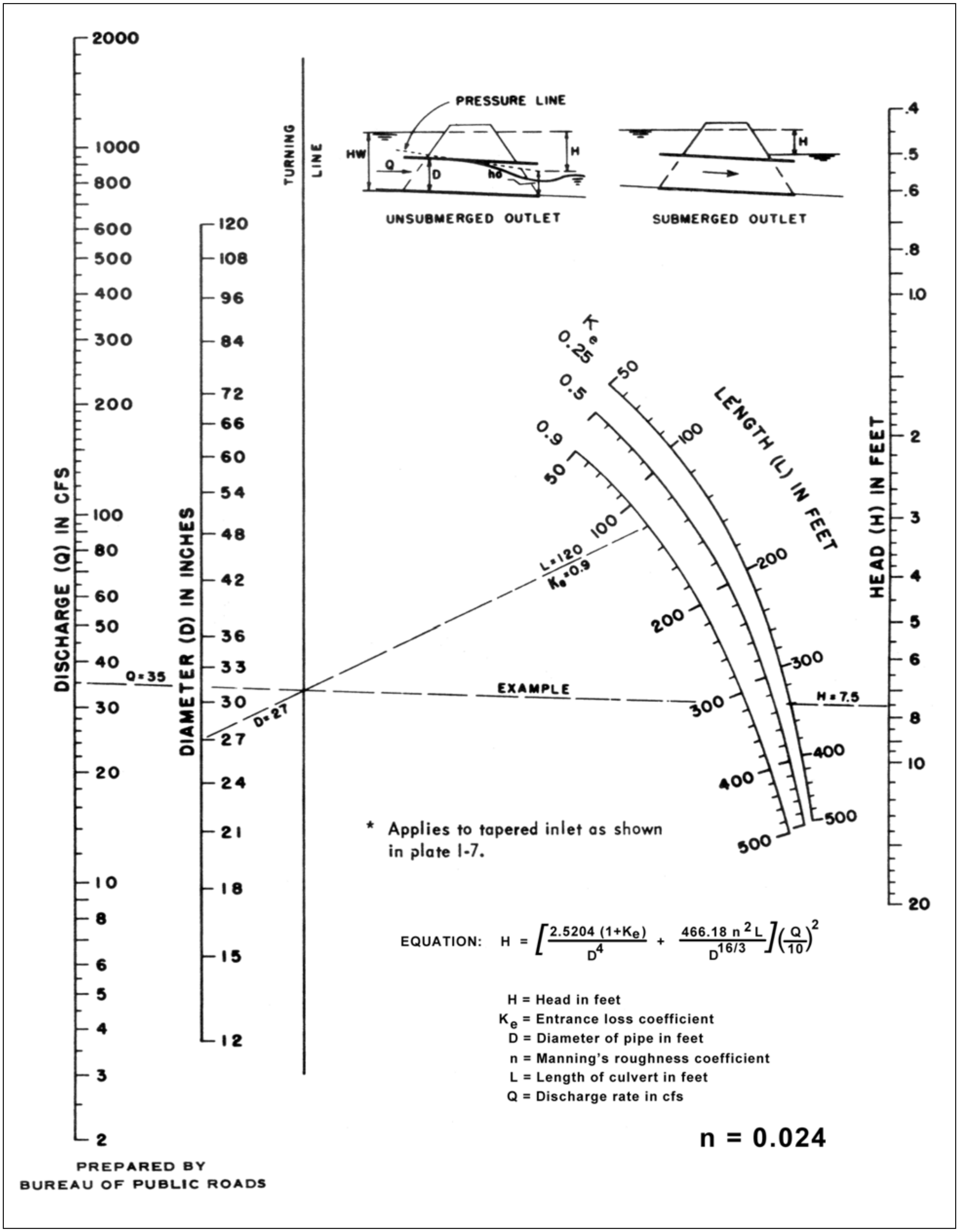
Figure 4-13. Head for Circular Pipe Culverts Flowing Full, *n* = 0.024



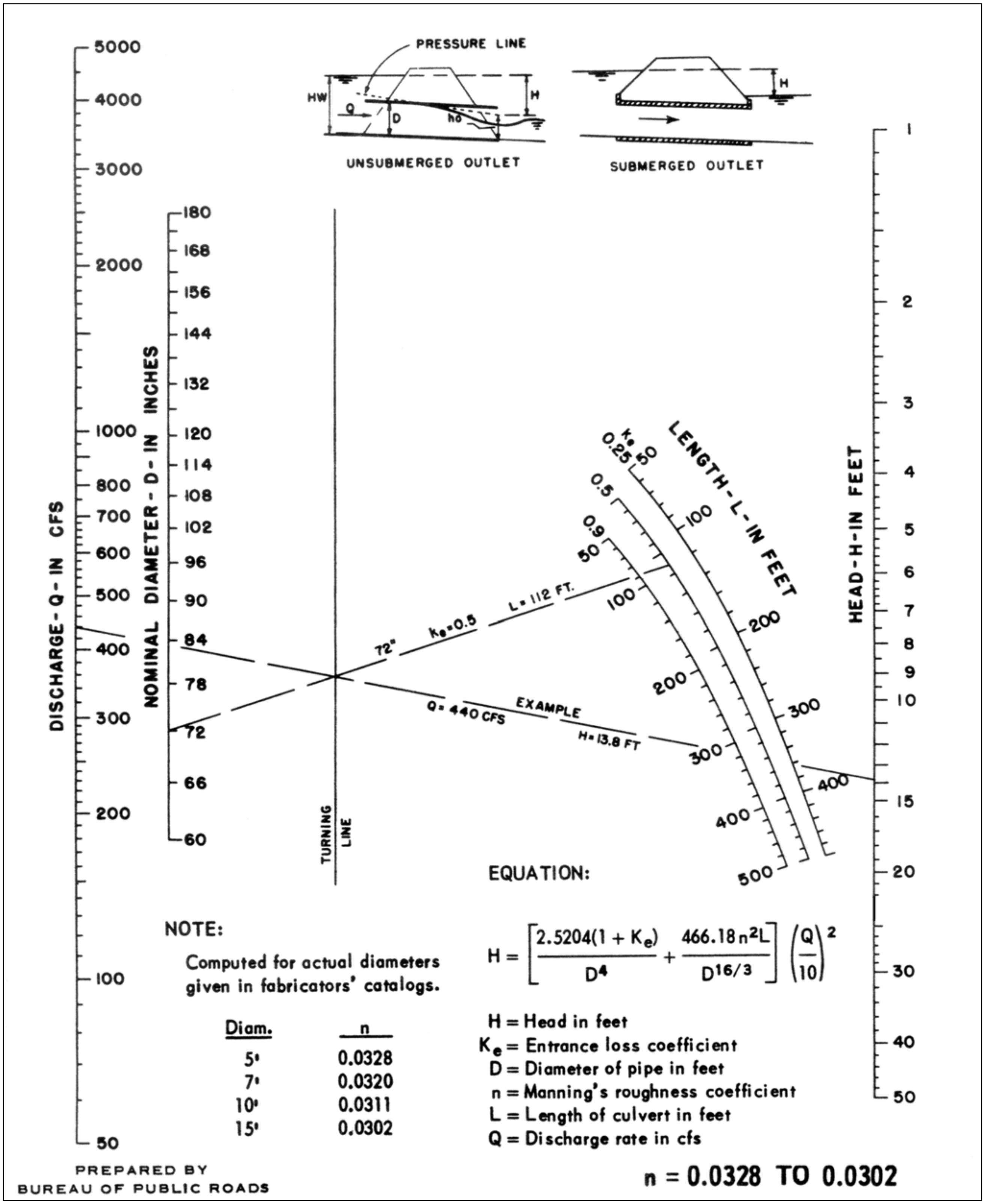
* Applies to tapered inlet as shown in plate I-7.

EQUATION: $$H = \left[\frac{2.5204\,(1+K_e)}{D^4} + \frac{466.18\,n^2 L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$$

H = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

n = 0.024

Figure 4-14. Head for Circular Pipe Culverts Flowing Full, *n* = 0.0328 to 0.0302



NOTE:

Computed for actual diameters given in fabricators' catalogs.

Diam.	n
5'	0.0328
7'	0.0320
10'	0.0311
15'	0.0302

EQUATION:

$$H = \left[\frac{2.5204(1+K_e)}{D^4} + \frac{466.18\,n^2L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$$

H = Head in feet
K_e = Entrance loss coefficient
D = Diameter of pipe in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

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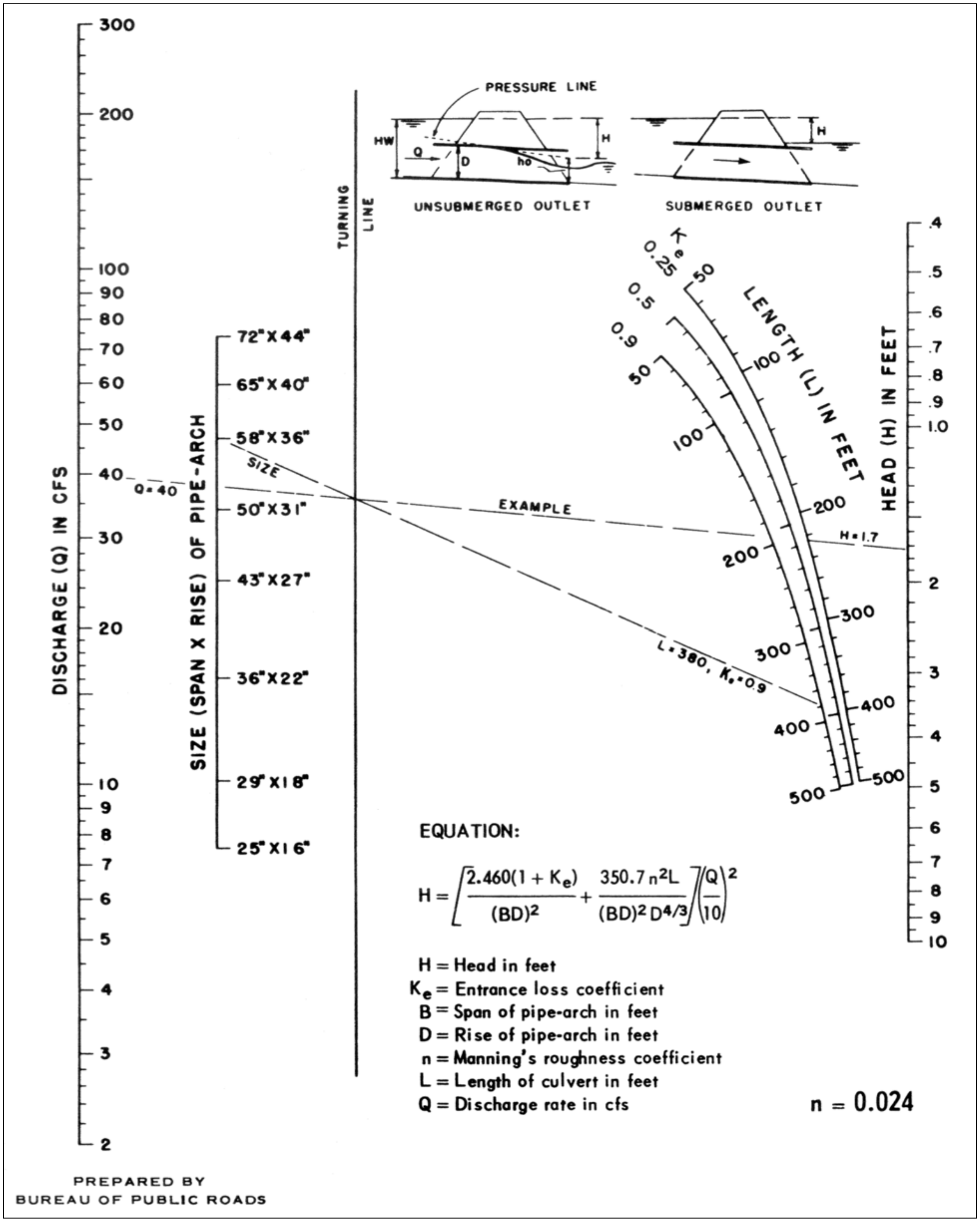
n = 0.0328 TO 0.0302

Figure 4-15. Head for Standard Corrugated Metal Pipe-Arch Culverts Flowing Full, *n* = 0.024



EQUATION:

$$H = \left[\frac{2.460(1 + K_e)}{(BD)^2} + \frac{350.7\, n^2 L}{(BD)^2 D^{4/3}}\right]\left(\frac{Q}{10}\right)^2$$

H = Head in feet
K_e = Entrance loss coefficient
B = Span of pipe-arch in feet
D = Rise of pipe-arch in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

$n = 0.024$

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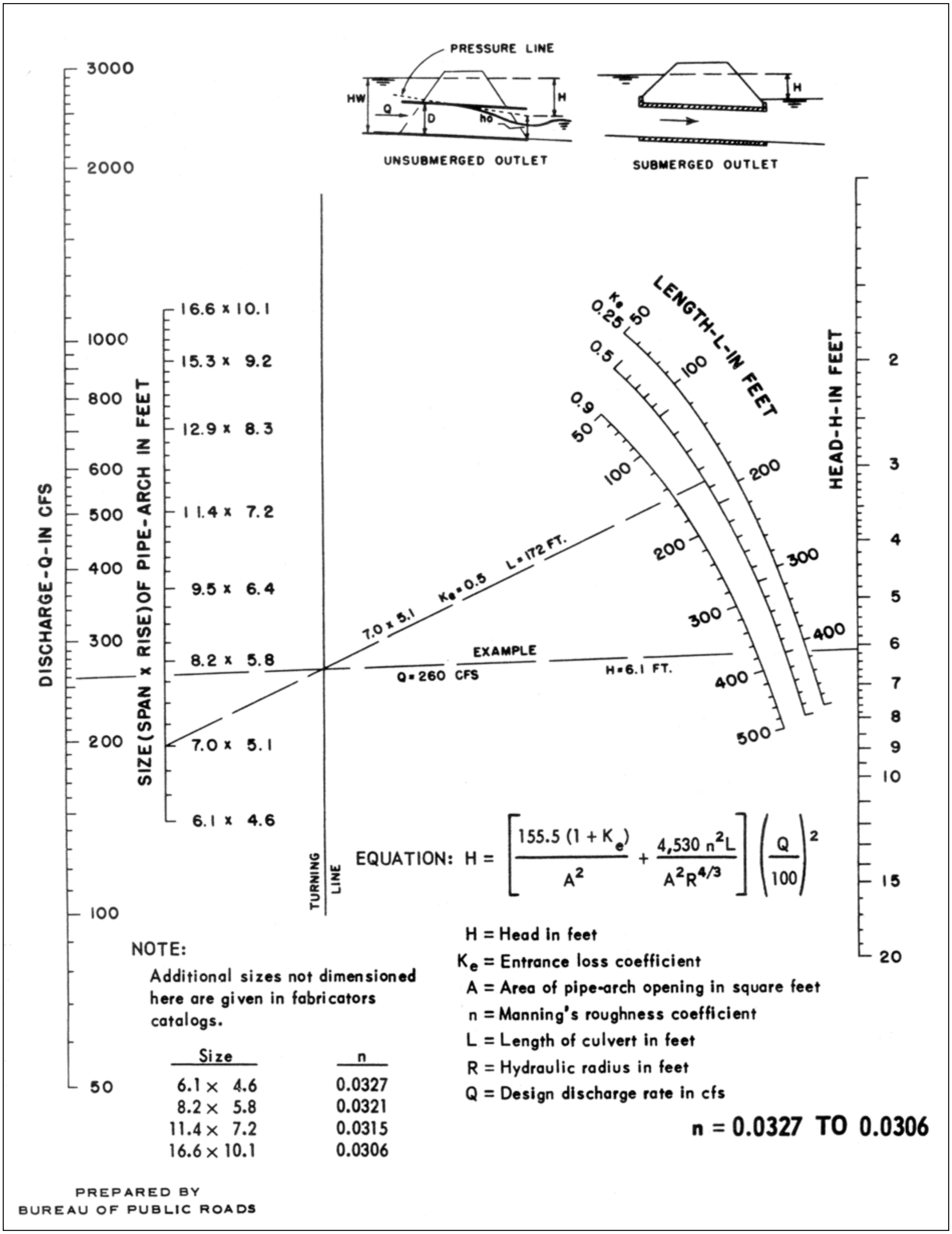
Figure 4-16. Head for Field-Bolted Structural Plate Pipe-Arch Culverts 18 in. Corner Radius Flowing Full, *n* = 0.0327 to 0.0306



EQUATION: $H = \left[\frac{155.5\,(1 + K_e)}{A^2} + \frac{4{,}530\, n^2 L}{A^2 R^{4/3}}\right]\left(\frac{Q}{100}\right)^2$

H = Head in feet
K_e = Entrance loss coefficient
A = Area of pipe-arch opening in square feet
n = Manning's roughness coefficient
L = Length of culvert in feet
R = Hydraulic radius in feet
Q = Design discharge rate in cfs

NOTE:
Additional sizes not dimensioned here are given in fabricators catalogs.

Size	n
6.1 × 4.6	0.0327
8.2 × 5.8	0.0321
11.4 × 7.2	0.0315
16.6 × 10.1	0.0306

n = 0.0327 TO 0.0306

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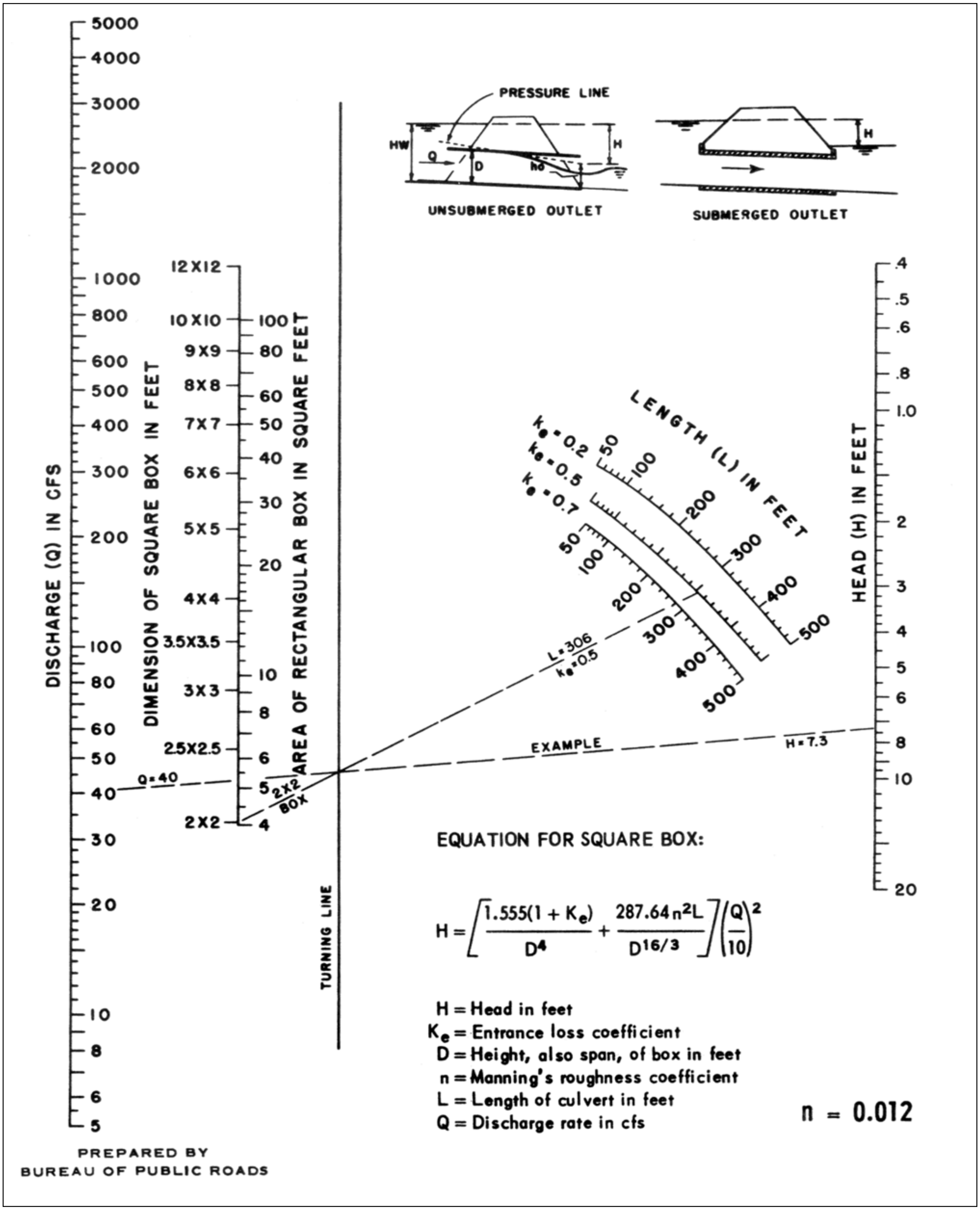
Figure 4-17. Head for Concrete Box Culverts Flowing Full, *n* = 0.012



EQUATION FOR SQUARE BOX:

$$H = \left[\frac{1.555(1 + K_e)}{D^4} + \frac{287.64\,n^2 L}{D^{16/3}}\right]\left(\frac{Q}{10}\right)^2$$

H = Head in feet
K_e = Entrance loss coefficient
D = Height, also span, of box in feet
n = Manning's roughness coefficient
L = Length of culvert in feet
Q = Discharge rate in cfs

$n = 0.012$

4-4.1.5 **Tailwater Elevation at or Above the Top of the Culvert Barrel Outlet (Figure 4-10, A)**. The tailwater (TW) depth is equal to h_o, and the relation of headwater to other terms in Equation 4-3 is illustrated in Figure 4-18.

Figure 4-18. Tailwater Elevation at or Above the Top of the Culvert

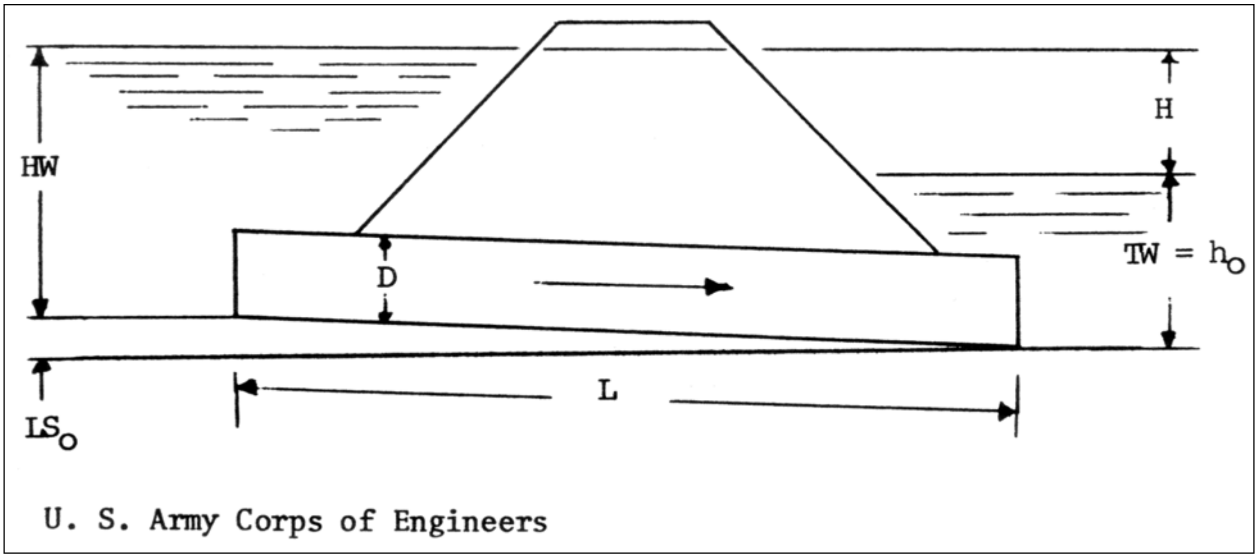


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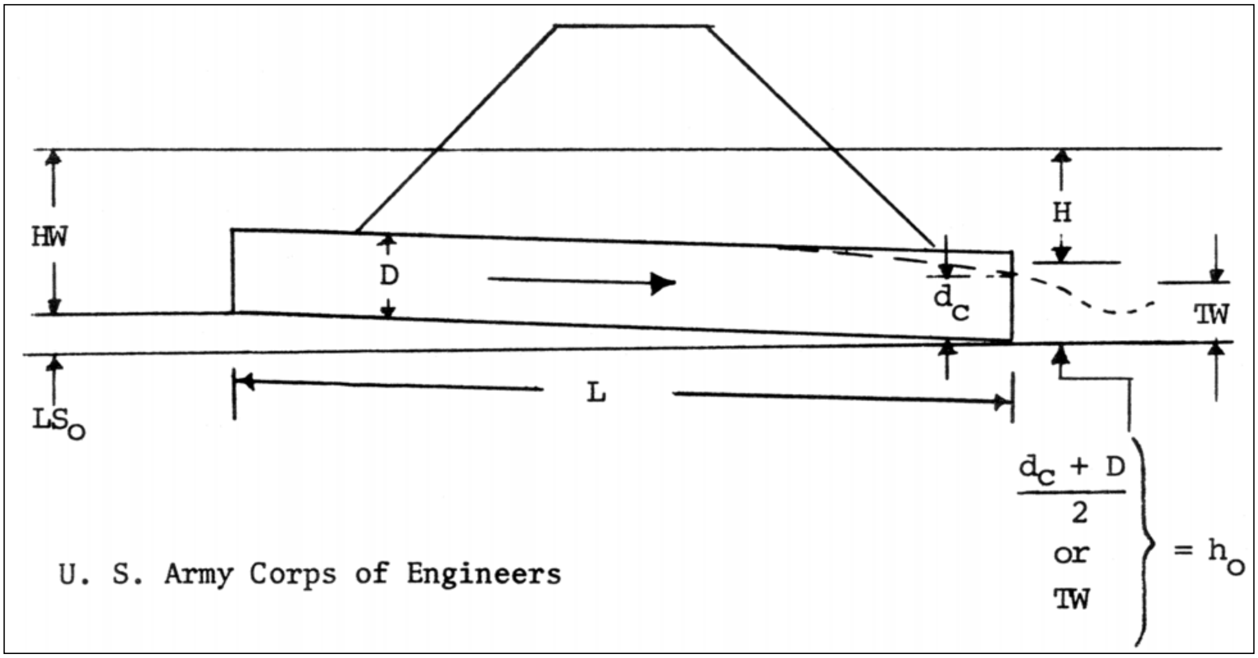
Figure 4-19. Tailwater Below the Top of the Culvert



$$\left.\begin{matrix}\frac{d_c + D}{2}\\ \text{or}\\ TW\end{matrix}\right\} = h_o$$

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