CHAPTER

DESIGN OF CULVERTS 4

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4.1 Introduction

Primary considerations for the final selection of any drainage structure are that its design be based upon appropriate hydraulic principles, economy, and minimized effects on adjacent property by the resultant headwater depth and outlet velocity. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the highway. It is this allowable headwater depth that is the primary basis for sizing a culvert.

Performance curves should be developed for all culverts for evaluating the hydraulic capacity of a culvert for various headwaters. These will display the consequence of high flow rates at the site and any possible hazards. Sometimes a small increase in flow rate can affect a culvert design. If only the design peak discharge is used in the design, the engineer cannot assess what effects increases in the estimated design discharge will have on the culvert design.

4.2 Symbols And Definitions

To provide consistency within this chapter as well as throughout this manual the following symbols will be used. These symbols were selected because of there wide use in many culvert design publications.

Table 4-1 Symbols And Definitions

Symbol	Definition	Units
A	Area of cross section of flow	sq. ft
B	Barrel width	ft
C_d	Overtopping discharge coefficient	-
D	Culvert diameter or barrel depth	in. or ft
d	Depth of flow	ft
d_c	Critical depth of flow	ft
d_u	Uniform depth of flow	ft
g	Acceleration of gravity	ft/s
H_f	Depth of pool or head, above the face section of invert	ft
h_o	Height of hydraulic grade line above outlet invert	ft
HW	Headwater depth above invert of culvert (depth from inlet invert to upstream total energy grade line)	ft
K_e	Inlet loss coefficient	-
L	Length of culvert	ft
N	Number of barrels	-
Q	Rate of discharge	cfs
S	Slope of culvert	ft/f
TW	Tailwater depth above invert of culvert	ft
V	Mean velocity of flow	ft/s
V_c	Critical velocity	ft/s

4.3 Engineering Design Criteria

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The following design criteria should be considered for all culvert designs as applicable.

Frequency Flood - The design storm for culverts is the 100-year storm using future development land use conditions, assuming no detention. The design for lateral systems shall be based on the 25-year storm event using future development land use conditions assuming no detention. The 100-year frequency storm shall be routed through all culverts to be sure building structures (i.e., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

Velocity Limitations - Both minimum and maximum velocities should be considered when - designing a culvert. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. The maximum allowable velocity for a pipe flowing full is 15 feet per second. A minimum velocity of 3.0 feet per second, for the 2-year flow velocity, when the culvert is flowing partially full is required to ensure a self-cleaning condition during partial depth flow.

Buoyancy Protection - Headwalls, endwalls, slope paving or other means of anchoring should be considered for all culverts where buoyancy may be a problem.

Length And Slope - The culvert length and slope should be chosen to approximate existing topography, and to the degree practicable: the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment. The maximum slope using concrete pipe is 10% and for CMP is 14% before pipe restraining methods must be taken. The maximum drop in a drainage structure is 10 feet.

Debris Control - In designing debris control structures it is recommended that the Hydraulic Engineering Circular No. 9 entitled "Debris - Control Structures" be consulted.

Headwater Limitations - The allowable headwater elevation is determined from an evaluation of land use upstream of the culvert and the proposed or existing roadway elevation. Headwater is the depth of water above the culvert invert at the entrance end of the culvert.

The following criteria related to headwater should be considered:

- The allowable headwater for design frequency conditions should allow for the following upstream controls.
  - 18 inch freeboard.
  - Upstream property damage.
  - Elevations established to delineate flood plain zoning.
  - Low point in the road grade that is not at the culvert location.
  - Ditch elevation of the terrain that will permit flow to divert around culvert.
    - Following HW/D criteria -
      1. For drainage facilities with cross-section area equal to or less than 30 sq. ft - HW/D = to or < 1.5.
      2. For drainage facilities with cross-section area greater than 30 sq. ft - HW/D = to or < 1.2.
    - The headwater should be checked for the 100-year flood to ensure compliance with flood plain management criteria and for most facilities the culvert should be sized to maintain flood-free conditions on major thoroughfares with 18 inches freeboard at the low-point of the road.
    - The maximum acceptable outlet velocity should be identified (see Section 5.2.3 in Open Channel Design chapter). Either the headwater should be set to

produce acceptable velocities or stabilization or energy dissipation should be provided where these velocities are exceeded.

- Other site-specific design considerations should be addressed as required.
- In general the constraint which gives the lowest allowable headwater elevation establishes the criteria for the hydraulic calculations.

Tailwater Considerations - The hydraulic conditions downstream of the culvert site must be evaluated to determine a tailwater depth for a range of discharge. At times there may be a need for calculating backwater curves to establish the tailwater conditions. The following conditions must be considered:

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.
- For culverts which discharge to an open channel, the stage-discharge curve for the channel must be determined. See Open Channel Design Chapter.
- If an upstream culvert outlet is located near a downstream culvert inlet, the headwater elevation of the downstream culvert may establish the design tailwater depth for the upstream culvert.
- If the culvert discharges to a lake, pond, or other major water body, the expected high water elevation of the particular water body may establish the culvert tailwater.

Storage - If storage is being assumed upstream of the culvert, consideration should be given to:

- the total area of flooding,
- the average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and
- ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

Culvert Inlets - Hydraulic efficiency and cost can be significantly affected by inlet conditions. The inlet coefficient K_e, is a measure of the hydraulic efficiency of the inlet, with lower values indicating greater efficiency. Recommended inlet coefficients are given in Table 4-2.

Inlets With Headwalls - Headwalls may be used for a variety of reasons including increasing the efficiency of the inlet, providing embankment stability, providing embankment protection against erosion, providing protection from buoyancy, and shorten the length of the required structure. Headwalls are usually required for all culverts and where buoyancy protection is necessary.

If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron should be provided at the toe of the headwall. This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

Wingwalls And Aprons - Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable or where the culvert is skewed to the normal channel flow.

Improved Inlets - Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance at the culvert.

Material Selection - Reinforced concrete pipe (RCP) is recommended for use (1) under a roadway, (2) when pipe slopes are less than 1%, or (3) for all flowing streams. RCP and fully coated corrugated metal pipe with paved invert can be used in all other cases. High Density

Polyethylene pipe may also be used as approved by DeKalb County. Table 4-3 gives recommended Manning's n values for different materials. Aluminized steel type 2 corrugated steel pipe is an approved material for use outside the public right-of-way.

Culvert Skews - Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval.

Culvert Sizes - The minimum size road culvert shall be 18 inches.

Weep Holes - Weep holes are sometimes used to relieve uplift pressure. Filter materials should be used in conjunction with the weep holes in order to intercept the flow and prevent the formation of piping channels. The filter materials should be designed as underdrain filter so that it will not become clogged and so that piping cannot occur through the pervious material and the weep hole.

Outlet Protection - Outlet protection should be provided where erosive potential is a design concern. See Energy Dissipation Chapter for information on the design of outlet protection.

Erosion And Sediment Control - Shall be in accordance with the latest approved DeKalb County Soil Erosion and Sediment Control Ordinance. See the Manual For Erosion and Sediment Control in Georgia for design standards and details related to erosion and sediment control.

Environmental Considerations - Where compatible with good hydraulic engineering, a site should be selected that will permit the culvert to be constructed to cause the least impact on the stream or wetlands. This selection must consider the entire site, including any necessary lead channels.

4.4 Design Procedures

4.4.1 Inlet And Outlet Control

Inlet Control - If the culvert is operating on a steep slope it is likely that the entrance geometry will control the headwater and the culvert will be on inlet control.

Outlet Control - If the culvert is operating on a mild slope, the outlet characteristics will probably control the flow and the culvert will be on outlet control.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information on inlet and outlet control see the Federal Highway Administration publication entitled - Hydraulic Design Of Highway Culverts, HDS-5, 1985, and AASHTO Model Drainage Manual, 1998.

Table 4-2 Inlet Coefficients

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (grove-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 = 1/12(D)]	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal[1]	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° 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 [1/12(D)] or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of [1/12(D)] or beveled top edge	0.2
Wingwalls at 10° or 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

[1] Although laboratory tests have not been completed on K_e values for High Density Polyethylene (HDPE) pipes, the K_e values for corrugated metal pipes are recommended for HDPE pipes.

* Note: End Section conforming to fill slope, made of either metal or concrete, 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**.**

Table 4-3 Manning's n Values

Type of Conduit	**Wall & Joint Description**	**Manning's n**
Concrete Pipe	Good joints, smooth walls	0.013
	Good joints, rough walls	0.016
	Poor joints, rough walls	0.017
Concrete Box	Good joints, smooth finished walls	0.012
	Poor joints, rough, unfinished walls	0.018
Corrugated	2 2/3 by 1/2 inch corrugations	0.024
Metal Pipes and	6 by 1 inch corrugations	0.025

Boxes Annular Corrugations	5 by 1 inch corrugations	0.026
	3 by 1 inch corrugations	0.028
	6 by 2 inch structural plate	0.035
	9 by 2 1/2 inch structural plate	0.035
Corrugated Metal Pipes, Helical Corrugations, Full Circular Flow	2 2/3 by 1/2 inch corrugated 24 inch plate width	0.020
Spiral Rib Metal Pipe	3/4 by 3/4 in recesses at 12 inch spacing, good joints	0.013
High Density Polyethylene (HDPE)		
	Corrugated Smooth Liner	0.011
	Corrugated	0.024
Polyvinyl Chloride (PVC)		0.011

Note: For further information concerning Manning n values for selected conduits consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5, page 163

4.4.2 Procedures

There are two procedures for designing culverts: (1) the manual use of inlet and outlet control nomographs and (2) the use of a personal computer system such as HY8 - Culvert Analysis Microcomputer Program (Section 4.8 of this chapter). The following will outline the design procedures for use of the nomograph.

4.4.3 Nomographs

The use of nomographs require a trial and error solution. The solution is quite easy and provides reliable designs for many applications. It should be remembered that velocity, hydrograph routing, roadway overtopping, and outlet scour require additional, separate computations beyond what can be obtained from the nomographs.

Figures 4-1 and 4-2 show examples of an inlet control and outlet control nomograph that can be used to design concrete pipe culverts. For culvert designs not covered by these nomographs, refer to the complete set of nomographs given in Appendix A at the end of this chapter.

4.4.4 Steps In Design Procedure

The design procedure requires the use of inlet and outlet nomographs.

Step Action

(1) List design data:

Q = discharge (cfs)
S = culvert slope (ft/ft)
V = velocity for trial diameter (ft/s)
L = culvert length (ft)
TW= tailwater depth (ft)
K_e= inlet loss coefficient
HW= allowable headwater depth for the design storm (ft)

(2) Determine trail culvert size by assuming a trial velocity 3 to 5 ft/s and computing the culvert area, $A = Q/V$. Determine the culvert diameter (inches).

(3) Find the actual HW for the trial size culvert for both inlet and outlet control.

- For inlet control, enter inlet control nomograph with D and Q and find HW/D for the proper entrance type.
- Compute HW and, if too large or two small, try another culvert size before computing HW for outlet control.
- For outlet control enter the outlet control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter.
- To compute HW, connect the length scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from the equation:

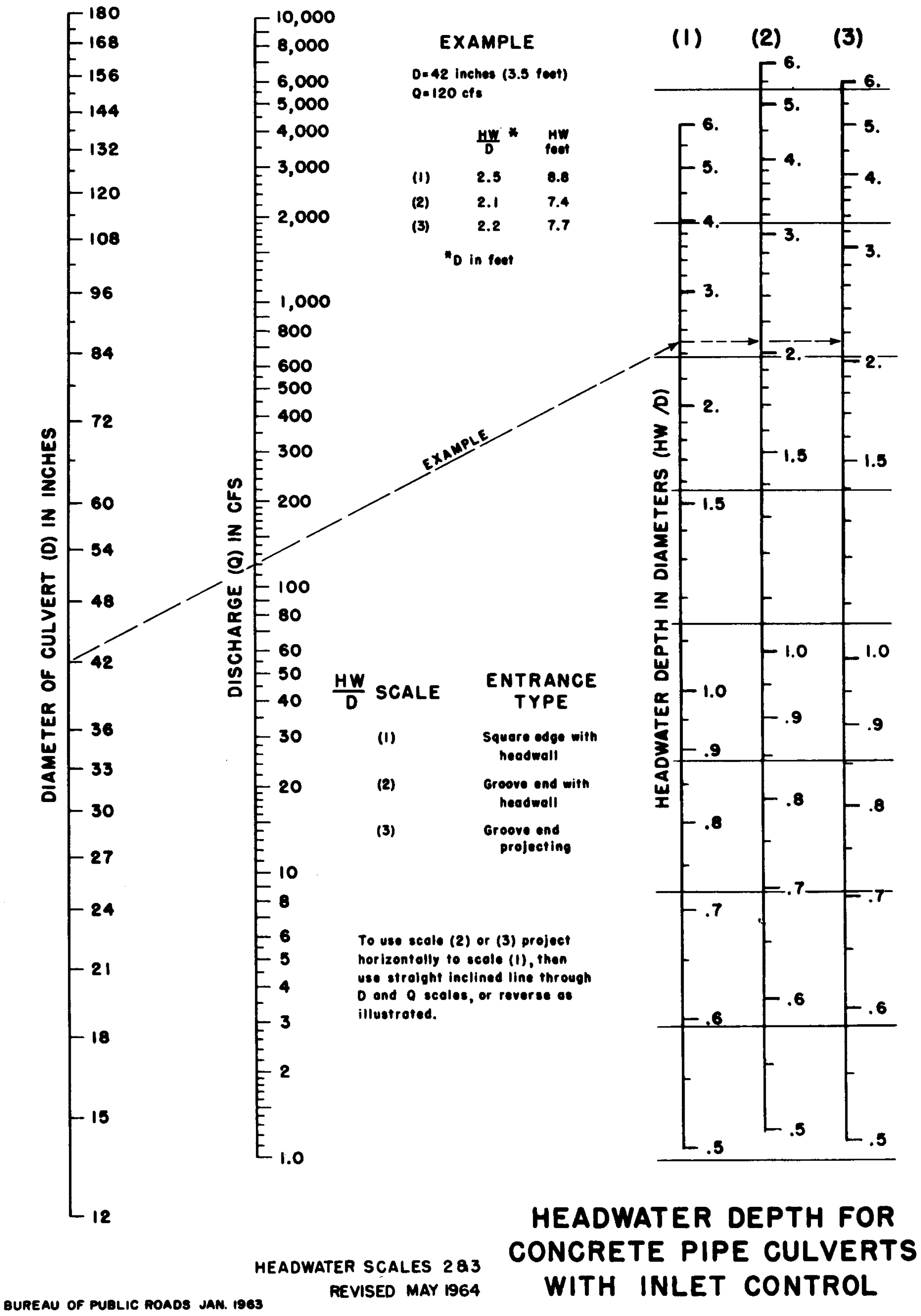
$$\mathbf{HW = H + h_o - LS} \qquad \mathbf{(4.1)}$$

Where: h_o = ½ (critical depth + D), or tailwater depth, whichever is greater.

(4) Compare the computed headwaters and use the higher HW nomograph to determine if the culvert is under inlet or outlet control.

If outlet control governs and the HW is unacceptable, select a larger trial size and find another HW with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable HW by the inlet control nomographs, the inlet control for the larger pipe need not be checked.

(5) Calculate exit velocity and expected streambed scour to determine if an energy dissipator is needed.



EXAMPLE

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

	$\frac{HW}{D}$ *	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

$\frac{HW}{D}$ 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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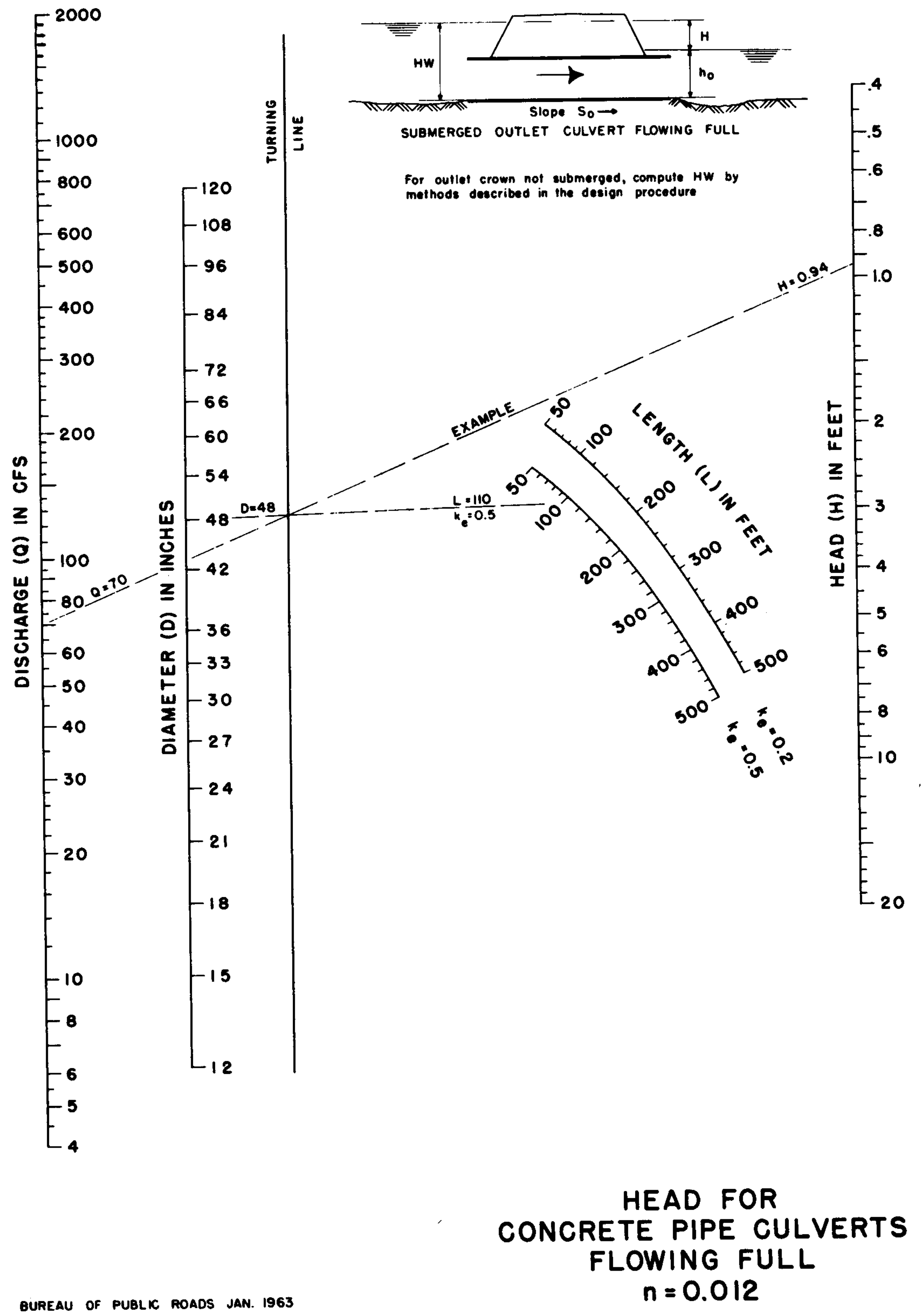
HEADWATER SCALES 2&3
REVISED MAY 1964

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

Figure 4-1



SUBMERGED OUTLET CULVERT FLOWING FULL
HW
H
h_o
Slope S_o
For outlet crown not submerged, compute HW by methods described in the design procedure
DISCHARGE (Q) IN CFS
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
DIAMETER (D) IN INCHES
120
108
96
84
72
66
60
54
48
42
36
33
30
27
24
21
18
15
12
TURNING LINE
LENGTH (L) IN FEET
50
100
200
300
400
500
k_e = 0.2
k_e = 0.5
HEAD (H) IN FEET
.4
.5
.6
.8
1.0
2
3
4
5
6
8
10
20
EXAMPLE
Q=70
D=48
L=110
k_e=0.5
H=0.94
HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL
n = 0.012
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Figure 4-2

4.4.5 Performance Curves - Roadway Overtopping

A performance curve for any culvert can be obtain from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater vs. discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes. Such computations are made much easier by the computer program discussed in Section 4.8 of this chapter.

To complete the culvert design, roadway overtopping should be analyzed. A performance curve showing the culvert flow as well as the flow across the roadway is a useful analysis tool. Rather than using a trial and error procedure to determine the flow division between the overtopping flow and the culvert flow, an overall performance curve can be developed.

The overall performance curve can be determined as follows:

Step Action

(1) Select a range of flow rates and determine the corresponding headwater elevations for the culvert flow alone. The flow rates should fall above and below the design discharge and cover the entire flow range of interest. Both inlet and outlet control headwaters should be calculated.

(2) Combine the inlet and outlet control performance curves to define a single performance curve for the culvert.

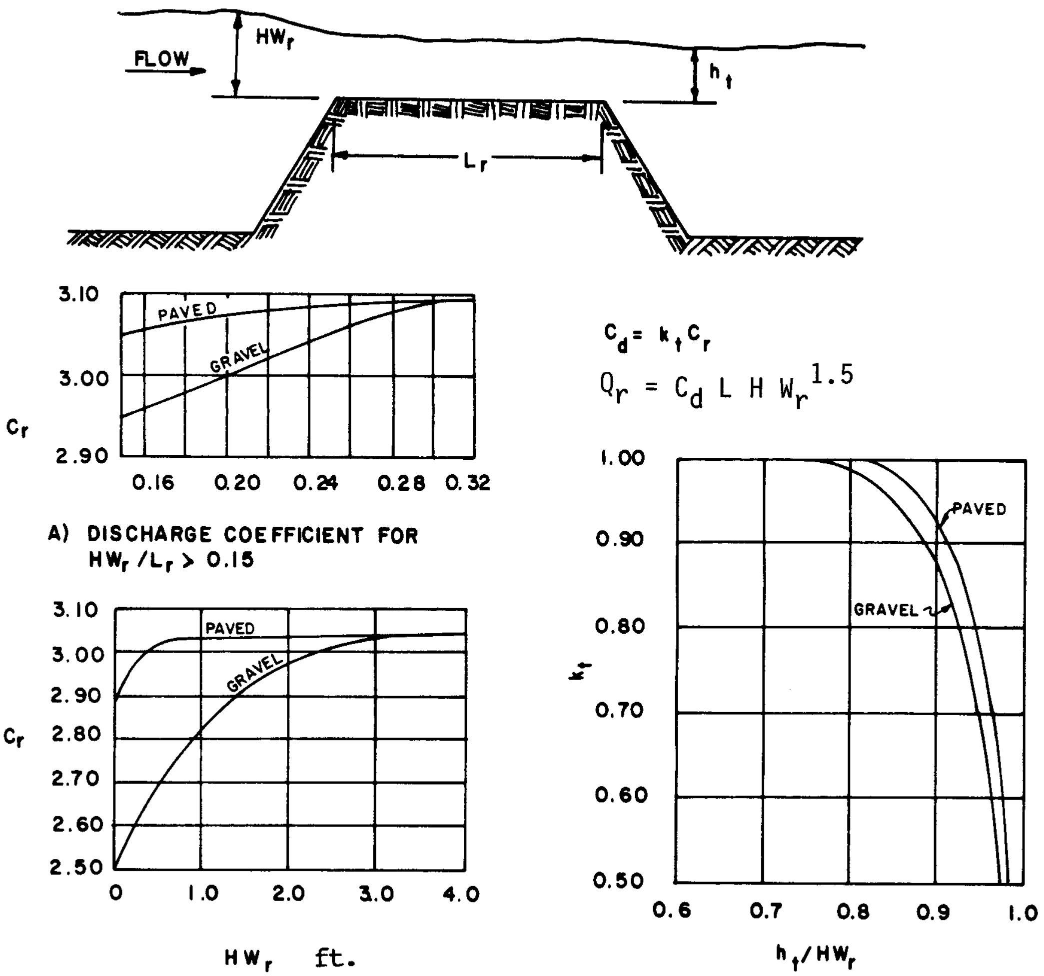
(3) When the culvert headwater elevations exceed the roadway crest elevation, overtopping will begin. Calculate the equivalent upstream water surface depth above the roadway (crest of weir) for each selected flow rate. Use these water surface depths and equation 4.2 to calculate flow rates across the roadway.

$$\mathbf{Q = C_d L(HW)^{1.5}} \qquad \mathbf{(4.2)}$$

Where: Q = overtopping flow rate (cfs/s)
C_d = overtopping discharge coefficient
L = length of roadway (ft)
HW = upstream depth, measured from the roadway crest to the water surface upstream of the weir drawdown (ft)

Note: See Figure 4-3 on the next page for guidance in determining a value for C_d. For more information on calculating overtopping flow rates see pages 39 - 42 in HDS No. 5.

(4) Add the culvert flow and the roadway overtopping flow at the corresponding headwater elevations to obtain the overall culvert performance curve.



A) DISCHARGE COEFFICIENT FOR $HW_r/L_r > 0.15$

B) DISCHARGE COEFFICIENT FOR $HW_r/L_r \leq 0.15$

C) SUBMERGENCE FACTOR

Figure 4-3
Discharge Coefficients for Roadway Overtopping

4.4.6 Storage Routing

A significant storage capacity behind a highway embankment attenuates a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert, and its size, may be reduced considerably. If significant storage is anticipated behind a culvert, the design should be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. Routing procedures are outlined in Hydraulic Design of Highway Culverts, Section V - Storage Routing, HDS No. 5, Federal Highway Administration.

The storage should be taken into consideration only if the storage area will remain available for the life of the culvert as a result of purchase of ownership or right-of-way or an easement has been acquired.

4.5 Culvert Design Example

4.5.1 Introduction

The following example problem illustrates the procedures to be used in designing culverts using the nomographs.

4.5.2 Example

Size a culvert given the following example data which were determined by physical limitations at the culvert site and hydraulic procedures described elsewhere in this handbook.

4.5.3 Example Data

<u>Input Data</u>

Discharge for 2-yr flood = 39 cfs
Discharge for 100-yr flood = 70 cfs
Allowable H_W for 100-yr discharge = 7.0 ft
Length of culvert = 100 ft
Natural channel invert elevations - inlet = 15.50 ft, outlet = 15.35 ft
Culvert slope = 0.0015 ft/ft
Tailwater depth for 100-yr discharge = 4.0 ft
Tailwater depth is the normal depth in downstream channel
Entrance type = Groove end with headwall

4.5.4 Computations

<u>Steps</u> <u>Computation</u>

1. Assume a culvert velocity of 5 ft/s. Required flow area = 70 cfs/5 ft/s = 14 sq. ft (for the 100-yr recurrence flood).

2. The corresponding culvert diameter is about 48 in. This can be calculated by using the formula for area of a circle: Area = $(3.14D^2)/4$ or D = $(\text{Area times } 4/3.14)^{0.5}$. Therefore: D = $((14 \text{ sq ft} \times 4)/3.14)^{0.5} \times 12$ in./ft) = 50.7 in.

3. A grooved end culvert with a headwall is selected for the design. Using the inlet control nomograph (Figure 4-1), with a pipe diameter of 48 in. and a discharge of 70 cfs; read a HW/D value of 0.93.

4. The depth of headwater (HW) is (0.93) x (4) = 3.72 ft which is less than the allowable headwater of 4.5 ft.

5. The culvert is checked for outlet control by using Figure 4-2.

   With an entrance loss coefficient K_e of 0.20, a culvert length of 100 ft, and a pipe diameter of 48 in., an H value of 0.77 ft is determined. The headwater for outlet control is computed by the equation: $HW = H + h_o - LS$

   For the tailwater depth lower than the top of culvert,
   $h_o = T_w$ or ½ (critical depth in culvert + D) which ever is greater.
   $h_o = 3.0$ ft or $h_o = ½ (2.55 + 4.0) = 3.28$ ft

   The headwater depth for outlet control is:
   $HW = H + h_o - LS = 0.77 + 3.28 - (100) \times (0.0015) = 3.90$ ft

6. Since HW for outlet control (3.90 ft) is greater than the HW for inlet control (3.72 ft), outlet control governs the culvert design.

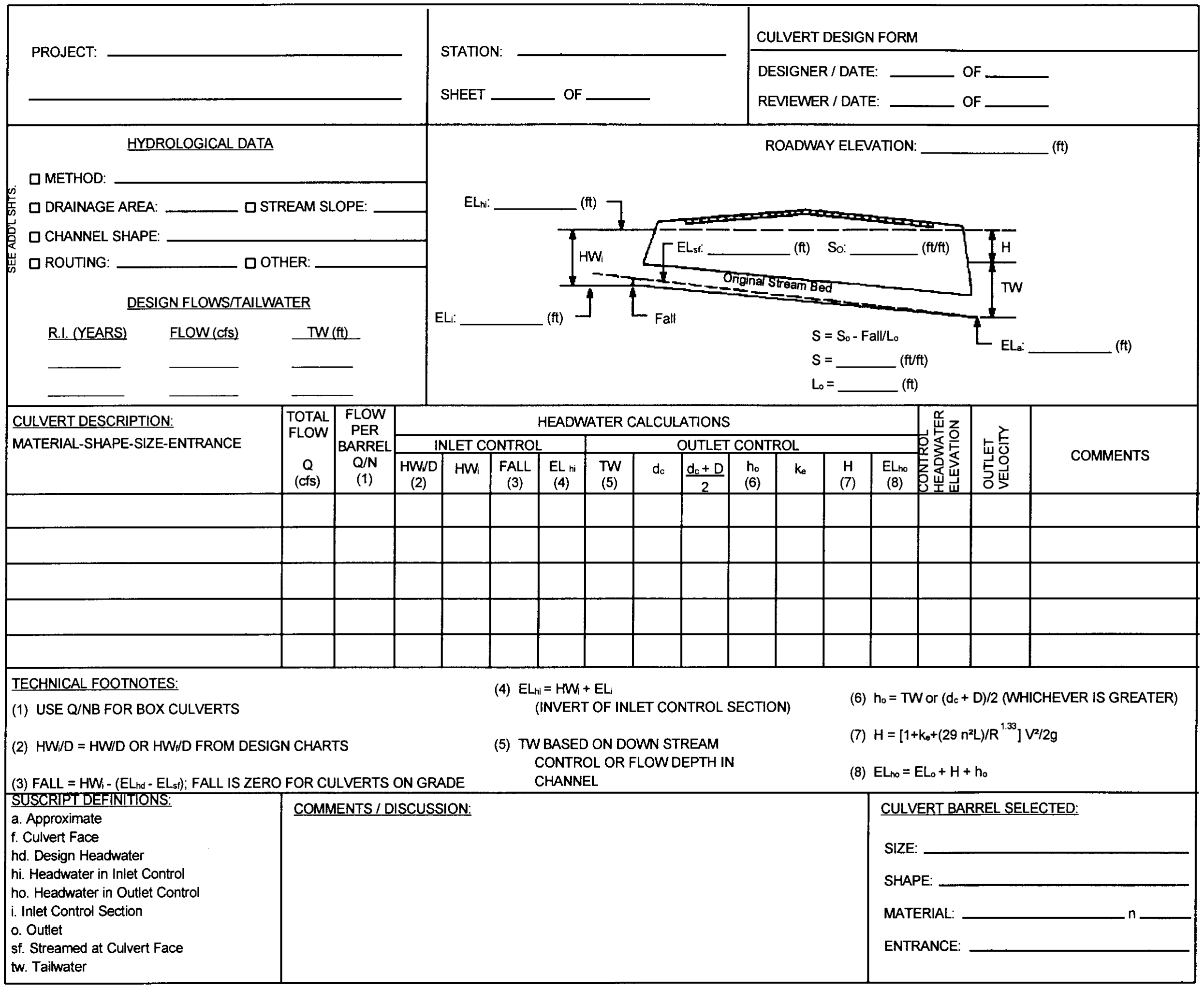
   Thus, the maximum headwater expected for a 100-yr recurrence flood is 3.90 ft, which is less than the allowable headwater of 4.5 ft.

7. Estimate outlet exit velocity. Since this culvert is on outlet control and discharges into an open channel downstream, the culvert will be flowing full at the flow depth in the channel. Using the 100-year design peak discharge of 70 cfs and the area of a 48 inch or 4.0 ft diameter culvert the exit velocity will be: $Q = VA$
   Therefore: $V = 70 / (3.14(4.0)^2)/4 = 5.6$ ft/s

8. Check for minimum velocity using the 2-year flow of 39 cfs.
   Therefore: $V = 39 / (3.14(4.0)^2)/4 = 3.1$ ft/s > minimum of 3.0 – OK

9. The 100-year flow should be routed through the culvert to determine if any flooding problems will be associated with this flood.

Figure 4-4 provides a convenient form to organize culvert design calculations.



PROJECT: ______________

____

STATION: ______________

SHEET ______ OF ______

CULVERT DESIGN FORM

DESIGNER / DATE: ______ OF ______

REVIEWER / DATE: ______ OF ______

HYDROLOGICAL DATA

☐ METHOD: ______________

☐ DRAINAGE AREA: ______ ☐ STREAM SLOPE: ______

☐ CHANNEL SHAPE: ______________

☐ ROUTING: ______ ☐ OTHER: ______

SEE ADD'L SHTS.

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOW (cfs)	TW (ft)

ROADWAY ELEVATION: ______________ (ft)

EL_{hi}: __________ (ft)

HW_i

EL_i: __________ (ft)

Fall

EL_{sf}: __________ (ft)

S_O: __________ (ft/ft)

Original Stream Bed

H

TW

EL_a: __________ (ft)

$S = S_o - Fall/L_o$

S = ________ (ft/ft)

L_o = ________ (ft)

CULVERT DESCRIPTION: MATERIAL-SHAPE-SIZE-ENTRANCE	TOTAL FLOW	FLOW PER BARREL	HEADWATER CALCULATIONS											CONTROL HEADWATER ELEVATION	OUTLET VELOCITY	COMMENTS
			INLET CONTROL				OUTLET CONTROL									
	Q (cfs)	Q/N (1)	HW/D (2)	HW_i	FALL (3)	EL_{hi} (4)	TW (5)	d_c	$\frac{d_c + D}{2}$	h_o (6)	k_e	H (7)	EL_{ho} (8)			

TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) $HW_i/D = HW/D$ OR HW_f/D FROM DESIGN CHARTS

(3) FALL = $HW_i - (EL_{hd} - EL_{sf})$; FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL

(6) $h_o = TW$ or $(d_c + D)/2$ (WHICHEVER IS GREATER)

(7) $H = [1+k_e+(29\ n^2L)/R^{1.33}]\ V^2/2g$

(8) $EL_{ho} = EL_o + H + h_o$

SUSCRIPT DEFINITIONS:

a. Approximate
f. Culvert Face
hd. Design Headwater
hi. Headwater in Inlet Control
ho. Headwater in Outlet Control
i. Inlet Control Section
o. Outlet
sf. Streamed at Culvert Face
tw. Tailwater

COMMENTS / DISCUSSION:

CULVERT BARREL SELECTED:

SIZE: ______________

SHAPE: ______________

MATERIAL: ______________ n ______

ENTRANCE: ______________

Figure 4-4

The following symbols are used in these figures:

B - Width of culvert barrel or diameter of pipe culvert
D - Height of box culvert or diameter of pipe culvert
H_f - Depth of pool or head, above the face section of invert
N - Number of barrels
Q - Design discharge

4.6 Design Procedures For Beveled-Edged Inlets

4.6.1 Introduction

Improved inlets include inlet geometry refinements beyond those normally used in conventional culvert design practice. Several degrees of improvements are possible, including bevel-edged, side-tapered, and slope-tapered inlets. Those designers interested in using side- and slope-tapered inlets should consult the detailed design criteria and example designs outlined in the U. S. Department of Transportation publication Hydraulic Engineering Circular No. 5 entitled, Hydraulic Design of Highway Culverts.

4.6.2 Design Figures

Four inlet control figures for culverts with beveled edges are included in Appendix A at the end of this chapter.

Chart	Page	Use for -
3	4A-3	circular pipe culverts with beveled rings
10	4A-10	90^o headwalls (same for 90^o wingwalls)
11	43A-11	skewed headwalls
12	4A-12	wingwalls with flare angles of 18 to 45 degrees

4.6.3 Design Procedure

The figures for bevel-edged inlets are used for design in the same manner as the conventional inlet design nomographs discussed earlier. Note that Charts 10, 11, and 12 apply only to bevels having either a 33^o angle (1.5:1) or a 45^o angle (1:1).

For box culverts the dimensions of the bevels to be used are based on the culverts dimensions. The top bevel dimension is determined by multiplying the height of the culvert by a factor. The side bevel dimensions are determined by multiplying the width of the culvert by a factor. For a 1:1 bevel, the factor is ½ inch/ft. For a 1.5:1 bevel the factor is 1 inch/ft. For example the minimum bevel dimensions for a 8 ft x 6 ft box culvert with 1:1 bevels would be:

Top Bevel = d = 6 ft x ½ inch/ft = 3 inches
Side Bevel = b = 8 ft x ½ inch/ft = 4 inches

For a 1.5:1 bevel computations would result in d = 6 and b = 8 inches.

4.6.4 Design Figure Limits

The improved inlet design figures are based on research results from culvert models with barrel width, B, to depth, D, ratios of from 0.5:1 to 2:1. For box culverts with more than one barrel, the figures are used in the same manner as for a single barrel, except that the bevels must be sized on the basis of the total clear opening rather than on individual barrel size.

For example, in a double 8 ft by 8 ft box culvert:

Top Bevel - is proportioned based on the height of 8 ft which results in a bevel of 4 in. for the 1:1 bevel and 8 in. for the 1.5:1 bevel.
Side Bevel - is proportioned based on the clear width of 16 ft which results in a bevel of 8 in. for the 1:1 bevel and 16 in. for the 1.5:1 bevel.

4.6.5 Multibarrel Installations

For multibarrel installations exceeding a 3:1 width to depth ratio, the side bevels become excessively large when proportioned on the basis of the total clear width. For these structures, it is recommended that the side bevel be sized in proportion to the total clear width, B, or three times the height, whichever is smaller. The top bevel dimension should always be based on the culvert height.

The shape of the upstream edge of the intermediate walls of multibarrel installations is not as important to the hydraulic performance of a culvert as the edge condition of the top and sides. Therefore, the edges of these walls may be square, rounded with a radius of one-half their thickness, chamfered, or beveled. The intermediate walls may also project from the face and slope downward to the channel bottom to help direct debris through the culvert.

Multibarrel pipe culverts should be designed as a series of single barrel installations since each pipe requires a separate bevel.

4.6.6 Skewed Inlets

It is recommended that Figure 4A-11 in Appendix A for skewed inlets not be used for multiple barrel installations, as the intermediate wall could cause an extreme contraction in the downstream barrels. This would result in under design due to a greatly reduced capacity. Skewed inlets should be avoided whenever possible, and should not be used with side- or slope-tapered inlets. It is important to align culverts with streams in order to avoid erosion problems associated with changing the direction of the natural stream flow.

4.7 Flood Routing And Culvert Design

4.7.1 Introduction

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. By not considering flood routing it is possible that the findings from culvert analyses will be conservative. If the selected allowable headwater is considered acceptable without flood routing, then costly over design of both the culvert and outlet protection may result, depending on the amount of temporary storage involved. However, if storage is used in the design of culverts, consideration should be given to:

- the total area of flooding,
- the average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and
- ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

Ignoring temporary storage effects on reducing the selected design flood magnitude by assuming that this provides a factor of safety is not recommended. This practice results in inconsistent factors of safety at culvert sites as it is dependent on the amount of temporary storage at each site. Further, with little or no temporary storage at a site the factor of safety would be unity thereby precluding a factor of safety. If a factor of safety is desired, it is essential that flood routing practices be used to insure consistent and defensible factors of safety are used at all culvert sites.

4.7.2 Design Procedure

The design procedure for flood routing through a culvert is the same as for reservoir routing. The site data and roadway geometry are obtained and the hydrology analysis completed to include estimating a hydrograph. Once this essential information is available, the culvert can be designed. Flood routing through a culvert can be time consuming. It is recommended that the HY8 computer program be used as it contains software that very quickly routes floods through a culvert to evaluate an existing culvert (review), or to select a culvert size that satisfies given criteria (design). However, the engineer should be familiar with the culvert flood routing design process.

A Multiple trial and error procedure is required for culvert flood routing. In general:

- a trial culvert(s) is selected,
- a trial discharge for a particular hydrograph time increment (selected time increment to estimate discharge from the design hydrograph) is selected,
- flood routing computations are made with successive trial discharges until the flood routing equation is satisfied,
- the hydraulic findings are compared to the selected site criteria, and
- if the selected site criteria are satisfied then a trial discharge for the next time increment is selected and this procedure is repeated; if not, a new trial culvert is selected and the entire procedure is repeated.

4.8 HY8 Culvert Analysis Microcomputer Program

It is recommended that the HY8 computer model be used for culvert design. This culvert design model is available in many computer software packages and is included in the HYDRAIN system available from McTrans Software (address given under References below). The personal computer system HYDRAIN uses the theoretical basis for the nomographs to size a culvert. In addition, this system can evaluate improved inlets, generate and route hydrographs, consider road overtopping, and evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.

References

American Association of State Highway and Transportation Officials. 1982. Highway Drainage Guidelines.

American Association of State Highway and Transportation Officials. 1998. Model Drainage Manual.

Debo, Thomas N. and Andrew J. Reese. Municipal Storm Water Management. Lewis Publishers. 1995.

Federal Highway Administration. 1978. Hydraulics of Bridge Waterways. Hydraulic Design Series No. 1.

Federal Highway Administration. 1985. Hydraulic design of highway culverts. Hydraulic Design Series No. 5.

Federal Highway Administration. 1971. Debris-Control Structures. Hydraulic Engineering Circular No. 9.

Federal Highway Administration. 1987. HY8 Culvert Analysis Microcomputer Program Applications Guide. Hydraulic Microcomputer Program HY8.

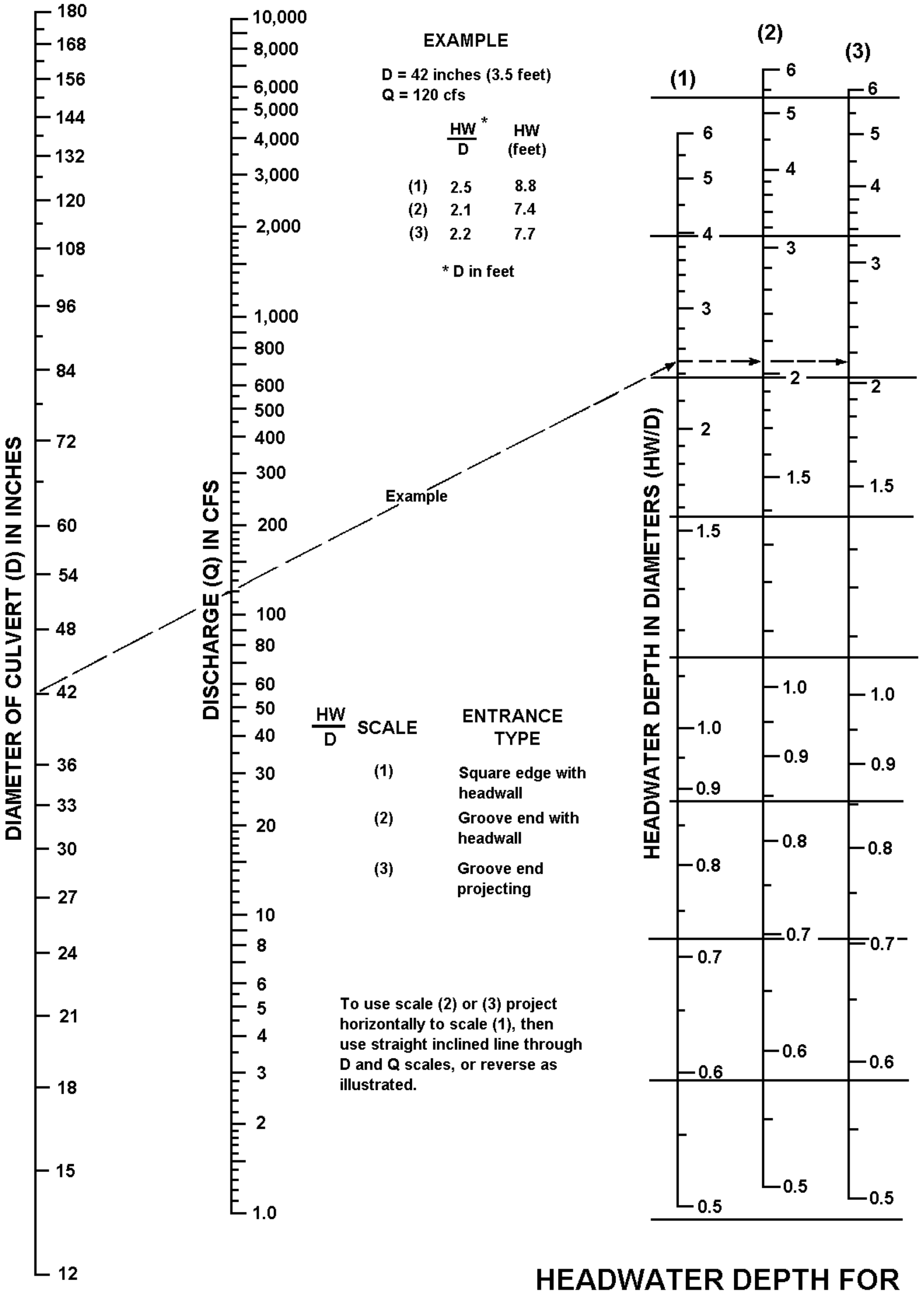
Federal Highway Administration. 1996. Urban Drainage Design Manual. Hydraulic Engineering Circular No. 22.

HYDRAIN Culvert Computer Program (HY8). Available from McTrans Software, University of Florida, 512 Weil Hall, Gainesville, Florida 32611.

U. S. Department of Interior. 1983. Design of small canal structures.

Appendix A - Design Charts and Nomographs

CHART 1



EXAMPLE

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

	$\frac{HW}{D}$ *	HW (feet)
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

* D in feet

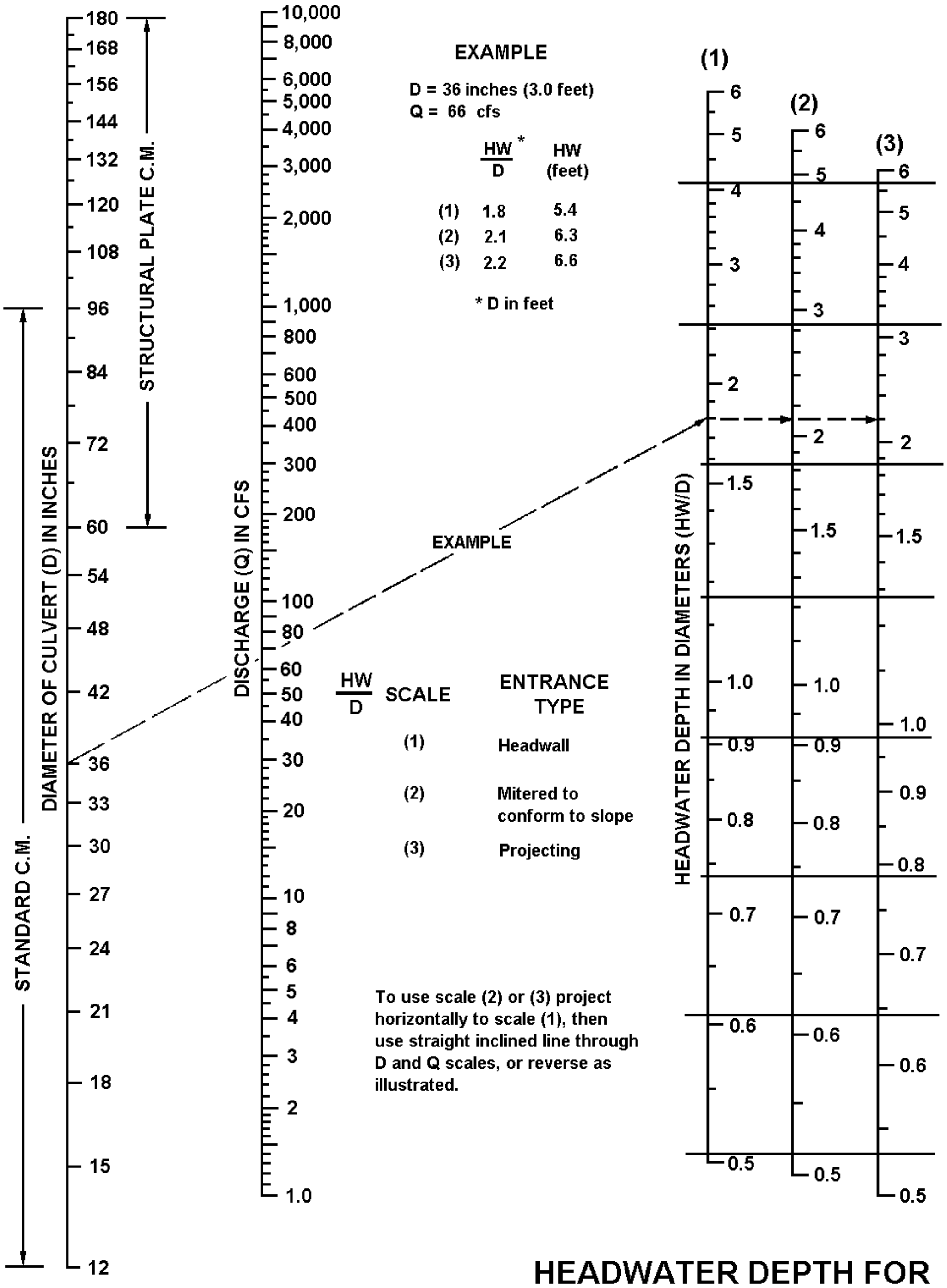
$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

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.

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963
HEADWATER SCALES 2&3 REVISED MAY 1964

CHART 2



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

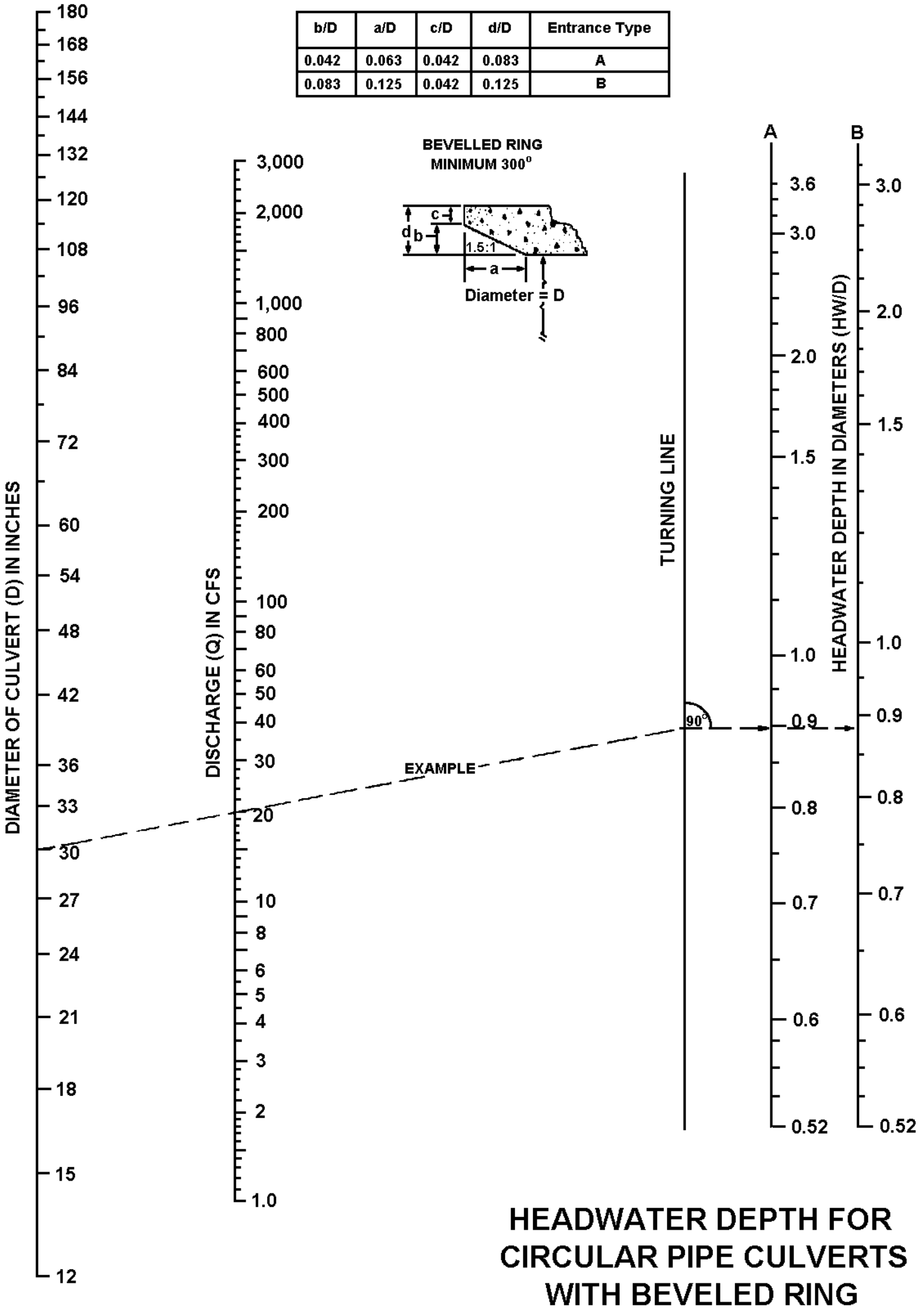
$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Headwall
(2)	Mitered to conform to slope
(3)	Projecting

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.

HEADWATER DEPTH FOR C.M. PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 3

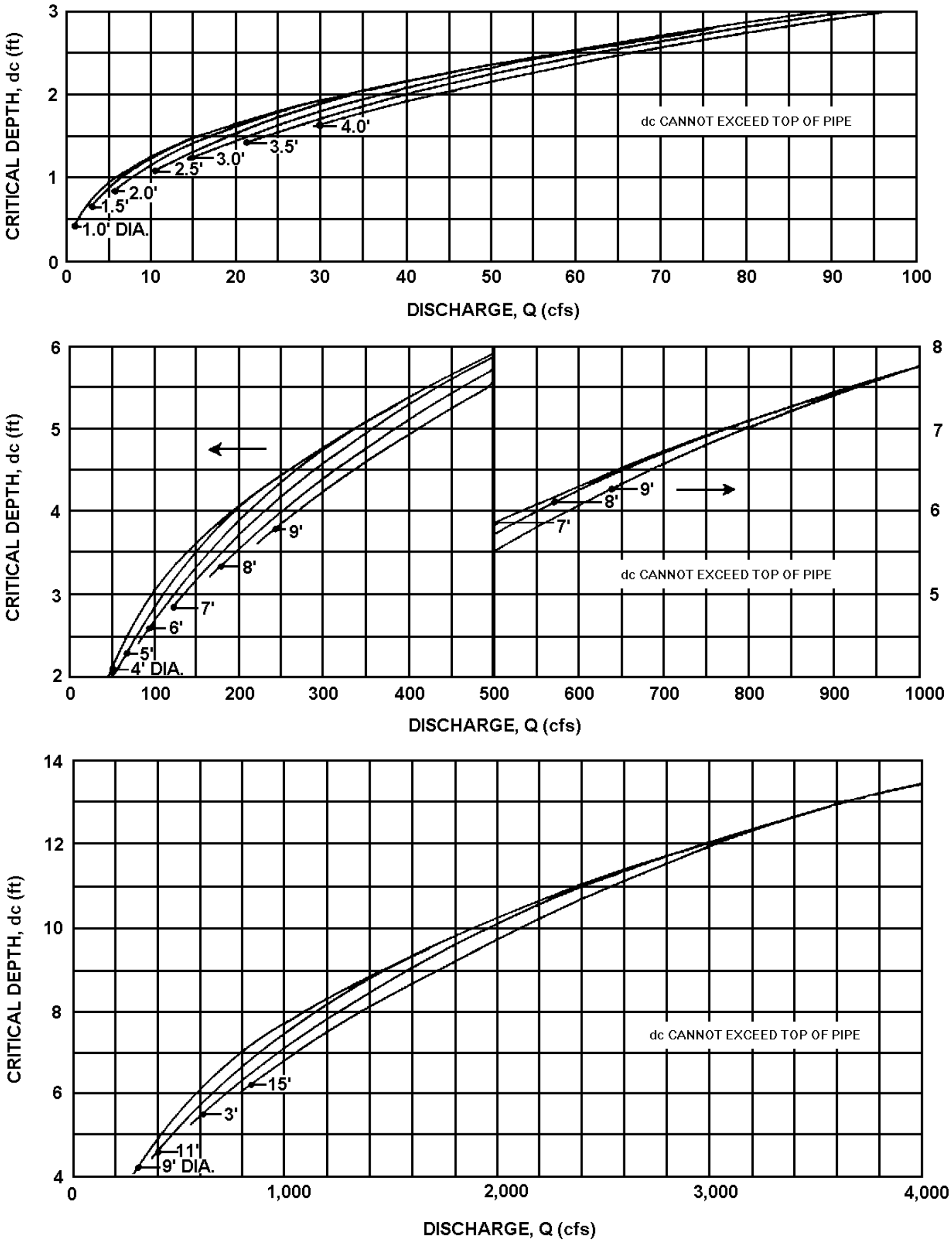


b/D	a/D	c/D	d/D	Entrance Type
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

FEDERAL HIGHWAY ADMINISTRATION MAY 1973

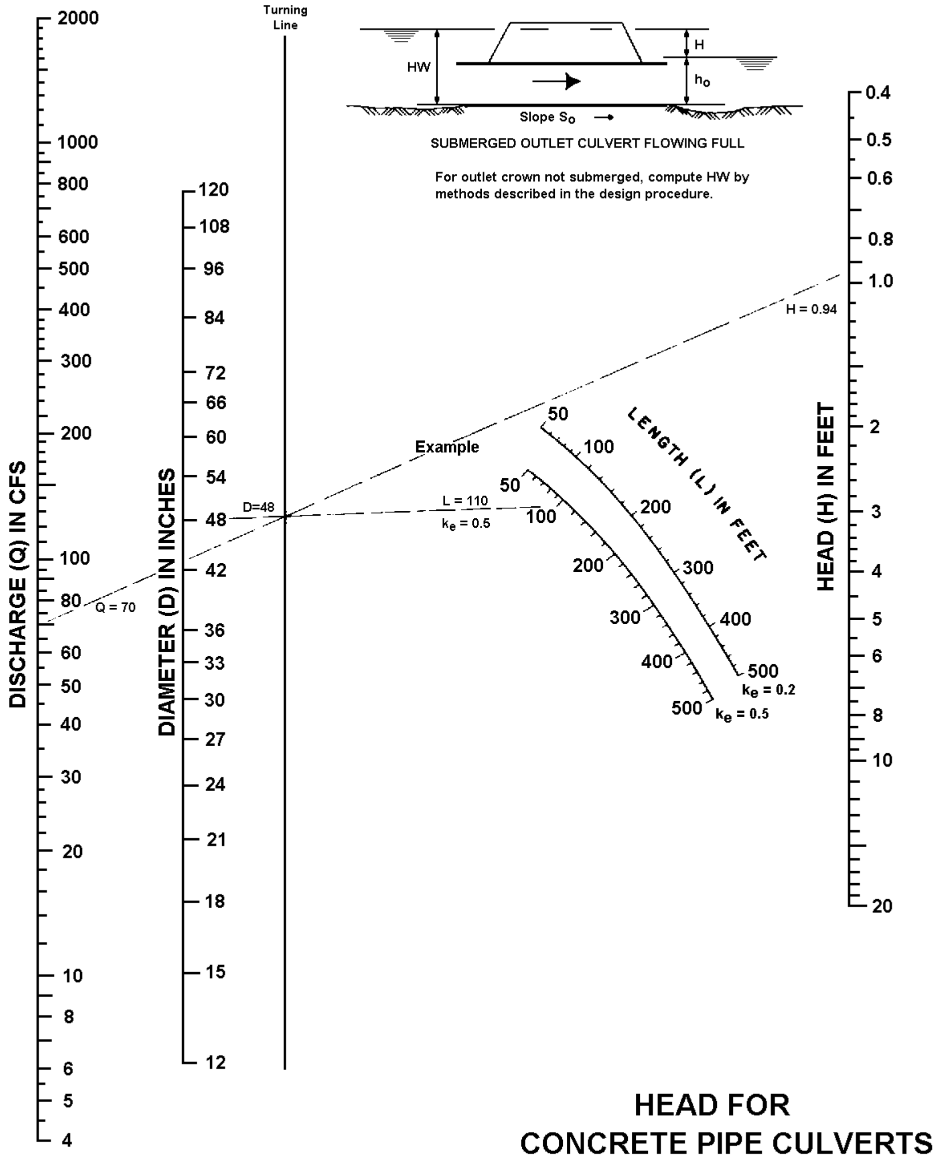
CHART 4



BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

CHART 5



SUBMERGED OUTLET CULVERT FLOWING FULL

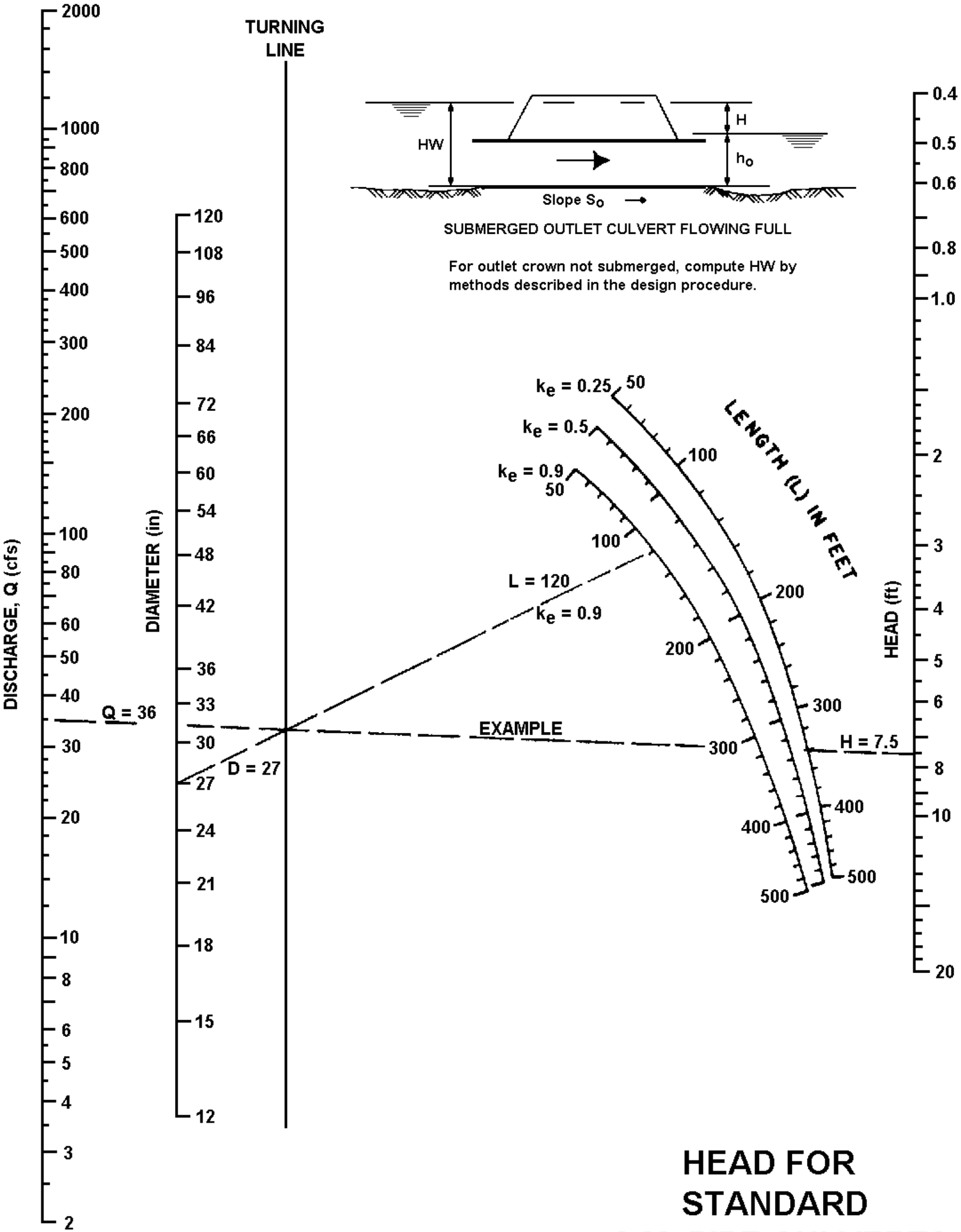
For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL

n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

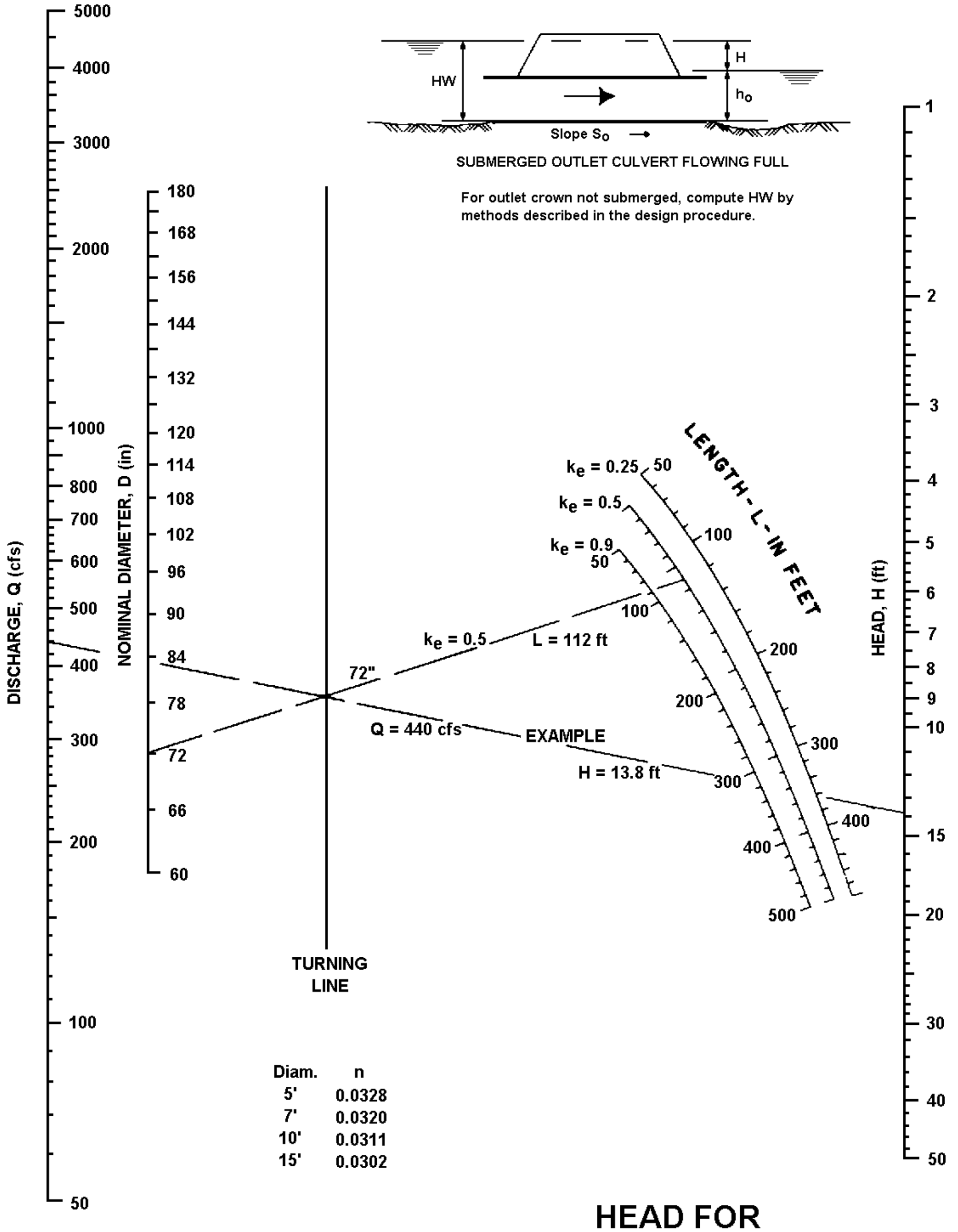
CHART 6



HEAD FOR STANDARD C.M. PIPE CULVERTS FLOWING FULL n = 0.024

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 7

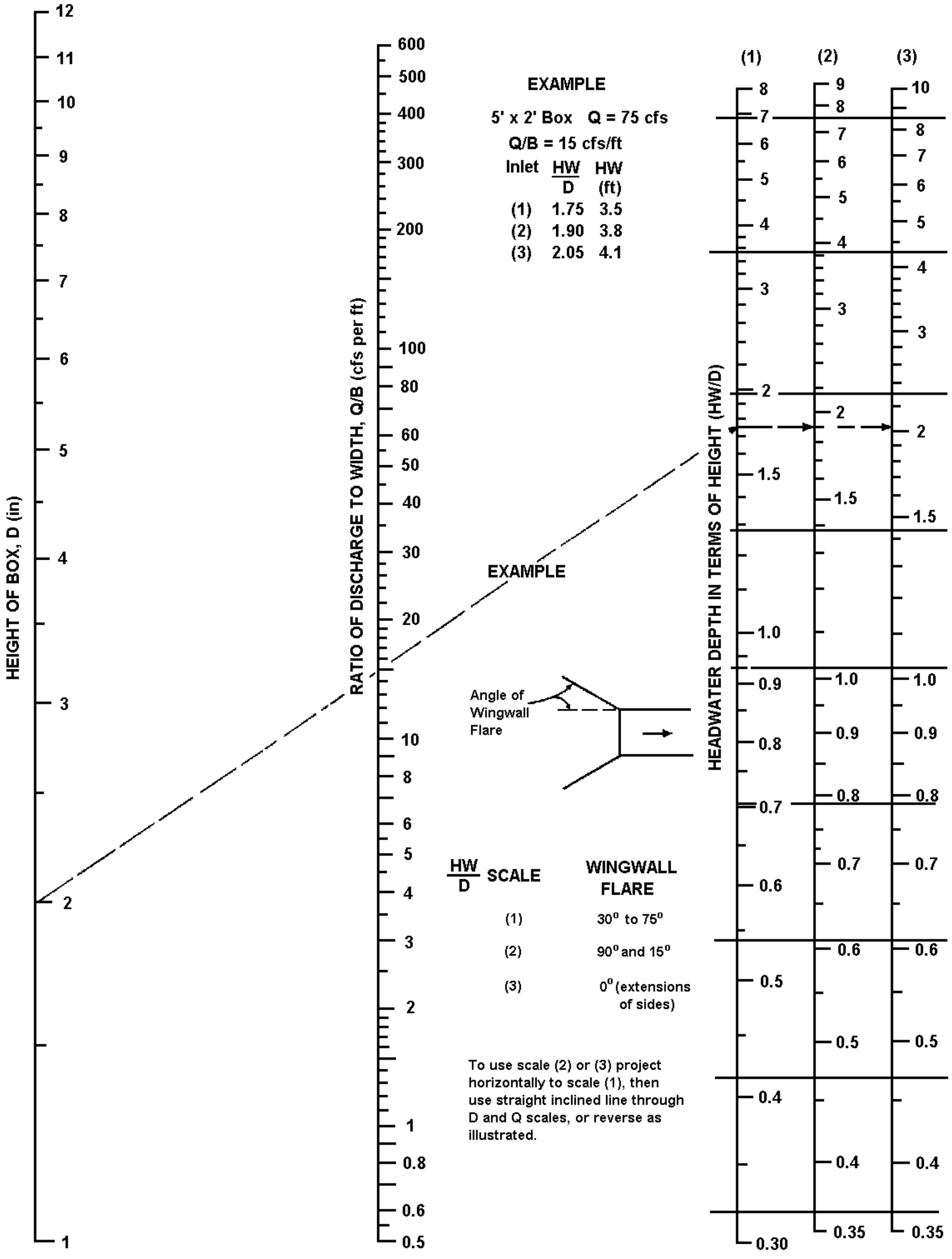


Diam.	n
5'	0.0328
7'	0.0320
10'	0.0311
15'	0.0302

HEAD FOR
STRUCTURAL PLATE
CORR. METAL PIPE CULVERTS
FLOWING FULL
n = 0.0328 TO 0.0302

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 8



EXAMPLE

5' x 2' Box Q = 75 cfs

Q/B = 15 cfs/ft

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

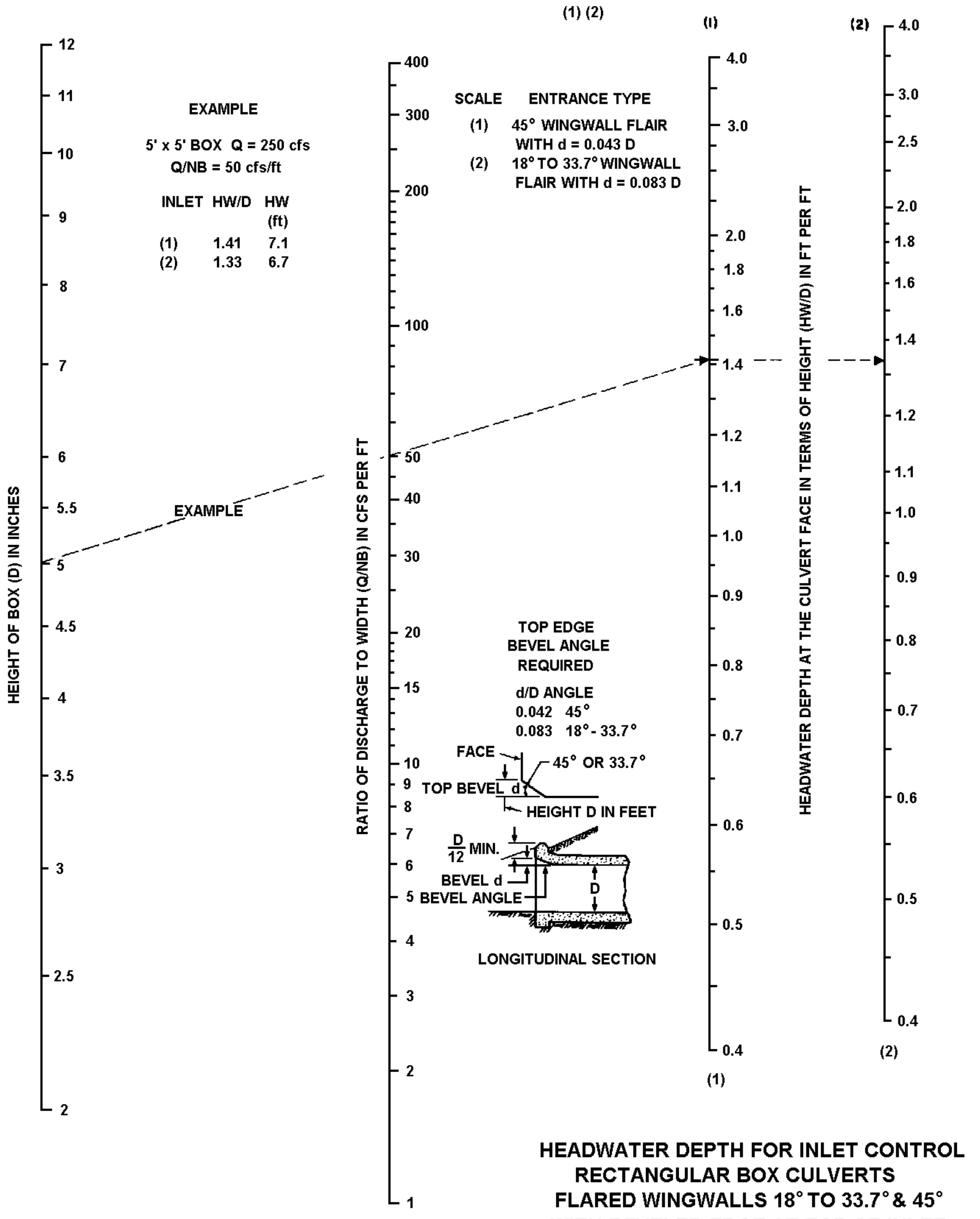
$\frac{HW}{D}$ SCALE	WINGWALL FLARE
(1)	30° to 75°
(2)	90° and 15°
(3)	0° (extensions of sides)

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.

HEADWATER DEPTH
FOR BOX CULVERTS
WITH INLET CONTROL

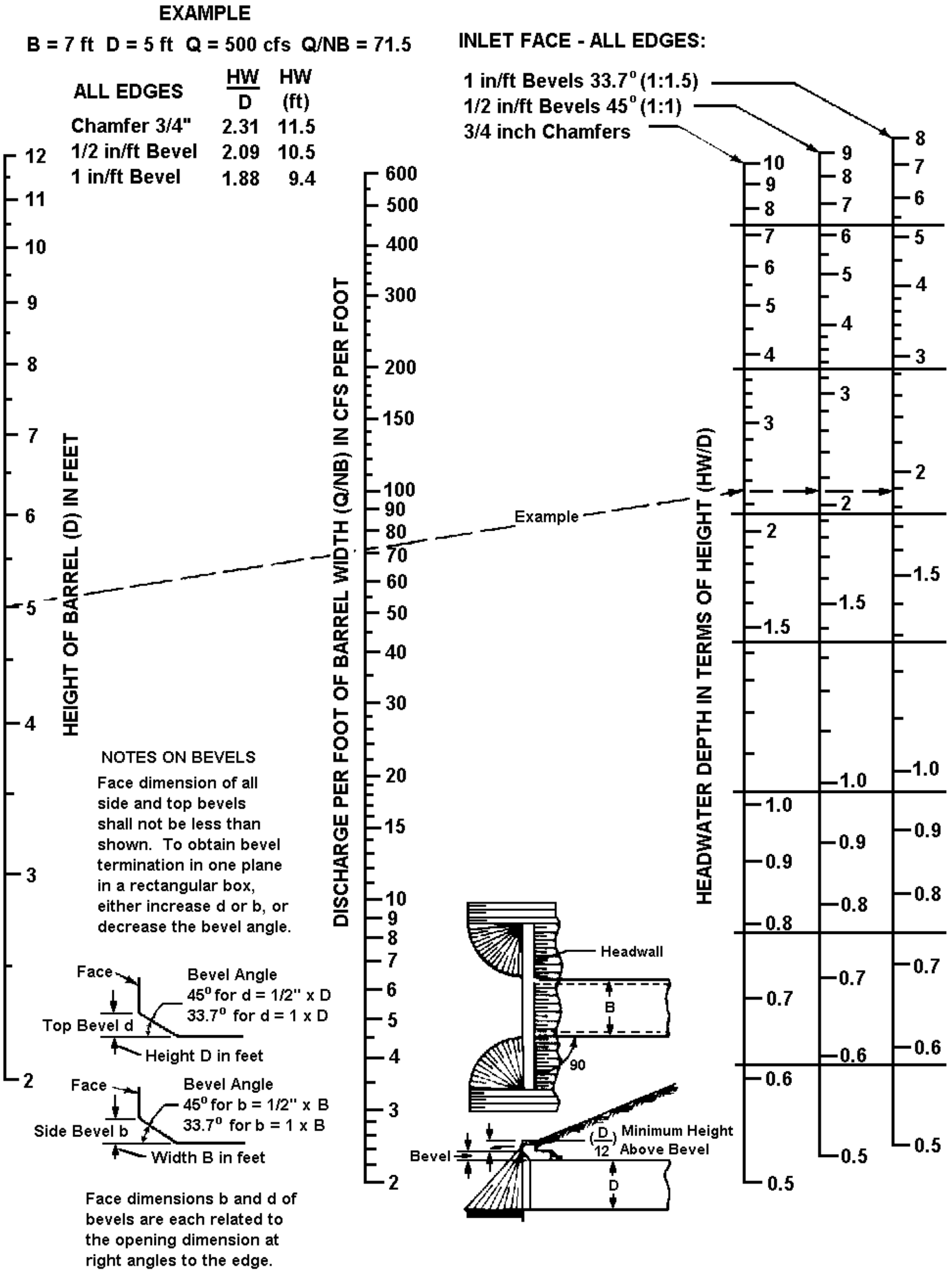
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 9



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

CHART 10



EXAMPLE

B = 7 ft D = 5 ft Q = 500 cfs Q/NB = 71.5

ALL EDGES	HW/D	HW (ft)
Chamfer 3/4"	2.31	11.5
1/2 in/ft Bevel	2.09	10.5
1 in/ft Bevel	1.88	9.4

INLET FACE - ALL EDGES:

1 in/ft Bevels 33.7° (1:1.5)
1/2 in/ft Bevels 45° (1:1)
3/4 inch Chamfers

NOTES ON BEVELS

Face dimension of all side and top bevels shall not be less than shown. To obtain bevel termination in one plane in a rectangular box, either increase d or b, or decrease the bevel angle.

Face dimensions b and d of bevels are each related to the opening dimension at right angles to the edge.

FEDERAL HIGHWAY ADMINISTRATION MAY 1973

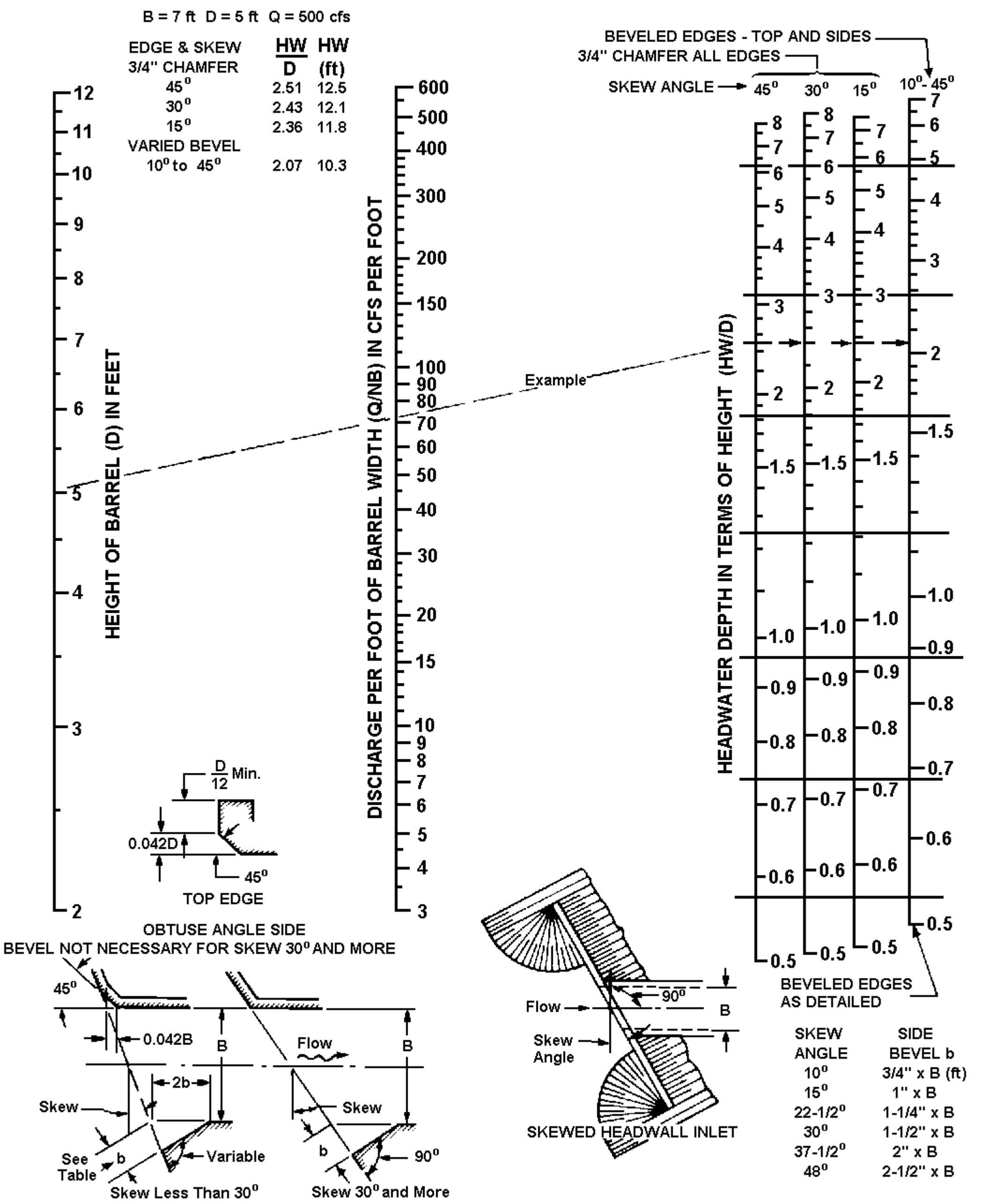
HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

CHART 11

EXAMPLE

B = 7 ft D = 5 ft Q = 500 cfs

EDGE & SKEW	HW/D	HW (ft)
3/4" CHAMFER		
45°	2.51	12.5
30°	2.43	12.1
15°	2.36	11.8
VARIED BEVEL		
10° to 45°	2.07	10.3

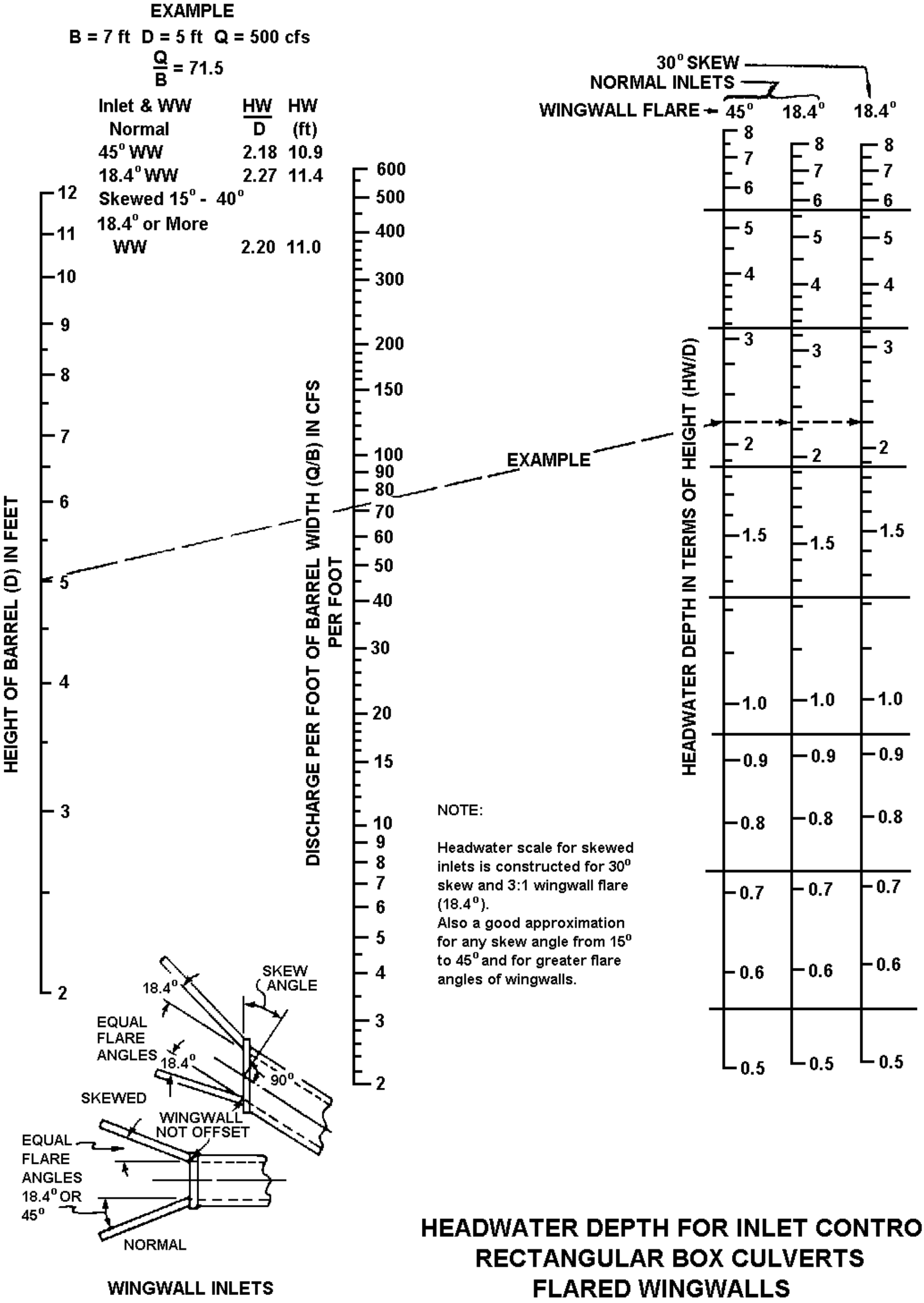


SKEW ANGLE	SIDE BEVEL b
10°	3/4" x B (ft)
15°	1" x B
22-1/2°	1-1/4" x B
30°	1-1/2" x B
37-1/2°	2" x B
48°	2-1/2" x B

HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION MAY 1973

CHART 12



EXAMPLE

B = 7 ft D = 5 ft Q = 500 cfs

$\frac{Q}{B} = 71.5$

Inlet & WW	$\frac{HW}{D}$	HW (ft)
Normal		
45° WW	2.18	10.9
18.4° WW	2.27	11.4
Skewed 15° - 40°		
18.4° or More WW	2.20	11.0

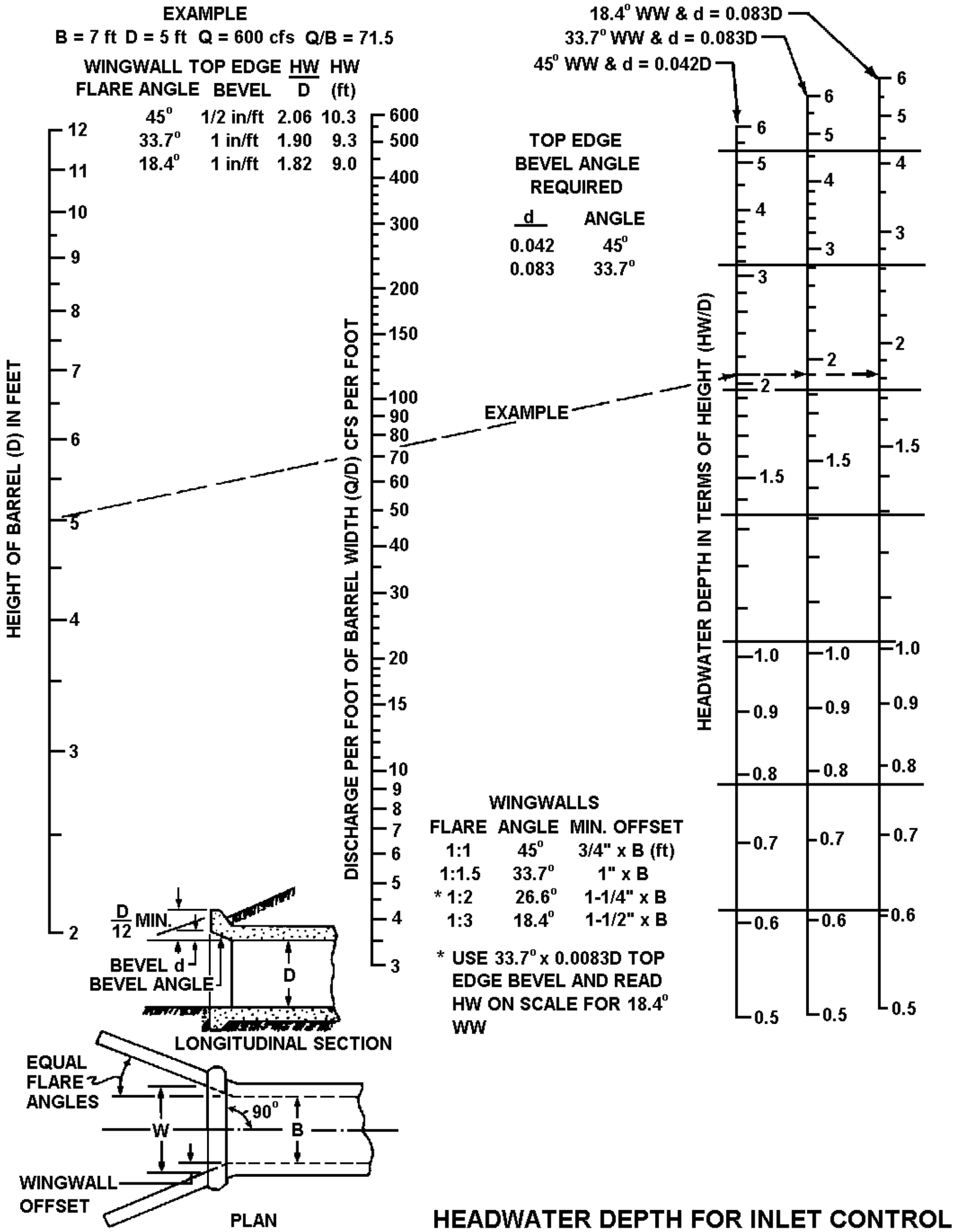
NOTE:

Headwater scale for skewed inlets is constructed for 30° skew and 3:1 wingwall flare (18.4°).
Also a good approximation for any skew angle from 15° to 45° and for greater flare angles of wingwalls.

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING

BUREAU OF PUBLIC ROADS
OFFICE OF R&D AUGUST 1968

CHART 13



EXAMPLE

B = 7 ft D = 5 ft Q = 600 cfs Q/B = 71.5

WINGWALL FLARE ANGLE	TOP EDGE BEVEL	HW/D	HW (ft)
45°	1/2 in/ft	2.06	10.3
33.7°	1 in/ft	1.90	9.3
18.4°	1 in/ft	1.82	9.0

TOP EDGE BEVEL ANGLE REQUIRED

d	ANGLE
0.042	45°
0.083	33.7°

WINGWALLS

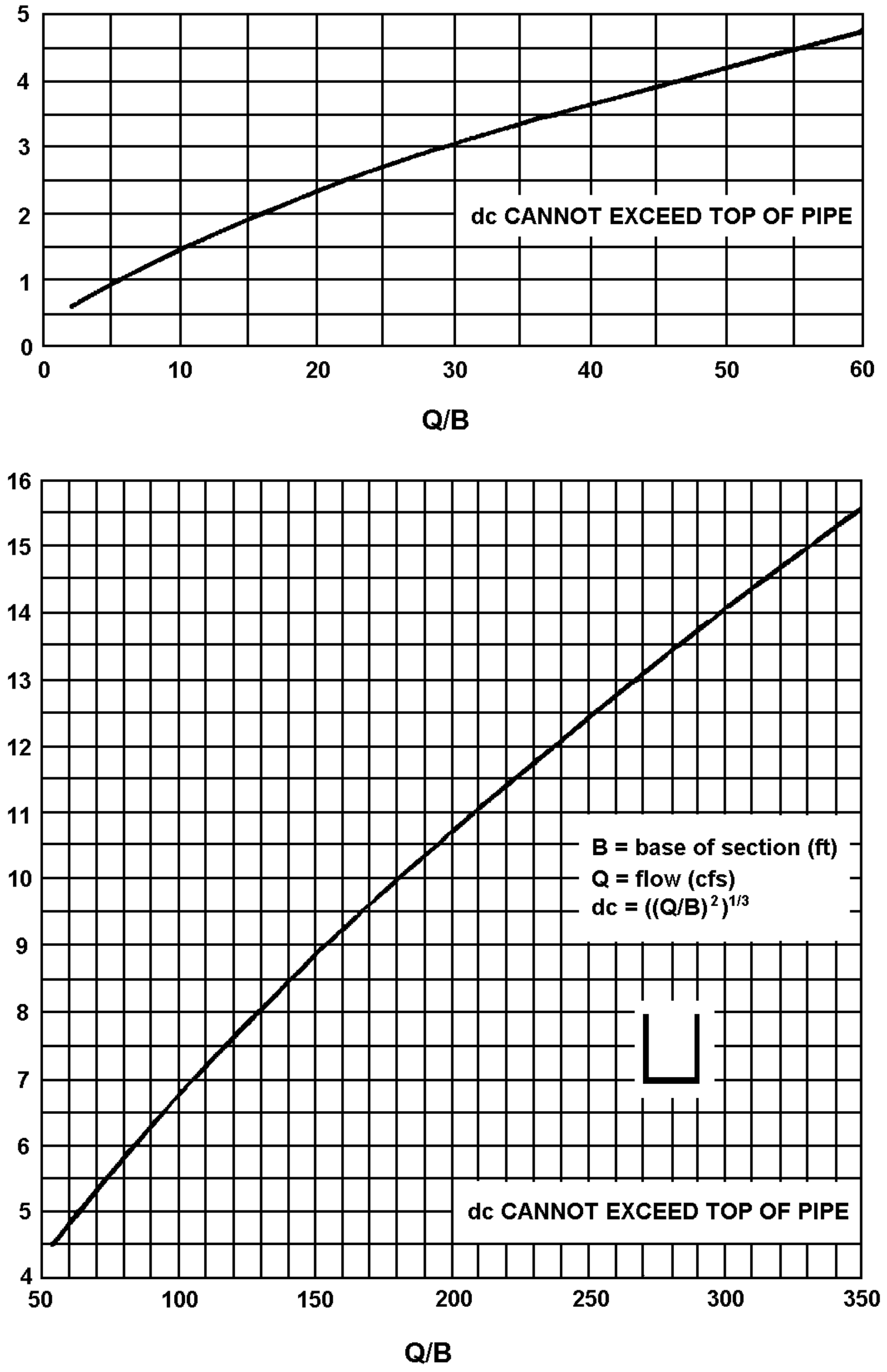
FLARE	ANGLE	MIN. OFFSET
1:1	45°	3/4" x B (ft)
1:1.5	33.7°	1" x B
* 1:2	26.6°	1-1/4" x B
1:3	18.4°	1-1/2" x B

* USE 33.7° x 0.0083D TOP EDGE BEVEL AND READ HW ON SCALE FOR 18.4° WW

HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
OFFSET FLARED WINGWALLS
AND BEVELED EDGE AT TOP OF INLET

BUREAU OF PUBLIC ROADS
OFFICE OF R&D AUGUST 1968

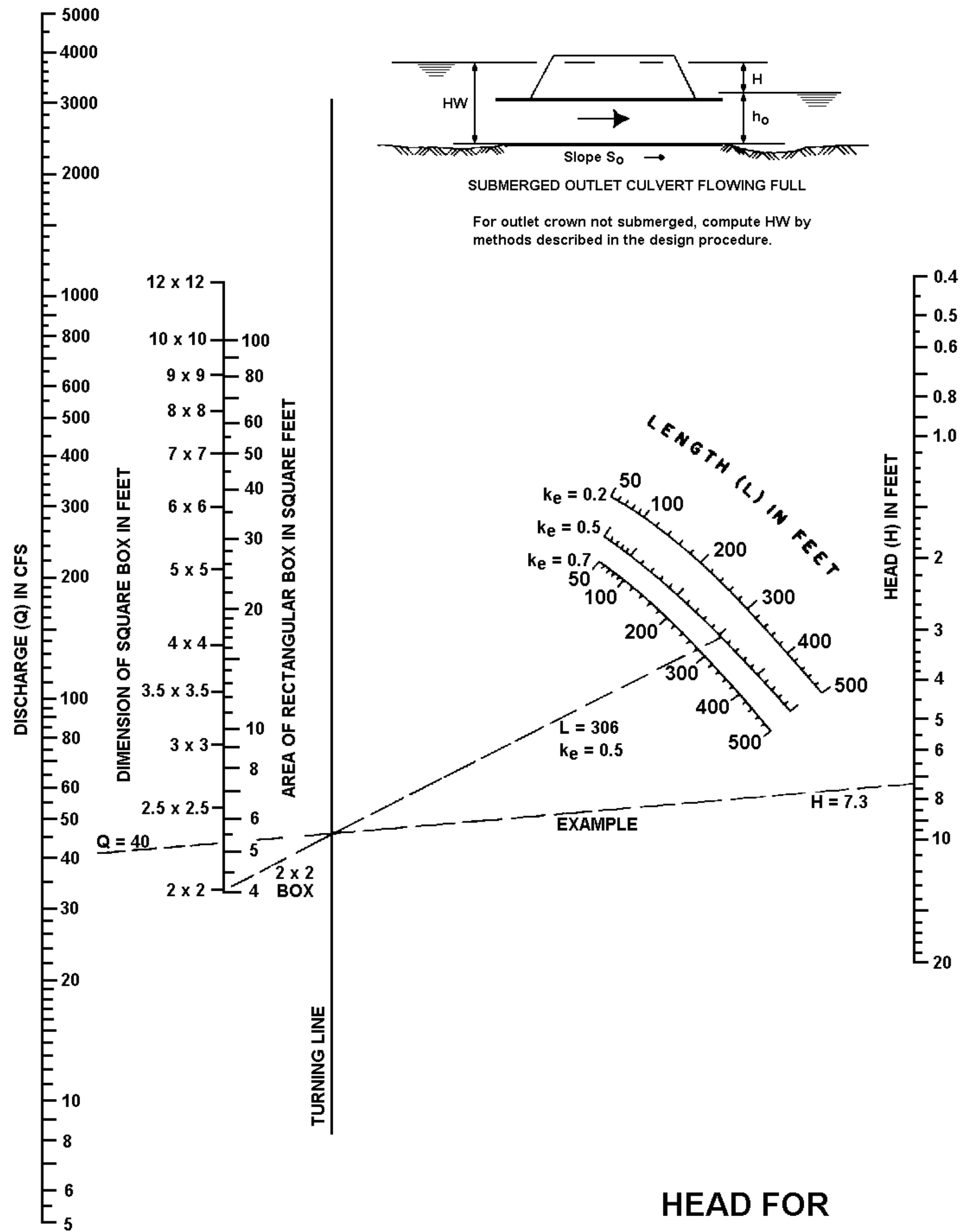
CHART 14



BUREAU OF PUBLIC ROADS JAN. 1963

CRITICAL DEPTH
RECTANGULAR SECTION

CHART 15

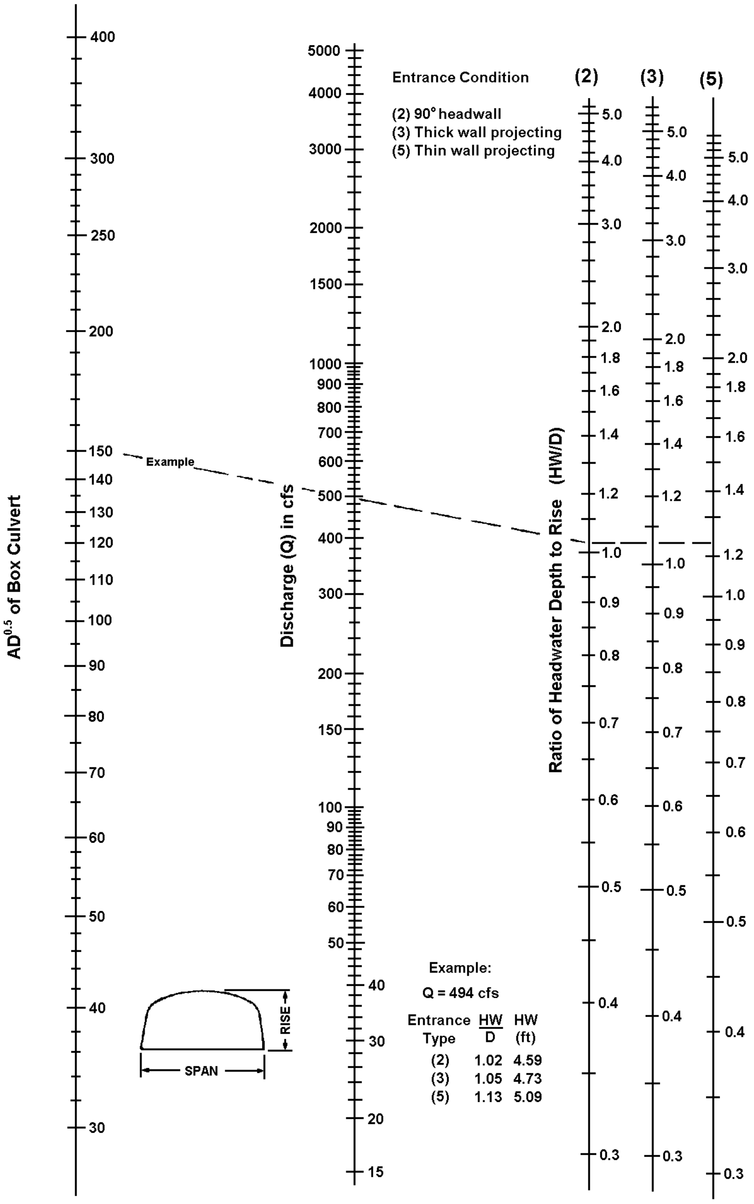


HEAD FOR CONCRETE BOX CULVERTS FLOWING FULL

n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

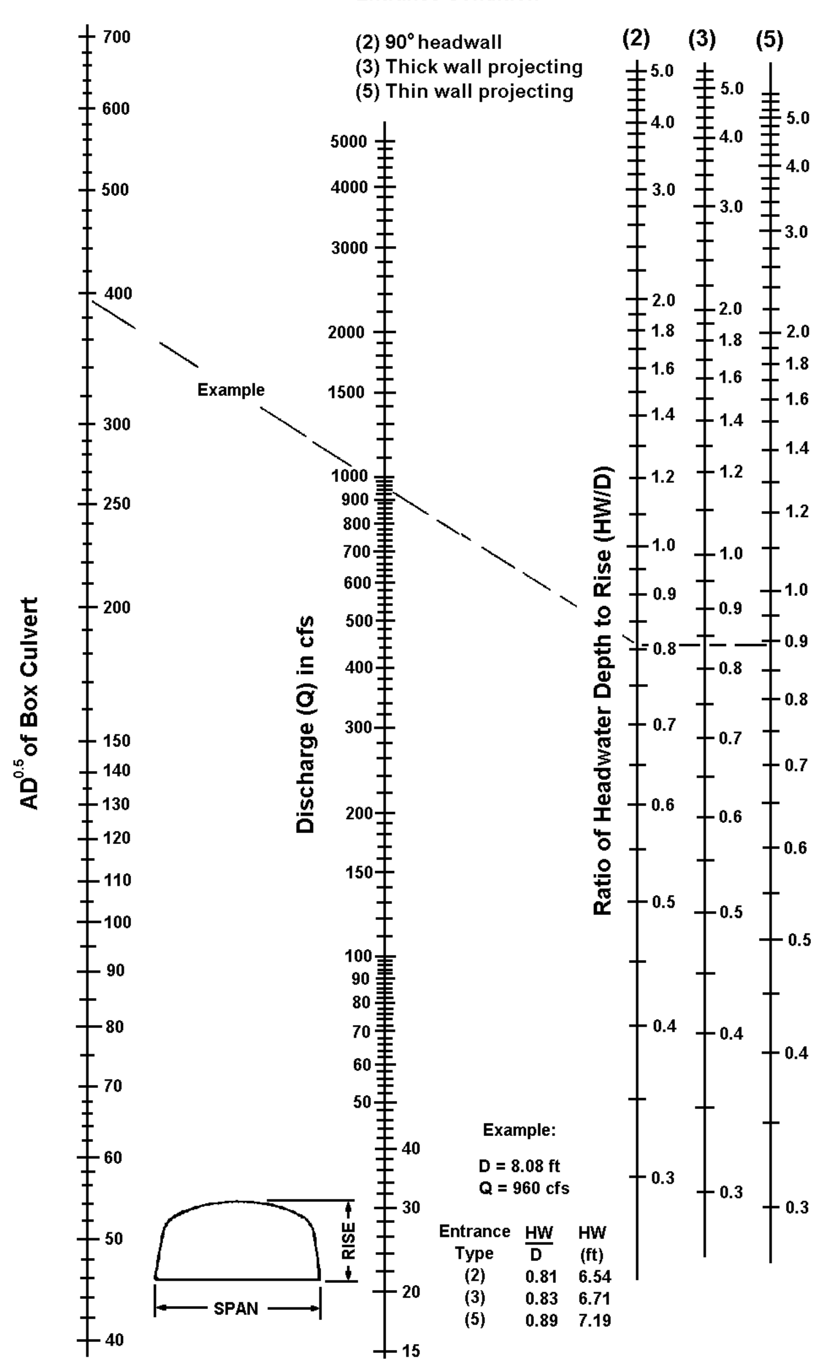
CHART 16



Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.

HEADWATER DEPTH FOR C.M. BOX CULVERTS RISE/SPAN < 0.3 WITH INLET CONTROL

CHART 17



Example:

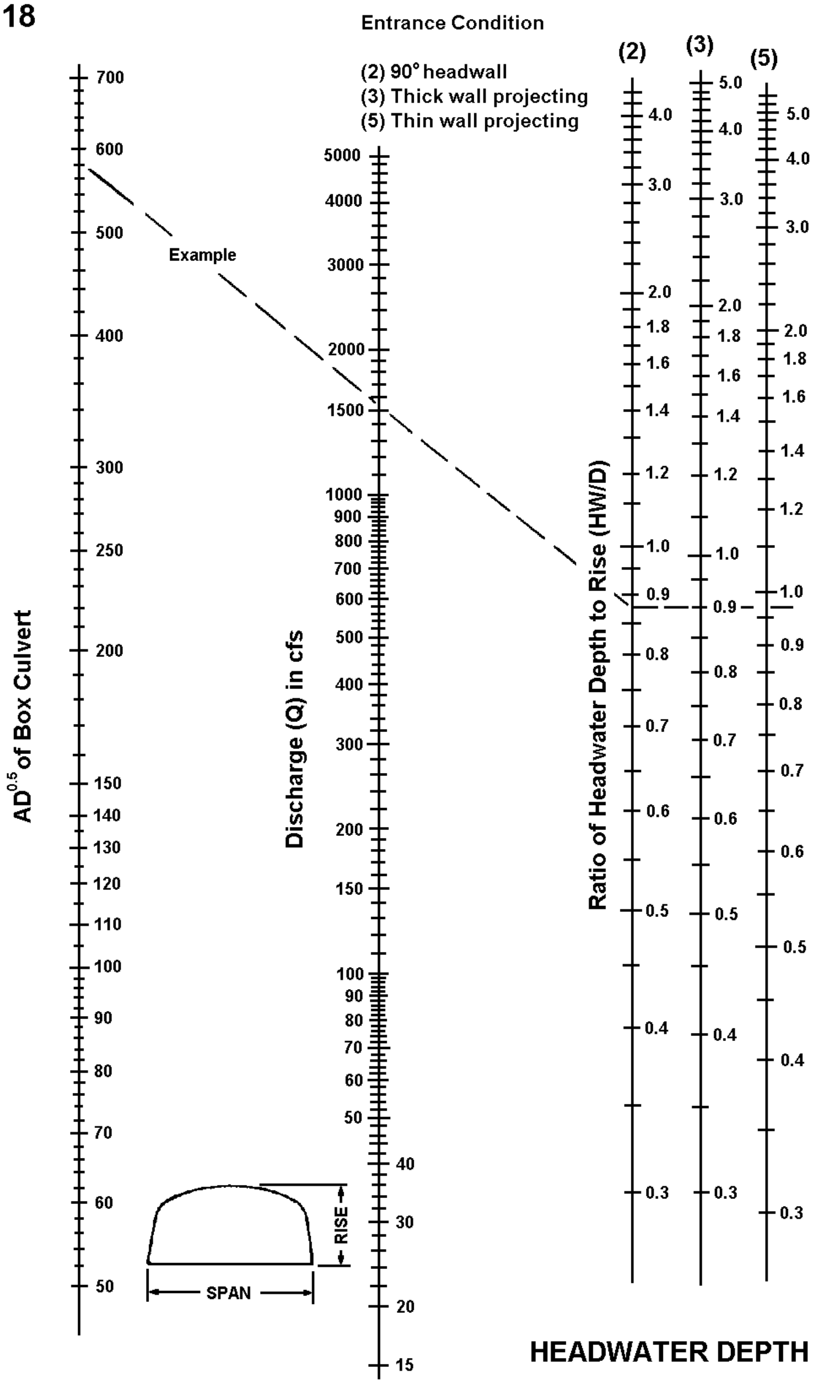
D = 8.08 ft
Q = 960 cfs

Entrance Type	HW/D	HW (ft)
(2)	0.81	6.54
(3)	0.83	6.71
(5)	0.89	7.19

HEADWATER DEPTH FOR C.M. BOX CULVERTS 0.3≤ RISE/SPAN < 0.4 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 18



Example:

D = 9.67 ft

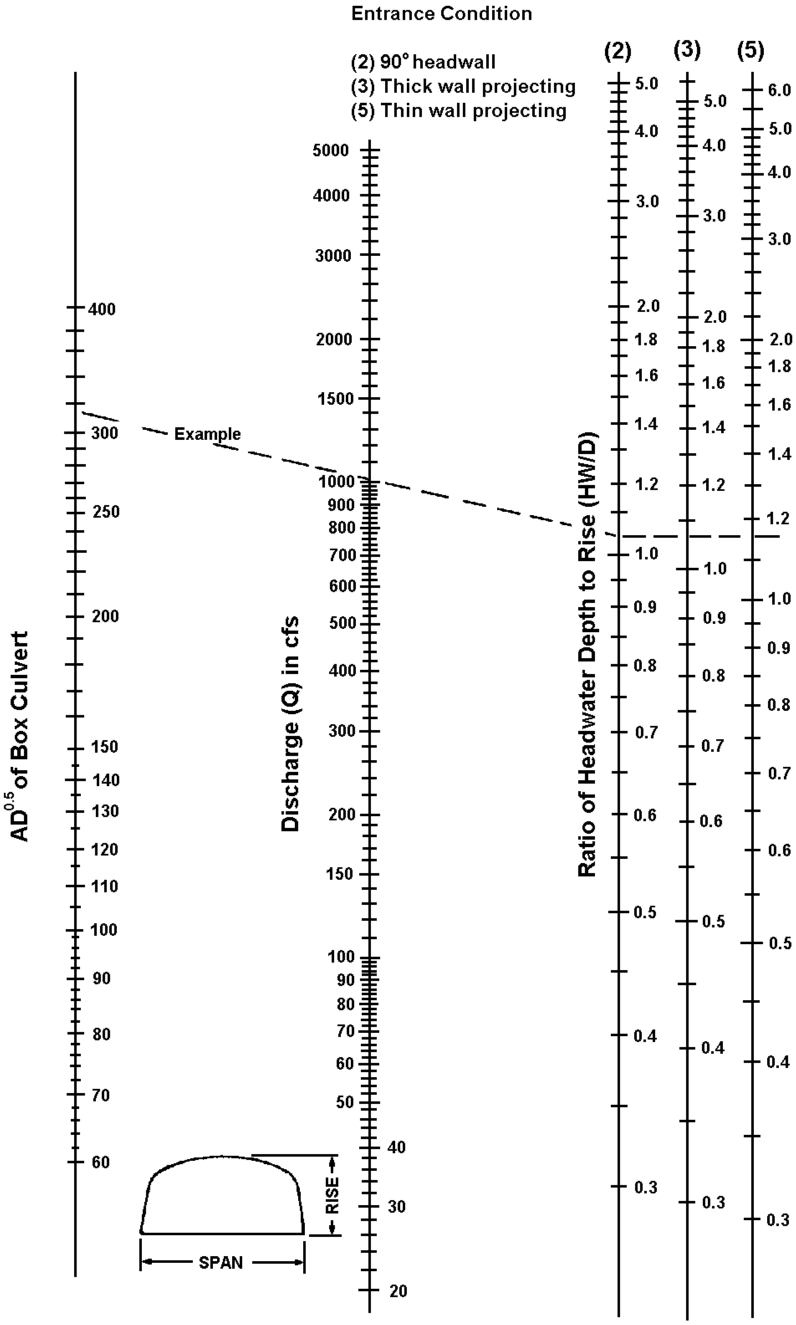
Q = 1520 cfs

Entrance Type	HW D	HW (ft)
(2)	0.88	8.51
(3)	0.90	9.38
(5)	0.97	9.38

HEADWATER DEPTH FOR C.M. BOX CULVERTS $0.4 \leq$ RISE/SPAN < 0.5 WITH INLET CONTROL

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 19



Example:

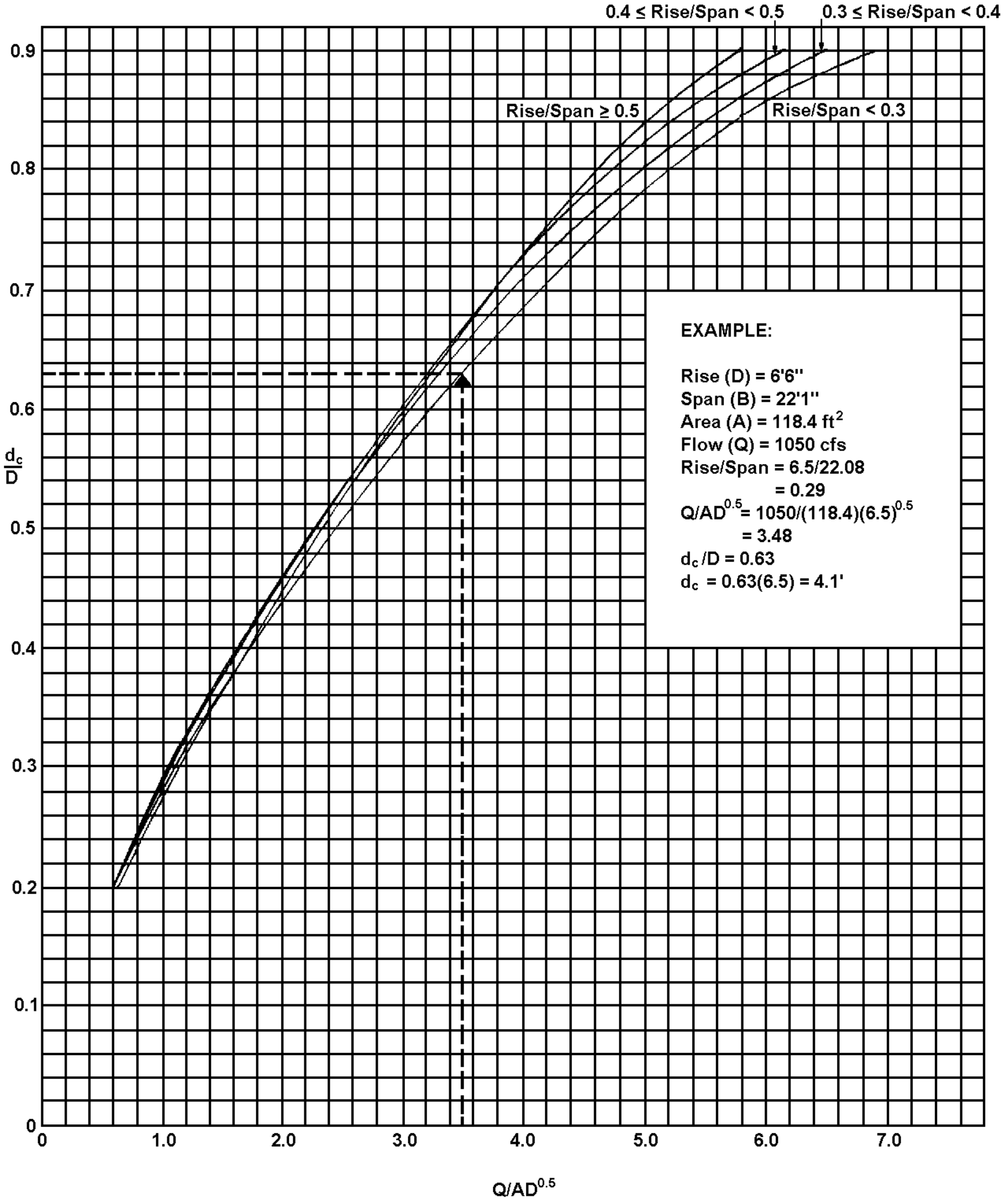
D = 8.0 ft
Q = 1004 cfs

Entrance Type	HW / D	HW (ft)
(2)	1.04	8.32
(3)	1.07	8.58
(5)	1.15	9.20

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.

HEADWATER DEPTH FOR C.M. BOX CULVERTS $0.5 \leq$ RISE/SPAN WITH INLET CONTROL

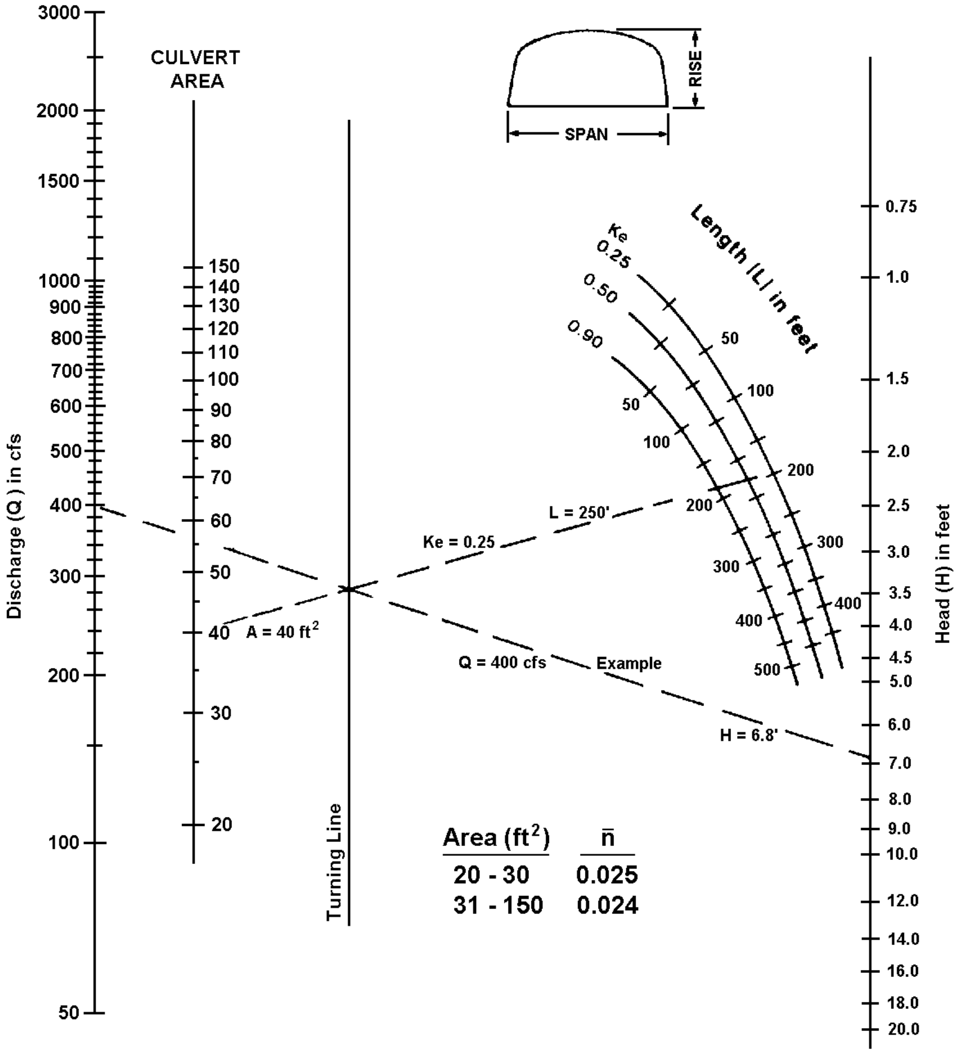
CHART 20

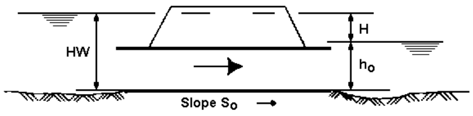


EXAMPLE:

Rise (D) = 6'6"
Span (B) = 22'1"
Area (A) = 118.4 ft^2
Flow (Q) = 1050 cfs
Rise/Span = 6.5/22.08
= 0.29
$Q/AD^{0.5} = 1050/(118.4)(6.5)^{0.5}$
= 3.48
$d_c/D = 0.63$
$d_c = 0.63(6.5) = 4.1'$

CHART 21





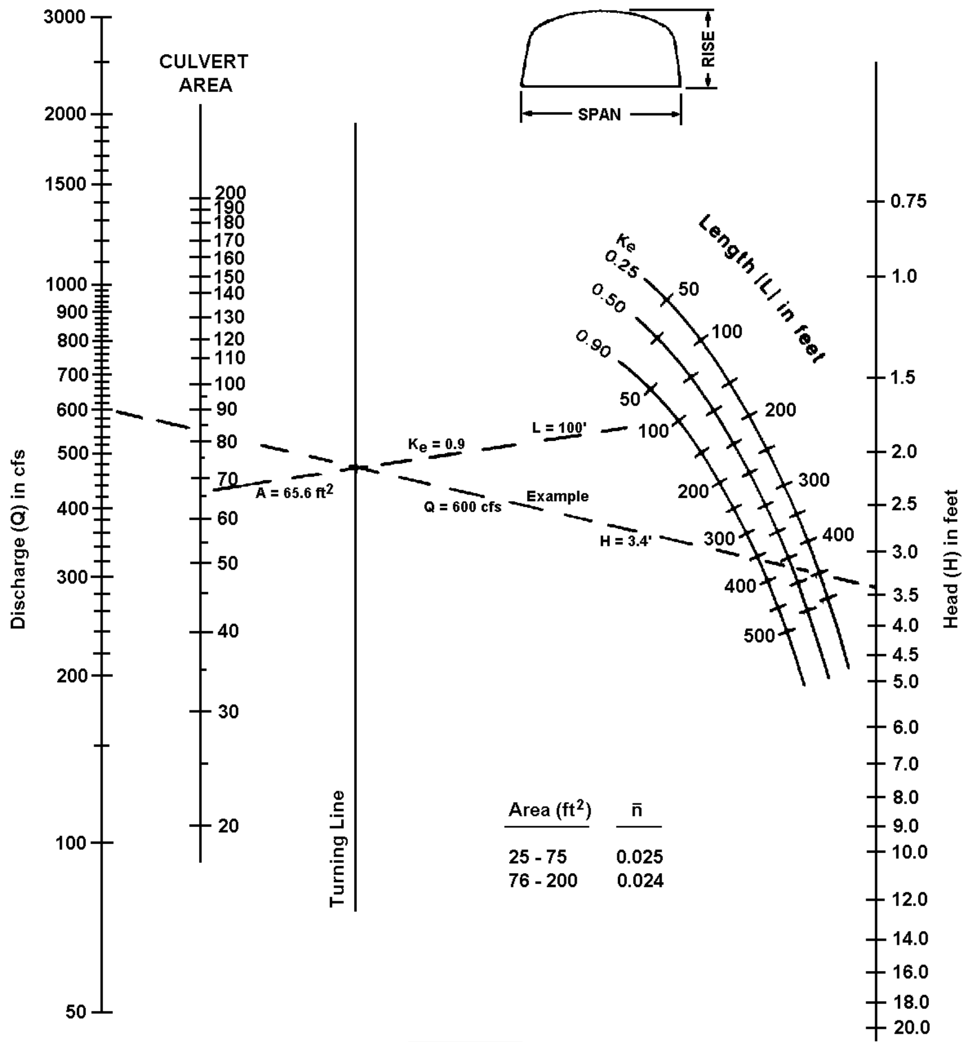
SUBMERGED OUTLET CULVERT FLOWING FULL

For outlet crown not submerged, compute HW by methods described in the design procedure.

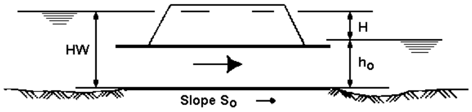
HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM RISE/SPAN < 0.3

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 22



Area (ft²)	n̄
25 - 75	0.025
76 - 200	0.024



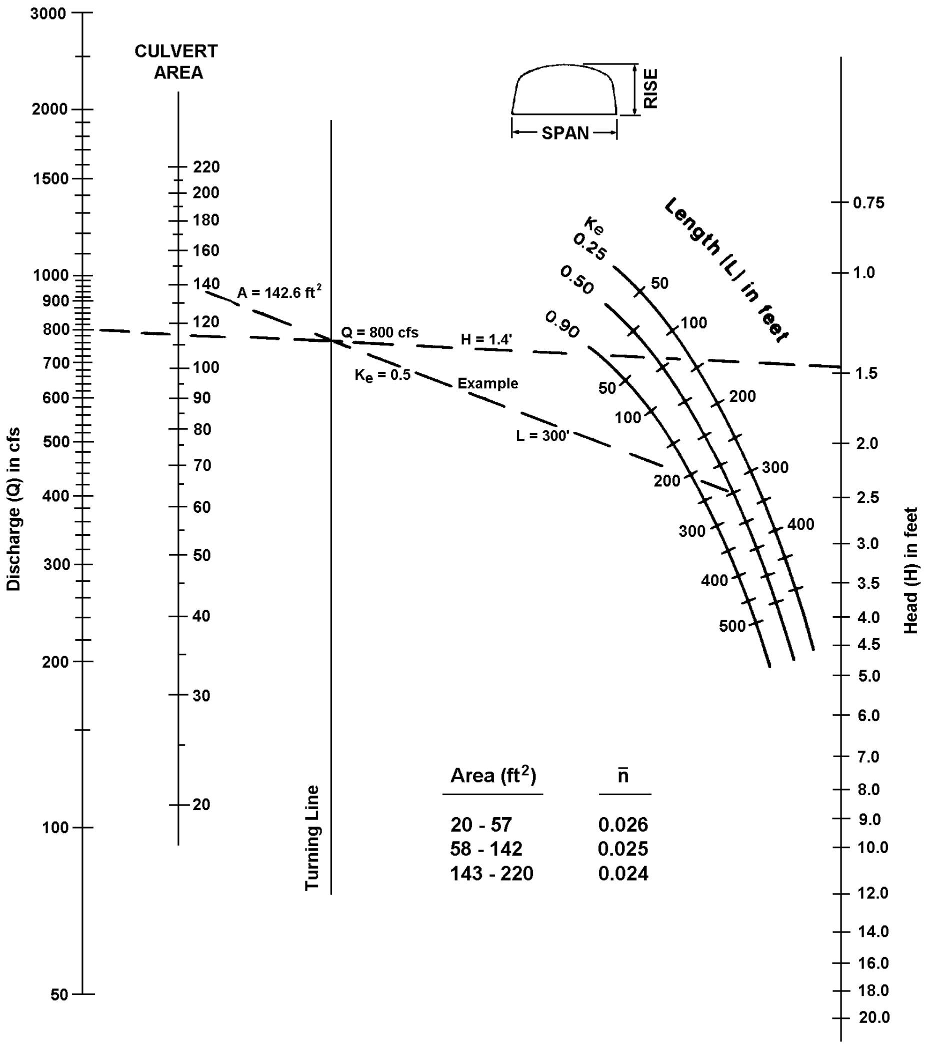
SUBMERGED OUTLET CULVERT FLOWING FULL

For outlet crown not submerged, compute HW by methods described in the design procedure.

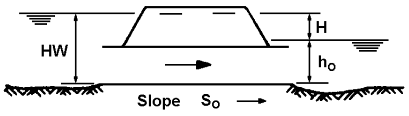
HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.3 ≤ RISE/SPAN < 0.4

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 23



Area (ft^2)	n
20 - 57	0.026
58 - 142	0.025
143 - 220	0.024

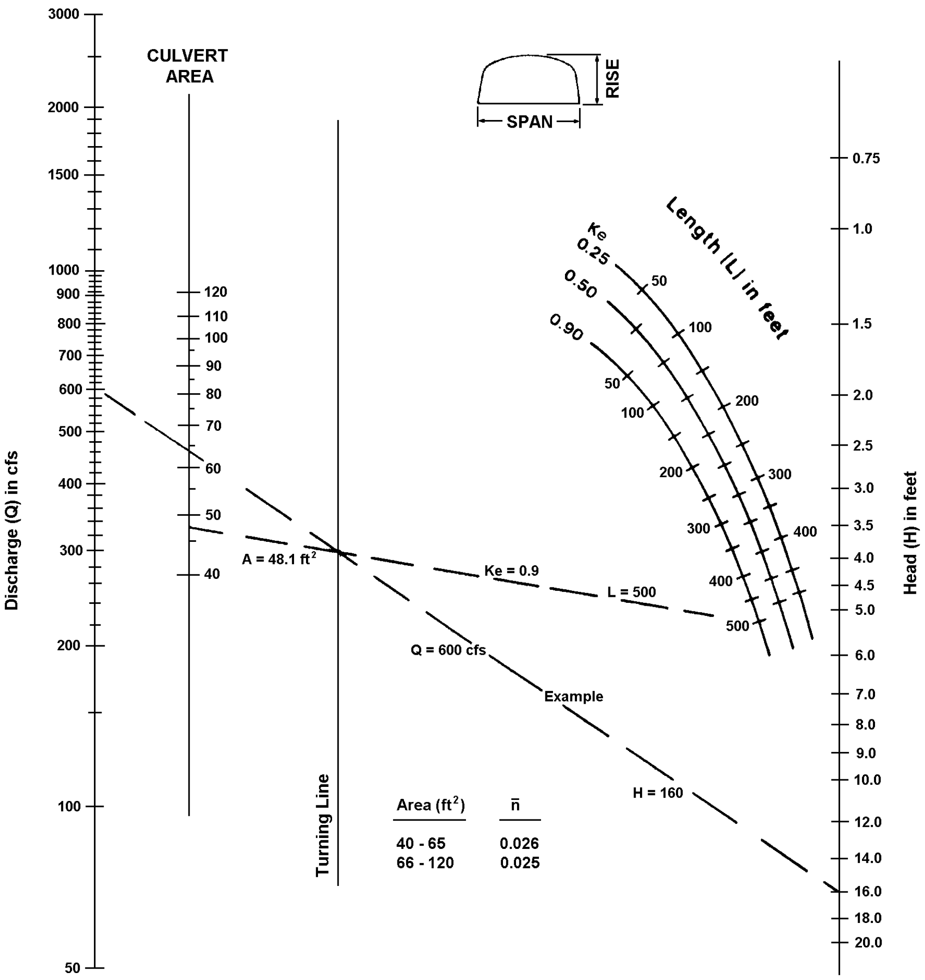


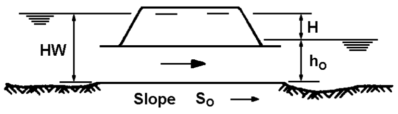
SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 24



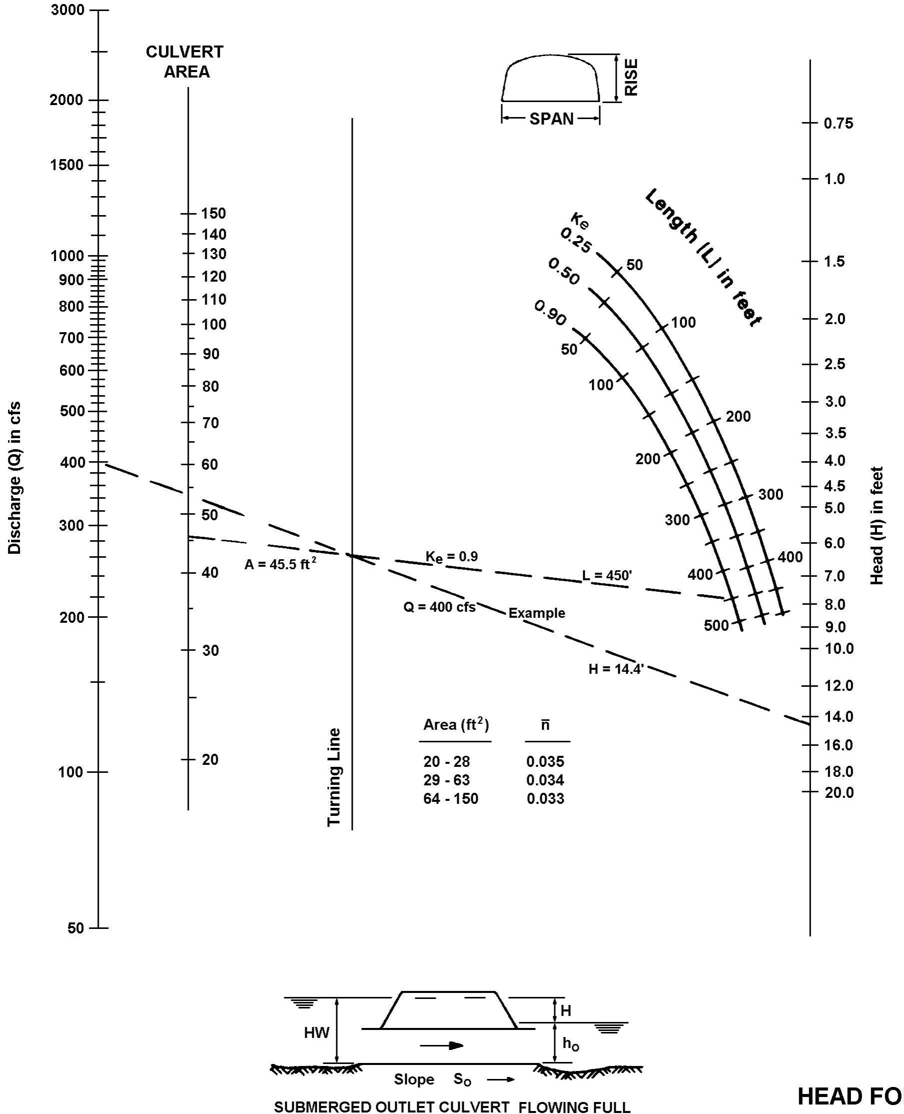


SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.5 ≤ RISE/SPAN

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 25



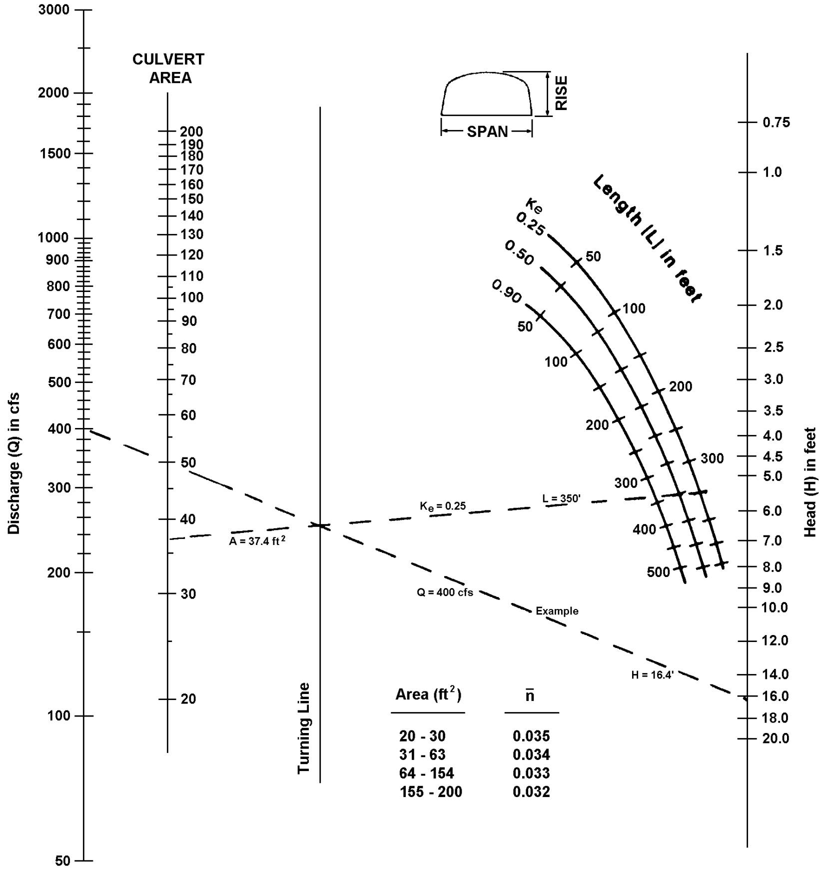
Area (ft²)	n̄
20 - 28	0.035
29 - 63	0.034
64 - 150	0.033

SUBMERGED OUTLET CULVERT FLOWING FULL

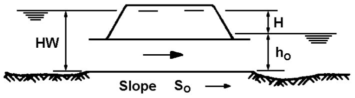
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

**HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.3< RISE/SPAN**

CHART 26



Area (ft^2)	$\bar{n}$
20 - 30	0.035
31 - 63	0.034
64 - 154	0.033
155 - 200	0.032

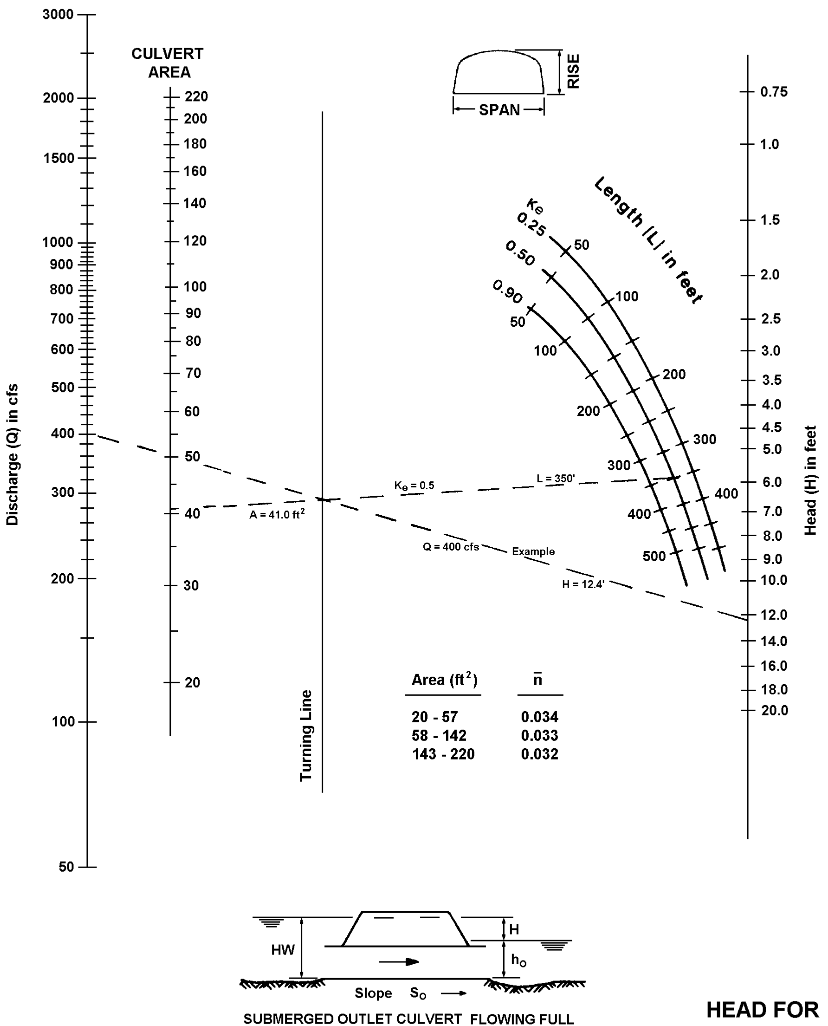


SUBMERGED OUTLET CULVERT FLOWING FULL

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.4 ≤ RISE/SPAN < 0.5

CHART 27

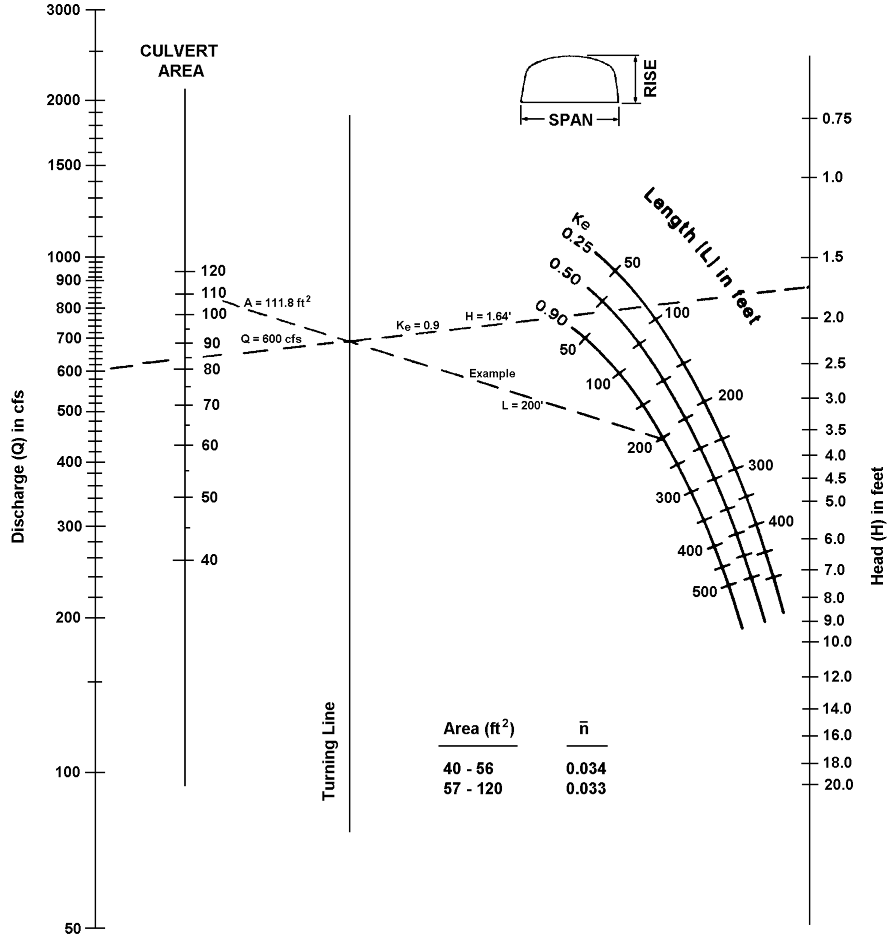


Area (ft^2)	$\bar{n}$
20 - 57	0.034
58 - 142	0.033
143 - 220	0.032

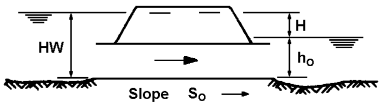
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM $0.4 \leq$ RISE/SPAN < 0.5

CHART 28



Area (ft^2)	$\bar{n}$
40 - 56	0.034
57 - 120	0.033

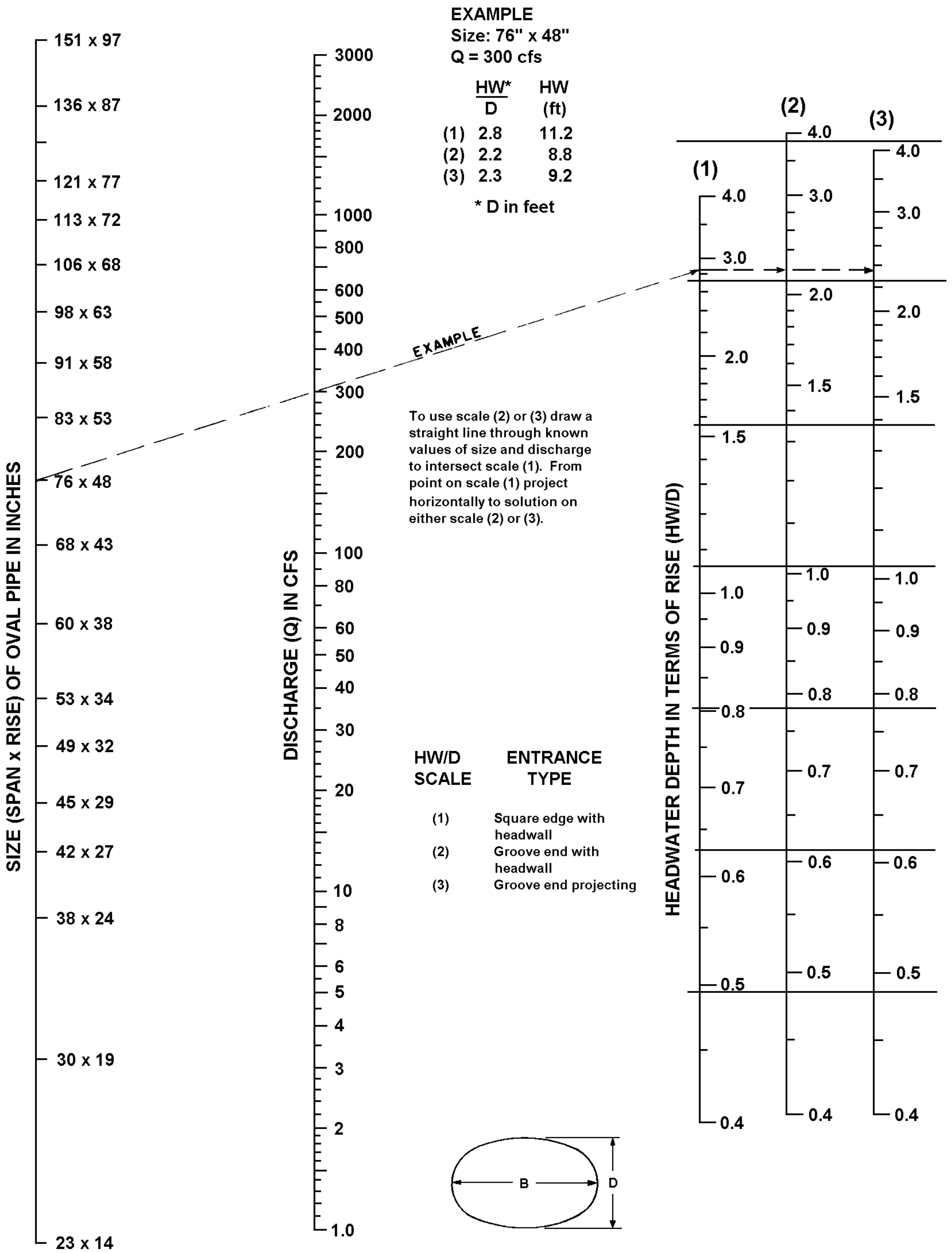


SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.5 ≤ RISE/SPAN

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 29



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

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

* D in feet

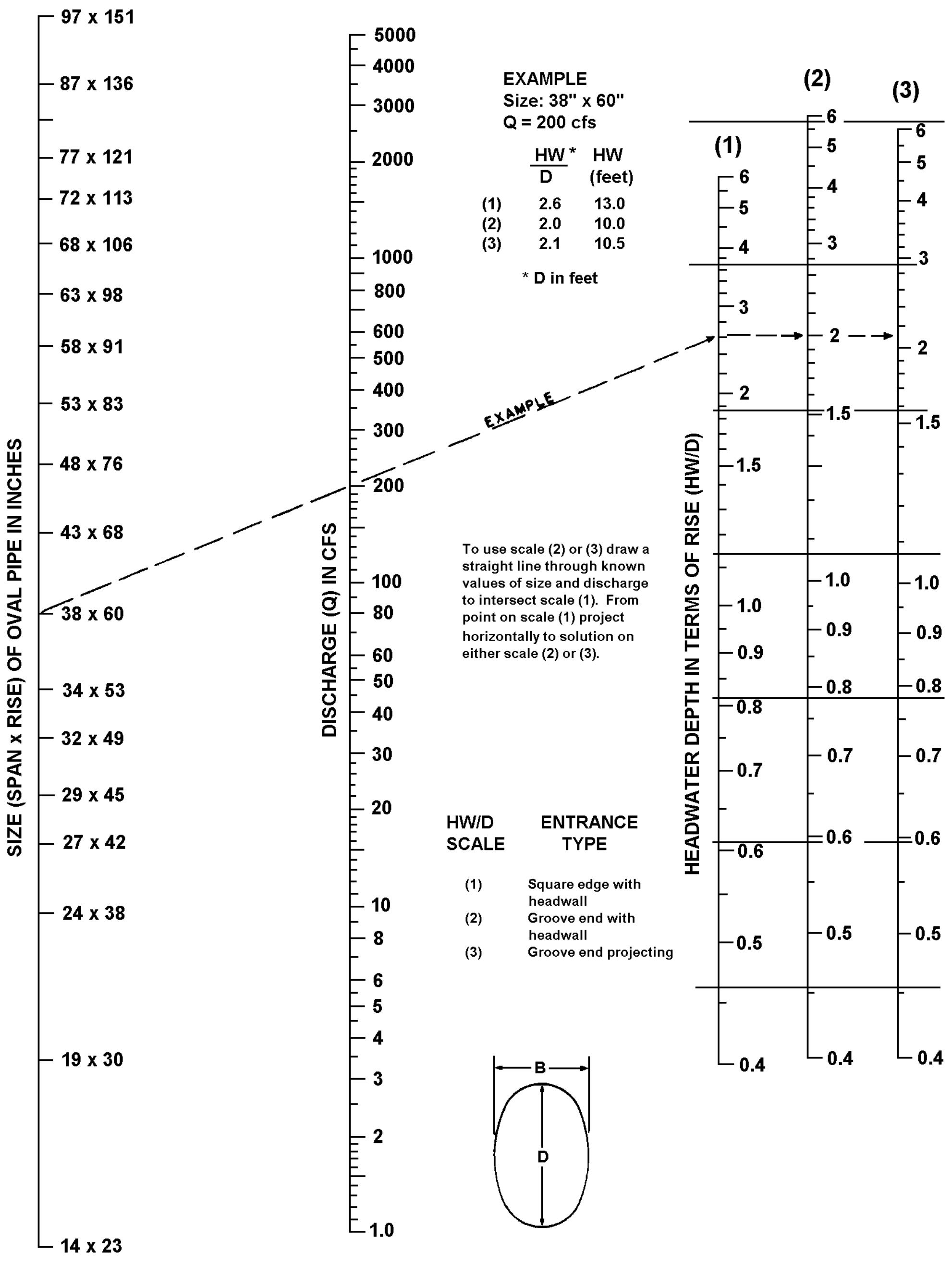
To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

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

HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 30



EXAMPLE
Size: 38" x 60"
Q = 200 cfs

	HW* / D	HW (feet)
(1)	2.6	13.0
(2)	2.0	10.0
(3)	2.1	10.5

* D in feet

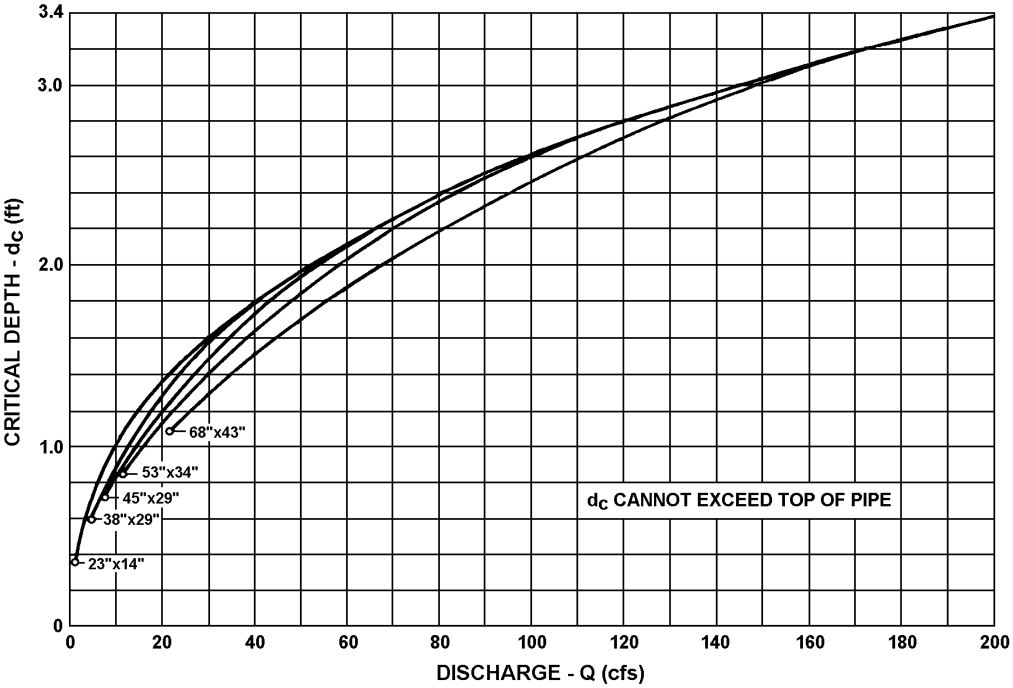
To use scale (2) or (3) draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1) project horizontally to solution on either scale (2) or (3).

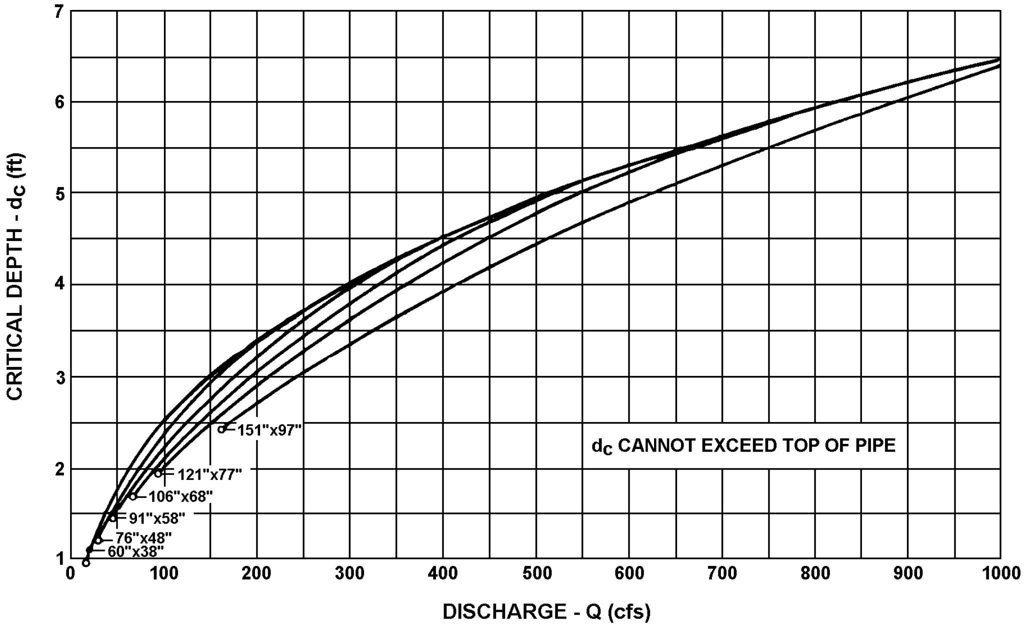
HW/D SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS VERTICAL
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 31

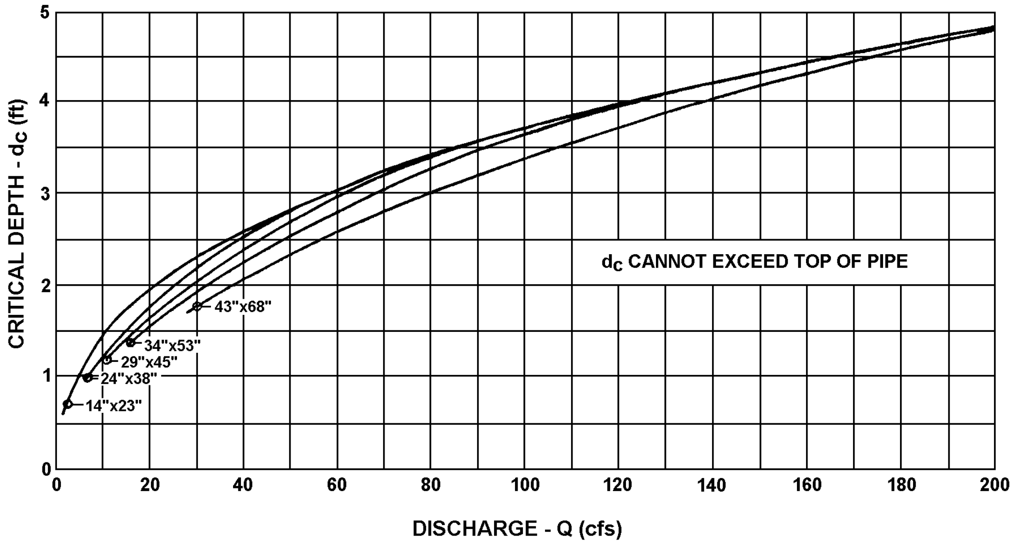


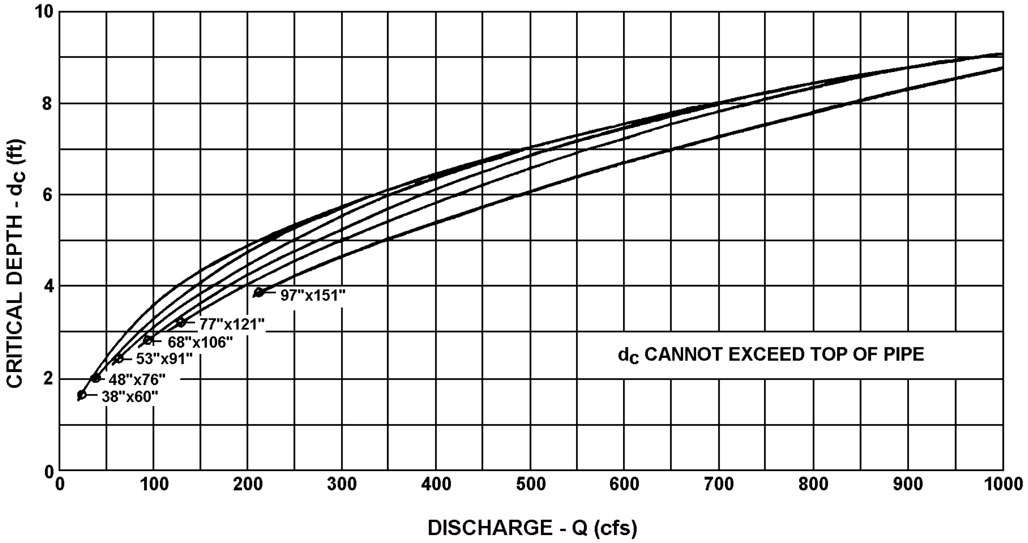


BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

CHART 32

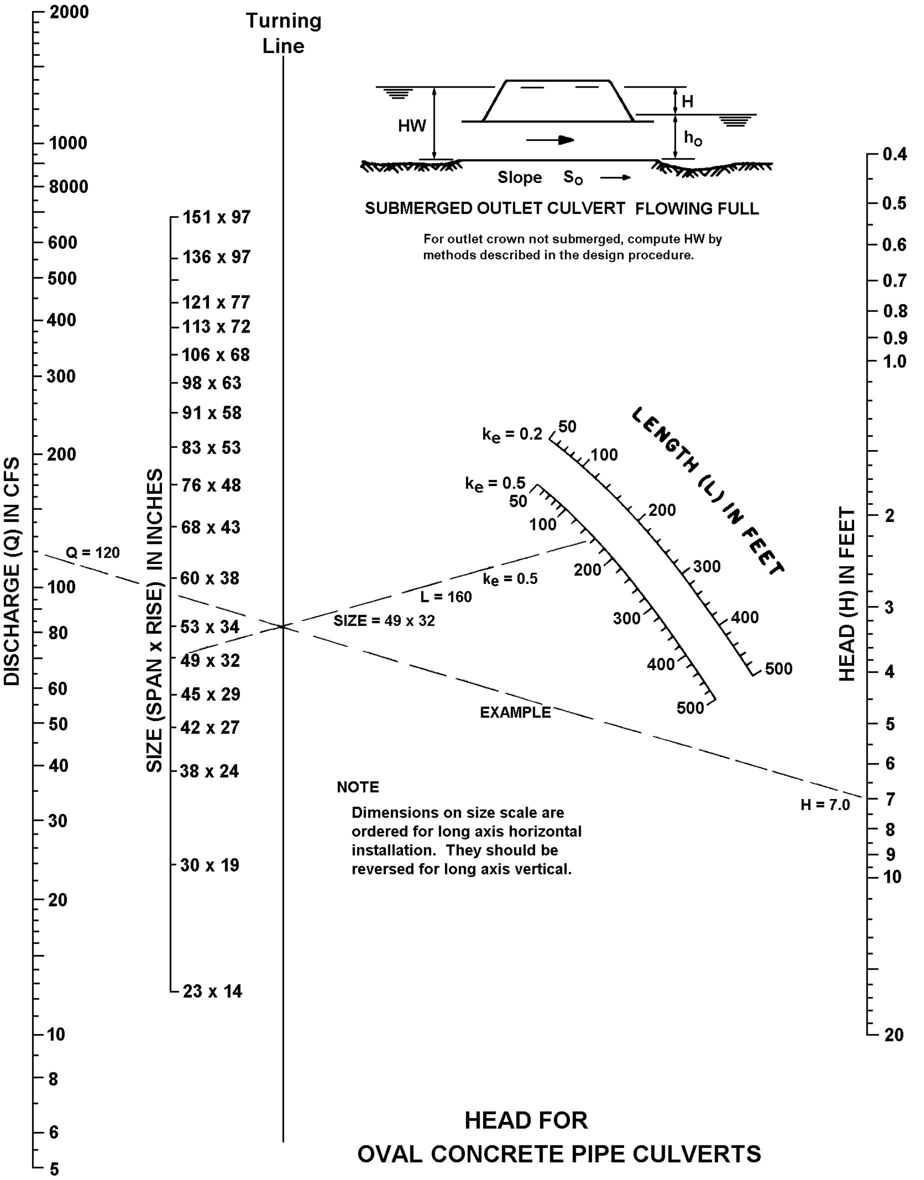




BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

CHART 33



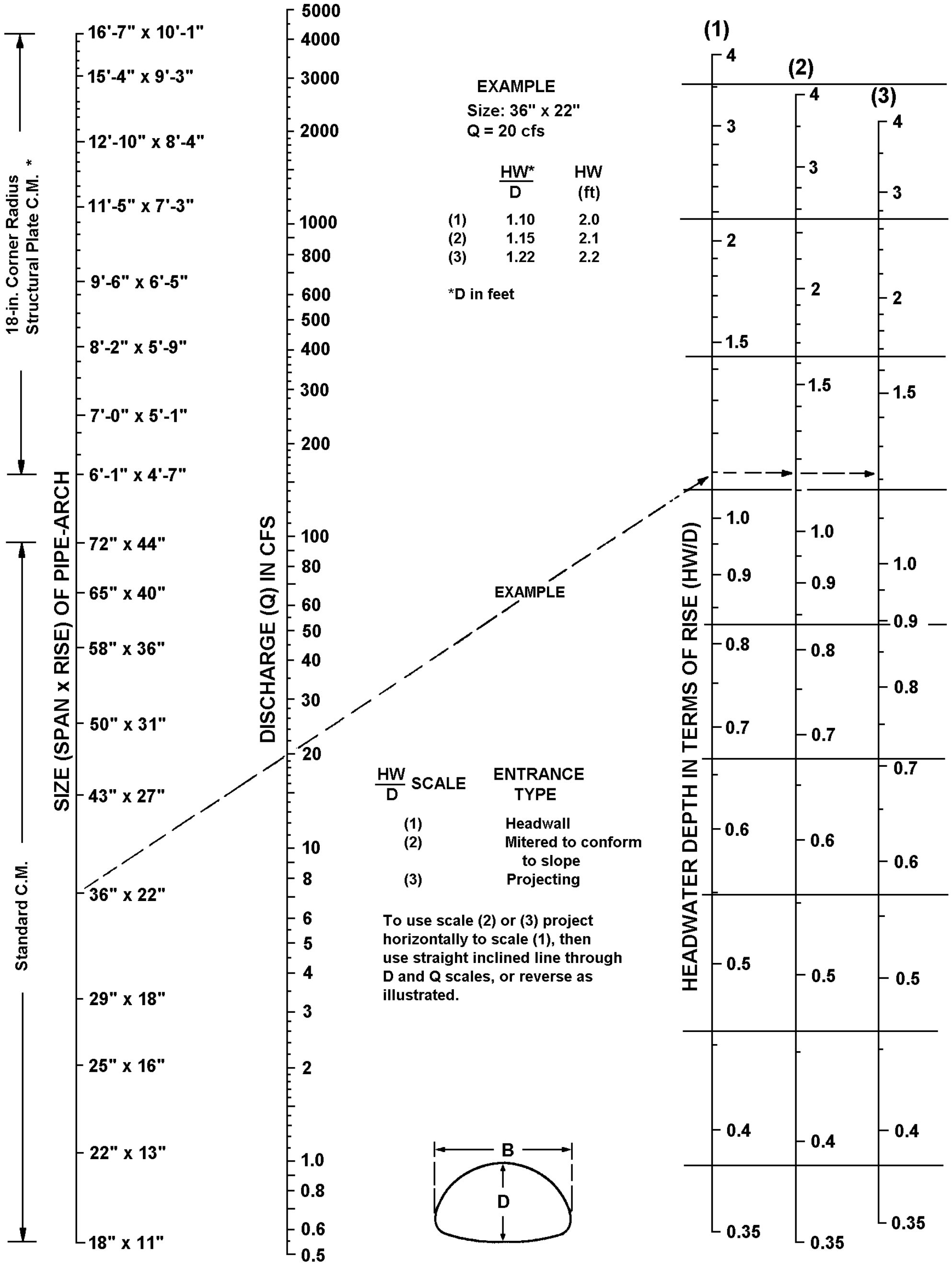
NOTE

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

HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 34



EXAMPLE
Size: 36" x 22"
Q = 20 cfs

	HW*/D	HW (ft)
(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.

* Additional sizes not dimensioned are listed in fabricator's catalog.

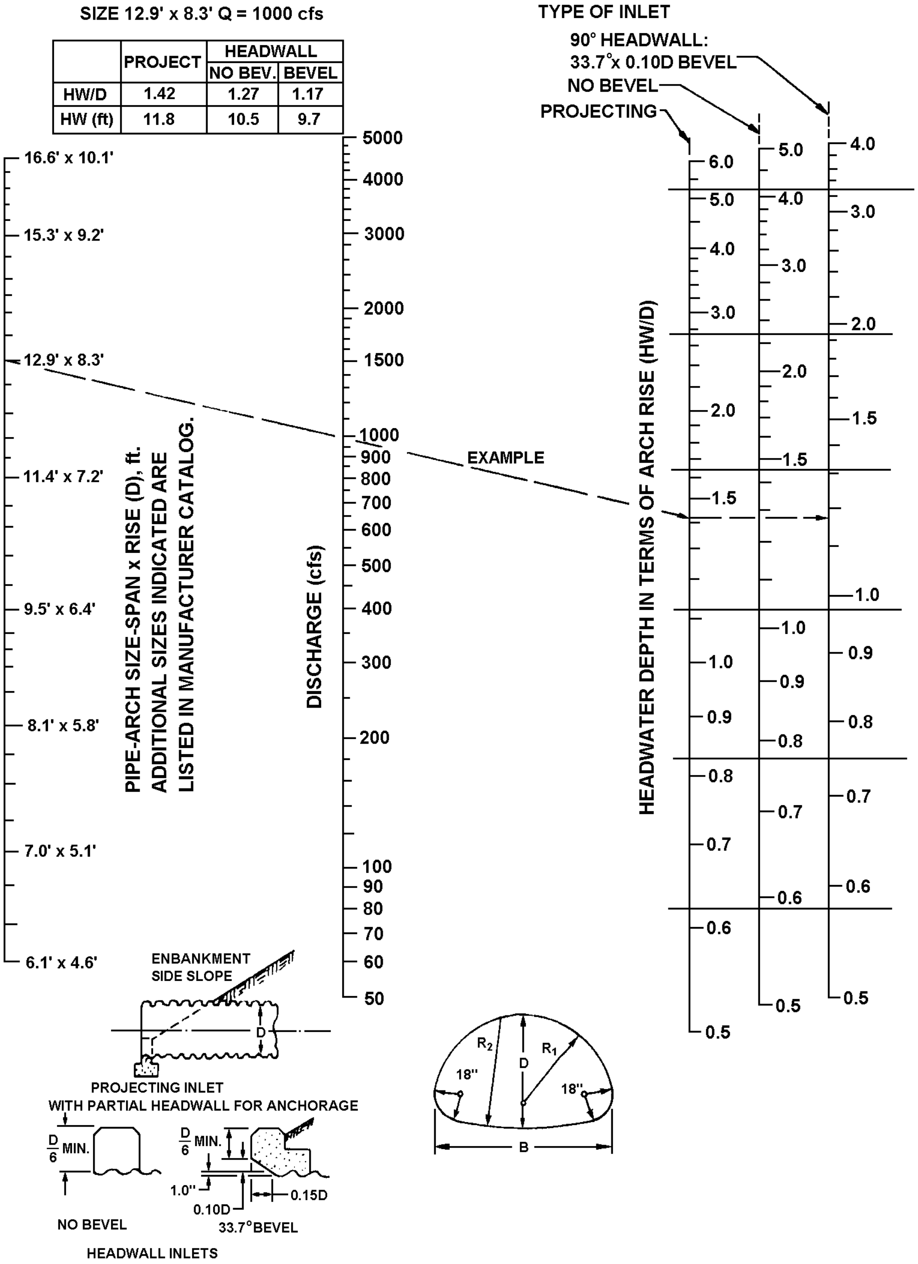
HEADWATER DEPTH FOR C.M. PIPE-ARCH CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 35

EXAMPLE
SIZE 12.9' x 8.3' Q = 1000 cfs

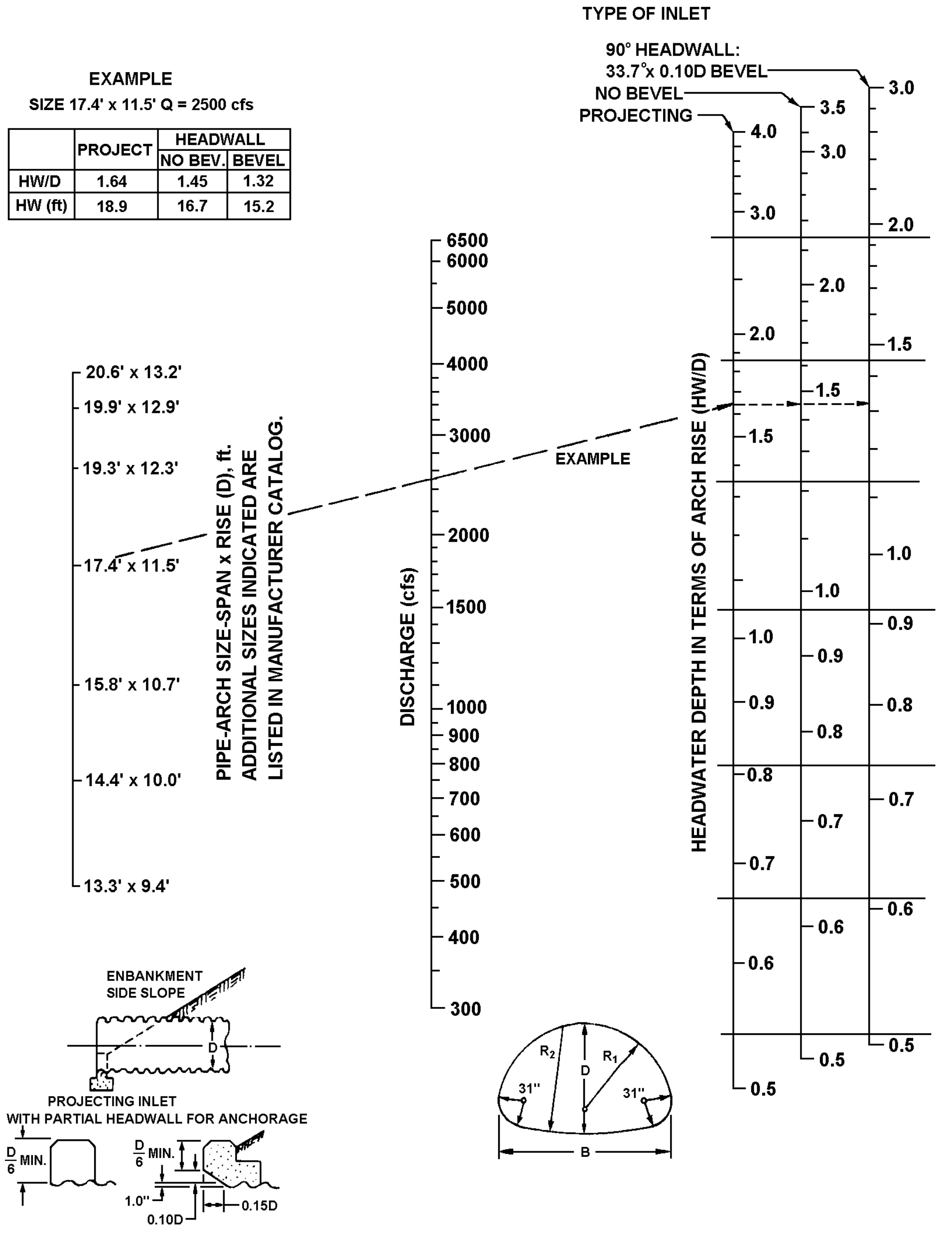
	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW/D	1.42	1.27	1.17
HW (ft)	11.8	10.5	9.7



BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1968

HEADWATER DEPTH FOR INLET CONTROLS
STRUCTURAL PLATE PIPE-ARCH CULVERTS
18 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

CHART 36


EXAMPLE

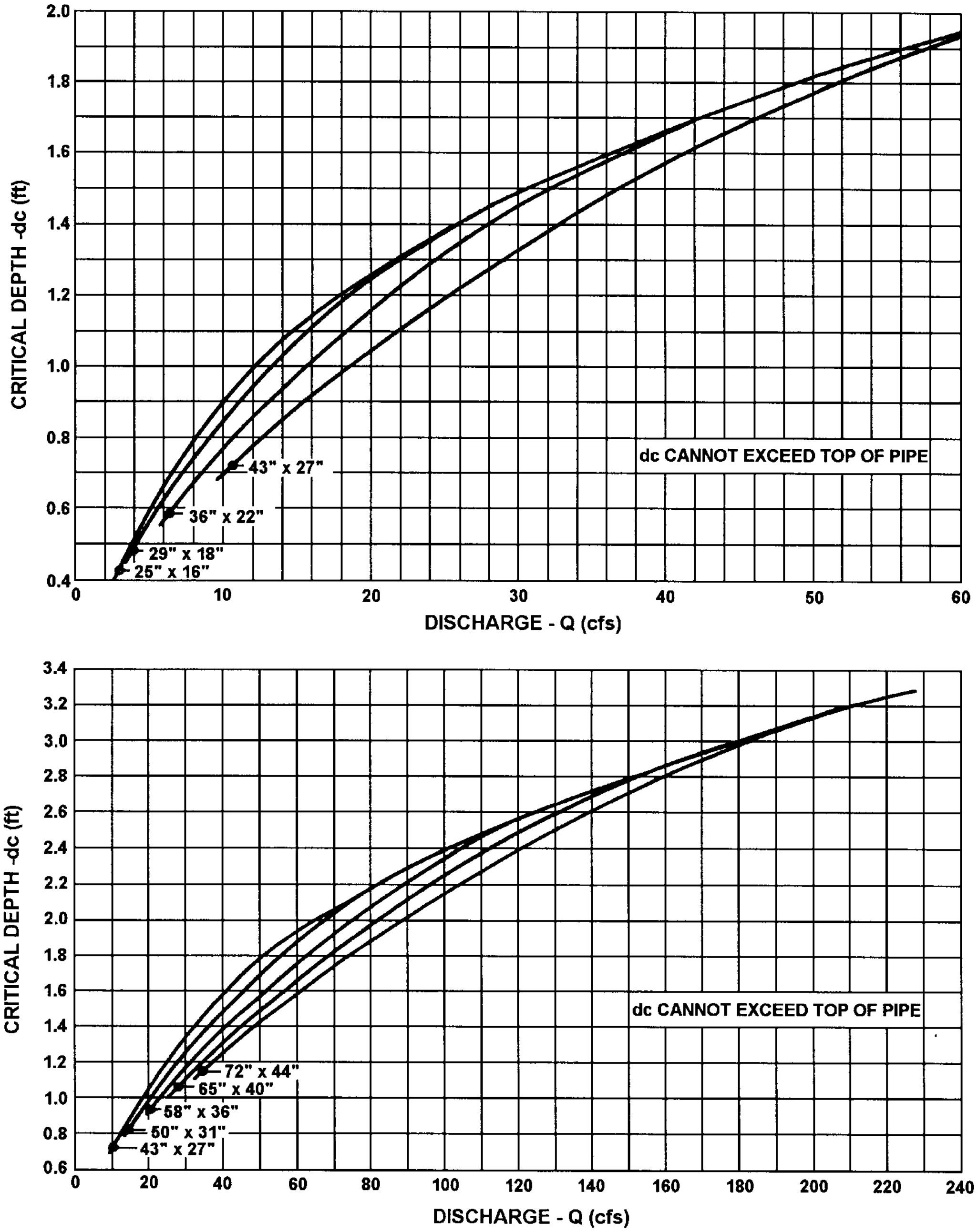
SIZE 17.4' x 11.5' Q = 2500 cfs

	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW/D	1.64	1.45	1.32
HW (ft)	18.9	16.7	15.2

HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
31 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1966

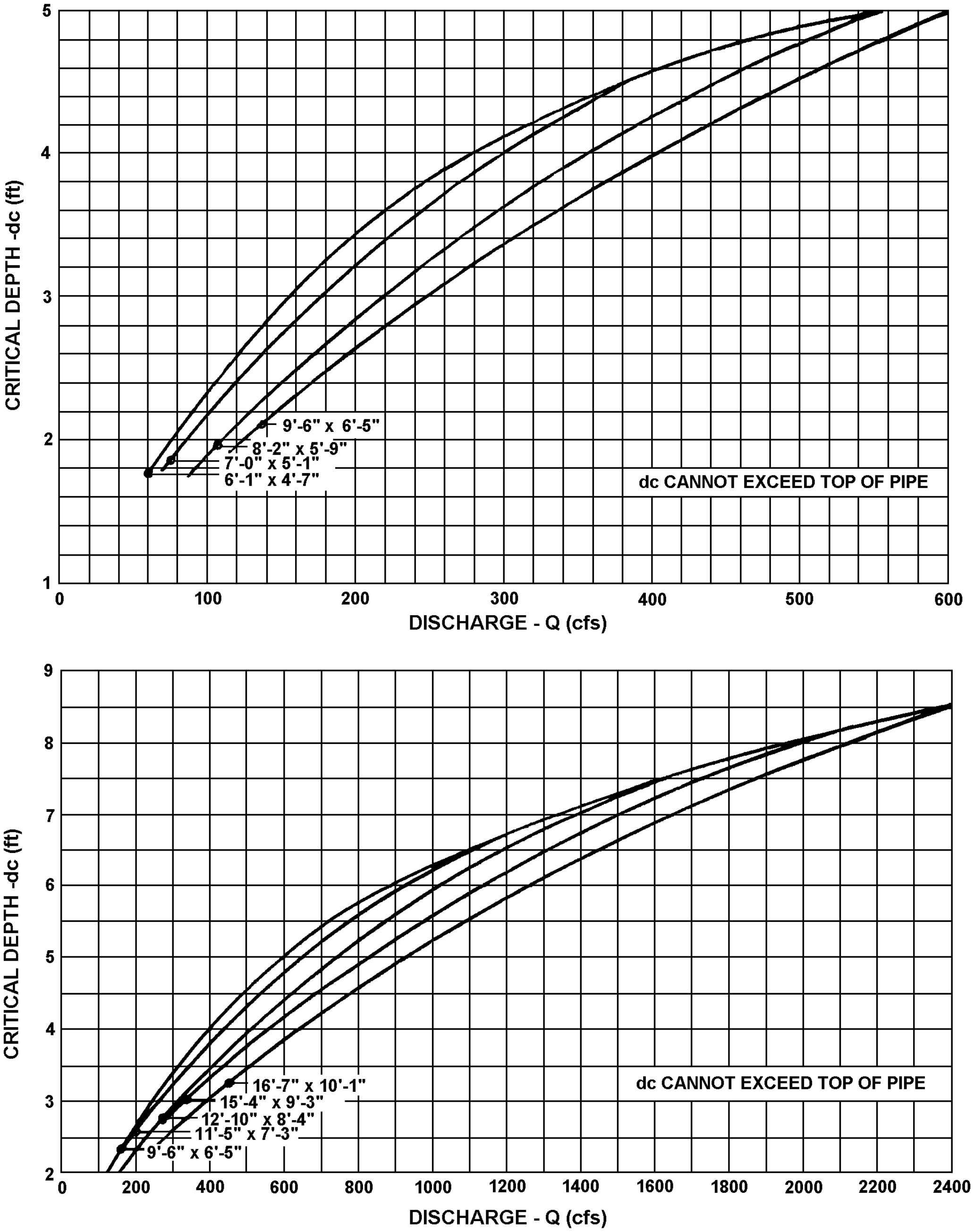
CHART 37



CRITICAL DEPTH
STANDARD C.M. PIPE ARCH

BUREAU OF PUBLIC ROADS
JAN. 1964

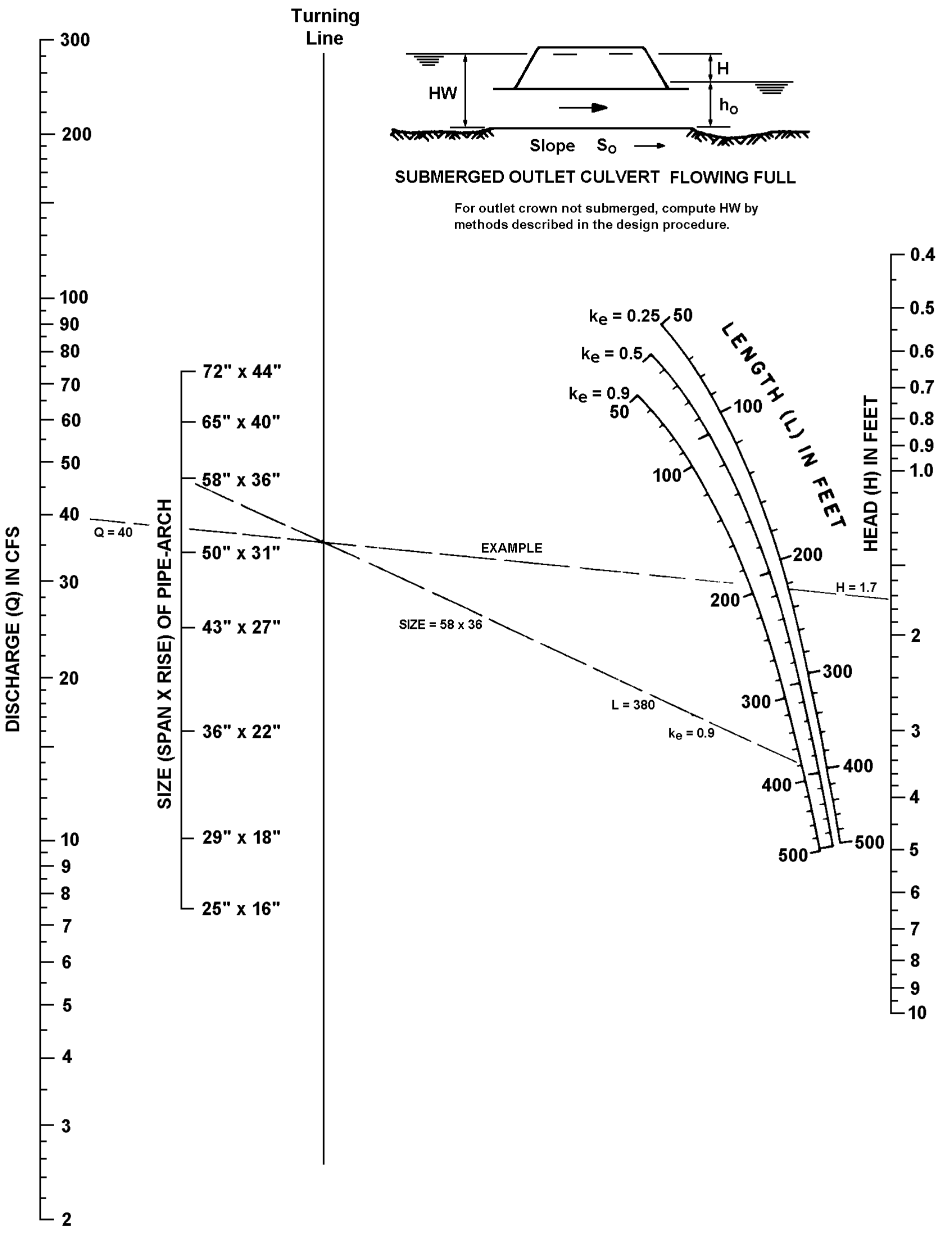
CHART 38



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C.M. PIPE ARCH
18 in. CORNER RADIUS

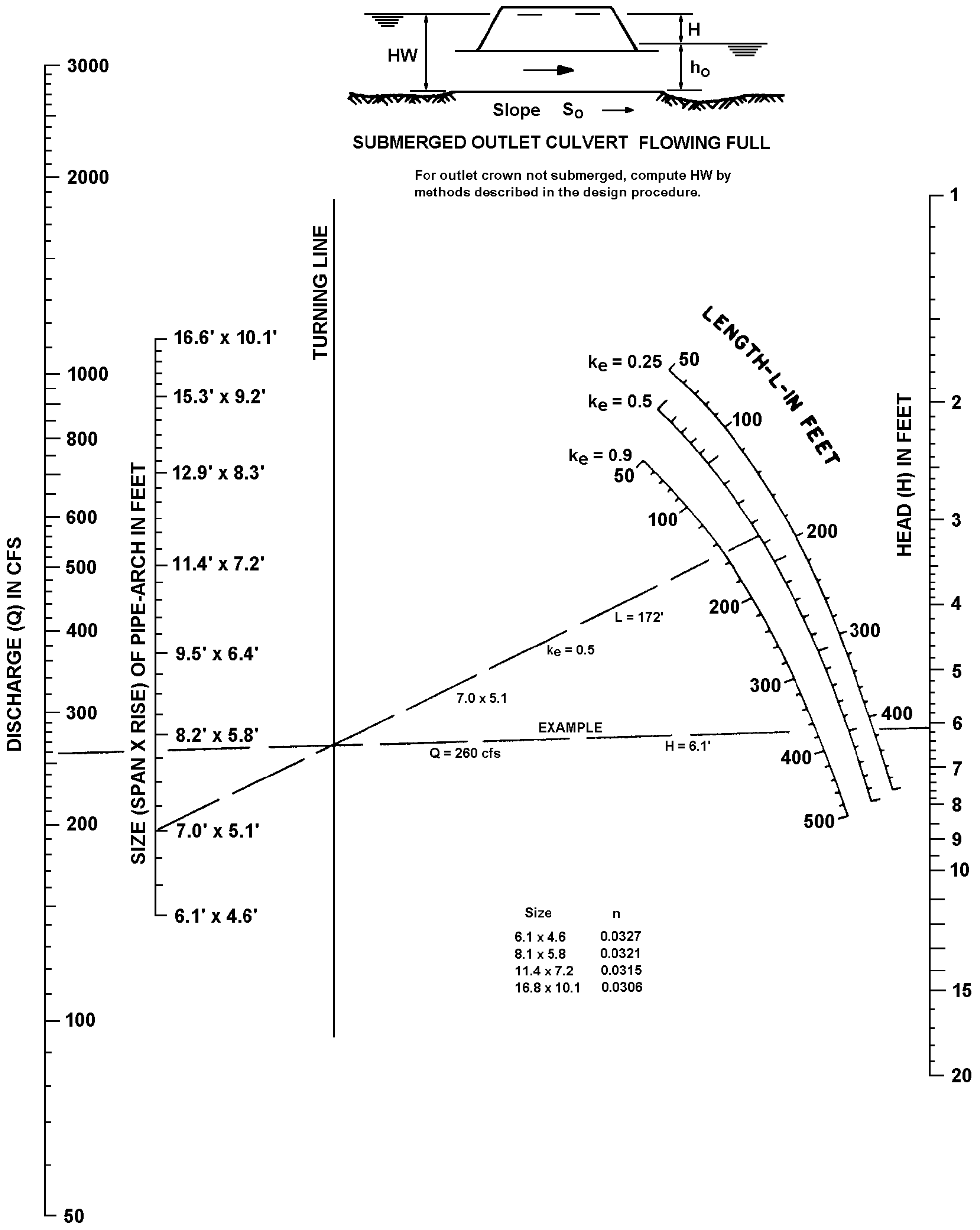
CHART 39



HEAD FOR
STANDARD C.M. PIPE-ARCH CULVERTS
FLOWING FULL
n = 0.024

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 40

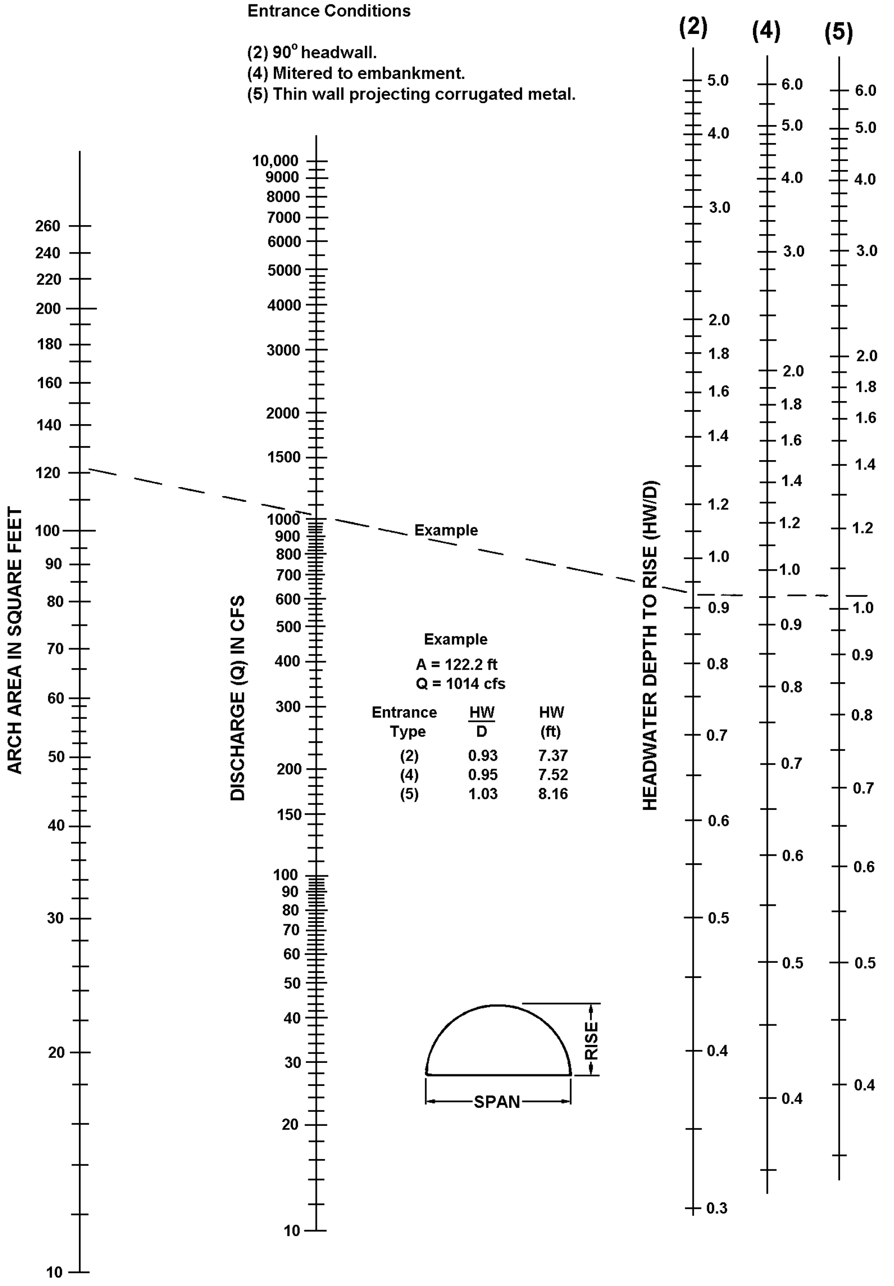


Size	n
6.1 x 4.6	0.0327
8.1 x 5.8	0.0321
11.4 x 7.2	0.0315
16.8 x 10.1	0.0306

BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR
STRUCTURAL PLATE
C.M. PIPE ARCH CULVERTS
18 in. CORNER RADIUS
FLOWING FULL
n = 0.0327 TO 0.0306

CHART 41



Entrance Conditions

(2) 90° headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.

Example

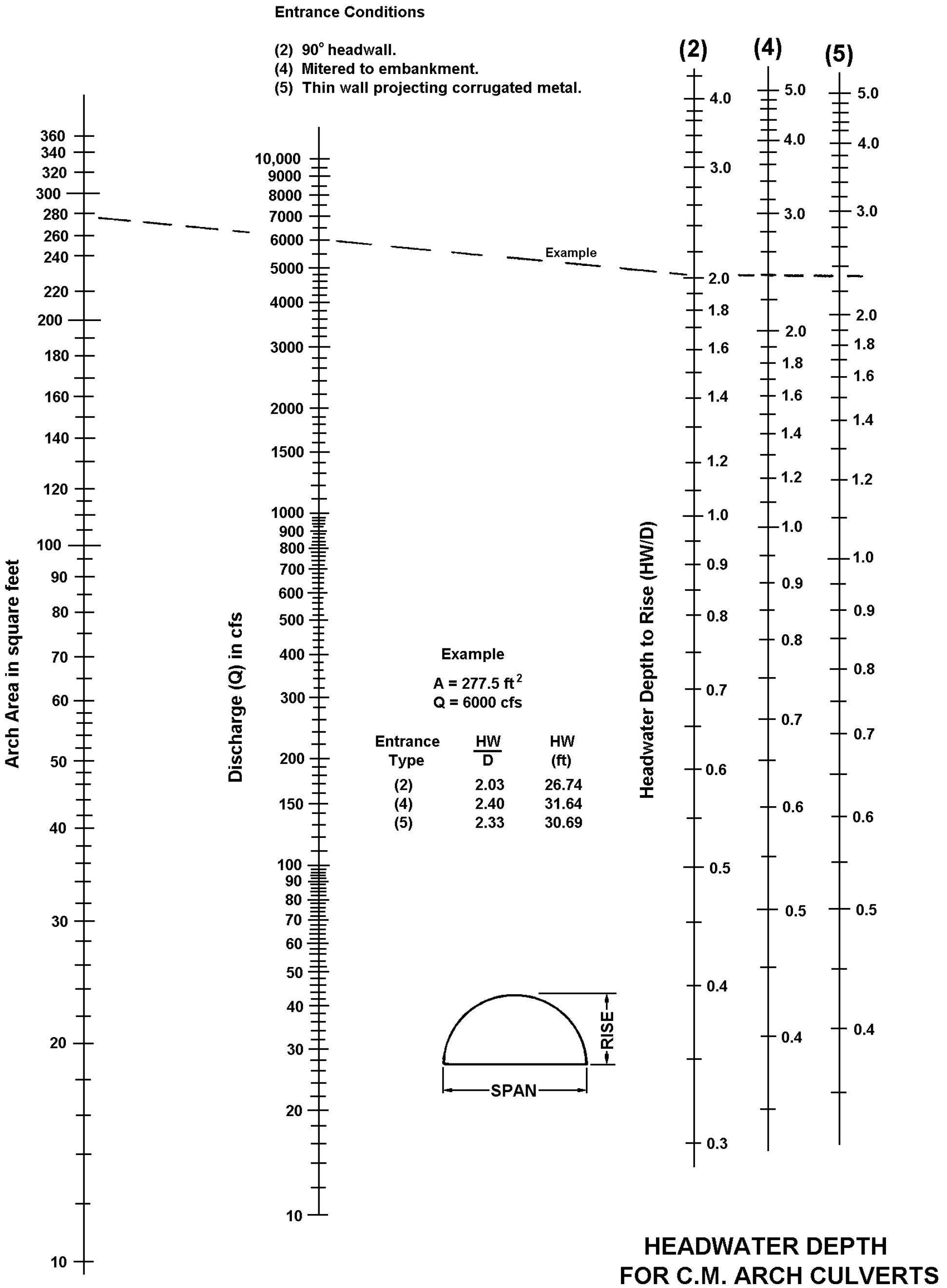
A = 122.2 ft
Q = 1014 cfs

Entrance Type	HW/D	HW (ft)
(2)	0.93	7.37
(4)	0.95	7.52
(5)	1.03	8.16

HEADWATER DEPTH FOR C.M. ARCH CULVERTS 0.3 ≤ RISE/SPAN < 0.4 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 42



Example

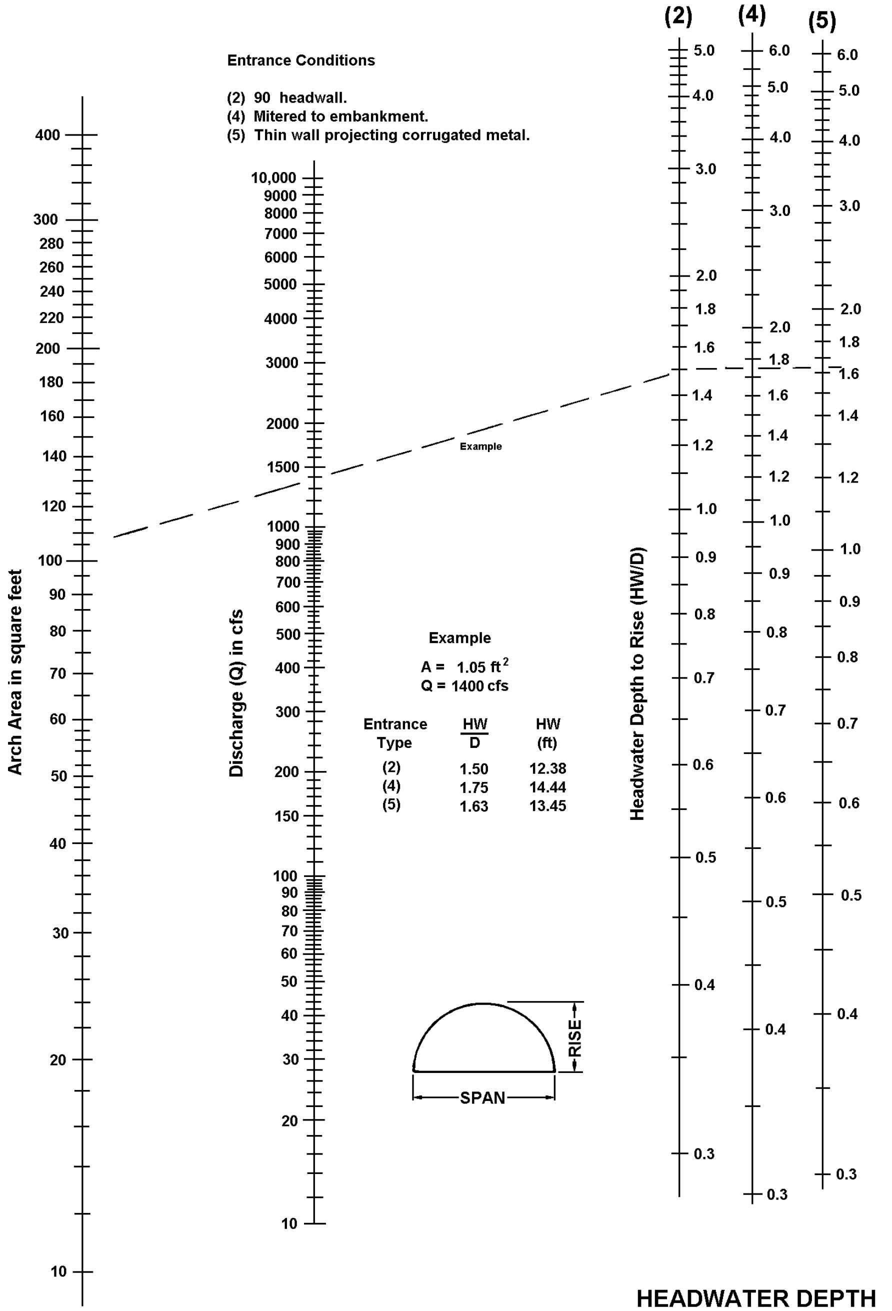
A = 277.5 ft^2
Q = 6000 cfs

Entrance Type	HW/D	HW (ft)
(2)	2.03	26.74
(4)	2.40	31.64
(5)	2.33	30.69

HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.4 ≤ RISE/SPAN < 0.5
WITH INLET CONTROL

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 43



Entrance Conditions

(2) 90 headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.

Example

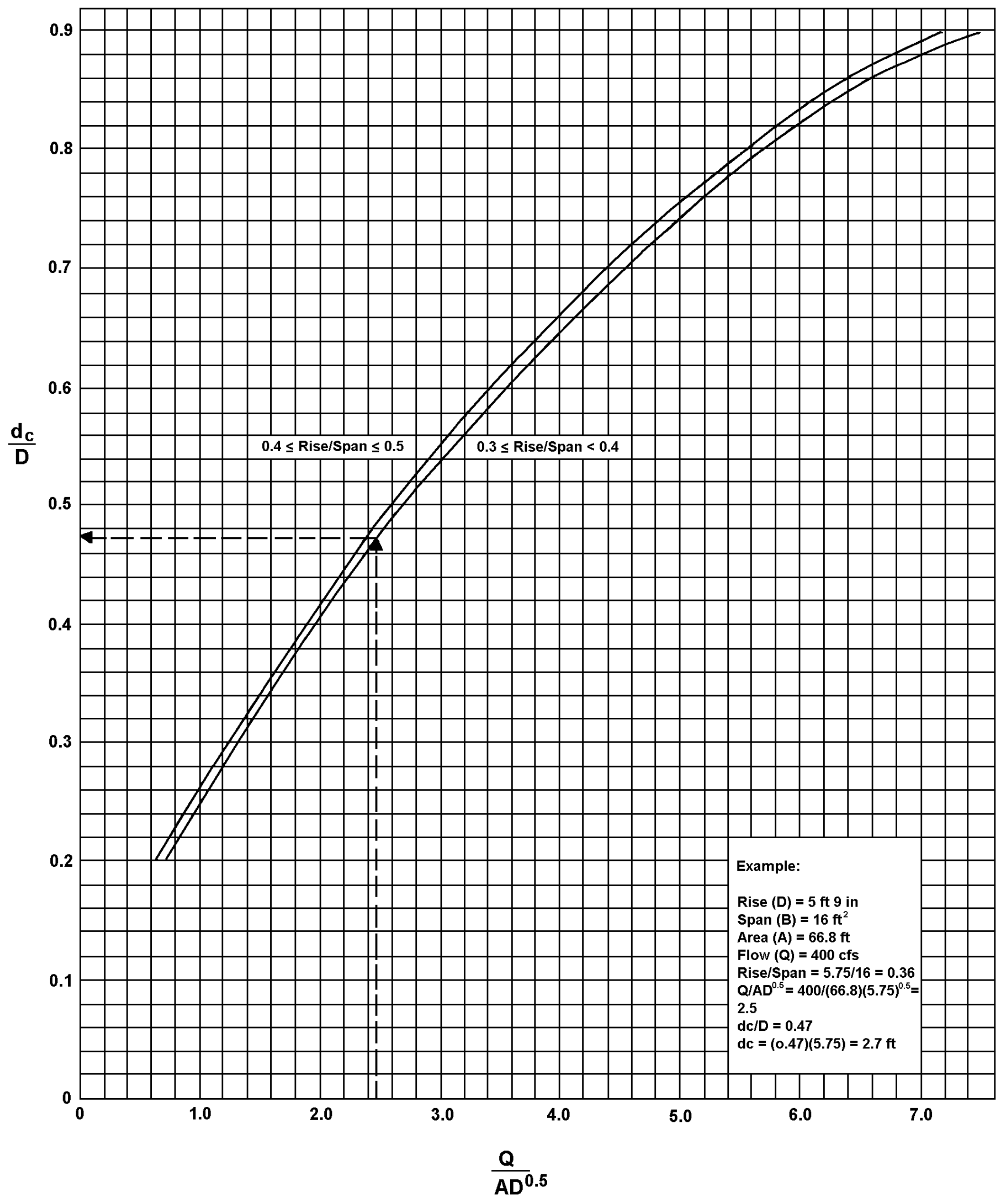
A = 1.05 ft^2
Q = 1400 cfs

Entrance Type	HW/D	HW (ft)
(2)	1.50	12.38
(4)	1.75	14.44
(5)	1.63	13.45

HEADWATER DEPTH FOR C.M. ARCH CULVERTS 0.5 ≤ RISE/SPAN WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 44

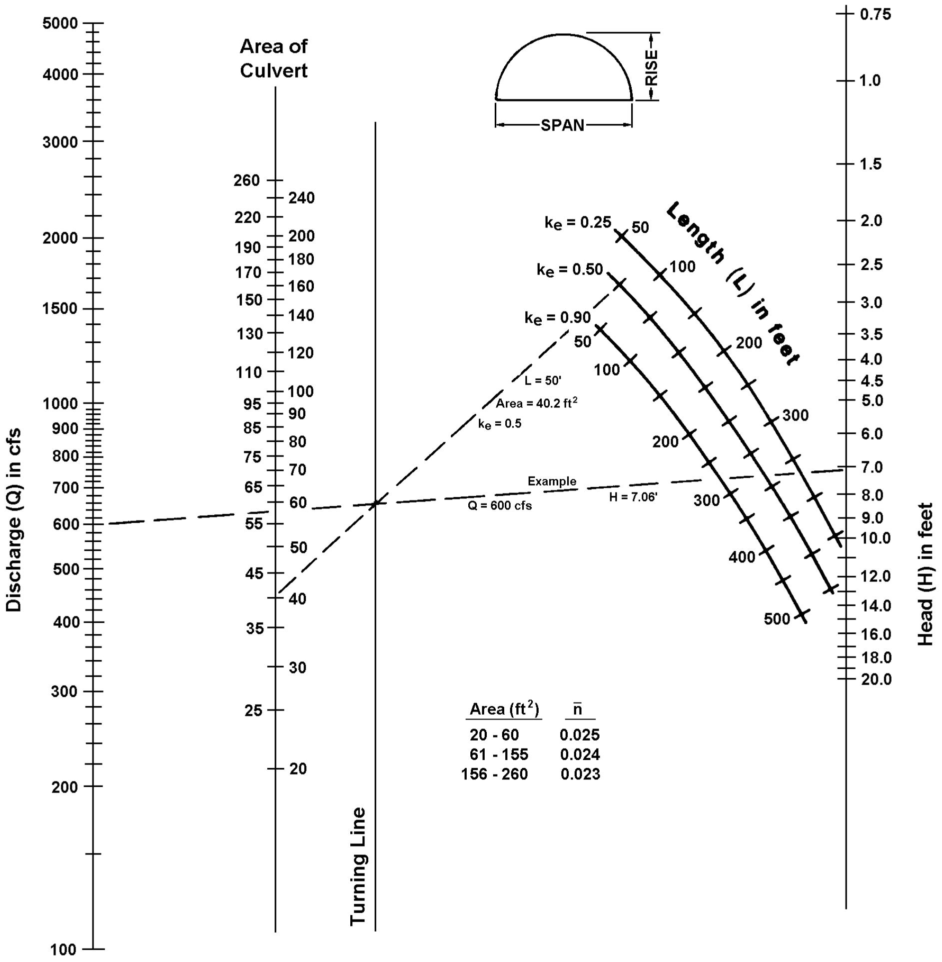


Example:

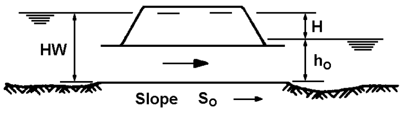
Rise (D) = 5 ft 9 in
Span (B) = 16 ft^2
Area (A) = 66.8 ft
Flow (Q) = 400 cfs
Rise/Span = 5.75/16 = 0.36
Q/AD$^{0.5}$= 400/(66.8)(5.75)$^{0.5}$= 2.5
dc/D = 0.47
dc = (o.47)(5.75) = 2.7 ft

DIMENSIONLESS CRITICAL DEPTH CHART
FOR C.M. ARCH CULVERTS

CHART 45



Area (ft^2)	$\bar{n}$
20 - 60	0.025
61 - 155	0.024
156 - 260	0.023

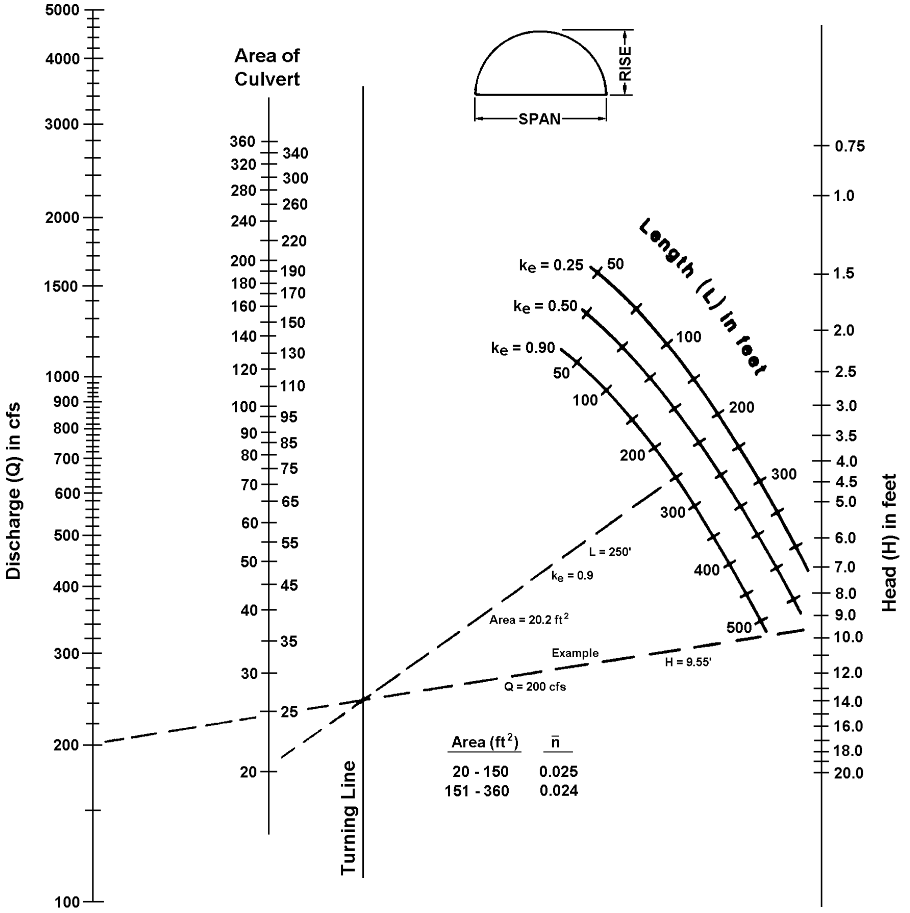


SUBMERGED OUTLET CULVERT FLOWING FULL

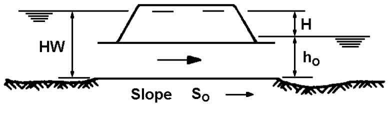
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.3 ≤ RISE/SPAN < 0.4

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 46



Area (ft^2)	$\bar{n}$
20 - 150	0.025
151 - 360	0.024

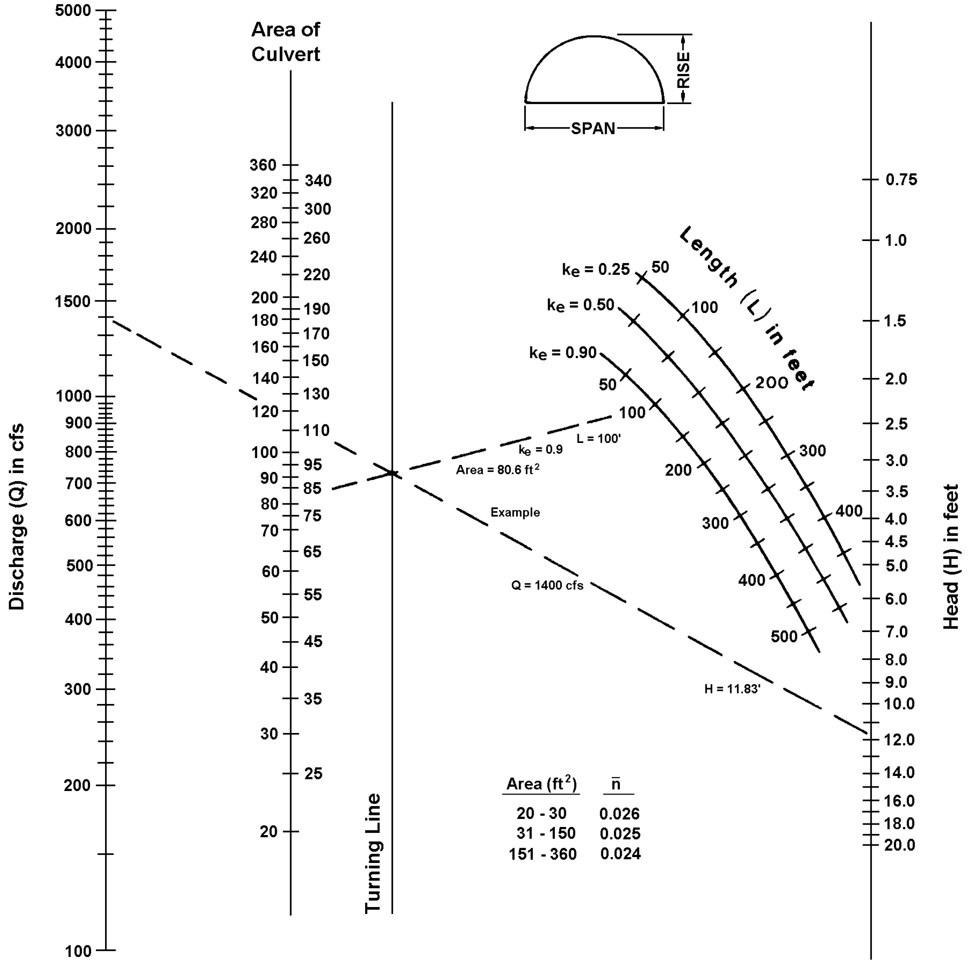


SUBMERGED OUTLET CULVERT FLOWING FULL

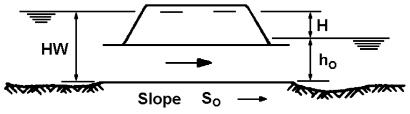
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 47



Area (ft²)	n̄
20 - 30	0.026
31 - 150	0.025
151 - 360	0.024

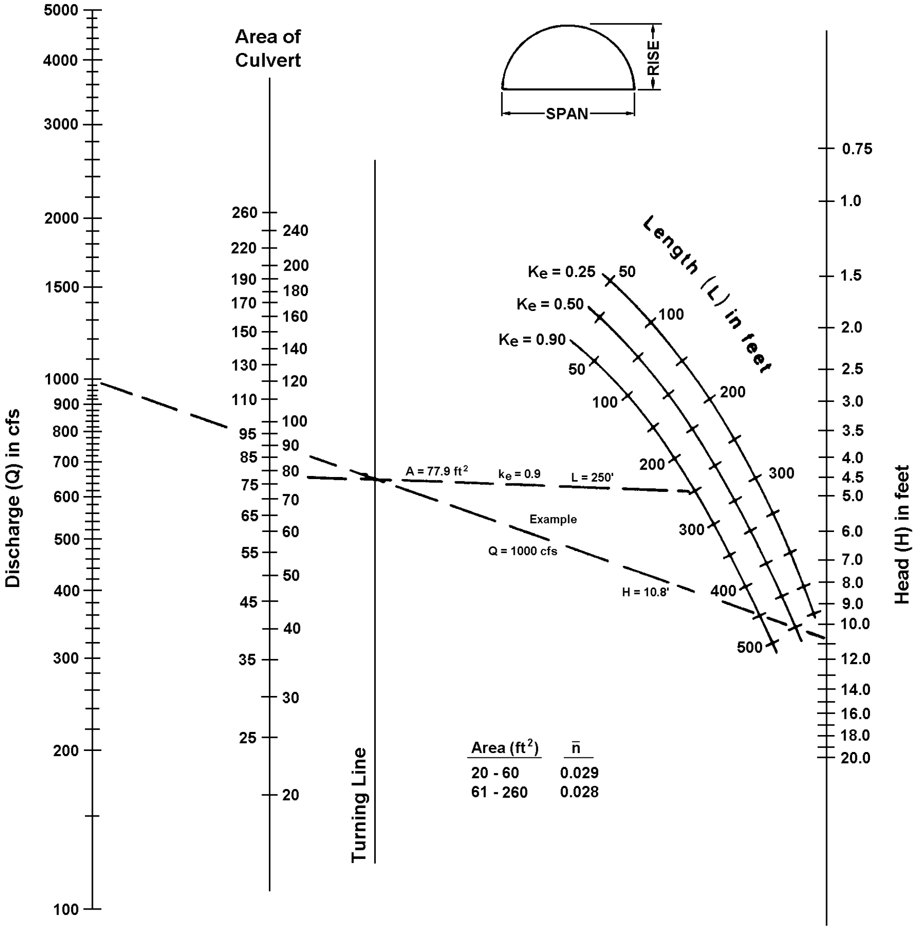


SUBMERGED OUTLET CULVERT FLOWING FULL

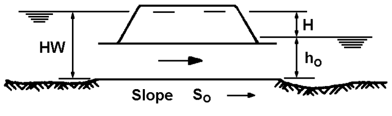
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.5 ≤ RISE/SPAN

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 48



Area (ft²)	n̄
20 - 60	0.029
61 - 260	0.028

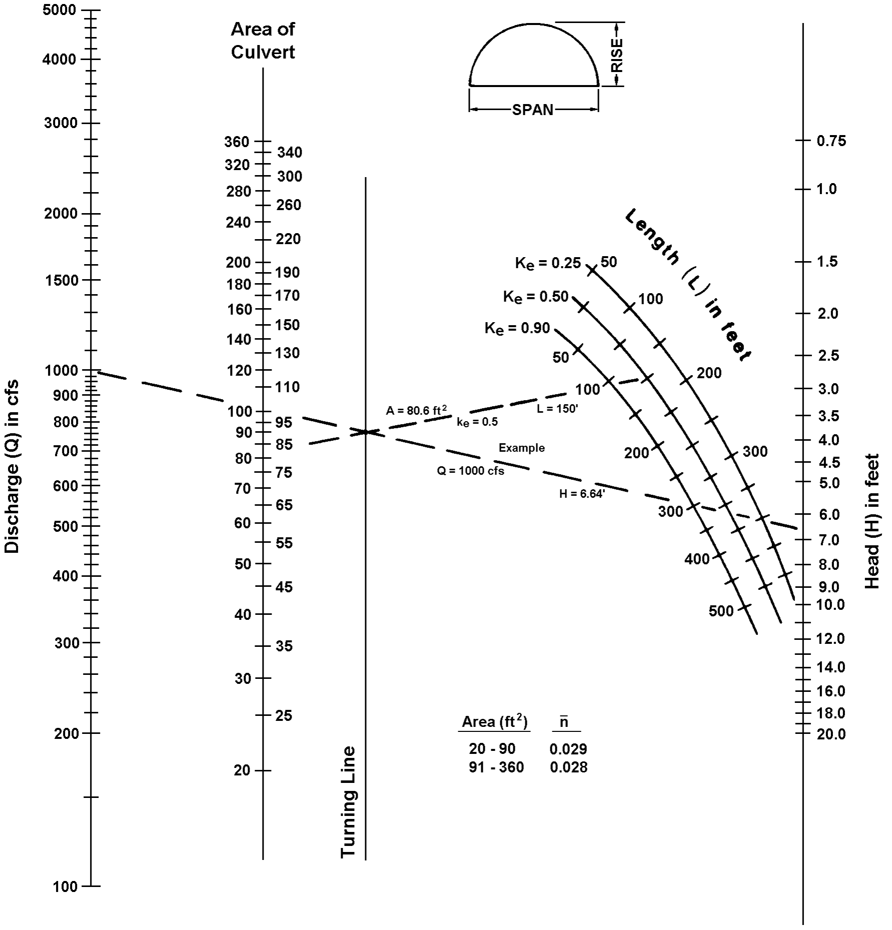


SUBMERGED OUTLET CULVERT FLOWING FULL

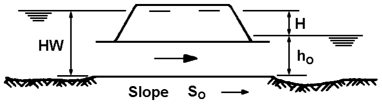
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.3 ≤ RISE/SPAN < 0.4

Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 49



Area (ft²)	n̄
20 - 90	0.029
91 - 360	0.028

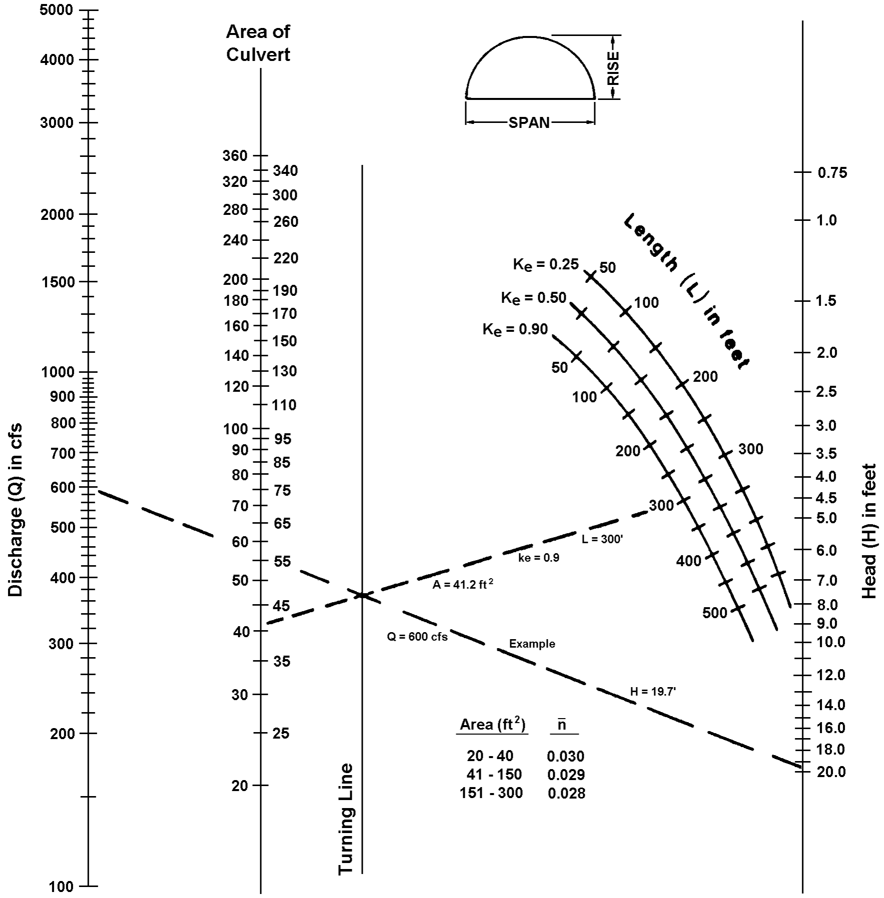


SUBMERGED OUTLET CULVERT FLOWING FULL

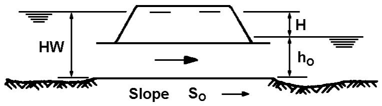
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.4 ≤ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 50



Area (ft²)	n̄
20 - 40	0.030
41 - 150	0.029
151 - 300	0.028

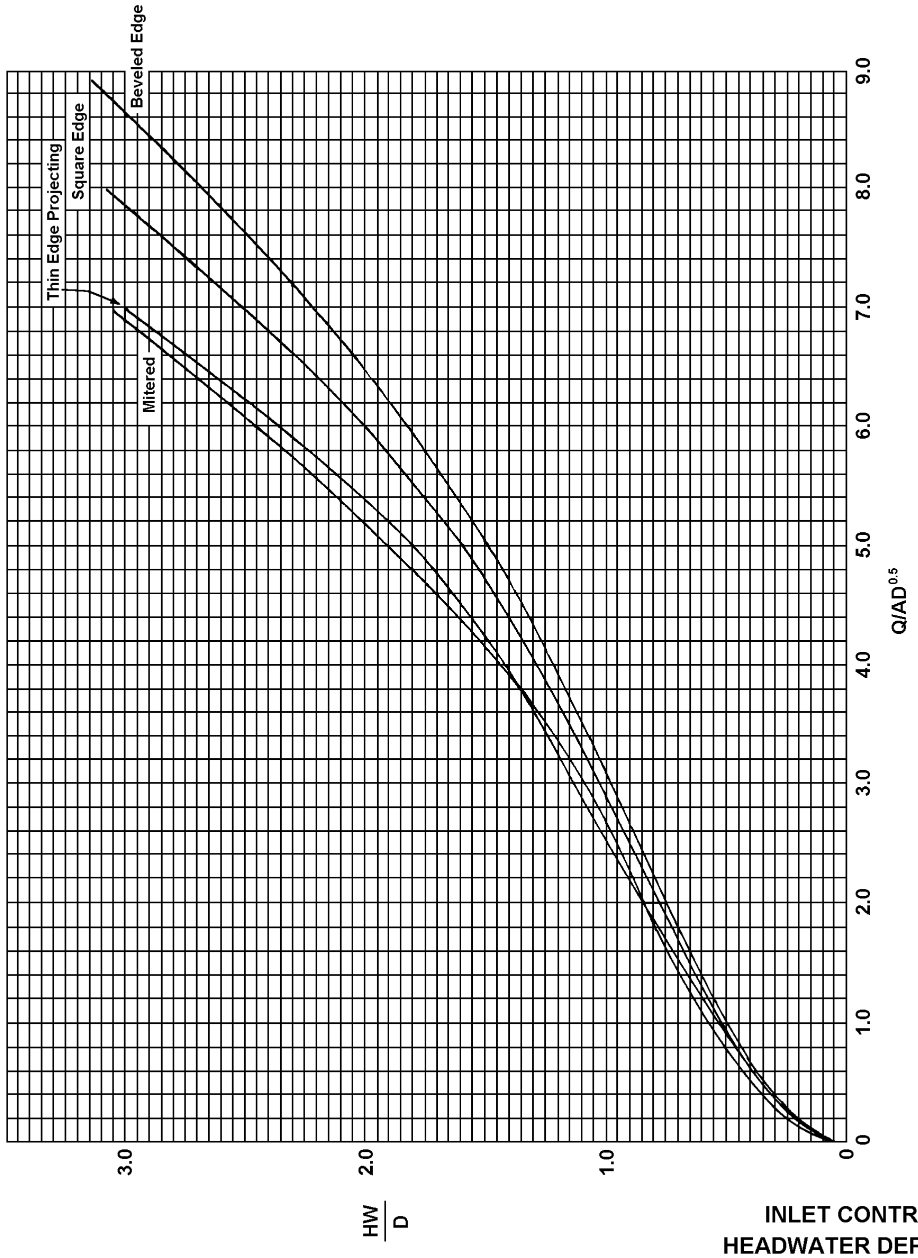


SUBMERGED OUTLET CULVERT FLOWING FULL

HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.5 ≤ RISE/SPAN

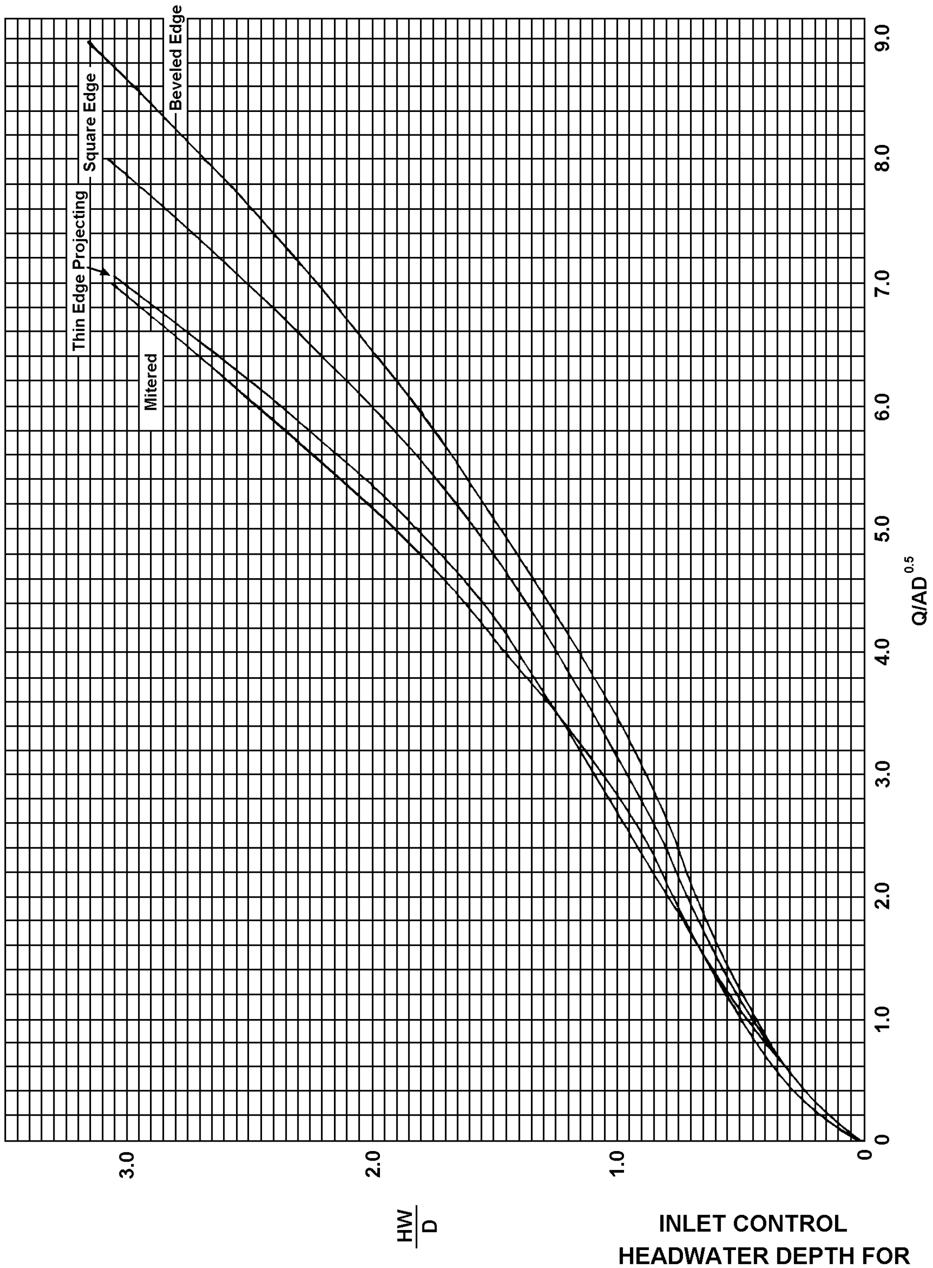
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 51



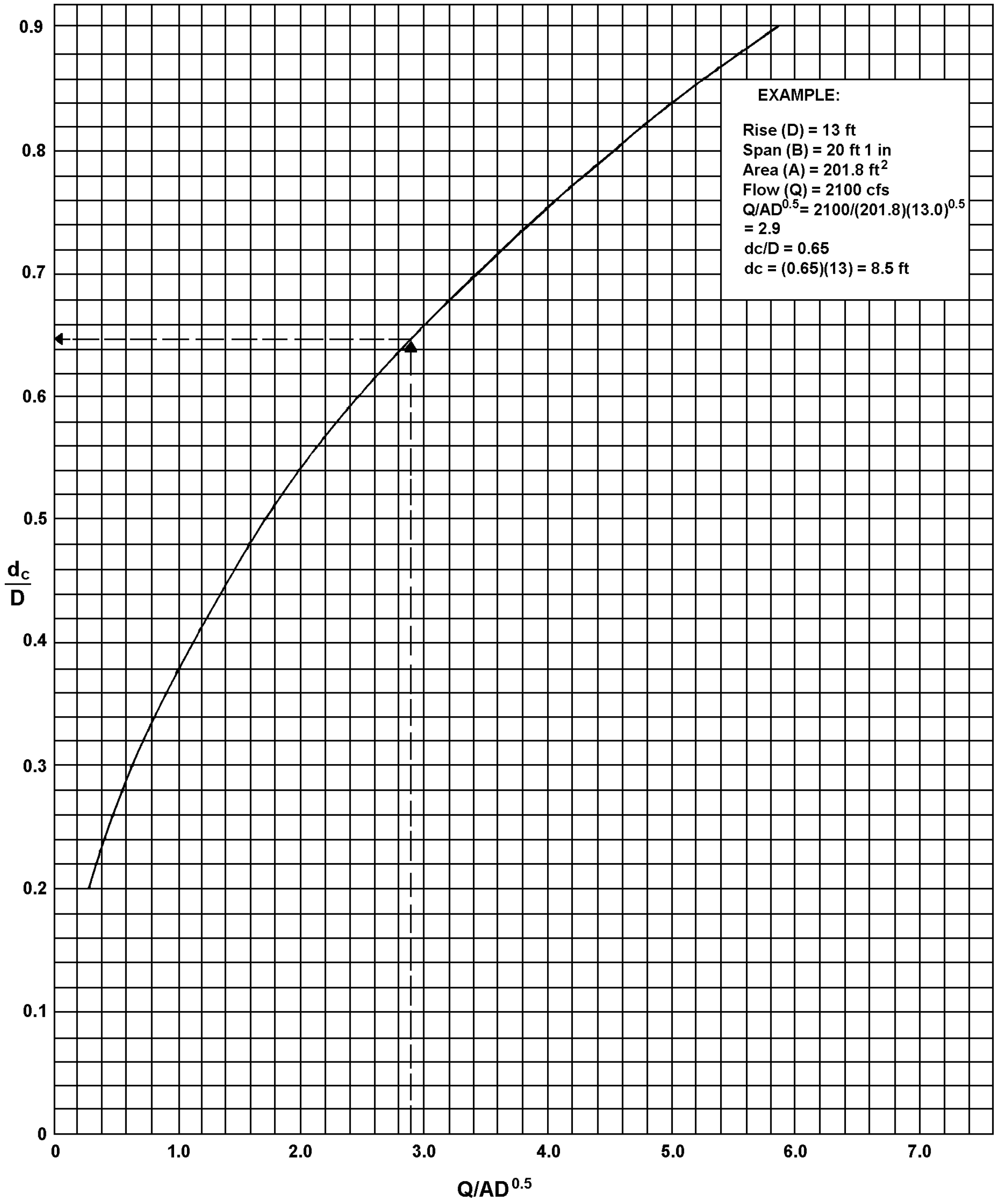
INLET CONTROL
HEADWATER DEPTH FOR
CIRCULAR OR ELLIPTICAL
STRUCTURAL PLATE
C.M. CONDUITS

CHART 52



**INLET CONTROL
HEADWATER DEPTH FOR
HIGH AND LOW PROFILE
STRUCTURAL PLATE
C.M. ARCH**

CHART 53

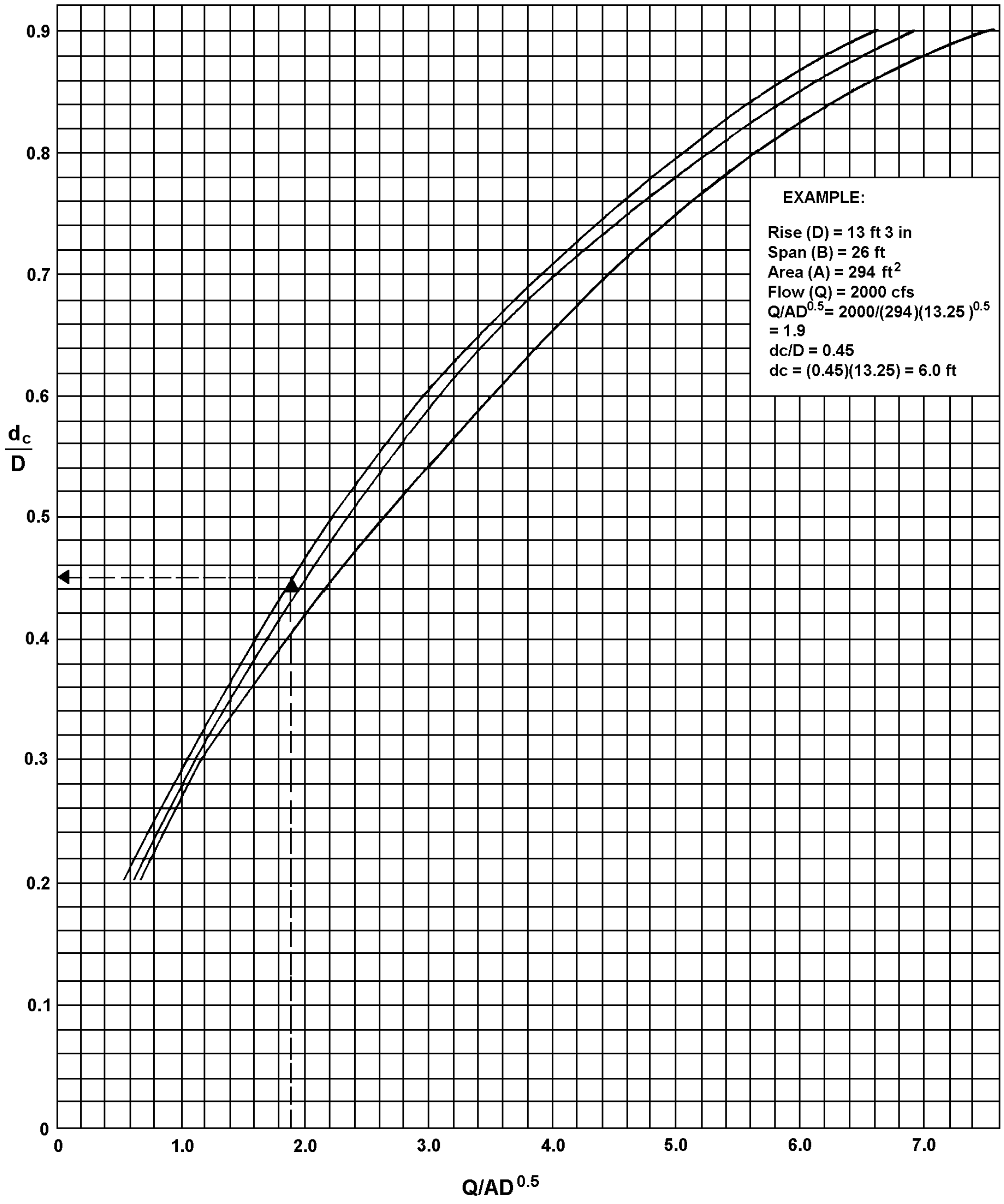


EXAMPLE:

Rise (D) = 13 ft
Span (B) = 20 ft 1 in
Area (A) = 201.8 ft^2
Flow (Q) = 2100 cfs
$Q/AD^{0.5} = 2100/(201.8)(13.0)^{0.5}$
= 2.9
dc/D = 0.65
dc = (0.65)(13) = 8.5 ft

DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
ELLIPSE LONG AXIS HORIZONTAL

CHART 54

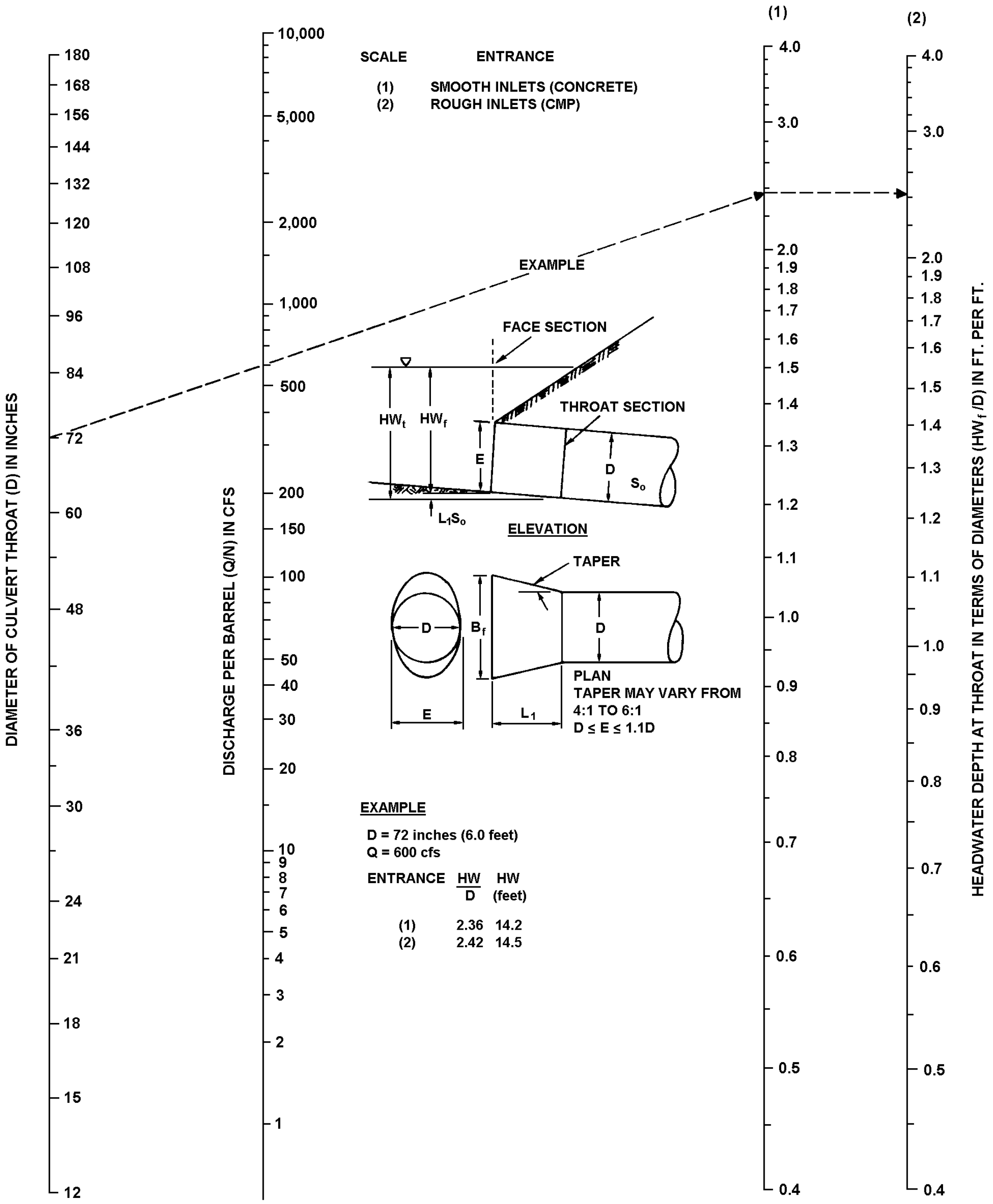


EXAMPLE:

Rise (D) = 13 ft 3 in
Span (B) = 26 ft
Area (A) = 294 ft^2
Flow (Q) = 2000 cfs
$Q/AD^{0.5} = 2000/(294)(13.25)^{0.5}$
= 1.9
dc/D = 0.45
dc = (0.45)(13.25) = 6.0 ft

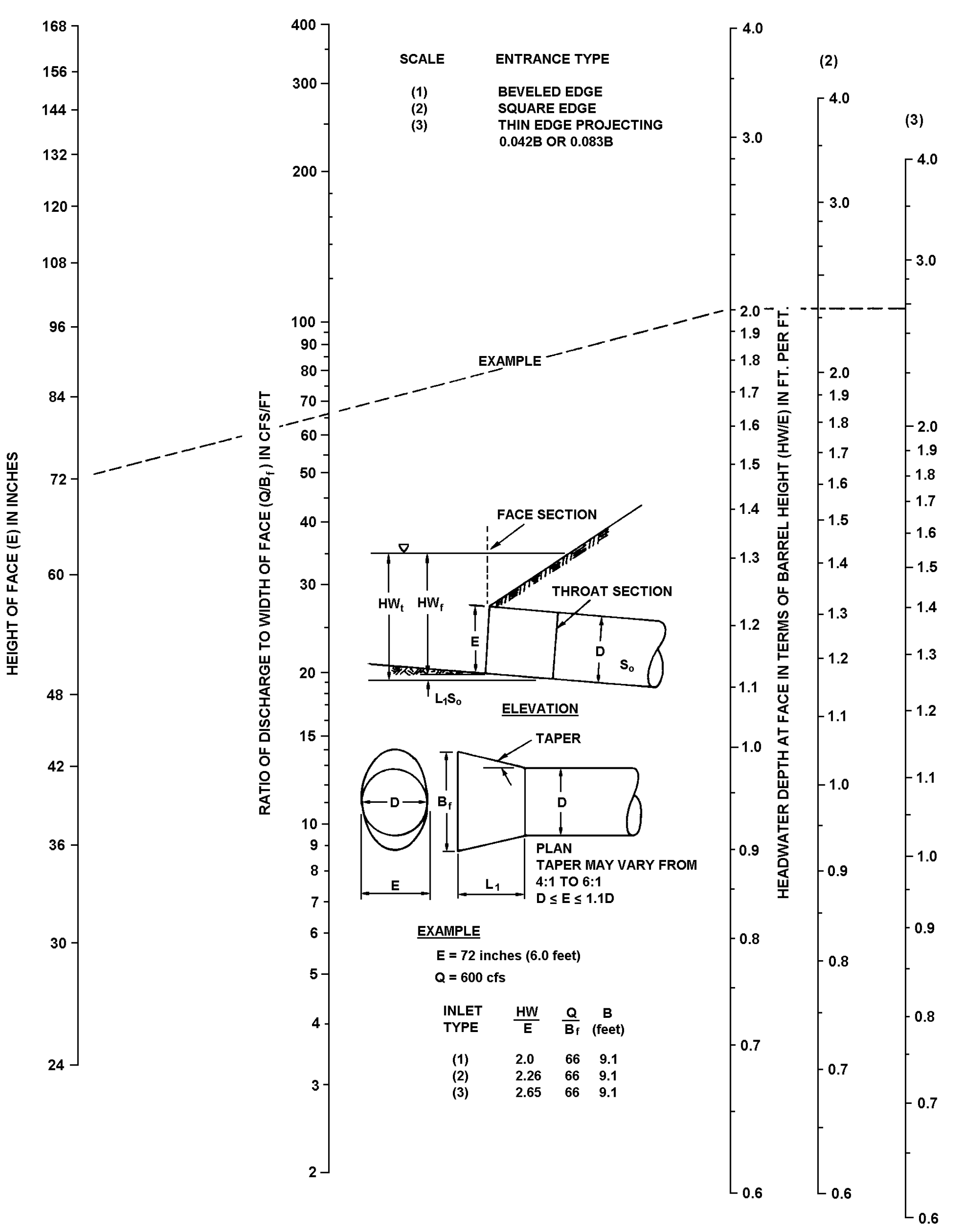
DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
LOW- AND HIGH-PROFILE ARCHES

CHART 55



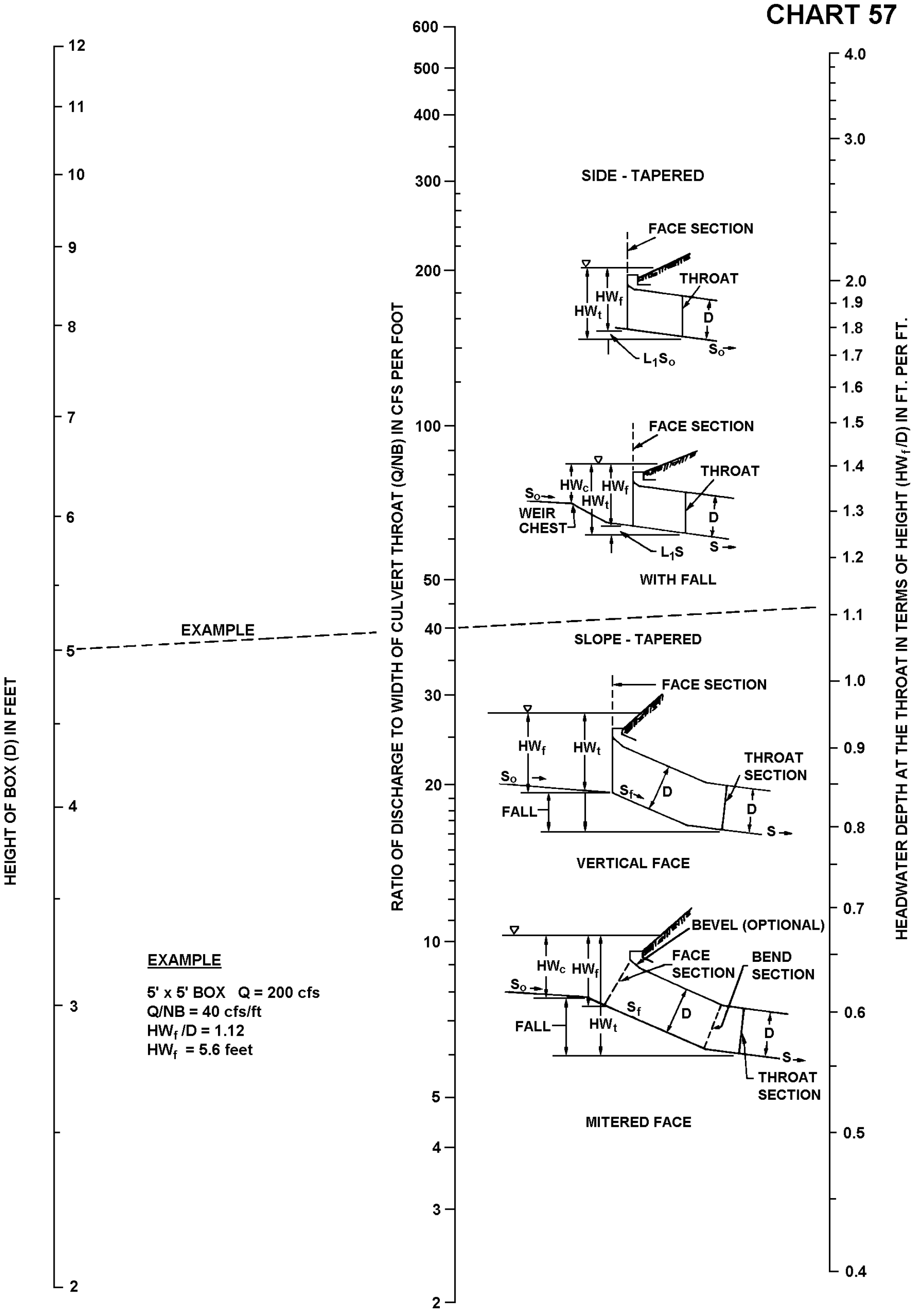
THROAT CONTROL
FOR SIDE-TAPERED INLETS
TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

CHART 56



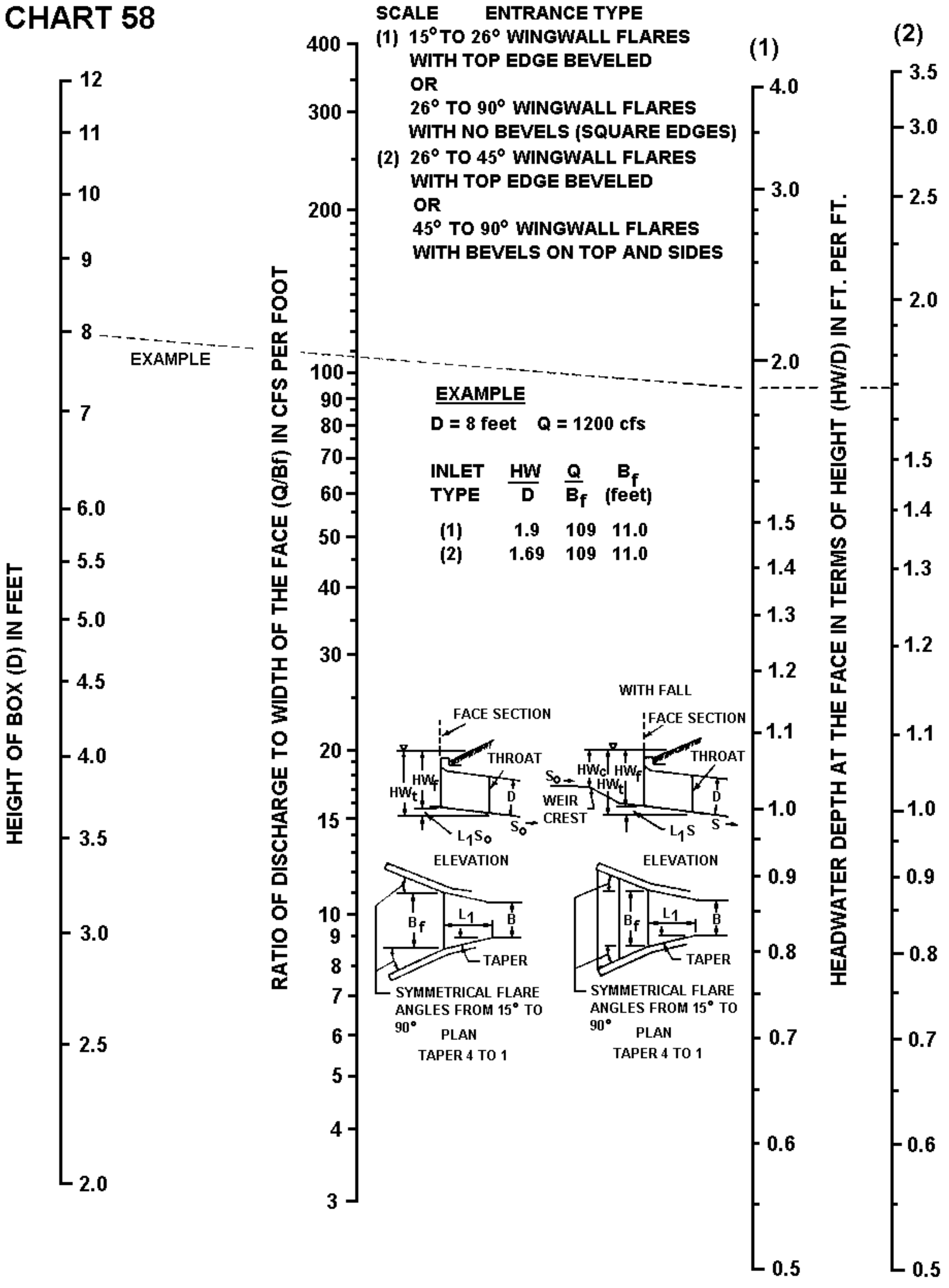
FACE CONTROL FOR SIDE-TAPERED
INLETS TO PIPE CULVERTS
(NON-RECTANGULAR SECTIONS ONLY)

CHART 57



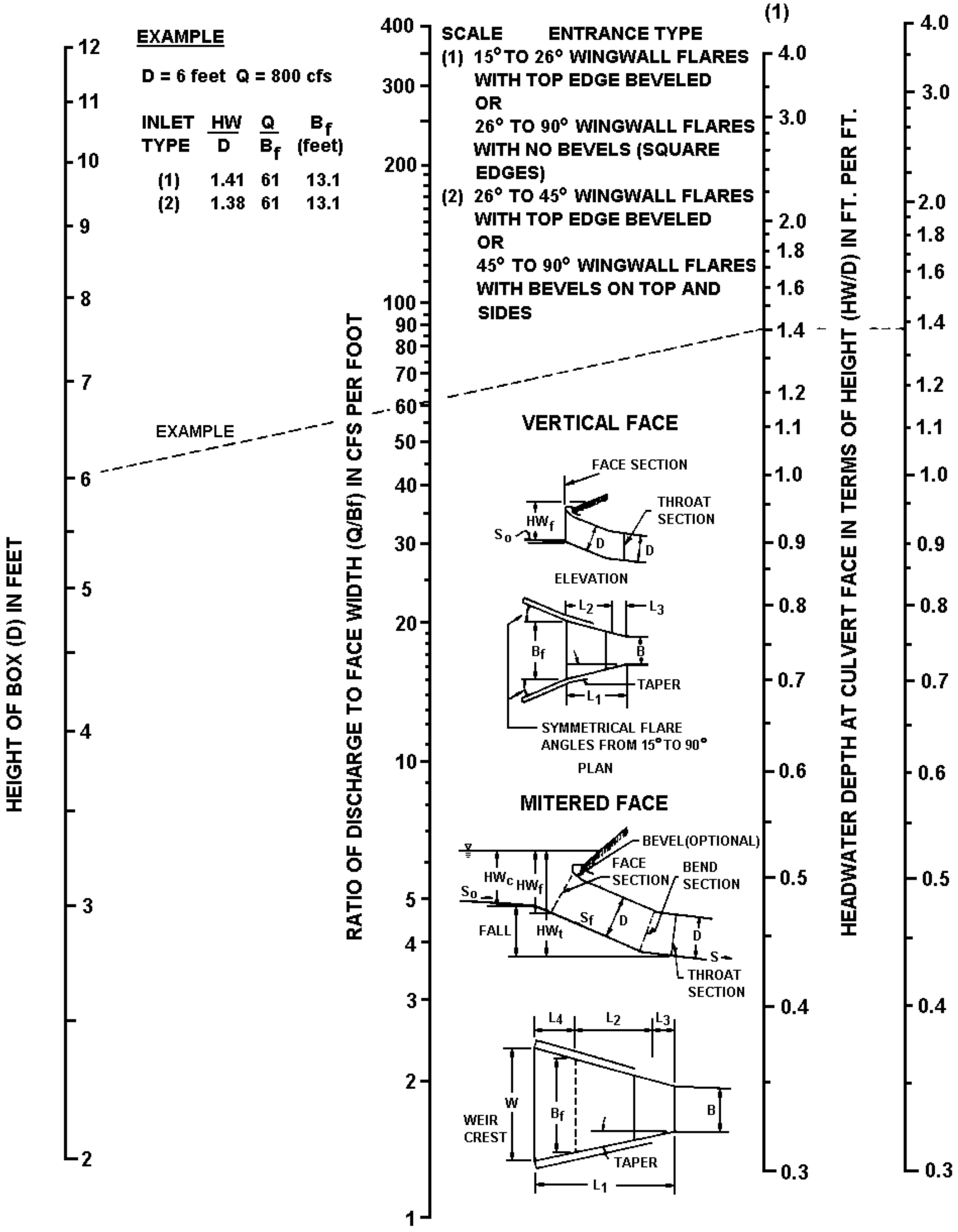
THROAT CONTROL FOR BOX CULVERTS WITH TAPERED INLETS

CHART 58



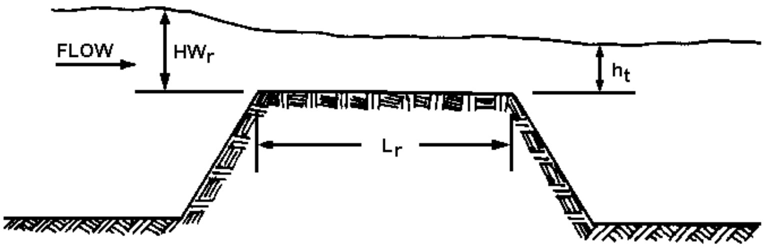
FACE CONTROL FOR BOX CULVERTS
WITH SIDE-TAPERED INLETS

CHART 59



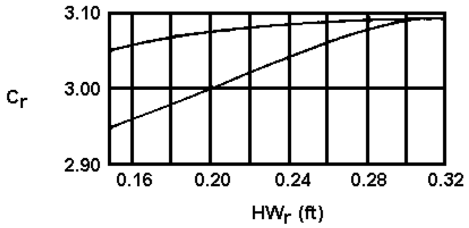
FACE CONTROL FOR BOX CULVERTS WITH SLOPE TAPERED INLETS

CHART 60

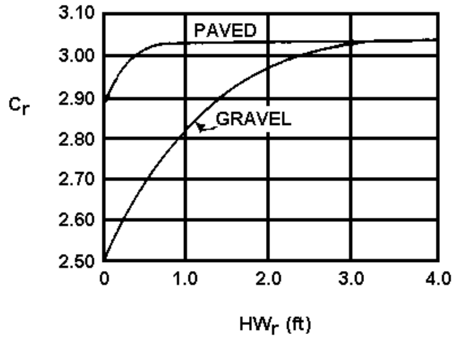


$C_d = k_t C_r$

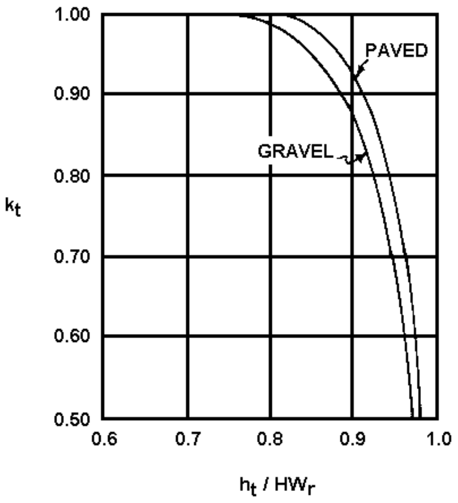
$Q_r = C_d L HW_r^{1.5}$



A) DISCHARGE COEFFICIENT FOR $HW_r / L_r > 0.15$



B) DISCHARGE COEFFICIENT FOR $HW_r / L_r \leq 0.15$



C) SUBMERGENCE FACTOR

DISCHARGE COEFFICIENTS FOR ROADWAY OVERTOPPING