



PDHonline Course H148 (2 PDH)

An Introduction to Hydraulic Design of Culverts

Instructor: J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

An Introduction to Hydraulic Design of Culverts

J. Paul Guyer, P.E., R.A.

CONTENTS

- 1. GENERAL**
- 2. INLET CONTROL**
- 3. OUTLET CONTROL**
- 4. PROCEDURES FOR SELECTION OF CULVERT SIZE**
- 5. INSTRUCTIONS FOR USE OF INLET-CONTROL NOMOGRAPHS**
- 6. INSTRUCTION FOR USE OF OUTLET-CONTROL NOMOGRAPHY**
- 7. CULVERT CAPACITY CHARTS**

(This publication is adapted from the *Unified Facilities Criteria* of the United States government which are in the public domain, have been authorized for unlimited distribution, and are not copyrighted.)

(Figures, tables and formulas in this publication may at times be a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS PUBLICATION IF THIS LIMITATION IS NOT ACCEPTABLE TO YOU.**)

1. GENERAL.

1.1 THIS PUBLICATION PRESENTS diagrams, charts, coefficients and related information useful in design of culverts. The information largely has been obtained from the U.S. Department of Transportation, Federal Highway Administration (formerly, Bureau of Public Roads), supplemented or modified as appropriate by information from various other sources and as required for consistency with good design practice.

1.2 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 or pending 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.

2. INLET CONTROL. The discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HIV) 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 1. A mitered entrance (fig 1C) produces little if any 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. Nomography for determining culvert capacity for inlet control were developed by the Division of Hydraulic Research, Bureau of Public Roads. (See *Hydraulics of Bridge Waterways*.) These nomography (figs 2 through 9) give headwater-discharge relations for most conventional culverts flowing with inlet control.

3. OUTLET CONTROL.

3.1 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 (fig 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 (fig 10A and B). The other two common types of outlet-control flow are shown in figure 10C and D. The procedure given in this publication for outlet-control flow does not give an exact solution for a free-water-surface condition throughout the barrel length shown in figure 10D. An approximate solution is given for this case when the headwater, HW, is equal to or greater than 0.75D, 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. 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 $V^2/2g$. The entrance loss varies with the type or design of the culvert inlet and is expressed as a coefficient times the velocity head or $K_0(V^2/2g)$. Values of K_0 for various types of culvert entrances are given in table 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 and the following expression:

$$H_f = ([29n^2L]/R^{1.333})(V^2/2g)$$

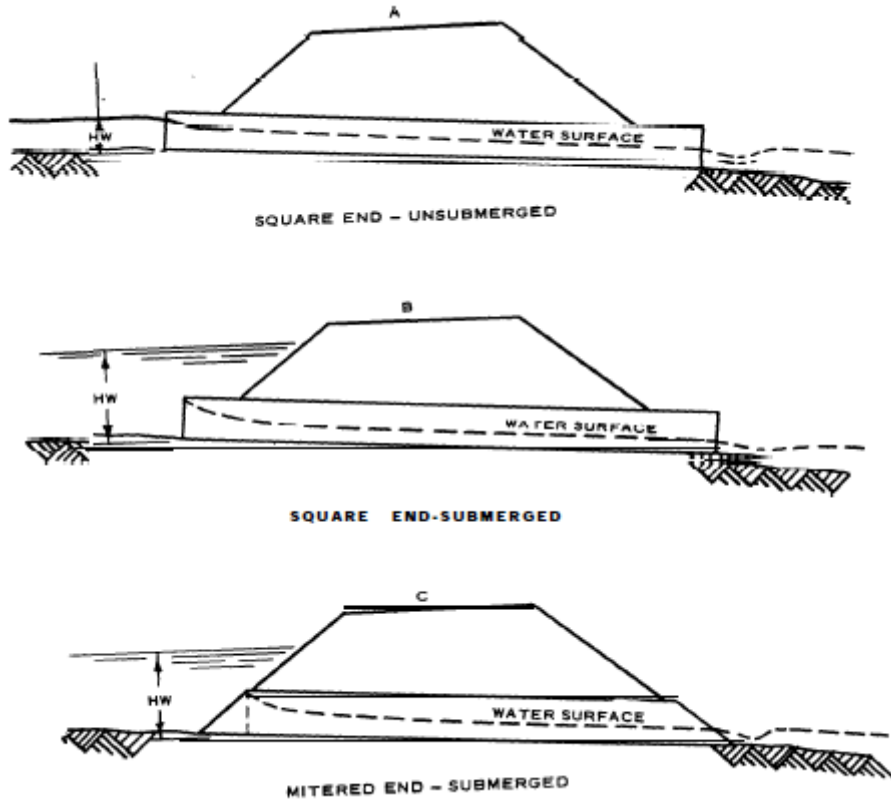


Figure 1
Inlet control

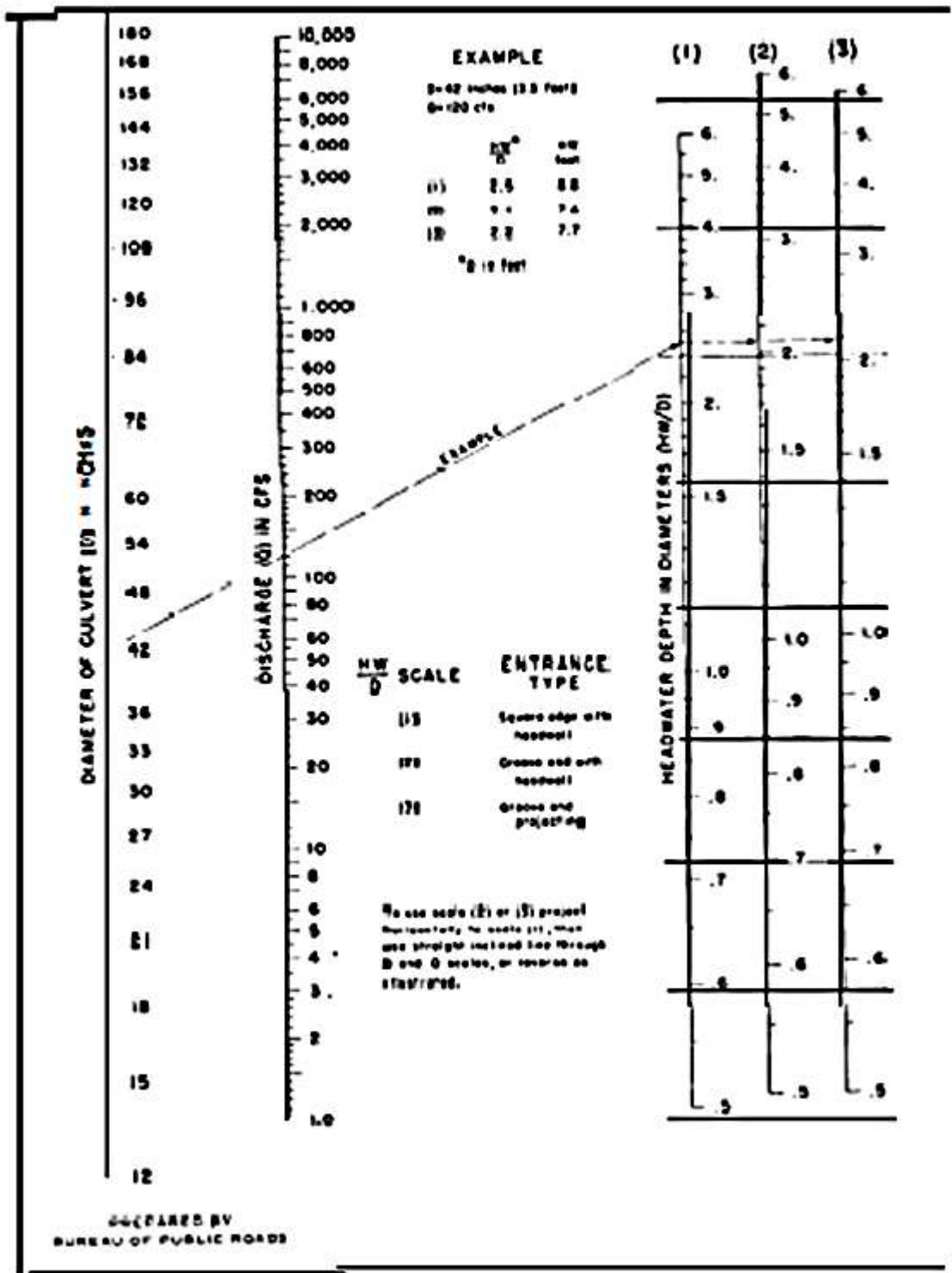


Figure 2

Headwater depth for concrete pipe culverts with inlet control

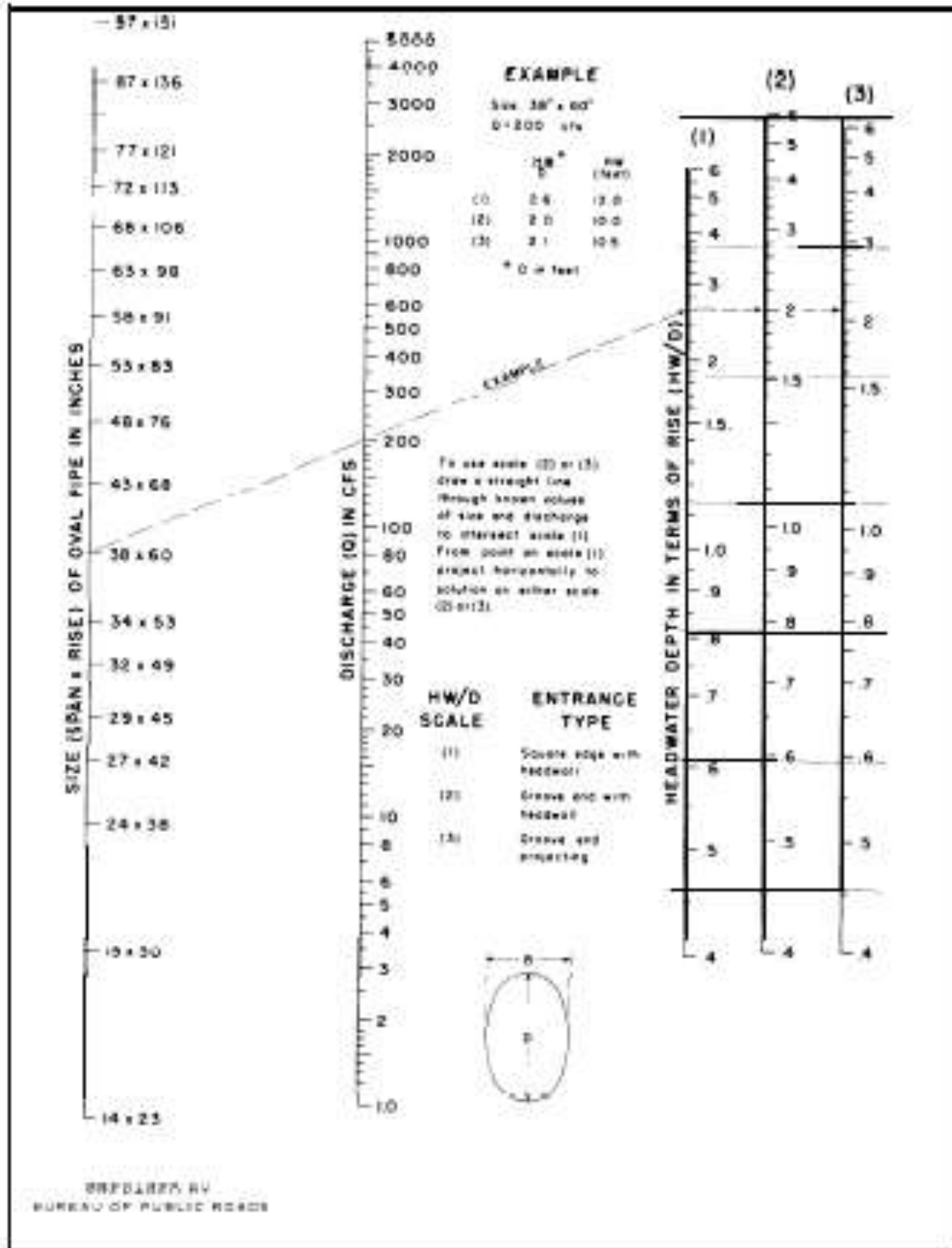


Figure 3
Headwater depth for oval concrete pipe culverts,
long axis vertical, with inlet control

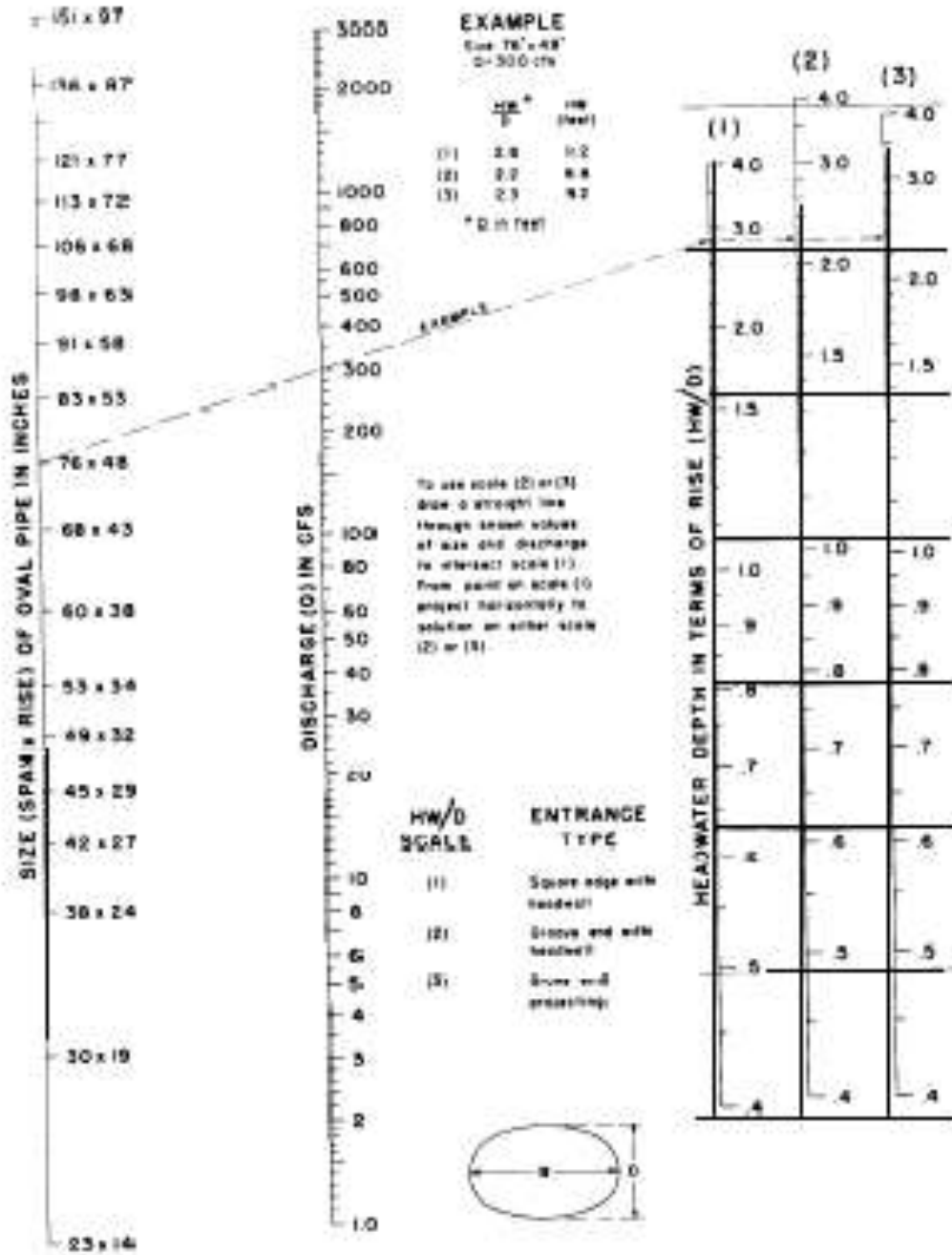


Figure 4
 Headwater depth for oval concrete pipe culverts,
 long axis horizontal, with inlet control

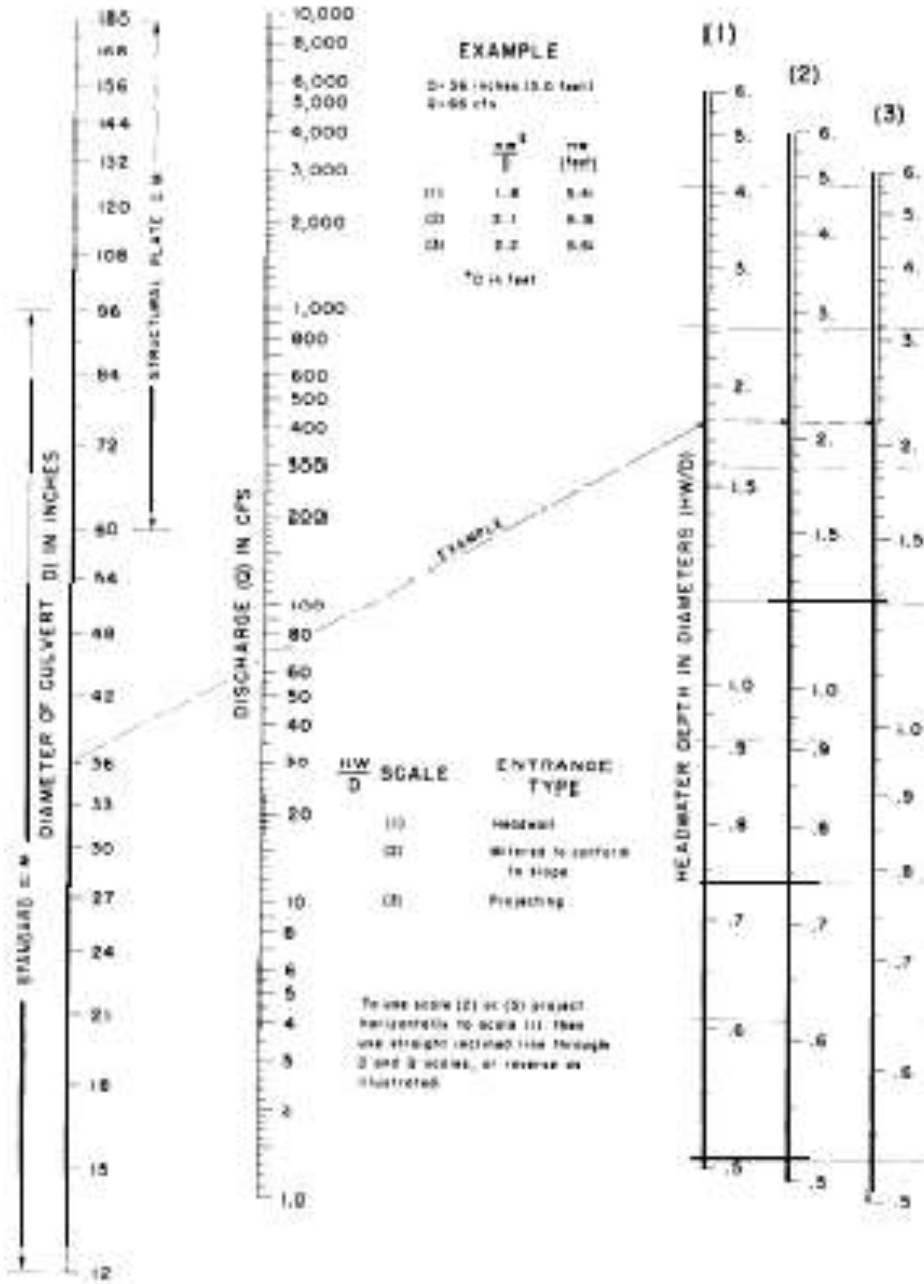


Figure 5
 Headwater depth for corrugated metal pipe culverts with inlet control

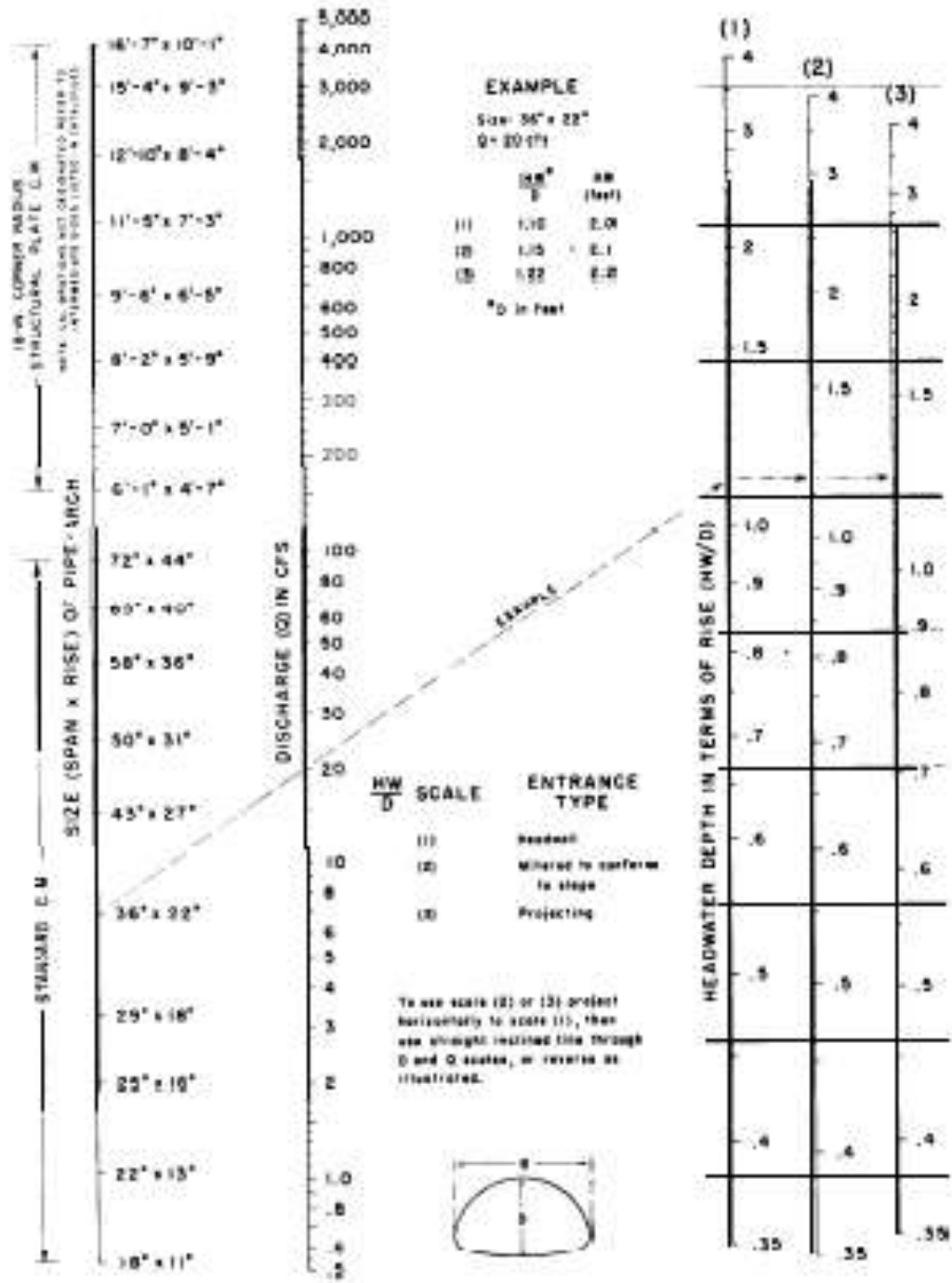


Figure 6
 Headwater depth for structural plate and standard corrugated metal pipe arch culverts with inlet control

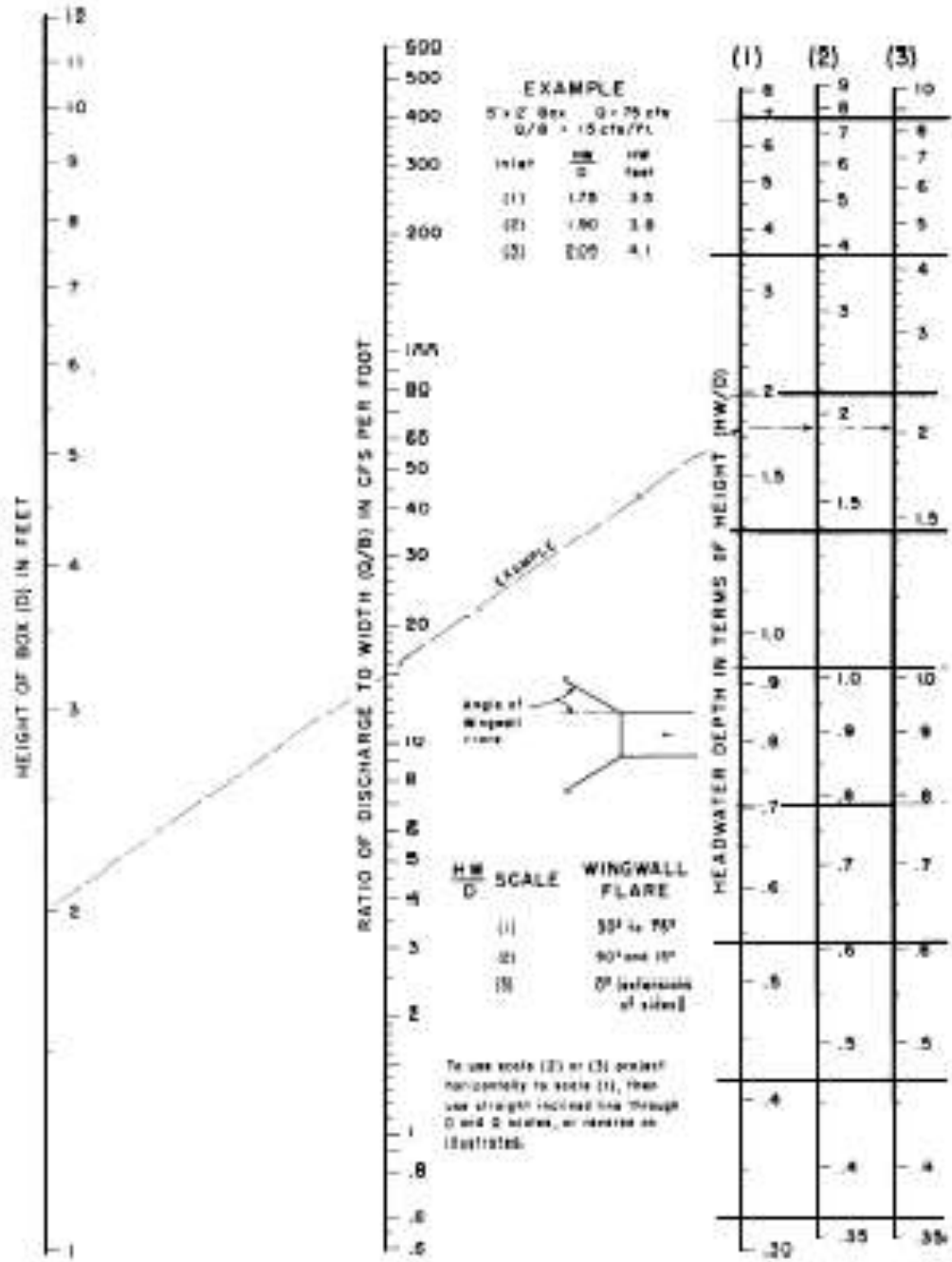


Figure 7
 Headwater depth for box culverts with inlet control.

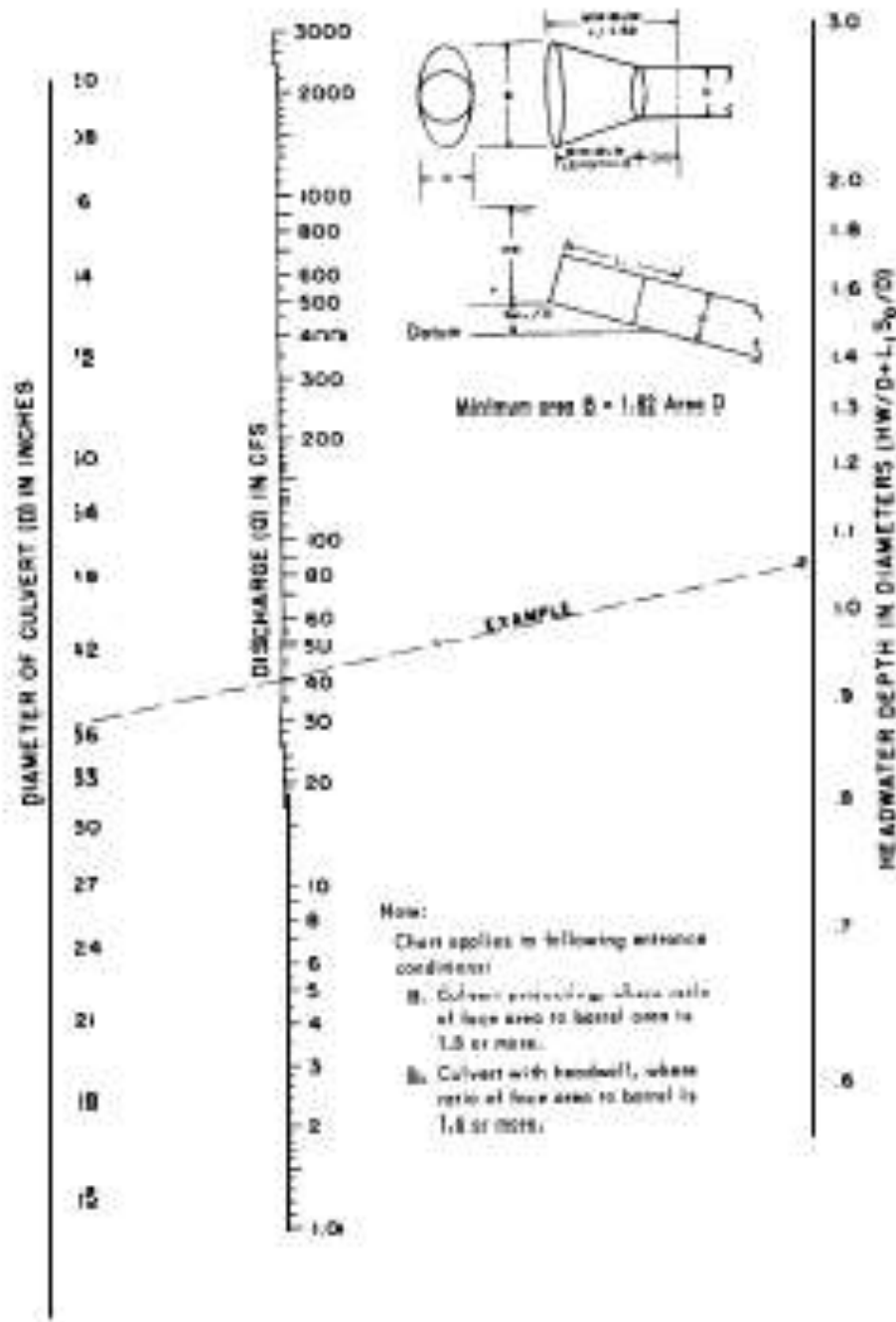


Figure 8
 Headwater depth for corrugated metal pipe culvert with tapered inlet-inlet control

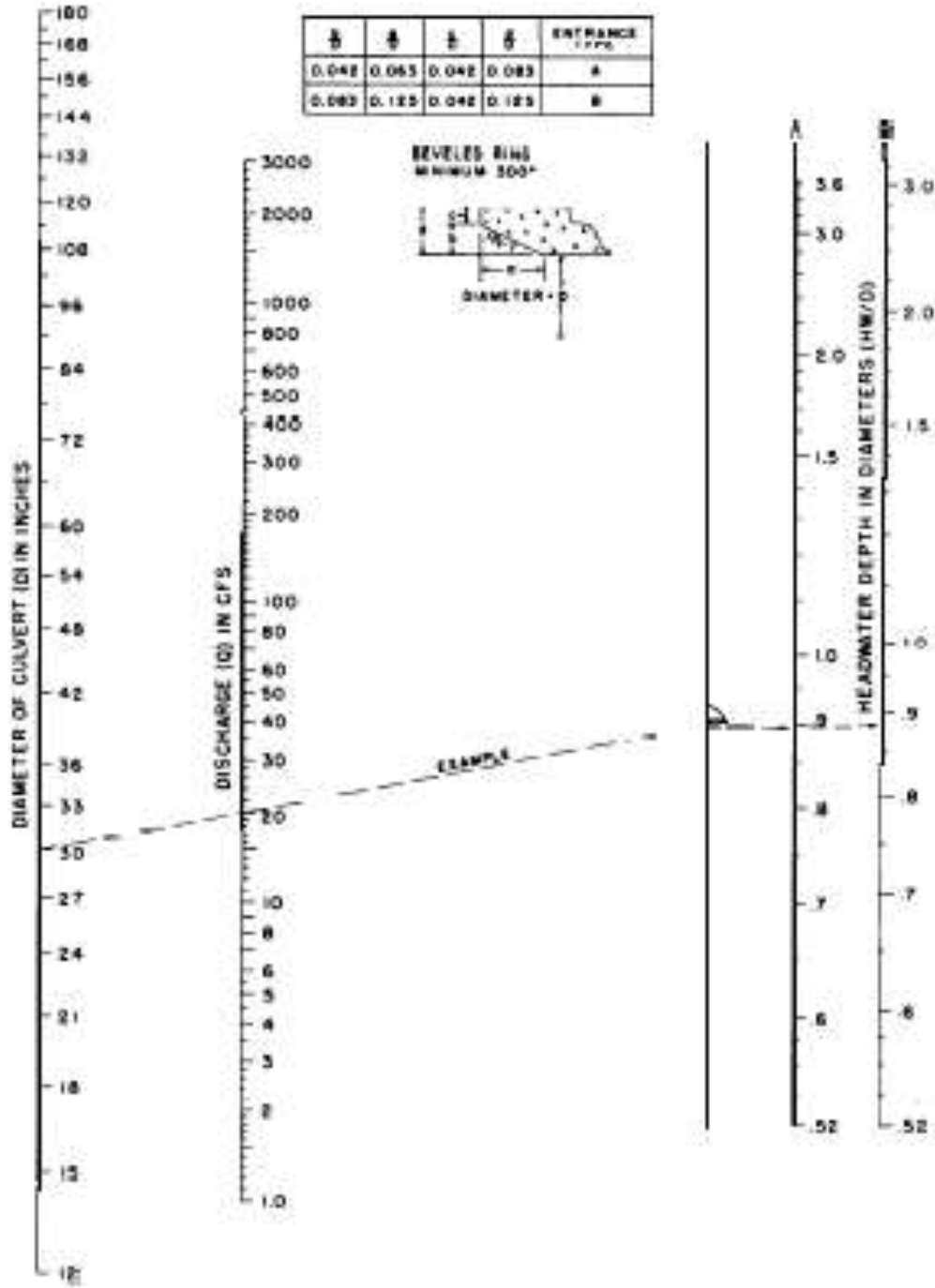


Figure 9
Headwater depth for circular pipe culverts
with beveled ring inlet control

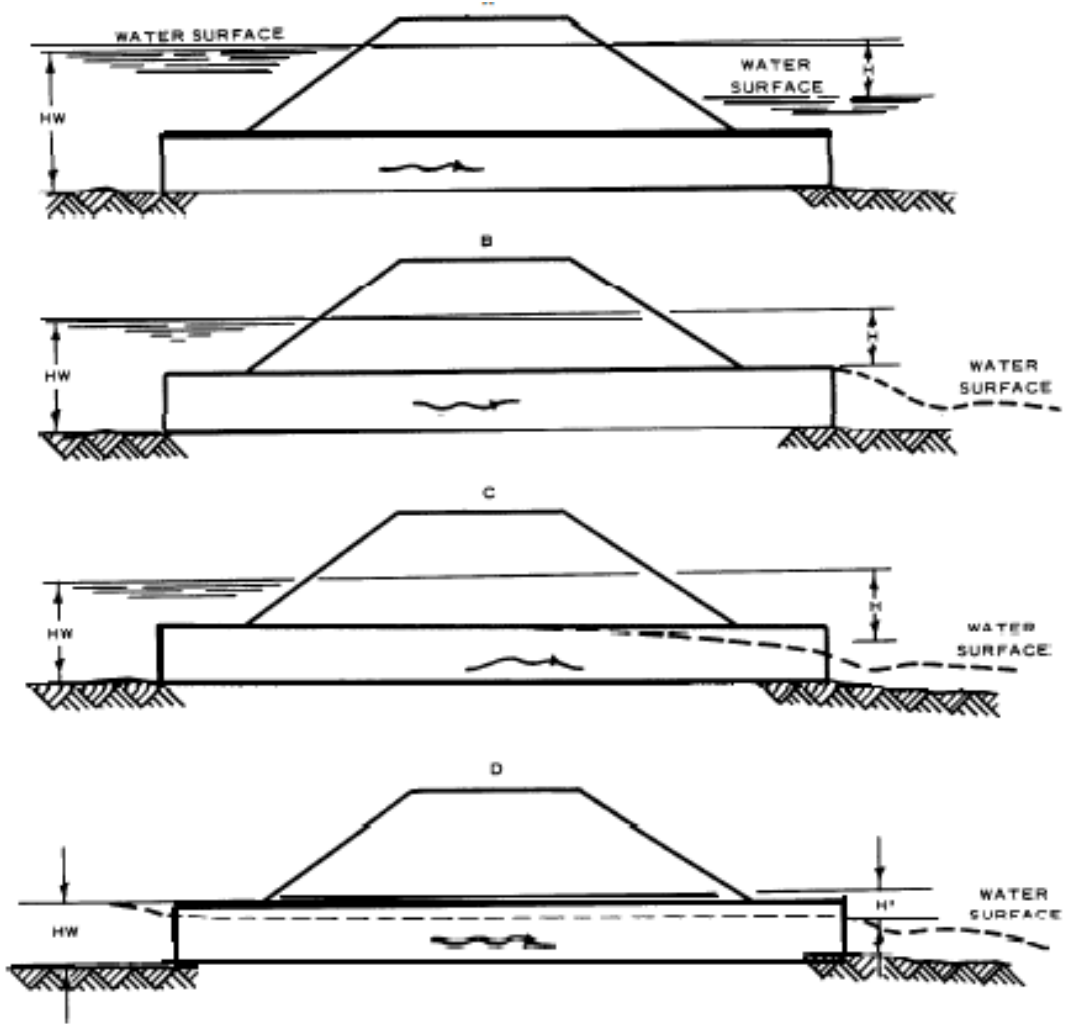


Figure 10
Outlet control

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

<i>Type of Structure and Design of Entrance</i>	<i>Coefficient K_e</i>
<i>Pipe, Concrete</i>	
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 = 1/12D)	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
<i>Pipe, or Pipe-Arch, Corrugated Metal</i>	
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° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
<i>Box, Reinforced Concrete</i>	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, 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 barrel dimension, or beveled top edge	0.2
Wingwall at 10° to 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
*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. 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.	

Table 1
Entrance loss coefficients, outlet control,
full or partly full, $H_e = K_e (V^2/2g)$

Adding the three terms and simplifying, yields for full pipe, outlet control flow the following expression:

$$H = (1 + K_e + [29n^2L/R^{1.333}])(V^2/2g) \quad (\text{eq 1})$$

This equation can be solved readily by the use of the full-flow nomograph, figures 11 through 17. The equations shown on these nomographs are the same as equation 1 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. The value of H must be measured from some "control" elevation at the outlet which 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. The following equation is used to compute headwater in reference to the inlet invert:

$$HW = h_o + H - LS_o \quad (\text{eq 2})$$

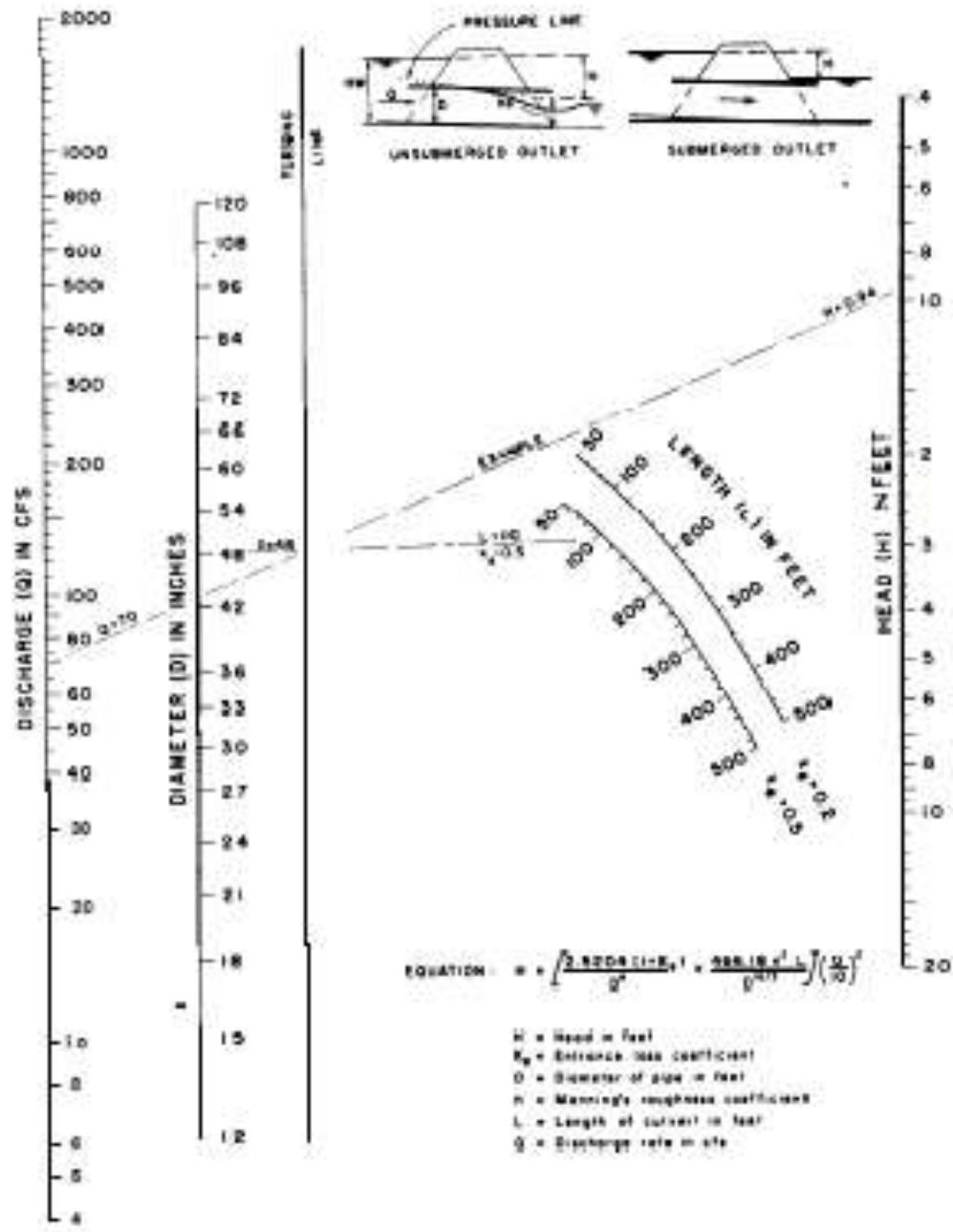


Figure 11
Head for circular pipe culverts flowing full, n = 0.012

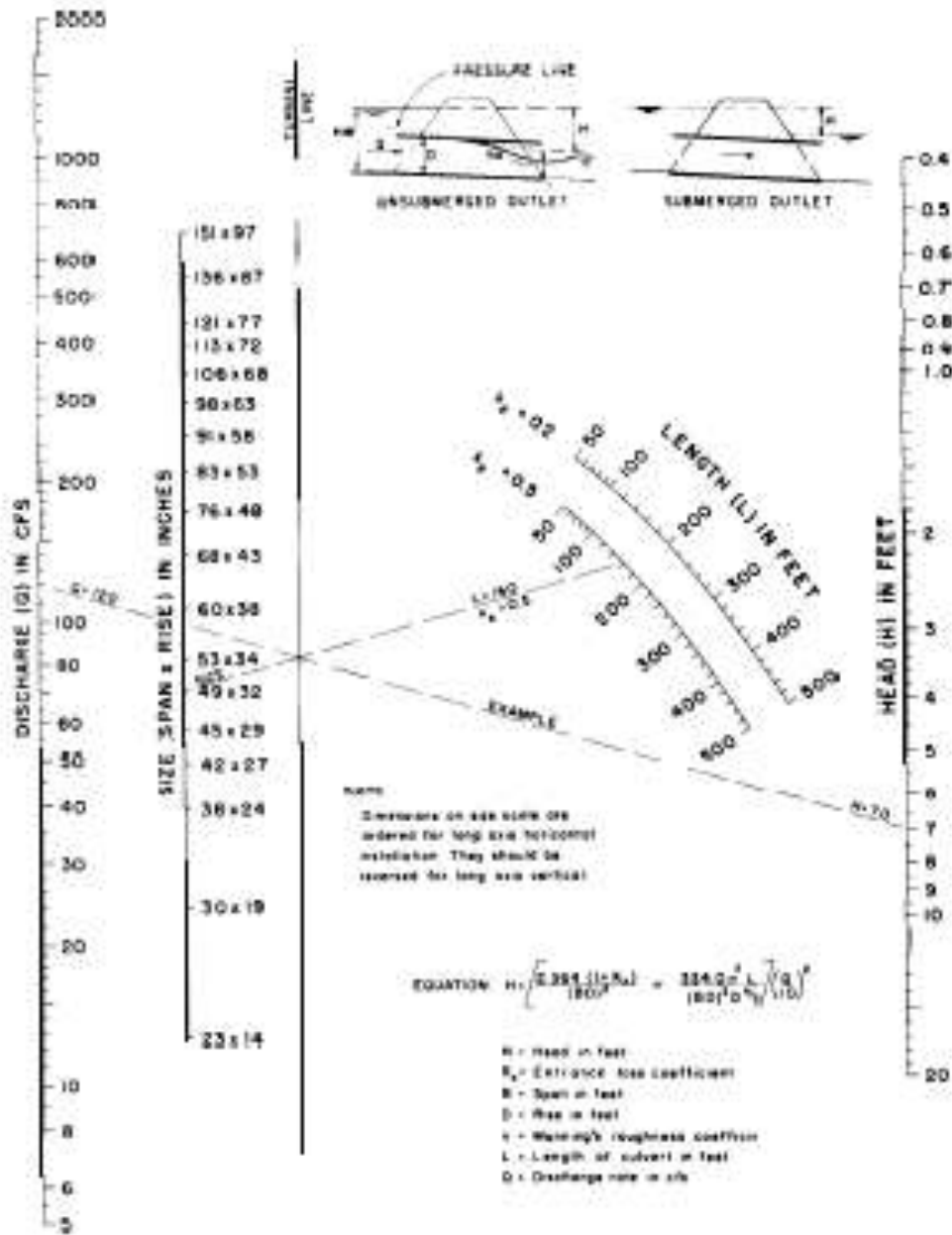


Figure 12
 Head for oval circular pipe culverts, long axis horizontal or vertical,
 flowing full, n = 0.012

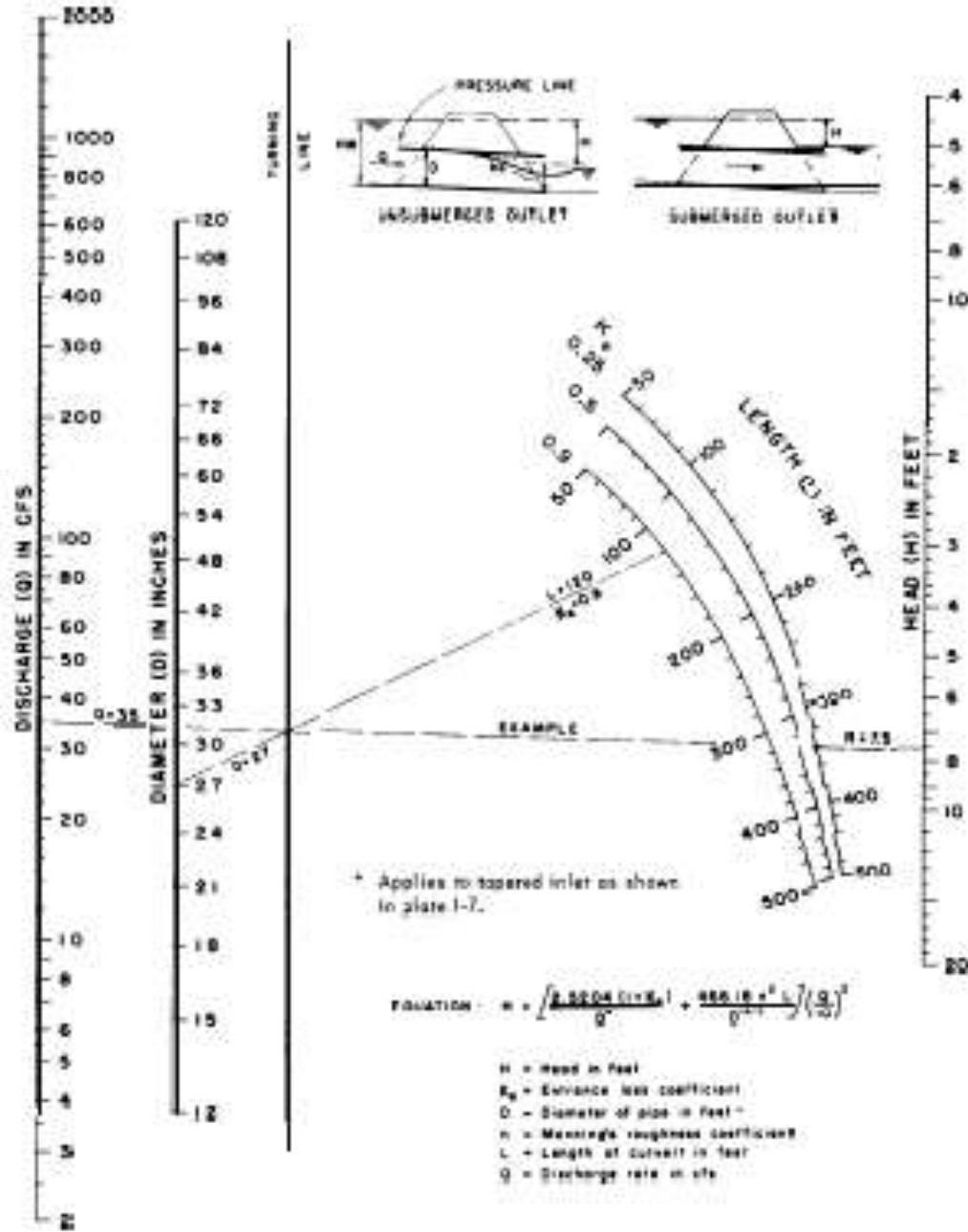


Figure 13
Head for circular pipe culverts flowing full, n = 0.024

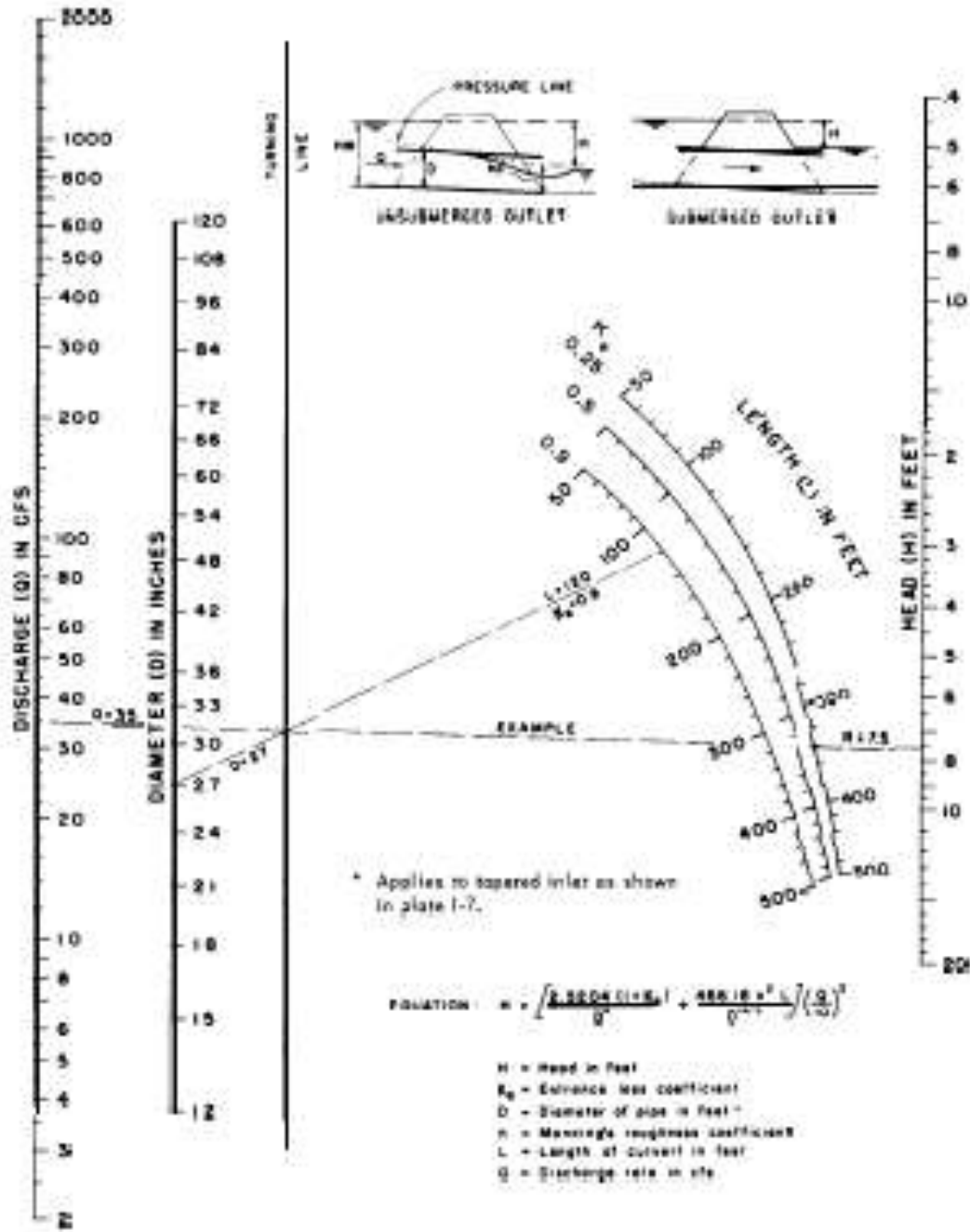


Figure 14
Head for circular pipe culverts flowing full, n = 0.024

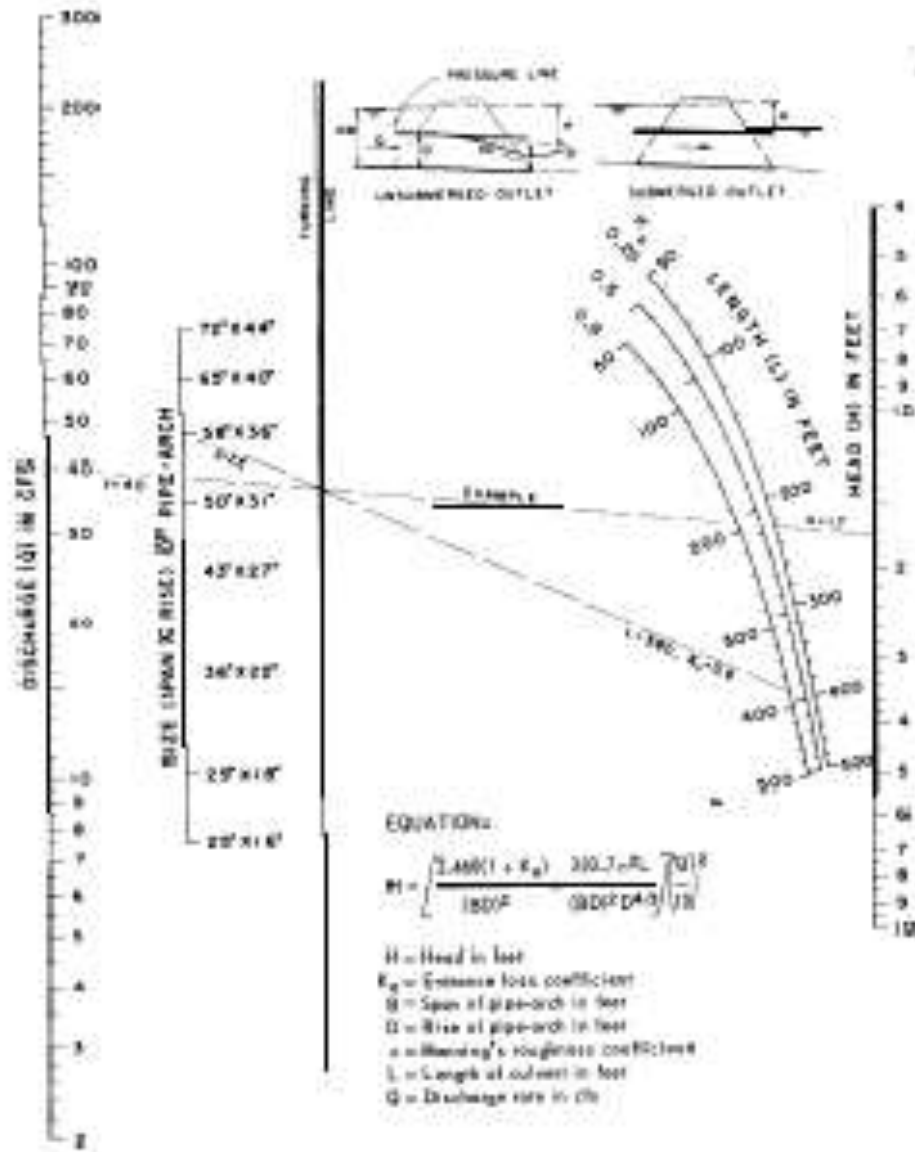


Figure 15
 Head for standard corrugated metal pipe arch culverts
 flowing full, $n = 0.024$

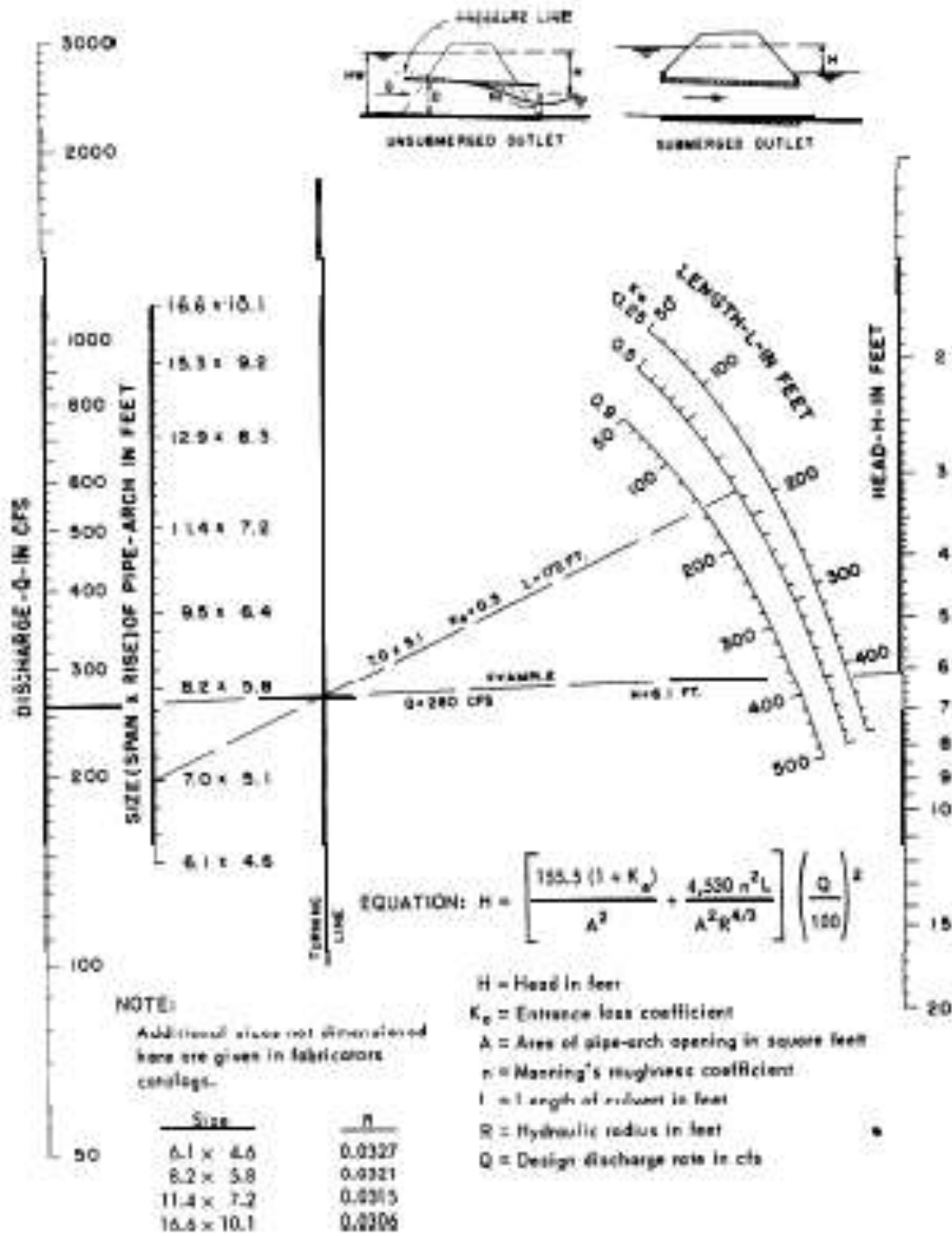


Figure 16
 Head for field-bolted structural plate pipe arch culverts,
 18 inch corner radius flowing full, n = 0.0327 to 0.0306

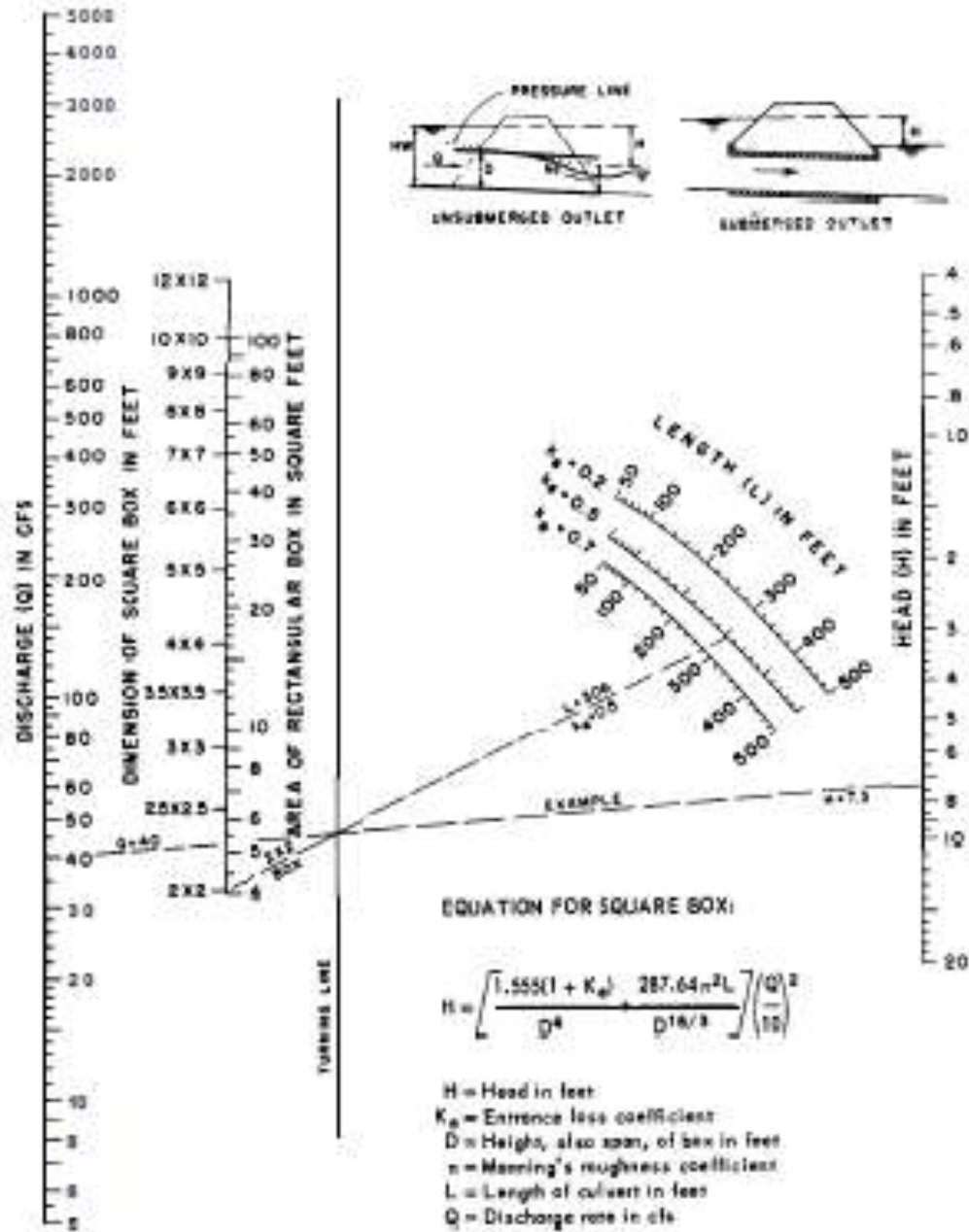


Figure 17
 Head for concrete box culverts flowing full, n = 0.012

3.2 TAILWATER ELEVATION AT OR ABOVE THE TOP OF THE CULVERT

BARREL OUTLET (FIG 10A). The tailwater (TW) depth is equal to h_o , and the relation of headwater to other terms in equation 2 is illustrated in figure 18.

3.3 TAILWATER ELEVATION BELOW THE TOP OR CROWN OF THE CULVERT

BARREL OUTLET. Figure 10B, C, and D are three common types of flow for outlet control with this low tailwater (TW) condition. In these cases h_o is found by comparing two values, TW depth in the outlet channel and $(d_c + D)/2$ and setting h_o equal to the larger value. The fraction $(d_c + D)/2$ is a simplified mean of computing h_o when the tailwater is low and the discharge does not fill the culvert barrel at the outlet. In this fraction, d_c is critical depth as determined from figures 18 through 23 and D is the culvert height. The value of d_c should never exceed D , making the upper limit of this fraction equal to D . Figure 19 shows the terms of equation 2 for the cases discussed above. Equation 2 gives accurate answers if the culvert flows full for a part of the barrel length as illustrated by figure 23. This condition of flow will exist if the headwater, as determined by equation 2, is equal to or greater than the quantity:

$$HW \geq D + (1 + K_e)(V^2/2g)$$

If the headwater drops below this point the water surface will be free throughout the culvert barrel as in figure 10D, and equation 2 yields answers with some error since the only correct method of finding headwater in this case is by a backwater computation starting at the culvert

outlet. However, equation 2 will give answers of sufficient accuracy for design purposes if the headwater is limited to values greater than $0.75D$. H' is used in figure B-10D to show that the head loss here is an approximation of H . No solution is given for headwater less than $0.75D$. The depth of tailwater is important in determining the hydraulic capacity of culverts flowing with outlet control. In many cases the downstream channel is of considerable width and the depth of water in the natural channel is less than the height of water in the outlet end of the culvert barrel, making the tailwater ineffective as a control, so that its depth need not be computed to determine culvert discharge capacity or headwater. There are instances, however, where the downstream water-surface elevation is controlled by a downstream obstruction or backwater from another stream. A field inspection of all major culvert locations should be made to evaluate downstream controls and determine water stages. An approximation of the depth of flow in a natural stream (outlet channel) can be made by using Manning's equation, $V = \frac{1.486}{n} R^{2/3} S^{1/2}$, if the channel is reasonably uniform in cross section, slope, and roughness. Values of n for natural streams in Manning's formula are given in table B-2. If the water surface in the outlet channel is established by downstream controls other means must be found to determine the tailwater elevation. Sometimes this necessitates a study of the stage-discharge relation of another stream into which the stream in question flows or the securing of data on reservoir elevations if a storage dam is involved.

Fairly regular section:	
Some grass and weeds, little or no brush	0.030-0.035
Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
Some weeds, light brush on banks	0.035-0.05
Some weeds, heavy brush on banks	0.05-0.07
Some weeds, dense willows on banks	0.06-0.08
For trees within channel, with <i>branches</i> submerged at high stage, increase all above values by	0.01-0.02
Irregular sections, with pools, slight channel meander; increase values given above about	
0.01-0.02	
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
Bottom of gravel, cobbles, and few boulders	0.04-0.05
Bottom of cobbles, with <i>large</i> boulders	0.05-0.07

Table 2

Manning's n for natural stream channels
(surface width at flood stage less than 100 feet)

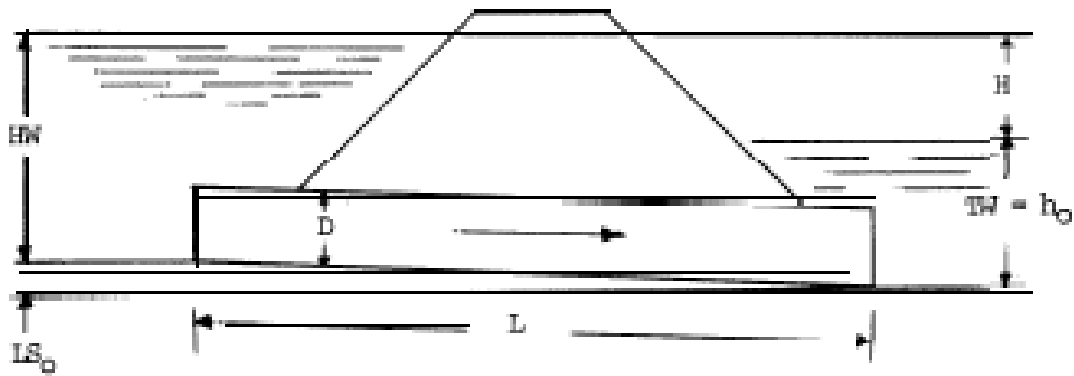


Figure 18

Tailwater elevation at or above top of culvert

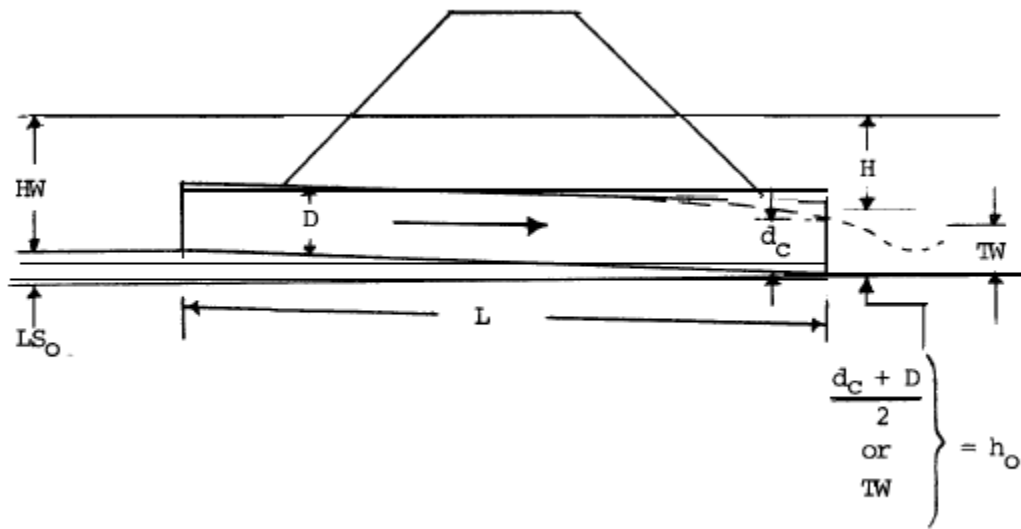


Figure 19
Tailwater below the top of the culvert

4. PROCEDURES FOR SELECTION OF CULVERT SIZE. Select the culvert size by the following steps:

Step 1: List given data.

- a. Design discharge, Q , in ft^3/sec
- b. Approximate length of culvert in feet
- c. Allowable headwater depth, in feet, which is the vertical distance from the culvert invert (flow line) at entrance to the water surface elevation permissible in the approach channel upstream from the culvert.
- d. Type of culvert, including barrel material, barrel cross sectional shape, and entrance type.
- e. Slope of culvert. (If grade is given in percent, convert to slope in feet per foot.)
- f. Allowable outlet velocity (if scour is a problem).

Step 2: Determine a trial-size culvert.

- a. Refer to the inlet control nomograph (Fig. 2 thru 9) for the type of culvert selected.
- b. Using an HW/D of approximately 1.5 and the scale for the entrance type to be used find a trial-size culvert by following the instructions for use of these nomographs. If reasons for greater or lesser relative depth of headwater in a particular case should exist, another value of HW/D may be used for this trial selection. If the trial size for the culverts is obviously too large because of limited height of embankment or availability of size, try a HW/D value or multiple culverts by dividing the discharge equally for the number of culverts used. Raising the embankment height or using pipe arch and box culverts with width greater than height should be considered. Selection should be based on an economic analysis.

Step 3. Find headwater depth for the trial size culvert.

- a. Determine and record headwater depth by use of the appropriate inlet control nomograph (figures 2 thru 9). Tailwater conditions are to be neglected in this determination. Headwater in this case is found by simply multiplying HW/D obtained from the nomograph by D .

b. Compute and record headwater for outlet control as instructed below:

(1) Approximate the depth of tailwater for the design flood condition in the outlet channel. The tailwater depth may also be due to backwater caused by another stream or some control downstream.

(2) For tailwater depths equal to or above the depth of the culvert at the outlet, set tailwater equal to h_o and find headwater by the following equation:

$$HW = h_o + H - S_oL$$

For tailwater elevations below the crown of culvert at the outlet use the following equation to find headwater:

$$HW = h_o + H - S_oL$$

where $h_o = (d_c + D)/2$ or TW, whichever is greater. When d_c (figures 20 thru 25) exceeds rectangular section, h_o should be set equal to D.

c. Compare the headwater found in Step 3a and Step 3b (inlet control and outlet control). The higher headwater governs and indicates the flow control existing under the given conditions.

d. Compare the higher headwater above with- that allowable at the site. If headwater is greater than allowable, repeat the procedure using a larger culvert. If headwater is less than allowable, repeat the procedure to investigate the possibility of using a smaller size.

Step 4: Check outlet velocities for size selected.

a. If outlet control governs in Step 3c, outlet velocity equals Q/A , where A is the cross-sectional area of flow at the outlet. If d_c or TW is less than the height of the culvert barrel, use cross-sectional area corresponding to d_c or TW depth, whichever gives the greater area of flow.

b. If inlet control governs in Step 3c, outlet velocity can be assumed to equal normal

velocity in open-channel flow as computed by Manning's equation for the barrel size, roughness, and slope of culvert selected.

Step 5: Try a culvert of another type or shape and determine size and headwater by the above procedure.

Step 6: Record final selection of culvert with size, type, outlet velocity, required headwater, and economic justification.

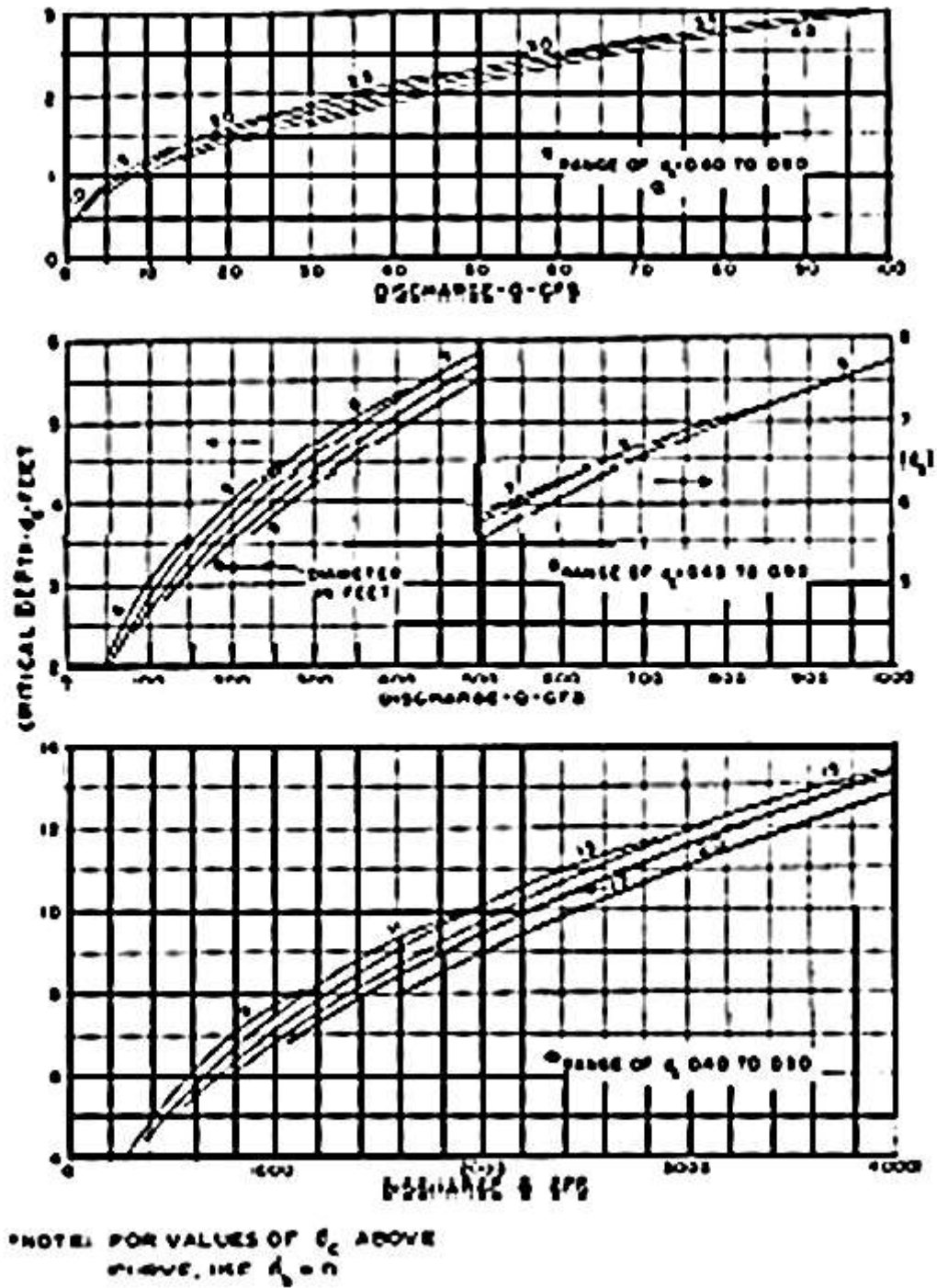


Figure 20
Circular pipe – critical depth

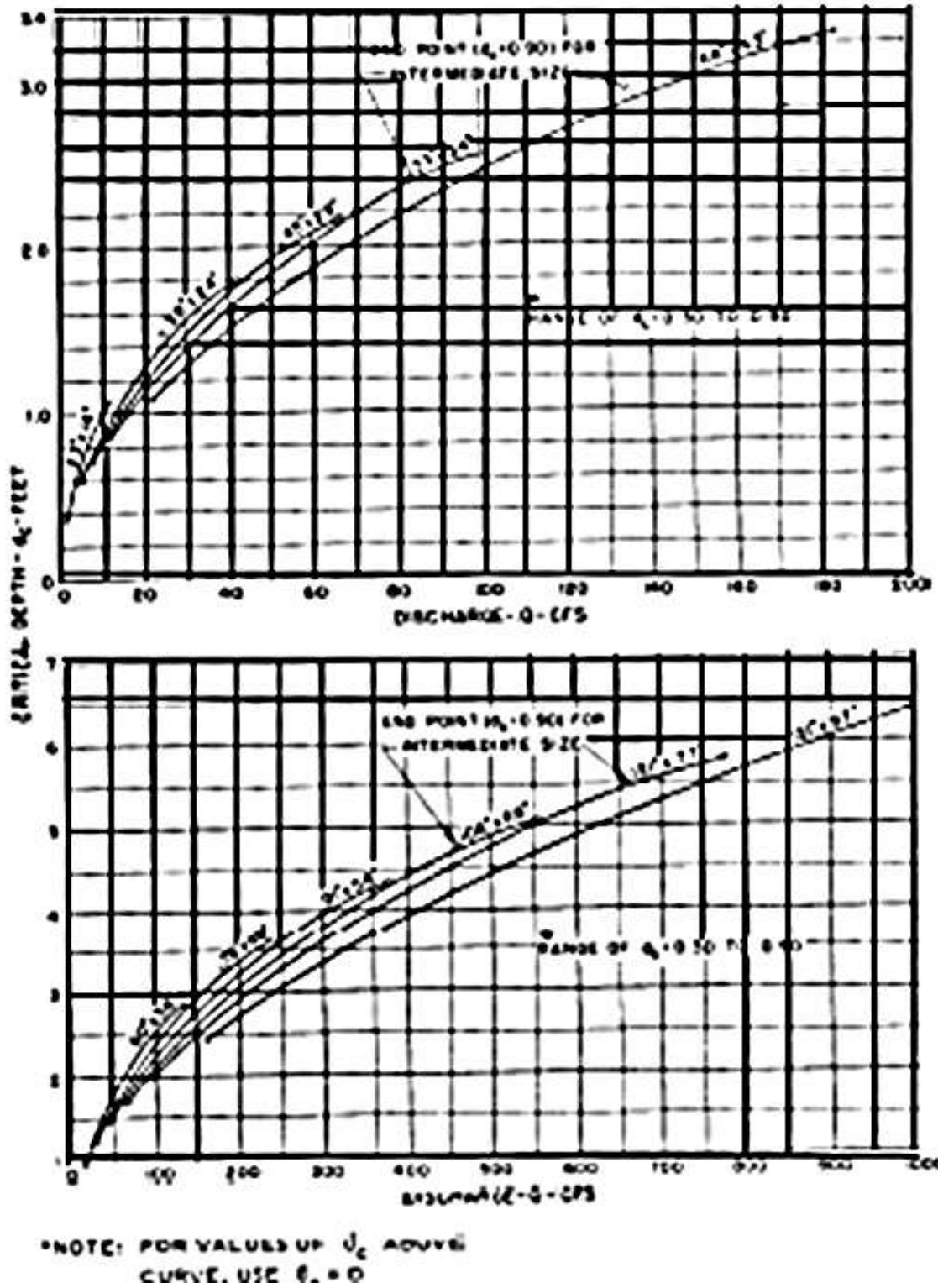


Figure 21

Oval concrete pipe long axis horizontal critical depth.

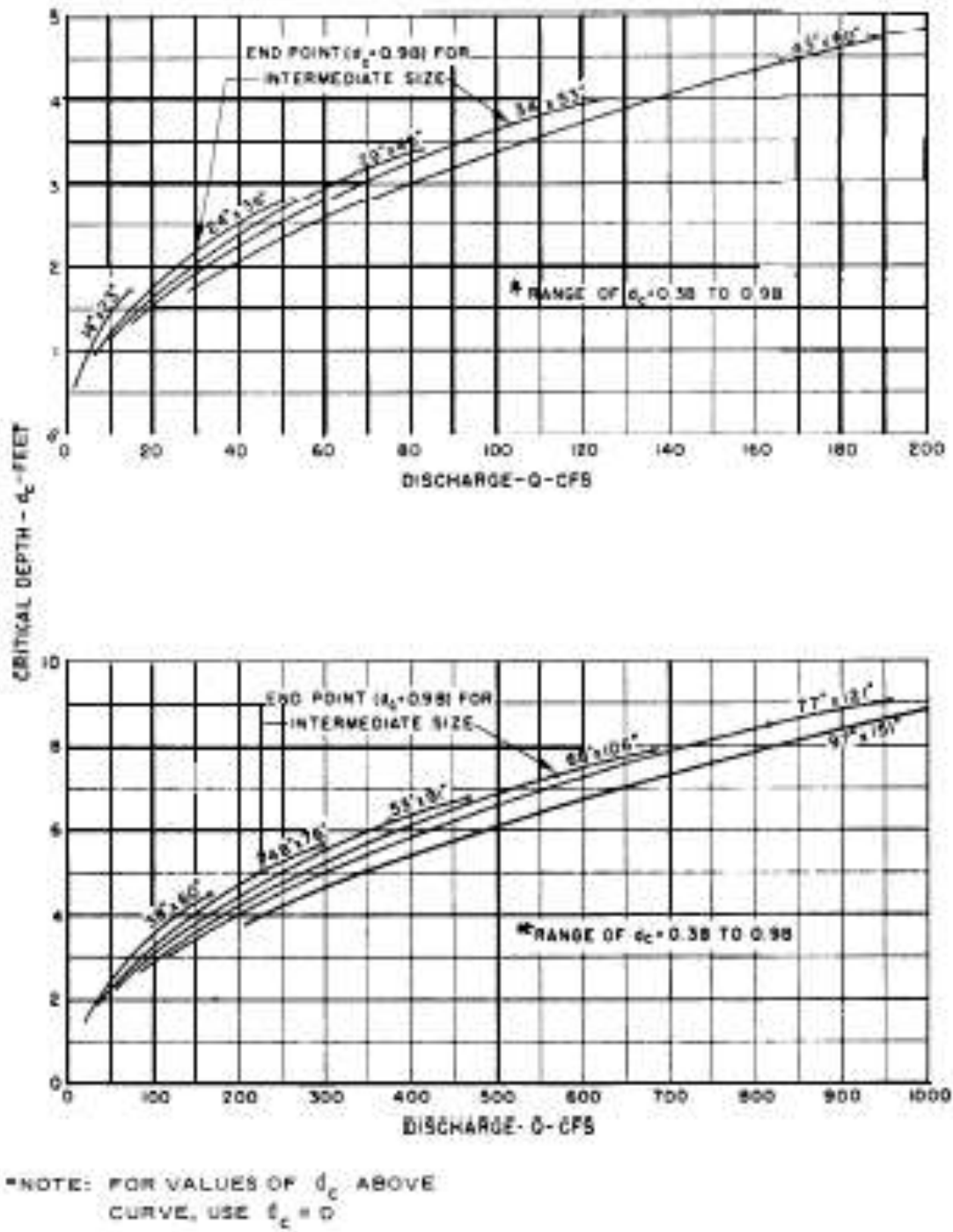


Figure 22
Oval concrete pipe long axis vertical critical depth

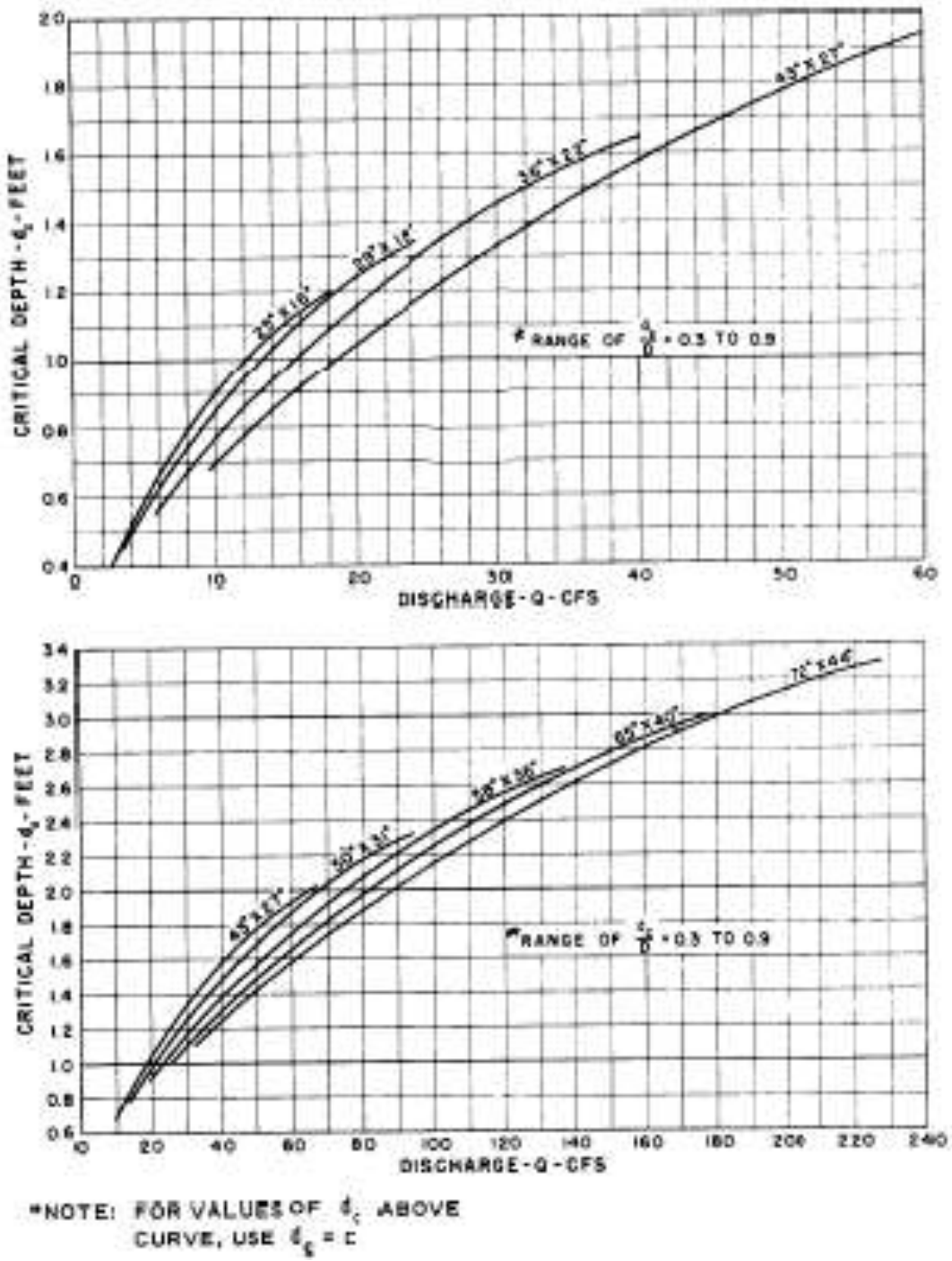
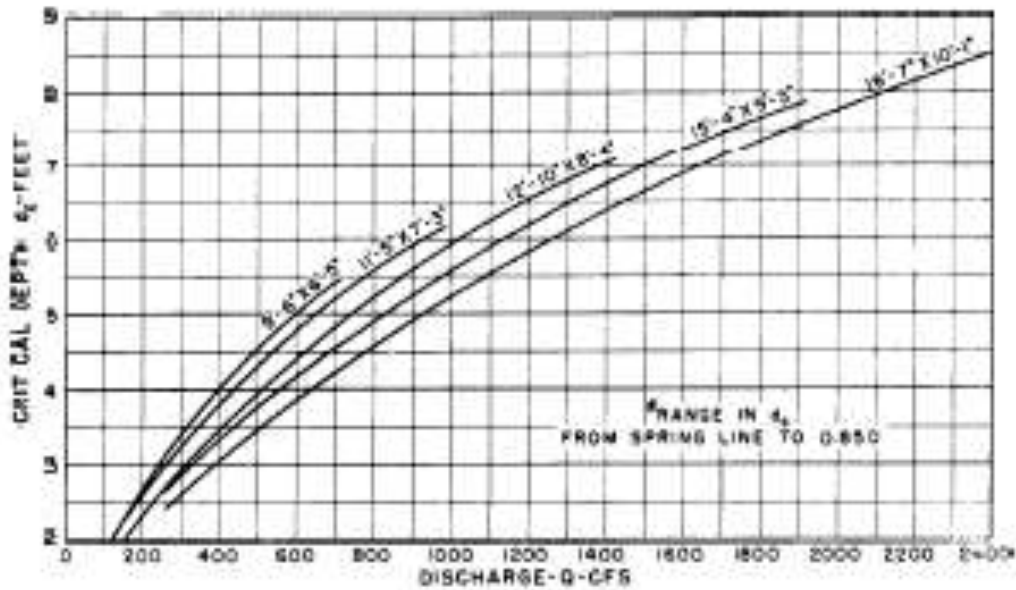
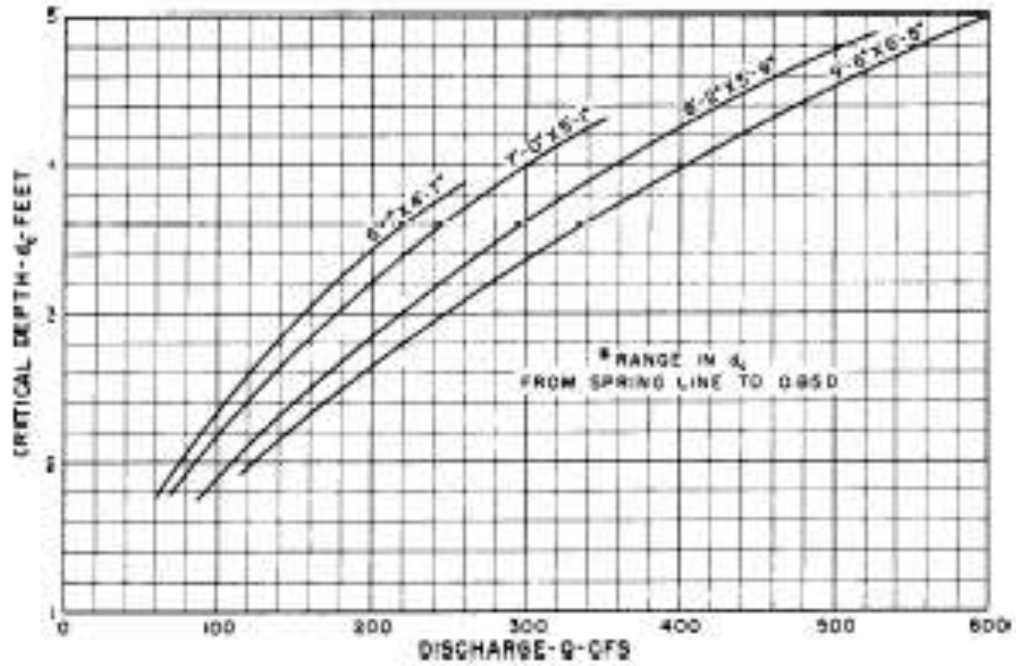


Figure 23
Standard corrugated metal pipe arch critical depth



*NOTE: FOR VALUES OF d_c ABOVE CURVE, USE d_c = 0

Figure 24
Structural plate pipe arch critical depth

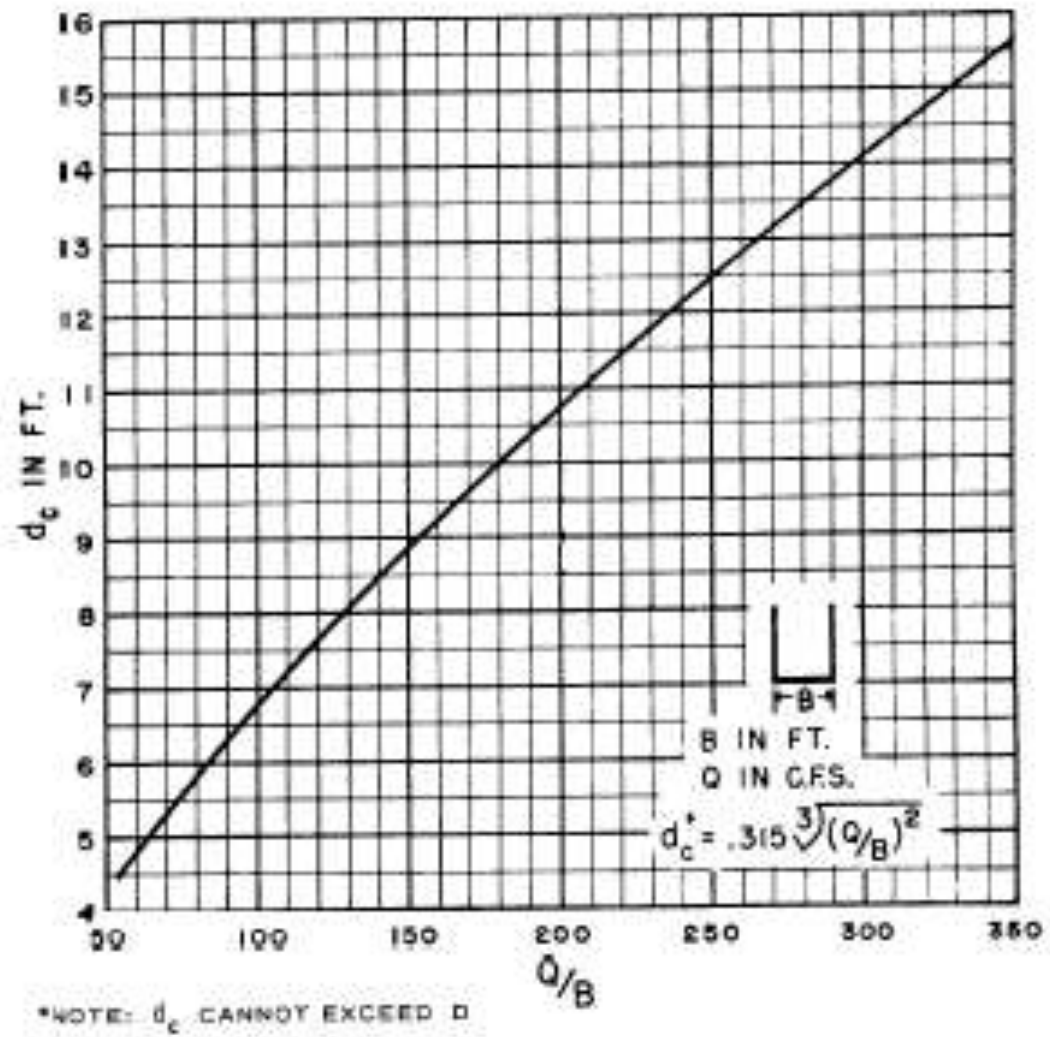
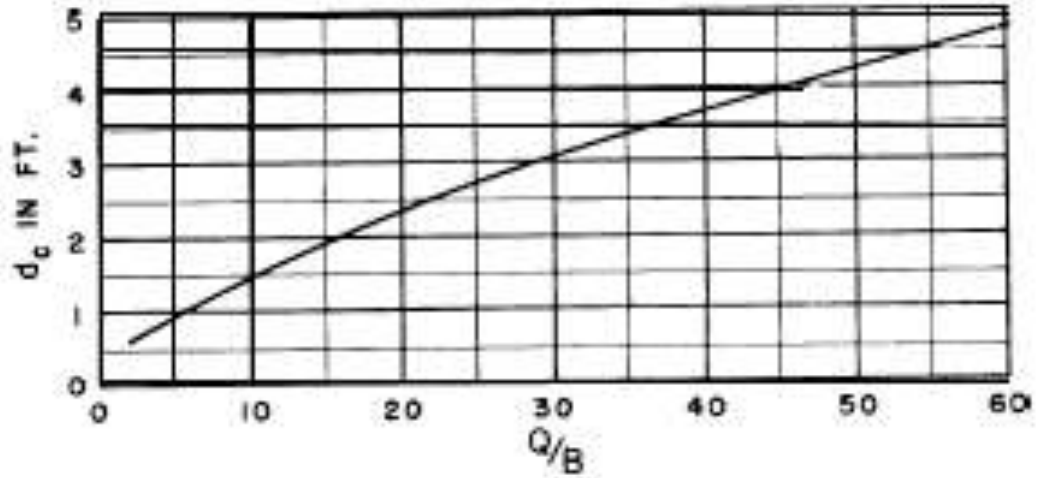


Figure 25
Critical depth rectangular section

5. INSTRUCTIONS FOR USE OF INLET-CONTROL NOMOGRAPHS (FIGURES 2 THROUGH 9)

a. To determine headwater.

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

(2) If HW/D scale 1 represents entrance type used, read HW/D on scale 1. If some other entrance type is used, extend the point of intersection ((1) above) horizontally to scale 2 or 3 and read HW/D.

(3) Compute headwater by multiplying HW/D by D .

b. To determine culvert size.

(1) Given an HW/D value, locate HW/D on scale for appropriate entrance type. If scale 2 or 3 is used, extend HW/D point horizontally to scale 1.

(2) Connect point on HW/D scale 1 as found in (1) above to given discharge and read diameter, height, or size of culvert required.

c. To determine discharge.

(1) Given HW and D , locate HW/D on scale for appropriate entrance type. Continue as in b(1) above.

(2) Connect point on HW/D scale as found in (1) above and the size of culvert on left scale and read Q or Q/B on the discharge scale.

(3) If Q/B is read, multiply by B to obtain Q .

6.. INSTRUCTION FOR USE OF OUTLET-CONTROL NOMOGRAPHY.

a. Figures B–11 through B–17 are nomography to solve for head when culverts flow full with outlet control. They are also used in approximating the head for some partially full flow conditions with outlet control. These nomography do not give a complete solution for finding headwater.

(1) Locate appropriate nomograph for type of culvert selected.

(2) Begin nomograph solution by locating starting point on length scale. To locate the proper starting point on the length scale, follow instructions below:

(a) If the n value of the nomograph corresponds to that of the culvert being used, find the proper K_e from table 1 and on the appropriate nomograph locate starting point on length curve for the K_e . If a K_e curve is not shown for the selected K_e , and (b) below. If the n value for the culvert selected differs from that of the nomograph, see (c) below.

(b) For the n of the nomograph and a K_e intermediate between the scales given, connect the given length on adjacent scales by a straight line and select a point on this line spaced between the two chart scales in proportion to the K_e values. For a different value of roughness coefficient n_1 than that of the chart n , use the length scales shown with an adjusted length L_1 , calculated by the formula:

$$L_1 = L(n_1/n)^2$$

(See subparagraph b below for n values.)

(3) Using a straight edge, connect point on length scale to size of culvert barrel and mark the point of crossing on the “turning line.” See instruction c below for size considerations for rectangular box culvert.

(4) Pivot the straight edge on this point on the turning line and-connect given discharge rate. Read head in feet on the head scale. For values beyond the limit of the chart scales, find H by solving equation given in nomograph or by $H = KQ^2$ where K is found by substituting values of H and Q from chart.

b. Table 3 is used to find the n value for the culvert selected.

c. To use the box-culvert nomograph (fig 17) for full flow for other than square boxes:

(1) Compute cross-sectional area of the rectangular box.

(Note: The area scale on the nomograph is calculated for barrel cross sections with span B twice the height D; its close correspondence with area of square boxes assures it may be used for all sections intermediate between square and $B = 2D$ or $B = 2/3D$. For other box proportions use equation shown in nomograph for more accurate results.)

$n = 0.012$ for smooth interior pipes of any size, shape or type*

***n* Value for Annular Corrugated Metal**

<u>Corrugation Size</u>	<u>Unpaved</u>	<u>25% Paved</u>
2½ by ¼ inch	0.024	0.021
3 by 1 inch	0.027	0.023
6 by 2 inch	0.028-0.033	0.024-0.028
9 by 2½ inch	0.033	0.028

***n* Values for helical corrugated metal (2½ by ¼ inch corrugations)**

<u>Pipe Diameter</u>	<u>Unpaved</u>	<u>25% Paved</u>
12-18 inches	0.011-0.014	▼
24-30 inches	0.016-0.018	0.015-0.016
36-96 inches	0.019-0.024	0.017-0.021

*Includes asbestos cement, bituminized fiber, cast iron, clay, concrete (precast or cast-in-place) or fully paved (smooth interior) corrugated metal pipe.

U.S. Army Corps of Engineers

• **NOTE: Limitations helical coefficient** - The designer must assure that fully developed spiral flow can occur in his design situation before selecting the lower resistance factor. Fully developed spiral flow, and the corresponding lower resistance factors, can only occur when the conduit flows full. For conduits shorter than 20 diameters long, it is felt that the full development of spiral flow cannot be assured. Bed load deposition on the culvert invert may hinder the development of spiral flow until sediment is washed out. When these conditions exist, the resistance factors for annular C.M.P. of the same size and corrugation shape should be used.

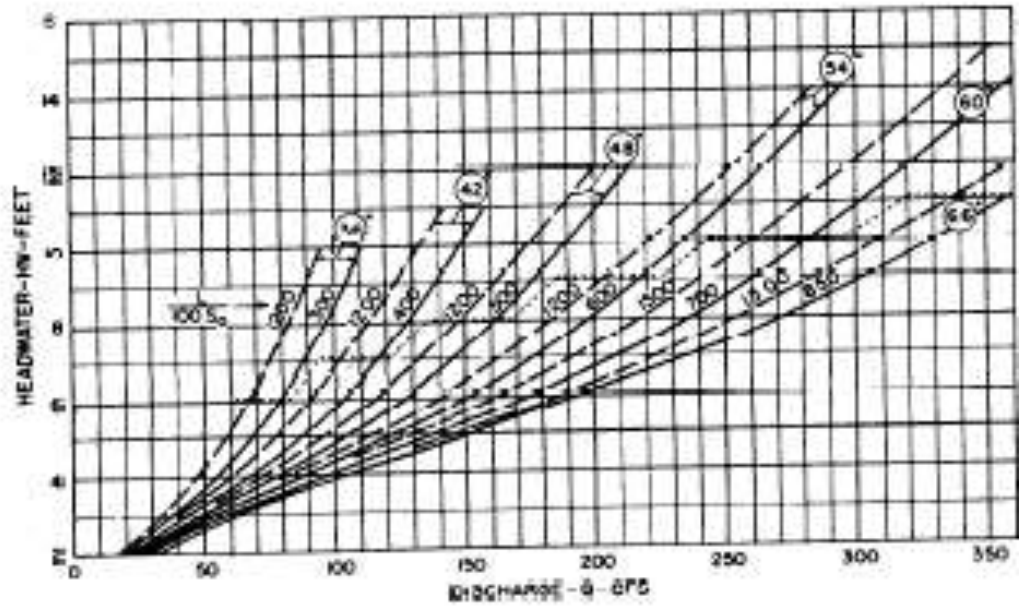
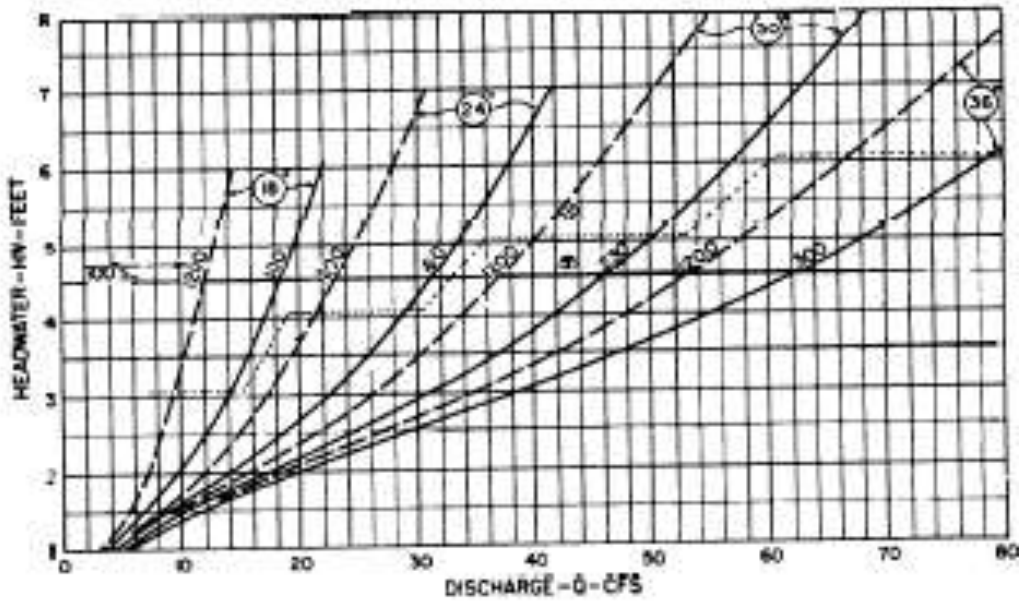
Table 3

Roughness coefficients for various pipes

(2) Connect proper point (see para 6b) on length scale to barrel area and mark point on turning line.

(3) Pivot the straight edge on this point on the turning line and connect given discharge rate. Read head in feet on the head scale.

7. CULVERT CAPACITY CHARTS. Figures 26 through 43 present headwater discharge relations convenient for use in design of culverts of the most common types and sizes. The solid-line curve for each type and size represents for a given length: slope ratio the culvert capacity with control at the inlet; these curves are based generally on model data. For those culvert types for which a dashed-line curve is shown in addition to a solid-line curve, the dashed line represents for a given length: slope ratio the discharge capacity for free flow and control at the outlet; these curves are based on experimental data and backwater computations. The length: slope ratio is $L/100S_o$ given on the solid line curve and in each case is the value at which the discharge with outlet control equals the discharge with inlet control. For culverts with free flow and control at the outlet, interpretation and extrapolation for different $L/100S_o$ values is permitted in the range of headwater depths equal to or less than twice the barrel height. The upper limit of this range of headwater depths is designated by a horizontal dotted line on the charts. Values of $L/100S_o$ less than those given in the chart do not impose any limitation; merely read the solid line curves. The symbol AHW means allowable headwater depth. The charts permit rapid selection of a culvert size to meet a given headwater limitation for various entrance conditions and types and shapes of pipe. One can enter with a given discharge and read vertically upward to the pipe size that will carry the flow to satisfy the headwater limitation of the design criteria. The major restriction on the use of the charts is that free flow must exist at the outlet. In most culvert installations free flow exists, i.e., flow passes through critical depth near the culvert outlet. For submerged flow conditions the solution can be obtained by use of the outlet control nomographs.



EXAMPLE

① GIVEN:
43 CFS ; HW = 5.4 FT.
L = 120 FT. ; $S_o = 0.002$

② SELECT 30"
HW = 4.7 FT.

Figure 26

Culvert capacity circular concrete pipe
groove-edged entrance 18" to 66"

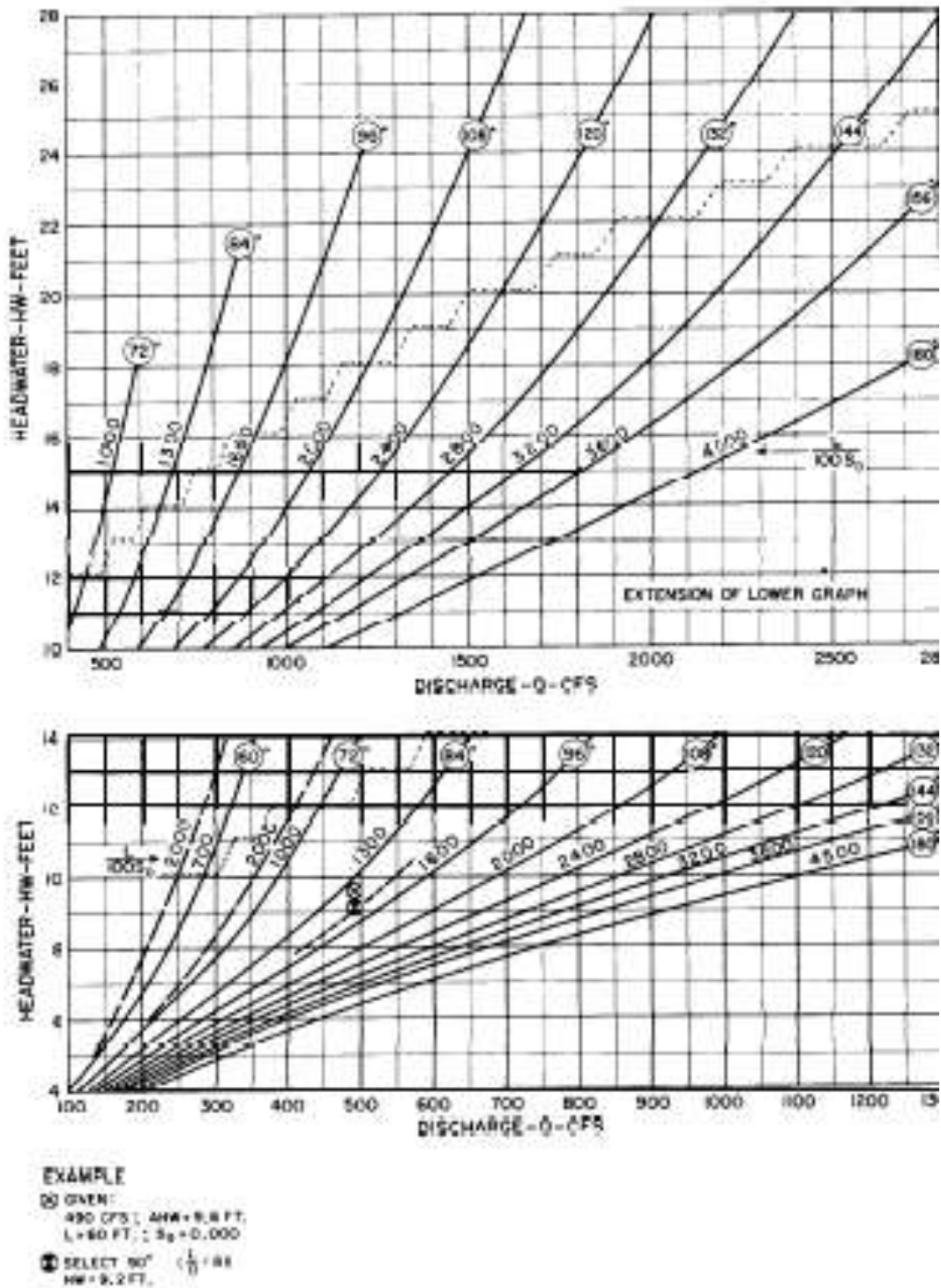


Figure 27

Culvert capacity circular concrete pipe groove-edged entrance 60" to 180"

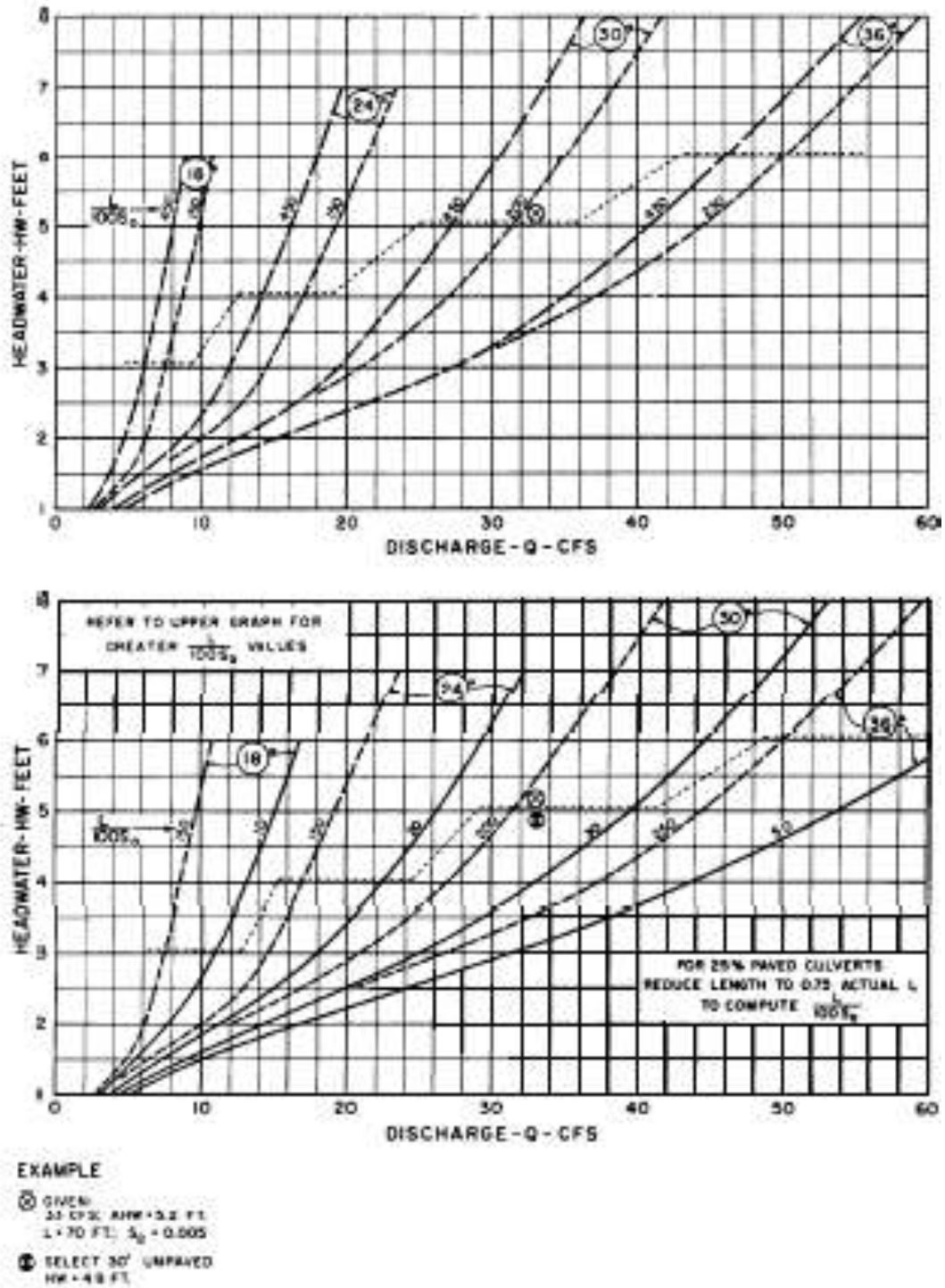
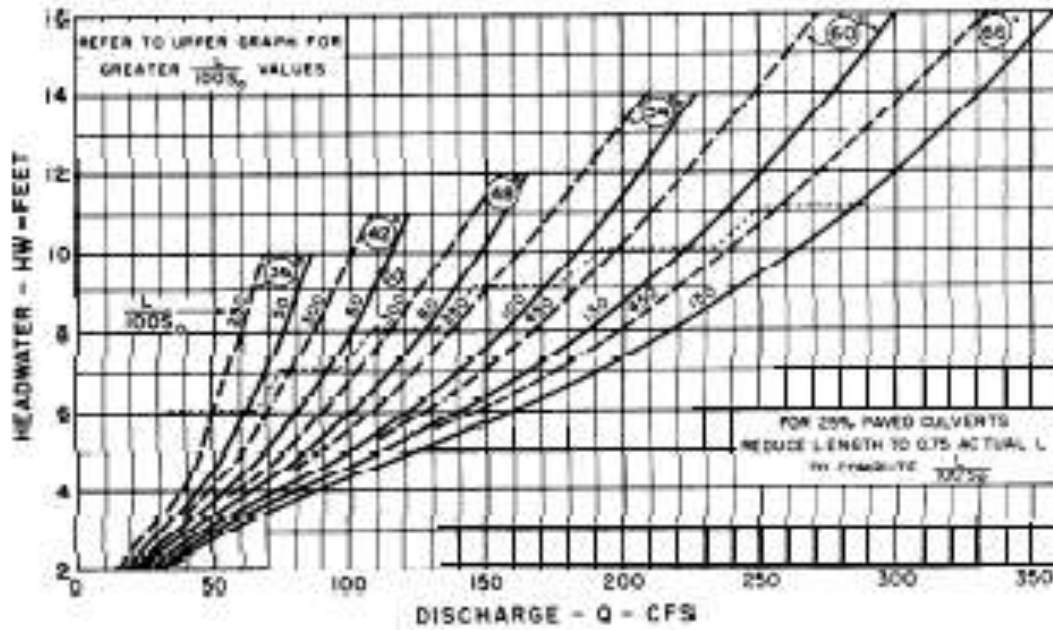
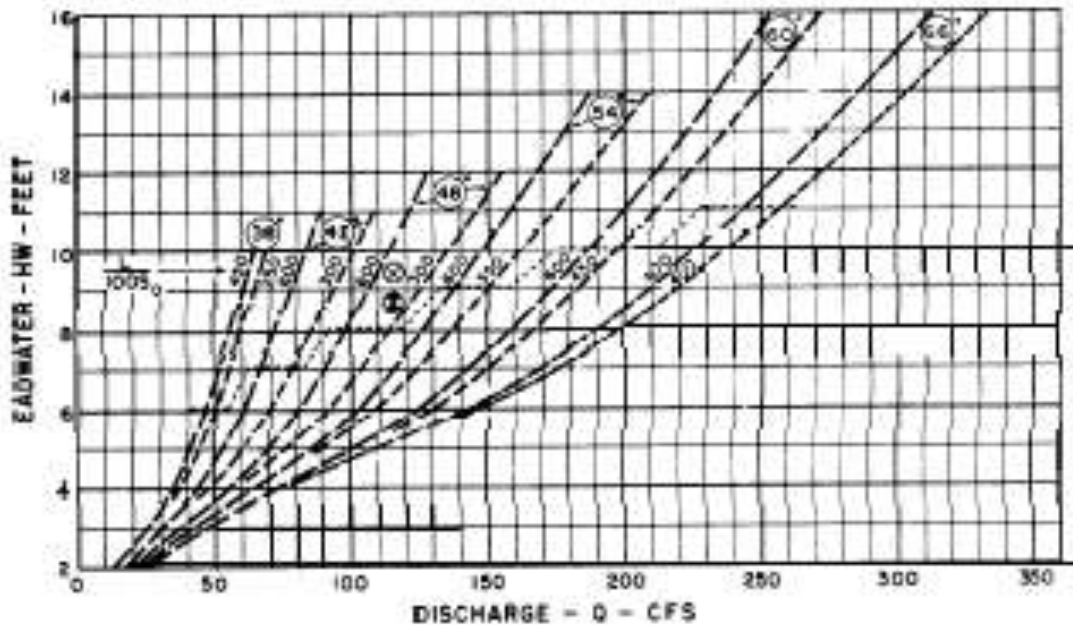


Figure 28
 Culvert capacity standard circular corrugations metal pipe
 projecting entrance 18" to 36"



EXAMPLE
 ① GIVEN:
 115 CFS; HW=10 FT.
 L=135 FT; $S_0=0.0034$
 ② SELECT 48" UNPAVED
 HW=10 FT.

Figure 29
 Culvert capacity standard circular corrugations metal pipe
 projecting entrance 36" to 66"

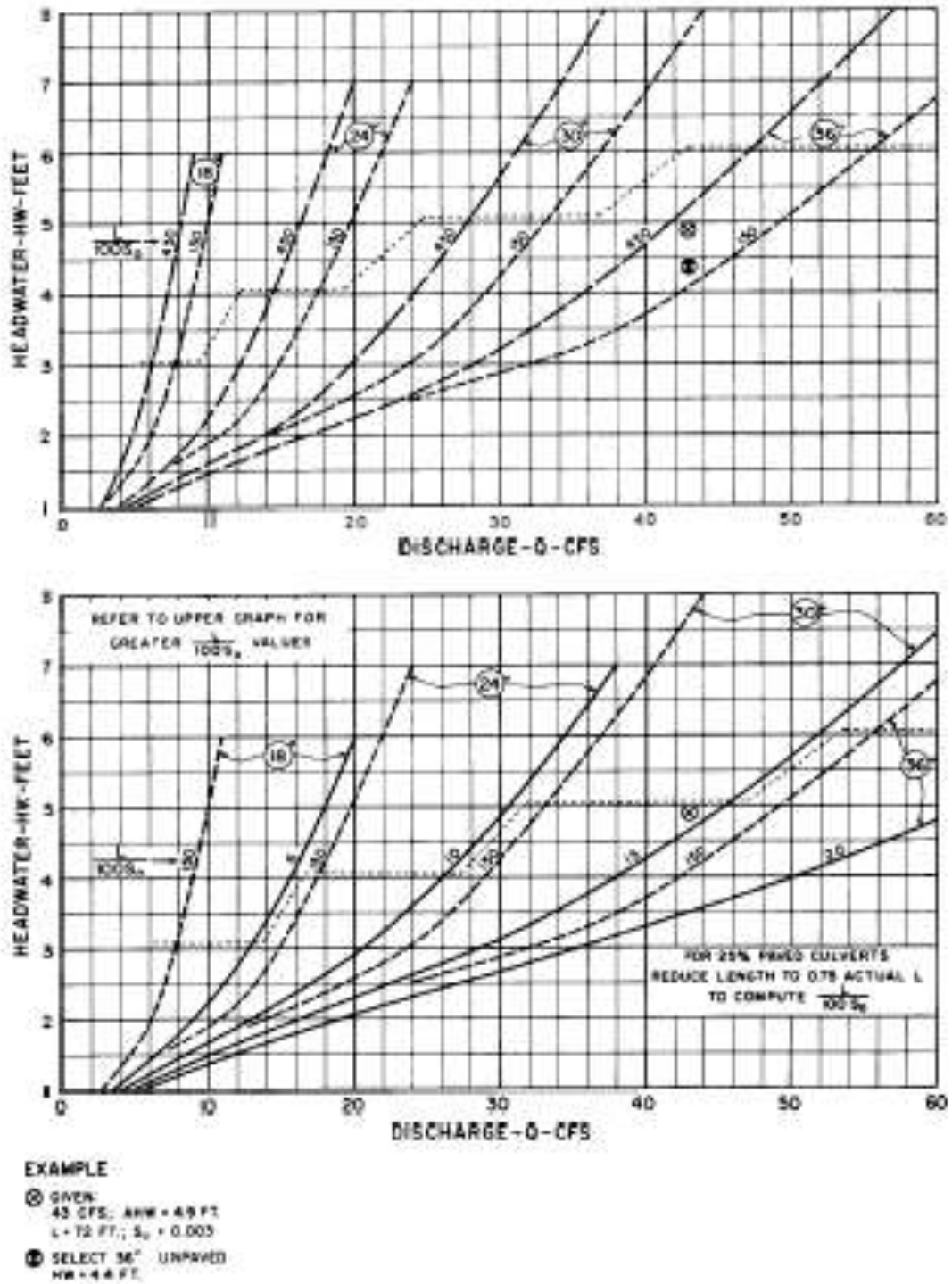
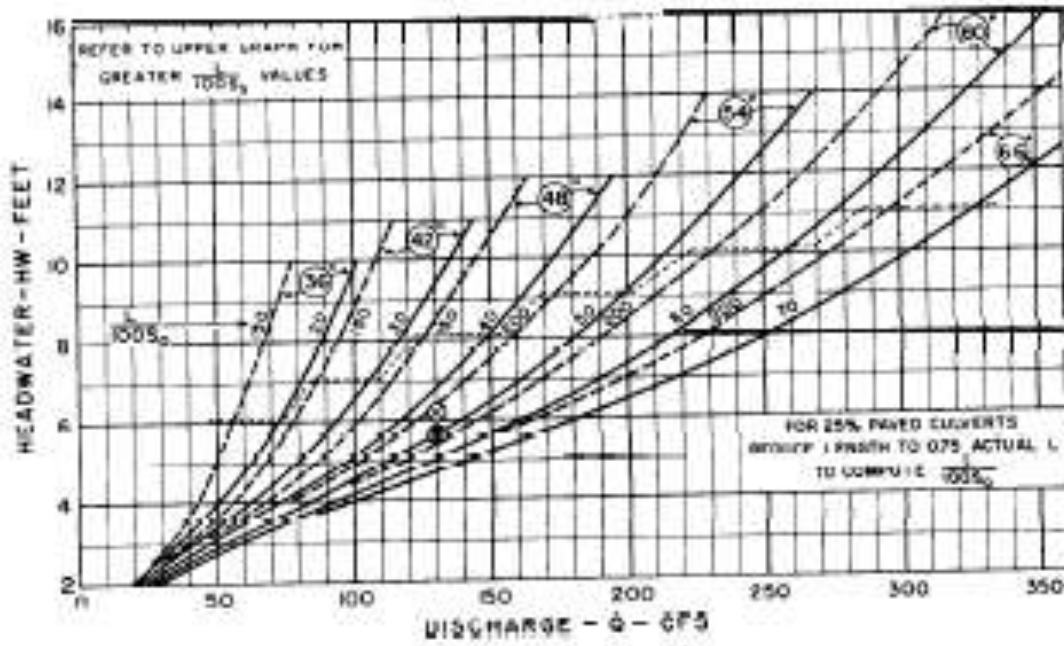
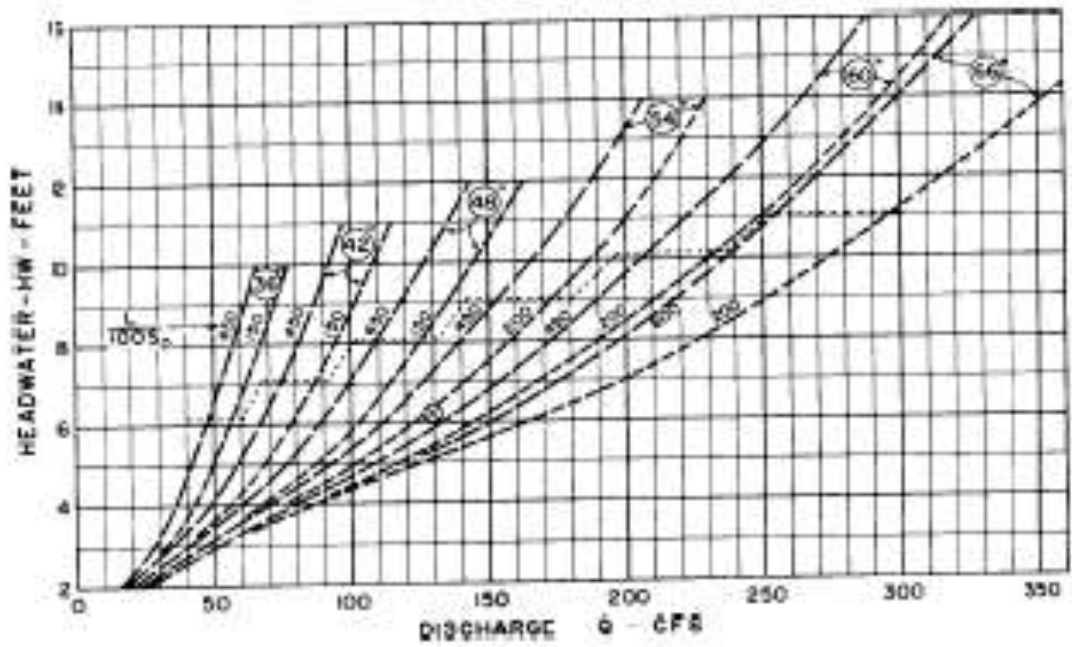


Figure 30
Culvert capacity standard circular corrugations
metal headwall entrance 18" to 36"



EXAMPLE

- ⊗ GIVEN:
150 CFS, $HW = 6.2$ FT,
 $L = 120$ FT, $S_c = 0.025$
- ⊙ SELECT 54" UNPAVED
 $HW = 5.6$ FT.

Figure 31

Culvert capacity standard circular corrugations
metal headwall entrance 36" to 66"

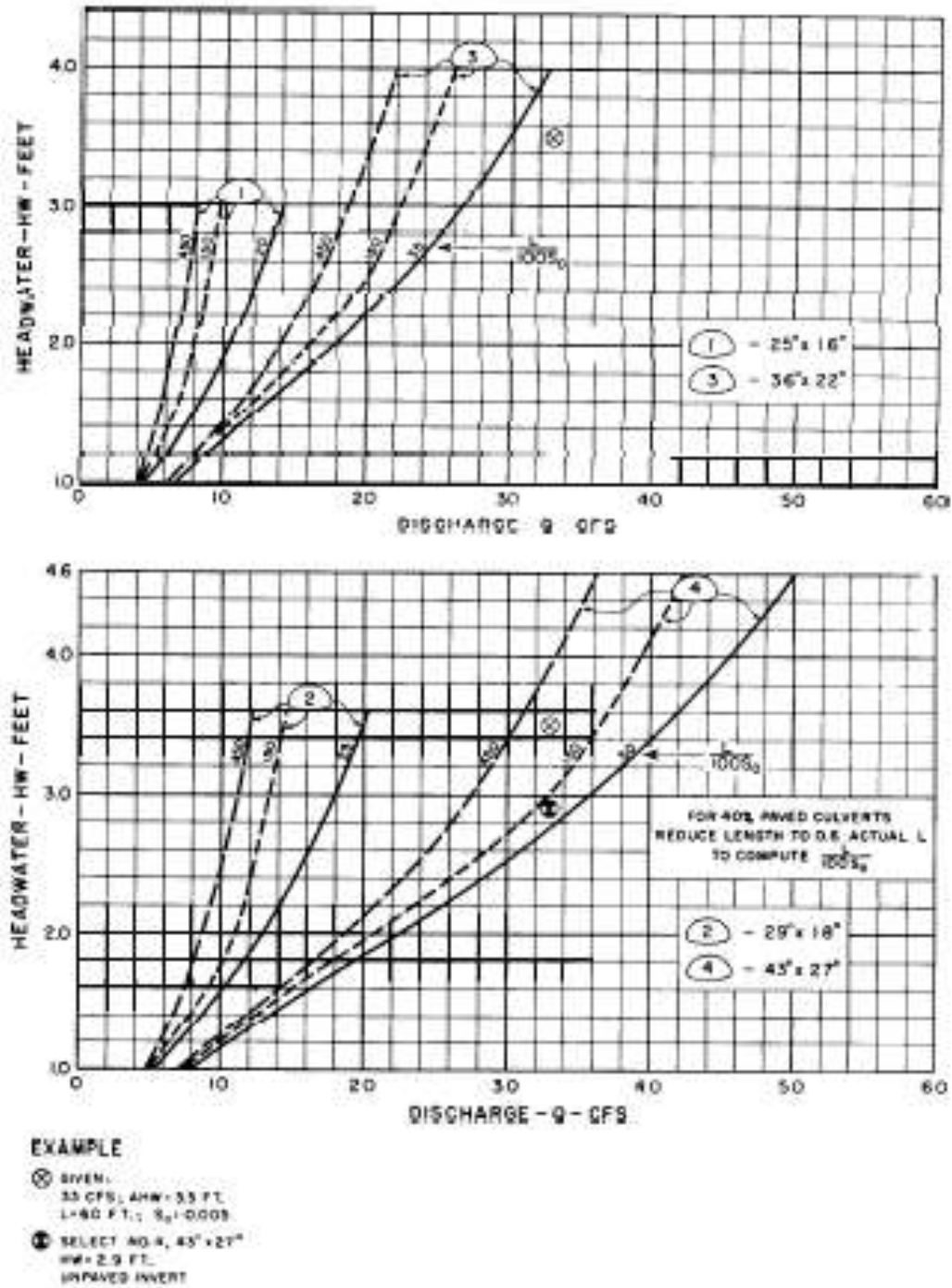
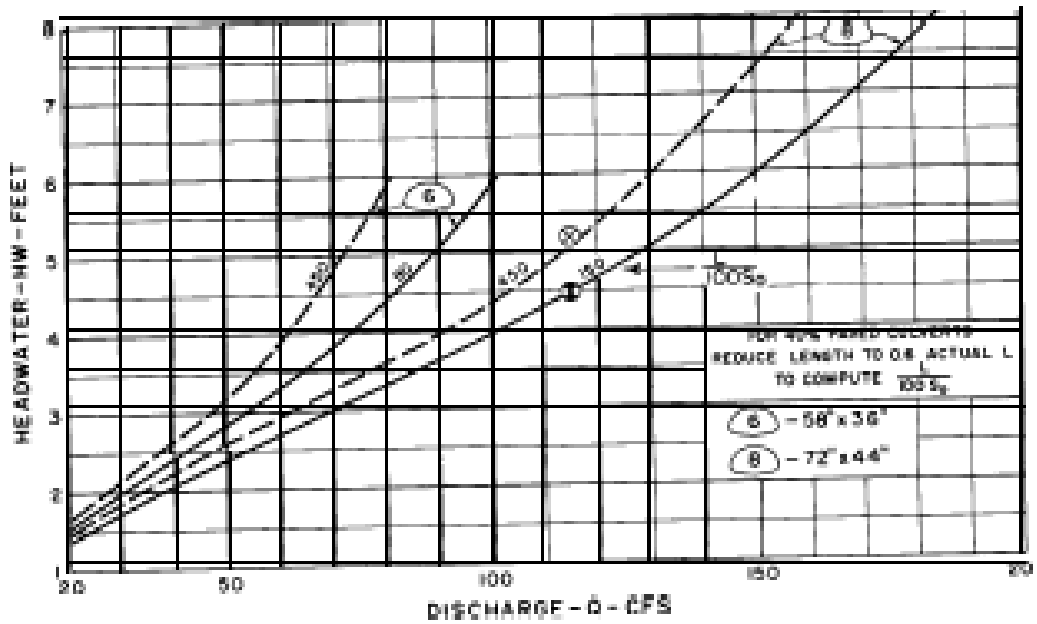
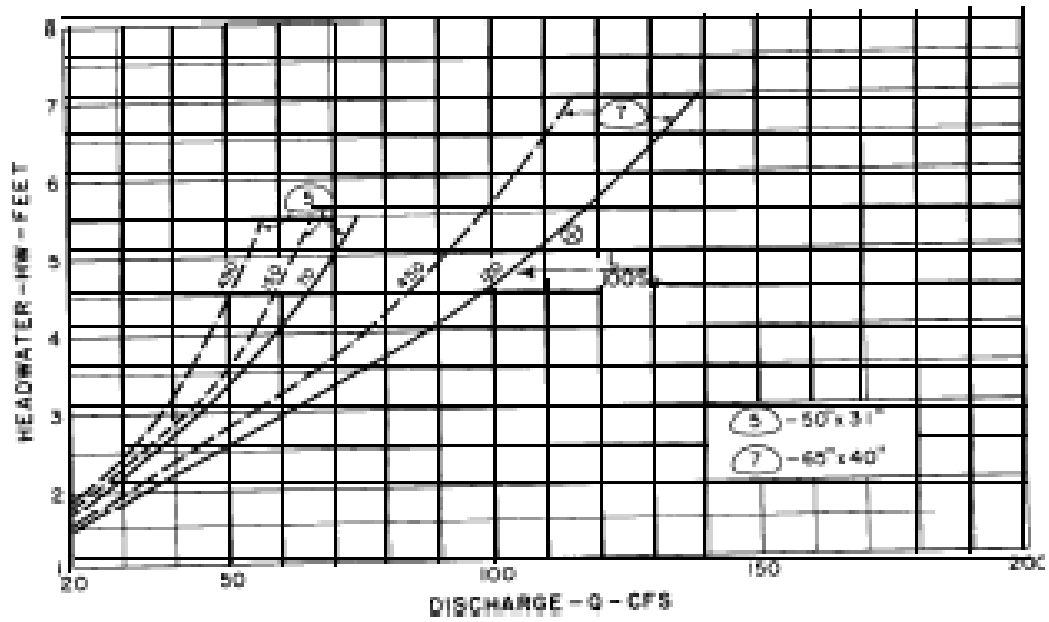


Figure 32

Culvert capacity standard corrugations metal pipe arch
projecting entrance 25" x 16" to 48" x 27"



EXAMPLE

- ⊙ GIVEN:
80 CFS, APPROX. FT.
LENGTH, S_e 0.0005
- ⊙ SELECT NO. 8, 72' x 44'
CONCRETE
PAVED INVERT

Figure 33

Culvert capacity standard corrugations metal pipe arch
projecting entrance 50" x 31" to 72" x 44"

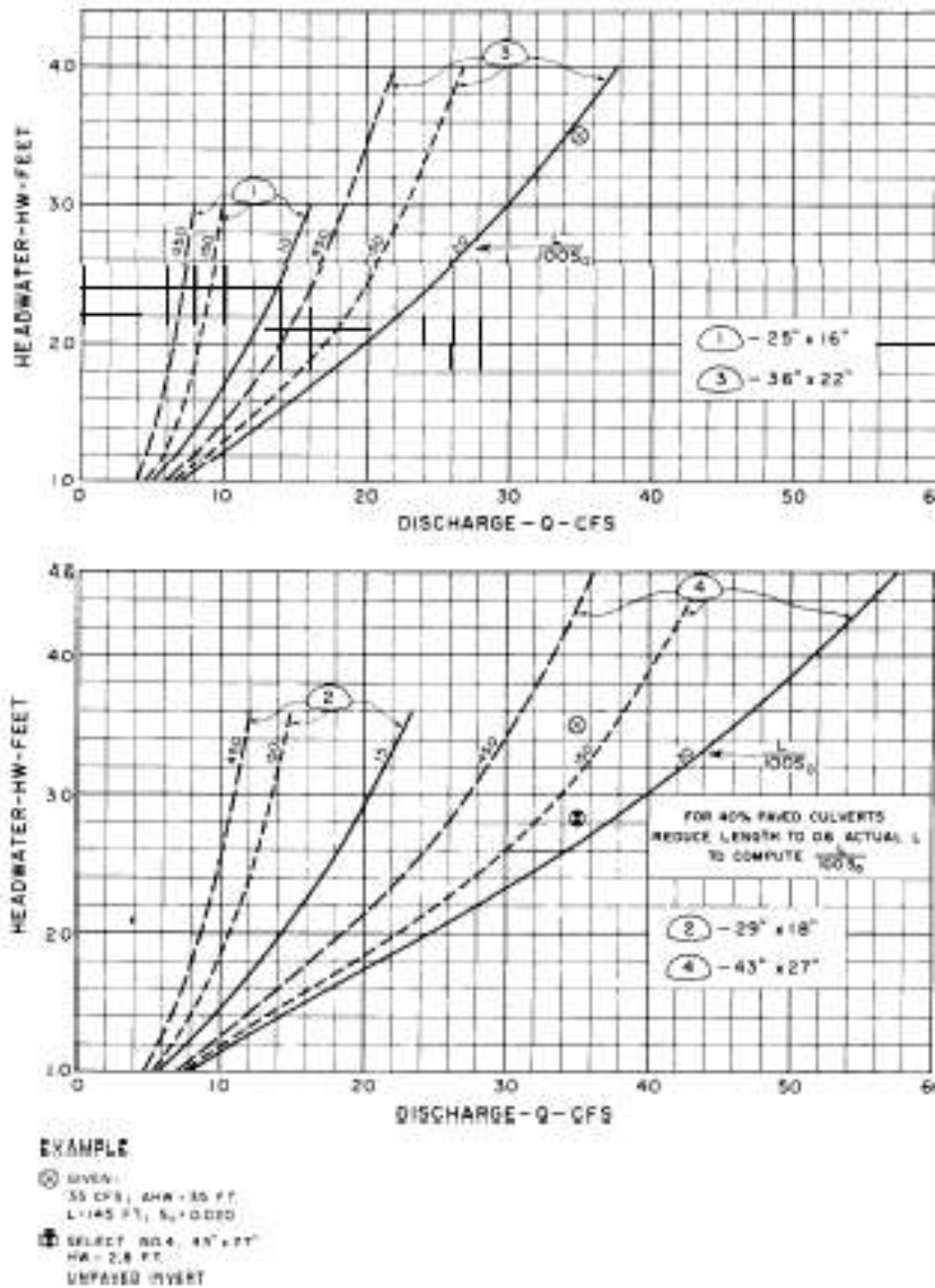
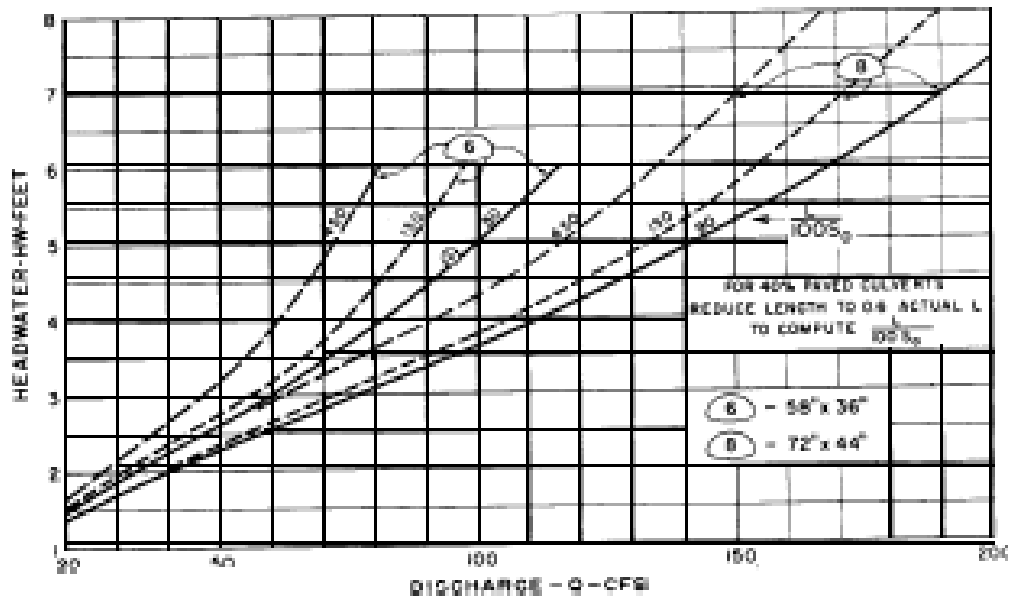
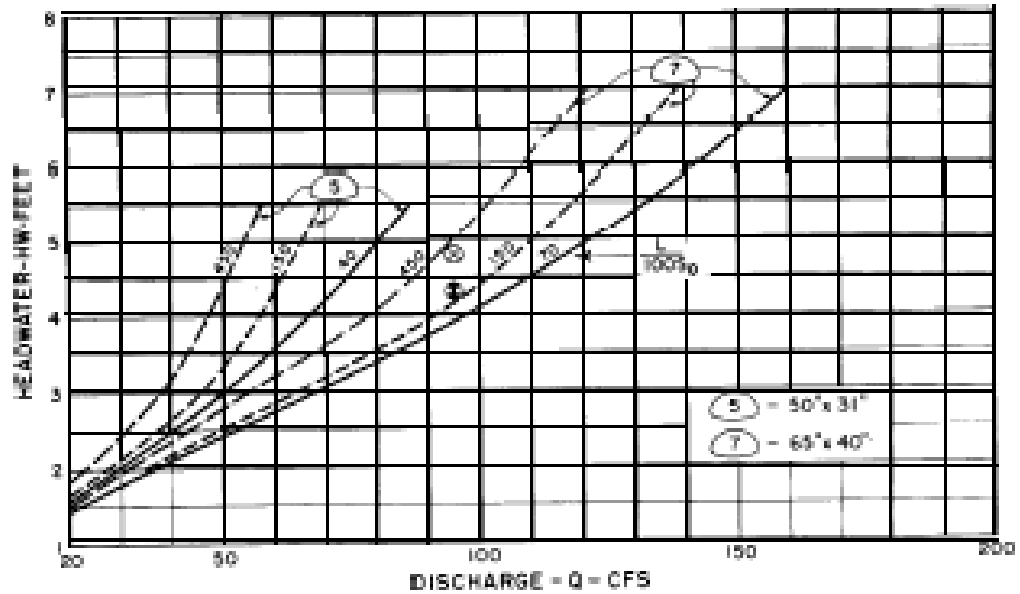


Figure 34

Culvert capacity standard corrugations metal pipe arch
 headwall entrance 25" x 16" to 43" x 27"



EXAMPLE

- ① GIVEN:
85 CFS; HW = 4.8 FT.
L = 240 FT; $S_0 = 0.012$
- ② SELECT NO. T. 63' x 40'
HW = 4.5 FT.
UNRAISED INVERT

Figure 35

Culvert capacity standard corrugations metal pipe arch
headwall entrance 50" x 31" to 72" x 44"

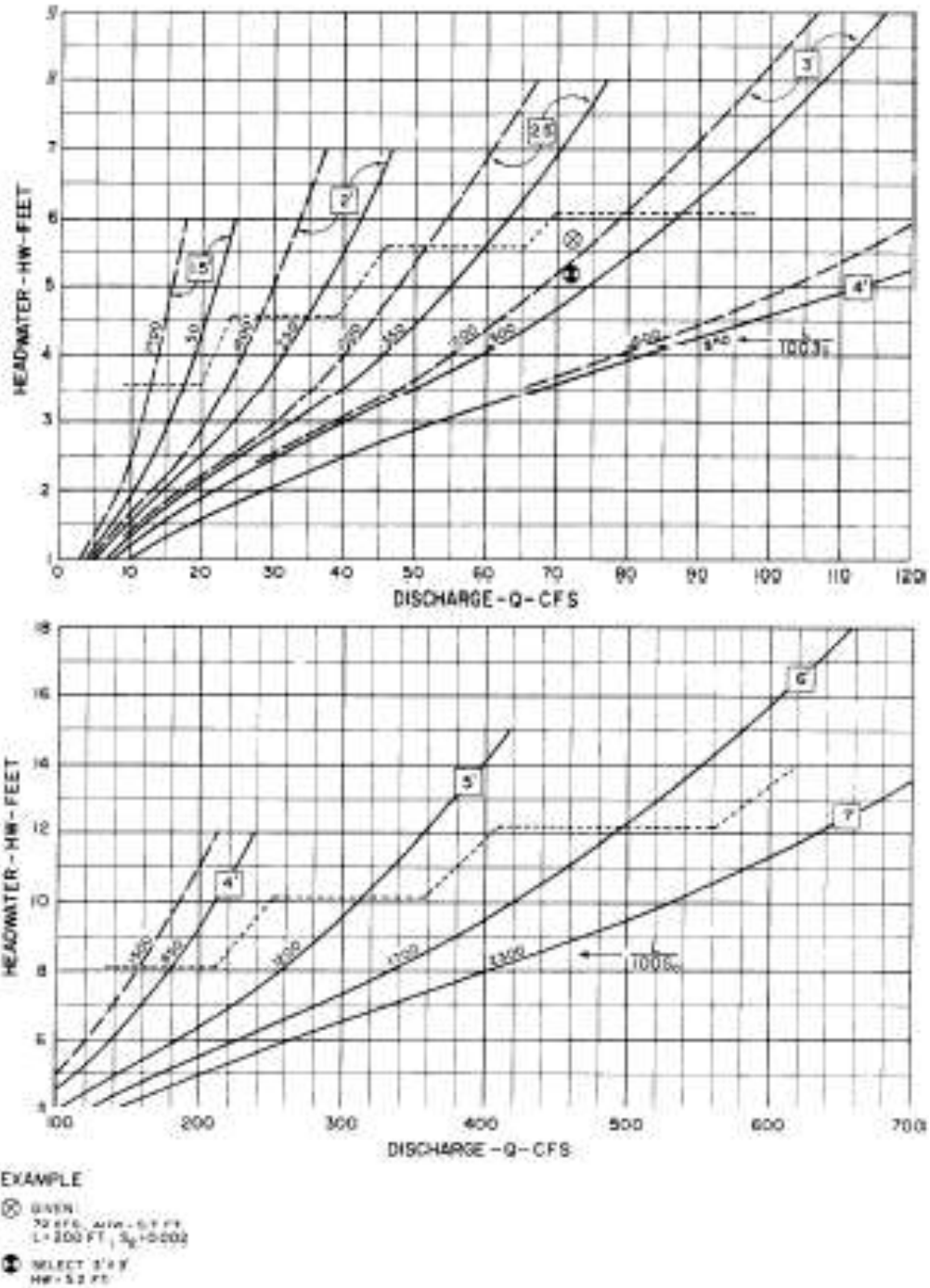
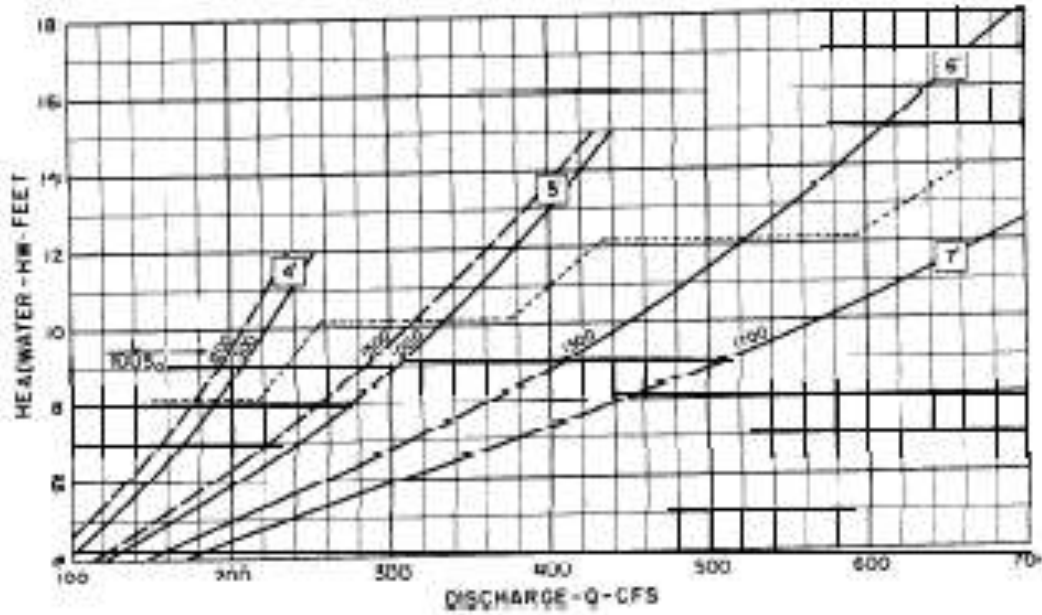
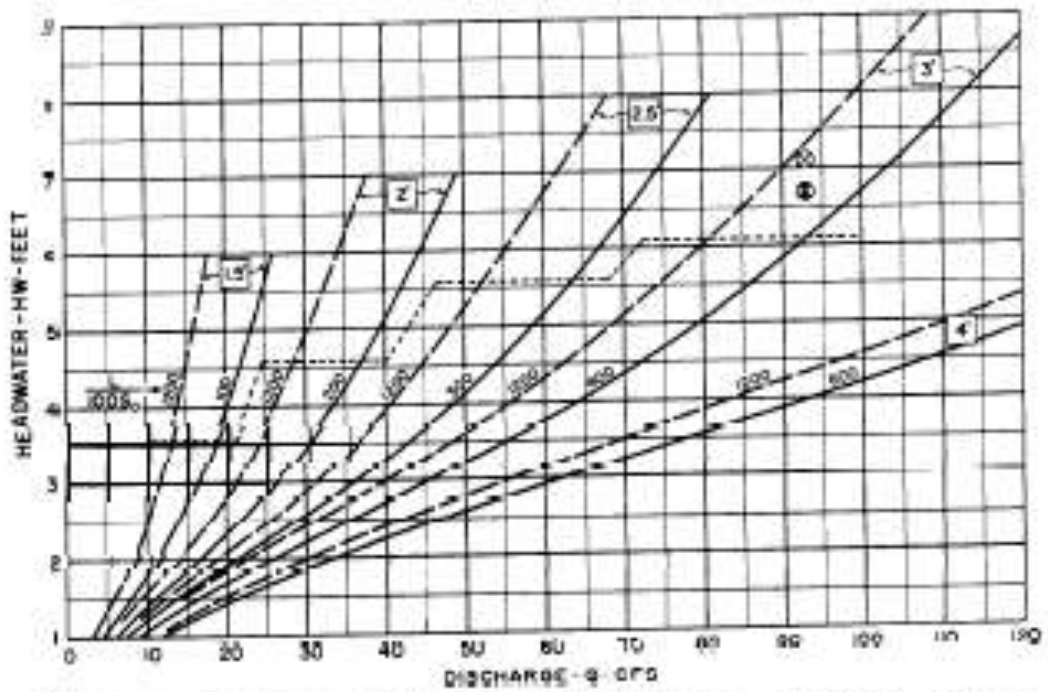


Figure 36

Culvert capacity square concrete box
 90° and 15° wingwall flare 1.5' x 1.5' to 7' x 7'



EXAMPLE

- ⊗ GIVEN:
95 CFS, HW = 6.7 FT
L = 280 FT, $S_o = 0.0039$
- ⊙ SELECT 3' x 3'
HW = 6.7 FT

Figure 37

Culvert capacity square concrete box
30° to 75° wingwall flare 1.5' x 1.5' to 7' x 7'

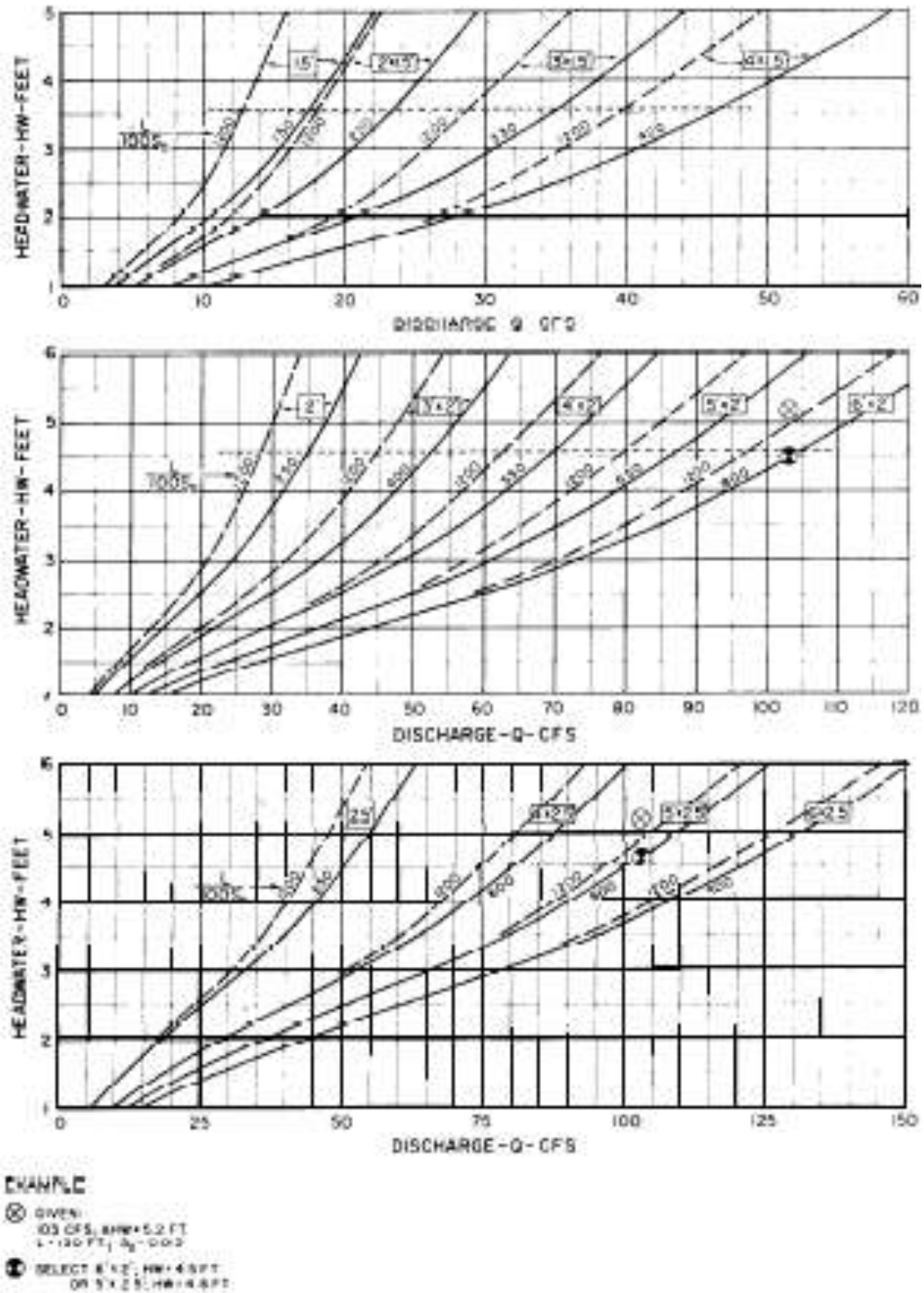


Figure 38

Culvert capacity rectangular concrete box
90° and 15° wingwall flare 1.5', 2.0' and 2.5' height'

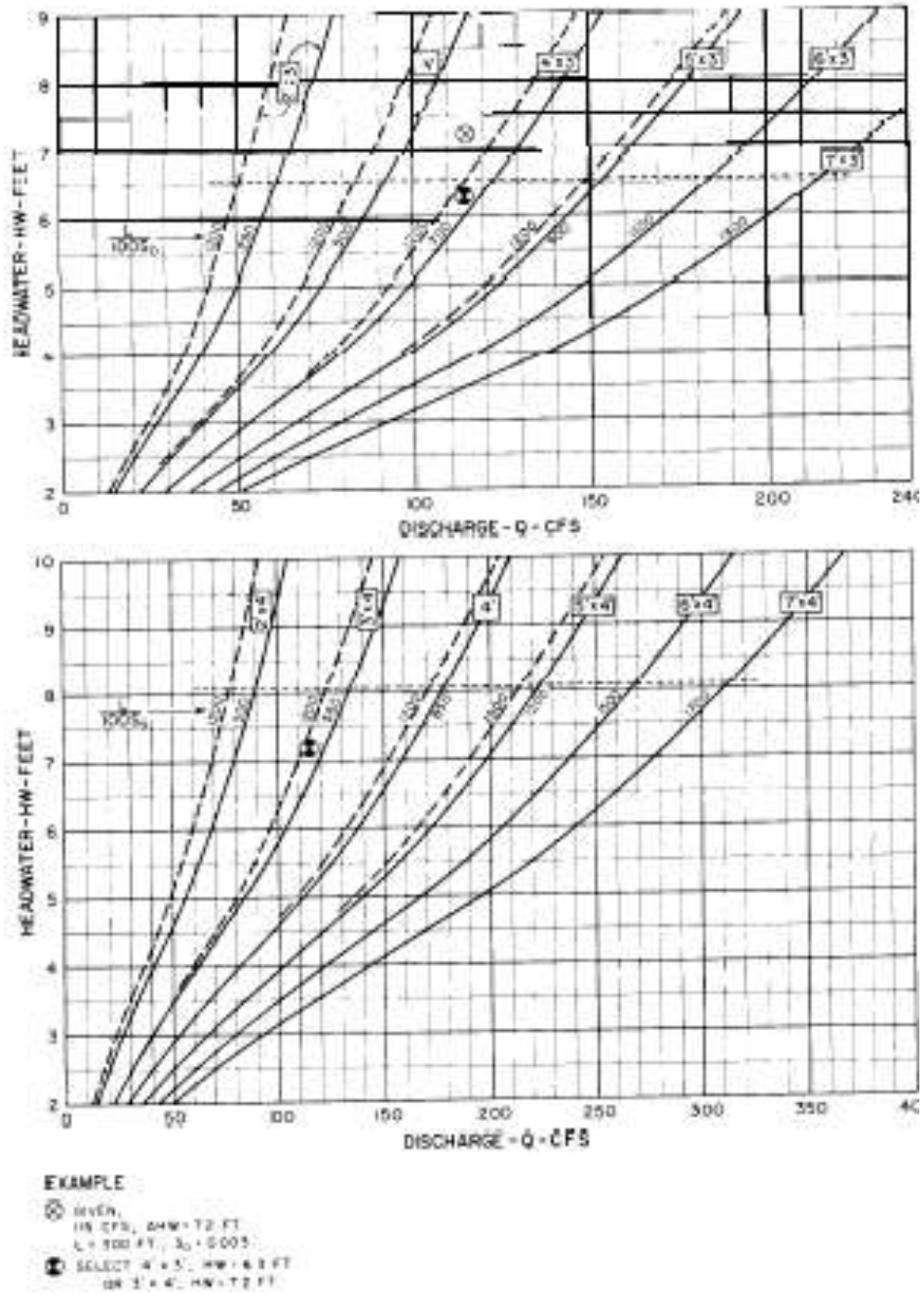


Figure 39

Culvert capacity rectangular concrete box
90° and 15° wingwall flare 3.0' and 4.0' height'

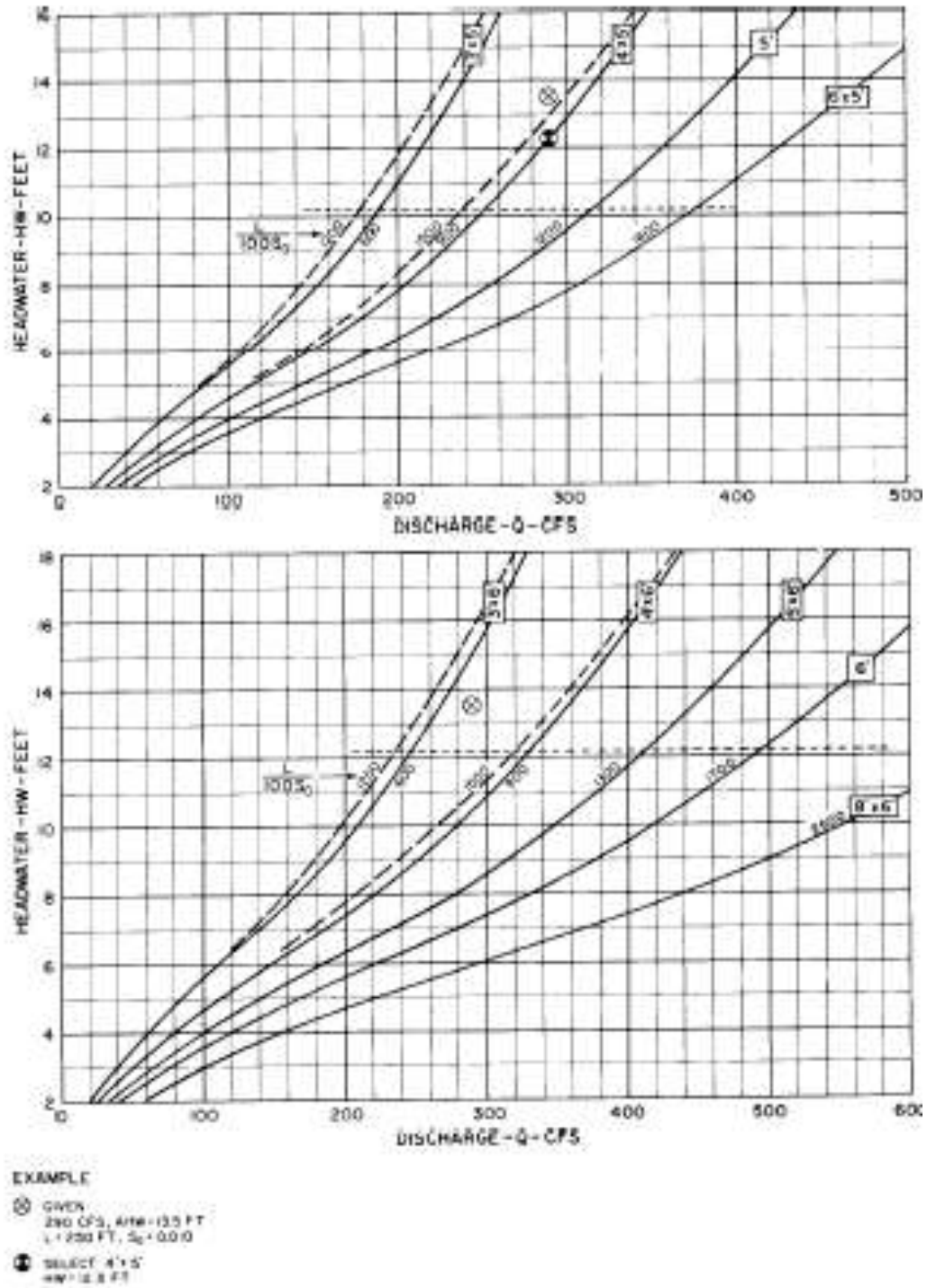


Figure 40

Culvert capacity rectangular concrete box
90° and 15° wingwall flare 5.0' and 6.0' height'

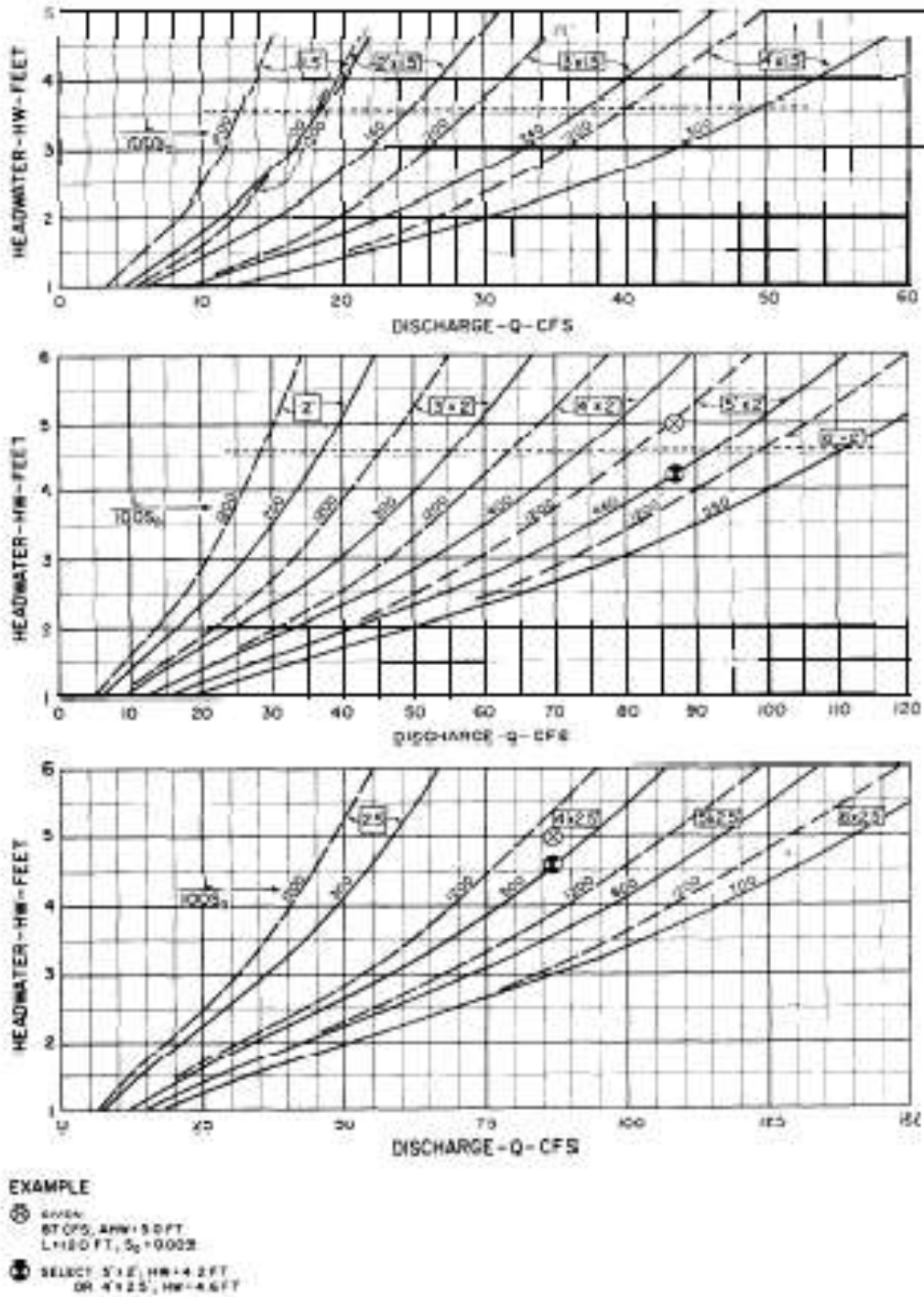


Figure 41
Culvert capacity rectangular concrete box
30° to 75° wingwall flare 1.5', 2.0' and 2.5' heights

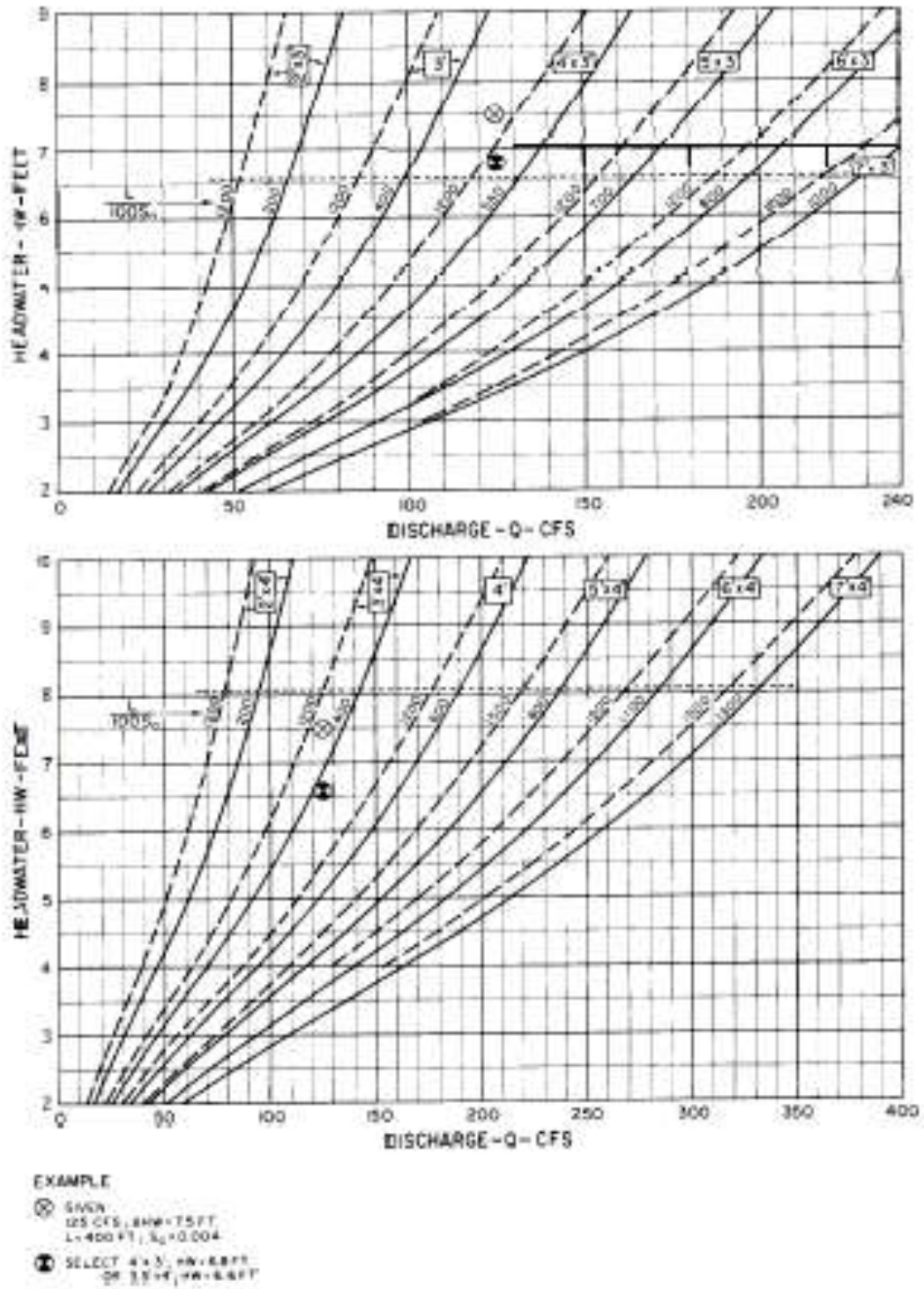


Figure 42
Culvert capacity rectangular concrete box
30° to 75° wingwall flare 3.0' and 4.0' heights

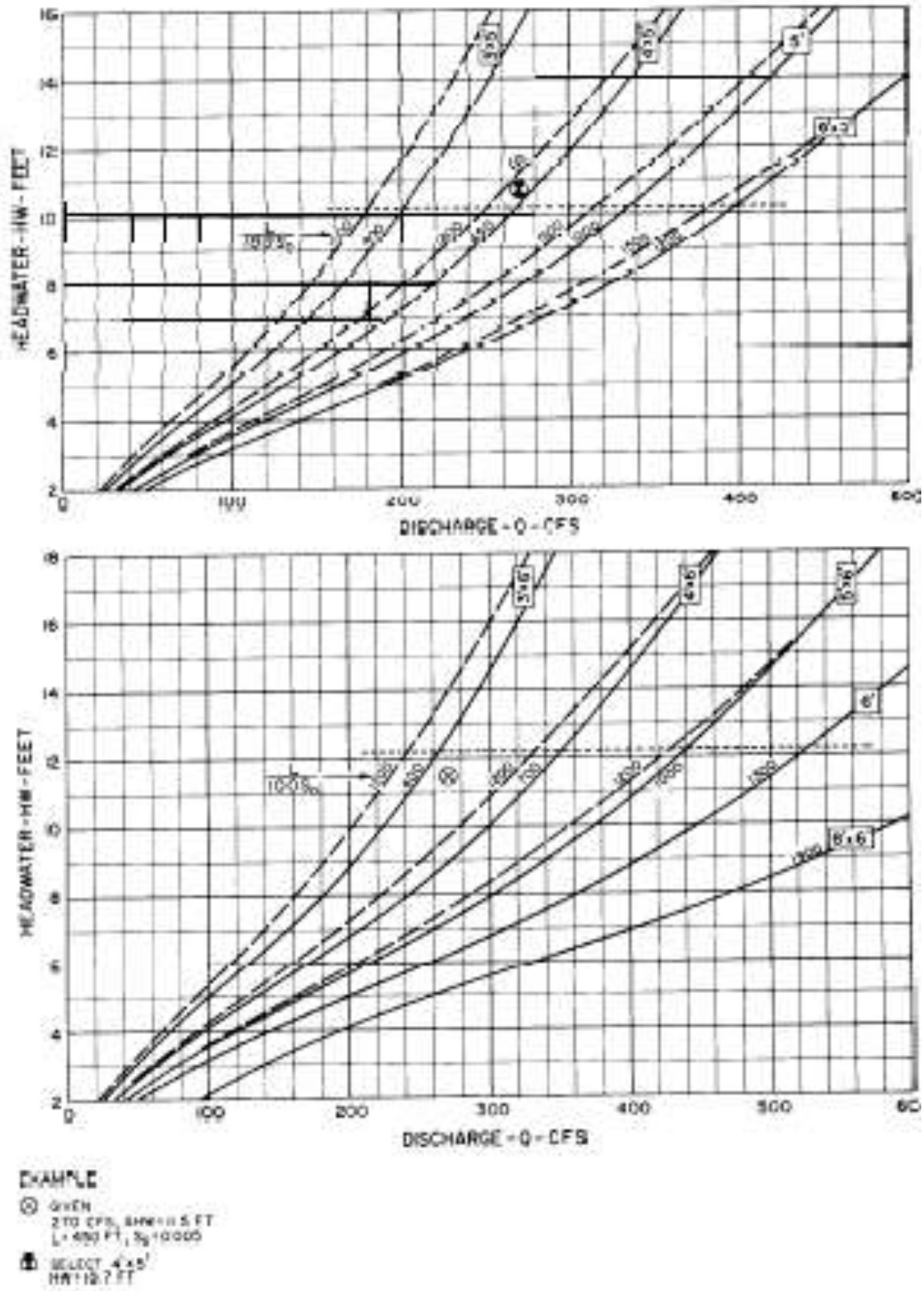


Figure 43

Culvert capacity rectangular concrete box
30° to 75° wingwall flare 5.0' and 6.0' heights