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4.0 CULVERTS AND BRIDGES

4.1 GENERAL

For small drainage areas the most economical means of moving open channel flow beneath a road or railroad is generally with culverts. Discussion in this section will address procedures for determining the most cost effective culvert size and shape given a design discharge and allowable headwater elevation. The design procedures for the culverts referenced in this section pertain only to those in the main channels and not those in roadside ditches which are covered in Section 5 - Storm Sewers and Overland Flow. In addition, this section will include a brief discussion of the hydraulic and hydrologic considerations pertinent to bridge design. This section considers all design to be completed for ultimate development. Where appropriate, the actual construction of a crossing may be phased as development occurs. In this case, both the ultimate and the interim phase must be shown on the construction plans. Calculations for each must be submitted for approval. The ultimate right-of-way is required even for an interim phase of construction.

4.2 CULVERTS

4.2.1 Design Frequency

All culverts in Fort Bend County shall be designed to handle the 100-year flood flow for fully developed conditions without causing upstream or downstream water surface profiles to exceed maximum levels as defined in Section 3.3.1.

4.2.2 Culvert Alignment

Culverts shall be aligned parallel to the longitudinal axis of the channel to insure maximum hydraulic efficiency and minimum erosion. In areas where a change in alignment is necessary, the turn shall be made upstream in the natural channel and appropriate erosion protection shall be provided.

4.2.3 Culvert Length

Culverts shall be designed to span the road or railroad right-of-way.

4.2.4 Headwalls

Headwalls and endwalls shall be utilized to control erosion and scour, to anchor the culvert against lateral pressures, and to insure bank stability. All headwalls shall be constructed of reinforced concrete and may be straight and parallel to the channel, flared or warped, with or without aprons, as required by site and hydraulic conditions. Protective guardrails should be included along culvert headwalls. Table 4-1 provides some general guidelines for choosing a headwall.

4.2.5 Minimum Culvert Sizes

The minimum pipe culvert diameter shall be 24 inches and the minimum box culvert dimensions shall be 2 feet by 2 feet. These restrictions are made to guard against flow obstruction. Sizes less than these shall be considered on a case-by-case basis.

4.2.6 Manning's "n" Values

The minimum Manning's "n" value to be used in concrete culverts shall be 0.013. For corrugated metal, the "n" value shall be as follows:

Corrugation (Span x Depth)	"n"
2-2/3" x 1/2"	0.024
3" x 1"	0.027
5" x 1"	0.027
6" x 2"	0.030

4.2.7 Erosion

Culverts, because of their hydraulic characteristics, generally increase the velocity of flow over that found in the natural channel. For this reason, the tendency for erosion, especially at the outlet, must be addressed. In general, culvert discharge velocities in unprotected channels should not exceed allowable channel velocities as defined in Table 3-3.

4.2.8 Structural Requirements

The following minimum structural requirements shall also be met for culvert design in Fort Bend County:

1. All precast reinforced concrete pipe should be ASTM C-76 (minimum).

2. All precast reinforced concrete box culverts with more than two feet of earth cover shall be ASTM C789-79.

3. All precast reinforced concrete box culverts with less than two feet of cover shall be ASTM 850-79.

4. All corrugated metal pipes shall be ASMT A-760.

5. ASSHTO HS20-44 loading should be used for all culverts.

6. Guardrails are suggested at all roadway culvert crossings. The approach ends of the guardrail shall be flared away from the roadway and properly anchored. Where guardrails encroach on access easements or maintenance berms, an additional easement shall be provided that ensures a minimum of 15 feet of clear access to the channel for maintenance equipment.

7. Joint sealing material for precast concrete culverts shall comply with "AASHTO Designation M-198 74 I, Type B, Flexible Plastic Gasket (Bitumen)", specifications.

8. Two sack per ton cement stabilized sand shall be used for backfill around culverts.

9. A 6-inch bedding of two sacks per ton cement stabilized sand required for all precast concrete box culverts.

4.3 CULVERT HYDRAULIC DESIGN

The fundamental objective of hydraulic design of culverts is to determine the most economical diameter at which the design discharge is passed without exceeding the allowable headwater elevation or causing erosion problems. However, there are numerous hydraulic considerations in culvert design which can render the decision-making process somewhat complex.

4.3.1 Culvert Design Procedure

The culvert design procedures presented here are based on information provided in the U.S. Department of Transportation (USDOT) publication Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular No. 5, December 1965.

The nomographs presented herein cover the range of pipe and box culverts commonly used in drainage design.

The inlet control nomographs are scaled to represent the headwater-discharge relationships developed by the National Bureau of Standards in their report No. 4444: Hydraulic Characteristics of Commonly Used Pipe Sizes, by John L. French, and Hydraulics of Conventional Highway Culverts, by H.G. Bossy. Charts 1 through 7 present the inlet control nomographs including examples of their use.

The outlet control nomographs (Charts 8-14) were developed by USDOT from iterative solutions of Equation 4-3 for various flow conditions combined with a range of culvert lengths, shapes and sizes. It should be noted that for flow depths less than 0.75D the nomograph solutions are not reliable and the reader is referred to USDOT HEC No. 10, Capacity Charts for the Hydraulic Design of Highway Culverts, for an alternative solution method other than hand calculation. However, a long-hand solution of Equation 4-1 provides the best analysis when HW is less than 0.75 D and/or the barrel length is less than 50 feet.

Alternatively, HEC-RAS can be used to design and analyze culverts.

4.3.2 Culvert Flow Types

The hydraulic capacity of a culvert is said to be either inlet-controlled or outlet-controlled. Inlet control means that the discharge in the culvert is limited by the hydraulic and physical characteristics of the inlet alone. These include headwater depth, barrel shape, barrel cross-sectional area, and the type of inlet edge. For inlet control, the barrel roughness, length, and slope are not factors in determining culvert capacity.

Under outlet control, the discharge capacity of the culvert is dependent on all of the hydraulic variables of the structure. These include headwater depth, tailwater depth as well as barrel shape, cross-sectional area, barrel roughness, slope, and length.

4.3.3 Headwater Depth

In all culvert design, headwater, or depth of ponding at the entrance to the culvert, is an important factor in culvert capacity. The headwater depth (HW) is the vertical distance from the culvert entrance invert to the energy line of the approaching flow. Due to low velocities in most entrance pools and the difficulty in determining velocity head in any flow, the energy line can often be assumed coincident with the water surface.

4.3.4 Tailwater Depth

For culverts under outlet control, tailwater depth is an important factor in computing both headwater depth and the hydraulic capacity of the culvert. If flow in the channel downstream of the culvert is subcritical, a computer-aided backwater analysis or calculation of normal depth is warranted to determine the tailwater elevation. If the downstream flow is supercritical, tailwater is inconsequential to the culvert's hydraulic capacity.

4.3.5 Inlet-Controlled Flow

Under inlet control, the culvert entrance may or may not be submerged. However, in all cases inlet-controlled flow through the culvert barrel is free surface flow. When the culvert inlet is submerged, the most reliable means for determining discharge is with standard empirical relationships. Nomographs (Charts 1 through 7), which plot headwater vs. discharge for various culvert sizes and shapes under inlet control, are based on laboratory research with models and full scale prototypes.

4.3.6 Outlet-Controlled Flow

Due to the flat terrain, a majority of the culverts in Fort Bend County are outlet-controlled.

Culverts, with outlet control, flow with the culvert barrel full or partially full for part or all of the barrel length. Both the headwater and tailwater may or may not submerge the culvert.

If the culvert is flowing, the energy required to pass a given quantity of water is stored in the head (H). From energy considerations it can be shown that H is the difference between the hydraulic grade line at the outlet and the energy grade line at the inlet (expressed in feet).

When a given discharge passes through a culvert, stored energy, represented by the total head (H) is dissipated in three ways. A portion is lost to turbulence at the entrance (H_e); a portion is lost to frictional resistance in the culvert barrel (H_f); and a portion is lost as the kinetic energy of flow through the culvert is dissipated in the tailwater (H_v). From this, the following relationship is evident:

$$H = H_e + H_f + H_v \quad (4\text{-}1)$$

The velocity head (H_v) is equal to $V^2/2g$ where V is the mean velocity of flow (in fps) in the culvert barrel.

The entrance loss (H_e) is expressed in terms of the velocity head multiplied by an entrance loss coefficient k_e.

An expression for the friction loss (H_f) is derived from Manning's equation:

$$H_f = \left(\frac{29n^2 L}{R^{1.33}} \right) \frac{V^2}{2g} \qquad (4\text{-}2)$$

Where n = Manning's roughness coefficient

L = culvert barrel length (ft)

R = the hydraulic radius (ft)

G = the gravitational constant (32.2 ft/sec^2)

V = mean velocity of flow in the culvert (ft/sec)

Rearranging Equation 4-1 it is seen that for full flow

$$H = \left(1 + k_e + \frac{29n^2 L}{R^{1.33}} \right) \frac{V^2}{2g} \qquad (4\text{-}3)$$

Equation 4-3 may be solved for H using the full flow nomographs (Charts 8-14) located at the conclusion of this section of the manual. Each nomograph is drawn for a particular barrel shape and material and a single value of Manning's "n" as noted on the respective charts. These nomographs may be used for other values of "n" by modifying the culvert length as directed in the instructions for use of the full-flow nomographs.

Figure 4-1 represents the various hydraulic elements of flow through a culvert and reveals graphically that the head (H) is equivalent to the vertical distance between the energy grade line at the inlet and the hydraulic grade line at the outlet.

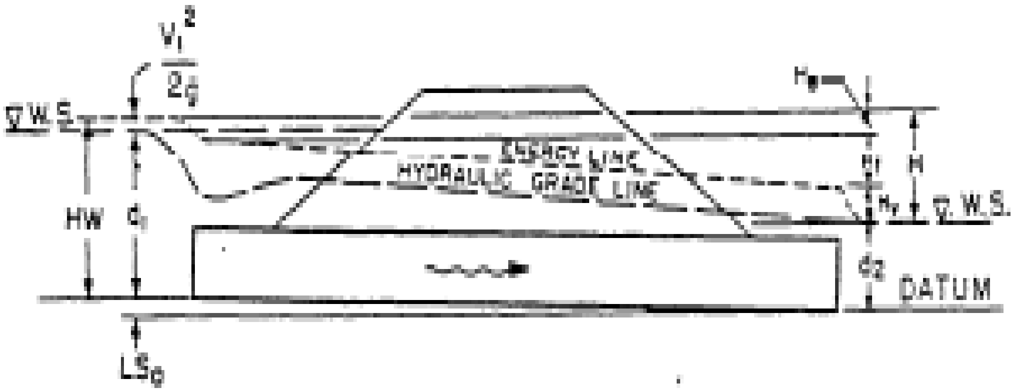


Figure 4-1 Hydraulic Elements of Flow through Culvert
(Source: Hydraulic Charts for the Selection of Highway Culverts, Federal Highway Administration, December 1965)

It also reveals the following relationship for full flow conditions:

$$H = H_v + H_e + H_f = d_1 + \frac{V_1^2}{2g} + LS_o - d_2 \qquad (4\text{-}4)$$

Where d_1, d_2 = flow depths as shown in Figure 4-1 (ft)

S_o = culvert barrel slope (ft/ft)

In culvert design it is generally required that the depth of the headwater (HW) be determined. The headwater depth is defined as the distance from the elevation of the culvert entrance invert to the elevation of the energy grade line in the headwater pool. From Figure 4-1, it is seen that $HW = D_1 + V_1^2/2g$. Since the velocity head in the entrance pool is usually small under ponded conditions, the headwater pool elevation can be assumed in most situations to be coincident with the energy grade line.

Rearranging Equation 4-4, the following expression for HW is derived:

$$HW = H + d_2 - LS \qquad (4\text{-}5)$$

When the culvert outlet is submerged by the tailwater, the above equation can be solved directly to determine HW. However, when the tailwater is below the crown of the culvert, it becomes necessary to redefine d_2, which is taken as the greater of the following two values:

(1) TW

(2) $\frac{d_c + D}{2}$

where d_c = critical depth in the culvert as read from Charts 15 through 20 (ft)

TW = tailwater depth above the invert of the culvert outlet (ft)

D = height of the culvert (ft)

4.3.7 Conditions at Entrance

Culvert performance is significantly affected by inlet efficiency, especially for conditions of inlet-controlled flow. Changes in the culvert edge geometry can significantly change discharge capacity. Selection of a particular inlet type is contingent on the relative weightings the engineer assigns to considerations of the effect on peak flows, cost, and topography. In other words, the ideal inlet geometry is not necessarily the most efficient.

The entrance head losses may be determined by the following equation:

$$H_e = K_e \left(\frac{V_2^2 - V_1^2}{2g}\right) \quad (4\text{-}6)$$

Where h_e = entrance head loss (ft)

V_2 = velocity of flow in culvert (fps)

V_1 = velocity of flow approaching culvert (fps)

K_e = entrance loss coefficient.

For calculation of headwater with inlet-controlled culverts, the design nomographs presented in this manual account for various typical kinds of inlet geometry.

For calculation of headwater with outlet-controlled culverts, typical values of the entrance coefficient (K_e) for a wide range of inlet types are provided in Table 4-2.

4.3.8 Step-by-Step Design Procedures

It is possible by involved hydraulic computations to determine the probably type of flow under which a culvert will operate for a given set of conditions. However, such computations can be avoided by determining the headwater necessary for a given discharge under both inlet and outlet flow conditions. The larger of the two will define the type of control and the corresponding headwater depth. The following is the recommended procedure for selection of culvert size:

Step 1: List design data.

a. Design discharge (Q), in cfs, with return period.

b. Approximate length (L) of culvert, in feet.

c. Slope of culvert. If grade is given in percent, convert to slope in feet per feet.

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

e. Flow velocities in the channel upstream and downstream of the proposed culvert location.

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

Step 2: Determine the first trial culvert size.

Since the procedure given is one of trial and error, the initial trial size can be determined in several ways:

a. Past experience and engineering judgment.

b. By using an approximating equation such as $\frac{Q}{6} = A$ from which the trial culvert dimensions are determined. A is the culvert barrel cross-sectional area and 6 is an estimate of barrel velocity in feet per second.

c. Initially, utilize the inlet control nomographs (Charts 1-7) for the culvert type selected. An $\frac{HW}{D}$ must be assumed, say $\frac{HW}{D} = 1.5$, along with the given Q to determine a trial size.

If any trial size is too large in dimension because of limited height of embankment or availability of size, multiple culverts may be used by dividing the discharge appropriately among the number of barrels used. Raising the embankment height or the use of pipe arch and box culverts with width greater than height should also be considered. Final selection should be based on applicability and costs.

Step 3: Find headwater depth for trial size culvert.

a. Assuming Inlet Control –

(1) Using the trial size from Step 2, find the headwater depth (HW) by use of the appropriate inlet control nomograph (Charts 1-7). Tailwater (TW) conditions are to be neglected in this determination. HW in this case is found by multiplying $\frac{HW}{D}$ obtained from the nomographs by the height of culvert (D).

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

b. Assuming Outlet Control –

(1) Approximate the depth of tailwater (TW), in feet, above the invert at the outlet for the design flood condition in the outlet channel. (See general discussion on tailwater, Section 4.3.3.)

(2) For tailwater (TW) elevation equal to or greater than the top of the culvert at the outlet, set d_2 equal to TW and find HW by the following equation:

$$HW = H + d_2 - LS_o \tag{4-5}$$

Where HW = vertical distance in feet from culvert invert (flowline) at entrance to the pool surface

H = head loss in feet as determined from the appropriate nomograph (Charts 8-14)

d_2 = vertical distance in feet from culvert invert at outlet to the hydraulic grade line

S_o = slope of barrel (feet/feet)

L = culvert length (feet)

(3) For tailwater (TW) elevations less than the top of the culvert at the outlet, find headwater HW by Equation 4-5 as in Step b(2) above except that

$d_2 = \frac{d_c + D}{2}$ or TW (whichever is greater)

Where d_c = critical depth in feet (Charts 15 through 20)

Note: d_c cannot exceed D

D = height of culvert opening (feet)

Note: Headwater depth determined in Step b(3) becomes increasingly less accurate as the headwater computed by this method falls below the value:

$$D + (1 = k_e)\frac{V^2}{2g}$$

c. Compare the headwaters 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 for the trial size selected.

d. If outlet control governs and the HW is higher than is acceptable, select a larger trial size and find HW as instructed under Step 3B. (Inlet control need not be checked, since the smaller size was satisfactory for this control as determined under Step 3a.)

Step 4: Try additional culvert types or shapes worthy of consideration and determine their size and HW by the above procedure.

Step 5: Compute outlet velocities for size and types to be considered in selection and determine need for channel protection.

a. If outlet control governs in Step 3c above, outlet velocity equals $\frac{Q}{A_o}$, where A_o is the cross-sectional area of flow in the culvert barrel at the outlet. If d_c or TW is less than the height of the culvert barrel, use A_o corresponding to d_c or TW depth, depending on whichever gives the greater area of flow. A_o should not exceed the total cross-sectional area A of the culvert barrel.

b. If inlet control governs in Step 3c, outlet velocity can be assumed to equal mean velocity in open-channel type flow in the barrel as computed by Manning's equation for the rate of flow, barrel size, roughness and slope of culvert selected.

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

4.4 BRIDGES

4.4.1 Bridge Design Considerations

Bridges must be designed to pass the 100-year design flow without causing adverse impacts or erosion problems in the channel or detention basin.

For new bridges, the low chord (at the center of the bridge) must be 1.5 feet or more above the existing or fully developed 100-year water surface elevation, whichever is higher. At no point shall the low chord of the new bridge be less than 1’ above the 100-year water surface elevation.

Newly constructed bridges must be designed to completely span the existing or proposed channel such that the channel will pass under the bridge without modifications. Energy losses due to flow transitions shall be minimized. In addition, provision must be made for future channel enlargements should they become necessary.

When a bridge is proposed to be replaced with a new structure, the low chord elevation and the cross-sectional area of the bridge opening should be equaled or exceeded. If this is not feasible, the bridge design must be coordinated with the Fort Bend County Drainage District Engineer.

When guardrails or bridge rails are proposed, and the rails and/or the structures will restrict access to drainage easements or maintenance berms, an additional easement shall be provided that ensures a minimum of 15 feet of clear access to the channel for maintenance equipment.

4.4.1.1 Bents and Abutments

Bents and abutments must be aligned parallel to the longitudinal axis of the channel so as to minimize obstruction of the flow. Bents shall be placed as far away from the channel centerline as possible and if possible should be eliminated entirely from the channel bottom.

4.4.1.2 Interim Channels

Bridges and bents constructed on existing or interim channels shall be designed to accommodate the ultimate channel section with a minimum of structural modifications.

4.4.1.3 Erosion Protection

Increased turbulence and velocities associated with flow in the vicinity of bridges requires the use of erosion protection in affected areas.

4.5 HEC-RAS

All hydraulic computations are to be computed in HEC-RAS version 3.1.3 (or newer) with differentiation between pressure flow and open channel flow for bridges and culverts. Versions of HEC-RAS must be consistent throughout each project.

Models other than HEC-RAS may be used for bridge and culvert computations. However, prior approval from the Drainage District is required to use hydraulic models other than HEC-RAS. Modeling that will require a FEMA submittal must use a FEMA approved model.

TABLE 4-1

HEADWALL GUIDELINES

In general, the following guidelines should be used in the selection of the type of headwall or endwalls.

Parallel Headwall and Endwall

1. Approach velocities are less than 6 fps.
2. Backwater pools may be permitted.
3. Approach channel is undefined.
4. Ample right-of-way or easement is available.
5. Downstream channel protection is not required.

Flared Headwall and Endwall

1. Channel is well defined.
2. Approach velocities are greater than 6 fps.
3. Medium amounts of debris exist.

The wings of flared walls should be located with respect to the direction of the approaching flow instead of the culvert axis.

Warped Headwall and Endwall

1. Channel is well defined and concrete lined.
2. Approach velocities are greater than 8 fps.
3. Medium amounts of debris exist.

These headwalls are effective with drop down aprons to accelerate flow through culvert, and are effective headwalls for transitioning flow from closed conduit flow to open channel flow. This type of headwall should be used only where the drainage structure is large and right-of-way or easement is limited.

Source: Drainage Criteria Manual, City of Austin, Texas.

TABLE 4-2

INLET LOSS COEFFICIENTS USED FOR

CULVERTS FLOWING WITH OUTLET CONTROL

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

Source: U.S. Department of Transportation (1965).

*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.

INLET-CONTROL NOMOGRAPHS
Charts 1 through 7
Instructions for Use

1. To determine headwater (HW), given Q, and size and type of culvert.

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

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

   c. Compute HW by multiplying $\frac{HW}{D}$ by D.

2. To determine discharge (Q) per barrel, given HW, and size and type of culvert.

   a. Compute $\frac{HW}{D}$ for given conditions.

   b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).

   c. Connect point $\frac{HW}{D}$ scale (1) as found in (b) above and the size of culvert on the left scale. Read Q or $\frac{Q}{B}$ on the discharge scale.

   d. If $\frac{Q}{B}$ is read in (c) multiply by B (span of box culvert) to find Q.

3. To determine culvert size, given Q, allowable HW and type of culvert.

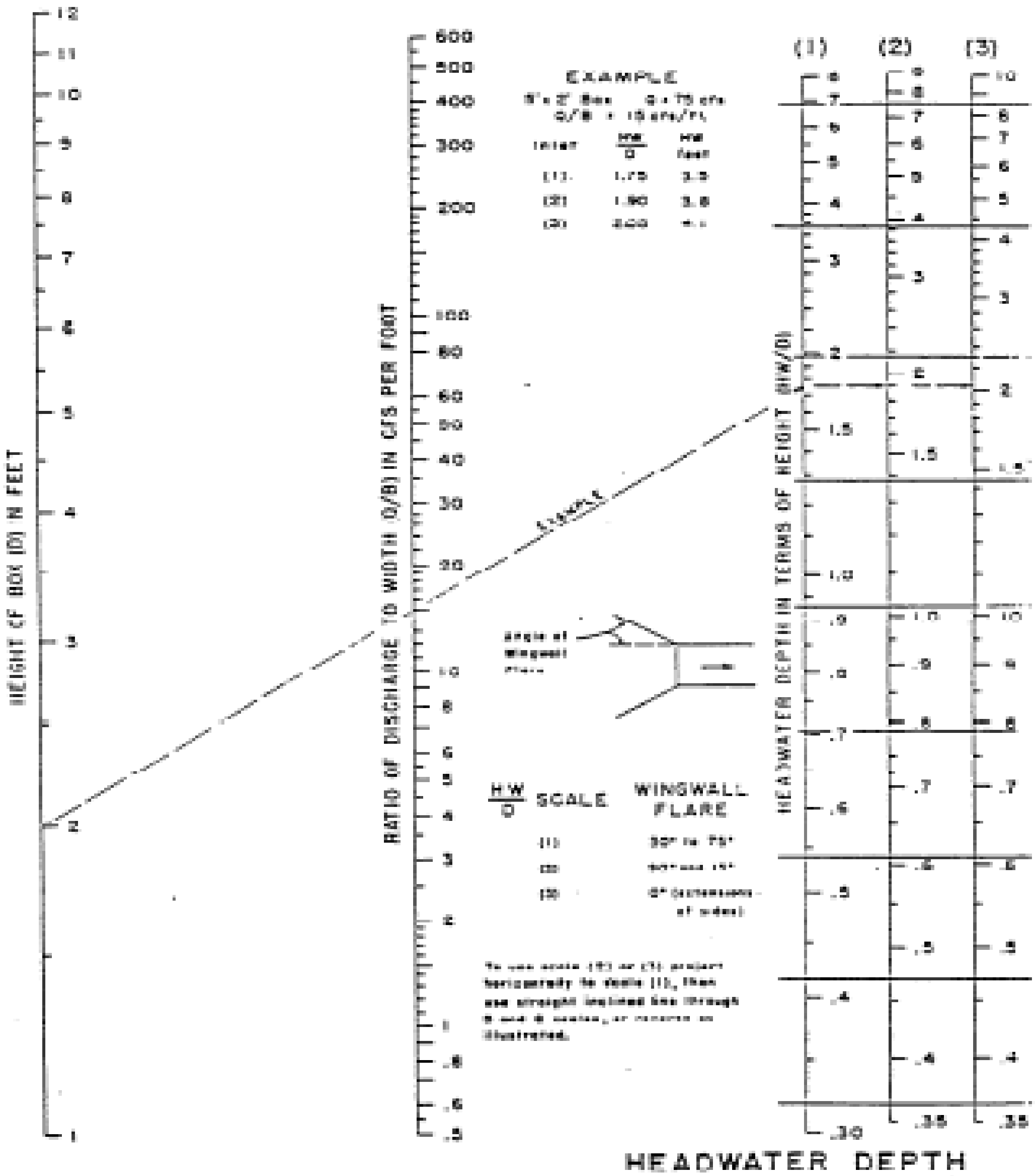
   a. Using a trial size, compute $\frac{HW}{D}$.

   b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).

   c. Connect point on $\frac{HW}{D}$ on scale (1) as found in (b) above to given discharge and read diameter, height or size of culvert required for $\frac{HW}{D}$ value.

   d. If D is not that originally assumed, repeat procedure with a new D.

CHART 1



HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

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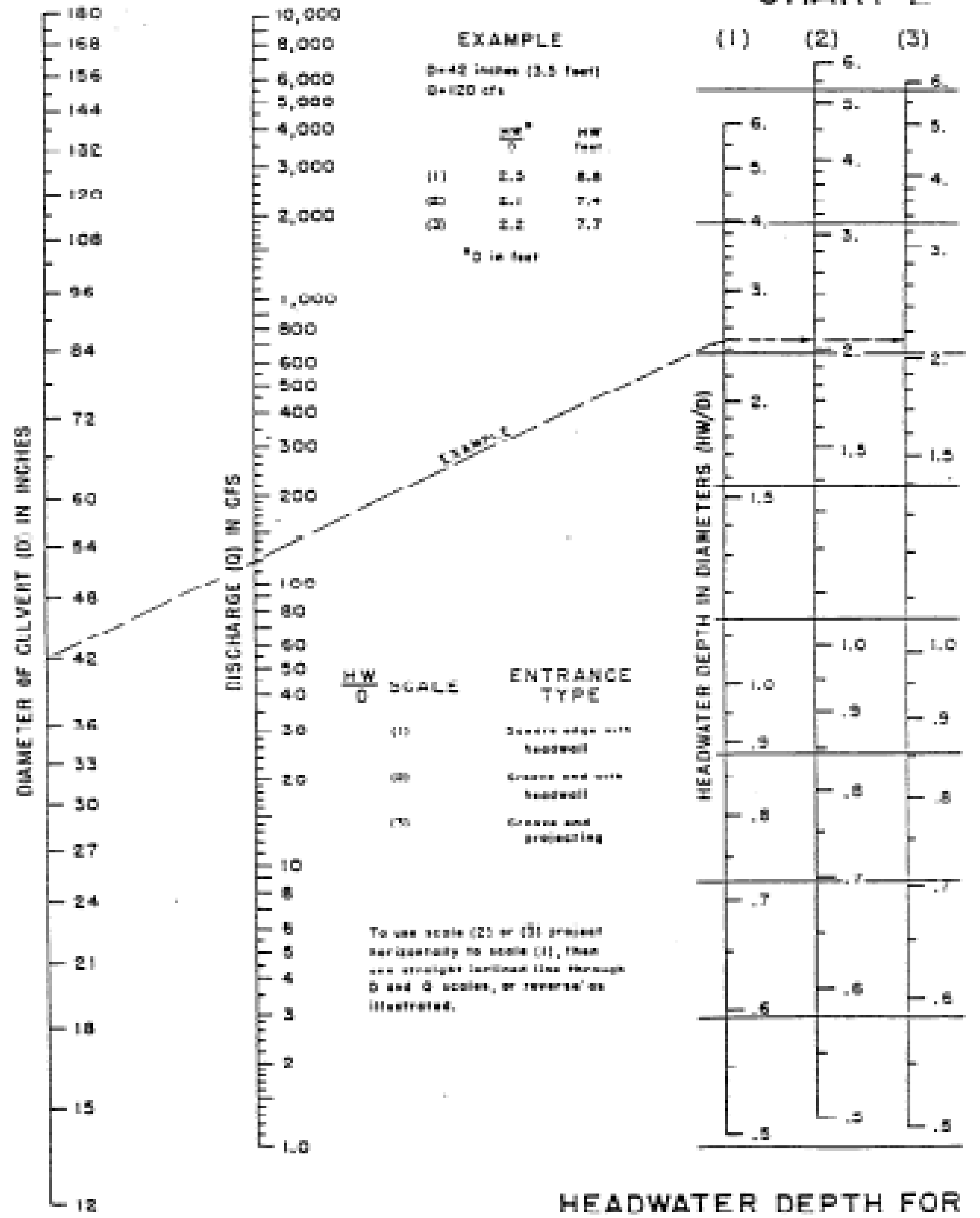
CHART 2

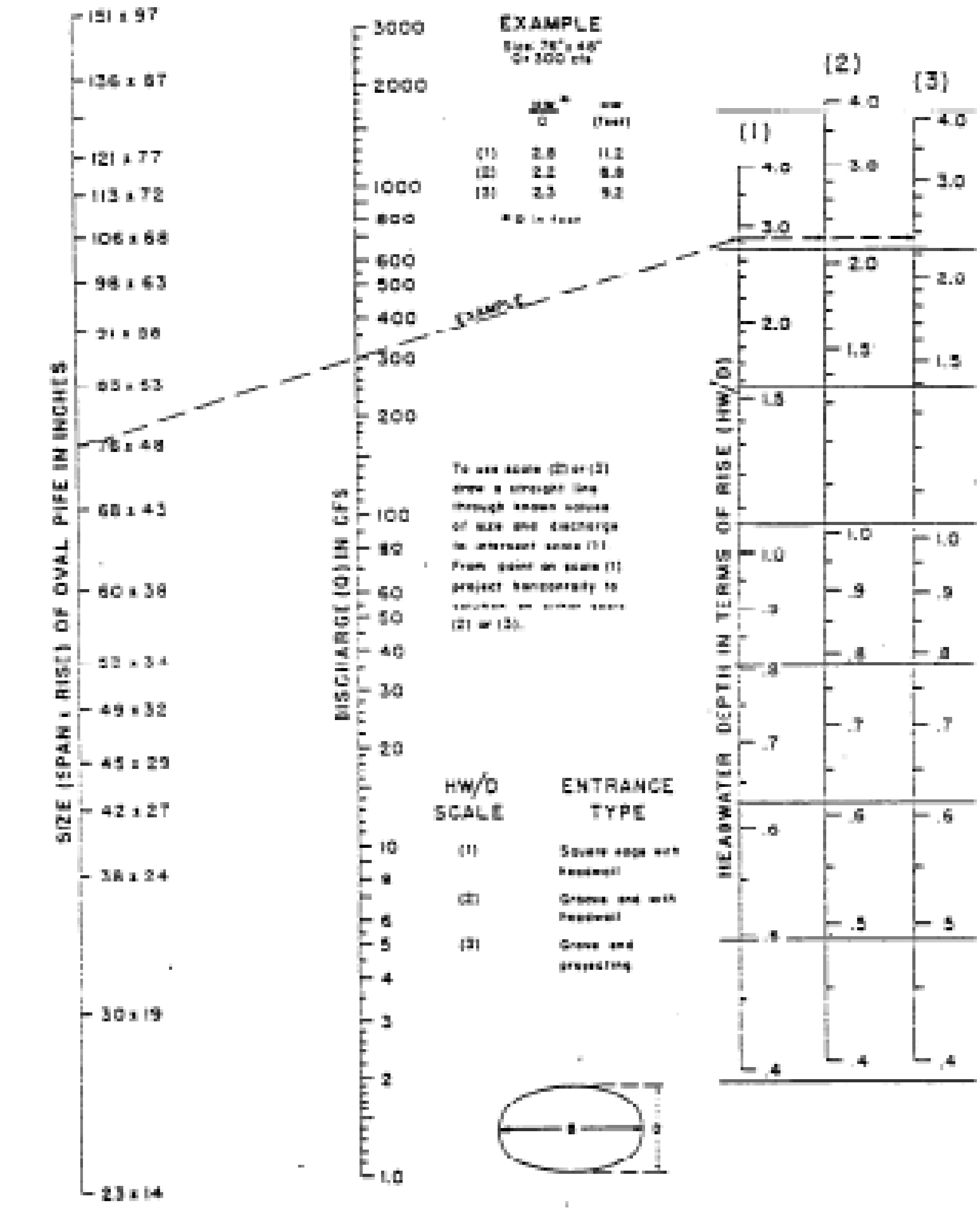


HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3
REVISED MAY 1964

BUREAU OF PUBLIC ROADS JAN. 1963

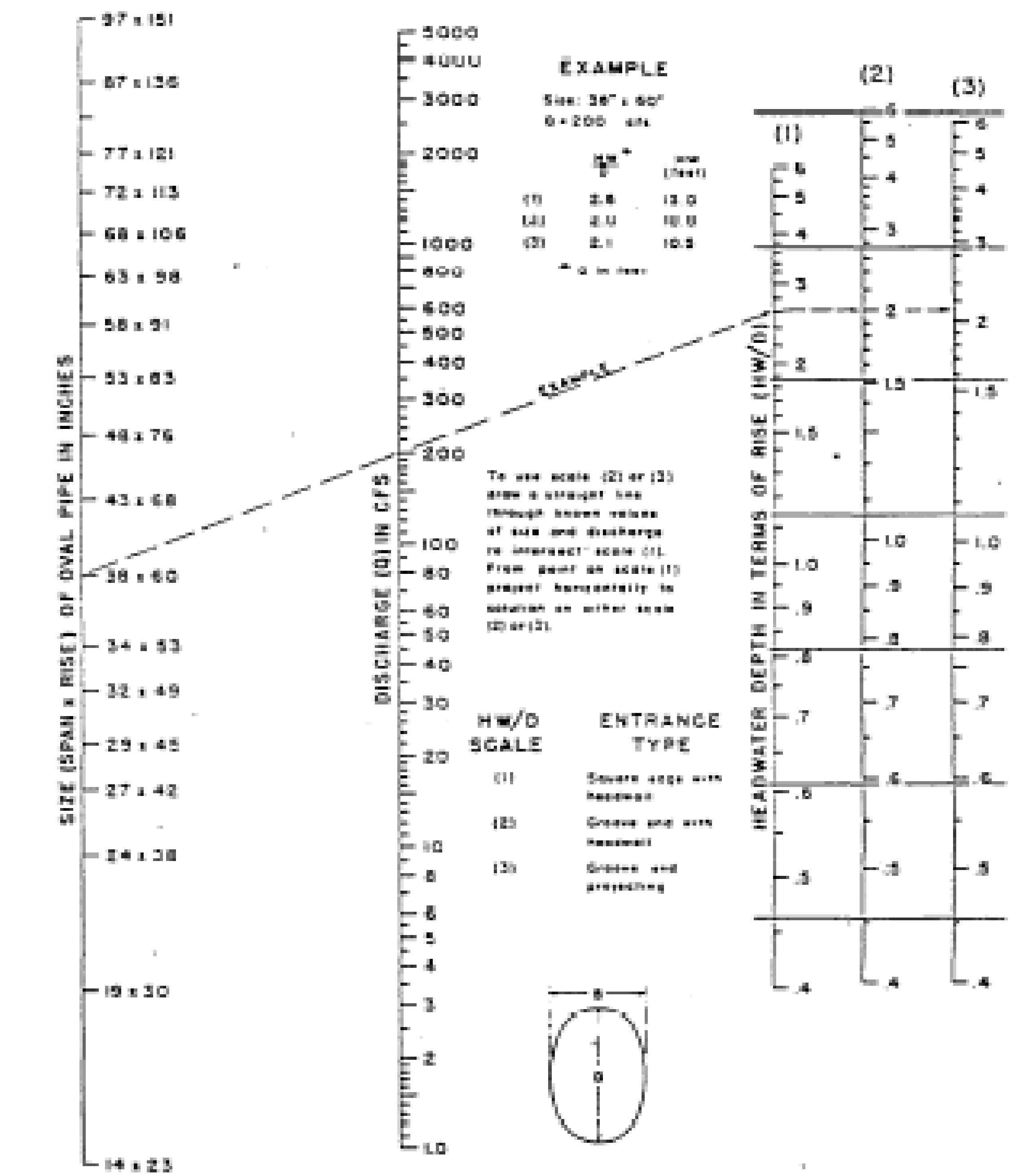
CHART 3



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

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 4



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

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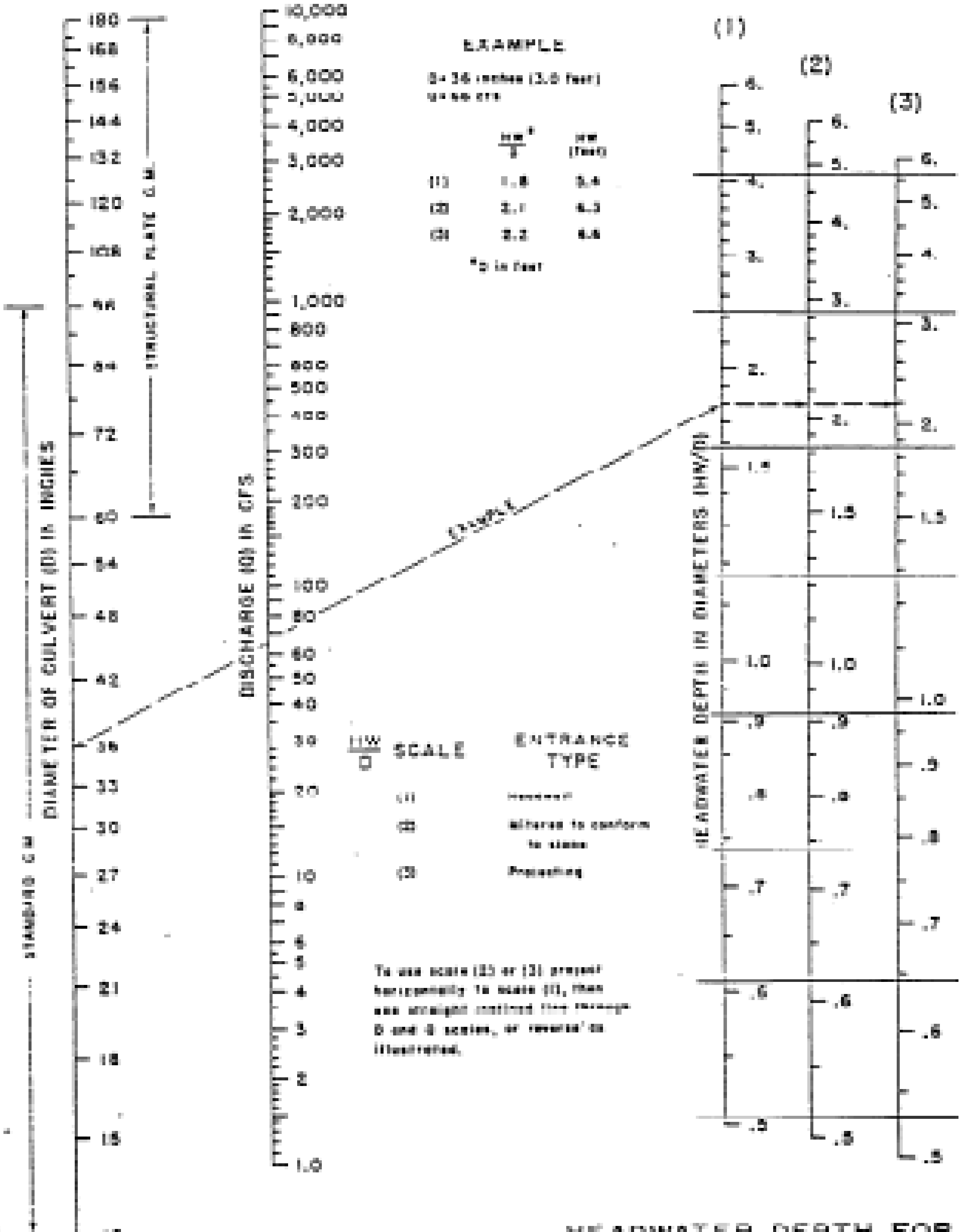
CHART 5



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

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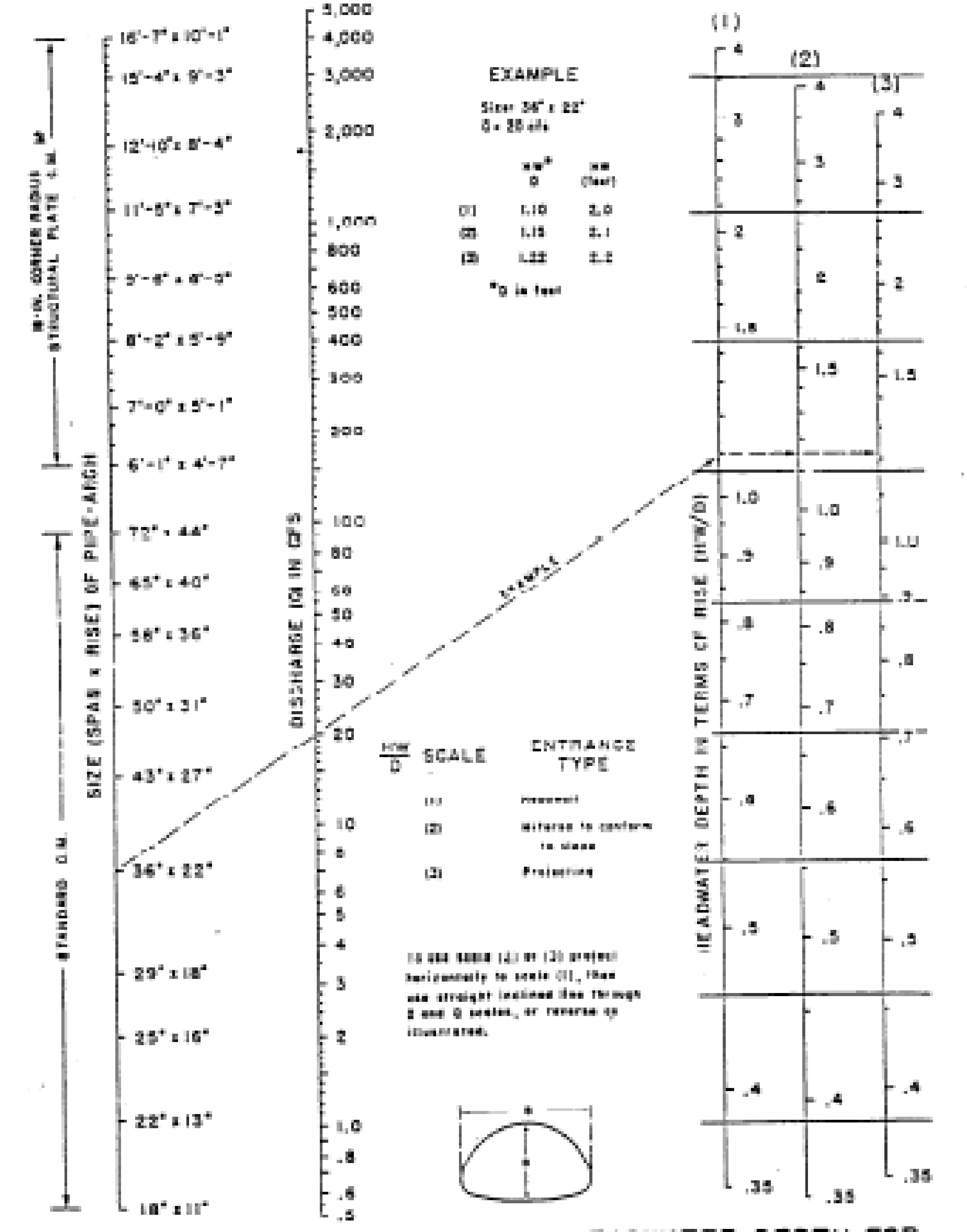
CHART 6



*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

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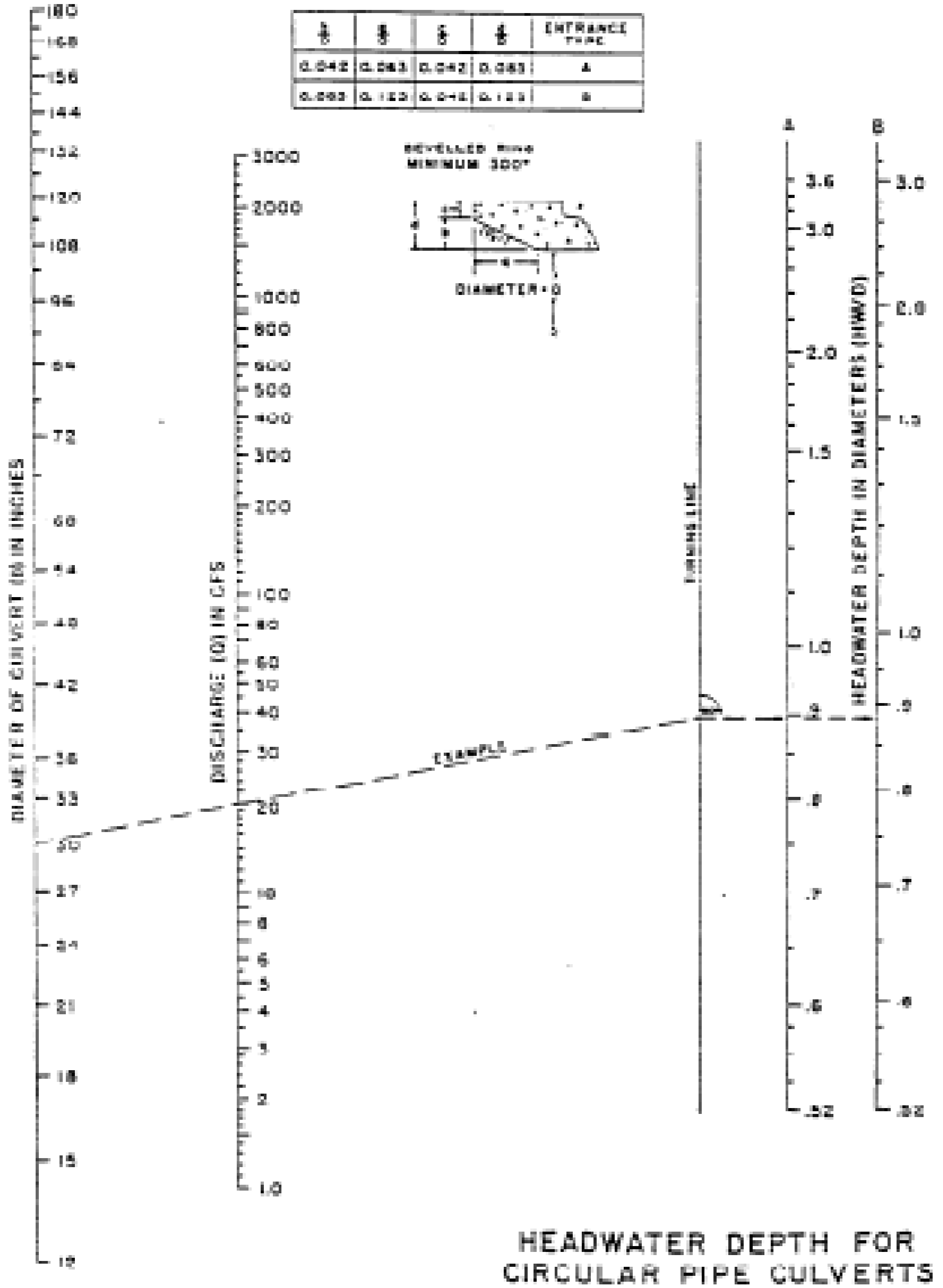
HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

CHART 7



HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELLED RING INLET CONTROL

BUREAU OF PUBLIC ROADS
MARCH 1964

OUTLET-CONTROL NOMOGRAPHS

Charts 8 through 14

Instructions for Use

Outlet control nomographs solve Equation 4-3, for head H when the head H for some part-full flow conditions with outlet control. These nomographs do not give a complete solution for finding headwater HW, since they only give H in Equation 4-5, $HW = H+d_2-LS_0$.

1. To determine head H for a given culvert and discharge Q.
   a. Locate appropriate nomograph for type of culvert selected. Find k_e for entrance type in Table 4-2.
   b. Begin nomograph solution by locating starting point on length scale. To locate the proper starting point on the length scales, follow instructions below:
      (1) If the n value of the nomograph corresponds to that of the culvert being used, select the length curve for the proper k_e and locate the starting point at the given culvert length. If a k_e curve is not shown for the selected k_e, see (2) below. If the n value for the culvert selected differs from that of the nomograph, see (3) below.
      (2) For the n value 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.
      (3) For a different 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:

$$L_1 = L\left(\frac{n_1}{n}\right)^2$$ See instruction 2 for n values.

c. Using a straightedge, connect point on length scale to size of culvert barrel and mark the point of crossing on the "turning line". See instruction 3 below for size considerations for rectangular box culvert.

d. Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale. For values beyond the limit of the chart scales, find H by solving Equation 4-3.

2. For appropriate values of n, section 4.2.6.

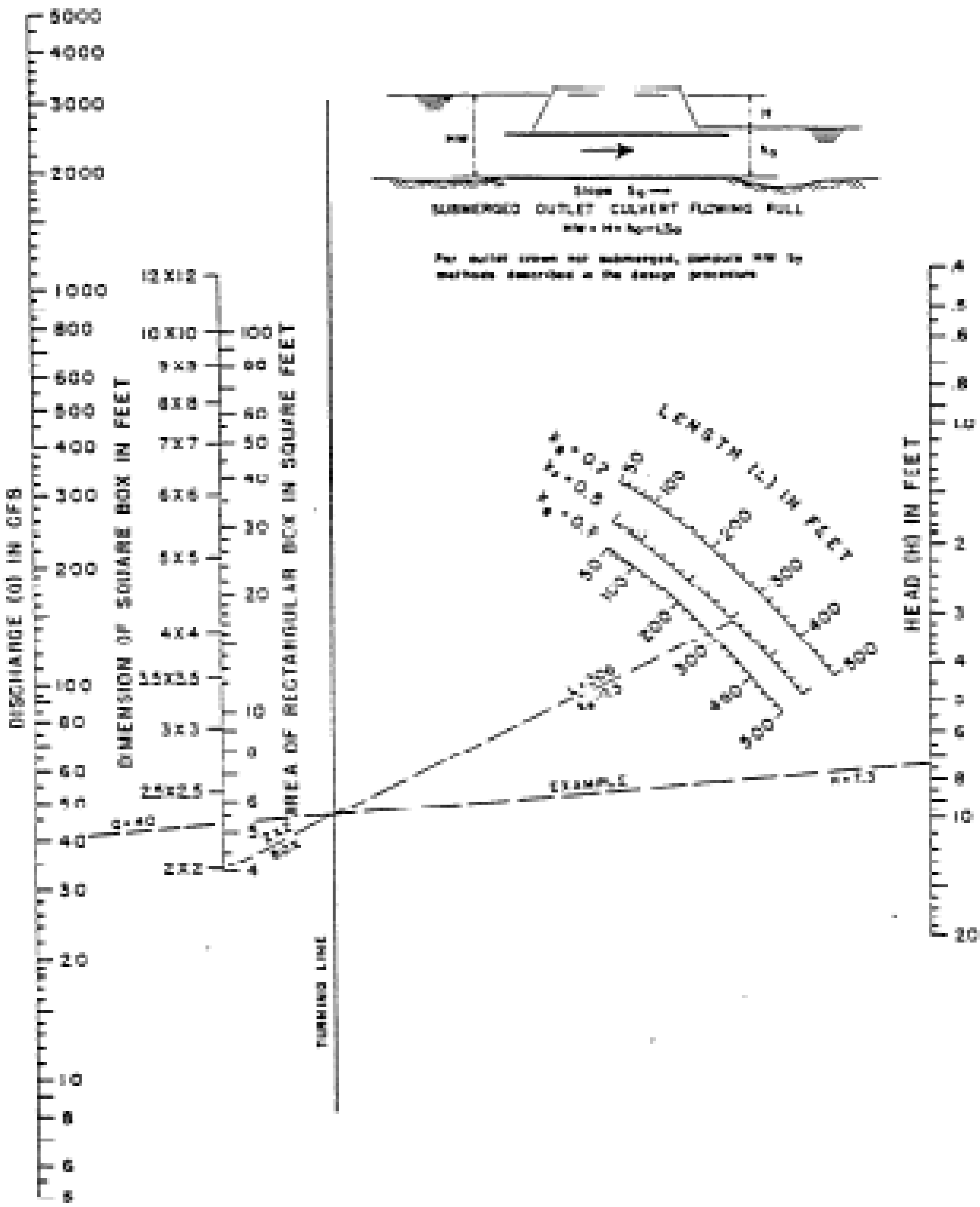
3. To use the box culvert nomograph, chart 8, for full-flow for other than square boxes.

a. Compute cross-sectional area of the rectangular box.

b. Connect proper point (see instructions 1) on length scale to barrel area[1] and mark point on turning line.

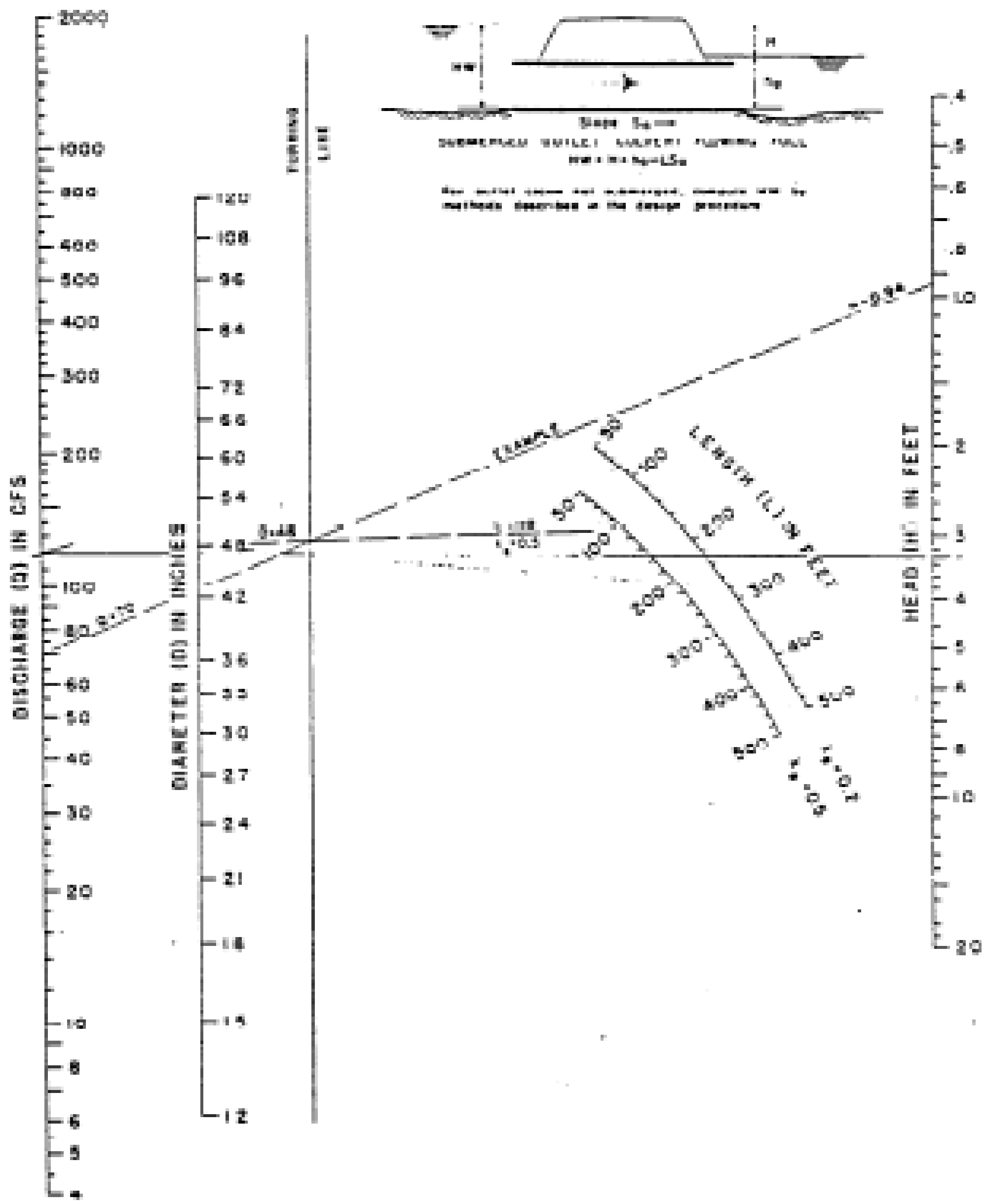
c. Pivot the straightedge on this point on the turning line of connect given discharge rate. Read head in feet on the head (H) scale.

[1] 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 = 1/2D. For other box proportions use equation 4-3 for more accurate results.



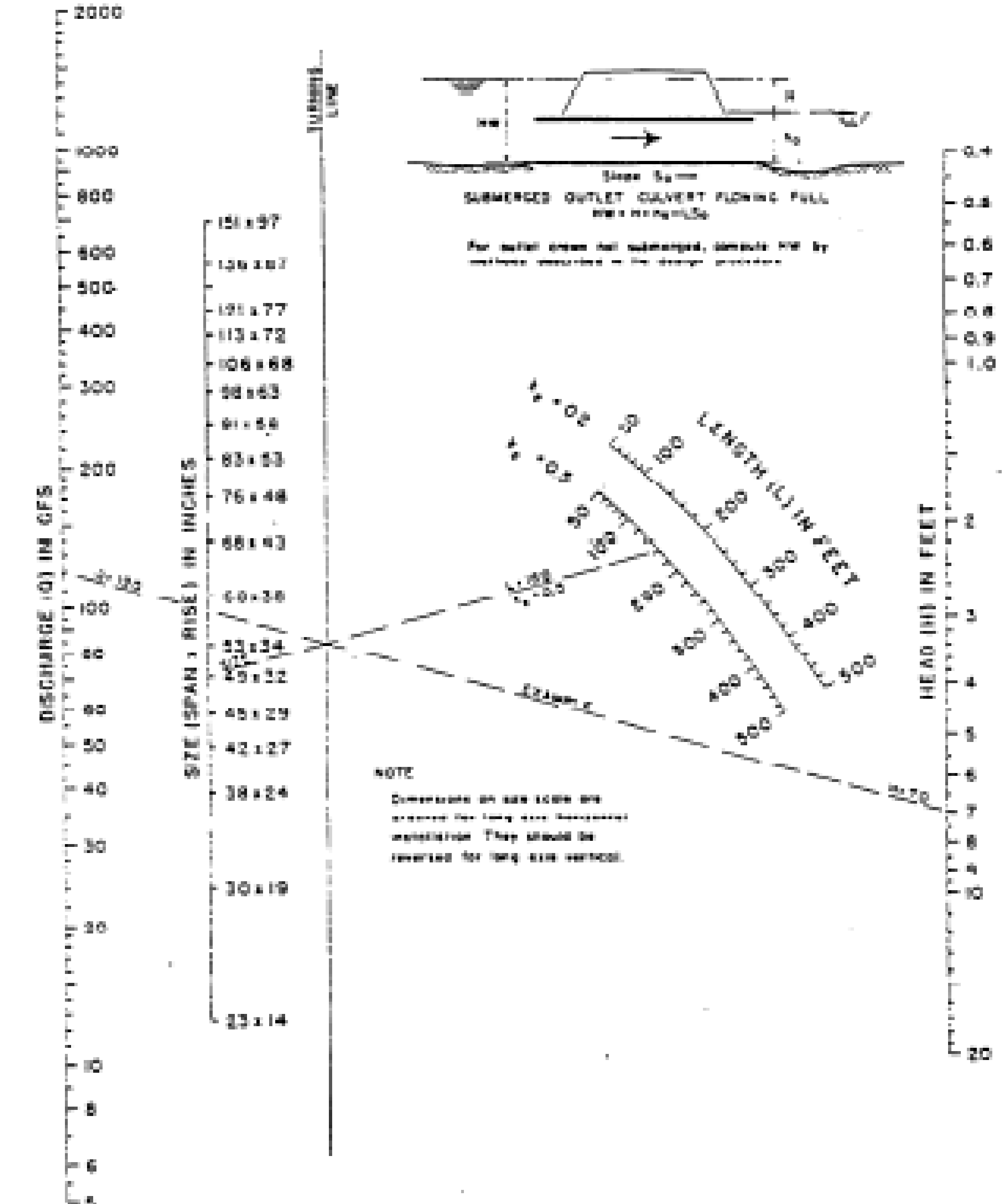
BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

CHART 10



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

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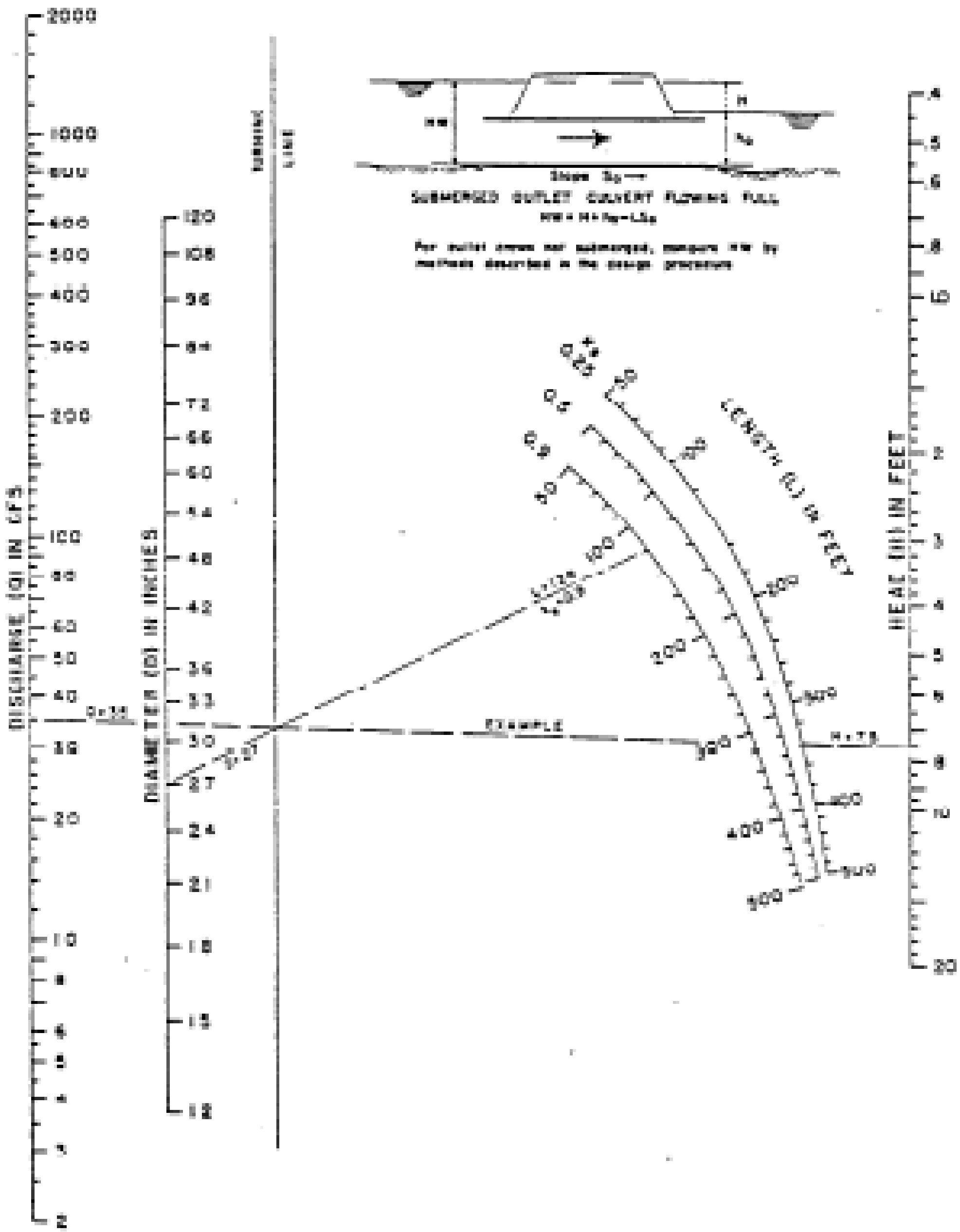
CHART 11



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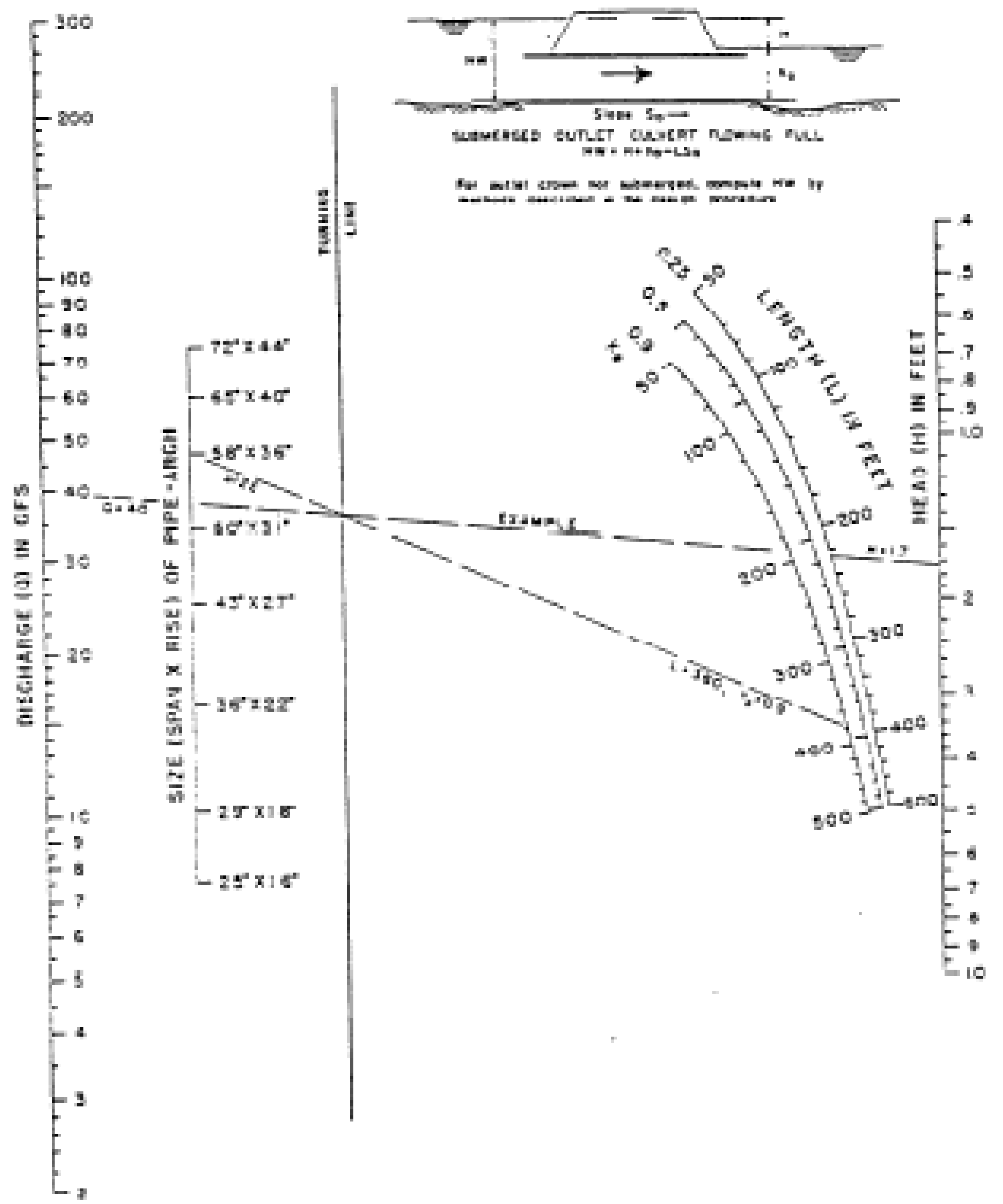
HEAD FOR STANDARD C. M. PIPE CULVERTS FLOWING FULL n = 0.024

CHART 12



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

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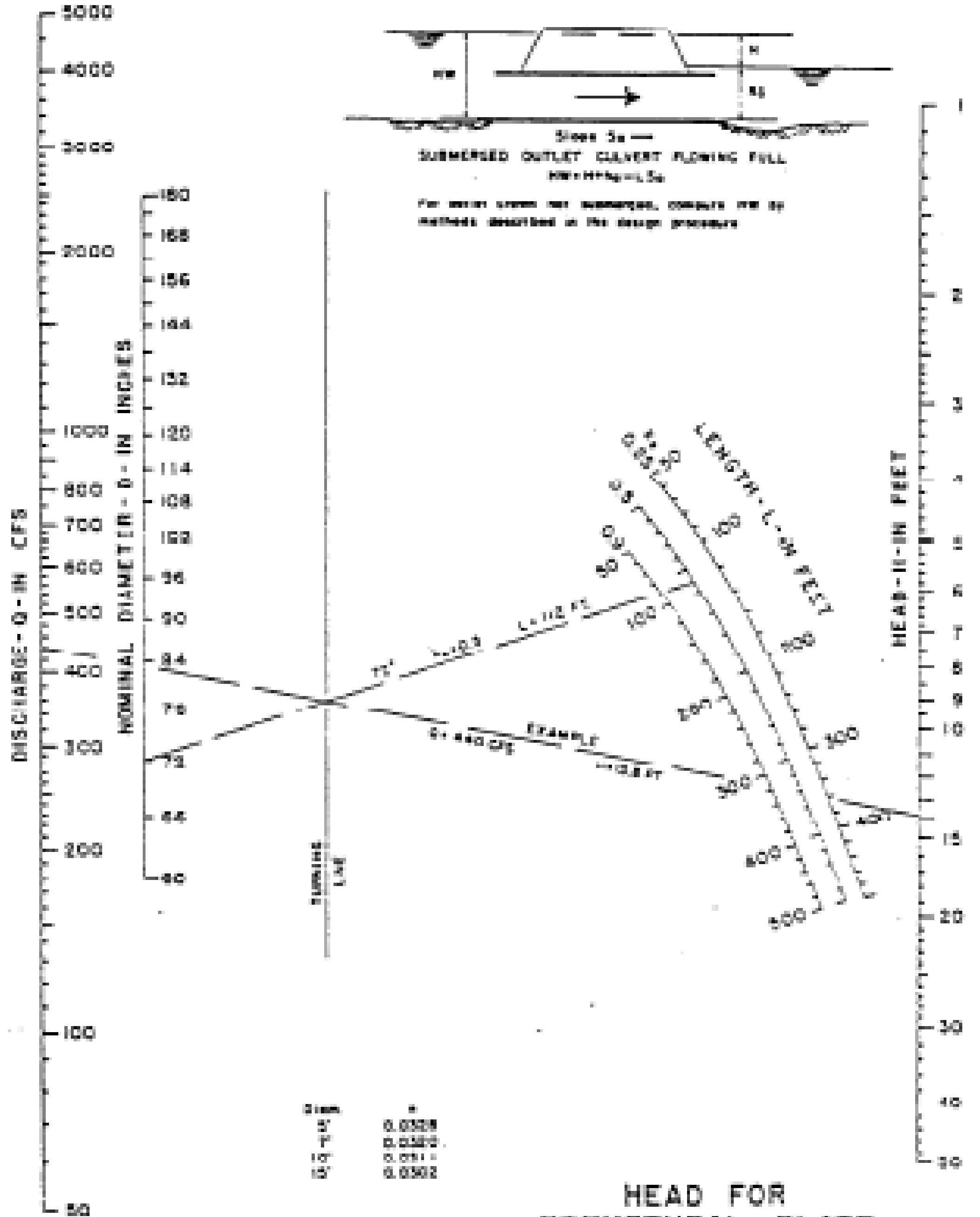
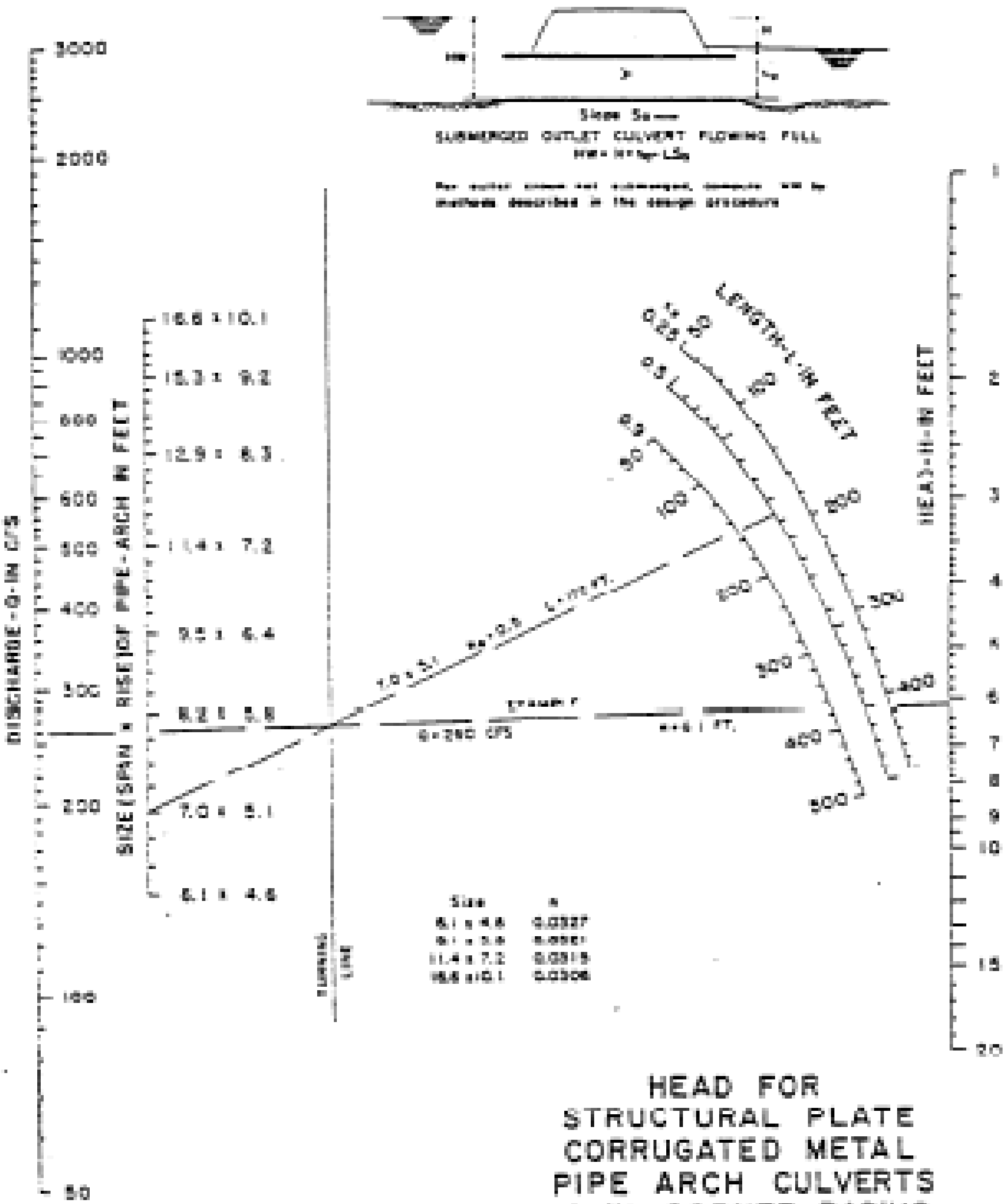
CHART 13



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

BUREAU OF PUBLIC ROADS JAN. 1963



HEAD FOR
STRUCTURAL PLATE
CORRUGATED METAL
PIPE ARCH CULVERTS
18 IN. CORNER RADIUS
FLOWING FULL
n=0.0327 TO 0.0306

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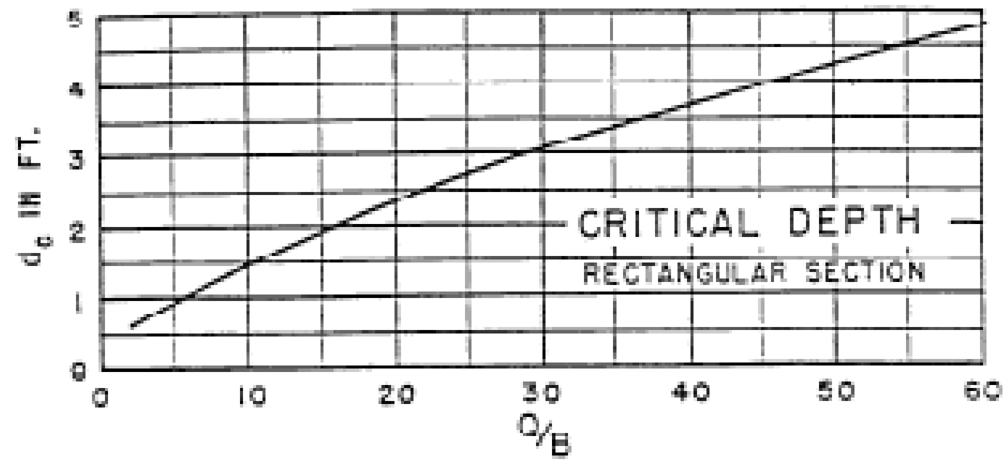
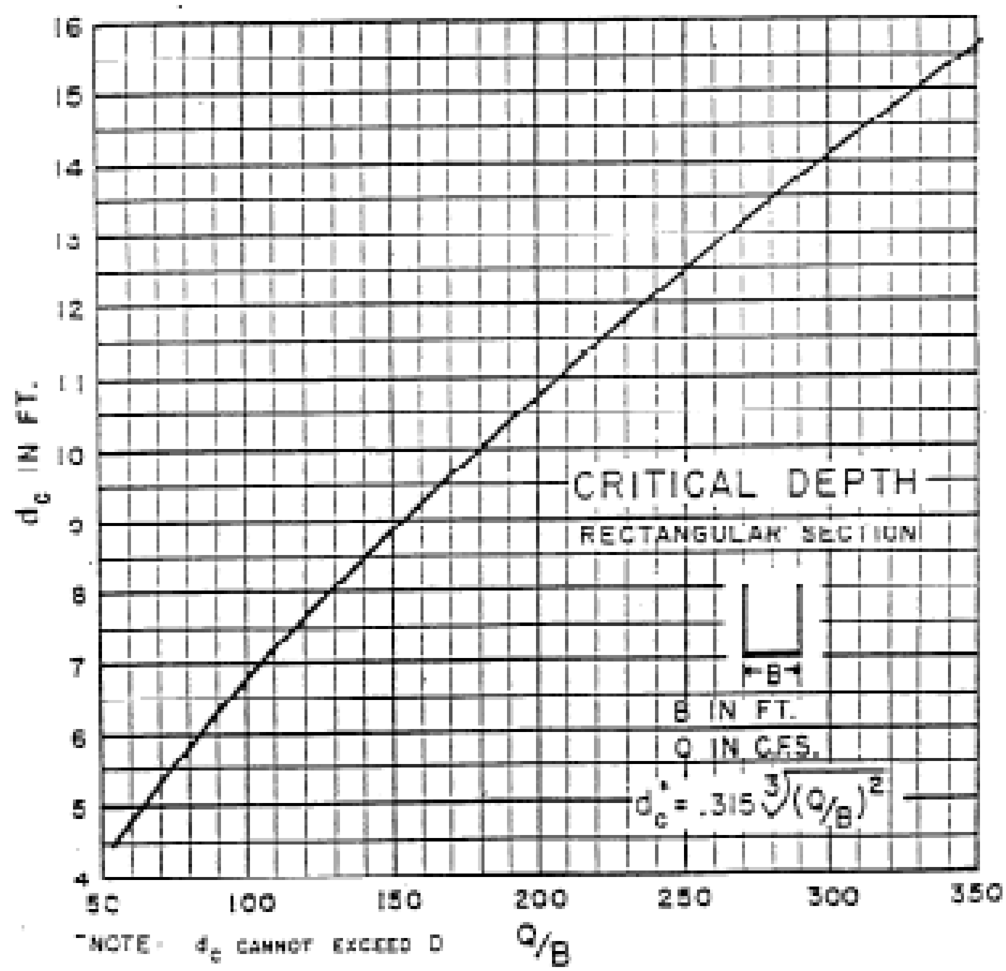
CHART 15

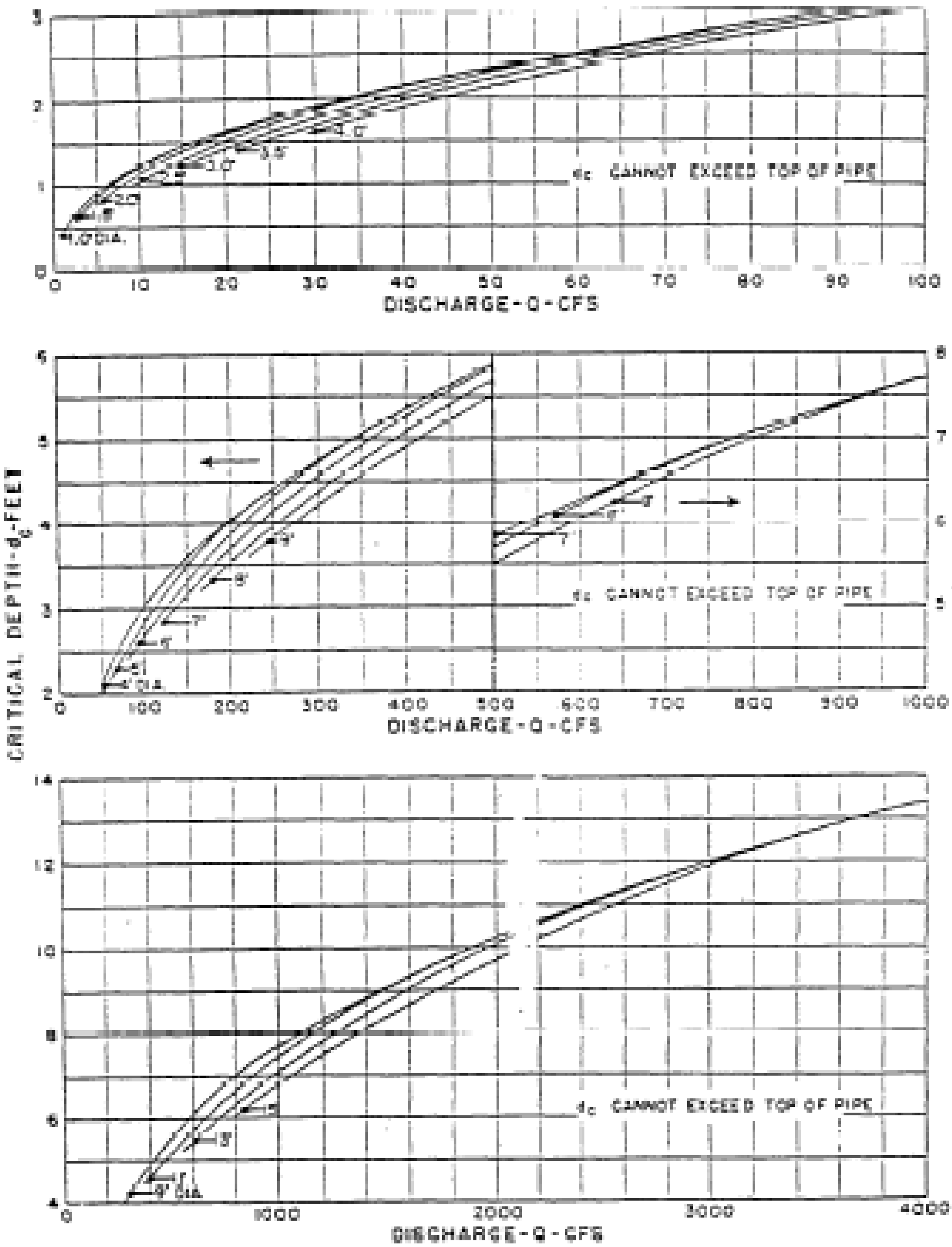




*NOTE: d_c CANNOT EXCEED D

BUREAU OF PUBLIC ROADS JAN 1963

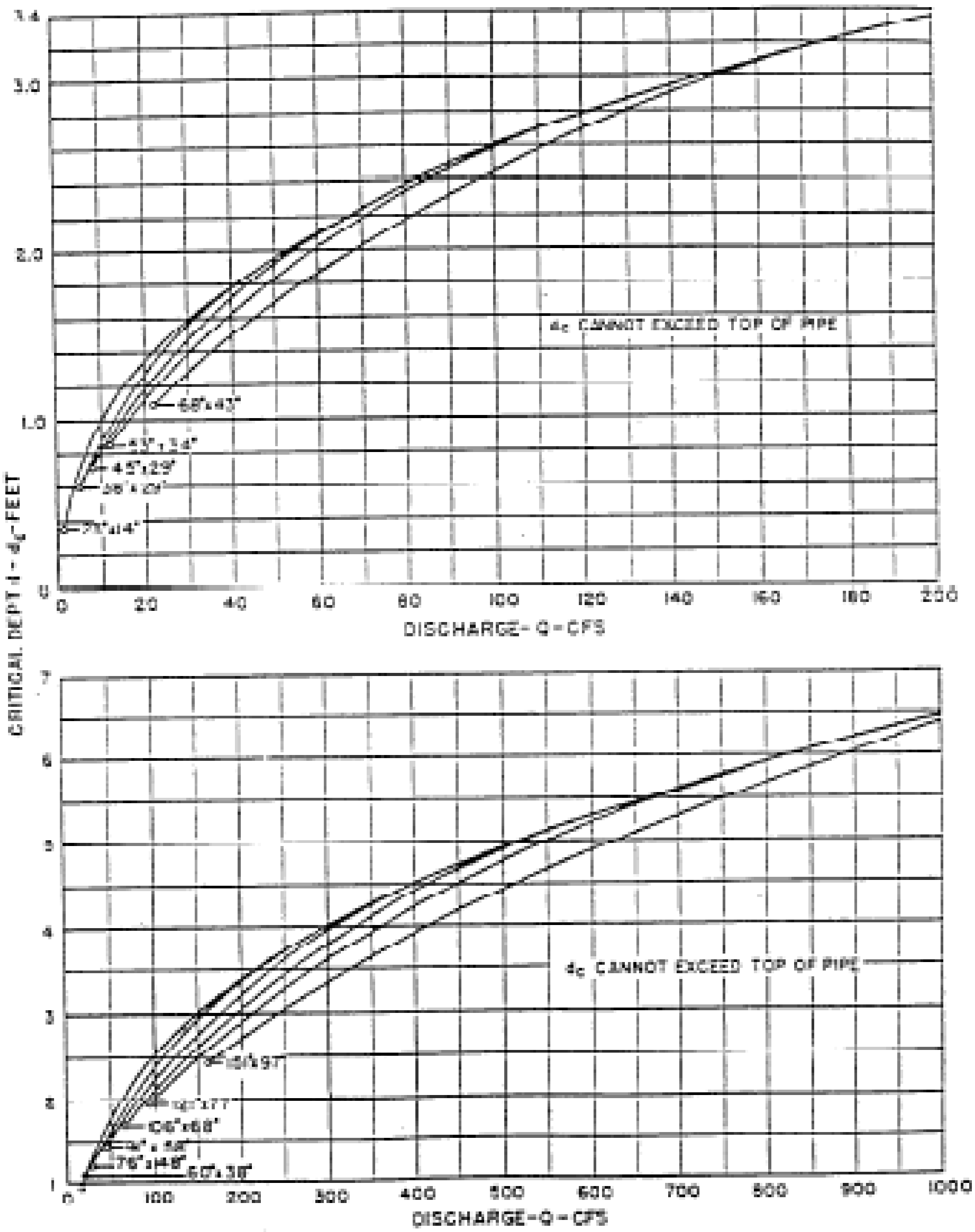
CHART 16



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

CHART 17

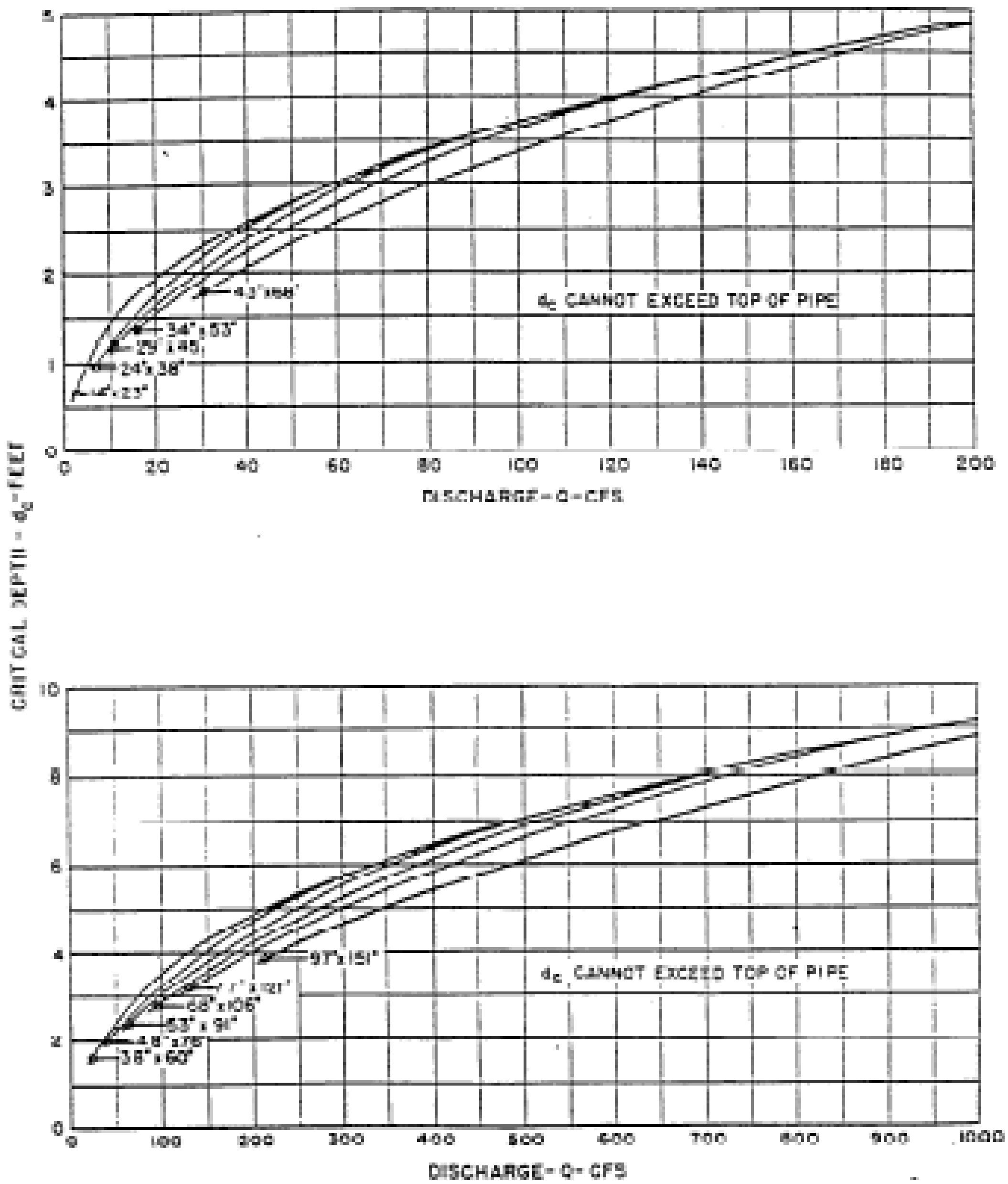


BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

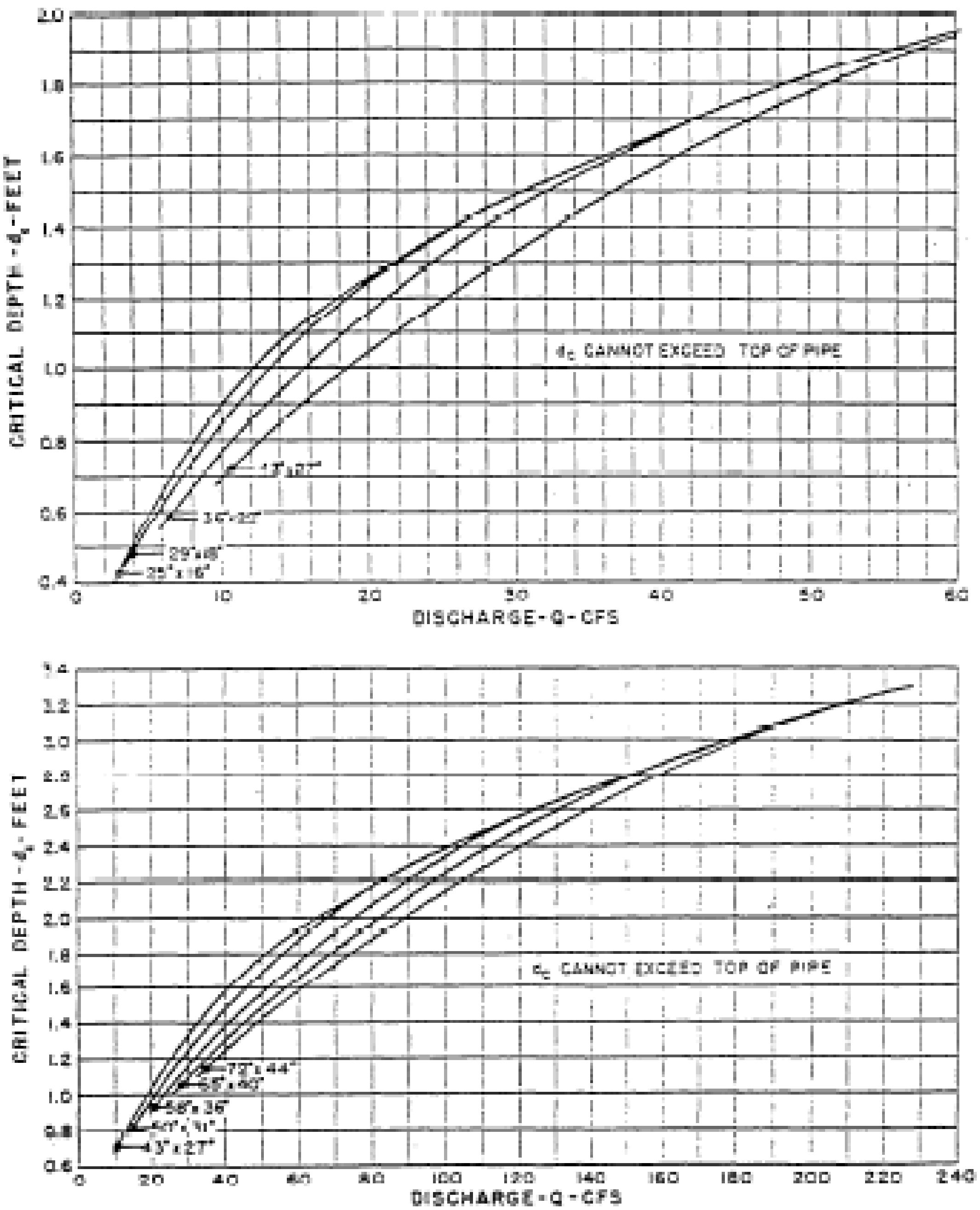
CHART 18



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

CHART 19



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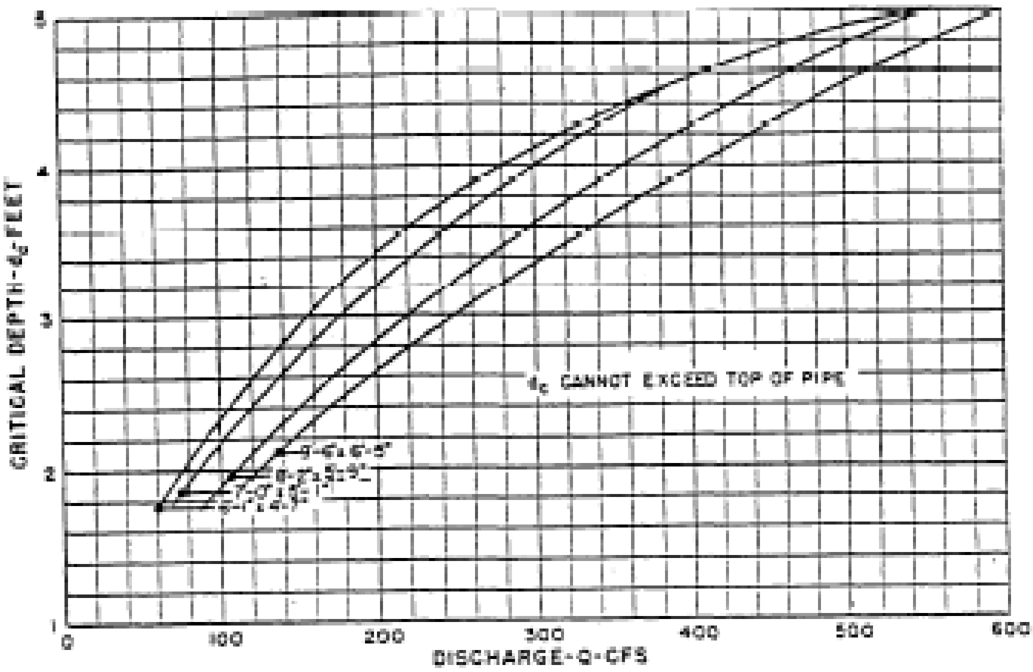
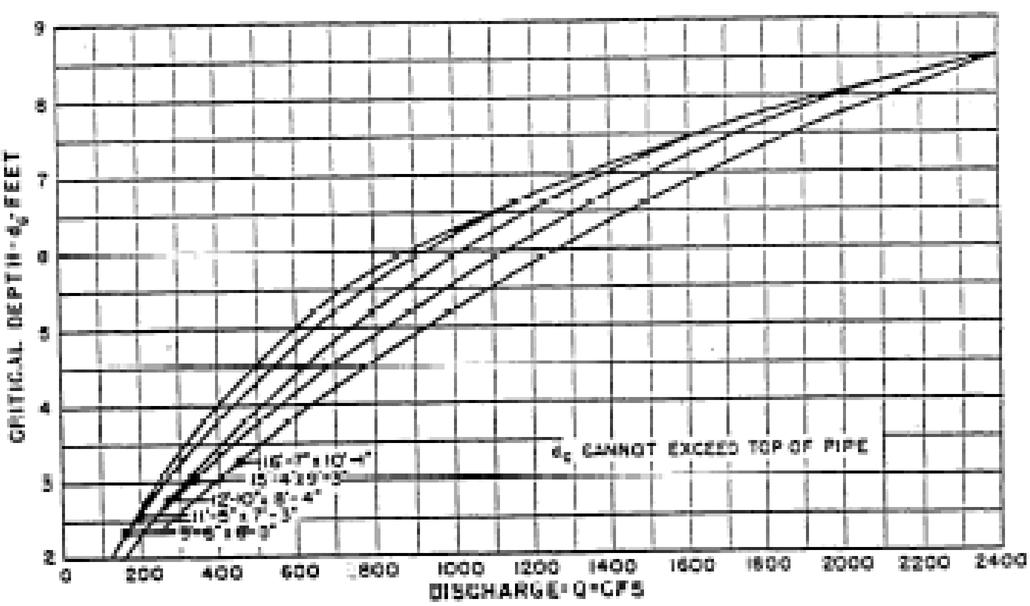
CRITICAL DEPTH
STANDARD C.M. PIPE-ARCH

CHART 20





BUREAU OF PUBLIC ROADS
JAN. 1964

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