

Appendix C PIPE FLOW DESIGN CHARTS

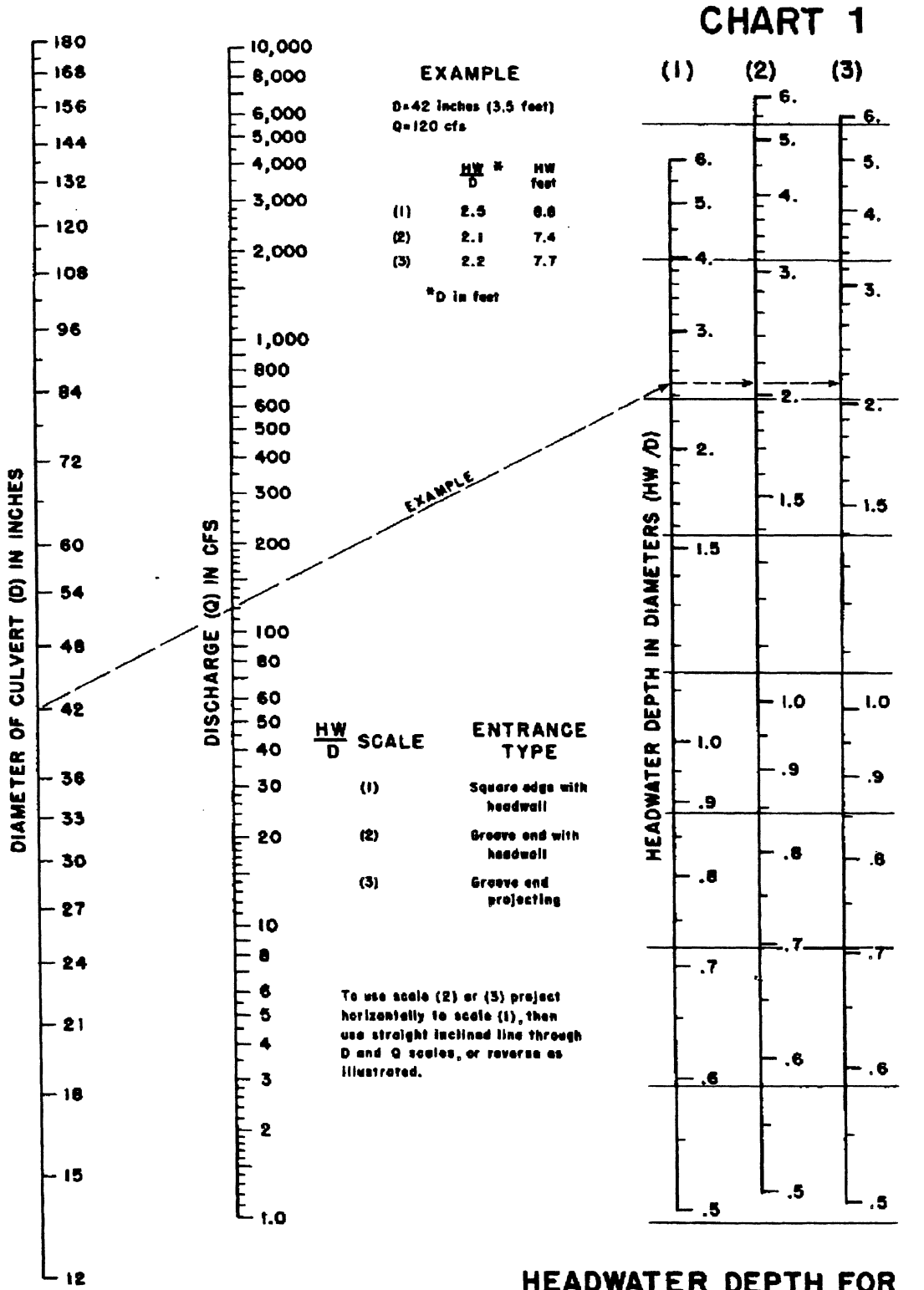
HDS-5, *Hydraulic Design of Highway Culverts* (FHWA, 1985) contains pipe design charts. Some of these charts have been reproduced in this appendix. An index of the design charts provided is given below, not all charts included in the FHWA manual are reproduced in this document.

Design curves were developed for common conduit shapes, sizes and inlet edge configurations constants using a set of design equations. The design equations used to develop the inlet control nomographs are based on the research conducted by the National Bureau of Standards (NBS) under the sponsorship of the Bureau of Public Roads (now the Federal Highway Administration). Seven progress reports were produced as a result of this research. These reports were one source of the equation coefficients and exponents, along with other references and unpublished FHWA notes on the development of the nomographs.

A constant slope value of 2 percent (0.02) was selected for the development of design curves. This is because the slope effect is small and the resultant headwater is conservatively high for sites with slopes exceeding 2 percent except for mitered inlets.

In formulating inlet and outlet control design nomographs, a certain degree of error is introduced into the design process. This error is due to the fact that the nomograph construction involves graphical fitting techniques resulting in scales which do not exactly match the equations. Checks by the authors and others indicate that all of the nomographs from HDS-5 (FHWA, 1985) have a precision of ± 10 percent of the equation values in terms of headwater (inlet control) or head loss (outlet control).

<u>Chart Number</u>	<u>Shape</u>	<u>Control Section</u>	<u>Material</u>	<u>Type</u>
1	Circular	Inlet	Concrete	
2	Circular	Inlet	Metal	
3	Circular	Inlet	Metal	Beveled Ring Control
4	Circular	Critical		
5	Circular	Outlet	Concrete	$n = 0.012$
6	Circular	Outlet	Metal	$n = 0.024$
7	Circular	Outlet	Metal	$n = 0.0328$ to 0.0302
8	Box	Inlet	Concrete	
9	Box	Inlet	Concrete	Wingwalls 18° to 33.7° and 45°
10	Box	Inlet	Concrete	90° Headwall, Beveled Edges
11	Box	Inlet	Concrete	Skewed Headwalls, Beveled Edges
12	Box	Inlet	Concrete	Flared Wingwalls, Normal and Skewed
13	Box	Inlet	Concrete	Offset Flared Wingwalls, Inlet Top beveled edge
14	Box	Critical	Concrete	Rectangular
15	Box	Outlet	Concrete	$n = 0.012$
34	Pipe Arch	Inlet	Metal	
35	Pipe Arch	Inlet	Metal	18 in. Corner Radius
36	Pipe Arch	Inlet	Metal	31 in. Corner Radius
37	Pipe Arch	Critical		Standard
38	Pipe Arch	Critical		Structural Plate
39	Pipe Arch	Outlet	Metal	$n = 0.024$
40	Pipe Arch	Outlet	Metal	18 in. Corner Radius
60	Roadway	Overtopping		Discharge Coefficients



**HEADWATER DEPTH FOR
CONCRETE PIPE CULVERTS
WITH INLET CONTROL**

HEADWATER SCALES 283
REVISED MAY 1964

CHART 2

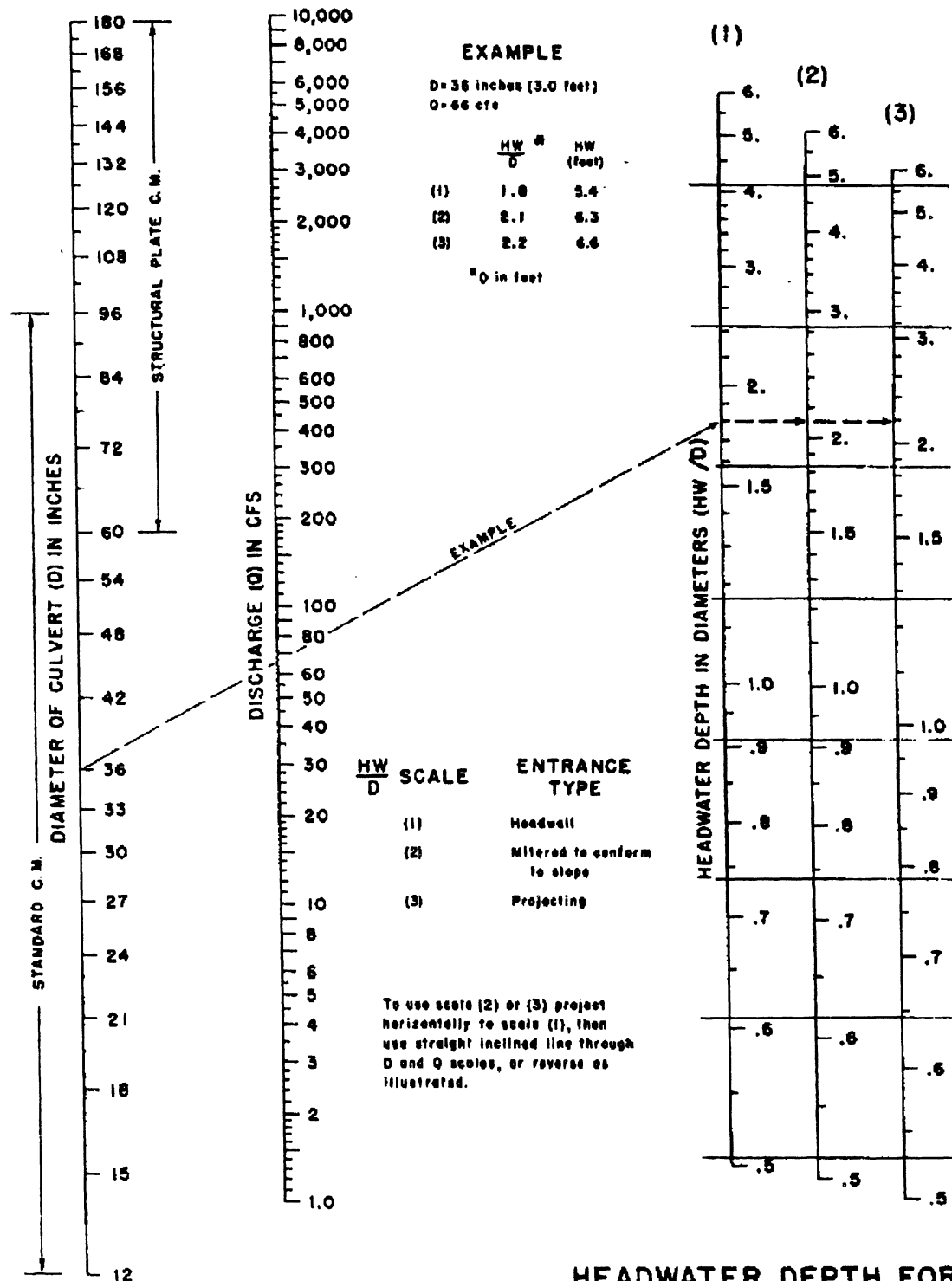


CHART 3

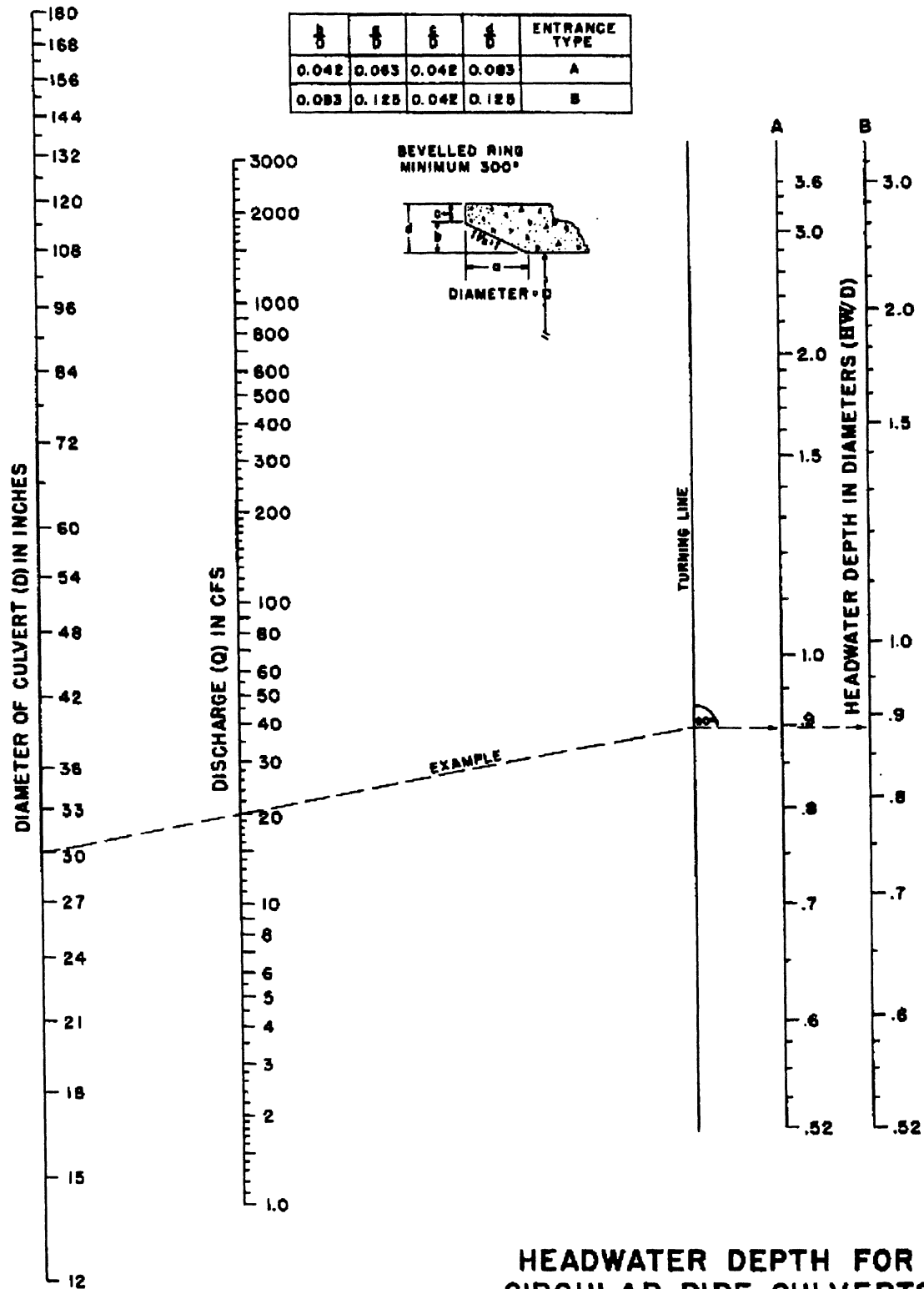
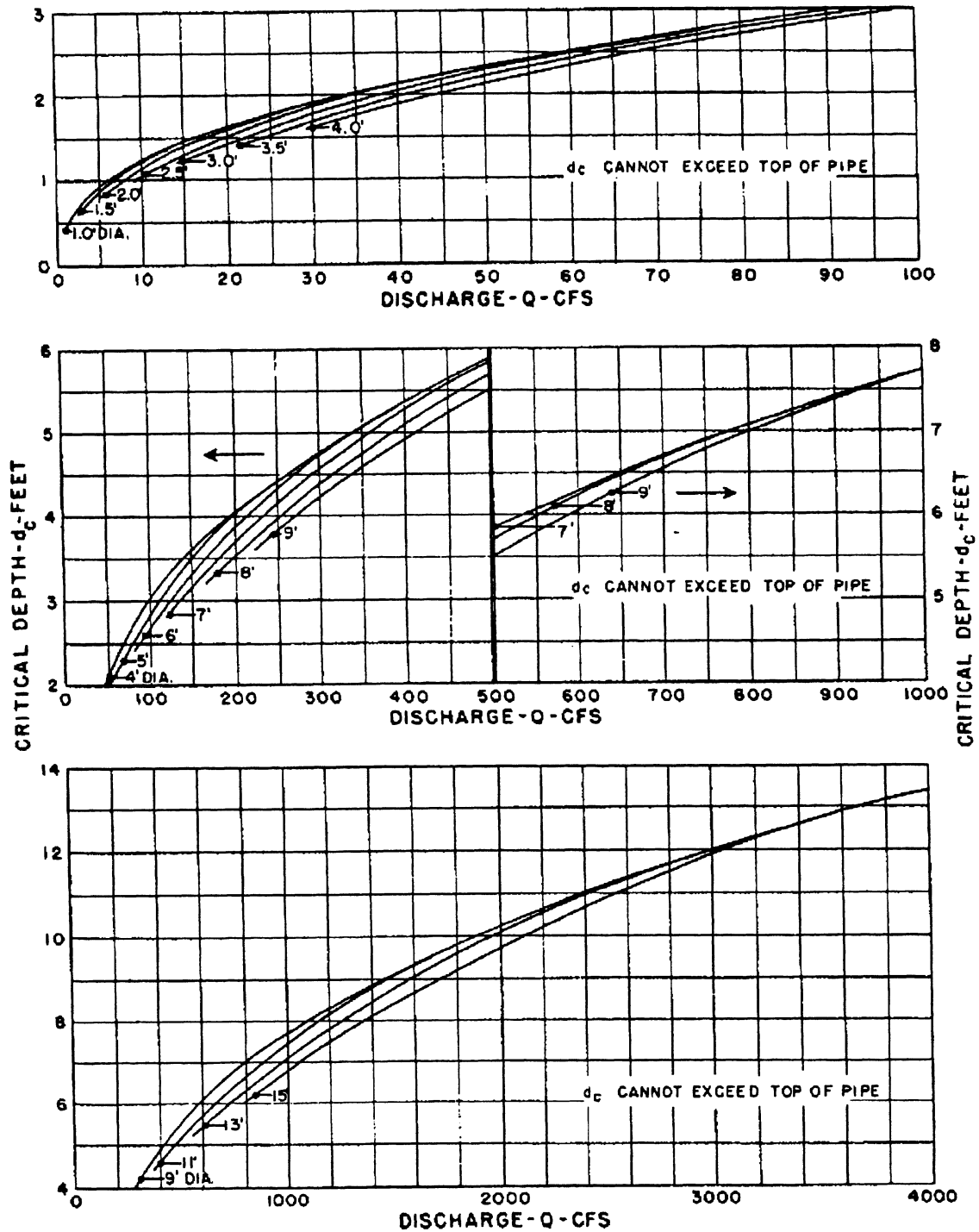


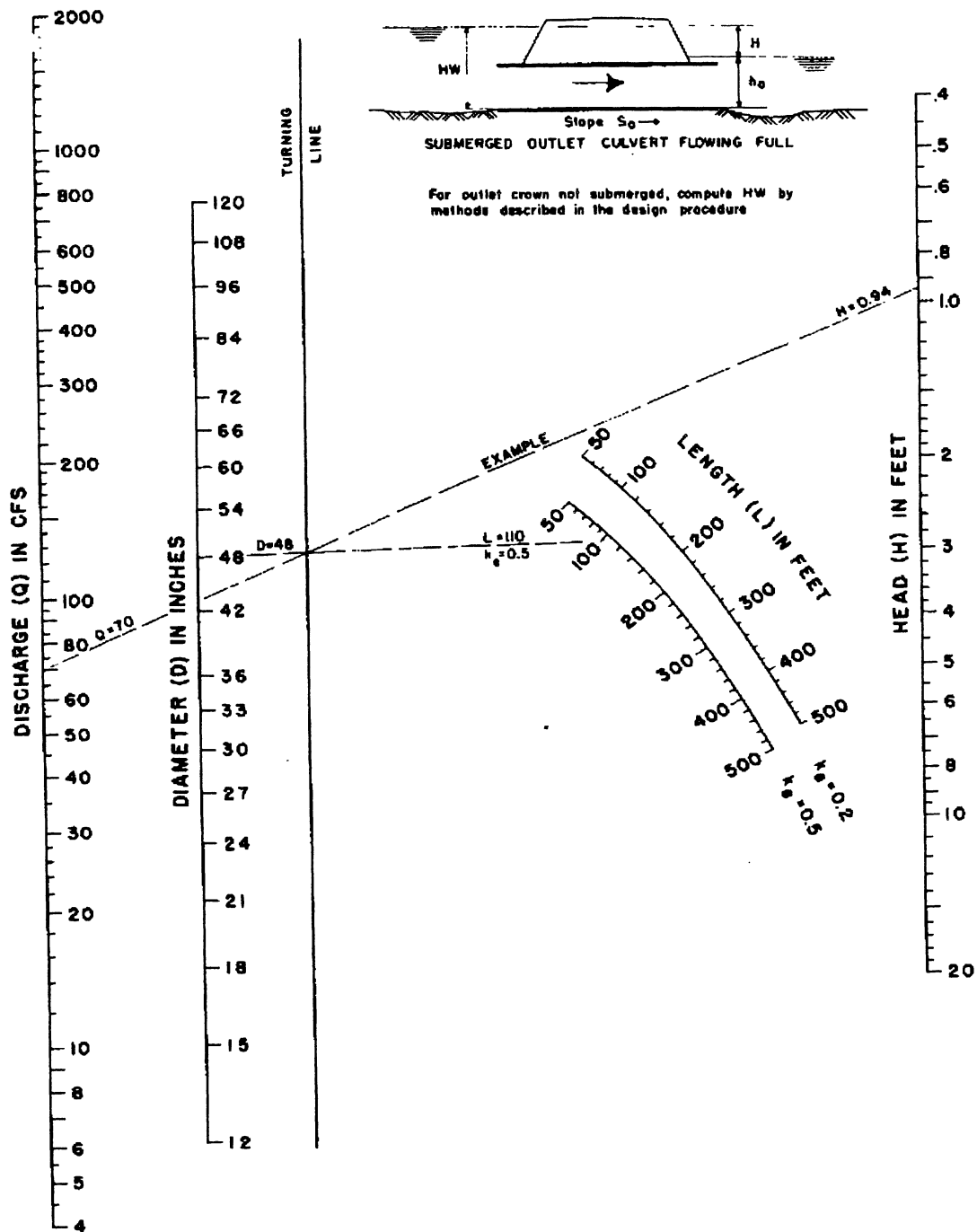
CHART 4



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JAN. 1964

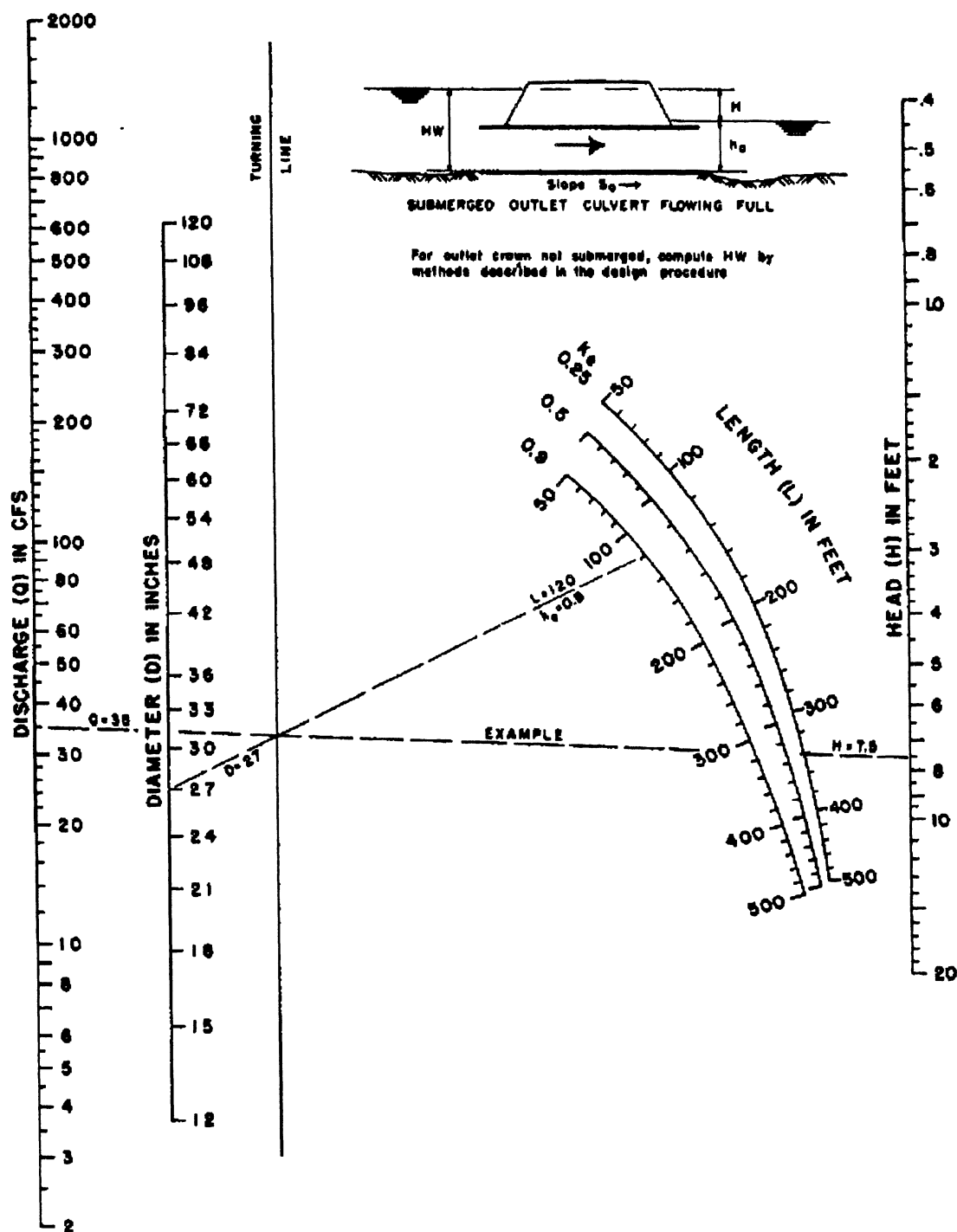
CRITICAL DEPTH
CIRCULAR PIPE

CHART 5



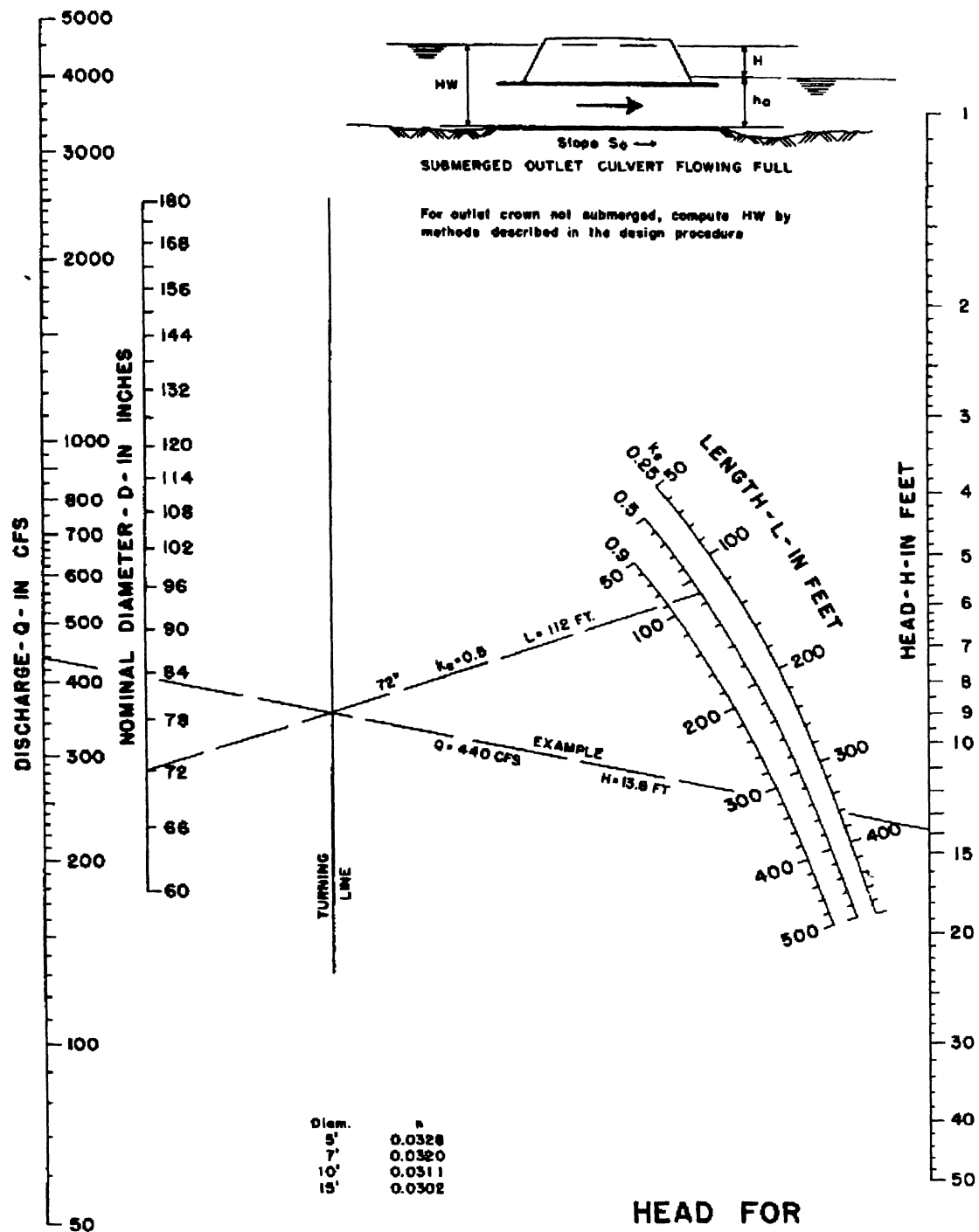
HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
 $n = 0.012$

CHART 6



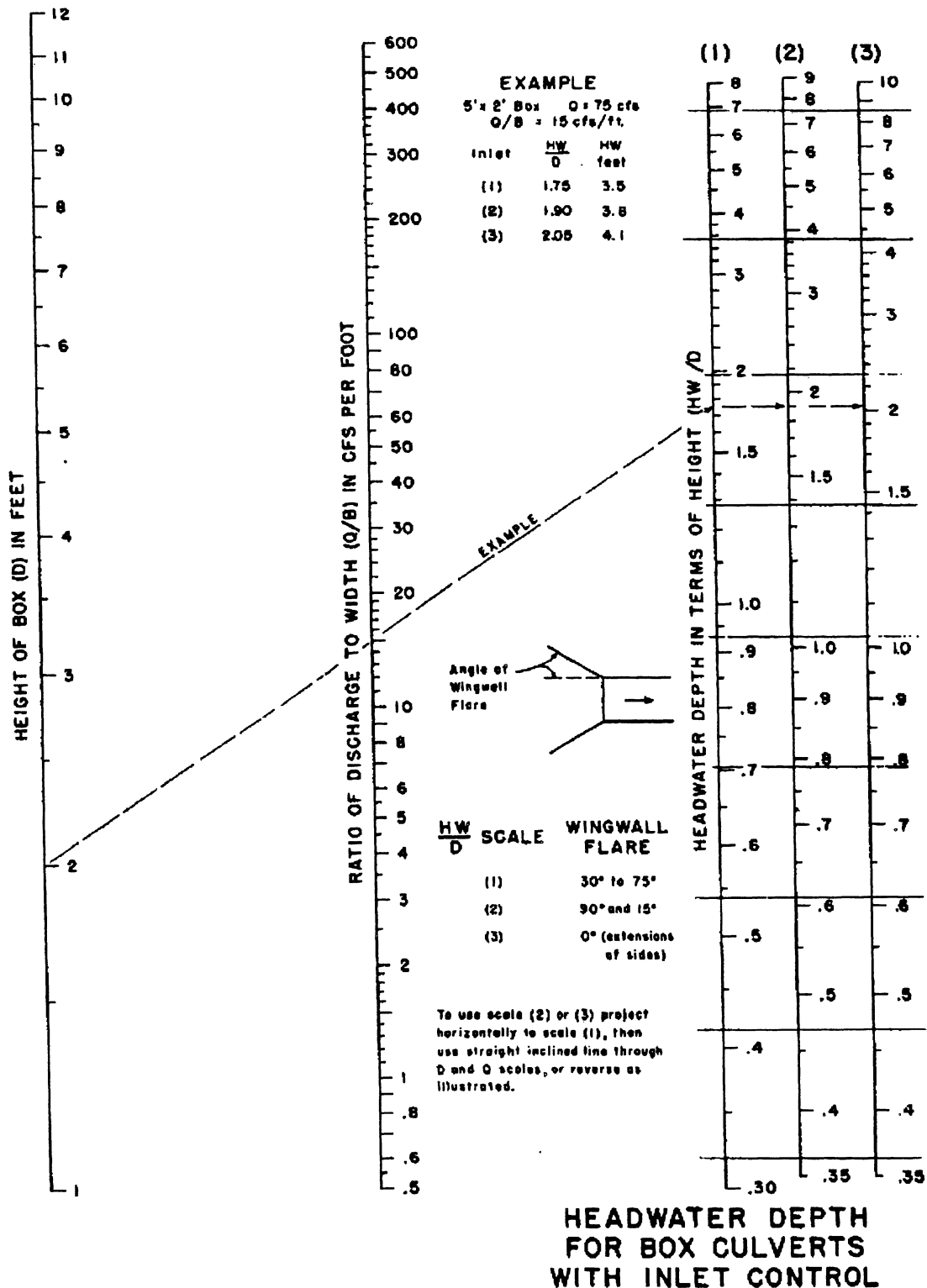
HEAD FOR
STANDARD
C. M. PIPE CULVERTS
FLOWING FULL
 $n = 0.024$

CHART 7



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

CHART 8



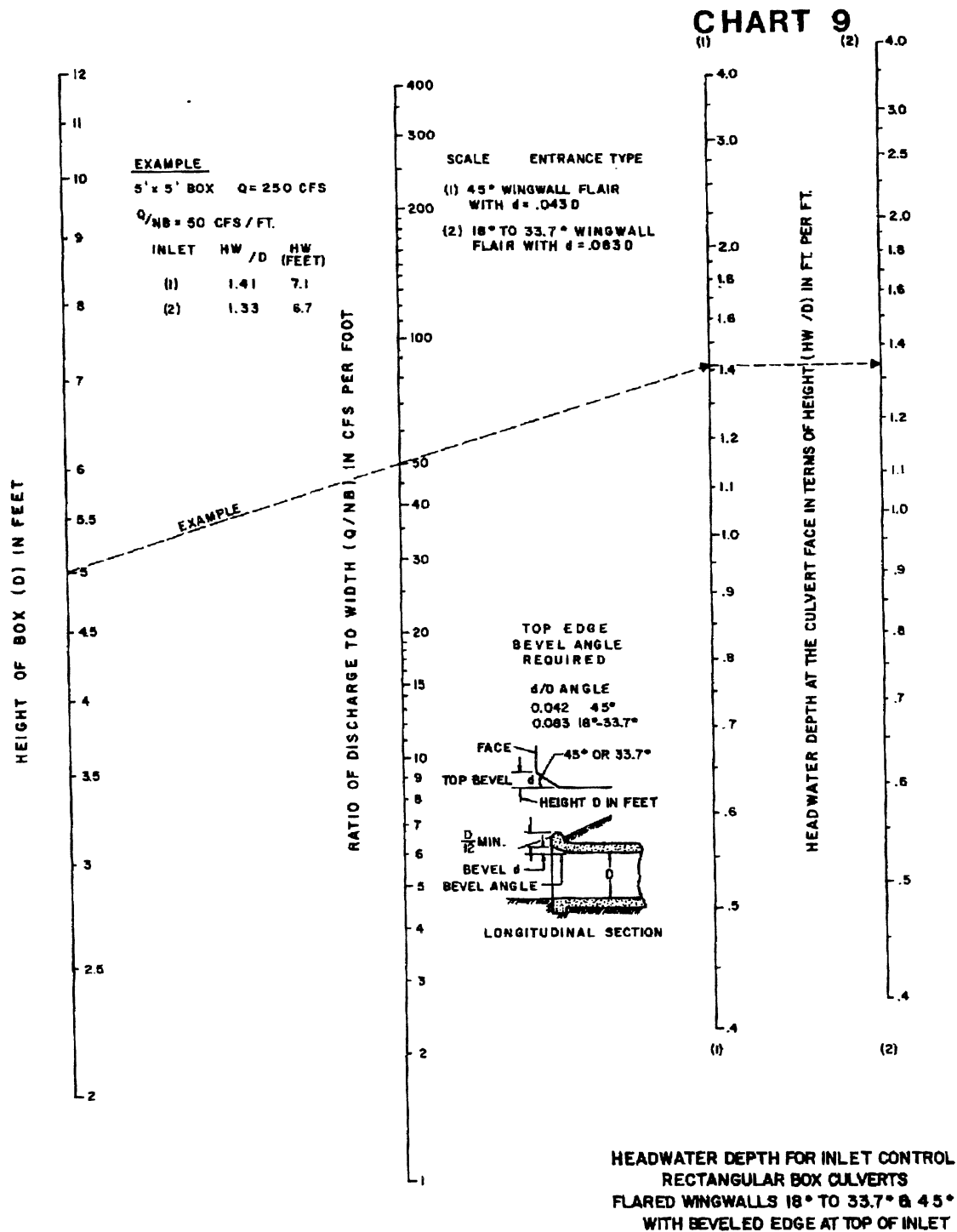


CHART 10

EXAMPLE

B=7 FT. D=5 FT. Q=500 CFS Q/NB=71.5

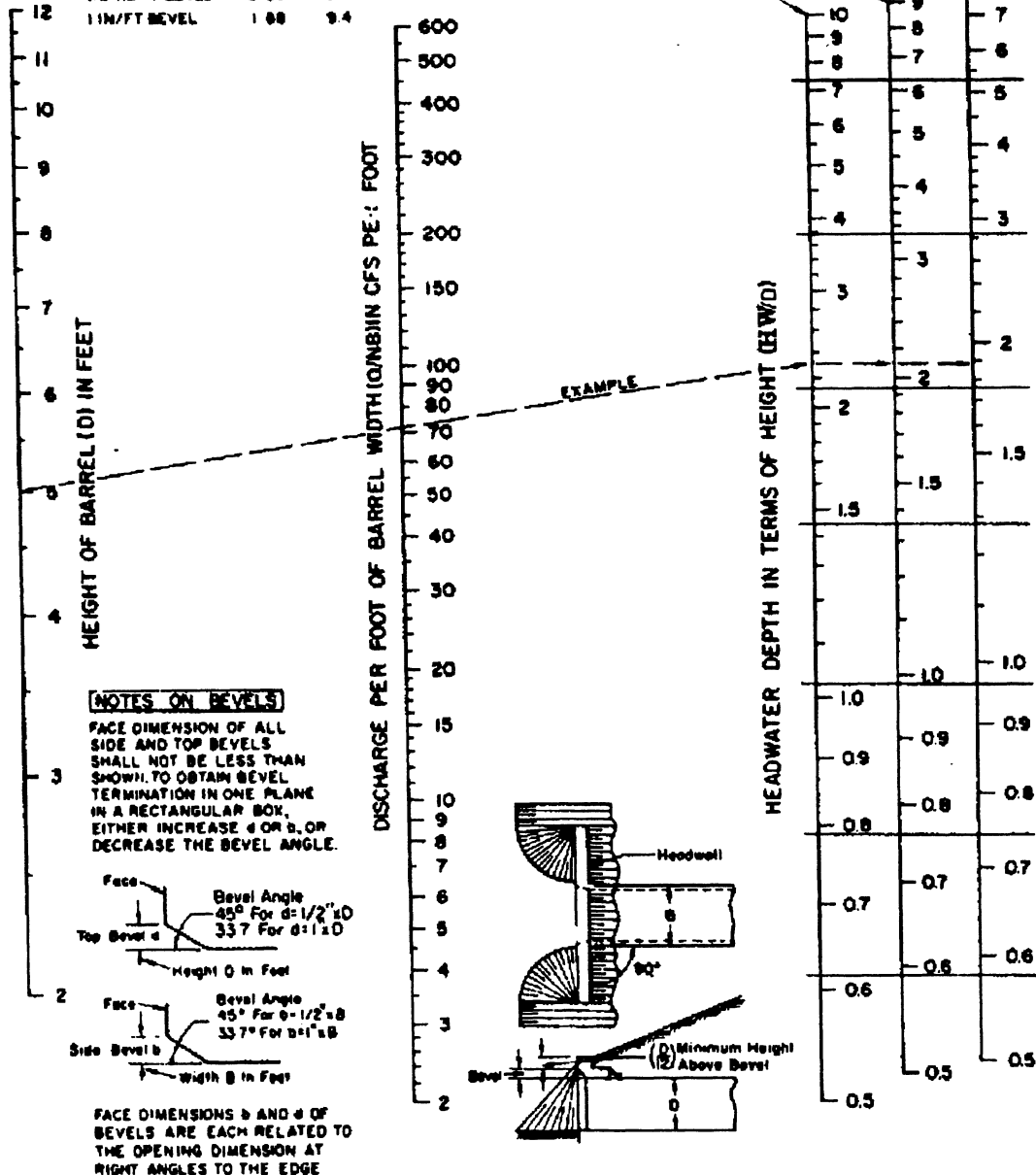
ALL EDGES	HW	HW
	D	feet
CHAMFER 3/4"	2.31	11.9
1/2 IN/FT BEVEL	2.09	10.4
1 IN/FT BEVEL	1.88	9.4

INLET FACE-ALL EDGES:

1 IN/FT. BEVELS 33.7° (1:1.5)

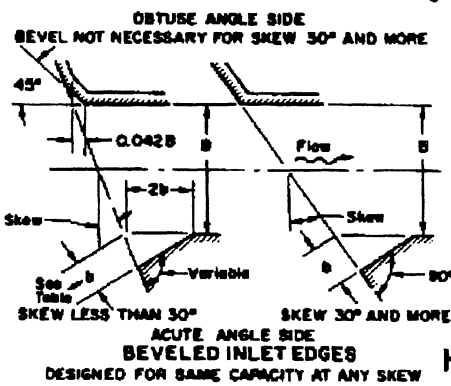
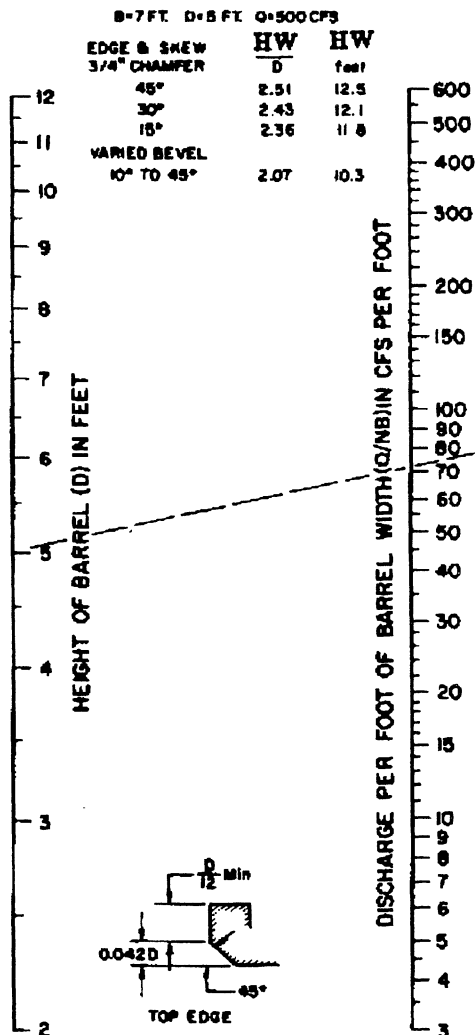
1/2 IN/FT BEVELS 45° (1:1)

3/4 INCH CHAMFERS



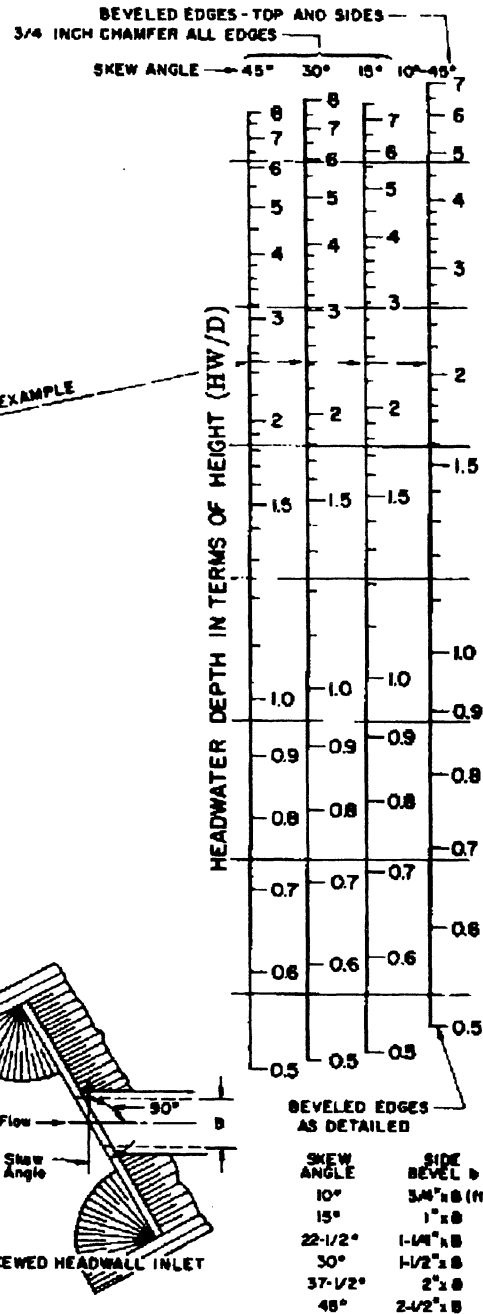
HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

EXAMPLE



FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

CHART 11



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

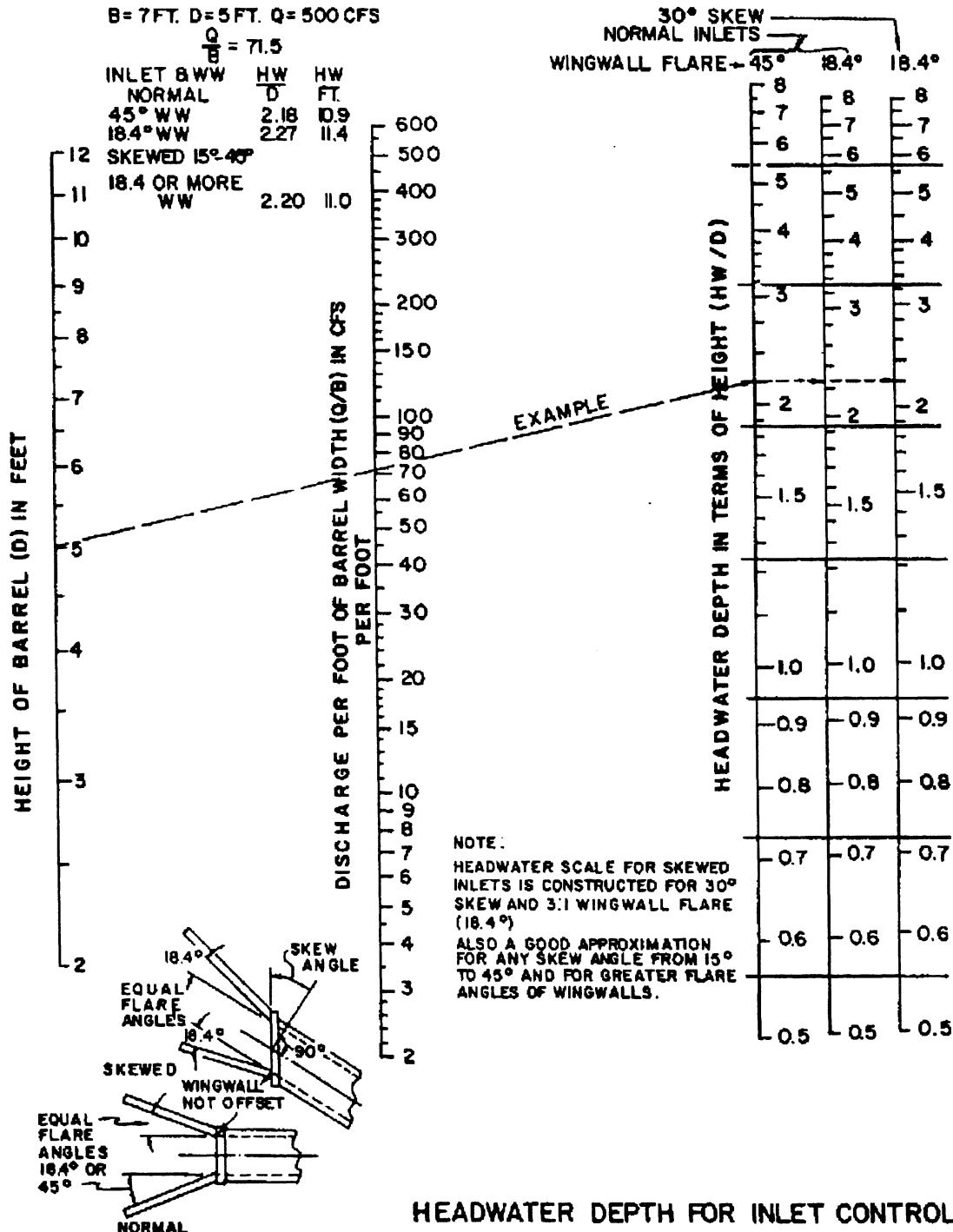
CHART 12

EXAMPLE

B = 7 FT. D = 5 FT. Q = 500 CFS

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

INLET & WW	HW D	HW FT.
NORMAL		
45° WW	2.18	10.9
18.4° WW	2.27	11.4
SKEWED 15°-45°		
18.4 OR MORE WW	2.20	11.0



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

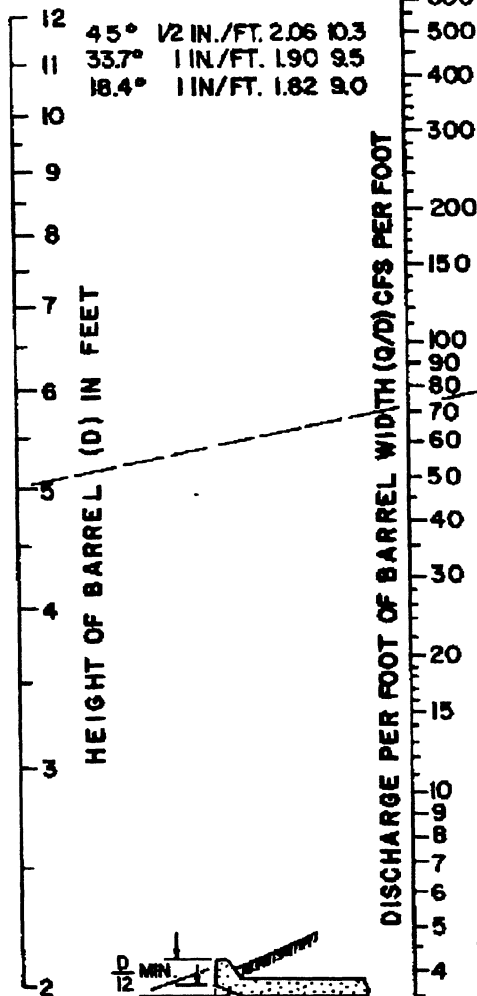
CHART 13

EXAMPLE

B = 7 FT. D = 5 FT. Q = 600 C.F.S.

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

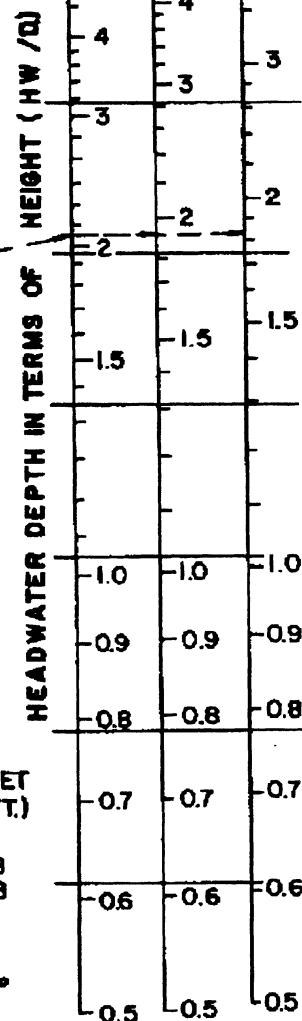
WINGWALL TOP EDGE
FLARE ANGLE BEVEL HW HW



18.4° WW & d = 0.083D
33.7° WW & d = 0.083D
45° WW & d = 0.042D

TOP EDGE
BEVEL ANGLE
REQUIRED

1 ANGLE
0.042 45°
0.083 33.7°

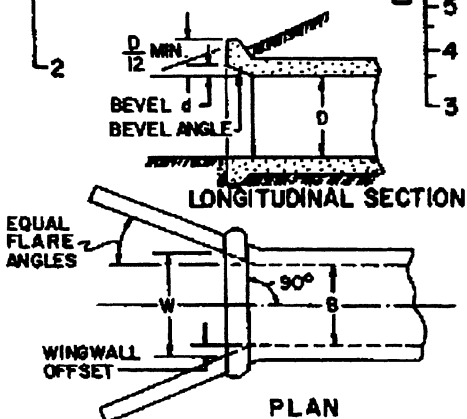


EXAMPLE

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



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OFFICE OF R&D AUGUST 1968

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

CHART 14

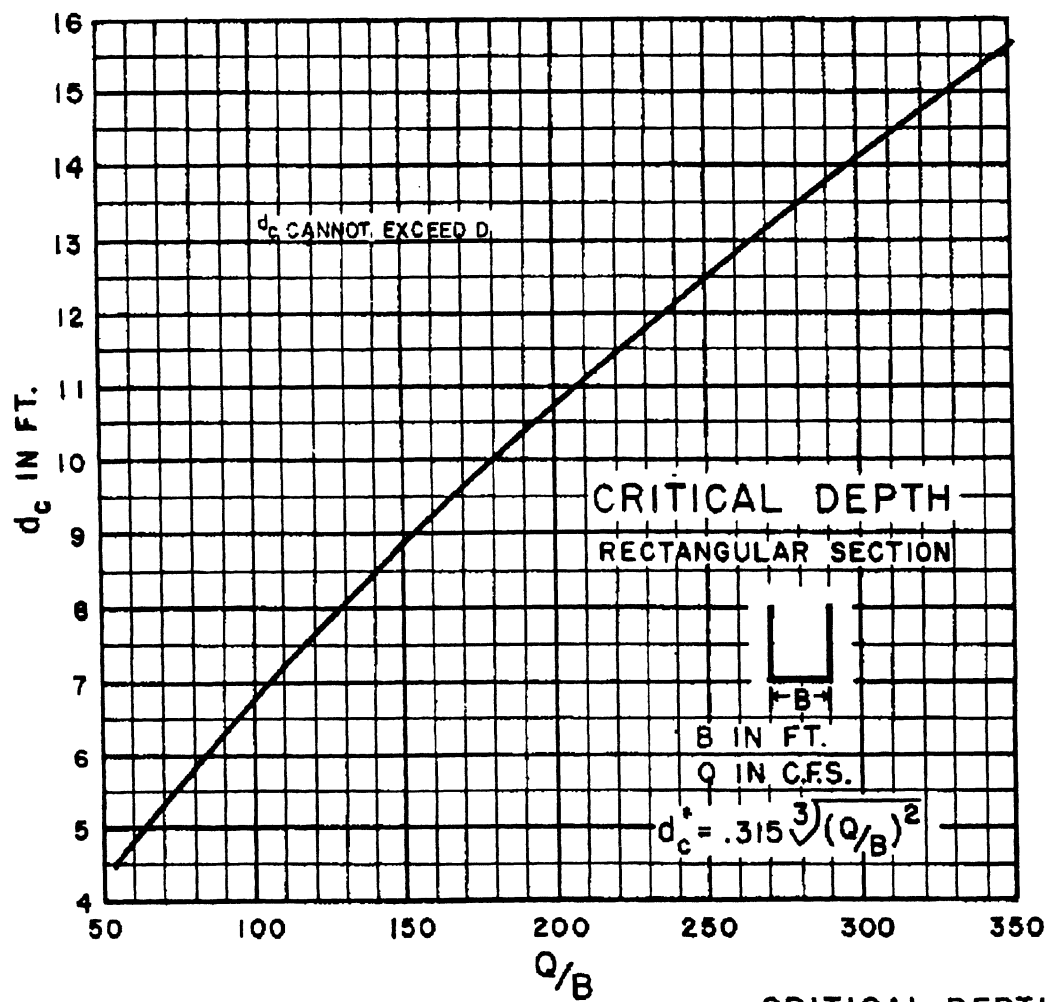
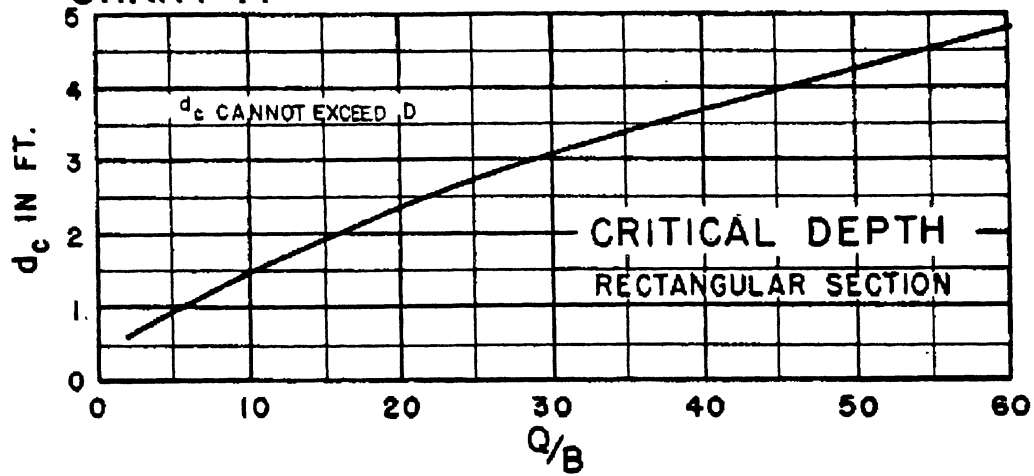
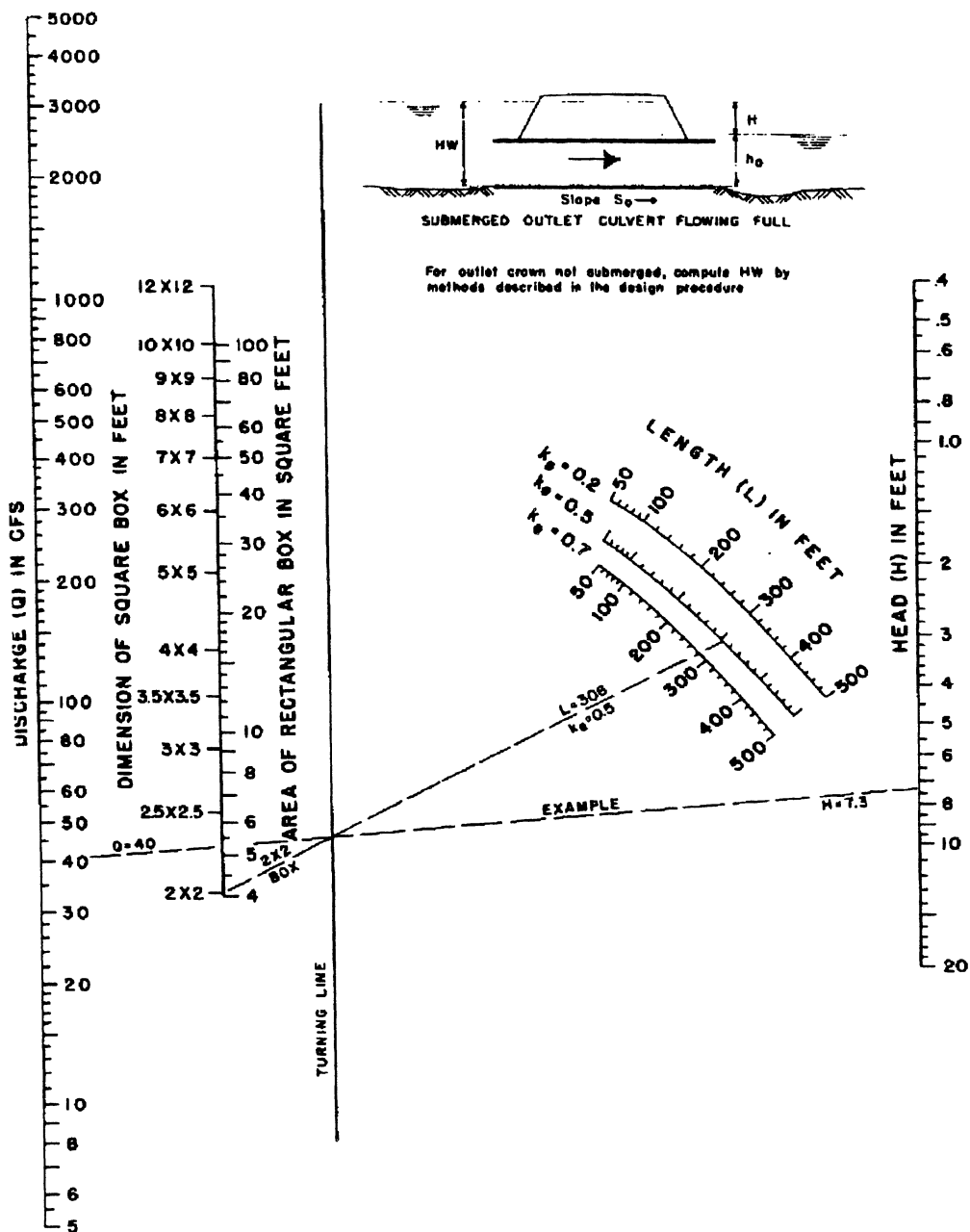


CHART 15



HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
 $n = 0.012$

18-IN. CORNER RADIUS
STRUCTURAL PLATE C.M.

SIZE (SPAN x RISE) OF PIPE-ARCH

STANDARD C.M.

DISCHARGE (Q) IN CFS

EXAMPLE

Size: 36" x 22"
 Q = 20 cfs

	$\frac{HW}{D}$	$\frac{HW}{D}$ (feet)
(1)	1.10	2.0
(2)	1.15	2.1
(3)	1.22	2.2

$\frac{HW}{D}$ in feet

ENTRANCE TYPE

(1)	Hoodwall
(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 IN TERMS OF RISE (HW/D)

Diagram: A cross-section of a culvert showing the water level (HW) and the depth (D) from the invert to the water surface.

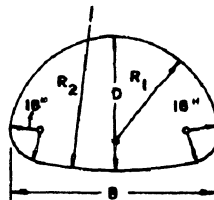
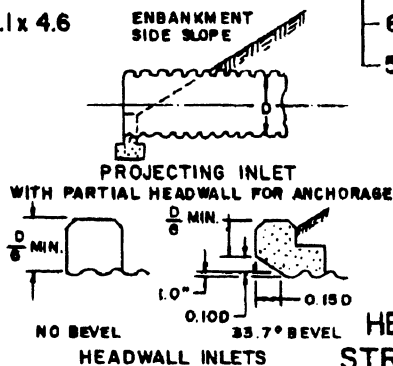
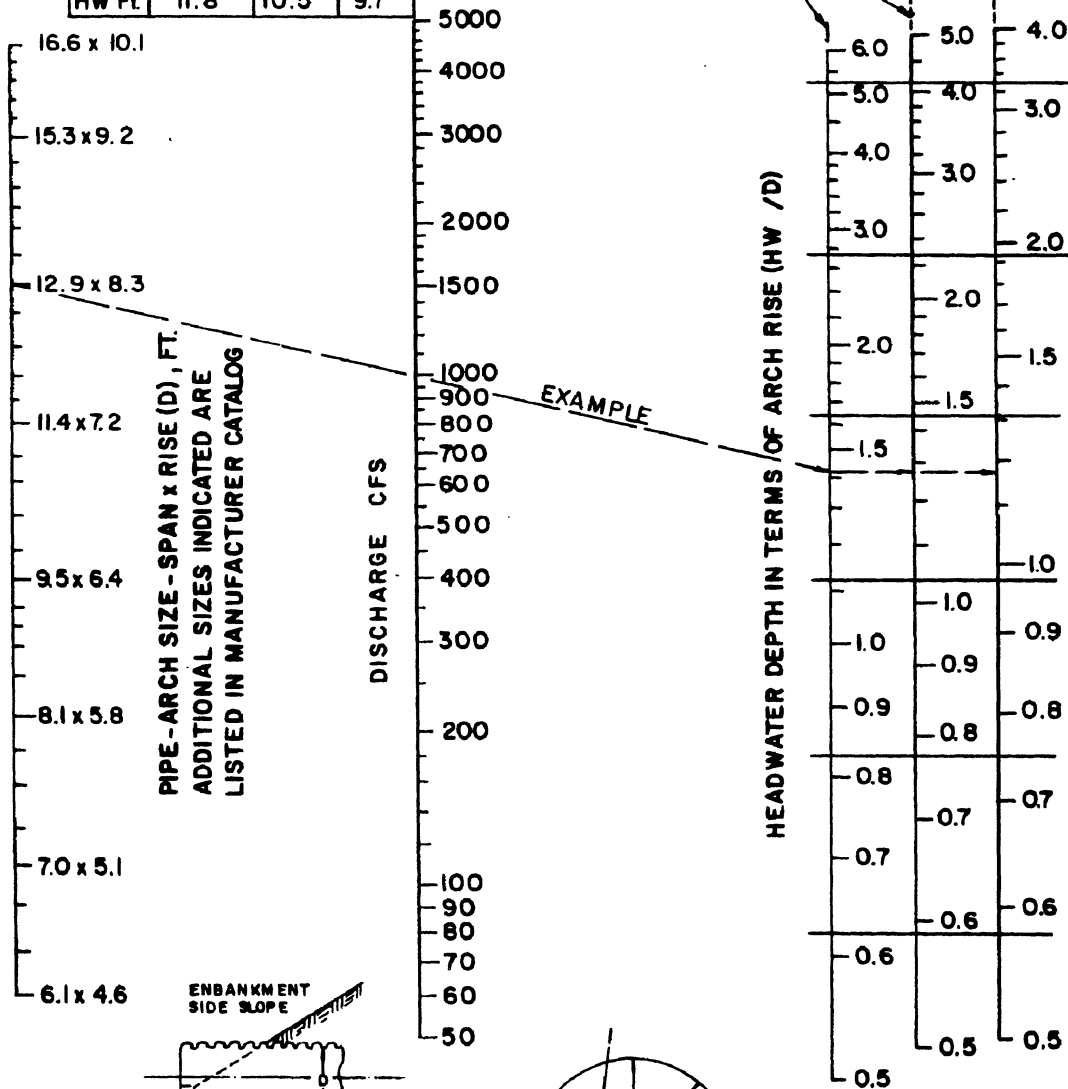
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HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

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



HEADWATER DEPTH FOR INLET CONTROL STRUCTURAL PLATE PIPE-ARCH CULVERTS

18-IN. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

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CHART 36

EXAMPLE
SIZE 17.4' x 11.5' Q = 2500 CFS

	PROJECT	HEADWALL	
		NO BEV	BEVEL
HW / D	16.4	14.5	13.2
HW FT.	18.9	16.7	15.2

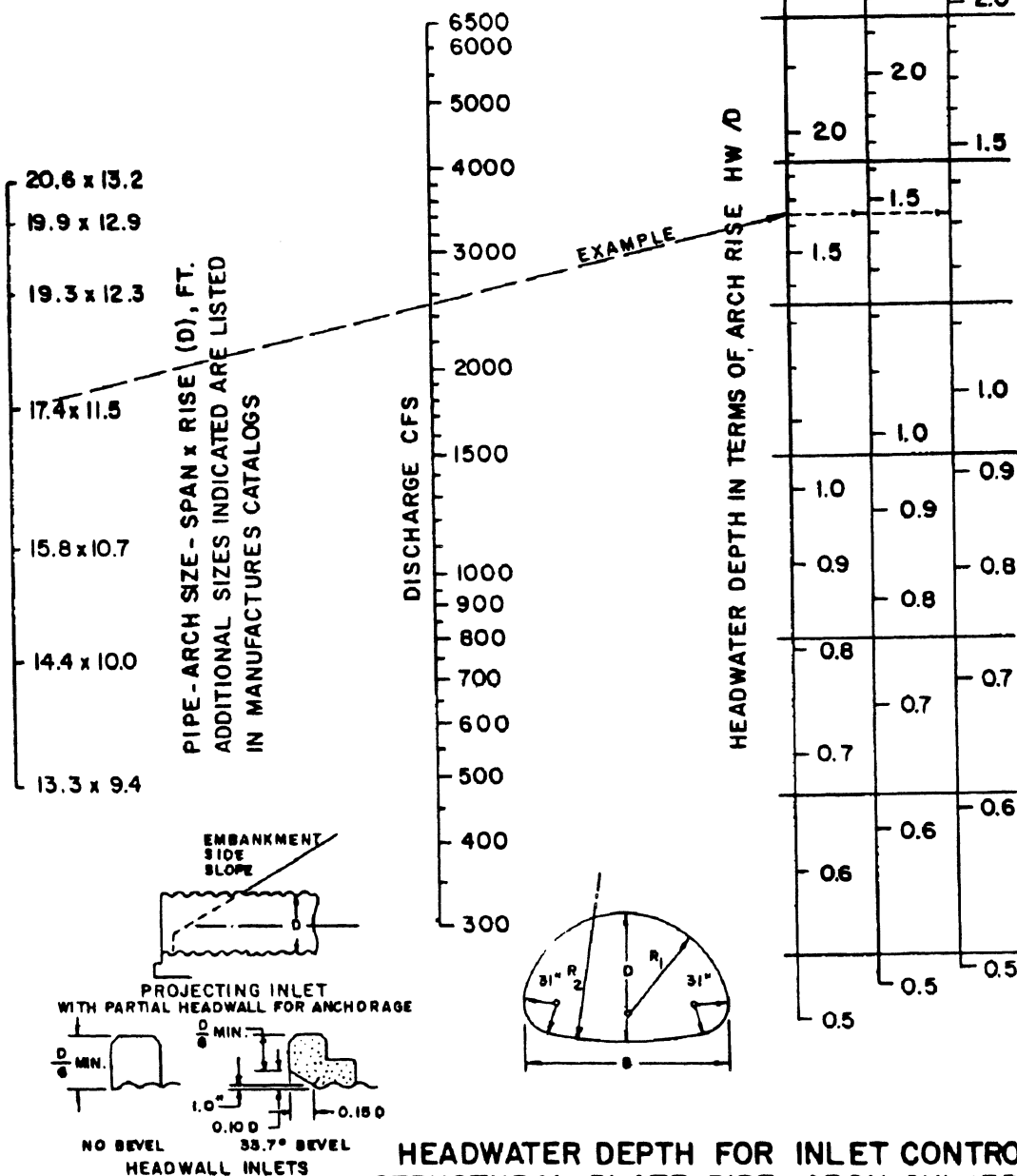
TYPE OF INLET

90° HEADWALL

33.7° x 0.10 D BEVEL

NO BEVEL

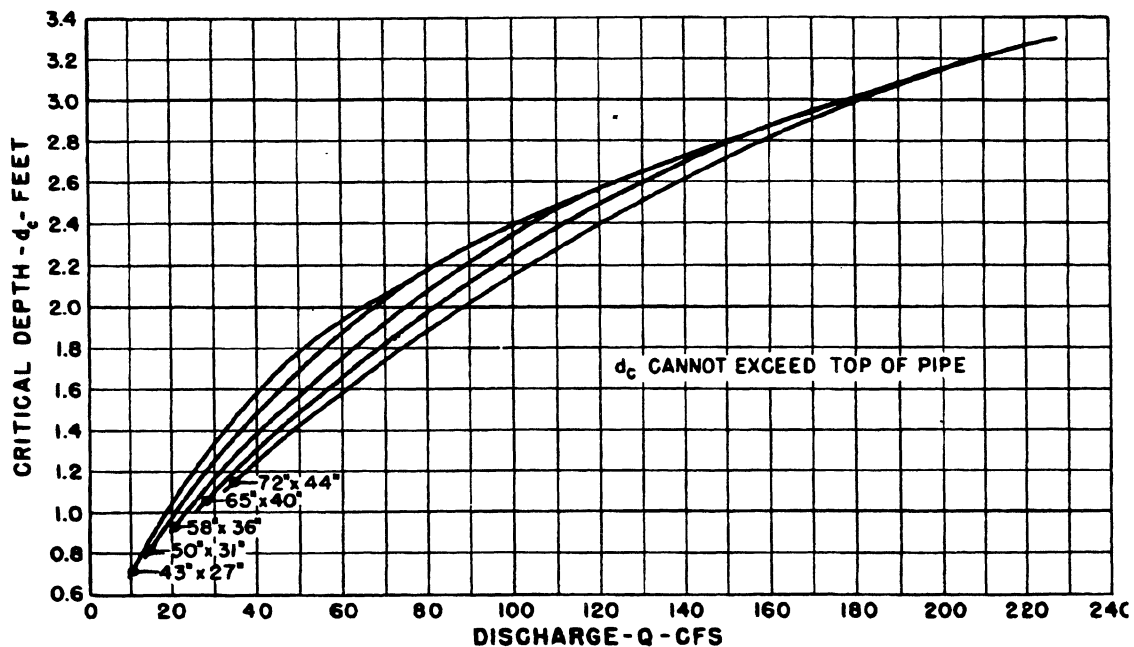
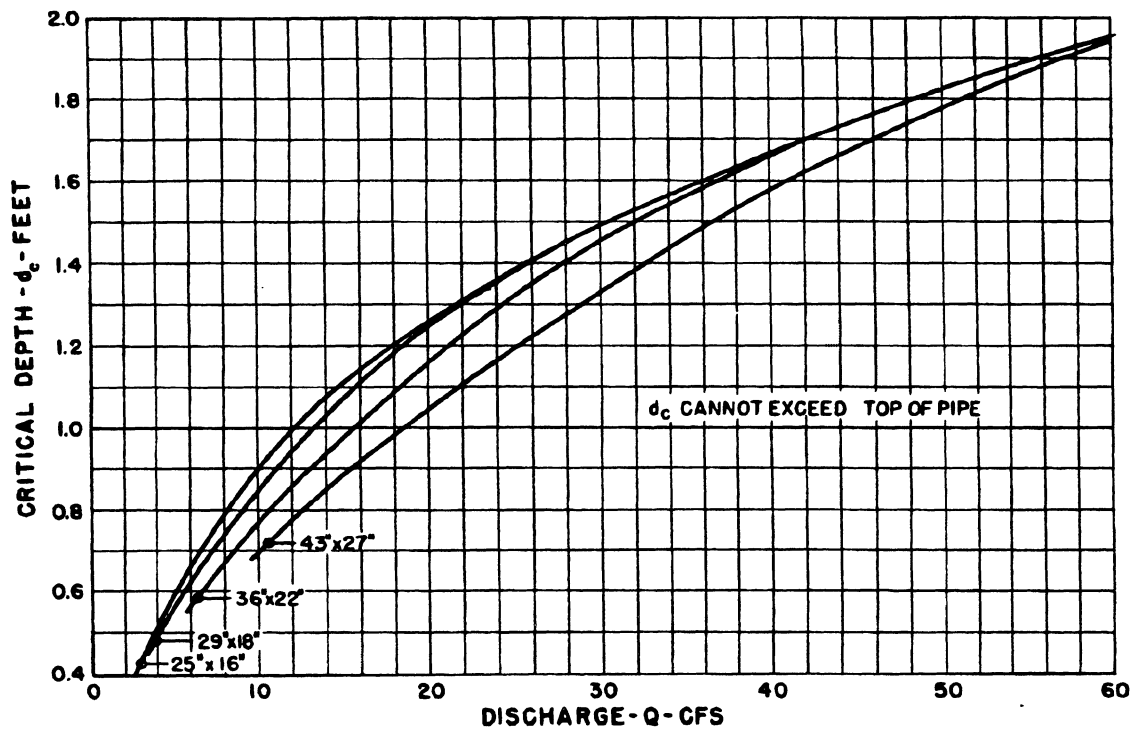
PROJECTING



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

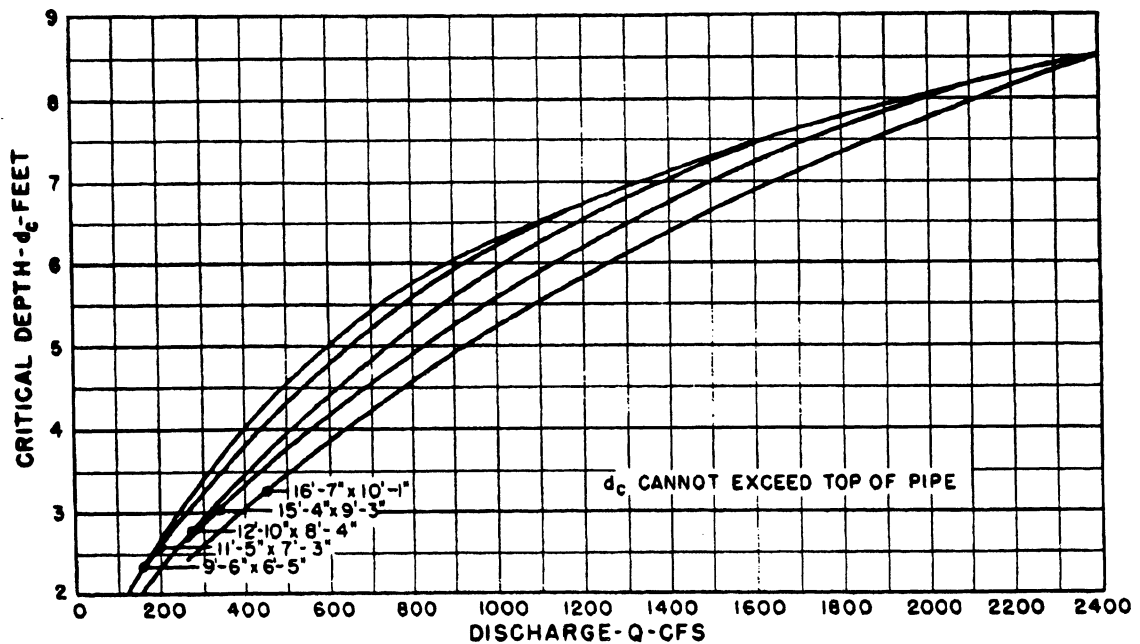
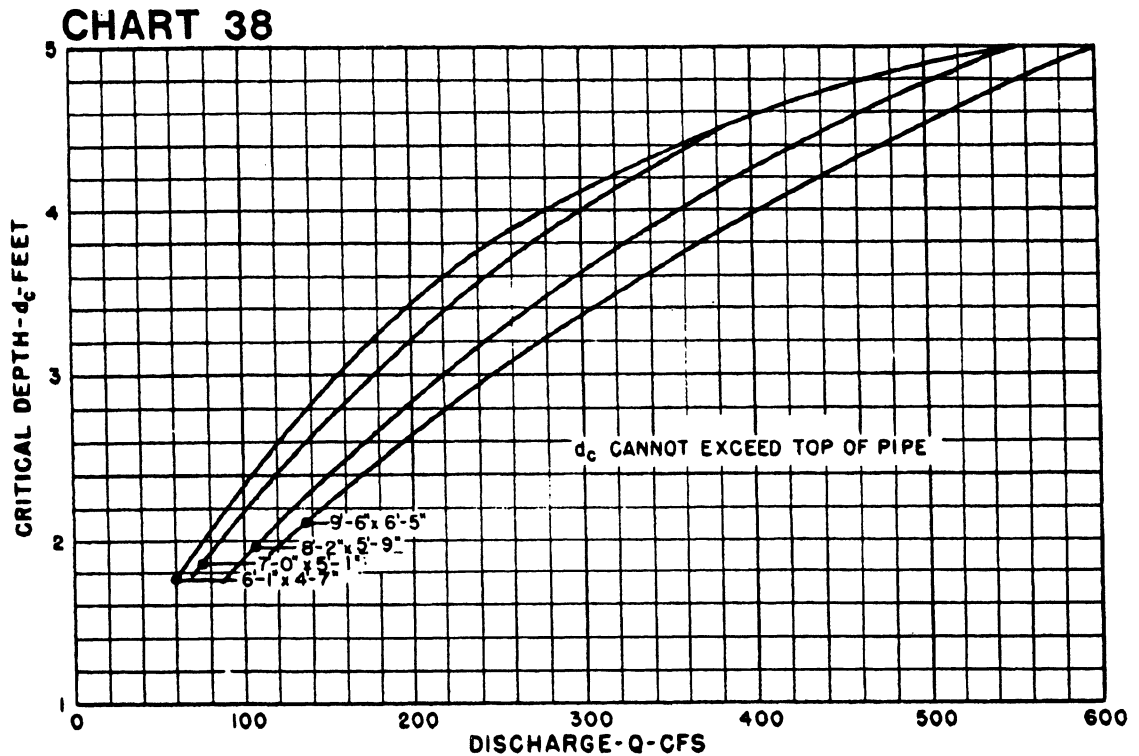
CHART 37



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CRITICAL DEPTH STANDARD C.M. PIPE-ARCH

Chart 37 can be used to approximate critical depth for comparably sized RCP-ARCH pipe



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

Chart 38 can be used to approximate critical depth for comparably sized RCP-ARCH pipe

Figure 10: Design Chart for Submerged Outlet Culverts Flowing Full

Schematic: A culvert on a slope S_o . Water level at inlet is H_W , at outlet is H . Depth at outlet is h_o . The culvert is flowing full.

Text: For outlet crown not submerged, compute H_W by methods described in the design procedure.

Chart Axes and Curves:

- Left Y-axis:** DISCHARGE (Q) IN CFS (logarithmic scale from 2 to 300).
- Inner Left Y-axis:** SIZE (SPAN X RISE) OF PIPE-ARCH (linear scale from 25" X 16" to 72" X 44").
- Right Y-axis:** HEAD (H) IN FEET (linear scale from 0.4 to 10).
- Inner Right Y-axis:** LENGTH (L) IN FEET (logarithmic scale from 50 to 500).
- Curves:** Loss coefficient K_s curves for 0.25, 0.5, 0.9, and 50.

Example Calculation:

- Discharge $Q = 40$ CFS.
- Length $L = 380$ ft.
- Loss coefficient $K_s = 0.9$.
- Resulting size: **SIZE = 58 x 36**.

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CHART 40

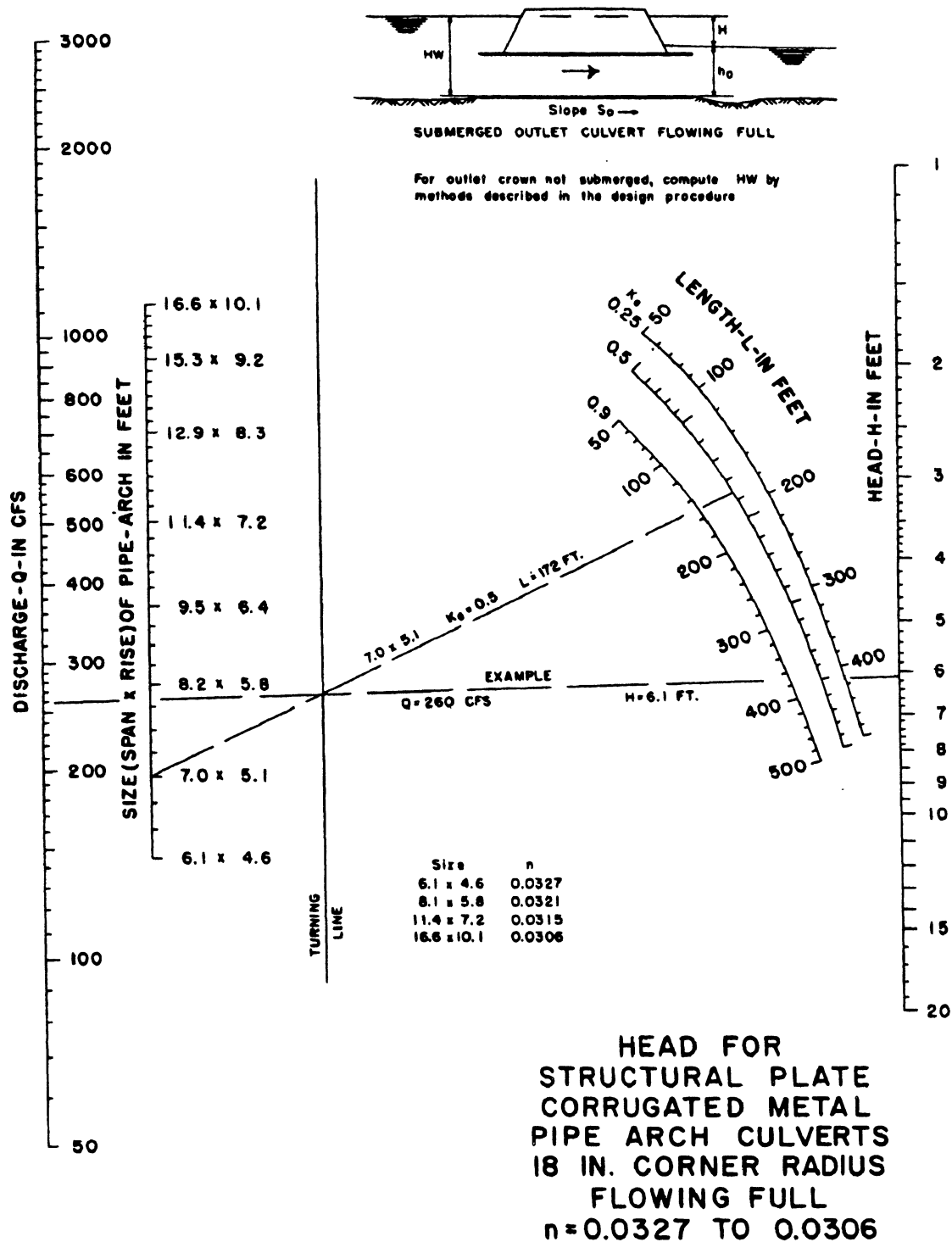
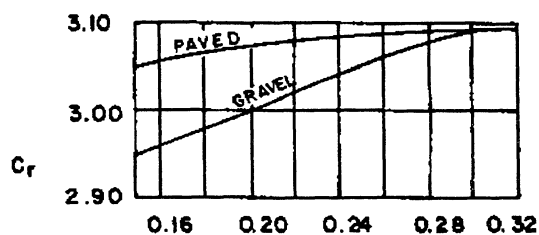
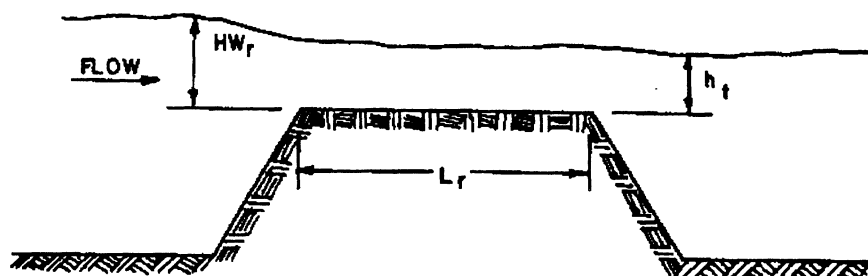
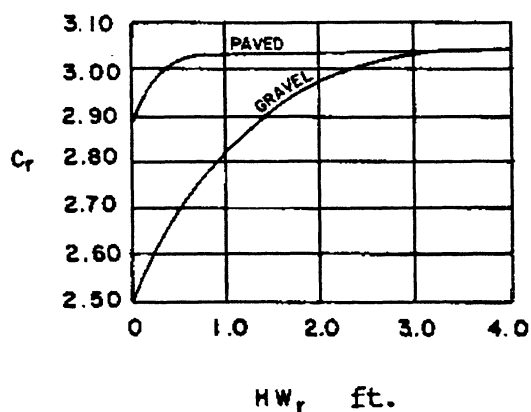


CHART 60



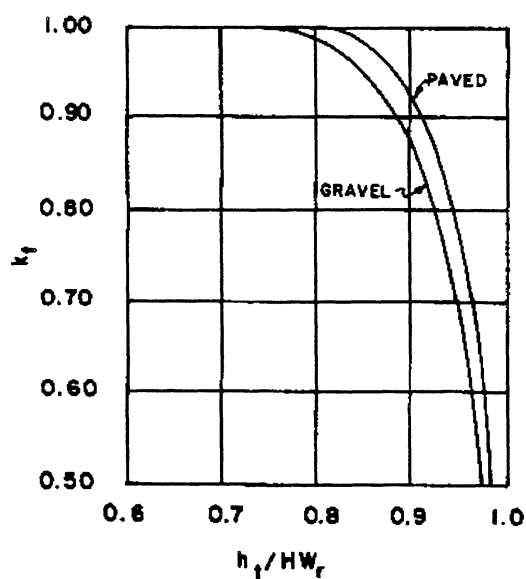
A) DISCHARGE COEFFICIENT FOR
 $HW_r/L_r > 0.15$



B) DISCHARGE COEFFICIENT FOR
 $HW_r/L_r < 0.15$

$$C_d = k_t C_r$$

$$Q_r = C_d L H W_r^{1.5}$$



C) SUBMERGENCE FACTOR

DISCHARGE COEFFICIENTS
FOR ROADWAY OVERTOPPING