APPENDIX 4

HYDRAULIC DATA FOR CULVERTS
(D) CULVERT ENTRANCE LOSSES

STRUCTURE AND ENTRANCE TYPE	COEFFICIENT k
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
Metered 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	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Metered 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
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 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.

Table 4.2

Culvert Discharge–Velocity Limitations

Downstream Condition	Maximum Allowable Discharge Velocity (FPS)
Earth	6 FPS
Sodded Earth	8 FPS
Paved or Riprap Apron	15 FPS
Shale	10 FPS
Rock	15 FPS

City of SPRINGDALE Arkansas

FORM HYD 4-1

CULVERT COMPUTATIONS
(SQUARE AND BEVELED EDGES)

PROJECT: _____

DESIGNER: _____

DATE: _____

HYDROLOGIC AND CHANNEL INFORMATION

HYDROLOGY

Q_1 ____ = ____ cfs

Q_2 ____ = ____ cfs

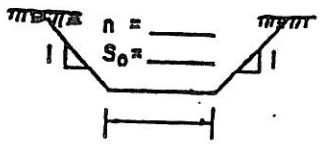
STREAM DATA

Tw_1 = ____

Tw_2 = ____

n = ____

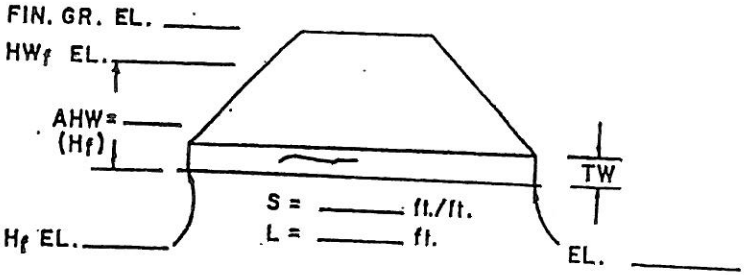
S_o = ____



OUTLET CHANNEL
(APPROX. DIMENSIONS)

SKETCH

STATION: _____



TRIAL NO.	SIZE	STRUCTURE TYPE & ENTRANCE DESIGN	Q / Q/NB / $\frac{Q}{NBD^{1/2}}$	HEADWATER COMPUTATION — OUTLET CONTROL (a) K_e	H	(b) d_c	(c) h_o	(d) TW	LS	(e) HW_o	INLET CONT. (f) $\frac{HW}{D}$	HW	CONTROLLING HW	OUTLET VELOCITY ft./sec.	COST	COMMENTS
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

(a) Entrance loss coefficient

(b) "d_c" cannot exceed D.

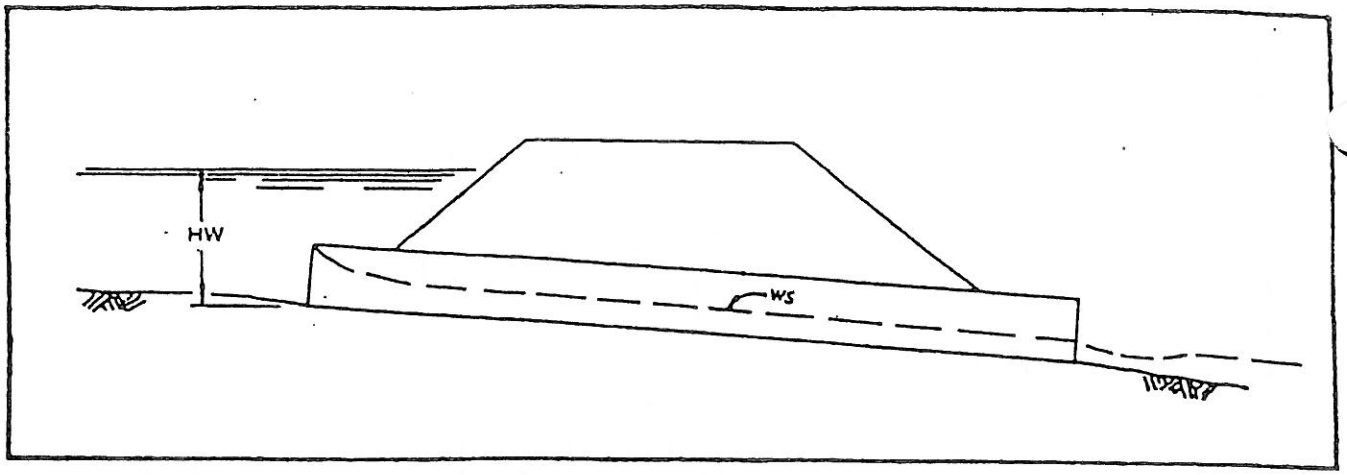
(c) $h_o = \frac{d_c + D}{2}$ or TW_1 whichever is larger.

(d) TW = d_n in natural channel, or other downstream control.

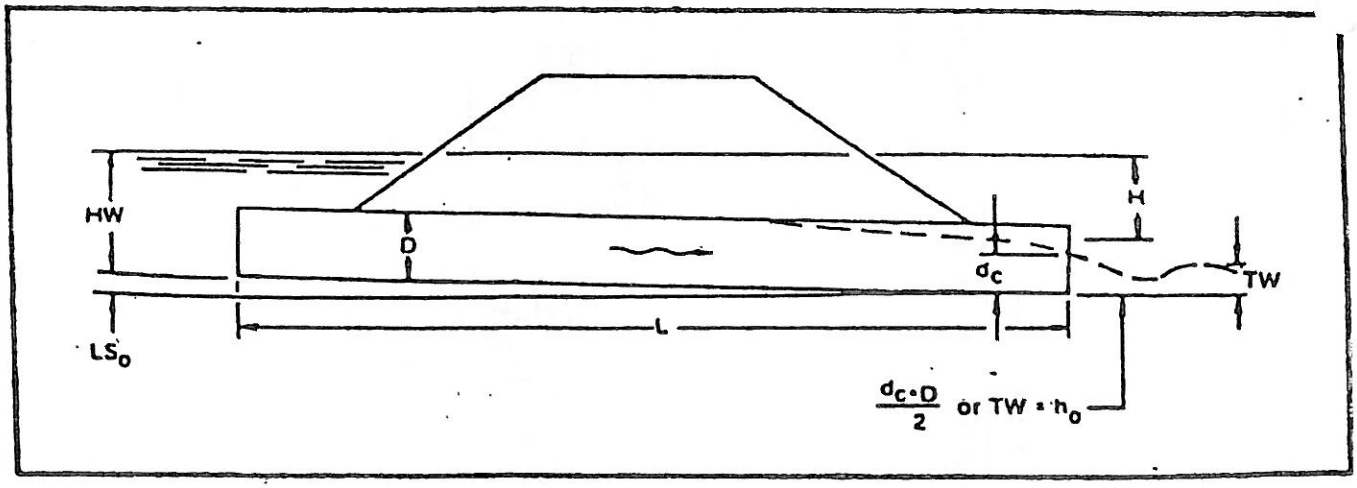
(e) $HW_o = H + H_o - LS$

(f) Use ____ for Conventional face.
Use ____ for Beveled Edge.

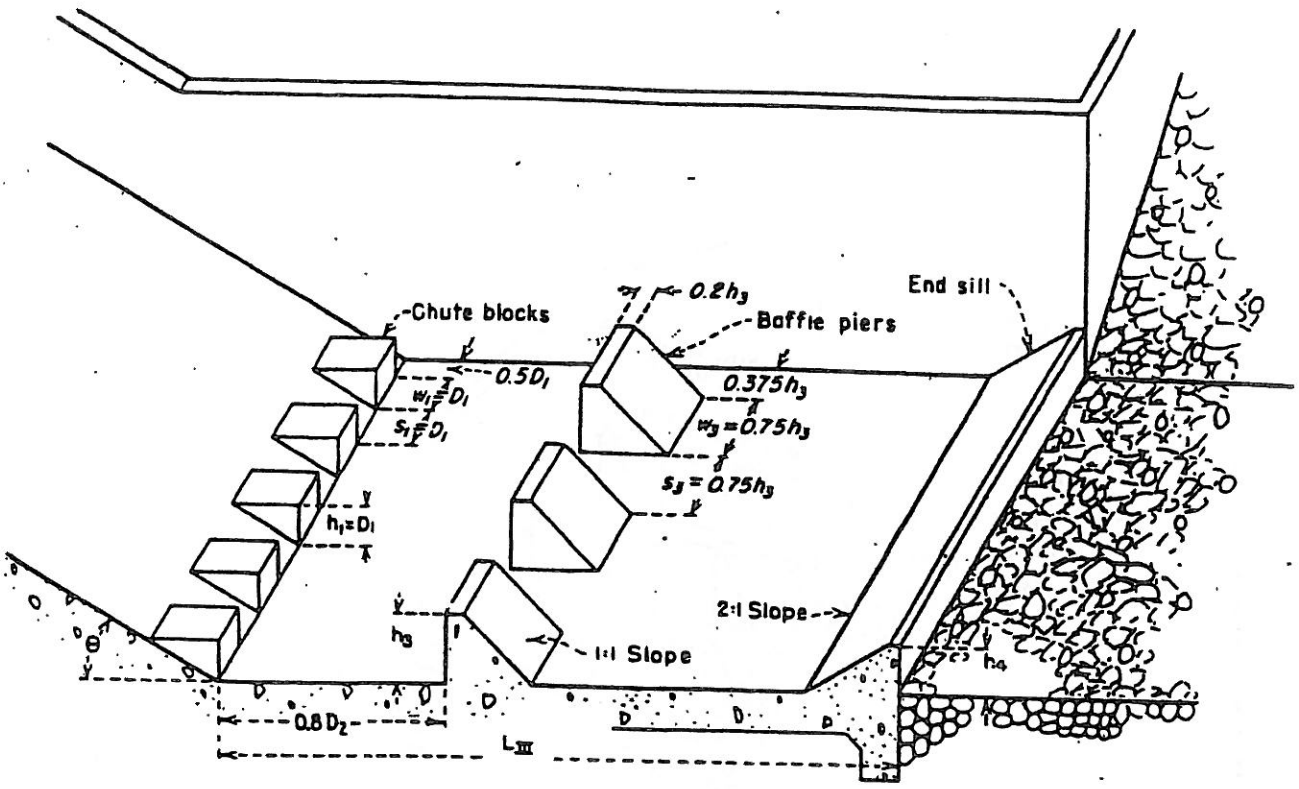
Table 4.3



INLET CONTROL



OUTLET CONTROL

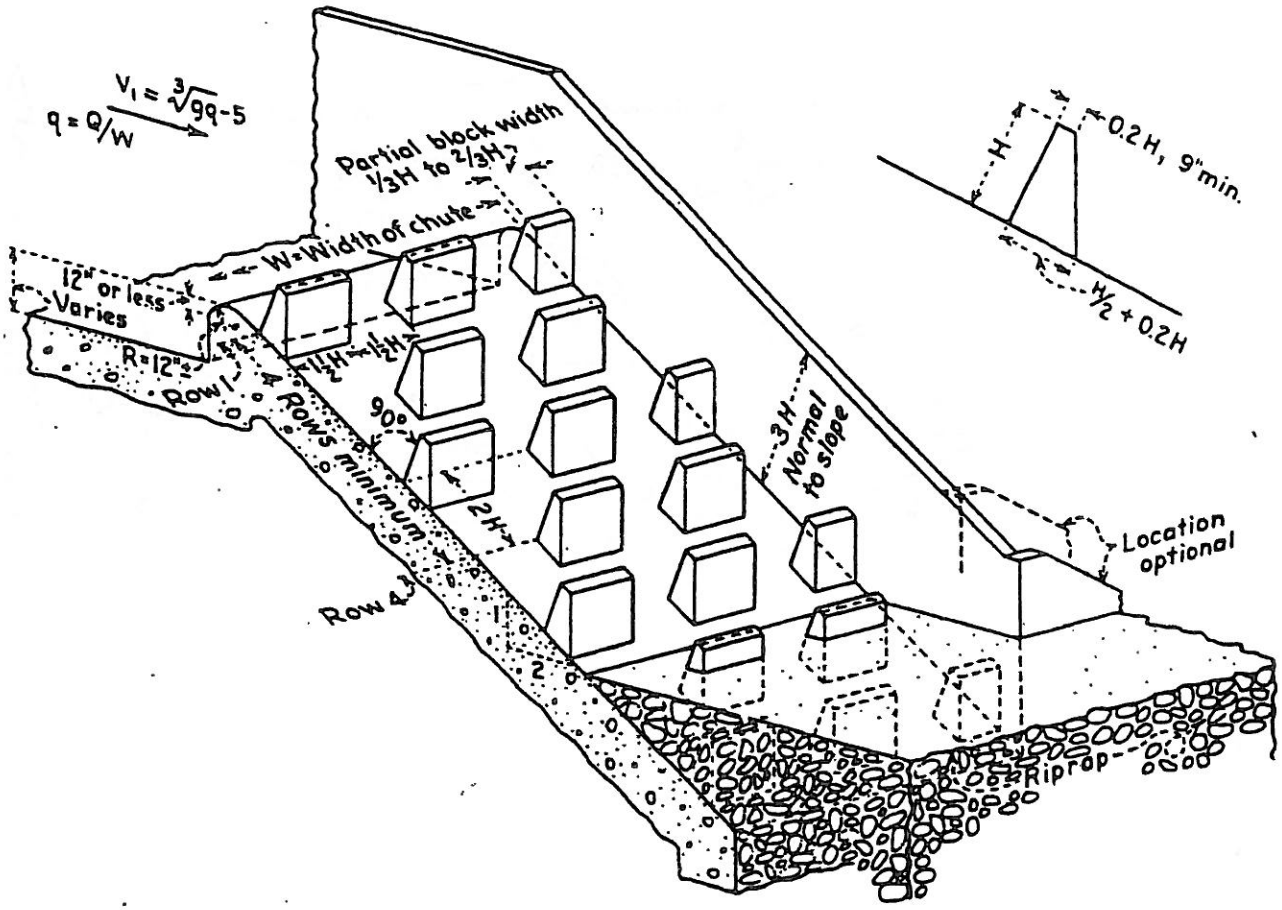


Note: See Figure 4.5 for design data

Source: "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR. January 1978

City of SPRINGDALE Arkansas	USBR TYPE III STILLING BASIN

Figure



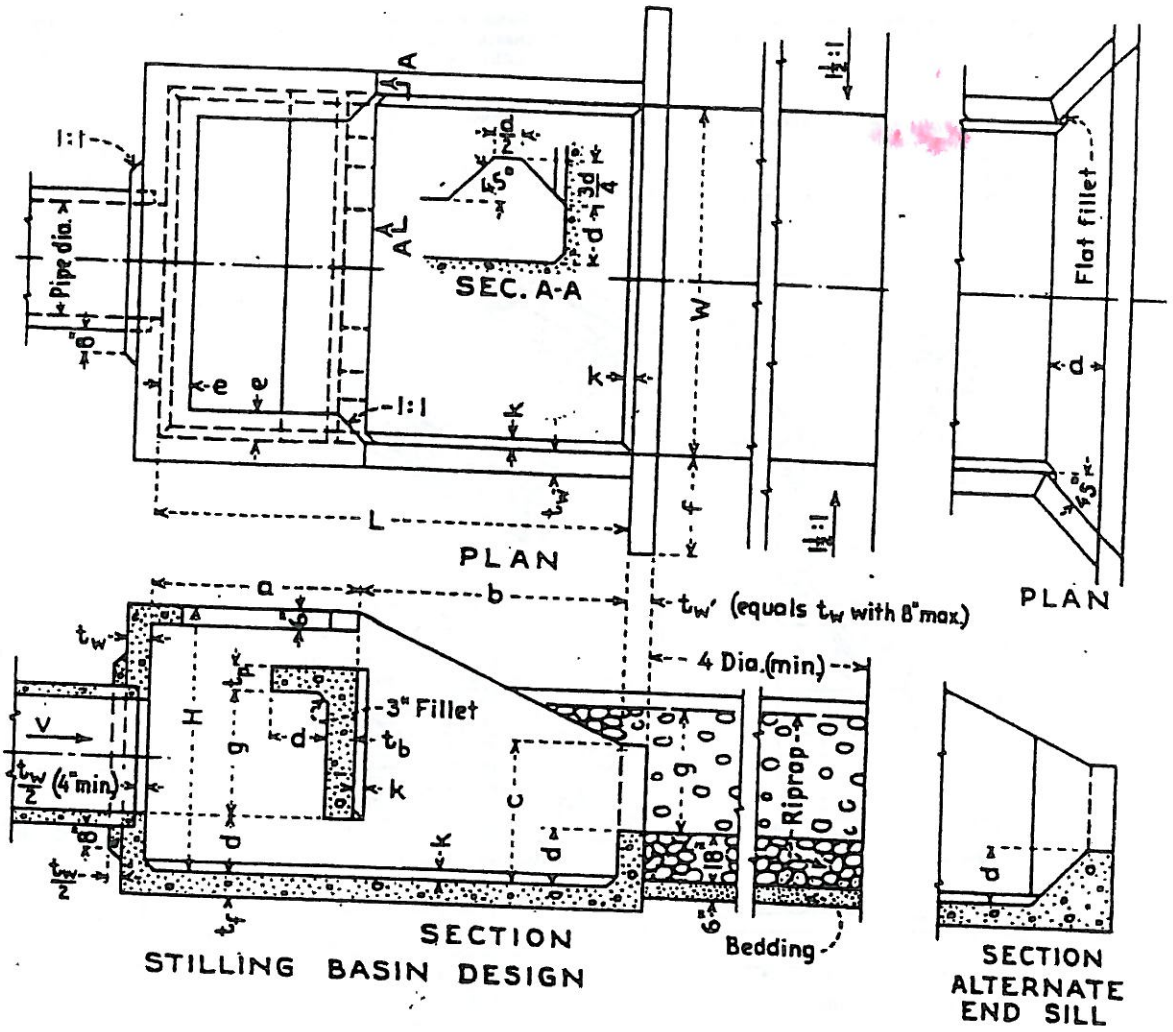
Note: See Figure 4.5 for design data

Source: "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR. January 1978

City of
SPRINGDALE
Arkansas

USBR TYPE IX
STILLING BASIN

Figure 4.3



Note: 1. See Figure 4.5 for design data
2. Refer to source for structural details

Source: "Design of Small Canal Structures"
USDI, BR, Denver 1974

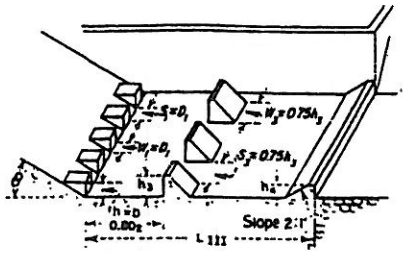
City of SPRINGDALE Arkansas	USBR TYPE VI STILLING BASIN

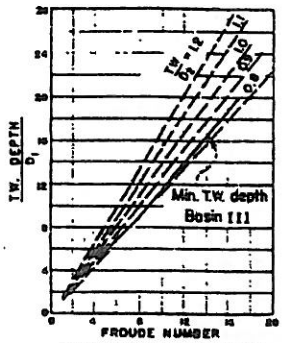
Figure 4.

SHORT STILLING BASINS FOR CANAL STRUCTURES, SMALL OUTLET WORKS AND SMALL SPILLWAYS (BASIN III)

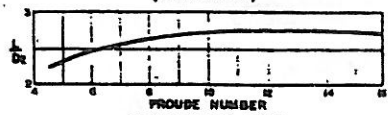
Jump and basin length reduced about 60 percent with chute blocks, baffle piers, and solid end sill.

For use on small spillways, outlet works, small canal structures where V_1 does not exceed 50–60 feet per second and Froude number is above 4.5.

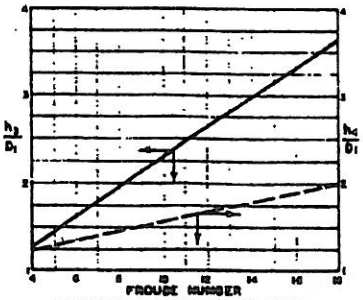




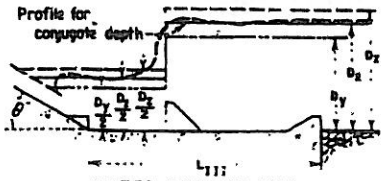
MINIMUM TW DEPTHS (SWEEPOUT)



LENGTH OF JUMP



HEIGHT OF BAFFLE BLOCKS AND END SILLS



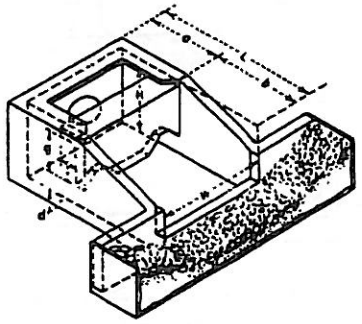
WATER SURFACE AND PRESSURE PROFILES

STILLING BASIN FOR PIPE ON OPEN CHANNEL OUTLET (BASIN VI)

For use on pipe or open channel outlets Sizes and discharges from table V_1 should not exceed 30 feet per second No tailwater required. Froude number usually 15 to 7 but not important

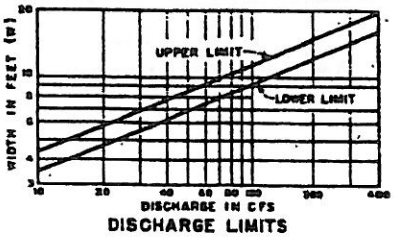
May substitute for Basin IV

Energy loss greater than in comparable jump, figure 4.4

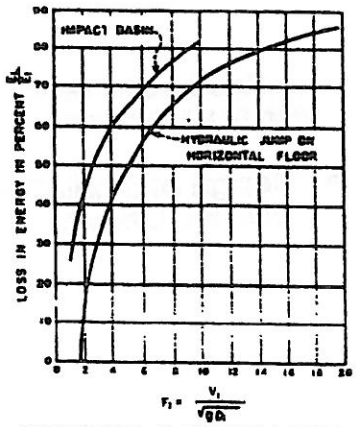


PIPE DIA IN	AREA SQ FT	Q	FEET AND INCHES W	H	L	a	b	c	d	g
18	1.77	21	5-6	4-3	7-4	3-3	4-1	2-4	0-11	2-1
24	3.14	36	6-9	5-3	9-8	3-11	5-1	2-10	1-2	2-6
30	4.91	59	8-0	6-3	10-0	4-7	6-1	3-4	1-4	3-0
36	7.07	85	9-3	7-3	12-4	5-3	7-1	3-10	1-7	3-6
42	9.62	115	10-6	8-3	14-8	6-0	8-0	4-5	1-9	3-11
48	12.57	151	11-9	9-3	16-8	6-9	8-11	4-11	2-0	4-5
54	15.90	191	13-0	9-9	17-4	7-4	10-0	5-5	2-2	4-11
60	19.63	236	14-3	10-9	19-0	8-0	11-0	5-11	2-5	5-4
72	28.27	339	16-6	12-3	22-0	9-3	12-9	6-11	2-9	6-2

BASIC DIMENSIONS



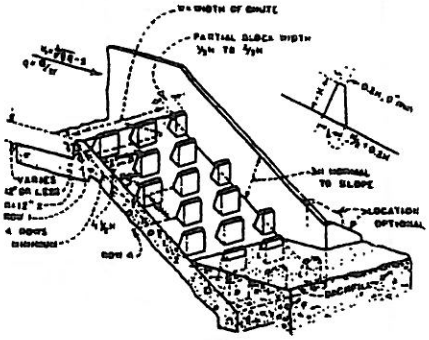
DISCHARGE LIMITS

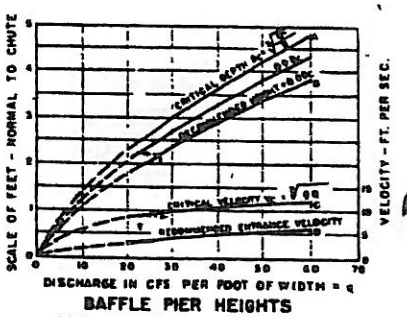


COMPARISON OF ENERGY LOSSES

BAFFLED APRON FOR CANAL OR SPILLWAY DROPS (BASIN IX)

For use in flow ways where water is to be lowered from one level to another. The baffle piers prevent undue acceleration of the flow as it passes down the chute. Since the flow velocities entering the downstream channel are relatively low, no stilling basin is required The chute may be designed to discharge up to 60 cubic feet per second per foot of width, and the drop may be as high as structurally feasible.





BAFFLE PIER HEIGHTS AND ALLOWABLE VELOCITIES

SIMPLIFIED DESIGN PROCEDURE

The baffled apron should be designed for the maximum expected discharge, Q, up to 60 c.f.s. per foot of width.

Entrance velocity V_1, should be as low as practical or $V_1 = \sqrt[4]{gq^2}$

See Figures 103, 105, 107 and 109 for sample approach pools.

Baffle pier height, H, should be about $0.8D_c$ to $0.9D_c$, Curve B above.

Baffle pier widths and spaces should be equal, up to $\frac{3}{4}$ H, but not less than H.

The slope distance between rows of baffle piers should be 2H, twice the baffle height H. See text for increase in row spacing on flat chutes.

Four rows of baffle piers are required to establish full control of the flow, although fewer rows have operated successfully At least one row of baffles should be buried in the backfill

The chute training walls should be three times as high as the baffle piers.

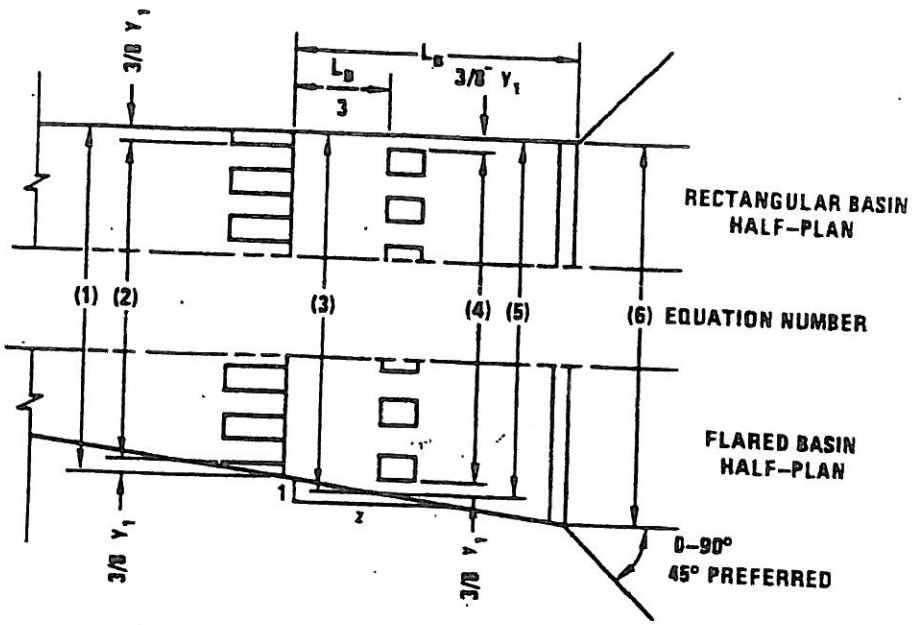
Riprap consisting of 6-to 12-inch stones should be placed at the downstream ends of training walls to prevent eddies from undermining the walls.

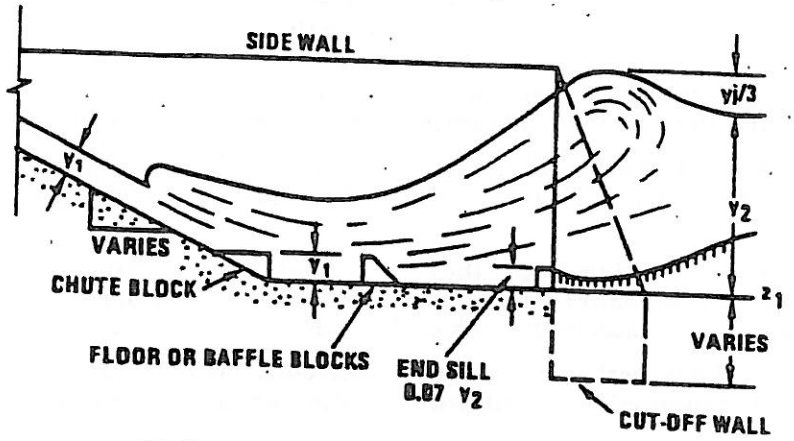
Source: "Hydraulic Design of Stilling Basins and Energy Dissipators", EM25 BR. January 1978

City of
SPRINGDALE
Arkansas

DESIGN DATA
USBR TYPE STILLING BASINS

Figure 4.5





(1) W_B = BASIN WIDTH UPSTREAM

(2) n BLOCKS AT 3/4 Y_1 ±

(3) 0.40 W_{B2} ≤ AGGREGATE BLOCK WIDTH ≤ 0.55 W_{B2}

(4) n BLOCKS AT 3/4 Y_1 $\frac{W_{B2}}{W_B}$ ±

(5) $W_{B2} = W_B + 2L_B/3z$

(6) $W_{B3} = W_B + 2L_B/z$

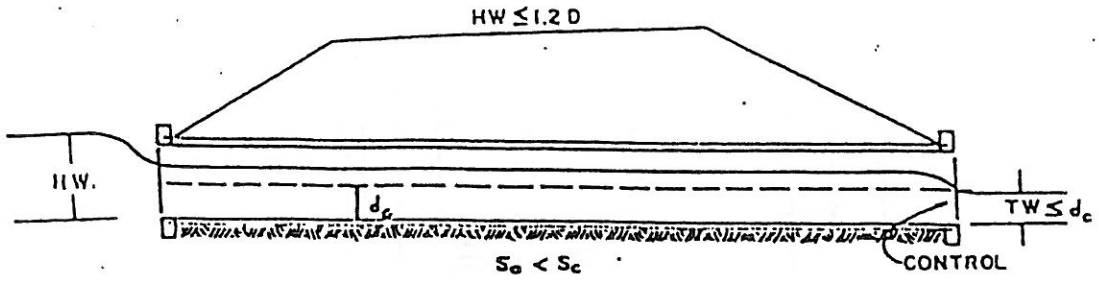
Source: "Hydraulic Design of Energy Dissipator for Culverts and Channels" HEC-14, FHWA, 1975

City of
SPRINGDALE
Arkansas

SAF TYPE
STILLING BASIN

Figure

Type 1
Culvert Flowing Part Full With Outlet Control and Tailwater Depth Below Critical Depth



Conditions

The entrance is unsubmerged (HW ≤ 1.2D), the slope at design discharge is sub-critical ($S_o < S_c$), and the tailwater is below critical depth (TW ≤ d_c).

The above condition is a common occurrence where the natural channels are on flat grades and have wide, flat flood plains. The control is critical depth at the outlet.

In culvert design, it is generally considered that the headwater pool maintains a constant level during the design storm. If this level does not submerge the culvert inlet, the culvert flows part full.

If critical flow occurs at the outlet the culvert is said to have "Outlet Control." A culvert flowing part full with outlet control will require a depth of flow in the barrel of the culvert greater than critical depth while passing through critical depth at the outlet.

The capacity of a culvert flowing part full with outlet control and tailwater depth below critical depth shall be governed by the following equation when the approach velocity is considered zero.

$$HW = d_c + \frac{V_c^2}{2g} + h_e + h_f - S_o L$$

HW = Headwater depth above the invert of the upstream end of the culvert in feet. Headwater must be equal to or less than 1.2D or entrance is submerged and Type 4 operation will result.

d_c = Critical depth of flow in feet = $\sqrt[3]{\frac{q^2}{32.2}}$

D = Diameter of pipe or height of box.

q = Discharge in cfs per foot.

V_c = Critical velocity in feet per second occurring at critical depth.

h_e = Entrance head loss in feet.

$$h_e = K_e \left(\frac{V_c^2}{2g} \right)$$

K_e = Entrance loss coefficient

h_f = Friction head loss in feet = $S_f L$.

S_f = Friction slope or slope that will produce uniform flow. For Type 1 operation the friction slope is based upon 1.1 d_c

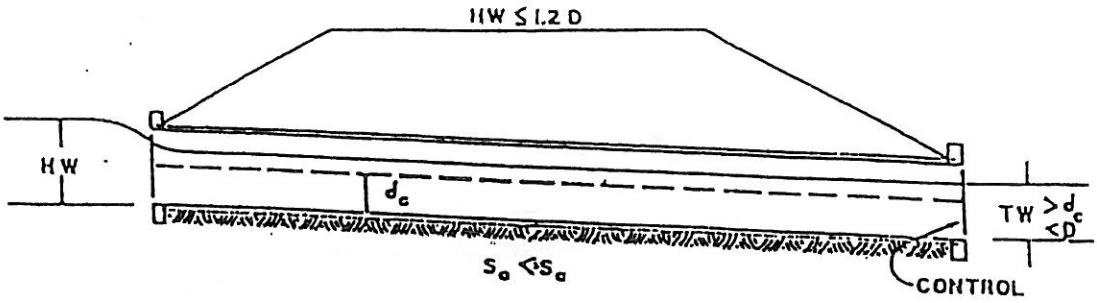
S_o = Slope of culvert in feet per foot.

L = Length of culvert in feet.

Source: City of Austin, TX

Type II

Culvert Flowing Part Full With Outlet Control And Tailwater Depth Above Critical Depth



Conditions

The entrance is unsubmerged (HW ≤ 1.2D), the slope at design discharge is subcritical ($S_o < S_c$), and the tailwater is above critical depth (TW > d_c).

The above condition is a common occurrence where the channel is deep, narrow and well defined.

If the headwater pool elevation does not submerge the culvert inlet, the slope at design discharge is subcritical, and the tailwater depth is above critical depth the control is said to occur at the outlet; and the capacity of the culvert shall be governed by the following equation when the approach velocity is considered zero.

$$HW = TW + \frac{V_{TW}^2}{2g} + h_e + h_f - S_oL$$

HW = Headwater depth above the invert of the upstream end of the culvert in feet. Headwater depth must be equal to or less than 1.2D or entrance is submerged and Type IV operation will result.

TW = Tailwater depth above the invert of the downstream end of the culvert in feet.

V_{TW} = Culvert discharge velocity in feet per second at tailwater depth.

h_e = Entrance head loss in feet.

$$h_e = K_e\left(\frac{V_{TW}^2}{2g}\right)$$

K_e = Entrance loss coefficient

h_f = Friction head loss in feet = S_fL

S_f = Friction slope or slope that will produce uniform flow. For Type II operation the friction slope is based upon TW depth.

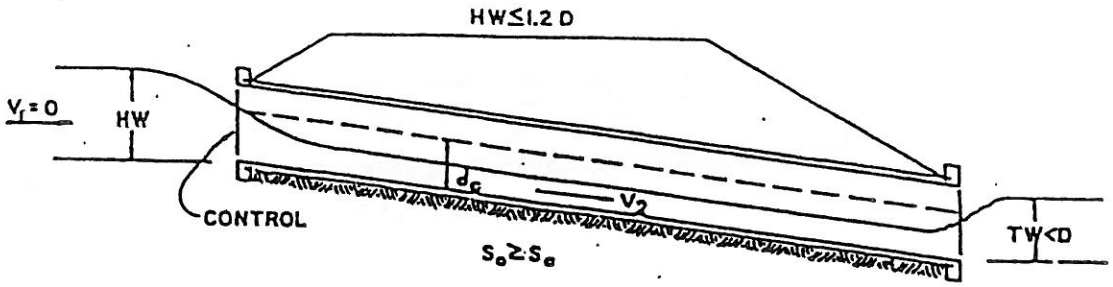
S_o = Slope culvert in feet per foot.

L = Length of culvert in feet.

Source: City of Austin, TX

Type III

Culvert Flowing Part Full With Inlet Control



Conditions

The entrance is unsubmerged (HW ≤ 1.2D) and the slope at design discharge is equal to or greater than critical (Supercritical) ($S_o \geq S_c$).

This condition is a common occurrence for culverts in rolling or mountainous country where the flow does not submerge the entrance. The control is critical depth at the entrance.

If critical flow occurs near the inlet, the culvert is said to have "Inlet Control". The maximum discharge through a culvert flowing part full occurs when flow is at critical depth for a given energy head. To assure that flow passes through critical depth near the inlet, the culvert must be laid on a slope equal to or greater than critical slope for the design discharge. Placing culverts which are to flow part full on slopes greater than critical slope will increase the outlet velocities but will not increase the discharge. The discharge is limited by the section near the inlet at which critical flow occurs.

The capacity of a culvert flowing part full with control at the inlet shall be governed by the following equation when the approach velocity is considered zero.

$$HW = d_c + \frac{V_2^2}{2g} + K_e \frac{V_2^2}{2g}$$

HW = Headwater depth above the invert of the upstream end of the culvert in feet. Headwater depth must be equal to or less than 1.2D or entrance is submerged and Type IV operation will result.

d_c = Critical depth of flow in feet = $\sqrt[3]{\frac{q^2}{32.2}}$

q = Discharge in cfs per foot.

V_2 = Velocity of flow in the culvert in feet per second.

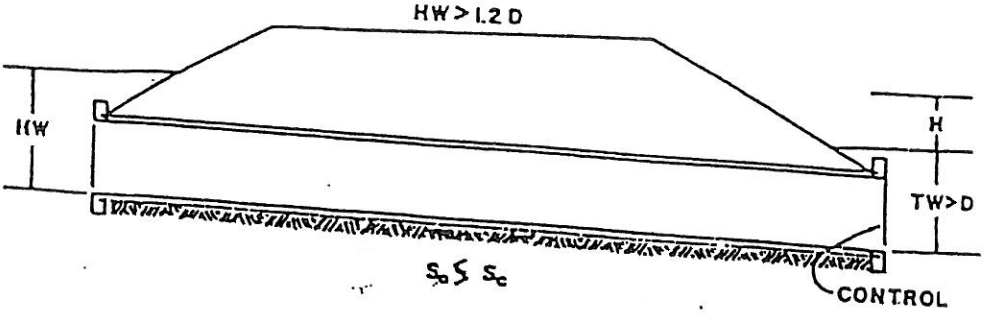
The velocity of flow varies from critical velocity at the entrance to uniform velocity at the outlet provided the culvert is sufficiently long. Therefore, the outlet velocity is the discharge divided by the area of flow in the culvert.

K_e = Entrance loss coefficient

Source: City of Austin, TX

Type IV-A

Culvert Flowing Full With Submerged Outlet



Conditions

(Submerged Outlet)

The entrance is submerged (HW > 1.2D). The tailwater completely submerges the outlet.

Most culverts flow with free outlet, but depending on topography, a tailwater pool of a depth sufficient to submerge the outlet may form at some installation. Generally, these will be considered at the outlet. For an outlet to be submerged, the depth at the outlet must be equal to or greater than the diameter of pipe of height of box. The capacity of a culvert flowing full with a submerged outlet shall be governed by the following equation when the approach velocity is considered zero. Outlet Velocity is based on full flow at the outlet.

$$HW = H + TW - S_oL$$

HW = Headwater depth above the invert of the upstream end of the culvert. Headwater depth must be greater than 1.2D for entrance to be submerged.

H = Head for culvert flowing full.

TW = Tailwater depth in feet.

S_o = Slope of culvert in feet per foot.

L = Length of culvert in feet.

Source: City of Austin, TX

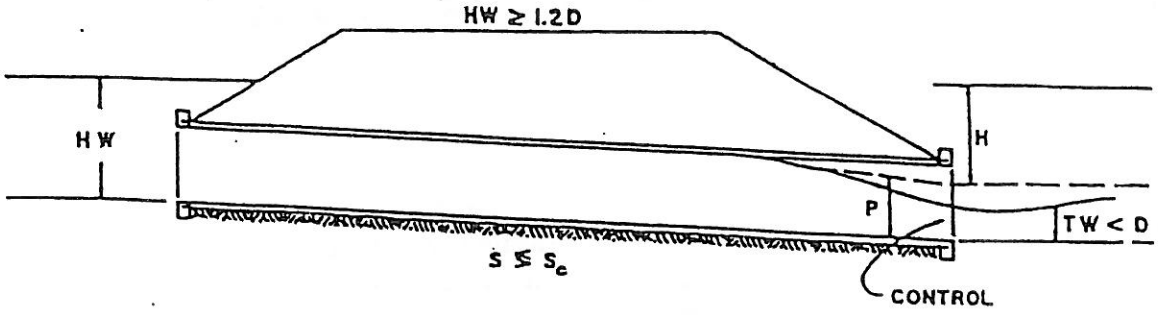
City of SPRINGDALE Arkansas

TYPES OF CULVERT FLOW

Figure 4.1(

Type IV-B

Culvert Flowing Full
With Partially Submerged Outlet



Conditions

(Partially Submerged Outlet)

The entrance is submerged (HW > 1.2D). The tailwater depth is less than D (TW < D).

The capacity of a culvert flowing full with a partially submerged outlet shall be governed by the following equation when the approach velocity is considered zero. Outlet velocity is based on critical depth if TW depth is less than critical depth. If TW depth is greater than critical depth, outlet velocity is based on TW depth.

$$HW = H + P - S_oL$$

HW = Headwater Depth above the invert of the upstream end of the culvert. Headwater depth must be greater than 1.2D for entrance to be submerged.

H = Head for culverts flowing full.

P = Pressure line height = $\frac{d_c + D}{2}$

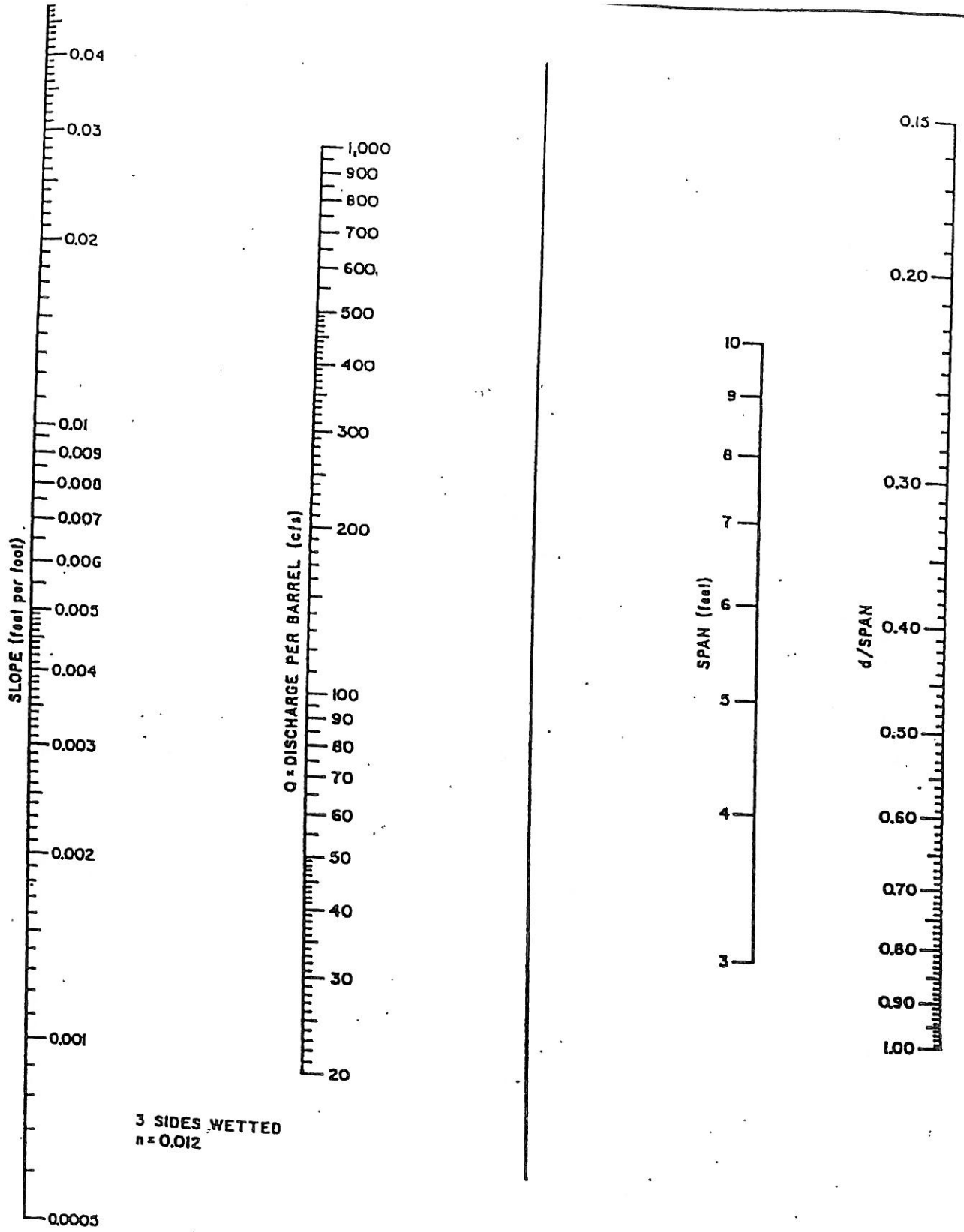
d_c = Critical depth in feet.

D = Diameter or height of structure in feet.

S_o = Slope of culvert in feet per foot.

L = Length of culvert in feet.

Source: City of Austin, TX

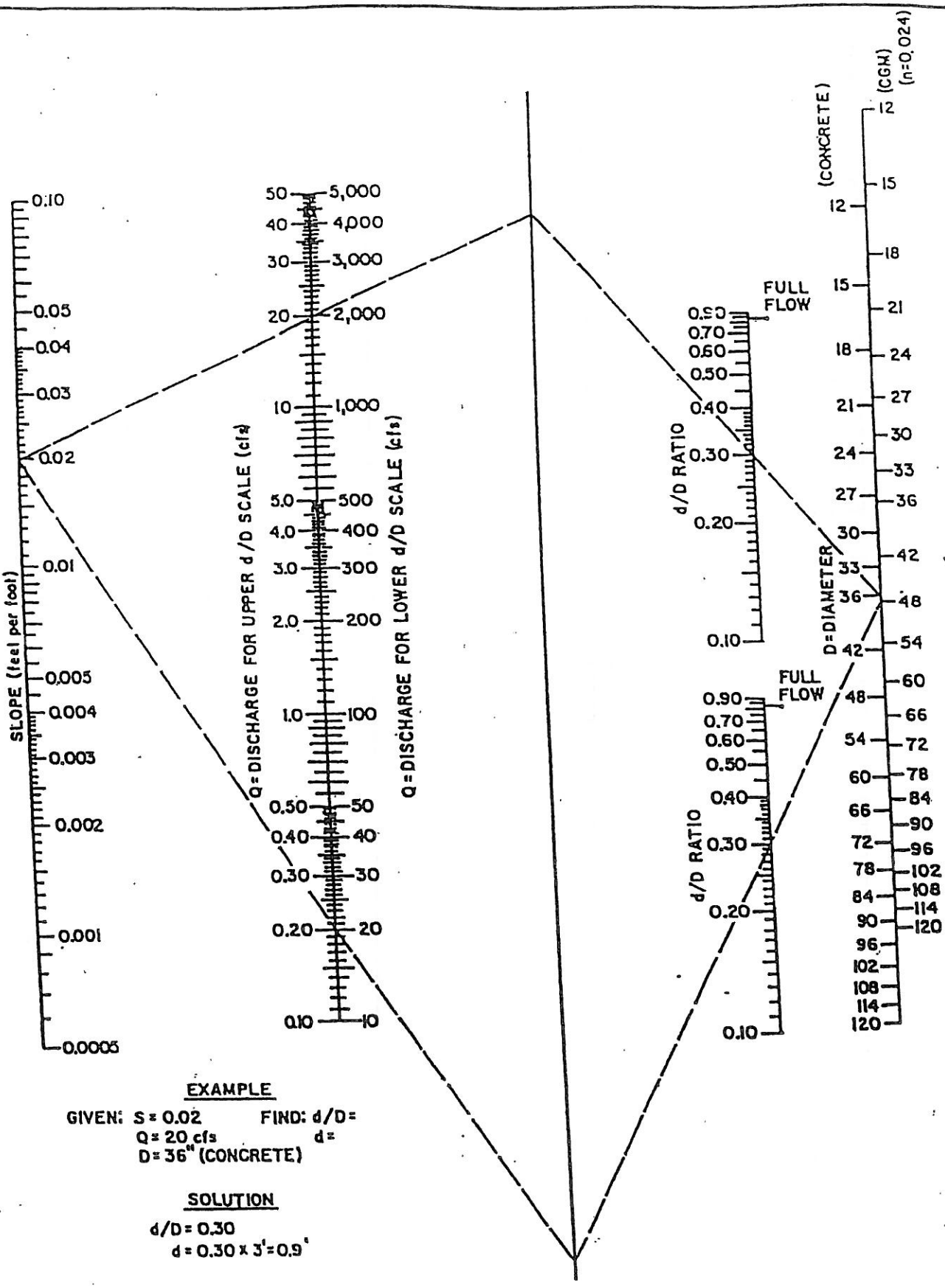


City of
SPRINGDALE
Arkansas

UNIFORM FLOW FOR BOX CULVERTS

Source: Texas Highway Department

Figure 4.12



EXAMPLE

GIVEN: S = 0.02 FIND: d/D =
Q = 20 cfs d =
D = 36" (CONCRETE)

SOLUTION

d/D = 0.30
d = 0.30 x 3' = 0.9'

City of SPRINGDALE Arkansas

UNIFORM FLOW FOR PIPE CULVERTS

Source: Texas Highway Department

Figure 4.13

Length Adjustment for Improved Hydraulics

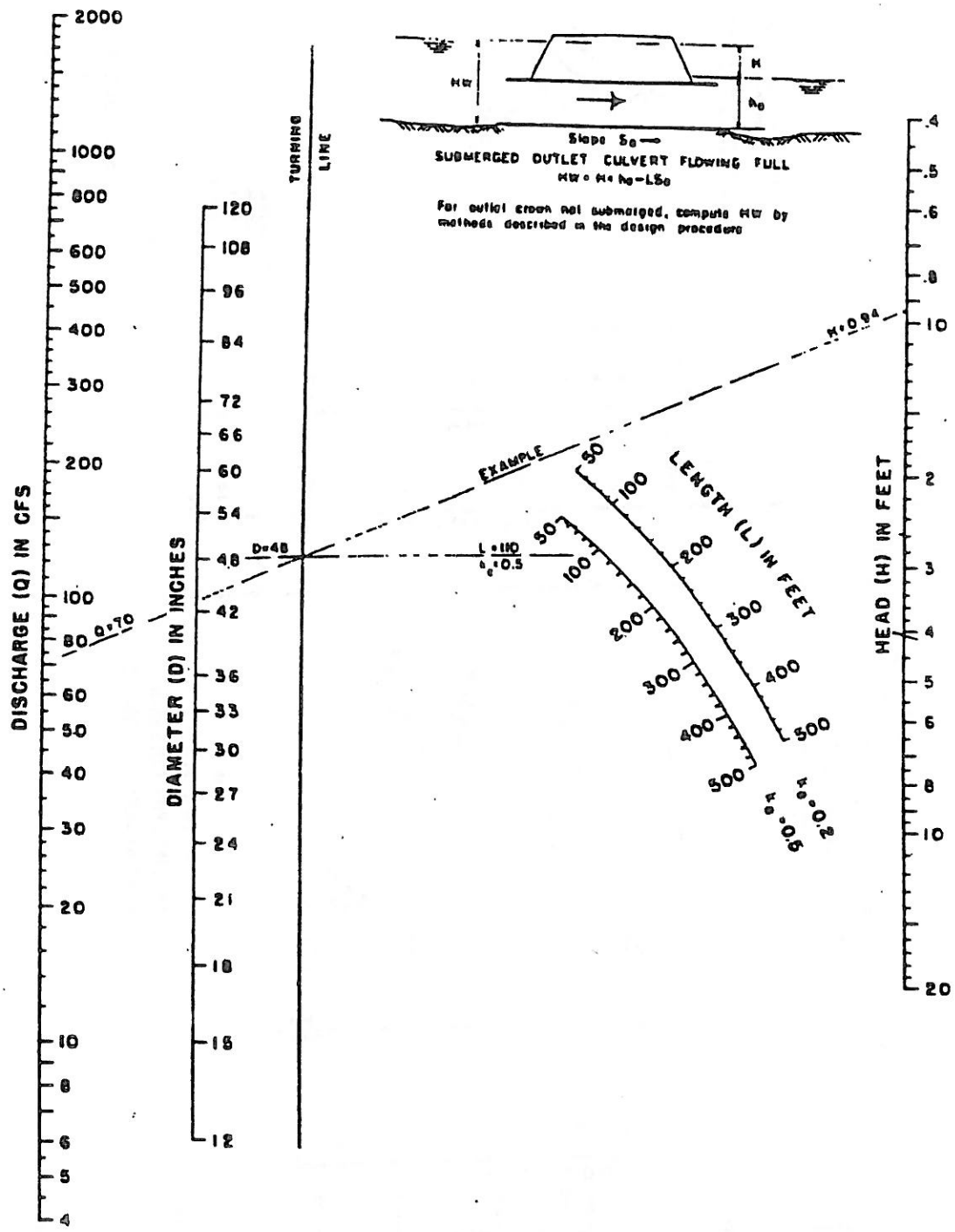
Pipe Diam. In Feet	Roughness Factor		Length Adjustment Factor $\left(\frac{n'}{n}\right)^2$
	Curves Based on $n=$	Actual $n'=$	
5'	.0328	.033	1.0
7'	.0320	.032	1.0
10'	.0311	.030	0.93
15'	.0302	.028	0.86

SOURCE: "HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
CIRCULAR CSP

Figure 4.

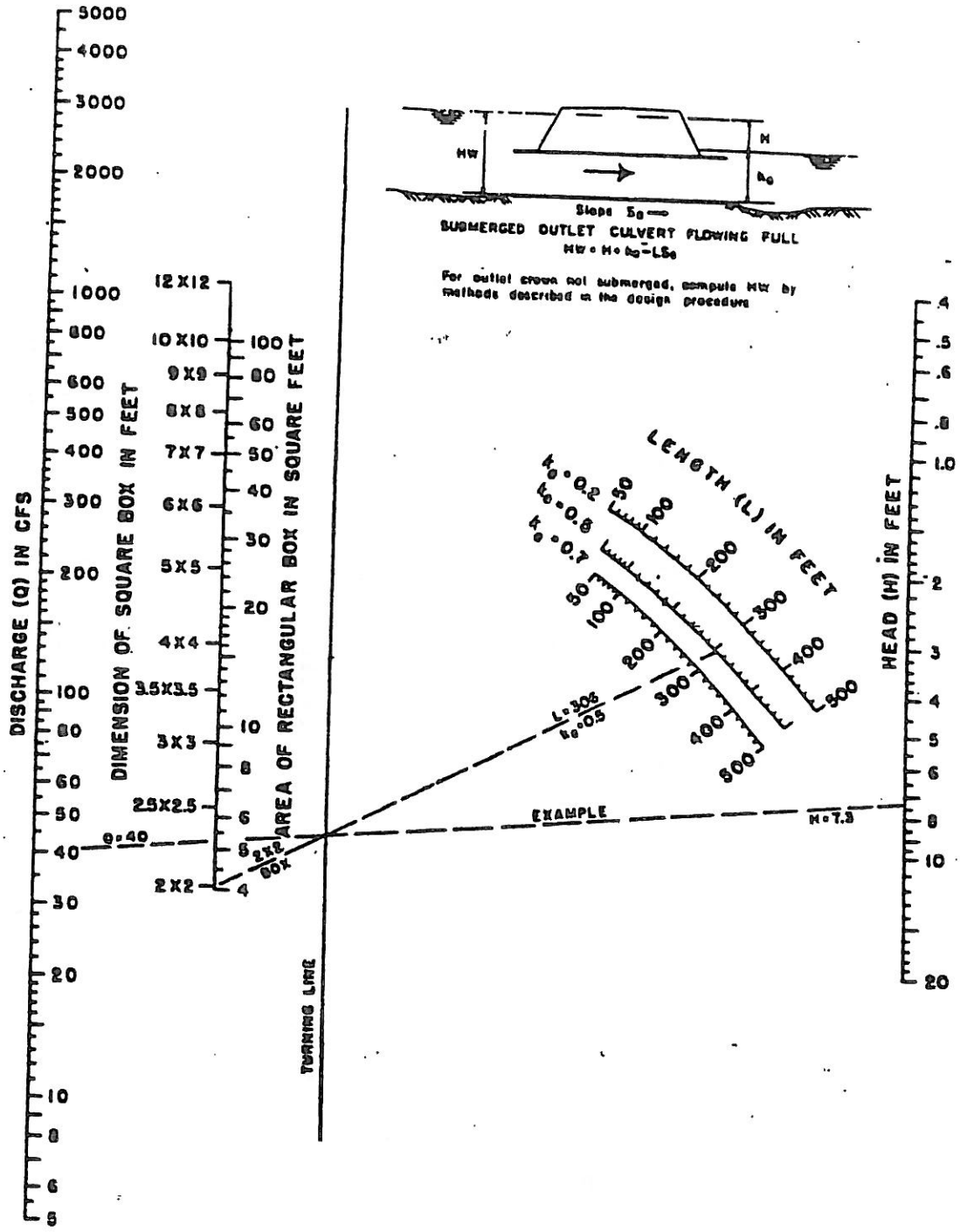


SOURCE: "HYDRAULIC CHARTS FOR THE SELECTION OF HIGHWAY CULVERTS", HEC-5, USDOT, FHA, DEC. 1965

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
CIRCULAR RCP

Figure 4.15

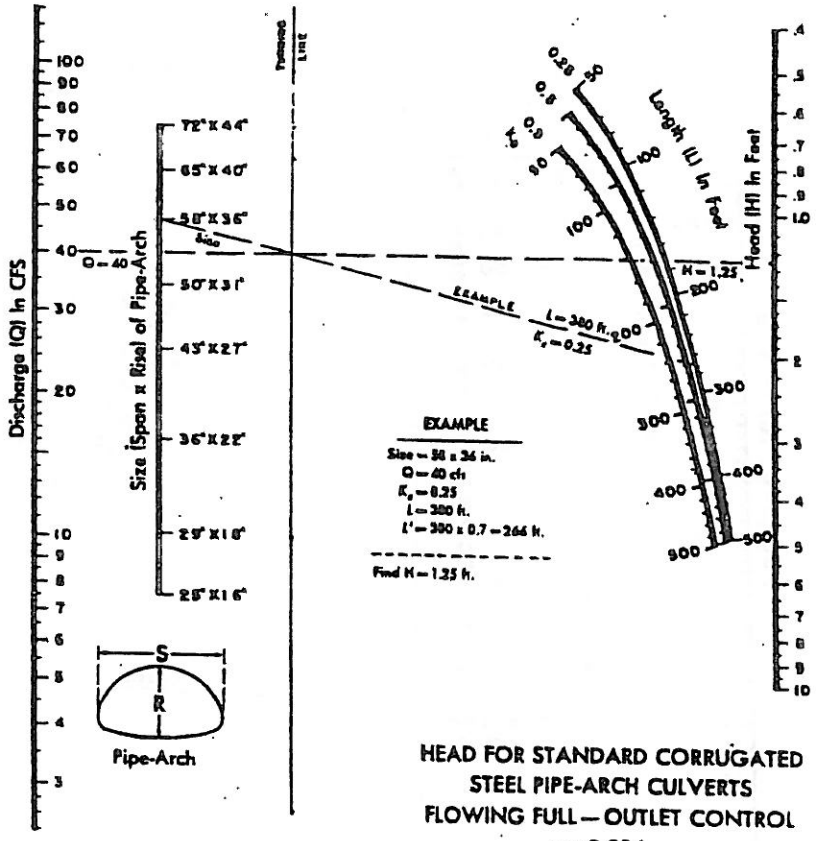


SOURCE: "HYDRAULIC CHARTS FOR THE SELECTION OF HIGHWAY CULVERTS", HEC-5, USDOT, FHA, DEC. 1965

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
BOX CULVERTS

Figure 4.1



HEAD FOR STANDARD CORRUGATED STEEL PIPE-ARCH CULVERTS FLOWING FULL — OUTLET CONTROL
$n = 0.024$

Length Adjustment for Improved Hydraulics

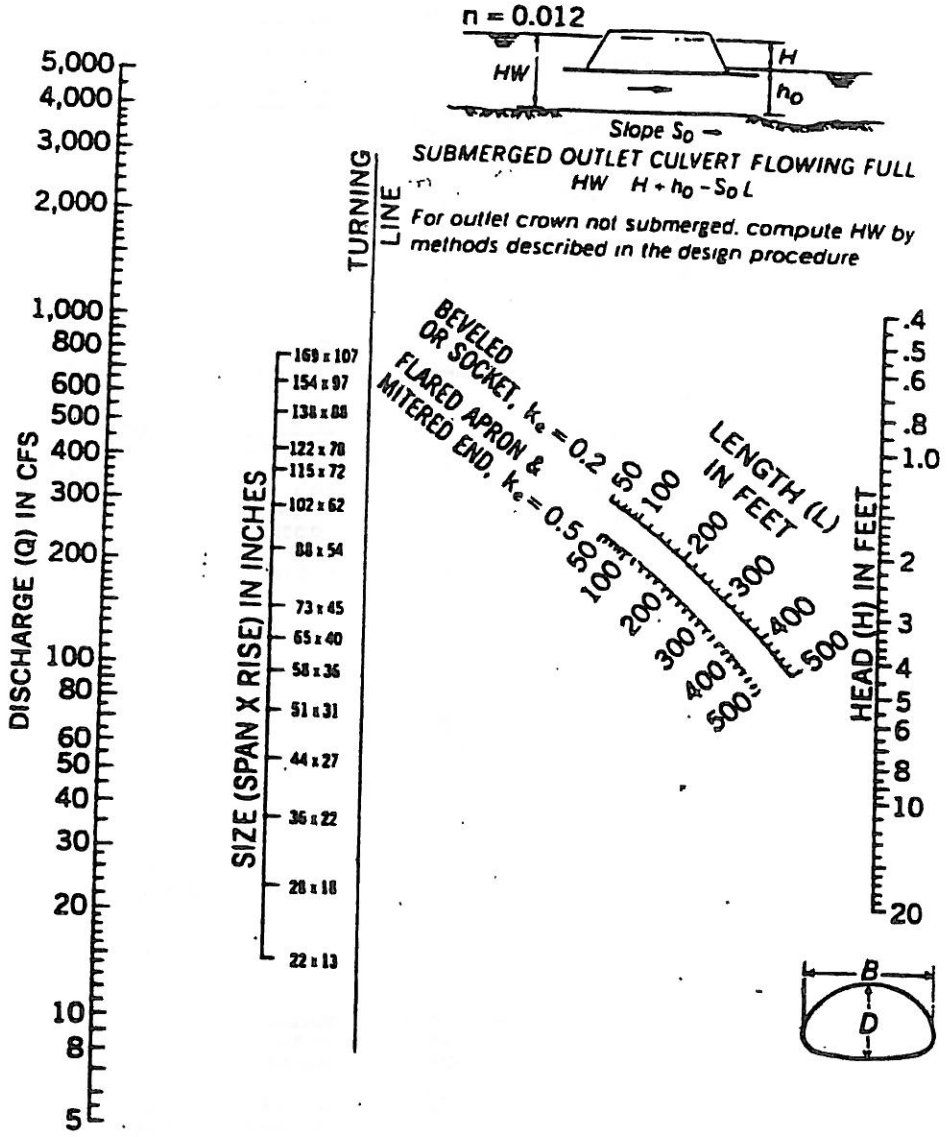
Pipe Diameter in Inches	Roughness Factor n' for Helical Corr.*	Length Adjustment Factor $\left(\frac{n'}{n}\right)^2$
12	.011	.21
24	.016	.44
36	.019	.61
48	.020	.70

SOURCE: "HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
CSP ARCH

Figure 4.17

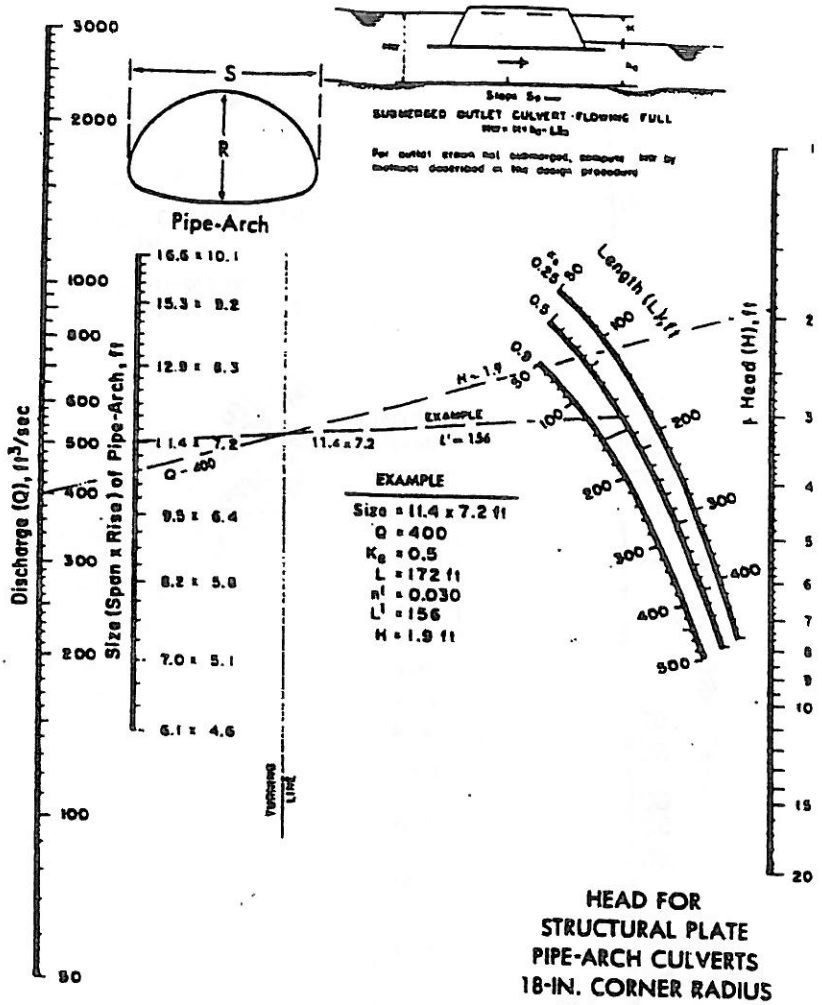


SOURCE: "CONCRETE PIPE DESIGN MANUAL", ACPA 1970

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
RCP ARCH

Figure 4.18



HEAD FOR
STRUCTURAL PLATE
PIPE-ARCH CULVERTS
18-IN. CORNER RADIUS
FLOWING FULL
OUTLET CONTROL

Outlet control. Head for *structural plate pipe-arch* culvert with 18-in. corner radius—with submerged outlet and flowing full. For 31-in. corner radius, use structure sizes with equivalent areas on the 18-in. corner radius scale.

Length Adjustment for Improved Hydraulics

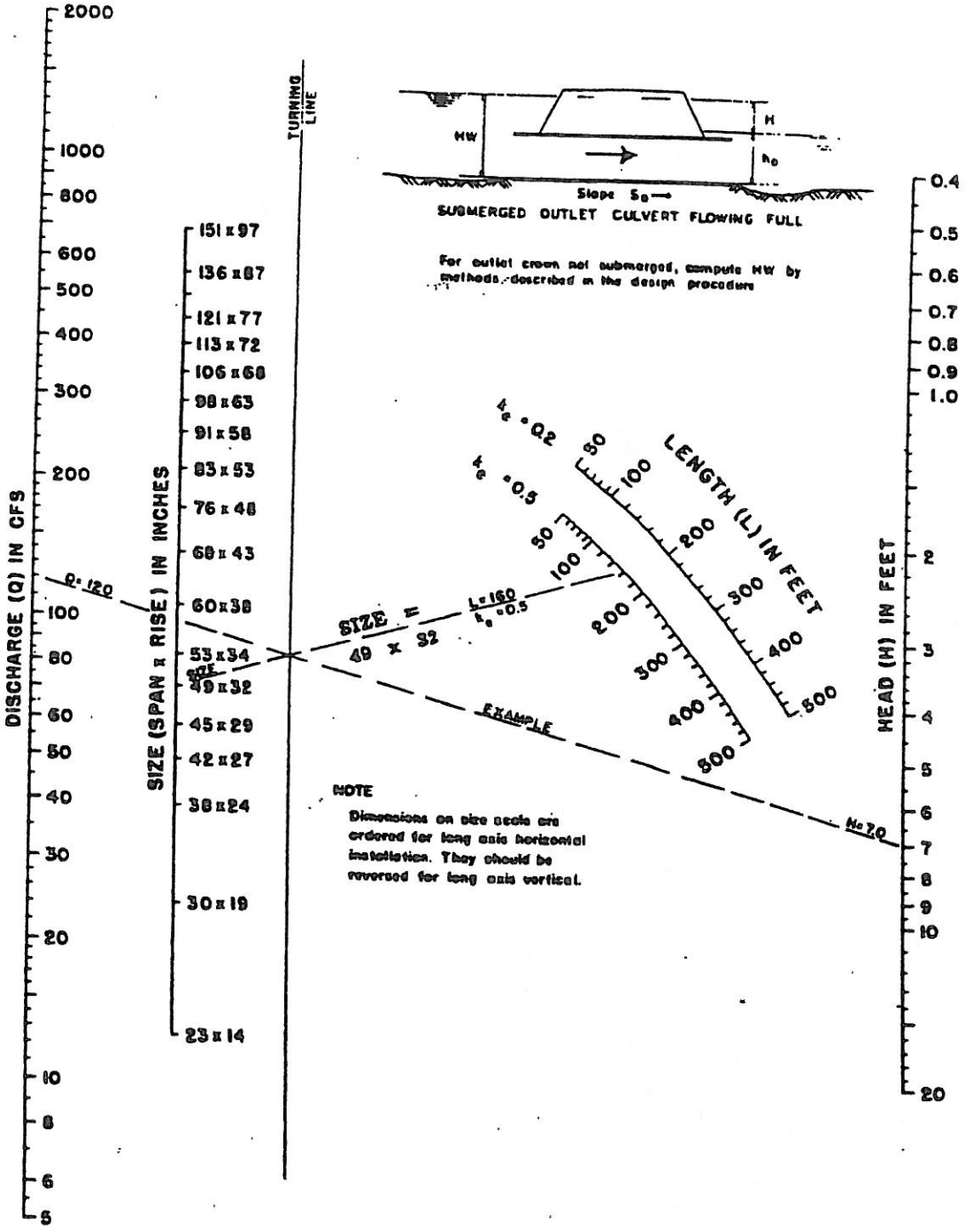
Pipe-Arch Size, ft	Roughness Factor		Length Adjustment Factor
	Curves based on n	Actual n' *	$\left(\frac{n'}{n}\right)^2$
6.1 × 4.6	0.0327	0.0327	1.0
8.1 × 5.8	0.0321	0.032	1.0
11.4 × 7.2	0.0315	0.030	0.907
16.6 × 10.1	0.0306	0.028	0.837

SOURCE: "HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
SPP ARCH

Figure 4.19



SOURCE: "HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

OUTLET CONTROL NOMOGRAPH
RCP ELLIPSE

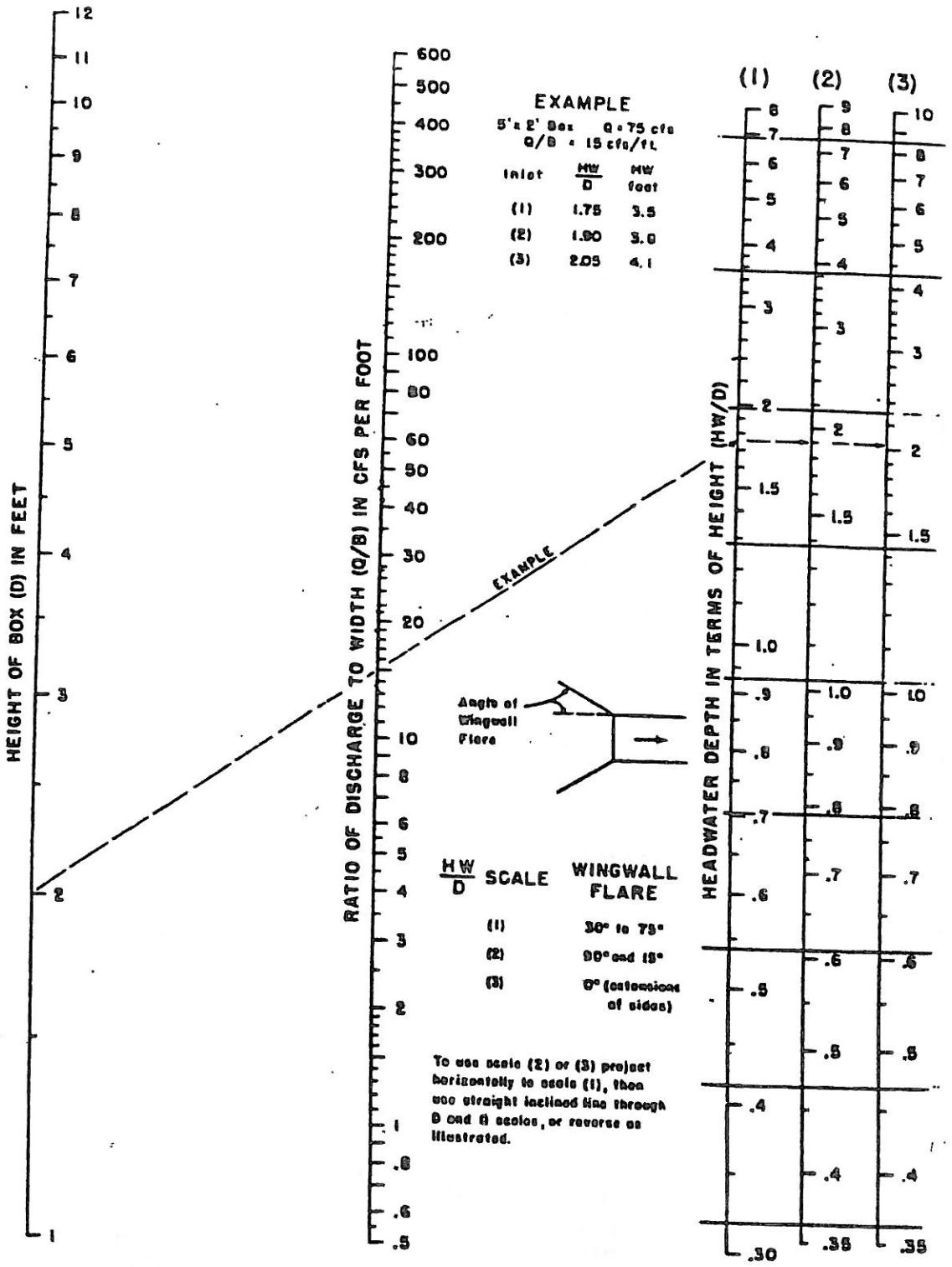
Figure 4.2

SOURCE: "CONCRETE PIPE DESIGN MANUAL", ACPA 1970
"HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

INLET CONTROL NOMOGRAPH
CIRCULAR PIPE

Figure 4.21

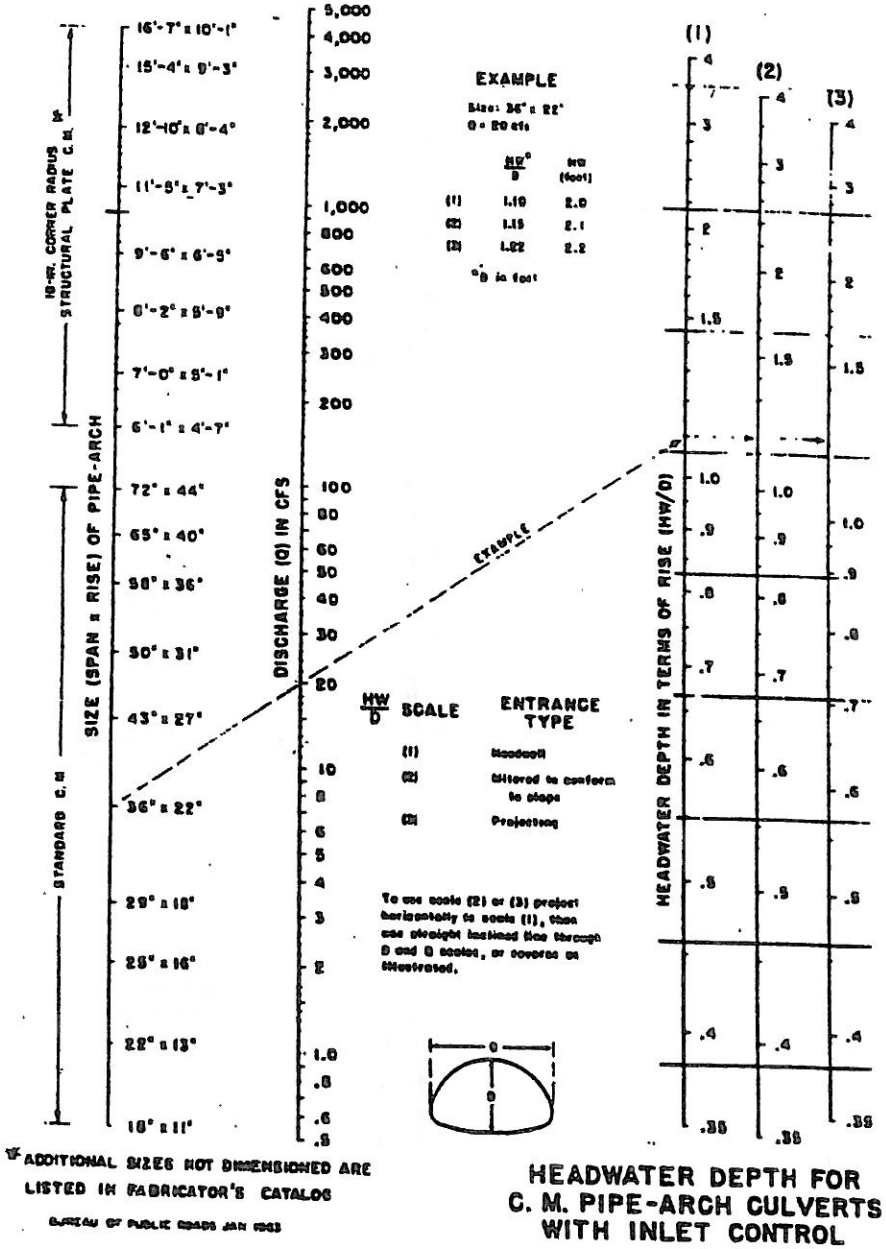


SOURCE: "HYDRAULIC CHARTS FOR THE SELECTION OF HIGHWAY CULVERTS", HEC-5, USDOT, FHA, DEC. 1965

City of SPRINGDALE Arkansas

INLET CONTROL NOMOGRAPH
BOX CULVERTS

Figure 4.1



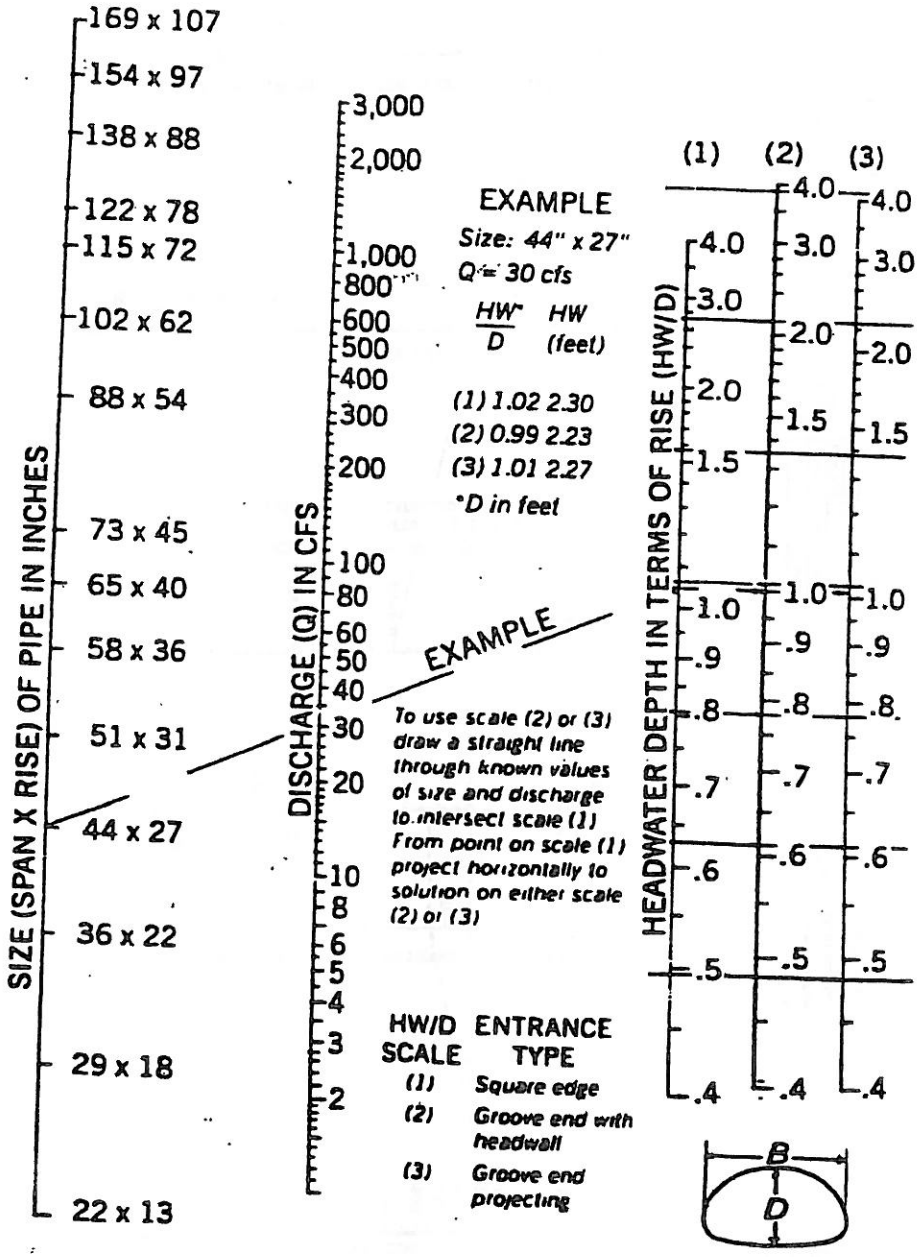
HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

SOURCE: "HYDRAULIC CHARTS FOR THE SELECTION OF HIGHWAY CULVERTS", HEC-5, USDOT, FHA, DEC. 1965

City of
SPRINGDALE
Arkansas

INLET CONTROL NOMOGRAPH
CSP ARCH

Figure 4.23

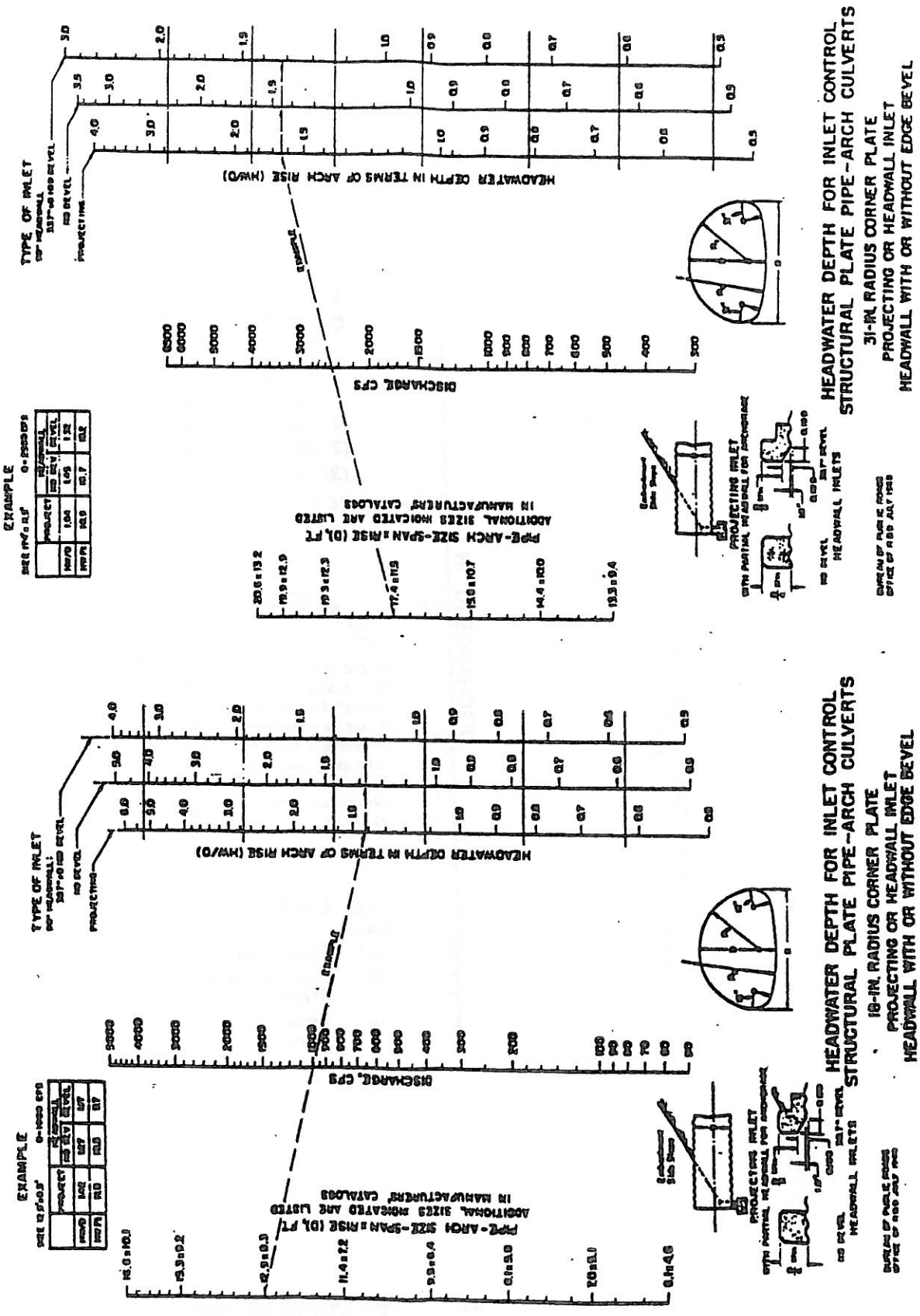


SOURCE: "CONCRETE PIPE DESIGN MANUAL", ACPA 1970

City of
SPRINGDALE
Arkansas

INLET CONTROL NOMOGRAPH
RCP ARCH

Figure 4

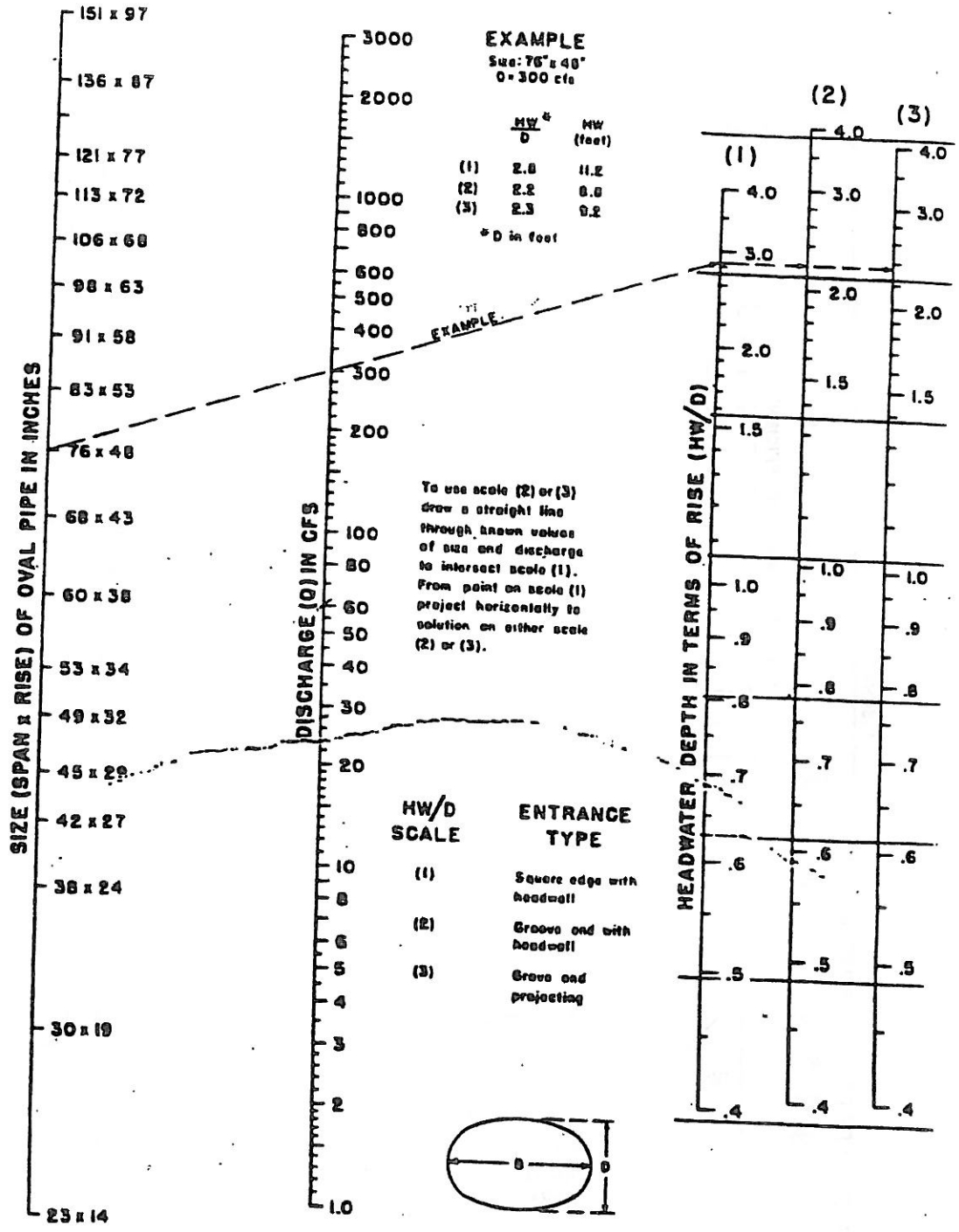


SOURCE: "HANDBOOK OF STEEL DRAINAGE & HIGHWAY CONSTRUCTION PRODUCTS", AISI 1971

City of
SPRINGDALE
Arkansas

INLET CONTROL NOMOGRAPH
SPP ARCH

Figure 4.25

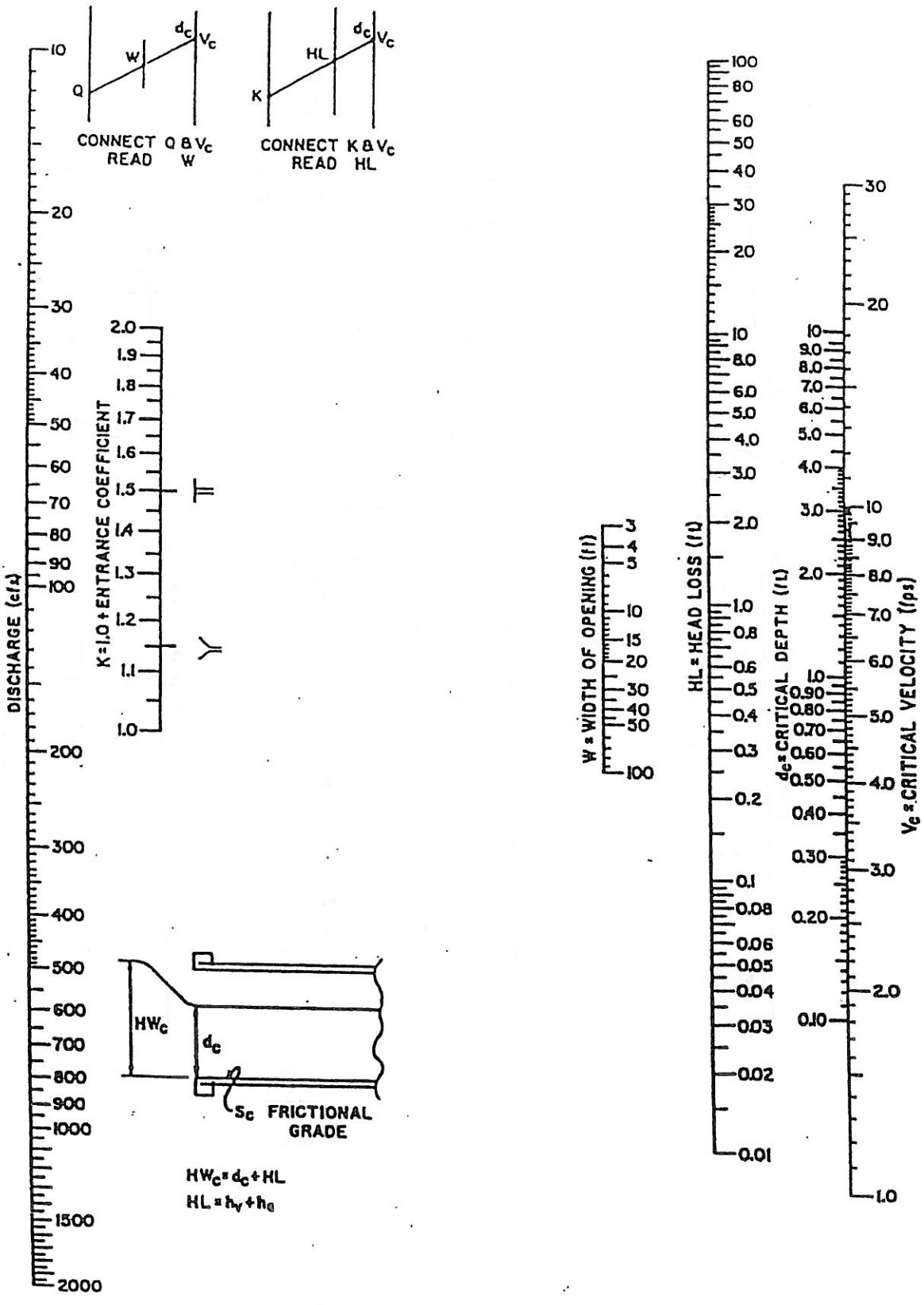


SOURCE: "HYDRAULIC CHARTS FOR THE SELECTION OF HIGHWAY CULVERTS", HEC-5, USDOT, FHA, DEC. 1965

City of
SPRINGDALE
Arkansas

INLET CONTROL NOMOGRAPH
RCP ELLIPSE

Figure 4.2



City of SPRINGDALE Arkansas

CRITICAL FLOW FOR BOX CULVERTS

SOURCE: Texas Highway Department

Figure 4.27