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SECTION III - FLOW IN STORM DRAINS AND DRAINAGE APPURTENANCES

FIGURES:

SECTION III - FLOW IN STORM DRAINS AND DRAINAGE APPURTENANCES

3.1 GENERAL

A general description of storm drainage systems and quantities of storm runoff is contained in this Section and Section II of this manual. It is the purpose of this section to consider the significance of the hydraulic elements of storm drain system.

Hydraulically, storm drainage systems are conduits (open or closed) in which unsteady and non-uniform free flow exists. Storm drains accordingly are designed for open-channel flow to satisfy, as well as possible, the requirements for unsteady and non-uniform flow. Steady flow conditions may or may not be uniform.

3.2 STORM SEWER DESIGN REQUIREMENTS

In preparation of storm sewer design, the following is a list of minimum requirements:

1. A plan of the drainage area that ties to the City of Bentonville monumentation network, which is available on the City of Bentonville's GIS map at www.bentonvillear.com. Contours shall be a minimum of 2 feet, regardless of the plan scale. This plan shall include all proposed street, drainage, and grading improvements with flow quantities and direction at all critical points. All areas and subareas for drainage calculations shall be clearly distinguished.

2. Complete hydraulic data showing all calculations, including a copy of all nomographs, graphs, charts and tables used for the calculations shall be submitted. Computer generated computations and output are accepted and subject to review by City Engineer.

3. A plan and profile of all proposed improvements at a scale of 1" = 20' to 1" = 50' horizontal and 1" = 5' vertical shall be submitted. This plan shall include the following: Location, sizes, flow line elevations and grades of pipes, channels, boxes, manholes and other structures drawn on standard plan-profiles; a list of the kind and quantities of materials; typical sections of all boxes and channels; location of property lines, street paving, sanitary sewers and other utilities; and standard installation details for all facilities.

4. A field study of the downstream capacity is highly suggested of all drainage facilities and the effect of additional flow from the area to be improved shall be submitted. If the effect is to endanger property or life, the problem must be resolved before the plan will be given approval.

5. Stormwater flow quantities in the street shall be shown at all street intersections and all inlet openings and locations where flow is removed from the streets. This shall include the hydraulic calculations for all inlet openings and street flow capacities. The street flow shall be limited according to Section VI, Flow in Streets.

6. Any additional information deemed necessary by the City Engineer for an adequate consideration of the storm drainage effect on the City of Bentonville and surrounding areas must be submitted.

3.3 REQUIREMENTS RELATIVE TO IMPROVEMENTS

3.3.1 DESIGN CRITERIA / STORM FREQUENCIES

Minimum design frequencies shall be as follows:

a. Dams	100 Year
b. BRIDGES for HIGHWAYS or ARTERIAL or COLLECTOR STREETS	100 Year
c. Conduits for HIGHWAYS and major ARTERIAL STREETS	50 Year
d. Conduits for minor ARTERIAL STREETS	25 Year
e. Conduits for COLLECTOR STREETS	25 Year
f. Conduits, other	10 Year
g. Conduits for local or Subdivision streets	10 Year
h. Open Channels	25 Year
i. Sidewalk and Trail conduits	10 Year
j. Other Land Use Areas	Refer to Street system, precipitation event table.

Note: For all scenarios, overflow limits for 100 year events shall be maintained.

Design frequencies above are minimum requirements. It is the Engineer's responsibility to comply with state and federal regulations and guidelines. It is also the Engineer's responsibility to ensure storm sewer design will not adversely impact adjacent properties.

3.3.2 BRIDGES AND CULVERTS

Bridges or culverts shall be provided where streets or alleys cross water courses and shall be designed to accommodate a <u>100</u>-year storm and meet Federal Emergency Management Agency (FEMA) regulations on FEMA regulated floodways or floodplains. Additionally, the following requirements shall be met: A 50-year frequency storm without overtopping on principal arterial roads and streets, 25-year frequency storm without overtopping for minor arterials and collectors, and a 10-year frequency storm without overtopping for all other streets. The structure shall be designed in accordance with current Arkansas Highway and Transportation Department specification materials and to carry a minimum H-20 loadings in any case.

Where same structure is to be constructed in a location other than existing or proposed street right-of-way, H-10 loadings may be used.

3.3.3 CLOSED STORM SEWER

Closed storm sewers for all conditions other than required in Section 3.3.1 above shall be designed to accommodate a 10-year frequency storm, based on the drainage area involved. Same shall either be R.C. box culverts for minimum H-20 loadings on street right-of-way or H-10 loadings elsewhere, or R.C. pipe ASTM Class III when sufficient cover is provided or ASTM Class IV when less than one-foot under paving or less than two feet of cover.

HDPE, corrugated metal, and other material pipe may be allowed at the discretion of the City Engineer.

3.3.4 MINIMUM GRADES

Storm drains should operate with velocities of flow sufficient to prevent excessive deposition of solid material; otherwise, objectionable clogging may result. The controlling velocity is near the bottom of conduits and considerably less than the mean velocity. Storm drains shall be designed to have a minimum velocity flowing full of 2.5 fps. Table 3.1 indicates the grades for both concrete pipe (n = 0.012) and for corrugated metal pipe (n = 0.024) to produce a velocity of 2.5 fps, which is considered to be the lower limit of scouring velocity. Grades for closed storm sewers and open paved channels shall be designed so that the velocity shall not be less than 2.5 fps nor exceed 12 fps. All other structures such as junction boxes or inlets shall be in accordance with City standard drawings. The minimum slope for standard construction procedures shall be 0.50 percent when possible. Any variance must be approved specifically in writing by the City Engineer.

Table 3.1
Minimum Slope Required
to Produce Scouring Velocity

Pipe Size (Inches)	Concrete Pipe Slope ft./ft.	Corrugated Metal Pipe ft./ft.
18	0.0018	0.0060
21	0.0015	0.0049
24	0.0013	0.0041
27	0.0011	0.0035
30	0.0009	0.0031
36	0.0007	0.0024
42	0.0006	0.0020
48	0.0005	0.0016
54	0.0004	0.0014
60	0.0004	0.0012
66	0.0004	0.0011
72	0.0003	0.0010
78	0.0003	0.0009
84	0.0003	0.0008
96	0.0002	0.0007

Closed storm sewers extending to farthest downstream point of development shall give consideration to velocities and discharge energy dissipaters to prevent erosion and scouring along downstream properties.

3.3.5 OPEN DITCHES (EARTH CHANNELS)

Open earth ditches shall be designed to carry the 25-year frequency storm and to accommodate the 100-year frequency storm without encroaching on existing buildings, infrastructures, or improvements. The 100-year water surface elevation must not be increased in conjunction with the ditch.

Ditches shall have a gradient to keep the velocity within 1.5 to 5.0 feet per second in unpaved channels unless approved by City Engineer. **Sod shall be required to the 25-year storm depth unless approved by the City Engineer. Side slopes shall have a minimum slope ratio of 3:1 unless approved specifically in writing by the City Engineer.** Designer's attention is directed to the fact that the Subdivision Ordinance prohibits encroachment of buildings and improvements on natural or designated drainage channels, or the channel's floodways. Floodplains are areas of land adjacent to an open channel (not in closed storm sewers) that may flood during a 100-year rain. Such floodways and floodplains shall be indicated on drainage improvement plans and individual plot plans.

3.3.6 OPEN PAVED CHANNELS

Open paved channels are to be used where flow velocity exceeds 5 fps or channel grade is less than 1.00%, unless approved by the City Engineer. Open paved storm drainage channels shall be designed to carry a 25-year frequency storm and to accommodate a 100-year frequency storm without encroaching on existing buildings, infrastructures, or improvements. Such channels may be of different shapes according to existing conditions. **The channel shall be of concrete with a minimum four-inch thickness paved to a point 1' above the 25-year storm depth. Six-inch minimum thickness is required where maintained by machinery.** Thickness of concrete and amount of reinforcing steel shall depend upon conditions at site and size of channel. Gabion or riprap lined channels may be used in place of paved channels where approved by the City Engineer.

3.4 FULL OR PART FULL FLOW IN STORM DRAINS

3.4.1 GENERAL

The size of closed storm sewers, open channels, culverts and bridges shall be designed so that their capacity will not be less than the volume computed by using the Manning Formula. All storm drains shall be designed by the application of the continuity equation and Manning Formula either through the appropriate charts and nomographs, or by direct solutions of the equations as follow:

$Q = AV$ and

$$Q = \frac{1.49}{n} AR^{2/3} S_f^{1/2}$$

Q = Capacity = discharge in cubic feet per second

A = Cross-sectional area in conduit or channel in square feet

R = Hydraulic radius = $A \div P$

P = Wetted perimeter (feet)

S_o = Slope of pipe (feet per feet)

S_f = Friction slope of energy grade line

n = Coefficient of roughness of pipe

V = Velocity in pipe (feet per second)

There are several general rules to be observed when designing storm sewer runs. When followed, they will tend to alleviate or eliminate the common mistakes made in storm sewer design. These rules are as follow:

1. Select pipe size and slope so that the velocity of flow will increase progressively, or at least will not appreciably decrease at inlets, bends or other changes in geometry or configuration. An 18" pipe diameter is the minimum acceptable pipe diameter for maintenance purposes. Where used, arch pipe sizes shall be hydraulically equivalent to the round pipe size.

2. Do not discharge the contents of a larger pipe into a smaller one, even though the capacity of the smaller pipe may be greater due to steeper slope.

3. At changes in pipe sizes, match the soffits or crown of the two pipes at the same level rather than matching the flow lines.

4. Conduits are to be checked at the time of their design with reference to critical slope. If the slope of the line is greater than critical slope, the unit will likely be operating under entrance control instead of the originally assumed normal flow. Conduit slopes should be kept below critical slope if at all possible. This also removes the possibility of a hydraulic jump within the line.

3.4.2 PIPE FLOW CHARTS

Pipe flow charts are nomographs for determining flow properties in circular pipe, elliptical pipe and pipe-arches. Figures 3.1 through 3.9 are nomographs based upon a value of "n" of 0.024 for corrugated metal and 0.012 for concrete. The charts are self-explanatory, and their use is demonstrated by the example in Figure 3.1.

For values of "n" other than 0.012, the value of Q should be modified by using the formula below:

$$Q_c = \frac{Q_n\,(0.012)}{n_c}$$

Q_c = Flow based upon n_c

n_c = Value of "n" other than 0.012

Q_n = Flow from nomograph based on n = 0.012

This formula is used in two ways. If $n_c = 0.015$ and Q_c is unknown, use the known properties to find Q_n from the nomograph, and then use the formula to convert Q_n to the required Q_c. If Q_c is one of the known properties, you must use the formula to convert Q_c (based on n_c) to Q_n (based on n = 0.012) first, and then use Q_n and the other known properties to find the unknown value on the nomograph.

Example 1:

Given: Slope = 0.005, depth of flow (d) = 1.8', diameter D = 36", n = 0.018

Find: Discharge (Q)

First determine d/D = 1.8'/3.0' = 0.6. Then enter Figure 3.1 to read Q_n = 34 cfs. Using the formula Q_c = 34 (0.012/0.018) = 22.7 cfs (answer).

Example 2:

Given: Slope = 0.005; diameter D = 36", Q = 22.7 cfs, n = 0.018

Find: Velocity of flow (fps)

First convert Q_c to Q_n so that nomograph can be used. Using the formula Q_n = 22.7 (0.018)/(0.012) = 34 cfs, enter Figure 3.1 to determine d/D = 0.6. Now enter Figure 3.3 to determine V = 7.5 fps (answer).

3.4.3 ROUGHNESS COEFFICIENTS

Roughness coefficients for storm drains are as follows on Table 3.2.

Table 3.2

Roughness Coefficients "n" for Storm Drains

Materials of Construction	Design Manning Coefficient	Range of Manning Coefficient
Concrete Pipe	0.013	0.011-0.015
Corrugated Metal Pipe		
o Plain or Coated	0.024	0.022-0.026
o Paved Invert	0.020	0.018-0.022

3.4.4 MANHOLE LOCATIONS

Manholes or maintenance access ports will be required whenever there is a change in size, direction, elevation, grade, or where there is a junction of two or more sewers. A manhole may be required at the beginning and/or at the end of a curved section of storm sewer. The maximum spacing between manholes for various pipe sizes shall be in accordance with the Chart below. The required manhole size shall be as follows:

Table 3.3
Manhole Size

Sewer Diameter	Round Manhole Inside Diameter
18" – 24"	4'
27" – 36"	5'
Larger than 36"	Not Allowed

Sewer Diameter	Rectangular Manhole Inside Lengths
18" – 36"	4' x 4'
42" – 48"	5' x 5'
Larger than 48"	Approved by City

Larger manhole diameters or a junction structure may be required when sewer alignments are not straight through or more than one sewer line goes through the manhole.

Table 3.4
Storm Sewer Alignment
And Size Criteria

Vertical Dimension of Pipe (inches	Maximum Allowable Distance Between Manholes and/or Cleanouts
18 and larger	500 feet

3.4.5 PIPE CONNECTIONS

Connections will be made by inlet or junction boxes. Precast structures are not allowed in public drainage systems.

3.4.6 MINOR HEAD LOSSES AT STRUCTURES

The following total energy head losses at structures shall be determined for inlets, manholes, wye branches or bends and other junctions in the design of closed conduit. See Figures 3.10 and 3.11 for details of each case. Minimum head loss used at any structure shall be 0.10 foot, unless otherwise approved.

The basic equation for most cases, where there are both upstream and downstream velocity, takes the form as set forth below with the various values of the coefficient of K_j shown in Tables 3.5, 3.6 and 3.7.

$$h_j = \frac{K_j (V_2^2 - V_1^2)}{2g}$$

h_j = junction or structure head loss in feet.

v_1 = velocity in upstream pipe in feet per second.

v_2 = velocity in downstream pipe in feet per second.

K_j = junction or structure coefficient of loss.

In the case where the initial velocity is negligible, the equation for head loss becomes:

$$h_j = \frac{K_j V_2^2}{2g}$$

Short radius bends may be used on 24 inch or larger pipes where flow must undergo a direction change at a junction or bend. Reductions in head loss at manholes may be realized in this way. A manhole shall always be located at the downstream end of such short radius bends.

The values of the coefficient "K_j" for determining the loss of head due to obstructions in pipe are shown in Table 3.6 and the coefficients are used in the following equation to calculate the head loss at the obstruction:

$$h_j = \frac{K_j V_2^2}{2g}$$

The values of the coefficient "K_j" for determining the loss of head due to sudden enlargements and sudden contractions in pipes are shown in Table 3.7 and the coefficients are used in the following equation to calculate the head loss at the change in Section:

$$h_j = \frac{K_j V^2}{2g}$$

3.5 UTILITIES

In the design of a storm drainage system, the Engineer is frequently confronted with the problem of grade conflict between the proposed storm drain and existing utilities, such as water, gas, sanitary sewer, electric, and communication lines.

When conflicts arise between a proposed drainage system and utility system, the owner of the utility system shall be contacted and made aware of the conflict. Any adjustments necessary to the drainage system or the utility can then be determined.

Due to the difficulty and expense to the public with regard to hand cleaning, clearing, and other ditch maintenance, the following ditch requirements are specified to expedite small equipment cleaning and access to drainage easements and ditches:

- Manholes are not allowed in drainage ditches, unless approved by the City Engineer.
- Access easements shall be required every 600 feet. Access to be provided from public street to drainage facility.
- Utility crossings above the channel flowline shall not be allowed unless approved specifically in writing by the City Engineer.
- Utilities shall not be located beneath a concrete ditch bottom except at crossings.
- Minimum drainage easement width shall be 20'.

See Figure 3.12 for dimensions of utility easements required when drainage facilities are installed within the same easement.

Table 3.5

Junction or Structure
Coefficient of Loss

Case No.	Reference Figure	Description of Condition	Coefficient K_j
I		Inlet on Main Line **	0.50
II		Inlet on Main Line with Branch Lateral **	0.25
III		Manhole on Main Line with 45° Branch Lateral	0.50
IV		Manhole on Main Line with 90° Branch Lateral	0.75
V		45° Wye Connection or Cut-in	0.25
VI		Inlet on Manhole at Beginning of Line	1.25
VII		Conduit on Curves for 90° ***	
		Curve Radius = Diameter	0.50
		(2 to 8) Diameter	0.40
		Curve Radius = (8 to 20) Diameter	0.25
VIII		Bends Where Radius is Equal to Diameter	
		90° Bend	0.50
		60° Bend	0.48
		45° Bend	0.35
		22 1/2° Bend	0.20
		Manhole on Line with 60° Lateral	0.35
		Manhole on Line with 22 1/2° Lateral	0.75

Source: City of Waco, Texas, Storm Drainage Design Manual notes

** Must be approved by City Engineer.
*** Where bends other than 90° are used, the 90° bend coefficient can be used with the following percentage factor applied:

60° Bend - 85%
45° Bend - 70%
22 1/2° Bend - 40%

TABLE 3.6

Head Loss Coefficients Due To Obstructions

$\frac{A}{A_o}$*	K_j	$\frac{A}{A_o}$	K_j
1.05	0.10	3.0	15.0
1.1	0.21	4.0	27.3
1.2	0.50	5.0	42.0
1.4	1.15	6.0	57.0
1.6	2.40	7.0	72.5
1.8	4.00	8.0	88.0
2.0	5.55	9.0	104.0
2.2	7.05	10.0	121.0
2.5	9.70		

* $\frac{A}{A_o}$ = Ratio of area of pipe to opening at obstruction.

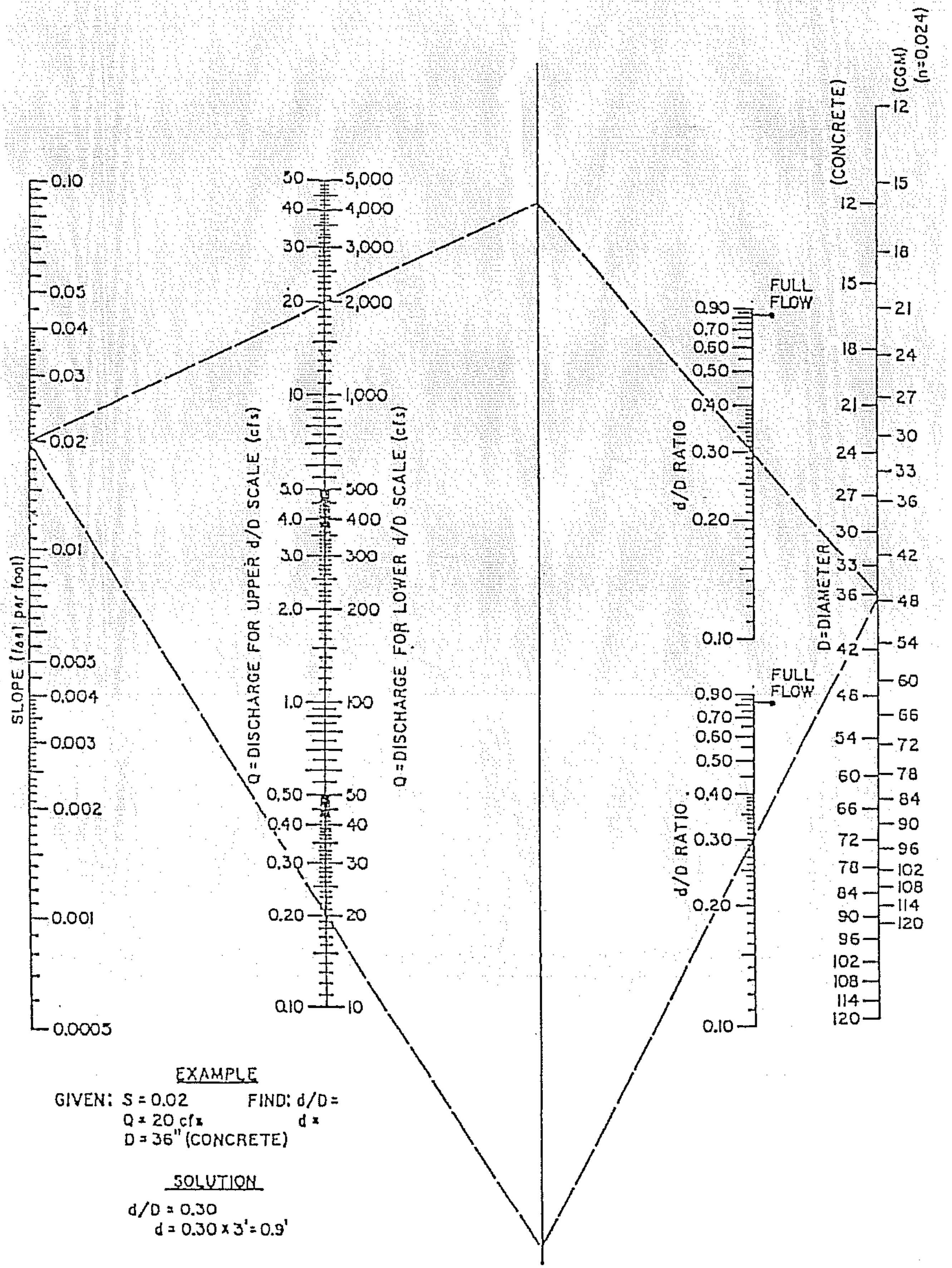
TABLE 3.7

Head Loss Coefficients Due To Sudden Enlargements And Contractions

$\frac{D_2}{D_1}$**	Sudden Enlargements K_j	Sudden Contractions K_j
1.2	0.10	0.08
1.4	0.23	0.18
1.6	0.35	0.25
1.8	0.44	0.33
2.0	0.52	0.36
2.5	0.65	0.40
3.0	0.72	0.42
4.0	0.80	0.44
5.0	0.84	0.45
10.0	0.89	0.46
	0.91	0.47

**$\frac{D_2}{D_1}$ = Ratio of larger to smaller diameter.

Source: City of Waco, Texas, Storm Drainage Design Manual



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'

SOURCE: AHTD

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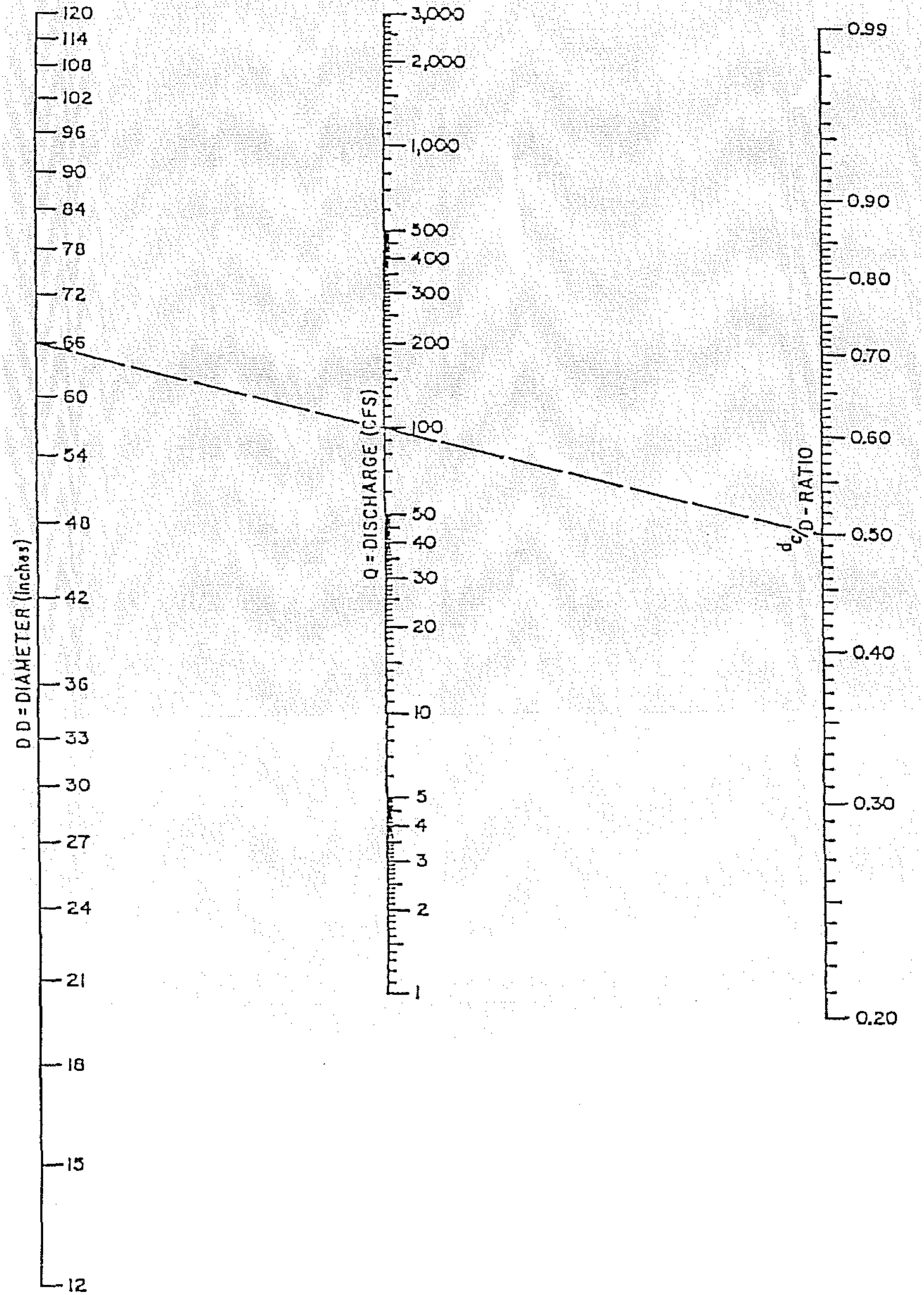
UNIFORM FLOW FOR PIPE CULVERTS

Figure 3.1



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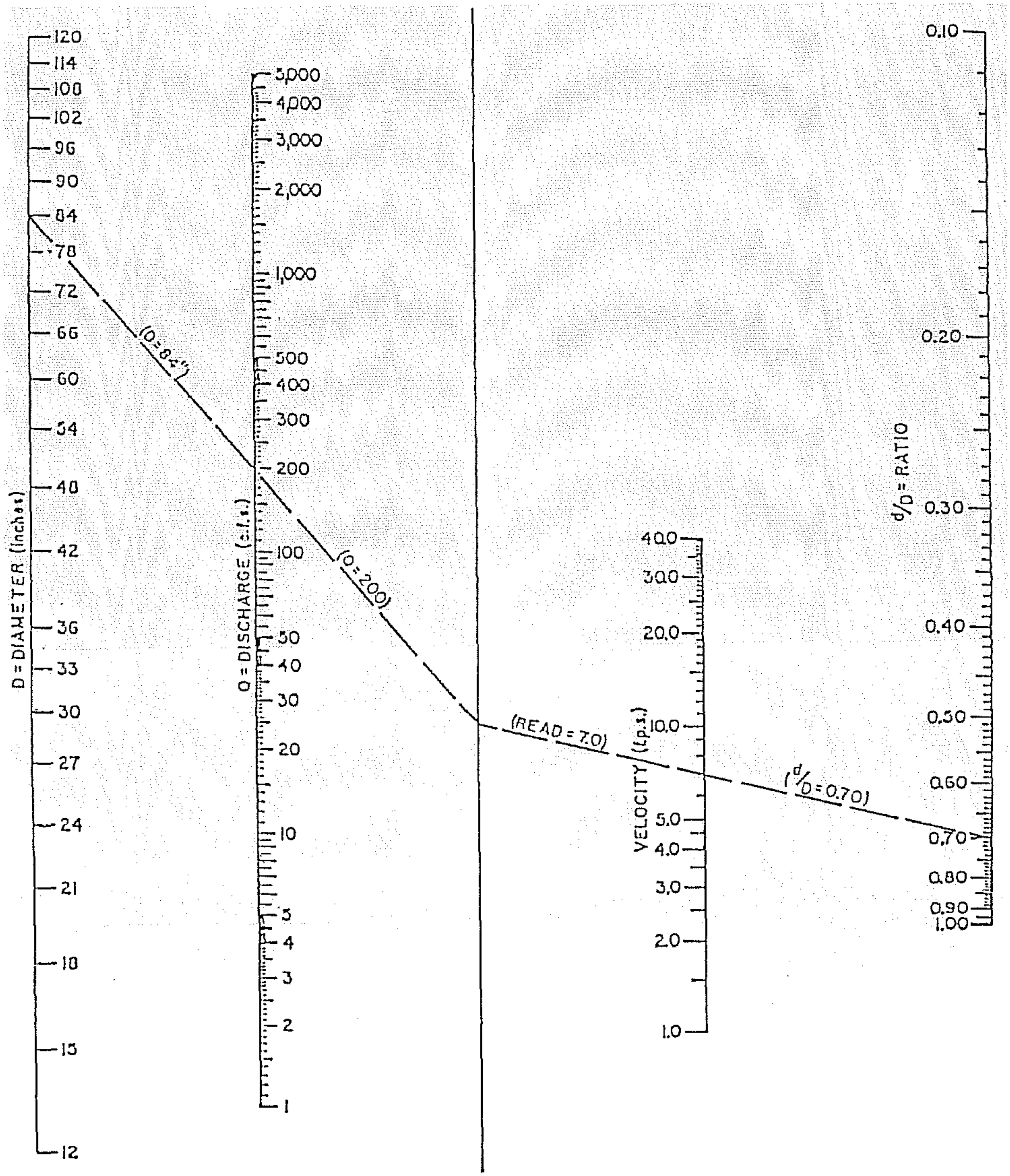
CRITICAL DEPTH OF FLOW FOR CIRCULAR CONDUITS

SOURCE: AHTD

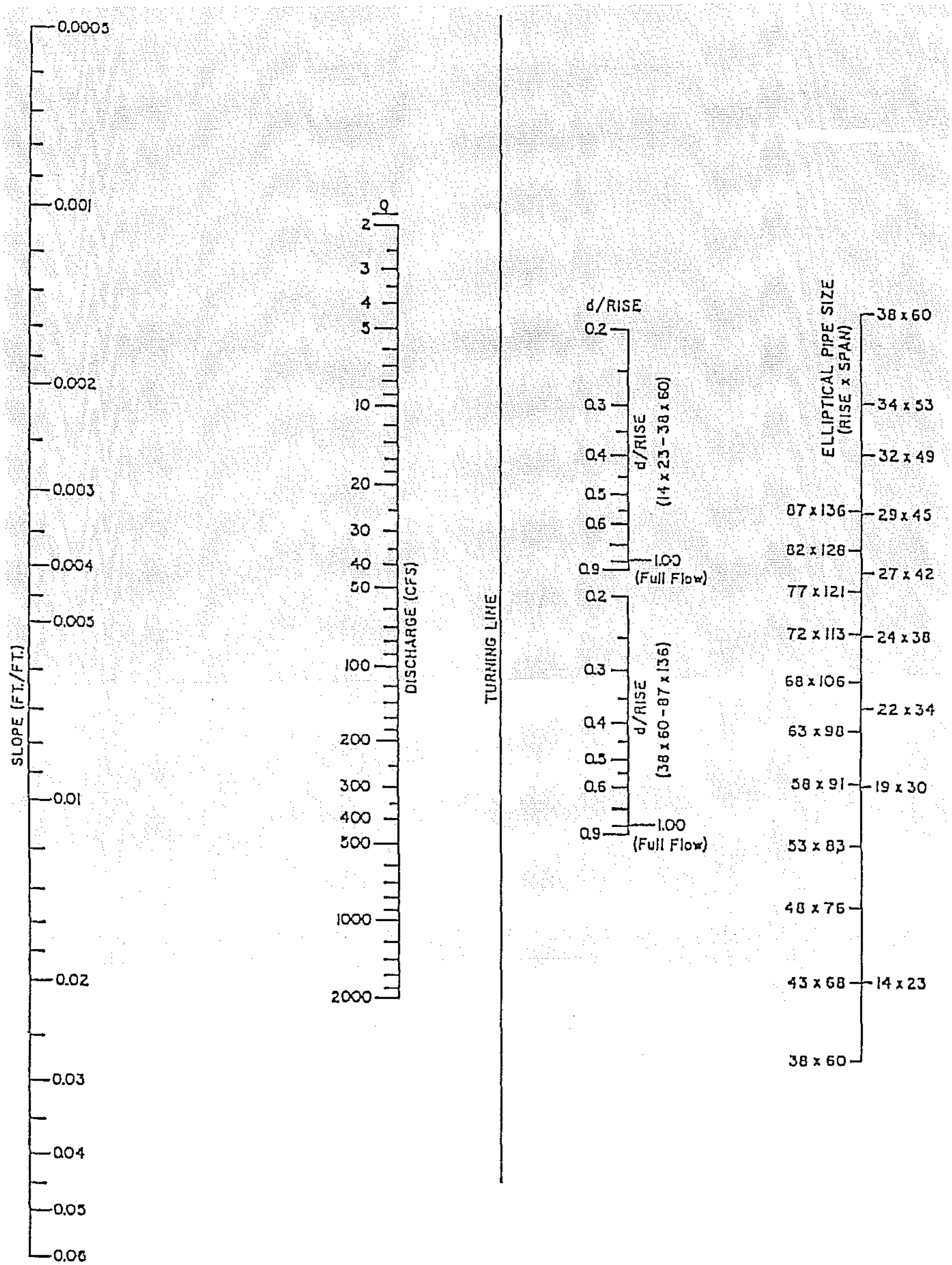
Figure 3.2



VELOCITY IN PIPE CONDUITS

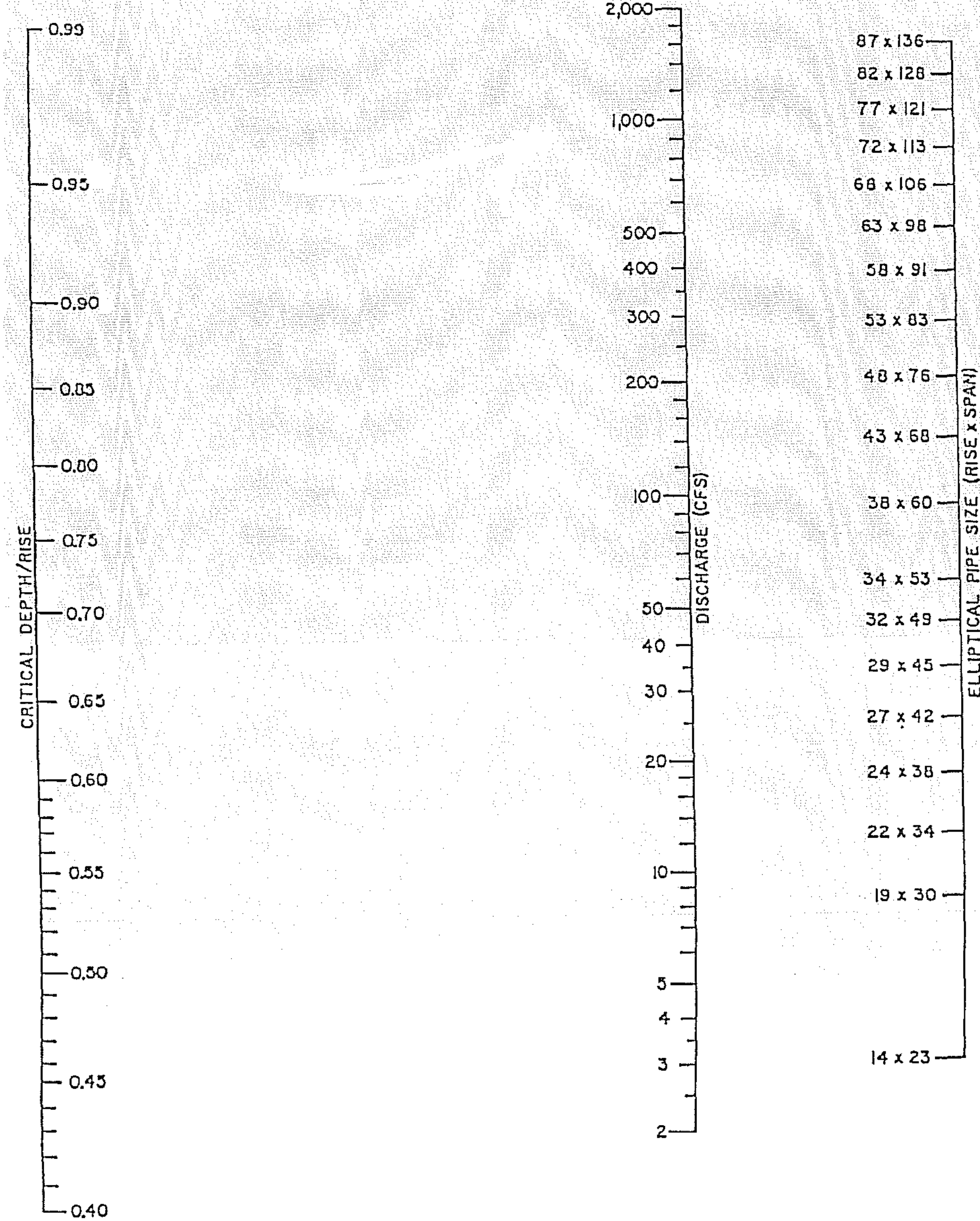
Source: AHTD for Figures 3.3 – 3.9

Figure 3.3



UNIFORM FLOW FOR CONCRETE ELLIPTICAL PIPE

Figure 3.4



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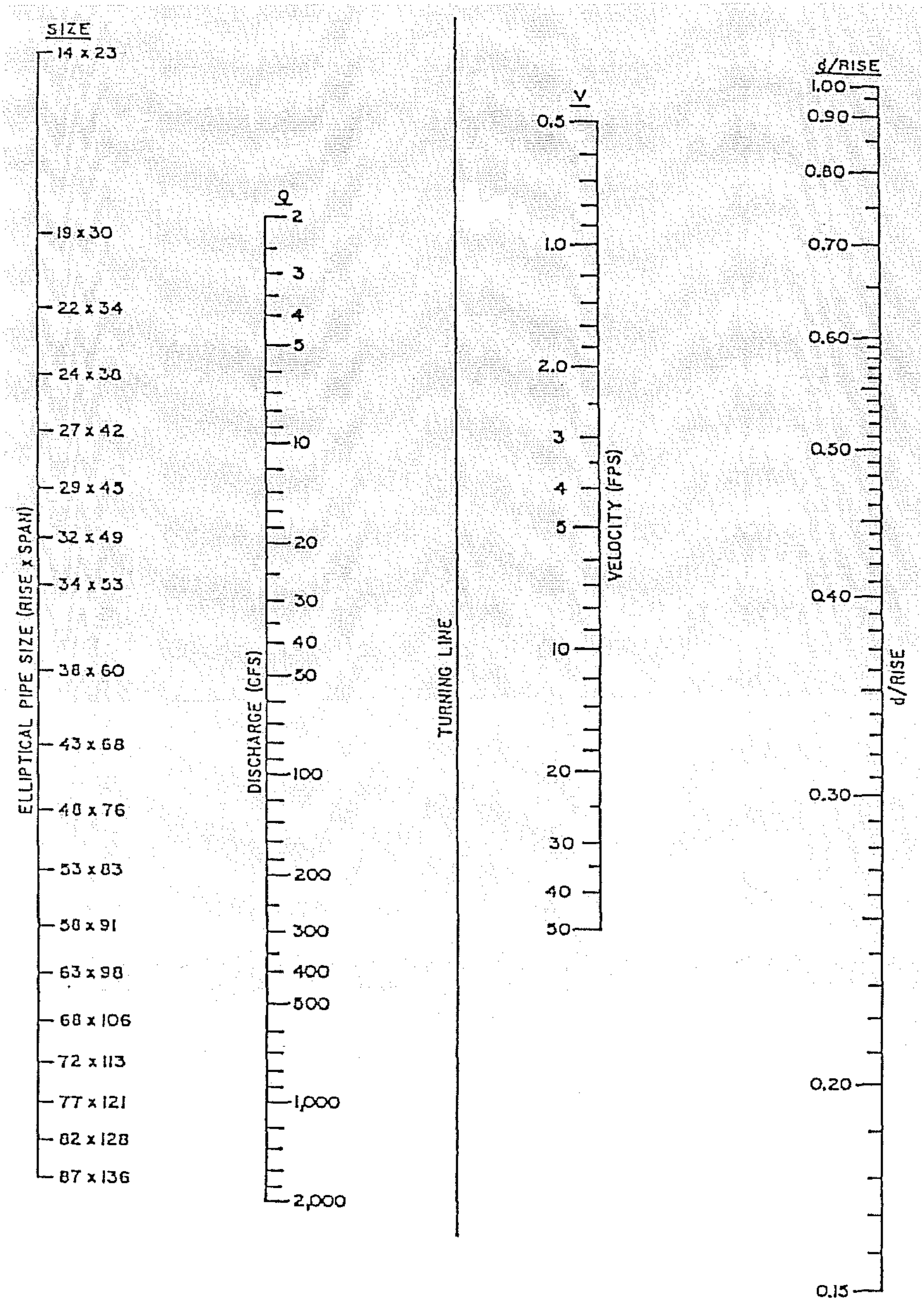
CRITICAL DEPTH FOR ELLIPTICAL PIPE

Figure 3.5



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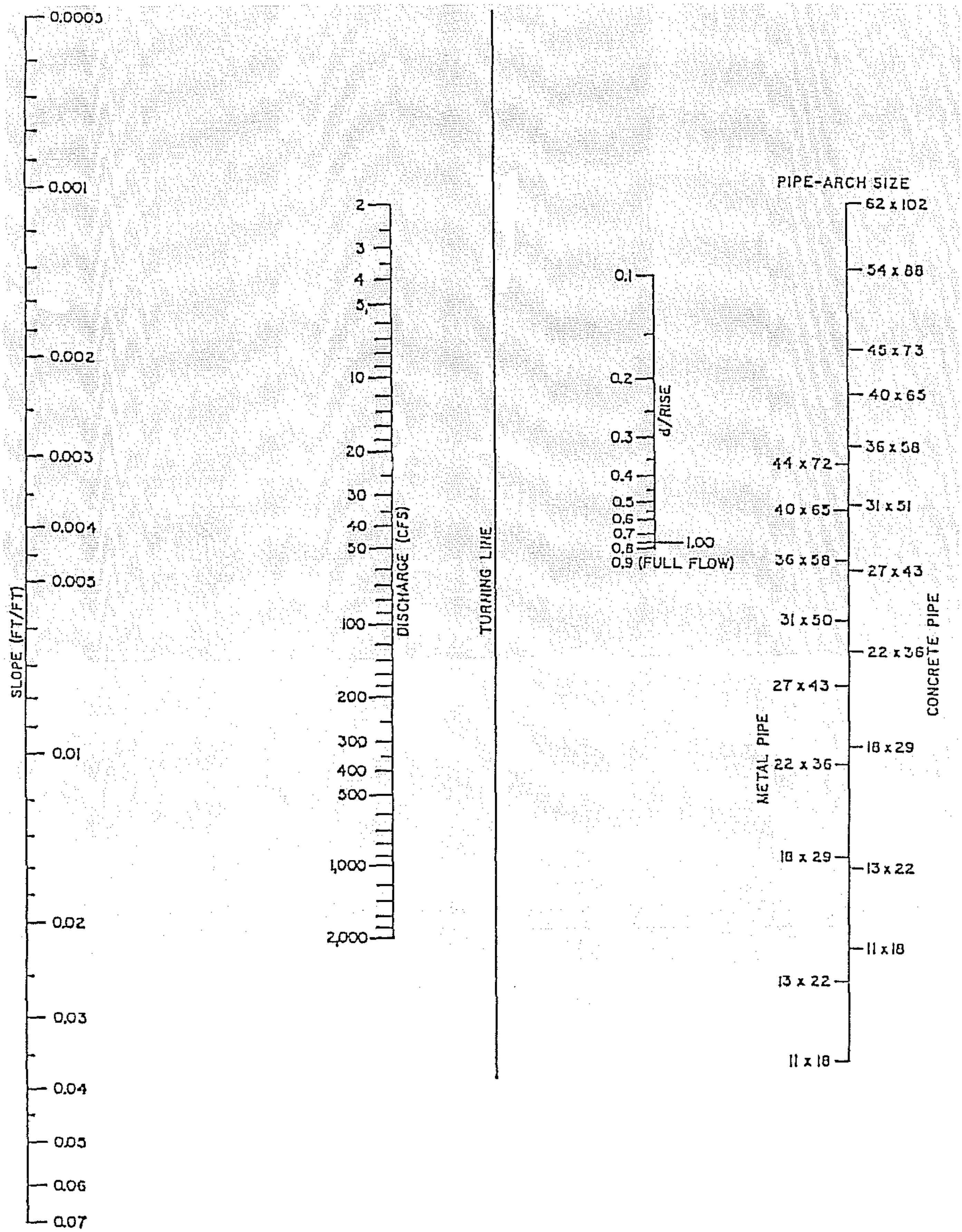
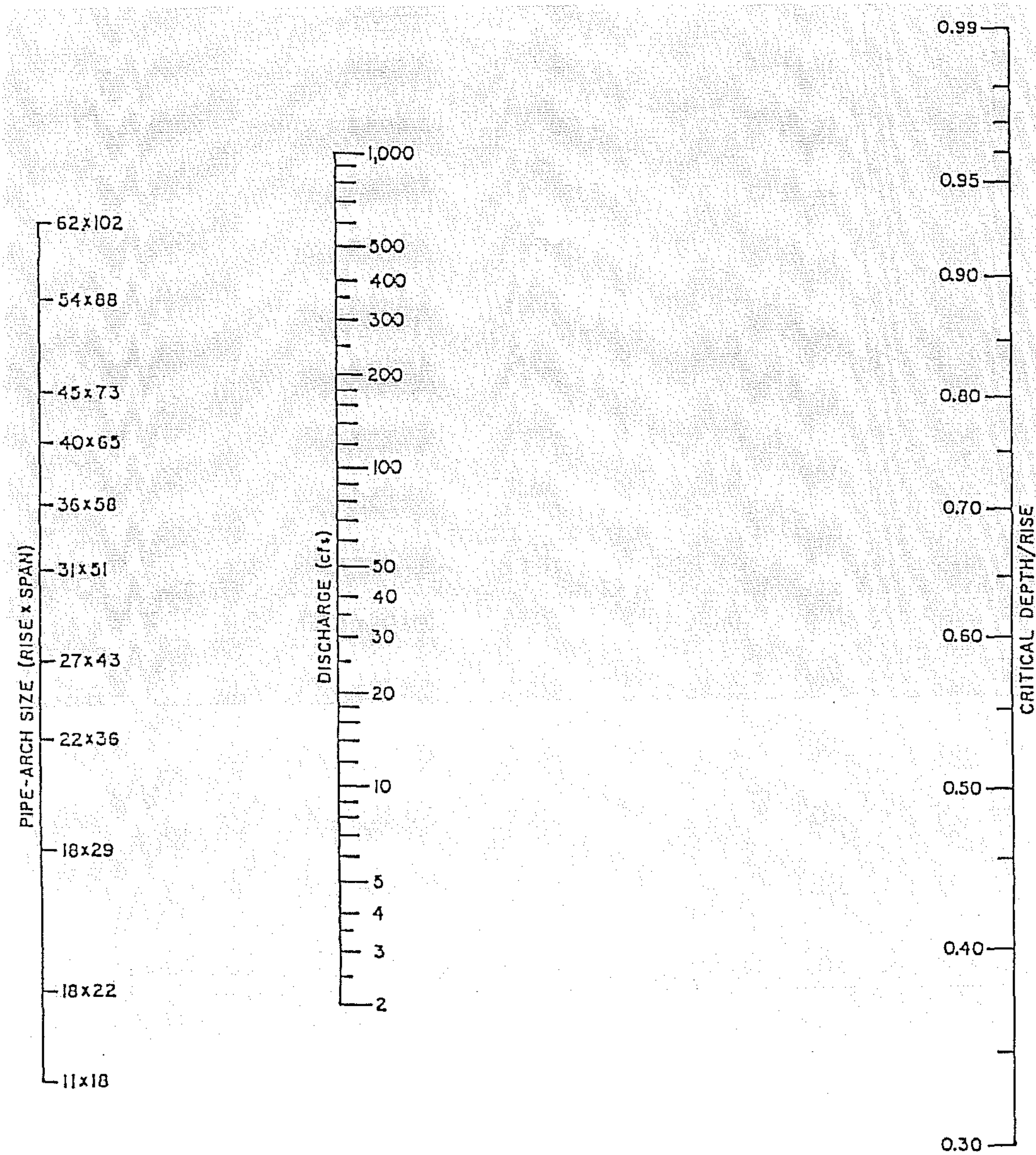
VELOCITY IN ELLIPTICAL PIPE

Figure 3.6



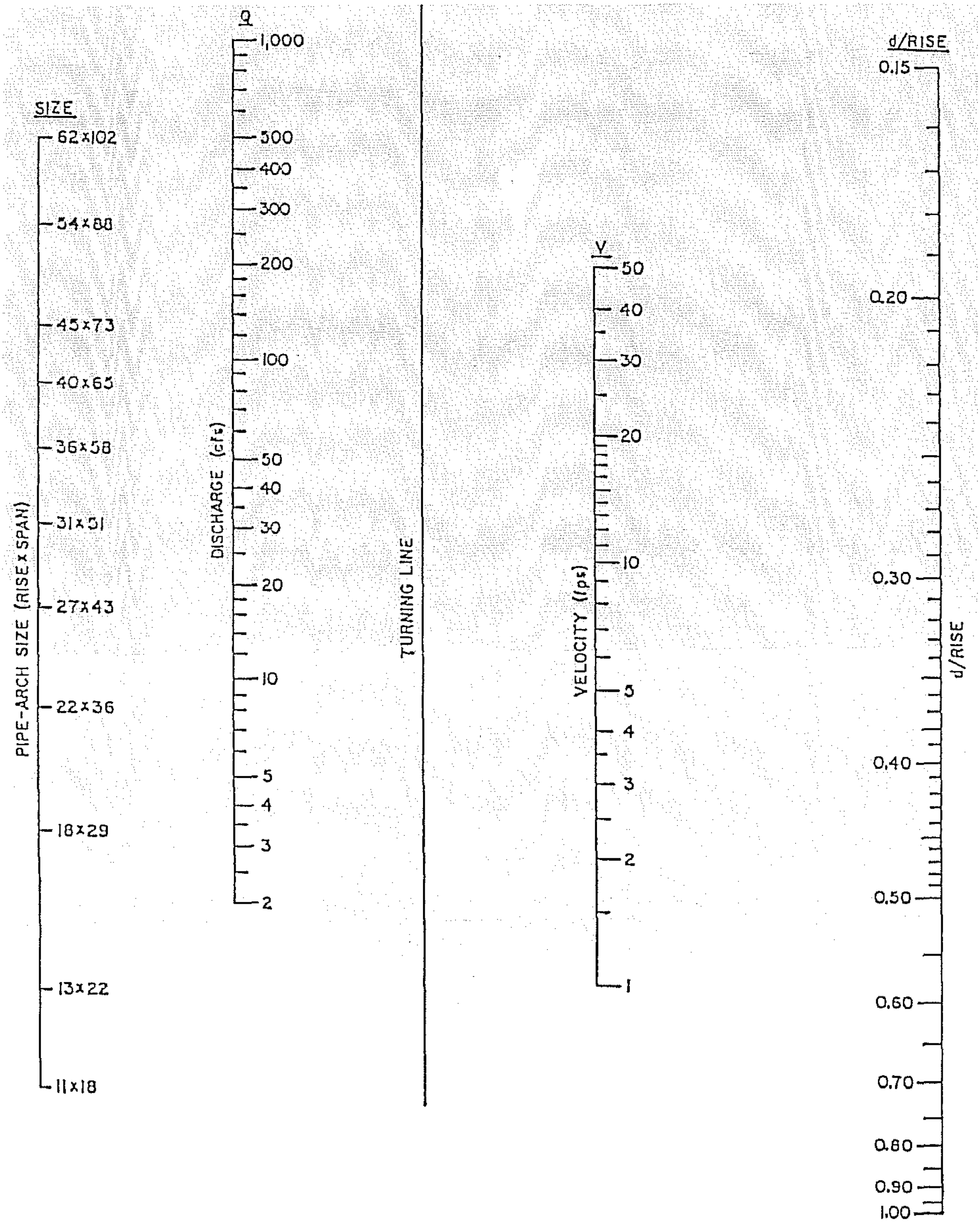
UNIFORM FLOW FOR ARCH PIPE

Figure 3.7



CRITICAL DEPTH FLOW FOR ARCH PIPE

Figure 3.8



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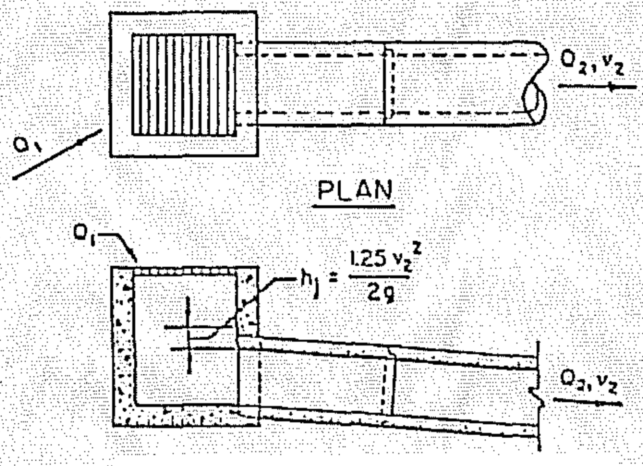
VELOCITY IN ARCH PIPE

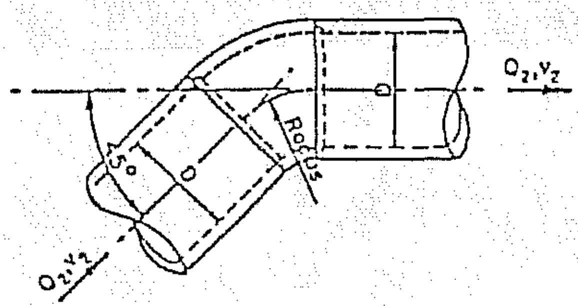
Figure 3.9



SECTION

CASE VI

INLET OR MANHOLE AT BEGINNING OF LINE



CASE VIII
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

(AS APPROVED CASE BY CASE)

NOTE: Head loss applied at beginning of bend.

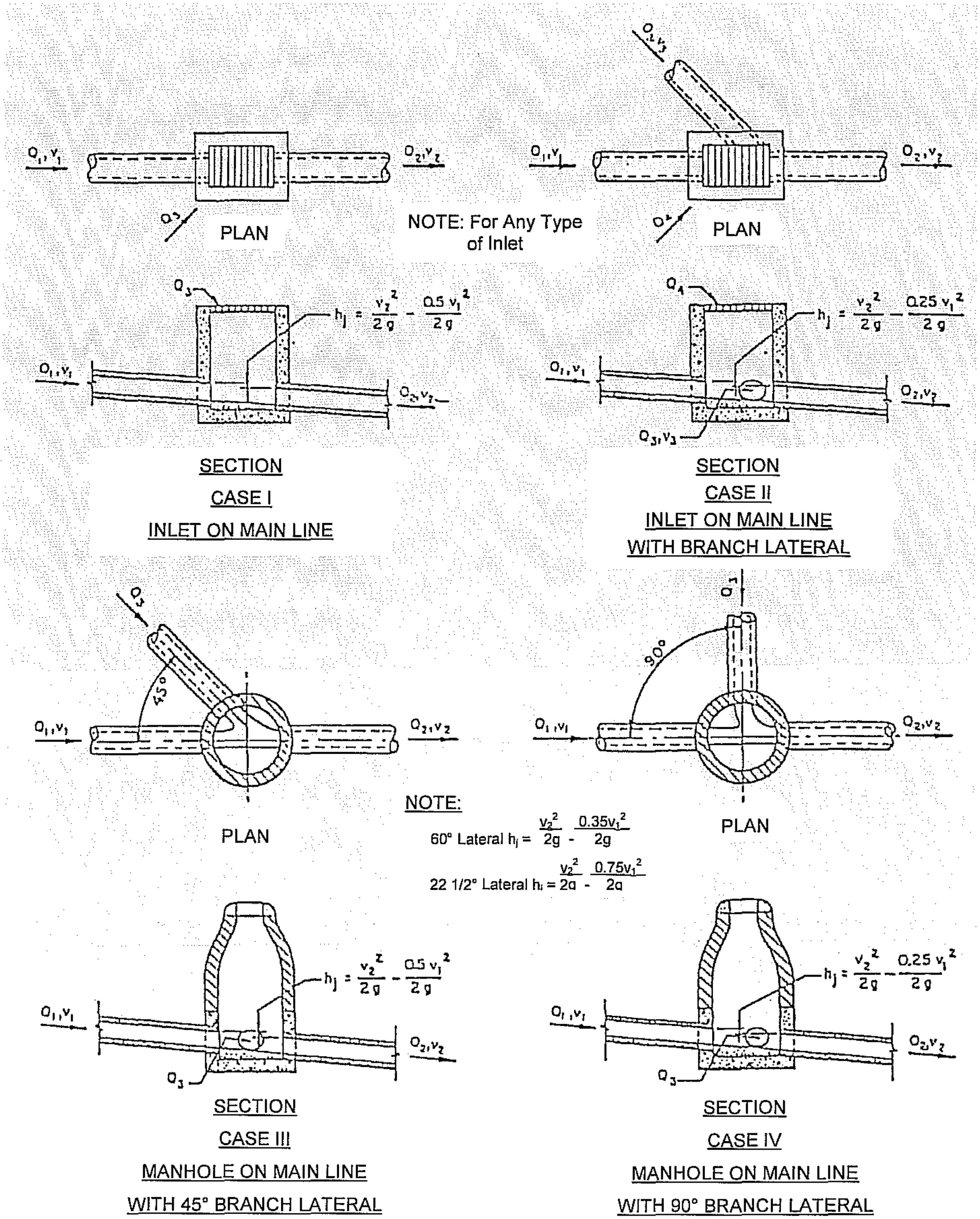
90° Bend $h_j = 0.50 \frac{v_2^2}{2g}$

60° Bend $h_j = 0.43 \frac{v_2^2}{2g}$

45° Bend $h_j = 0.35 \frac{v_2^2}{2g}$

22 1/2° Bend $h_j = 0.20 \frac{v_2^2}{2g}$

SOURCE: City of Austin, Tx.



SOURCE: City of Austin, Tx.

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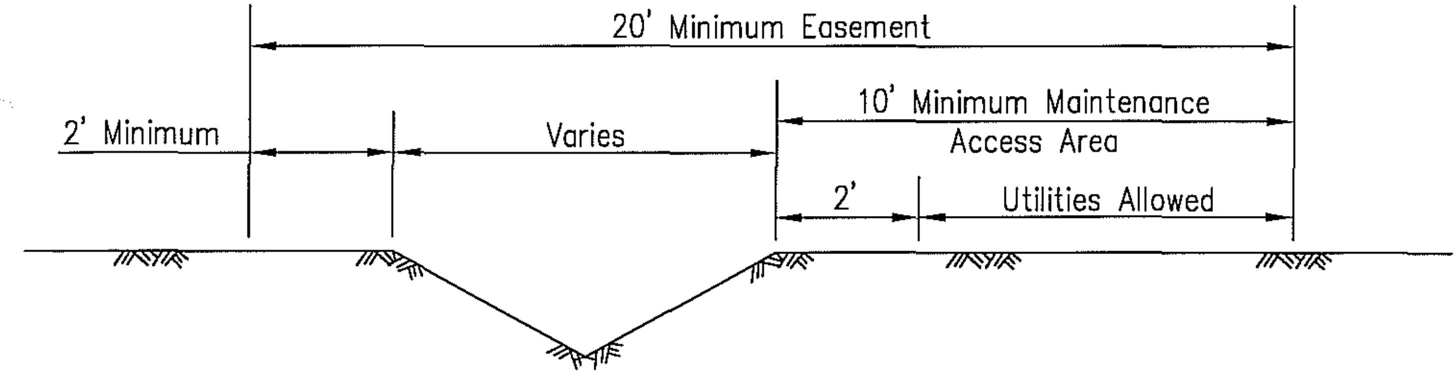
MINOR HEAD LOSSES DUE TO TURBULENCE AT STRUCTURES

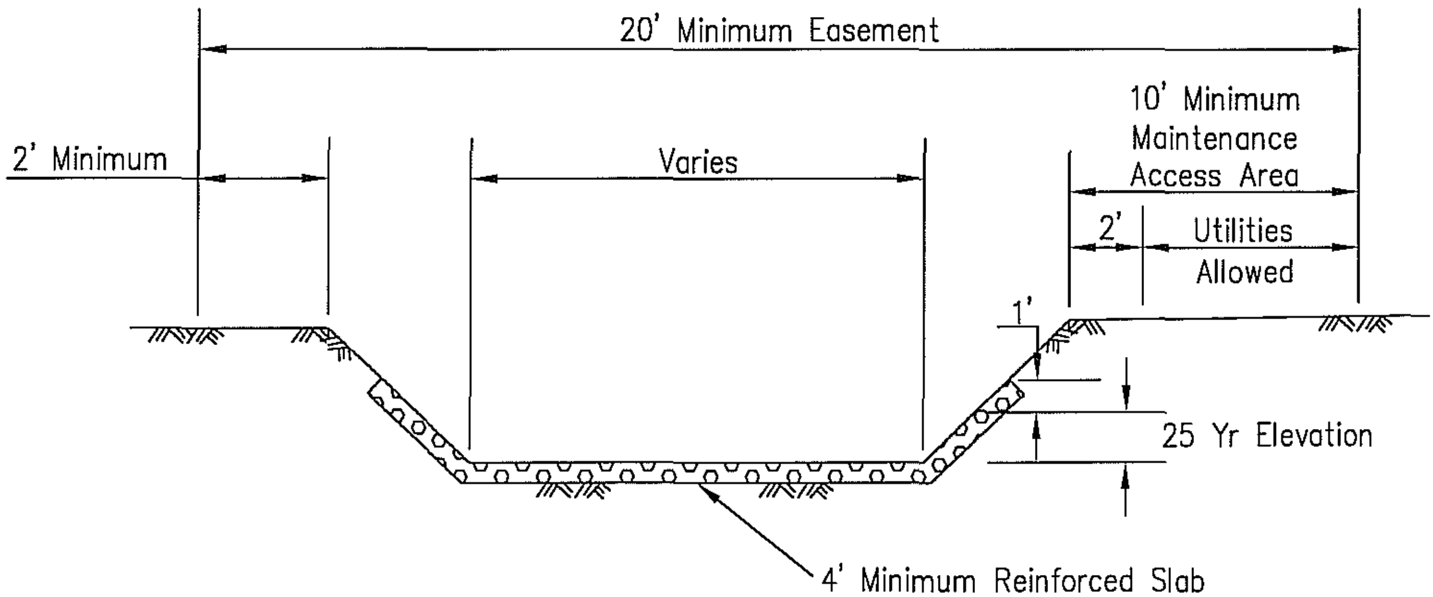
Figure 3.11



SMALL DITCH

GENERAL NOTES

* Utility crossing limited to one per block
* Access easement required every 600' (from public street to facility)
* Utilities shall not be located beneath a a concrete bottom except at crossings
* Manholes not allowed in ditches



LARGE DITCH

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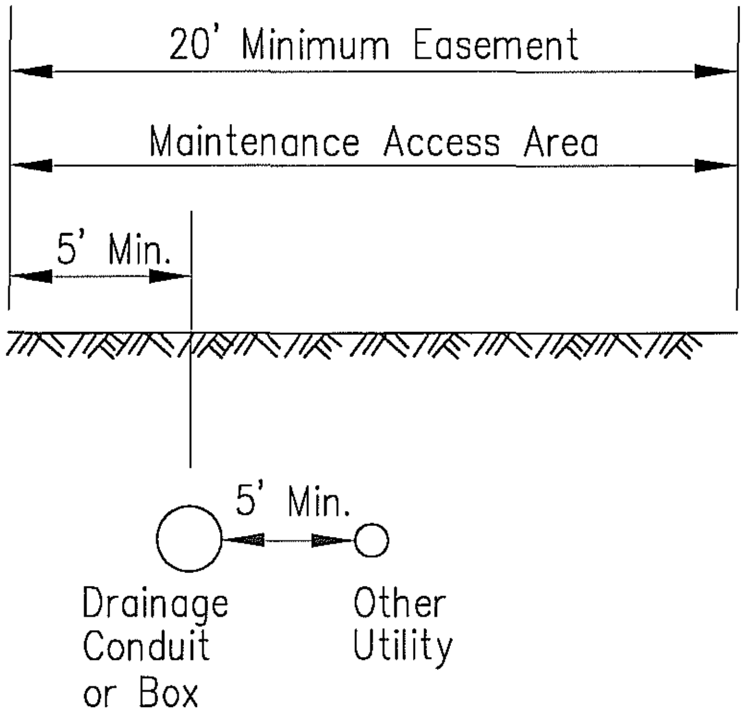
MINIMUM EASEMENTS FOR DRAINAGE AND UTILITIES

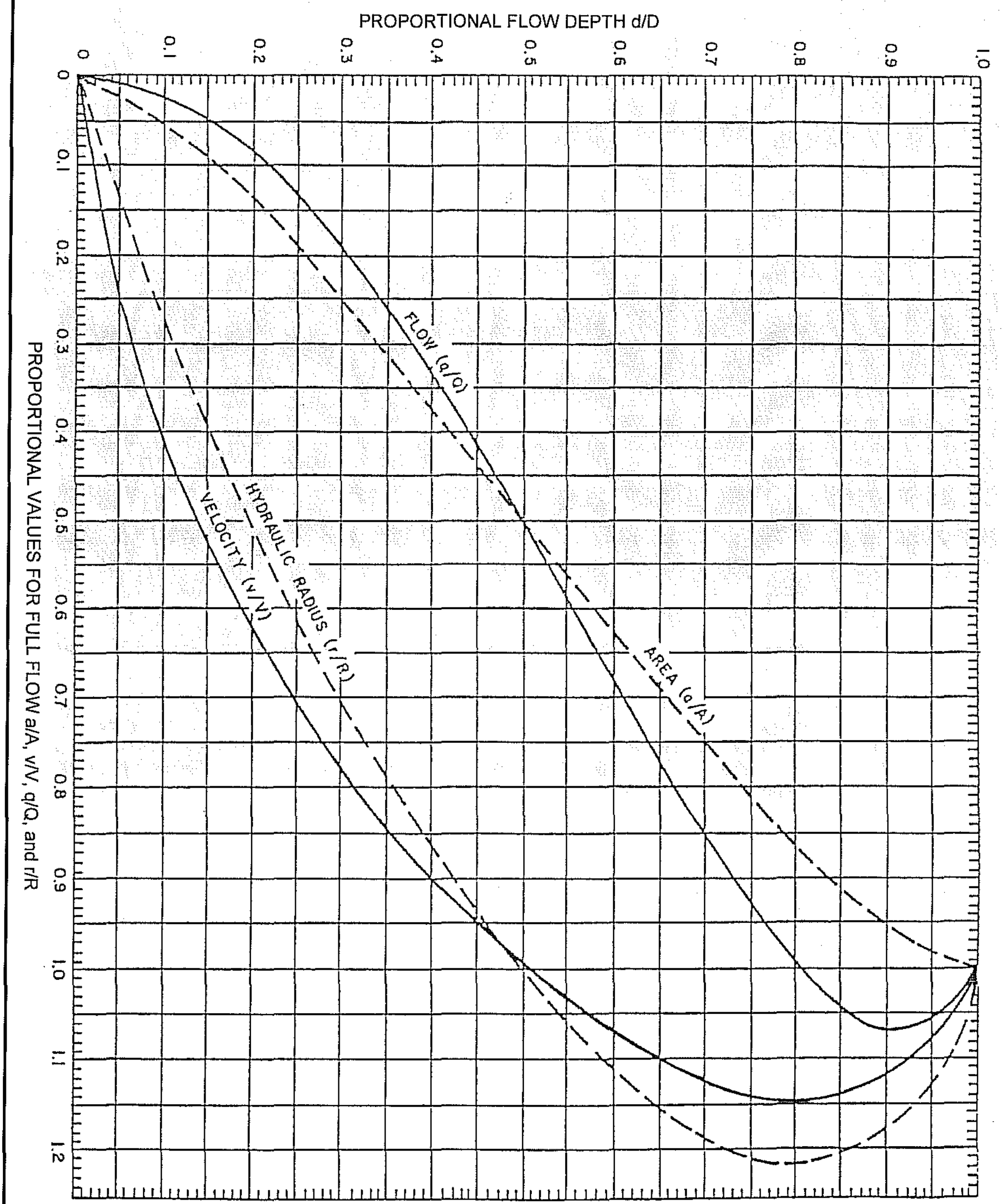
Figure 3.12



CONDUIT OR BOX

MINIMUM EASEMENTS FOR DRAINAGE AND UTILITIES

Figure 3.12 (cont)



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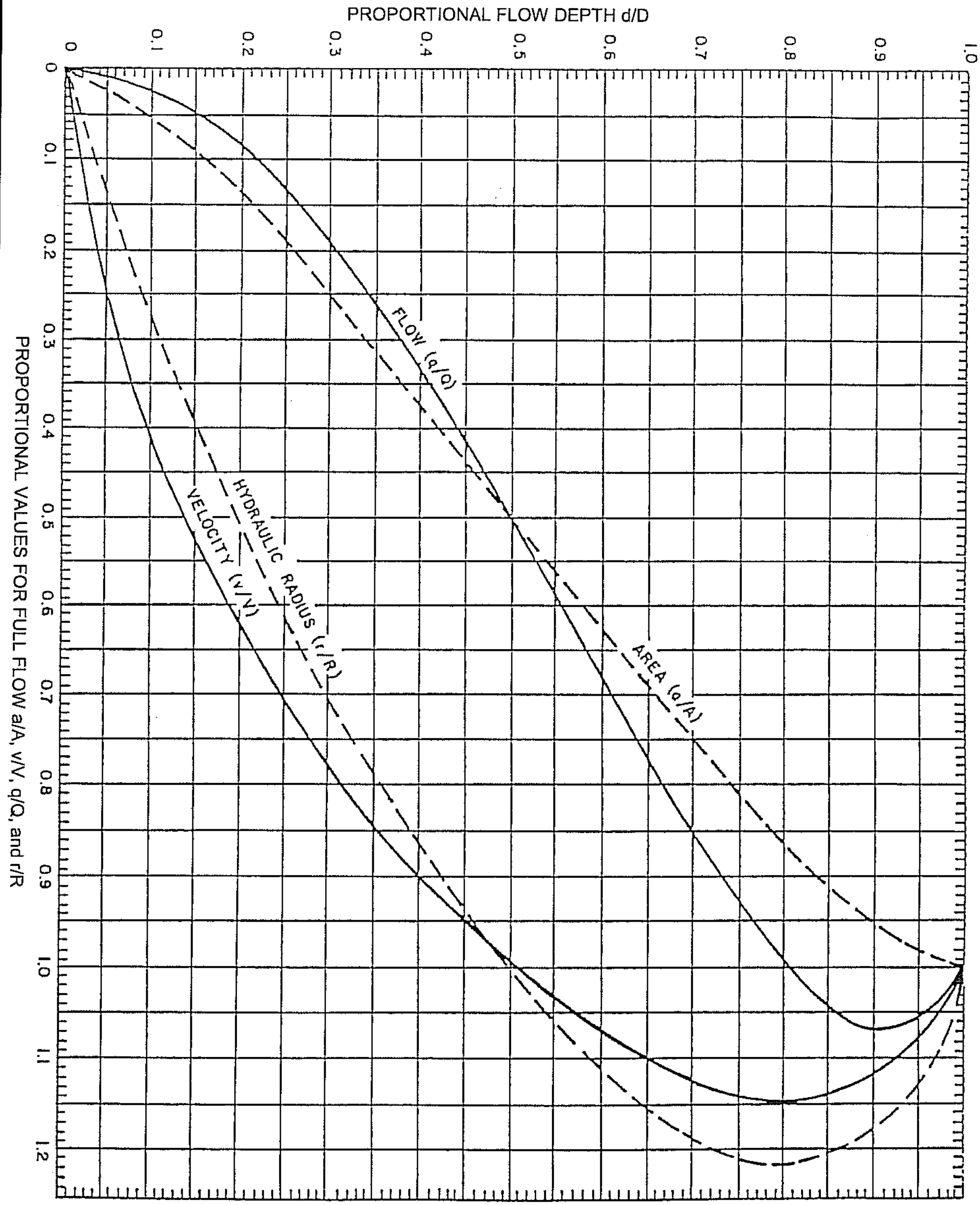
RELATIVE VELOCITY, AREA, AND DISCHARGE
IN A CIRCULAR PIPE FOR ANY DEPTH OF FLOW

Figure 3.13



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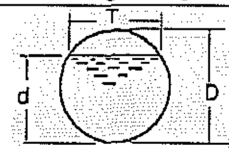
RELATIVE VELOCITY, AREA, AND DISCHARGE IN A CIRCULAR PIPE FOR ANY DEPTH OF FLOW

Figure 3.13

Hydraulic Properties of Circular Conduits Flowing Partly Full

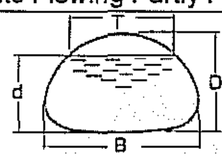
D = Depth of Flow
d_c = Critical depth
d_m = Mean depth
D = Diameter of pipe
A = Area of Flow
R = Hydraulic radius
T = Top width of flow



$\frac{d}{D}$ or $\frac{d_c}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{T}{D}$	$\frac{d_m}{D}$
1.00	0.7854	0.2500	----	----
0.95	0.7707	0.2865	0.4359	1.7681
0.90	0.7445	0.2980	0.6000	1.2408
0.85	0.7115	0.3033	0.7142	0.9962
0.80	0.6736	0.3042	0.8000	0.8420
0.75	0.6319	0.3017	0.8660	0.7297
0.70	0.5872	0.2962	0.9165	0.6407
0.65	0.5404	0.2882	0.9539	0.5665
0.60	0.4920	0.2776	0.9798	0.5021
0.55	0.4426	0.2649	0.9950	0.4448
0.50	0.3927	0.2500	1.0000	0.3927
0.45	0.3428	0.2331	0.9950	0.3445
0.40	0.2934	0.2142	0.9798	0.2994
0.35	0.2450	0.1935	0.9539	0.2568
0.30	0.1982	0.1709	0.9165	0.2163
0.25	0.1535	0.1466	0.8660	0.1773
0.20	0.1118	0.1206	0.8000	0.1397
0.15	0.0739	0.0929	0.7142	0.1035

Hydraulic Properties of Pipe Arch Conduits Flowing Partly Full

D = Depth of Flow
d_c = Critical depth
d_m = Mean depth
D = Diameter of pipe
A = Area of Flow
R = Hydraulic radius
T = Top width of flow



$\frac{d}{D}$ or $\frac{d_c}{D}$	$\frac{A}{BD}$	$\frac{R}{D}$	$\frac{T}{D}$	$\frac{d_m}{D}$
1.00	0.7879	0.2991	----	----
0.95	0.7762	0.3408	0.3489	2.225
0.90	0.7552	0.3549	0.4855	1.555
0.85	0.7283	0.3622	0.5848	1.245
0.80	0.6970	0.3649	0.6637	1.0503
0.75	0.6621	0.3639	0.7288	0.9085
0.70	06243	0.3595	0.7837	0.7966
0.65	0.5839	0.3520	0.8303	0.7033
0.60	0.5414	0.3415	0.8700	0.6223
0.55	0.4970	0.3282	0.9037	0.5500
0.50	0.4511	0.3120	0.9320	0.4840
0.45	0.4039	0.2928	0.9555	0.4227
0.40	0.3556	0.2705	0.9755	0.3616
0.35	0.3065	0.2451	0.9889	0.3100
0.30	0.2568	0.2162	0.9967	0.2577
0.25	0.2069	0.1839	0.9967	0.2076
0.20	0.1574	0.1484	0.9815	0.1603
0.15	0.10908	0.11022	0.9477	0.11505