CHAPTER 6 – STORM DRAINS AND INLETS

6.1 GENERAL

Roadway storm drainage systems collect stormwater runoff and convey it through the street right-of-way in a manner that adequately drains the roadway and minimizes the potential for flooding and erosion to properties adjacent to the right-of-way. Storm drainage systems consist of curbs, gutters, storm drains, channels and culverts.

The design of a drainage system must address the needs of the traveling public and those of the local community through which it passes. The drainage system for a roadway traversing an urbanized region is more complex than for roadways traversing sparsely settled rural areas. This is often due to:

- the wide roadway sections, flat grades (both in longitudinal and transverse directions), shallow water courses and absence of side channels;

- the more costly property damages that may occur from ponding of water or from flow of water through builtup areas; and

- the fact that the roadway section must carry traffic but also act as a channel to convey the water to a disposal point. Unless proper precautions are taken, this flow of water along the roadway will interfere with or possibly halt the passage of traffic.

The most serious effects of an inadequate roadway drainage system are:

- damage to surrounding or adjacent property, resulting from water overflowing the roadway curbs and entering such property;

- risk and delay to traffic caused by excessive ponding in sags or excessive spread along the roadway; and

- weakening of base and subgrade due to saturation from frequent ponding of long duration.

6.2 DESIGN CRITERIA

Storm drainage systems shall be designed according to the criteria listed below:

6.2.1 *Design Frequency*

6.2.1.1 Roadway Drainage/Gutter Spread

The design flood frequency for roadway drainage is related to the allowable gutter spread on the pavement and the roadway classification. Gutter spread may not extend into the clear zone of the street for the required design frequency. Roadways within the City of Fort Smith must be designed according to the minimum clear zone and design frequency requirements for the given roadway classification shown in TABLE 6-1 below:

TABLE 6-1. Design Frequency for Roadway Drainage

Roadway Classification	Design Frequency	Clear Zone
Residential	10-year	Can't Overtop Centerline
Residential Collector	10-year	Center 12 ft
Residential Collector (Restricted Parking)	10-year	Center 12 ft
Major Collector	25-year	Center 12 ft
Minor Arterial	50-year	Center 24 ft
Major Arterial	50-year	Center 24 ft
Boulevard	50-year	12 ft Each Side
Industrial	25-year	Center 12 ft

6.2.1.1 Storm Drains

Storm drains within the City of Fort Smith shall be designed for the frequencies shown in TABLE 2-1.

6.2.2 *Criteria for Storm Drains*

Storm drains shall be designed in accordance with the following criteria:

- All 10-year flows less than 50 cfs must be contained in an underground enclosed storm drain, unless carried in an Open Channel System designed to treat the required WQ_v.

- Maximum spacing between inlets and/or junction boxes is 400 ft. Inlets and/or junction boxes shall be placed at all grade changes, changes of direction, changes in structure size, and locations where storm drains intersect. Curb inlets shall be constructed on both sides of a street in sump areas.

- Inlets located in sump areas shall be designed to operate with 50 % blockage.

- Generally, only curb-opening or area inlets shall be allowed. However, with prior approval of the Engineering Department, grated or combination inlets may be used for special situations where curb-opening or area inlets are not sufficient. If used, grated and combination inlets must be designed to operate with 50 % blockage. Slotted drain inlets shall not be allowed.

- Any concentration of surface flow in excess of 6.0 cfs for a 10-year storm shall be intercepted before crossing the back of curb and carried by storm drains. No storm drain will be allowed to discharge into the street.

- The hydraulic grade line shall be calculated for all storm drains. Minimum freeboard shall be 9 inches from the water surface to:

    - the gutter flow line for curb inlets,
    - the throat invert for area inlets, or
    - the rim elevation for junction boxes.

- Minimum storm drain diameter for round pipe shall be 15 inches. Minimum storm drain size for arch pipe or elliptical pipe shall be 15 inch equivalent. Minimum size for box culverts shall be 4 feet by 4 feet.

- The minimum allowable fill or cover shall be 12 inches above the top of the storm drain. For storm drains under roadways there shall also be a minimum clearance of 6 inches from the top of the storm drain to the bottom of the pavement base. Special reinforced concrete boxes designed to carry traffic on the top slab do not have to meet minimum allowable fill requirements.

- As a minimum, pipes shall be Class III, Reinforced Concrete Pipe. Boxes shall also be constructed of reinforced concrete. A reinforced concrete inlet box, headwall/endwall, slope wall, or flared-end section shall be constructed at the entrance and outfall of each storm drain.

- The minimum allowable velocity for storm drains shall be 3 ft/s, and the maximum allowable velocity shall be 15 ft/s. The minimum slope for storm drains shall be 0.30 %.

- Tailwater depth at outlet may be calculated with Manning's Equation (Section 3.3.2) if Step Backwater Analysis is not required for the downstream channel. If the headwater elevation for a nearby downstream culvert or storm drain is greater than the normal depth for the channel, a Step Backwater Analysis shall be required. (Regardless of the method used, the minimum tailwater elevation shall be the invert elevation plus 0.8 times the pipe diameter.)

- Energy dissipators will be required at storm drain outfalls in earthen channels when the discharge velocity exceeds 6 ft/s. Energy dissipators shall be designed in accordance with the *Hydraulic Design of Stilling Basins and Energy Dissipators (1)*, developed by the U.S. Bureau of Reclamation.

- Storm drain pipes and boxes should not decrease in size in a downstream direction regardless of the available pipe gradient.

- At inlets and junctions, where practicable, soffits of inflowing pipes and boxes shall be placed at or above the soffit elevation of the outflowing pipes and boxes. In no instance shall the inverts of inflowing pipes and boxes be placed below the invert elevation of outflowing pipes and boxes.

6.2.3 *Additional Criteria*

Storm drainage systems shall also be designed according to the criteria listed below:

- Swales shall not be permitted across through streets.

- The maximum water surface elevation for the 100-year storm event shall be 1 foot lower than the floor elevation of adjacent buildings or structures.

6.3 GUTTER FLOW CALCULATIONS

6.3.1 *Introduction*

Gutter flow calculations are necessary to relate the quantity of flow (Q) in the curbed channel to the spread of water on the shoulder, parking lane or pavement section. The nomograph on Figure 6-1 can be utilized to solve uniform cross slope channels, composite gutter sections and V-shape gutter sections. Figure 6-3 is also useful in solving composite gutter section problems. Computer programs, such as the HYDRAIN program *(4)*, are also useful for this computation and inlet capacity. Composite gutter sections have a greater hydraulic capacity for normal cross slopes than uniform gutter sections and are therefore preferred. Example problems for each gutter section are shown in the following sections.

6.3.2 *Manning's n for Pavements*

The roughness of the pavement surface affects water spread. The methods for determining spread provided in this chapter use Manning's roughness coefficient (n). Refer to Table 6-2 for recommended values.

6.3.3 *Uniform Cross Slope Procedure*

The nomograph in Figure 6-1 is used with the following procedures to find gutter capacity for uniform cross slopes:

CONDITION 1: Find spread, given gutter flow:

Step 1 Determine input parameters, including longitudinal slope (S), cross slope (S_x), gutter flow (Q) and Manning's n.

TABLE 6-2. Manning's *n* for Street and Pavement Gutters

Type of Gutter or Pavement	Manning's n
Concrete Gutter, Broom finish	0.016
Asphalt Pavement, Rough texture	0.016
Concrete Pavement, Broom finish	0.016
For gutters with small slope, where sediment may accumulate, increase above n values by:	0.002

Source: Reference *(5)*.

Step 2 Draw a line between the S and S_x scales, and note where it intersects the turning line.

Step 3 Draw a line between the intersection point from Step 2 and the appropriate gutter flow value on the capacity scale. If Manning's n is 0.016, use Q from Step 1; if not, use the product of Q and n.

Step 4 Read the value of the spread (T) at the intersection of the line from Step 3 and the spread scale.

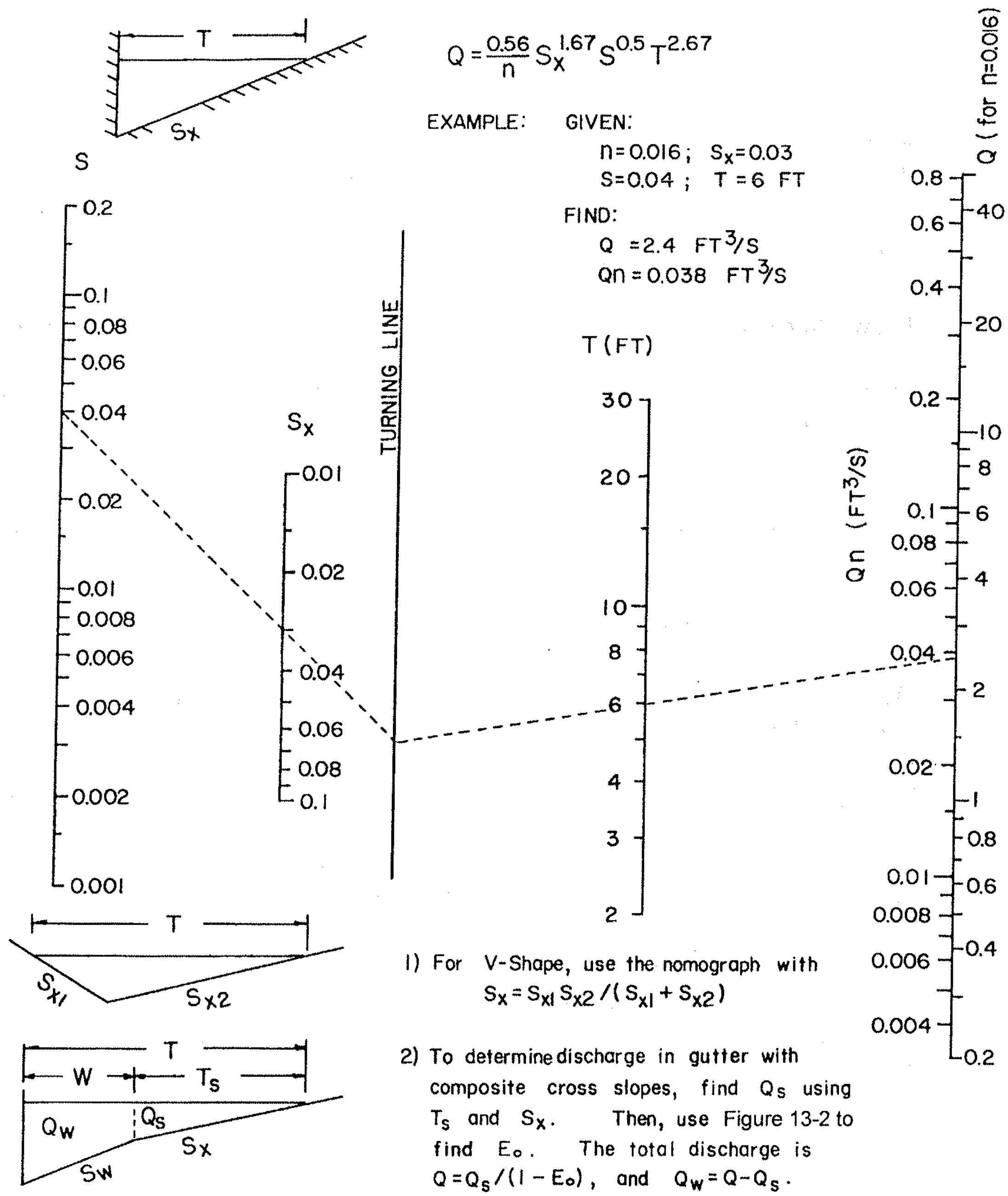
CONDITION 2: Find gutter flow, given spread:

Step 1 Determine input parameters, including longitudinal slope (S), cross slope (S_x), spread (T), and Manning's n.

Step 2 Draw a line between the S and S_x scales, and note where it intersects the turning line.

Step 3 Draw a line between the intersection point from Step 2 and the appropriate value on the T scale. Read the value of Q or Qn from the intersection of that line on the capacity scale.

Step 4 For Manning's n values of 0.016, the gutter capacity (Q) from Step 3 is selected. For other Manning's n values, the gutter capacity times $n(Qn)$ is selected from Step 3 and divided by the appropriate n value to give the gutter capacity.



Flow in Triangular Gutter Sections - English Units

FIGURE 6-1. Flow in Triangular Gutter Sections

Source: HEC 22 *(6)*.

6.3.4 *Composite Gutter Sections Procedure*

Figure 6-2 can be used to find the flow in a gutter section with width (W) less than the total spread (T). Such calculations are generally used for evaluating composite gutter sections or frontal flow for grate inlets:

CONDITION 1: Find spread, given flow:

Step 1 Determine input parameters, including longitudinal slope (S), cross slope (S_x), depressed section slope (S_w), depressed section width (W), Manning's n, gutter flow (Q) and a trial value of the gutter capacity above the depressed section (Q_s). (Example: $S = 0.01$; $S_x = 0.02$; $S_w = 0.06$; $W = 2$ ft; $n = 0.016$; $Q = 2.0$ ft^3/s; try $Q_s = 0.7$ ft^3/s).

Step 2 Calculate the gutter flow in W (Q_w), using the equation:

$$Q_w = Q - Q_s \quad (Q_w = 2.0 - 0.7 = 1.3 \text{ ft}^3/\text{s}) \tag{6.1}$$

Step 3 Calculate the ratios Q_w/Q and S_w/S_x, and use Figure 6-2 to find an appropriate value of W/T. ($Q_w/Q = 1.3/2.0 = 0.65$; $S_w/S_x = 0.06/0.02 = 3$. From Figure 6-2, $W/T = 0.27$).

Step 4 Calculate the spread (T) by dividing the depressed section width (W) by the value of W/T from Step 3. ($T = 2.0/0.27 = 7.41$ ft).

Step 5 Find the spread above the depressed section (T_s) by subtracting W from the value of T obtained in Step 4. ($T_s = 7.41 - 2.0 = 5.41$ ft).

Step 6 Use the value of T_s from Step 5 and Manning's n, S and S_x to find the actual value of Q_s from Figure 6-1. (From Figure 6-1, $Q_s = 0.5$ ft^3/s).

Step 7 Compare the value of Q_s from Step 6 to the trial value from Step 1. If values are not comparable, select a new value of Q_s and return to Step 1:

(Compare 0.5 to 0.7 "no good." Try $Q_s = 0.8$; then $2.0 - 0.8 = 1.2$, and $1.2/2.0 = 0.6$. From Figure 13-2, $W/T = 0.23$; then $T = 2.0/0.23 = 8.7$ ft and $T_s = 8.7 - 2.0 = 6.7$ ft. From Figure 13-1, $Q_s = 0.8$ ft^3/s—OK).

ANSWER: Spread $T = 8.7$ ft

CONDITION 2: Find gutter flow, given spread:

Step 1 Determine input parameters, including spread (T), spread above the depressed section (T_s), cross slope (S_x), longitudinal slope (S), depressed section slope (S_w), depressed section width (W), Manning's n and depth of gutter flow (d):

EXAMPLE: Allowable spread, $T = 10$ ft; $W = 2$ ft; $T_s = 10.0 - 2.0 = 8$ ft; $S_x = 0.04$; S = 0.005 ft/ft; $S_w = 0.06$; $n = 0.016$; $d = 0.43$ ft.

Step 2 Use Figure 6-1 to determine the capacity of the gutter section above the depressed section (Q_s). Use the procedure for uniform cross slopes, Condition 2, substituting T_s for T. (From Figure 6-1, $Q_s = 3.0$ ft^3/s).

Step 3 Calculate the ratios W/T and S_w/S_x and, from Figure 6-2, find the appropriate value of E_o (the ratio of Q_w/Q). ($W/T = 2.0/10.0 = 0.2$; $S_w/S_x = 0.06/0.04 = 1.5$; from Figure 6-1, $E_o = 0.46$).

Step 4 Calculate the total gutter flow using the equation:

$$Q = Q_s/(1 - E_o) \quad (6.2)$$

where:

Q = gutter flow rate, ft^3/s

Q_s = flow capacity of the gutter section above the depressed section, ft^3/s

E_o = ratio of frontal flow to total gutter flow (Q_w/Q)

($Q = 3.0 / (1 - 0.46) = 5.6$ ft^3/s)

Step 5 Calculate the gutter flow width (W), using Equation 6.1:

($Q_w = Q - Q_s = 5.6 - 3.0 = 2.6$ ft^3/s)

Note: Figure 6-3 can also be used to calculate the flow in a composite gutter section.

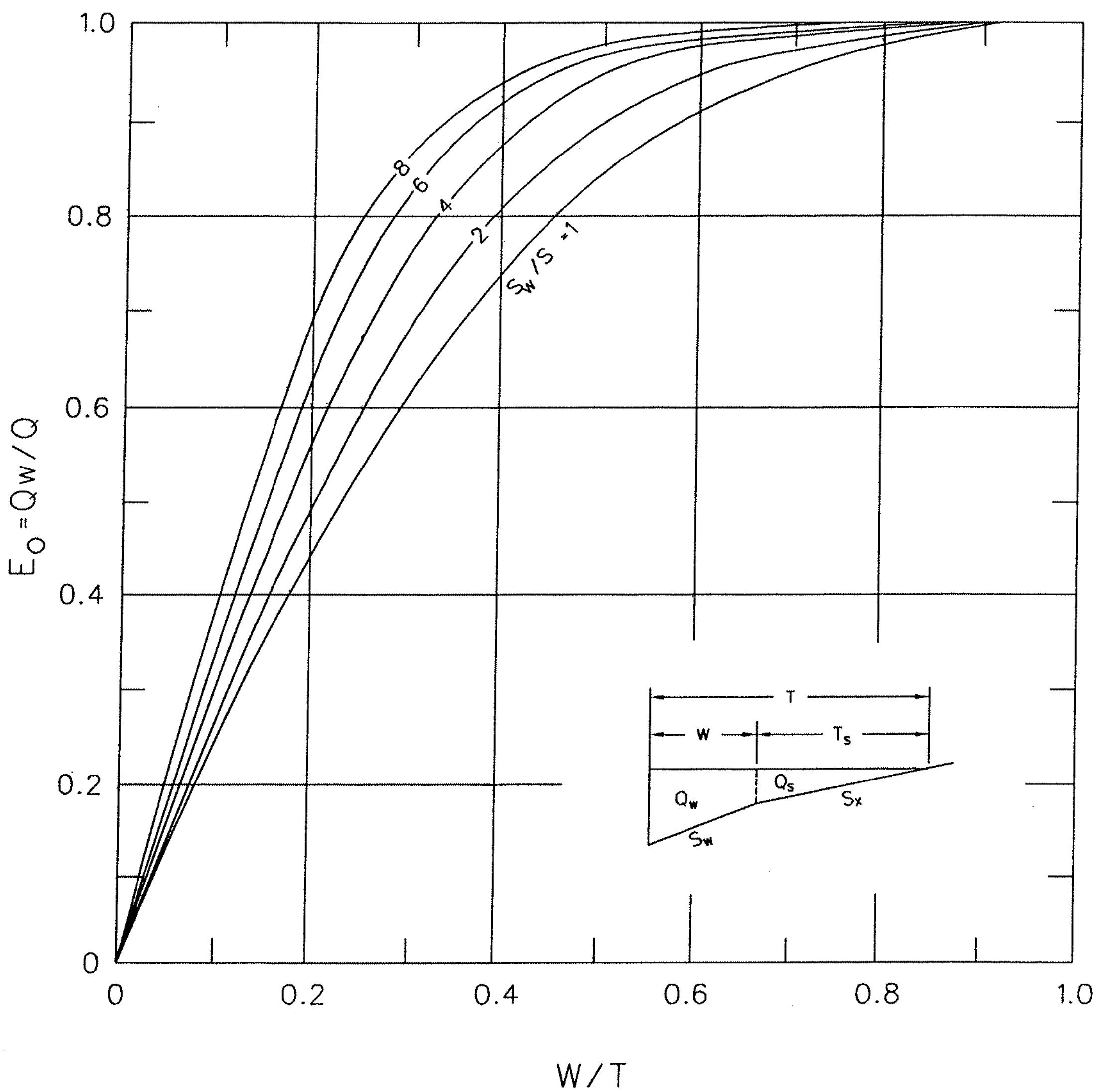


FIGURE 6-2. Ratio of Frontal Flow to Total Gutter Flow

Source: HEC 22 *(6)*.

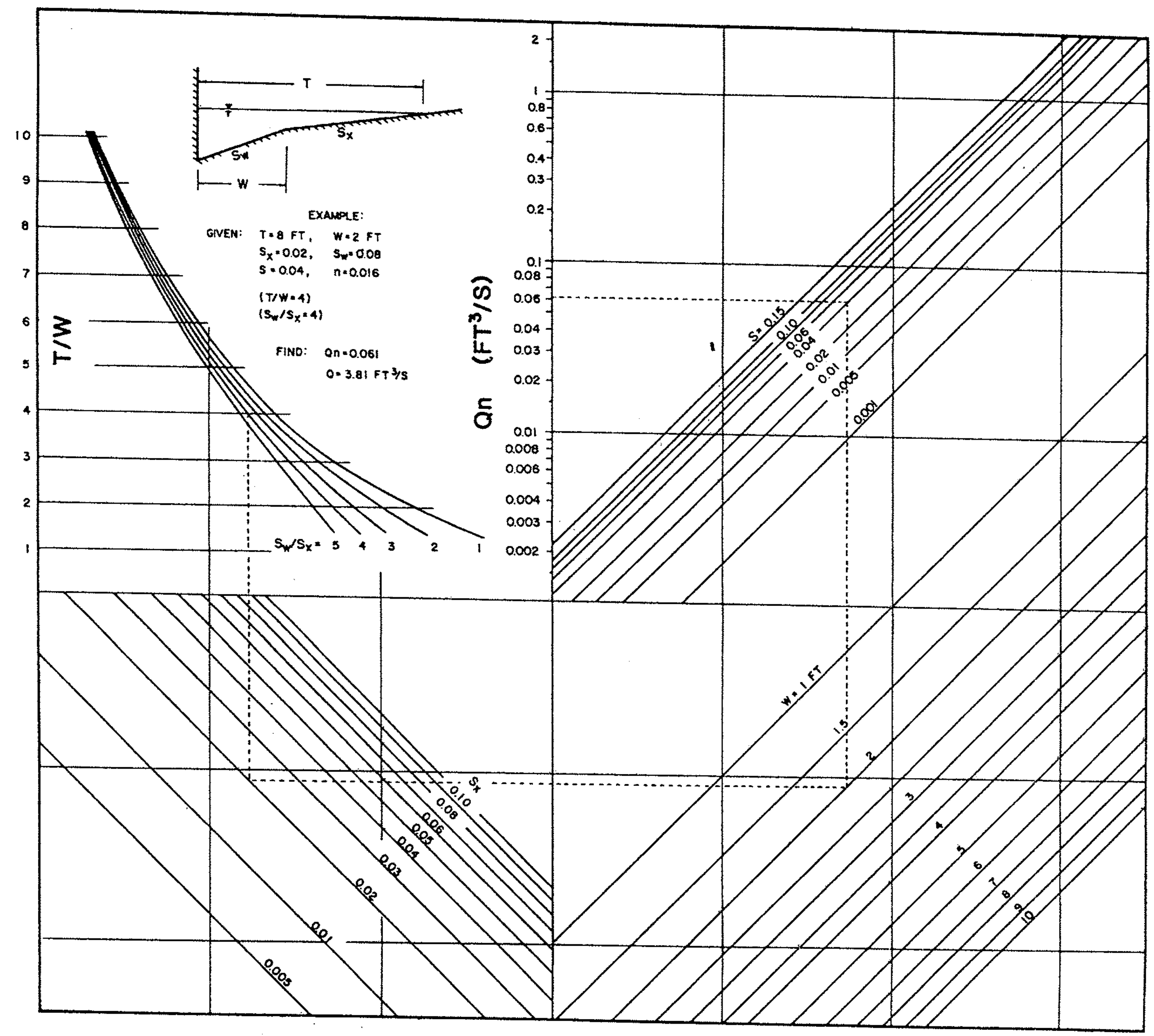


FIGURE 6-3. Flow in Composite Gutter Sections

Source: HEC 12 *(3)*.

6.3.5 *V-Type Gutter Sections (Procedures)*

Figure 6-1 can also be used to solve V-type channel problems. The spread (T) can be calculated for a given flow (Q), or the flow can be calculated for a given spread. This method can be used to calculate approximate flow conditions in the triangular channel adjacent to concrete median barriers. It assumes that the effective flow is confined to the V channel with spread T_1. Figure 6-4 illustrates the following procedure for a V-type gutter:

CONDITION 1: Given flow (Q), find spread (T):

Step 1 Determine input parameters, including longitudinal slope (S), cross slope $S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2})$, Manning's n, total flow (Q). (Example: $S = 0.01$, $S_{x1} = 0.06$, $S_{x2} = 0.04$, $S_{x3} = 0.015$, $n = 0.016$, $Q = 2.0$ ft^3/s, shoulder width = 6 ft).

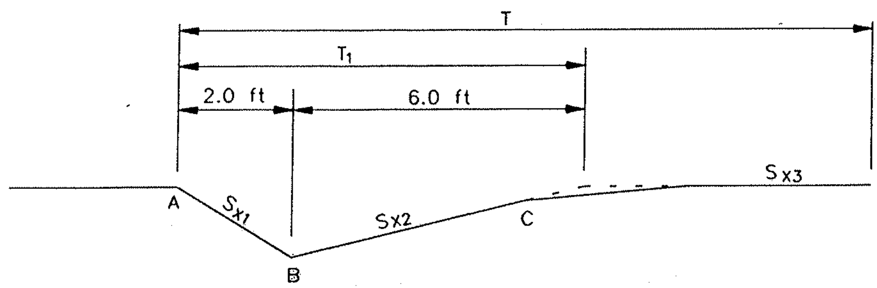


FIGURE 6-4. V-Type Gutter (Mountable Curb)

Step 2 Calculate S_x:

$S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2})$ $\quad\quad$ $S_x = (0.06)(0.04)/(0.06 + 0.04) = 0.024$

Step 3 Solve for T_1 using the nomograph on Figure 6-1:

T_1 is a hypothetical width that is correct if it is contained within S_{x1} and S_{x2}. From the nomograph, $T_1 = 8.4$ ft; however, because the shoulder width of 6 ft is less than 8.4 ft, S_{x2} is 0.04, and the pavement cross slope S_{x3} is 0.015. T will actually be greater than 8.4 ft, 8.4 - 2.0 = 6.4 ft, which is > 4.0 ft; therefore, the spread is greater than 8.4 ft.

Step 4 To find the actual spread, solve for depth at Points B and C:

Point B: 6.4 ft @ 0.04 = 0.26 ft
Point C: 0.26 ft - (4.0 ft @ 0.04) = 0.1 ft

Step 5 Solve for the spread on the pavement. (Pavement cross slope = 0.015):

$T_{0.015} = 0.1/0.015 = 6.7$ ft

Step 6 Find the actual total spread (T): T = 6.0 + 6.7 = 12.7 ft

CONDITION 2: Given spread (T), find flow (Q):

Step 1 Determine input parameters such as longitudinal slope (S), cross slope ($S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2})$, Manning's n and allowable spread. (Example: $n = 0.016$, $S = 0.015$, $S_{x1} = 0.06$, $S_{x2} = 0.04$, $T = 6.0$ ft).

Step 2 Calculate S_x:

$$S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2}) = (0.06)(0.04)/(0.06 + 0.04) = 0.024$$

Step 3 Using Figure 6-1, solve for Q: For $T = 6.0$ ft, $Q = 1.1$ ft^3/s

The equation shown on Figure 6-1 can also be used.

6.4 INLETS

6.4.1 *General*

Inlets are drainage structures utilized to collect surface water through curb or other similar openings and convey it to storm drains or to culverts. If grated or combination inlets are allowed, they must be safe for pedestrian, bicycle, and wheelchair traffic.

6.4.2 *Inlet Locations*

Inlets are required at locations needed to collect runoff within the design controls specified in the design criteria (see Section 6.2). In addition, there are a number of locations where inlets may be necessary with little regard to contributing drainage area. These locations should be marked on the plans prior to any computations regarding discharge, water spread, inlet capacity or runby. Examples of such locations are as follows:

- sag points in the gutter grade;
- upstream of median breaks, entrance/exit ramp gores, cross walks and street intersections;
- immediately upstream and downstream of bridges;
- immediately upstream of cross slope reversals;

- on side streets at intersections;
- at the end of channels in cut sections; and
- behind curbs, shoulders or sidewalks to drain low areas.

Inlets should not be located in the path where pedestrians are likely to walk.

6.5 INLET SPACING

6.5.1 *General*

A number of inlets are required to collect runoff at locations with little regard for contributing drainage area as discussed in Section 6.4.2. These should be plotted on the plan first. Next, it is recommended to start locating inlets from the crest and working downgrade to the sag points. The location of the first inlet from the crest can be found by determining the length of pavement and the area back of the curb sloping toward the roadway that will generate the design runoff. The design runoff can be computed as the maximum allowable flow in the curbed channel that will meet the design criteria as specified in Section 6.2. Where the contributing drainage area consists of a strip of land parallel to and including a portion of the highway, the first inlet can be calculated as follows:

$$L = \frac{43{,}560\ Q_t}{CIW} \tag{6.3}$$

where:

L = distance from the crest, ft
Q_t = maximum allowable flow, ft^3/s
C = composite runoff coefficient for contributing drainage area
W = width of contributing drainage area, ft
I = rainfall intensity for design frequency, in./h

If the drainage area contributing to the first inlet from the crest is irregular in shape, trial and error will be necessary to match a design flow with the maximum allowable flow. Equation 6.3 is an alternative form of the Rational Equation.

To space successive downgrade inlets, it is necessary to compute the amount of flow that will be intercepted by the inlet (Q_i) and subtract it from the total gutter flow to compute the runby. The runby from the first inlet is added to the computed flow to the second inlet, the total of which must be less than the maximum allowable flow dictated by the criteria. Figure 6-8 (Section 6.5.4) is an inlet spacing computation sheet that can be utilized to record the spacing calculations.

Inlet interception capacity for all types of inlets has been investigated by FHWA. References *(6)* and *(4)* may be used to analyze the flow in gutters and the interception capacity of all types of inlets on continuous grades and sags. Both uniform and composite cross slopes can be analyzed.

6.5.2 *Curb Inlets on Grade*

Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. They are a viable alternative to grates in many locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.

The length of a curb-opening inlet required for total interception of gutter flow on a pavement section with a straight cross slope is expressed by:

$$L_T = KQ^{0.42}S^{0.3}(1/nS_x)^{0.6} \quad (6.4)$$

where:
K = 0.6
L_T = curb-opening length required to intercept 100 percent of the gutter flow, ft

The efficiency of curb-opening inlets shorter than the length required for total interception is expressed by:

$$E = 1 - (1 - L/L_T)^{1.8} \quad (6.5)$$

where:
L = curb-opening length, ft

Figure 6-5 is a nomograph for the solution of Equation 6.4, and Figure 6-6 provides a solution of Equation 6.5.

The length of inlet required for total interception by depressed curb-opening inlets or curb openings in depressed gutter sections can be found by the use of an equivalent cross slope, S_e, in Equation 6.4:

$$S_e = S_x + S_w E_o \quad (6.6$$

where:
S_w = cross slope of the gutter measured from the cross slope of the pavement
= $(a/12W)$, ft/ft

a = gutter depression, in.
E_o = ratio of flow in the depressed section to total gutter flow. It is determined by the gutter configuration upstream of the inlet. Reference Figure 6-2 to determine E_o.

Note: S_e can be used to calculate the length of curb opening by substituting S_e for S_x in Equation 6.4.

Example Problem

The following example illustrates the use of this procedure:

Given: $S_x = 0.03$ ft/ft $S = 0.035$ ft/ft $n = 0.016$ $Q = 5$ ft^3/s

Find: (1) Q_i for 10-ft curb-opening inlet, uniform cross slope

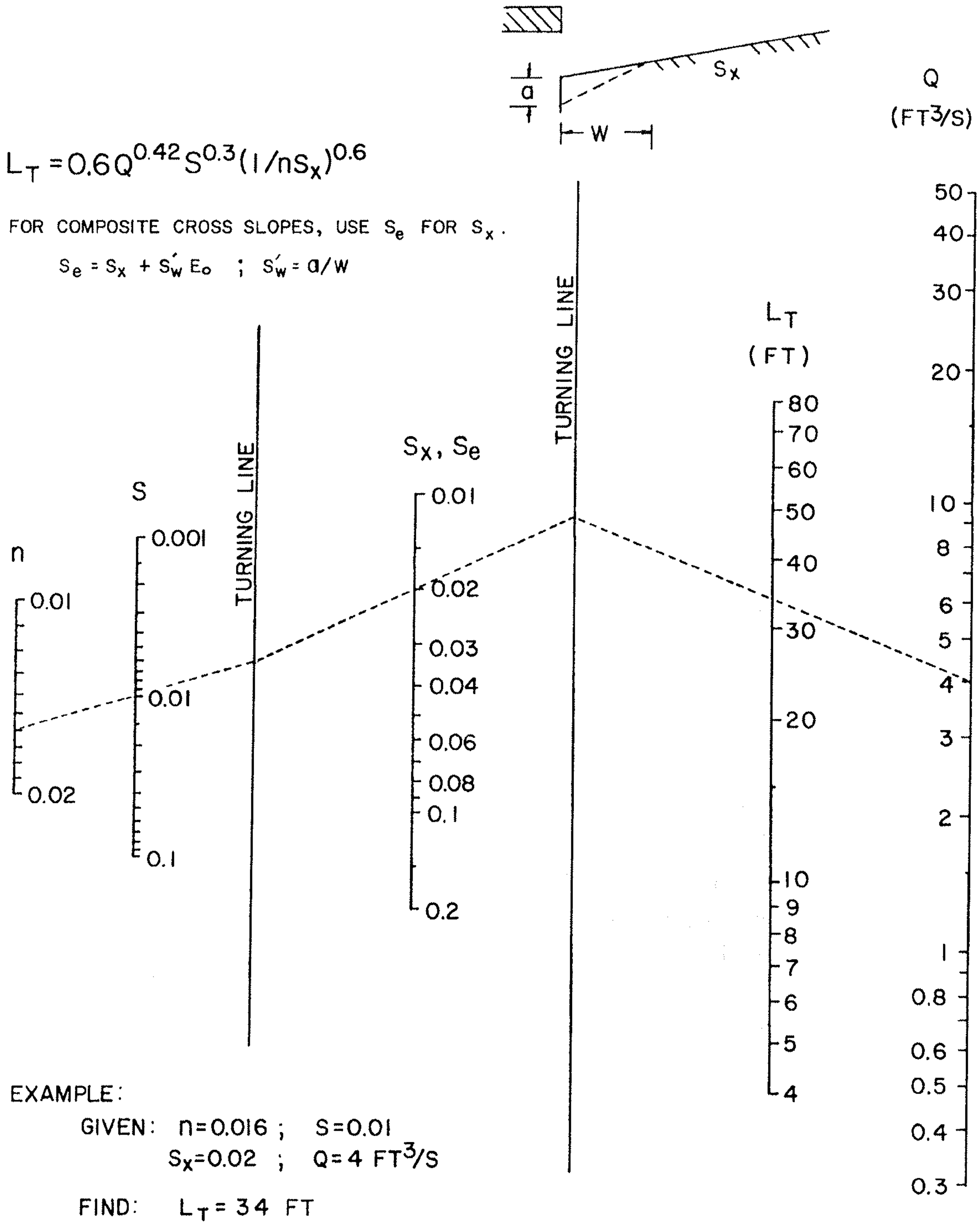
(2) Q_i for a depressed 10-ft curb-opening inlet with composite cross slope $a = 2$ in., $W = 2$ ft

(3) Q_i for a depressed 10-ft curb-opening inlet with uniform cross slope

Solution: (1) From Figure 6-1, $T = 8$ ft
From Figure 6-5, $L_T = 41$ ft
$L/L_T = 10/41 = 0.24$
From Figure 6-6, $E = 0.39$
$Q_i = EQ = (0.39)(5) = \underline{\underline{2 \text{ ft}^3/\text{s}}}$

(2) $Qn = (5)(0.016) = 0.08$ ft^3/s
$S_w/S_x = (0.03 + 0.085)/0.03 = 3.83$
From Figure 6-3, $T/W = 3.5$ and $T = 7$ ft
Then W/T (Depress) $= 2/7 = 0.29$
From Figure 6-2, $E_o = 0.74$
$S_e = S_x + S_w E_o = 0.03 + 0.085(0.74) = 0.09$
From Figure 6-5, $L_T = 21$ ft, then $L/L_T = 10/21 = 0.48$
From Figure 6-6, $E = 0.69$, then $Q_i = (0.69)(5) =$ ***3.5 ft³/s***

(3) $S_w/S_x = 0.03/0.03 = 1$
$W/T = 2/8 = 0.25$
From Figure 6-2, $E_o = 0.53$
$S_e = 0.03 + (0.085)(0.53) = 0.075$
From Figure 6-5, $L_T = 25$ ft, then $L/L_T = 10/25 = 0.4$
From Figure 6-6, $E = 0.60$, then $Q_i = (0.6)(5) =$ $\boldsymbol{3\ ft^3/s}$



Curb-opening & Slotted Drain Inlet Length for Total Interception - English Units

FIGURE 6-5. Curb-Opening Inlet Length for Total Interception

Source: HEC 22 *(6)*.

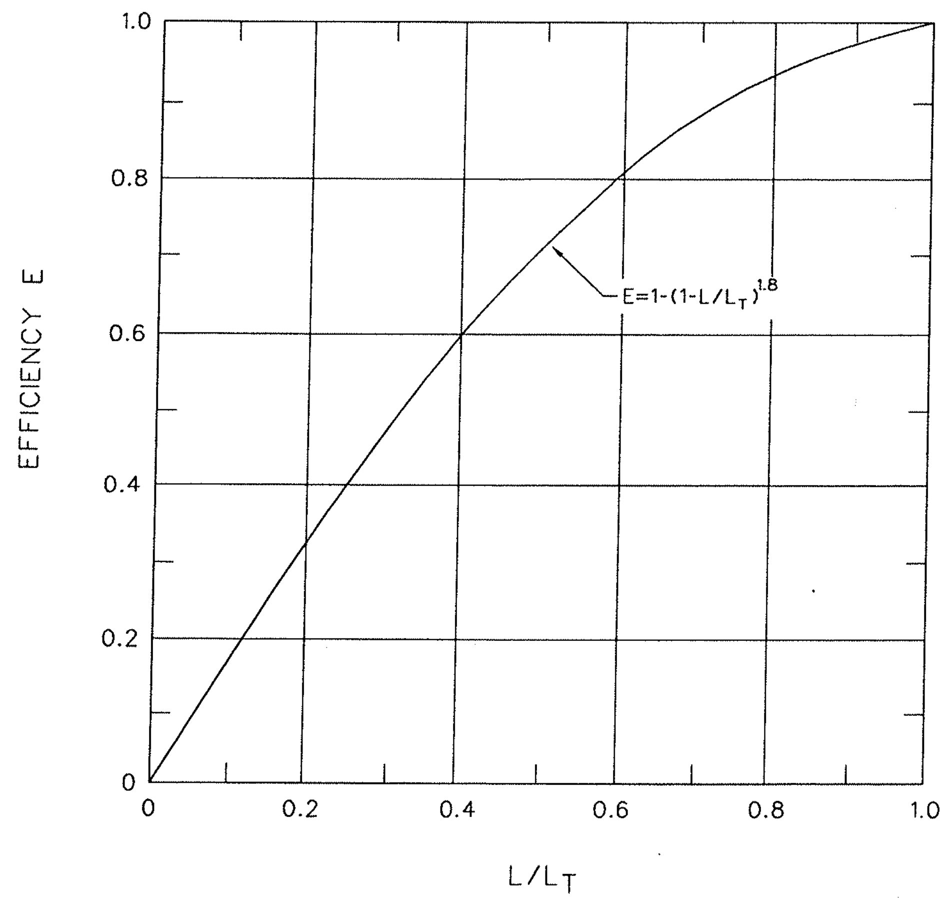


FIGURE 6-6. Curb-Opening and Slotted Drain Inlet Interception Efficiency

Source: HEC 22 *(6)*.

6.5.3 *Curb Inlets in Sag*

The capacity of a curb-opening inlet in a sag depends on water depth at the curb, the curb-opening length and the height of the curb opening. The inlet operates as a weir to depths equal to the curb-opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The equation for the interception capacity of a depressed curb-opening inlet operating as a weir is:

$$Q_i = C_W (L + 1.8W) d^{1.5} \tag{6.7}$$

where:

C_W = 2.3
L = length of curb opening, ft
W = width of depression, ft
d = depth of water at curb measured from the normal cross slope gutter flow line, ft

See Figure 6-7 for a definition sketch.

The weir equation for curb-opening inlets without depression becomes:

$$Q_i = C_W L d^{1.5} \tag{6.8}$$

The depth limitation for operation as a weir becomes: $d \leq h$.

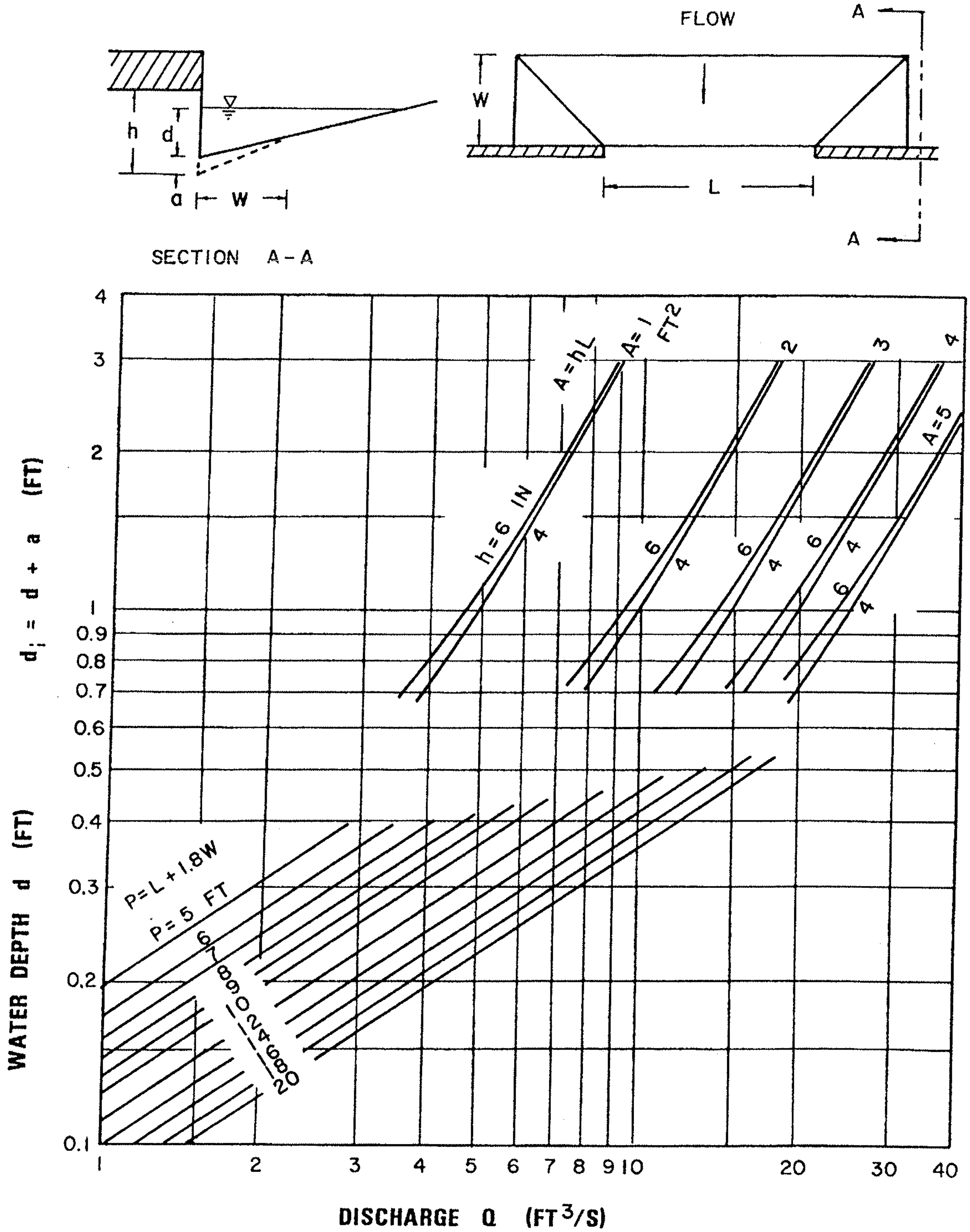
Curb-opening inlets operate as orifices at depths greater than approximately 1.4 × height of curb opening. The interception capacity can be computed by:

$$Q_i = C_o A[2g(d_i - h/2)]^{0.5} \tag{6.9}$$

where:

C_o = orifice coefficient (0.67)
h = height of curb-opening orifice, ft
A = clear area of opening, ft^2
d_i = depth at lip of curb opening, ft

The weir equations use an effective weir length and coefficient that is representative of the line of gutter transition to the depression. The user should be cautioned not to use the depth from the water surface to the depressed inlet throat, but to the undepressed depth (or more specifically, the



Depressed Curb-opening Inlet Capacity in Sump Locations - English Units

FIGURE 6-7. Depressed Curb-Opening Inlet Capacity in Sump Locations

Source: HEC 22 *(6).*

depth at the beginning of the transition). Otherwise, the capacity for weir flow will be overestimated.

Note: Equation 6.9 is applicable to depressed and undepressed curb-opening inlets, and the depth at the inlet includes any gutter depression.

Example Problem

The following Example illustrates the use of this procedure:

Given: Curb-opening inlet in a sump location:

$L = 5$ ft $h = 5$ in

(1) Undepressed curb opening:

$S_x = 0.05$ $T = 8$ ft

(2) Depressed curb opening:

$S_x = 0.05$ $W = 2$ ft
$a = 2$ in $T = 8$ ft

Find: Q_i

Solution: (1) $d = TS_s = (8)(0.05) = 0.4$ ft $d < h$; therefore, weir controls
$Q_i = C_W L d^{1.5} = (2.3)(5)(0.4)^{1.5} = 2.9$ ft^3/s

(2) $d = 0.4$ ft $< (1.4\ h) = 0.6$; therefore, weir controls
$P = L + 1.8W = 5 + 1.8(2) = 8.6$ ft
$Q_i = (2.3)(8.6)(0.4)^{1.5} = 5$ ft^3/s (Figure 6-7)

At $d = 0.4$ ft, the depressed curb-opening inlet has about 70 percent more capacity than an inlet without depression. In practice, the flow rate would be known and the depth at the curb would be unknown.

6.5.4 *Inlet Spacing Computations*

To design the location of the inlets for a given project, information such as a layout or plan sheet suitable for outlining drainage areas, road profiles, typical cross sections, grading cross sections, superelevation diagrams and contour maps are necessary. The inlet computation sheet, Figure 6-8, should be used to document the computations. A step-by-step procedure is as follows:

Step 1 Complete the blanks on top of the sheet to identify the job by S.P., route, date and your initials.

Step 2 Mark on the plan the location of inlets that are necessary even without considering any specific drainage area. See Section 6.4.2 for additional information.

Step 3 Start at one end of the job, at one high point and work towards the low point, then space from the other high point back to the same low point.

Step 4 Select a trial drainage area approximately 300 to 400 ft below the high point, and outline the area including any area that may come over the curb. (Use drainage area maps). Large areas of behind-the-curb drainage (producing 6 cfs or more during the design storm) should be intercepted before crossing the back of curb.

Step 5 (Col 1) Describe the location of the proposed inlet by number and station in Columns 1 and 2.

(Col 5) Identify the curb and gutter type in the Remarks, Column 19. A sketch of the cross section should be provided in the open area of the computation sheet.

Step 6 (Col 3) Compute the drainage area in acres and enter in Column 3.

Step 7 (Col 4) Select a *C* value from one of the tables in Chapter 2, Section 2.4, or compute a weighted value based on area and cover type.

Step 8 (Col 5) Compute a time of concentration for the first inlet. This will be the travel time from the hydraulically most remote point in the drainage area to the inlet. See additional discussion in Chapter 2. The minimum time of concentration should be 5 minutes. Enter value in Column 5.

Step 9 (Col 6) Using the Intensity-Duration-Frequency curves, select a rainfall intensity at the t_c for the design frequency. Enter in Column 6.

Step 10 (Col 7) Calculate Q by multiplying Column 3 × Column 4 × Column 6. Enter in Column 7.

Step 11 (Col 8) Determine the gutter slope at the inlet from the profile grade—check effect of superelevation. Enter in Column 8.

FIGURE 6-8. Inlet Spacing Computation Sheet

INLET COMPUTATION SHEET — DATE ________ SP ________ ROUTE ________

COMPUTED BY ________ SHEET ___ OF ___

LOCATION		GUTTER DISCHARGE Design Frequency ______					GUTTER DISCHARGE Allowable Spread ______								INLET DISCHARGE			REMARKS
INLET NO.	STAT.	DRAIN AREA "A" (ac)	RUNOFF COEF "C"	TIME OF CONC. "t_c" (min)	Rain Intensity "I" (in./h)	Q= CIA/360 (ft^3/s)	GRADE "S_o" (ft/ft)	CROSS SLOPE "S_x" (ft/ft)	PREV RUNBY (ft^3/s)	TOTAL GUTTER FLOW (ft^3/s)	DEPTH "d" (ft)	GUTTER WIDTH "W" (ft)	SPREAD "T" (ft)	W/T	INLET TYPE	INTER-CEPT "Q_i" (ft^3/s)	RUNBY "Q_r" (ft^3/s)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Step 12 (Col 9) (Col 13)	Enter cross slope adjacent to inlet in Column 9 and gutter width in Column 13. Sketch composite cross slope with dimensions.
Step 13 (Col 11)	For the first inlet in a series (high point to low point), enter Column 7 in Column 11 since no previous runby has occurred yet.
Step 14 (Col 12) (Col 14)	Using Figure 6-1 or the available computer model, determine the spread T, enter in Column 14, and calculate the depth d at the curb by multiplying T times the cross slope(s) and enter in Column 12. Compare with the allowable spread as determined by the design criteria in Section 6.2. If Column 15 is less than the curb height and Column 14 is near the allowable spread, continue on to Step 16. If not OK, expand or decrease the drainage area to meet the criteria and repeat Steps 5 through 14. Continue these repetitions until Column 14 is near the allowable spread, then proceed to Step 15.
Step 15 (Col 15)	Calculate *W*/*T* and enter in Column 15.
Step 16 (Col 16)	Select the inlet type and dimensions and enter in Column 16.
Step 17 (Col 17)	Calculate the Q intercepted (Q_i) by the inlet and enter in Column 17. Use Figures 6-1 and 6-2 or 6-3 to define the flow in the gutter. Use Figures 6-5 and 6-6 to calculate Q_i for a curb-opening inlet. See Section 6.5.2 for a curb-opening inlet example.
Step 18 (Col 18)	Calculate the runby by subtracting Column 17 from Column 11, and enter into Column 18 and Column 10 on the next line if an additional inlet exists downstream.
Step 19 (Col 1-4)	Proceed to the next inlet downgrade. Select an area approximately 300 to 400 ft below the first inlet as a first trial. Repeat Steps 5 through 7 considering only the area between the inlets.
Step 20 (Col 5)	Compute a time of concentration for the second inlet downgrade based on the area between the two inlets.
Step 21 (Col 6)	Determine the intensity based on the time of concentration determined in Step 19 and enter in Column 6.

Step 22 (Col 7)	Determine the discharge from this area by multiplying Column 3 × Column 4 × Column 6. Enter the discharge in Column 7.
Step 23 (Col 11)	Determine total gutter flow by adding Column 7 and Column 10 and enter in Column 11. Column 10 is the same as Column 18 from the previous line.
Step 24 (Col 12) (Col 14)	Determine "*T*" based on total gutter flow (Column 11) by using Figure 6-1 or 6-3 and enter in Column 14. (If "*T*" in Column 14 exceeds the allowable spread, reduce the area and repeat Steps 19 through 24. If "*T*" in Column 14 is substantially less than the allowable spread, increase the area and repeat Steps 19 through 24).
Step 25 (Col 16)	Select inlet type and dimensions and enter in Column 16.
Step 26 (Col 17)	Determine Q_i and enter in Column 17—see instruction in Step 17.
Step 27 (Col 18)	Calculate the runby by subtracting Column 17 from Column 7 and enter in Column 16. This completes the spacing design for this inlet.
Step 28	Go back to Step 19 and repeat Step 19 through Step 27 for each subsequent inlet. If the drainage area and weighted "*C*" values are similar between each inlet, the values from the previous inlet location can be reused. If they are significantly different, recomputation will be required.

6.6 STORM DRAINS

6.6.1 *Introduction*

After the preliminary locations of inlets, connecting pipes and outfalls with tailwaters have been determined, the next logical step is the computation of the rate of discharge to be carried by each reach of the storm drain, and the determination of the size and gradient of pipe required to convey this discharge. This is done by starting at the upstream reach, calculating the discharge and sizing the pipe, then proceeding downstream, reach by reach, to the point where the storm drain connects with other drains or the outfall.

The rate of discharge at any point in the storm drain is not necessarily the sum of the inlet flow rates of all inlets above that section of storm drain. It is generally less than this total. The time of concentration is most influential and, as the time of concentration grows larger, the rainfall intensity to be used in the design grows smaller. In some cases, where a relatively large drainage area with a short time of concentration is added to the system, the peak flow may be larger using the shorter time even though the entire drainage area is not contributing. The prudent designer will be alert for unusual conditions and determine which time of concentration controls for each pipe segment.

For ordinary conditions, storm drains should be sized on the assumption that they will flow full or practically full under the design discharge but will not flow under pressure head. The Manning's formula is recommended for capacity calculations.

6.6.2 *Design Procedures*

The design of storm drainage systems is generally divided into the following operations:

Step 1 Determine inlet location and spacing as outlined earlier in this chapter.

Step 2 Prepare the plan layout of the storm drainage system establishing the following design data:

a. location of storm drains;

b. direction of flow;

c. location of inlets and junction boxes; and

d. location of existing utilities (e.g., water, gas, underground cables and existing and proposed foundations).

Step 3 Determine drainage areas, runoff coefficients and a time of concentration to the first inlet. Using an Intensity-Duration-Frequency (IDF) curve, determine the rainfall intensity (i). Calculate the discharge by (CiA).

Step 4 Size the pipe to convey the discharge by varying the slope and pipe size as necessary. The storm drain systems are normally designed for full gravity-flow conditions using the design frequency discharges.

Step 5 Calculate travel time in the pipe to the next inlet or junction box by dividing pipe length by the velocity. This travel time is added to the time of concentration for a new time of concentration and a new rainfall intensity at the next entry point.

Step 6 Calculate the new area (A) and multiply by the runoff coefficient (C), add to the previous (CA) and multiply by the new rainfall intensity to determine the new discharge. Determine the size of pipe and slope necessary to convey the discharge.

Step 7 Continue this process to the storm drain outlet. Utilize the equations and/or nomographs to accomplish the design effort.

Step 8 Complete the design by calculating the hydraulic grade line as described in Section 6.6.4. The design procedure should include the following:

- Storm drain design computations can be made on forms as illustrated in Figure 6-13.
- All computations and design sheets should be clearly identified. The designer's initials and date of computations should be shown on every sheet. Voided or superseded sheets should be so marked. The origin of data used on one sheet but computed on another should be given.

6.6.3 *Hydraulic Capacity*

The most widely used formula for determining the hydraulic capacity of storm drains for gravity and pressure flows is the Manning's formula, expressed by the following equation:

$$V = \frac{1.486}{n} R^{2/3} \ S^{1/2} \tag{6.10}$$

where:
V = mean velocity of flow, ft/s
n = Manning's roughness coefficient
R = hydraulic radius, ft = area of flow divided by the wetted perimeter (A/WP)
S = the slope of the energy grade line, ft/ft

In terms of discharge, the above formula becomes:

$$Q = VA = \frac{1.486}{n} AR^{2/3} \ S^{1/2} \tag{6.11}$$

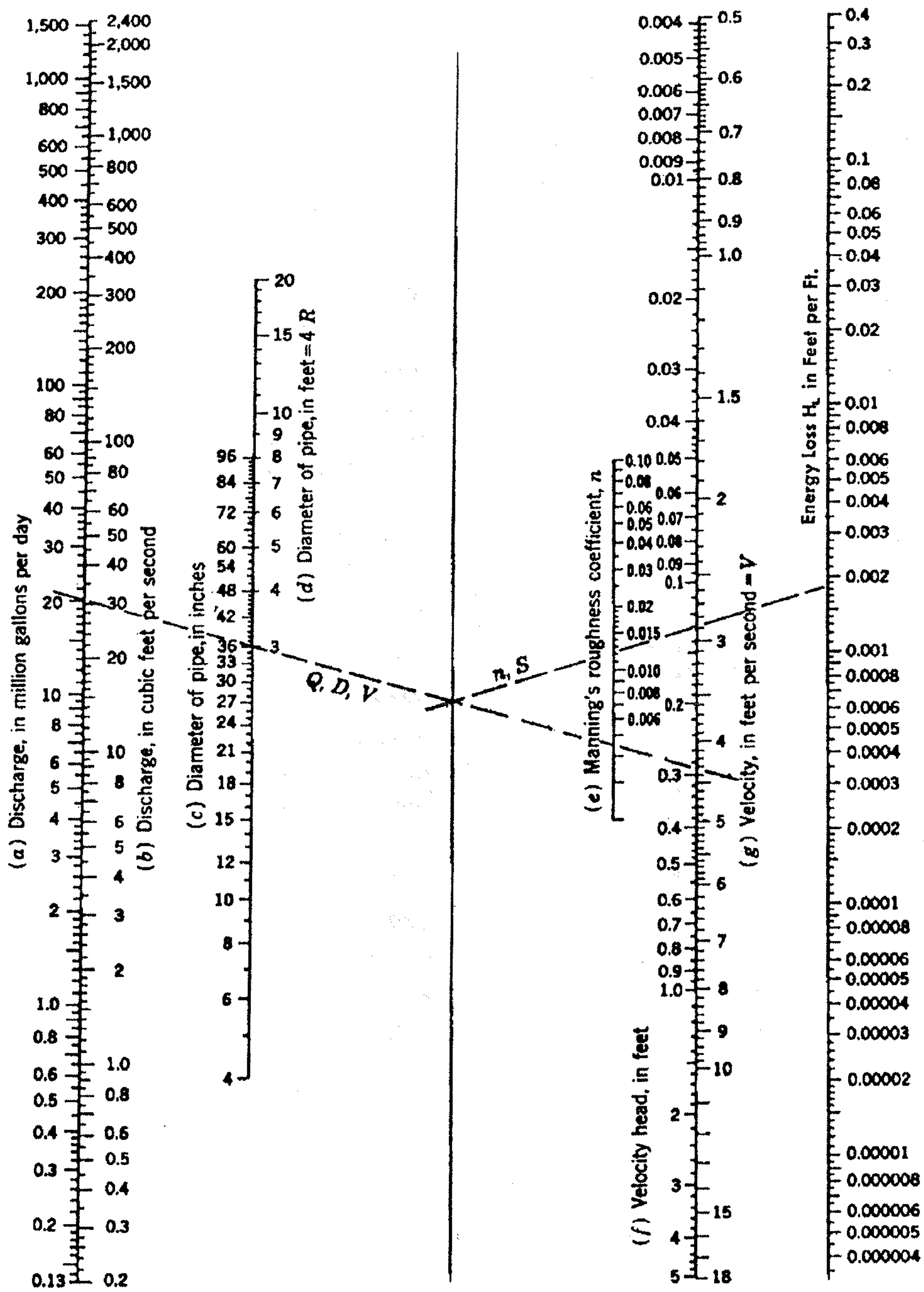
where:
Q = rate of flow, ft^3/s
A = cross sectional area of flow, ft^2

For circular storm drains flowing full, $R = D/4$ and Equations 6.10 and 6.11 become:

$$V = \frac{0.590}{n} D^{2/3} S^{1/2} \qquad Q = \frac{0.463}{n} D^{8/3} S^{1/2} \tag{6.12}$$

where:
D = diameter of pipe, ft

The nomograph solution of Manning's formula for full flow in circular storm drains is shown on Figure 6-9, Figure 6-10, and Figure 6-11. Figure 6-12 has been provided to assist in the solution of Manning's Equation for partial full flow in storm drains.



Alignment chart for energy loss in pipes, for Manning's formula.
Note: Use chart for flow computations, $H_L = S$

Solution of Manning's Equation for Flow in Storm Drains - English Units
(Taken from "Modern Sewer Design" by American Iron and Steel Intitute)

FIGURE 6-9. Manning's Formula for Full Flow in Storm Drains

Source: HEC 22 *(6)*.

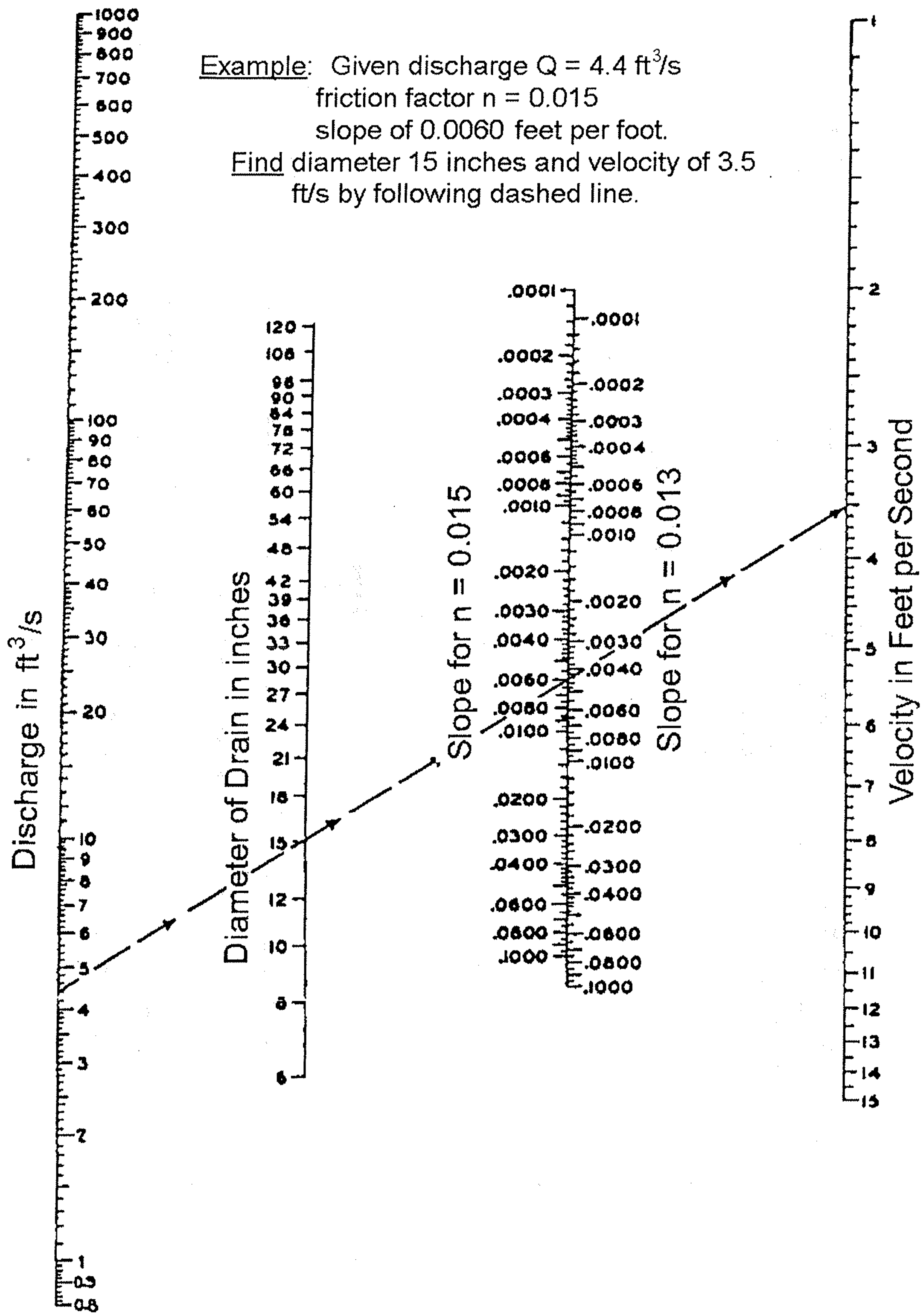


FIGURE 6-10. Nomograph for Computing Required Size of Circular Drain for Full Flow (*n* = 0.013 or 0.015)

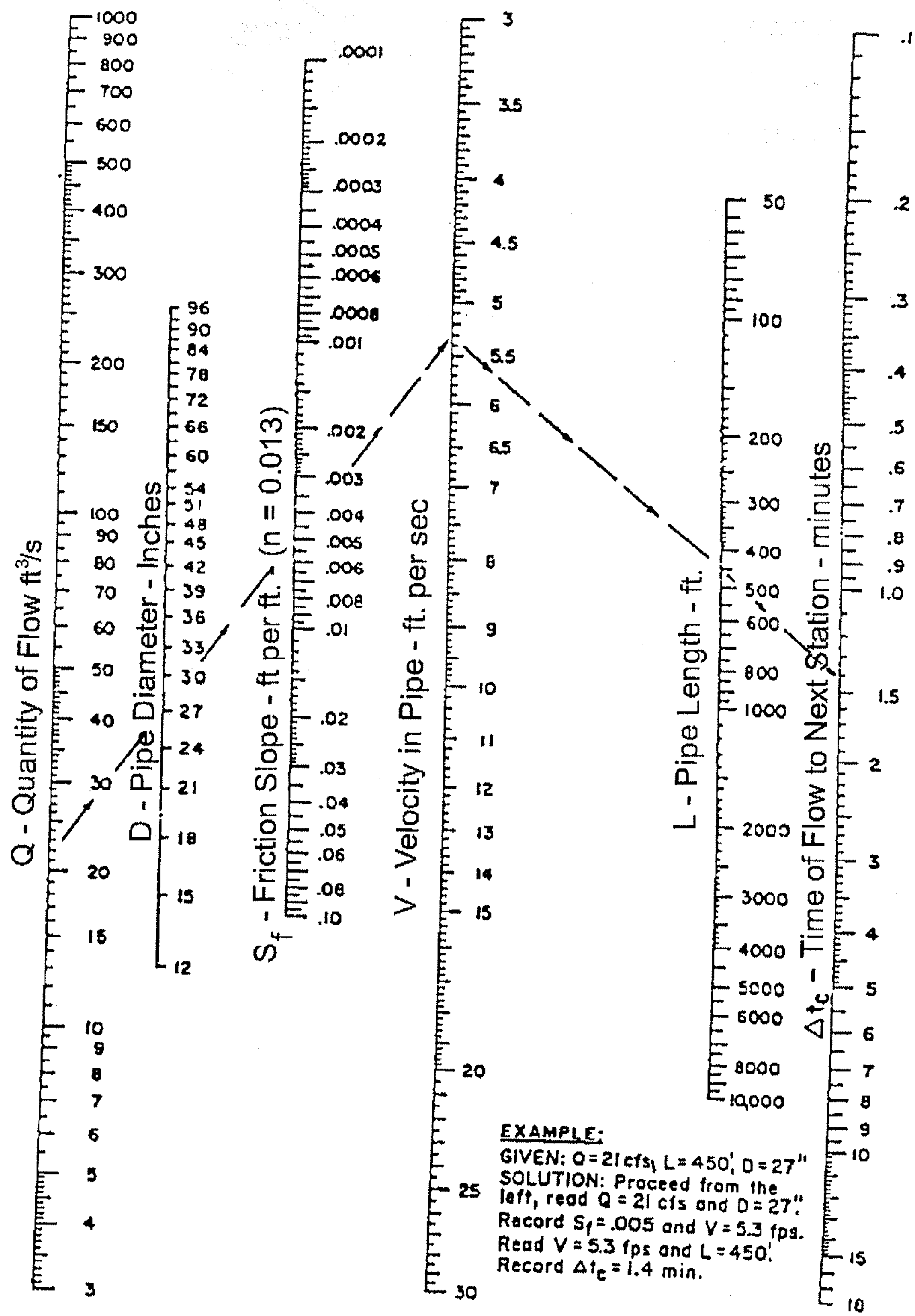
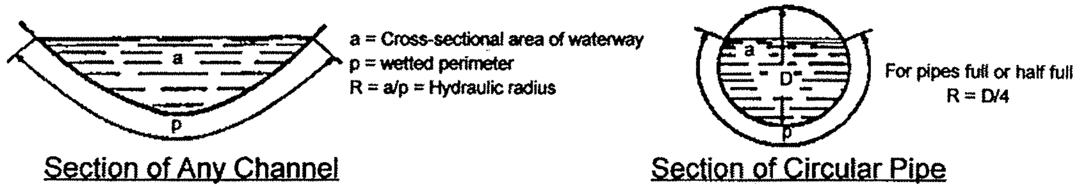
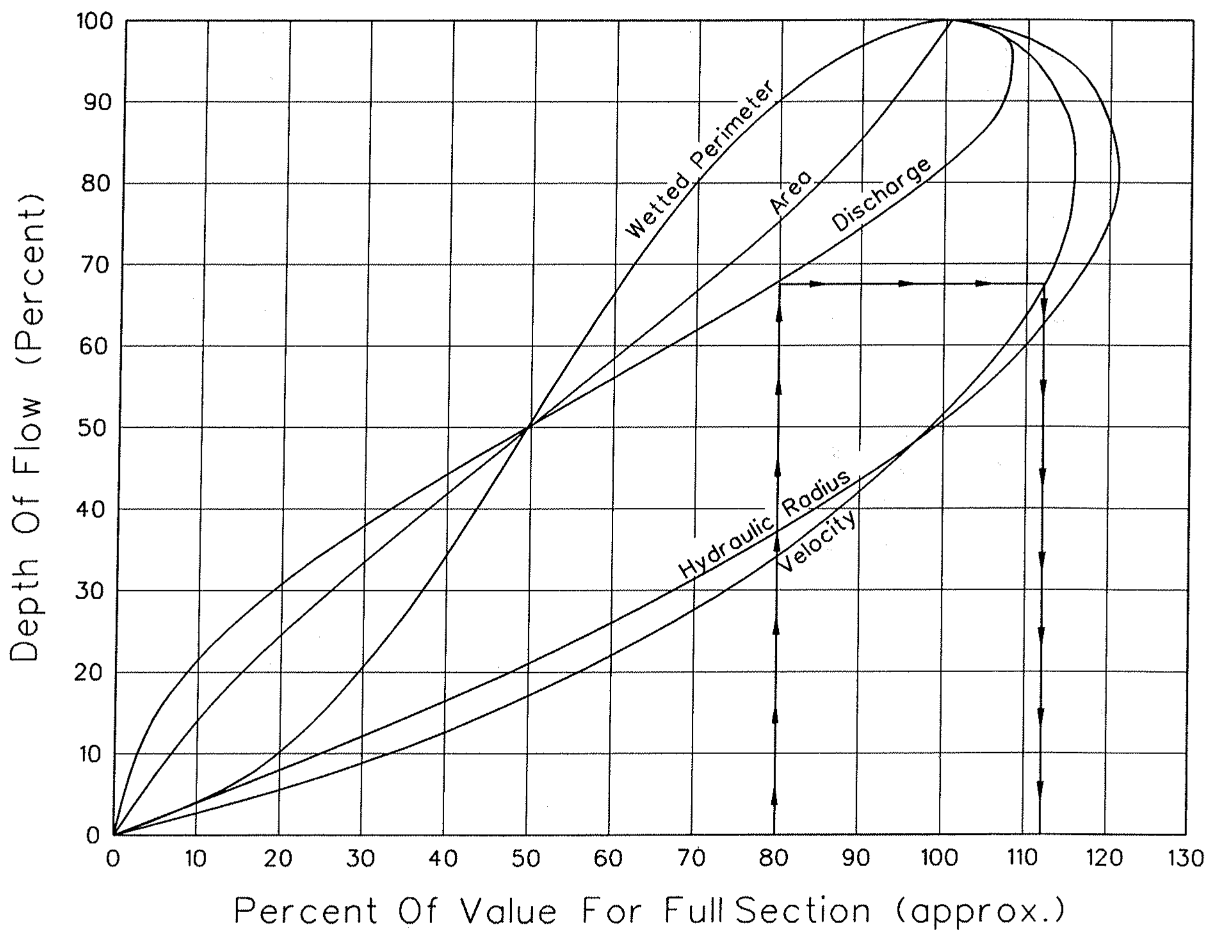


FIGURE 6-11. Concrete Pipe Flow Nomograph



V = Average or mean velocity in ft/s
Q = a V = Discharge of pipe or channel in ft^3/s
n = Coefficient of roughness of pipe or channel surface
S = Slope of hydraulic gradient (water surface in open channels or pipes not under pressure, same as slope of channel or pipe invert only when flow is uniform in constant section)

Hydraulic Elements of Channel Sections



Source: Reference *(2)*.

FIGURE 6-12. Values of Hydraulic Elements of Circular Section for Various Depths of Flow

Storm Drain Computation Sheet

Computed ________ Date ________

Checked ________ Date ________

Route ________

Section ________

County ________

Station		Length (ft)	Drainage Area A (ac)		Runoff Coefficient C	A x C		Flow Time (min)		Rainfall Intensity I (in/h)	Total Runoff 0.0278 CIA = Q (ft³/s)	Diameter Pipe (in)	Capacity Full (ft³/s)	Velocity (ft/s)		Inert Elev.		Manhole Invert Drop	Slope of Drain (ft/ft)
From	To		Increment	Total		Increment	Total	To Upper End	In Section					Flowing Full	Design Flow	Upper End	Lower End		

FIGURE 6-13. Storm Drain Computation Sheet

6.6.4 *Hydraulic Grade Line*

The hydraulic grade line (HGL) is the last important feature to be established for the hydraulic design of storm drains. This grade line aids the designer in determining the acceptability of the proposed system by establishing the elevations along the system to which the water will rise when the system is operating from a flood of design frequency.

All head losses in a storm drainage system are considered in computing the hydraulic grade line to determine the water surface elevations, under design conditions in the various inlets, junction boxes, etc. Hydraulic control is a set water surface elevation from which the hydraulic calculation are begun. All hydraulic controls along the alignment are established. If the control is at a mainline upstream inlet, the hydraulic grade line is the water surface elevation minus the entrance loss minus the differences in velocity head. If the control is at the outlet, the water surface is the outlet pipe hydraulic grade line.

6.6.4.1 Design Procedure

The head losses are calculated beginning from the control point to the first junction and the procedure is repeated for the next junction. The computation for an outlet control may be tabulated on Figure 6-14 using the following procedure:

Step 1 Enter in Col. 1 the station for the junction immediately upstream of the outflow pipe. Hydraulic grade line computations begin at the outfall and are worked upstream taking each junction into consideration.

Step 2 Enter in Col. 2 the outlet water surface elevation if the outlet will be submerged during the design storm or 0.8 diameter plus invert out elevation of the outflow pipe, whichever is greater.

Step 3 Enter in Col. 3 the diameter (D_o) of the outflow pipe.

Step 4 Enter in Col. 4 the design discharge (Q_o) for the outflow pipe.

Step 5 Enter in Col. 5 the length (L_o) of the outflow pipe.

Step 6 Enter in Col. 6 the friction slope (SF_o) in ft/ft of the outflow pipe. This can be determined by using the following formula:

$$SF = [(Qn)/(1.49AR^{2/3})]^2 \qquad (6.13)$$

where:
SF = friction slope, ft/ft

Step 7 Multiply the friction slope (SF_o) in Col. 6 by the length (L_o) in Col. 5 and enter the friction loss (H_f) in Col. 7.

HYDRAULIC GRADE LINE

PROJECT

STATION	Outlet Water Surface Elev.	D_o	Q_o	L_o	S_{f_o} %	H_f	JUNCTION LOSS											Final H	Inlet Water Surface Elev.	Rim Elev.
							V_o	H_o	Q_i	V_i	Q_iV_i	$\frac{V_i^2}{2g}$	H_i	Angle	H_Δ	H_t	1.3 H_t	0.5 H_t			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)

$H_i = 0.35 \frac{V_i^2}{2g}$ $H_o = 0.25 \frac{V_o^2}{2g}$ $H_\Delta = K \frac{V_i^2}{2g}$ FINAL $H = H_f + H_t$

$H_t = H_o + H_i + H_\Delta$

Figure 6-14. Hydraulic Grade Line Computation Form

Step 8 Enter in Col. 8 the outlet pipe velocity of the flow (V_o).

Step 9 Enter in Col. 9 the contraction loss (H_o) by using the formula $H_o = [0.25(V_o^2)]/2g$, where $g = 32.2$ ft/s^2.

Step 10 Enter in Col. 10 the design discharge (Q_i) for each pipe flowing into the junction, except lateral pipes with inflows of ten percent or less of the mainline outflow. Inflow must be adjusted to the mainline outflow duration time before a comparison is made.

Step 11 Enter in Col. 11 the velocity of flow (V_i) for each pipe flowing into the junction (for exception see Step 10).

Step 12 Enter in Col. 12 the product of Q_i x V_i for each inflowing pipe. When several pipes inflow into a junction, the line producing the greatest Q_i x V_i product is the line which will produce the greatest expansion loss (H_i). (For exception, see Step 10).

Step 13 Enter in Col. 13 the controlling expansion loss (H_i) using the formula $H_i = [0.35(V_i^2)]/2g$.

Step 14 Enter in Col. 14 the angle of skew of each inflowing pipe to the outflow pipe (for exception, see Step 10).

Step 15 Enter in Col. 15 the greatest bend loss (H_Δ) calculated by using the formula $H_\Delta = [K(V_i^2)]/2g$, where K = the bend loss coefficient corresponding to the various angles of skew of the inflowing pipes (see Figure 6-15).

Step 16 Enter in Col. 16 the total head loss (H_t) by summing the values in Col. 9 (H_o), Col. 13 (H_i), and Col. 15 (H_Δ).

Step 17 If the junction loss incorporates adjusted surface inflow of ten percent or more of the mainline outflow, i.e., drop inlet, increase H_t by 30 percent and enter the adjusted H_t in Col. 17.

Step 18 If the junction incorporates partial diameter inlet shaping, reduce the value of H_t by 50 percent and enter the adjusted value in Col. 18.

Step 19 Enter in Col. 19 the FINAL H, the sum of H_f and H_t, where H_t is the final adjusted value of H_t.

Step 20 Enter in Col. 20 the sum of the elevation in Col. 2 and the final H in Col. 19. This elevation is the potential water surface elevation for the junction under design conditions.

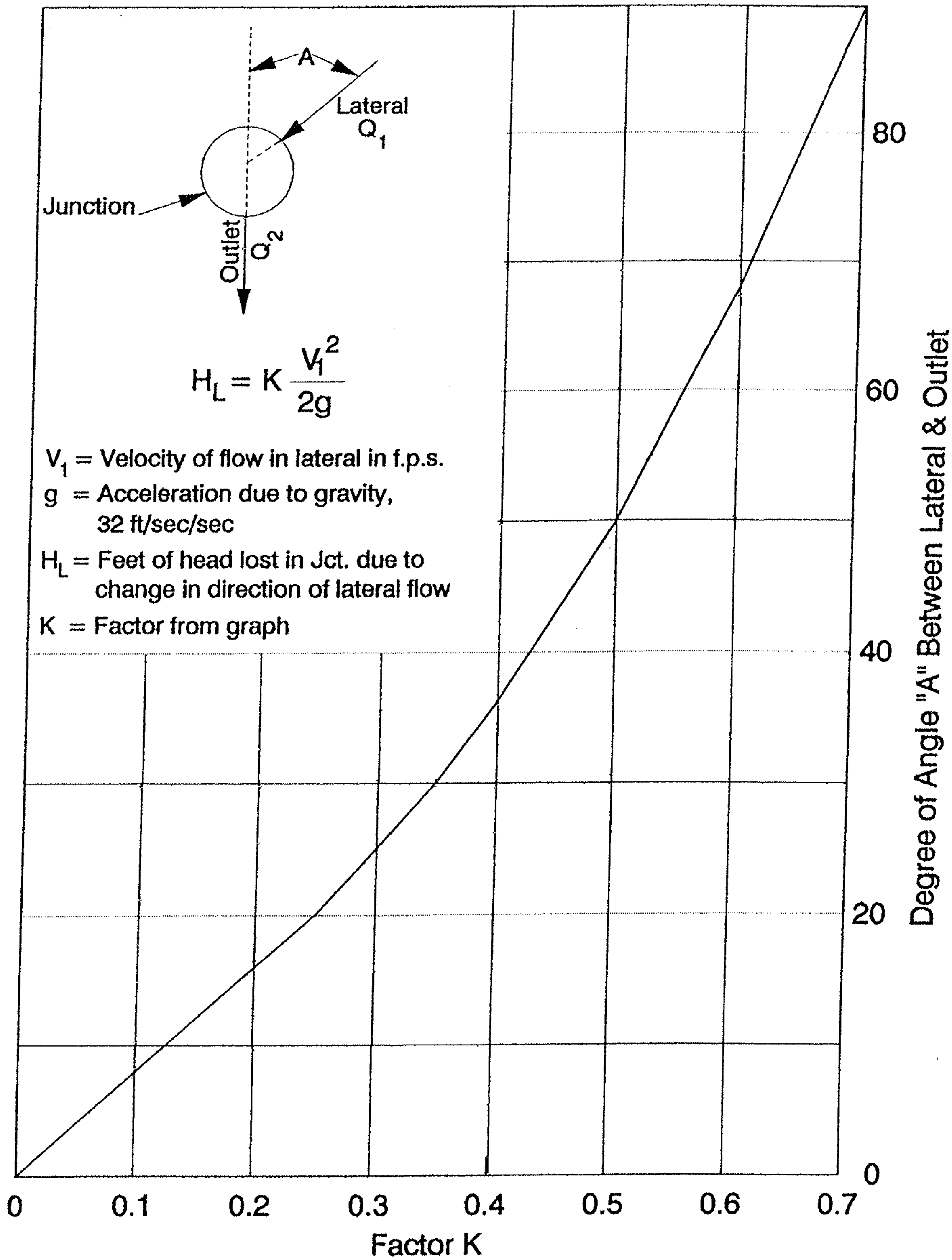


Figure 6-15. Loss In Junction Due To Change In Direction Of Flow In Lateral

Step 21 Enter in Col. 21 the rim elevation or the gutter flow line, whichever is lowest, of the junction under consideration in Col. 20. If the potential water surface elevation exceeds the 9-inch freeboard elevation (9 inches below the rim elevation or gutter flow line), adjustments are needed in the system to reduce the elevation of the hydraulic grade line.

Step 22 Repeat the procedure starting with Step 1 for the next junction upstream.

6.6.4.2 Computer Methods

Suitable computer programs may be used to determine the hydraulic grade line. All programs used must have approval of the Engineering Department.

6.7 REFERENCES

(1) AASHTO. *Highway Drainage Guidelines*. Chapter 9 in "Storm Drain Systems," Task Force on Hydrology and Hydraulics, American Association of State Highway and Transportation Officials, Washington, DC, 2003.

(2) Chow, V. T. *Open Channel Hydraulics*. McGraw-Hill Book Company, New York, 1959.

(3) FHWA. *Drainage of Highway Pavements*. Hydraulic Engineering Circular No. 12, FHWA-TS-84-202. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1984.

(4) FHWA. *HYDRAIN, Drainage Design Computer System*, Version 6.1. FHWA-IF-99-008. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1999.

(5) FHWA. *Design Charts for Open-Channel Flow*. Hydraulic Design Series No. 3, FHWA-EPD-86-102. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1961.

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