CHAPTER 3

STORM DRAINAGE SYSTEMS

3.4 Grate Inlets Design

3.4.1 Types

Inlets are drainage structures utilized to collect surface water through grate or curb openings and convey it to storm drains or direct outlet to culverts. Grate inlets subject to traffic should be bicycle safe and be load bearing adequate. Appropriate frames should be provided.

Inlets used for the drainage of highway surfaces can be divided into three major classes.

3.4.1.1 Grate Inlets – These inlets include grate inlets consisting of an opening in the gutter covered by one or more grates, and slotted inlets consisting of a pipe cut along the longitudinal axis with a grate of spacer bars to form slot openings.

3.4.1.2 Curb-Opening Inlets – These inlets are vertical openings in the curb covered by a top slab.

3.4.1.3 Combination Inlets – These inlets usually consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the gate

In addition, where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depress sections; it is good engineering practice to lace flanking inlets on each side of the inlet at the low point in the sag. The flanking inlets should be placed so that they will limit spread on low gradient approaches to the level point and act in relief of the inlet at the low point if it should become clogged or if the design spread is exceeded.

The design of grate inlets will be discussed in this section, curb inlet design in Section 3.5, and combination inlets in Section 3.6.

3.4.2 Grate Inlets On Grade

The capacity of an inlet depends upon its geometry and the cross slope, longitudinal slope, total gutter flow, depth of flow and pavement roughness. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb opening inlets. At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets, and a small portion of the flow along the length of the grate, termed side flow, is intercepted. On steep slopes, only a portion of the

frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. For grates less than 2 feet long, intercepted flow is small.

Inlet interception capacity has been investigated by agencies and manufacturers of grates. For inlet efficiency data for various sizes and shapes of grates, refer to Hydraulic Engineering Circular No. 12 Federal Highway Administration and inlet grate capacity charts prepared by grate manufacturers.

A parallel bar grate is the most efficient type of gutter inlet; however, when crossbars are added for bicycle safety, the efficiency is greatly reduced. When bicycle traffic is a design consideration, the curved vane grate and the tilt bar grate are recommended for both their hydraulic capacity and bicycle safety features. They also handle debris better than other grate inlets but the vanes of the grate must be turned in the proper direction. Where debris is a problem, consideration should be given to debris handling efficiency rankings of grate inlets from laboratory tests in which an attempt was make to qualitatively simulate field conditions. Table 3.4.2-1 presents the results of debris handling efficiencies of several grates.

The ratio of frontal flow to total gutter flow, E_O, for straight cross slope is expressed by the following equation:

$$E_O = Q_W / Q = 1 - (1 - W / T)2.67 \qquad \textbf{(Eq 3.4.2-1)}$$

Where: Q = total gutter flow, cfs

Q_W = flow in width W, cfs

W = width of depressed gutter or grate, ft

T = total spread of water in the gutter, ft

Table 3.4.2-1
Grate Debris Handling Efficiencies

Rank	Grate	Longitudinal Slope	
		(0.005)	(0.04)
1	CV – 3-1/4 - 4-1/4	46	61
2	30 – 3-1/4 – 4	44	55
3	45 – 3-1/4 – 4	43	48
4	P – 1-7/8	32	32
5	P – 1-7/8 – 4	18	28
6	45 – 2-1/4 – 4	16	23
7	Recticuline	12	16
8	P – 1-1/8	9	20

Source: "Drainage of Highway Pavements" (HEC-12), Federal Highway Administration, 1984.

Figure 3.4.2-1 provides a graphical solution of E_O for either depressed gutter sections or straight cross slopes. The ratio of side flow, Q_S, to total gutter flow is:

$$Q_S / Q = 1 - Q_W / Q = 1 - E_O \qquad \textbf{(Eq 3.4.2-2)}$$

The ratio of frontal flow intercepted to total frontal flow, R_f , is expressed by the following equation:

$$R_f = 1 - 0.09(V - V0) \qquad \textbf{(Eq 3.4.2-3)}$$

Where: V = velocity of flow in the gutter, ft/s (using Q from Figure 3.3.3-1)

V_O = gutter velocity where splash-over first occurs, ft/s (from Figure 3.4.2-1)

This ratio is equivalent to frontal flow interception efficiency. Figure 3.4.2-1 provides a solution of equation 3.4.2-3 which takes into account grate length, bar configuration and gutter velocity at which splash-over occurs. The gutter velocity needed to use Figure 3.4.2-1 is total gutter flow divided by the area of flow. The ratio of side flow intercepted to total side flow, R_S, or side flow interception efficiency, is expressed by:

$$R_S - 1/[1 + (0.15V1.8 / S_X L2.3)] \qquad \textbf{(Eq 3.4.2-4)}$$

Where: L= length of the grate, ft

Figure 3.4.2.2. provides a solution to equation 3.4.2-4.

The efficiency, E, of a grade is expressed as:

$$E = R_f E_O + R_S(1 - E_O) \qquad \textbf{(Eq 3.4.2-5)}$$

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = EQ = Q[R_f E_O + R_S(1 - E_O)] \qquad \textbf{(Eq 3.4.2-6)}$$

The following example illustrates the use of this procedure.

Given: W = 2ft T = 8 ft

S_X = 0.025 ft/ft S = 0.01 ft/ft

E_O = 0.69 Q = 3.0 cfs

Figure 3.4.2-1

Grate Inlet Frontal Flow Interception Efficiency

Source: HEC-12

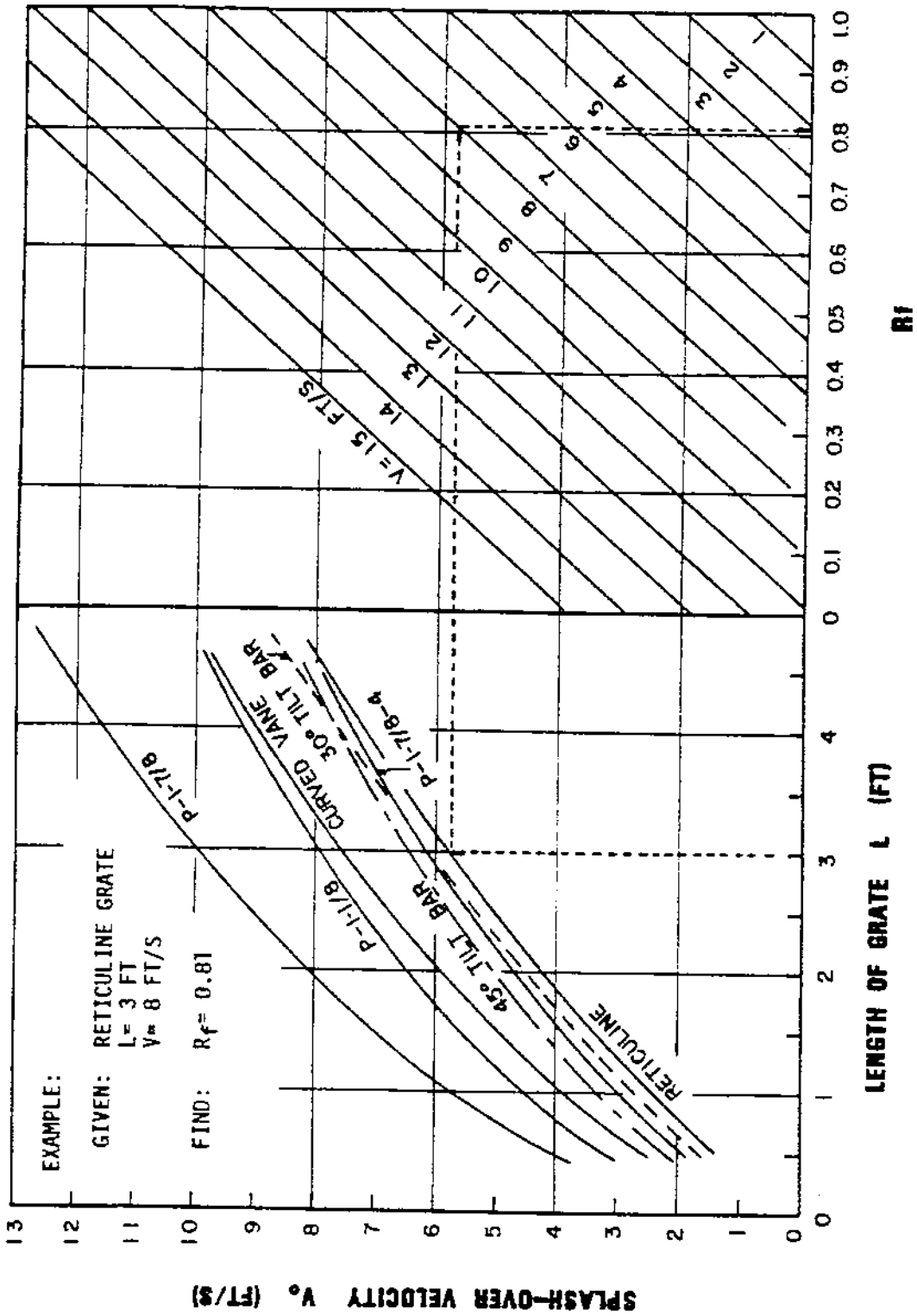
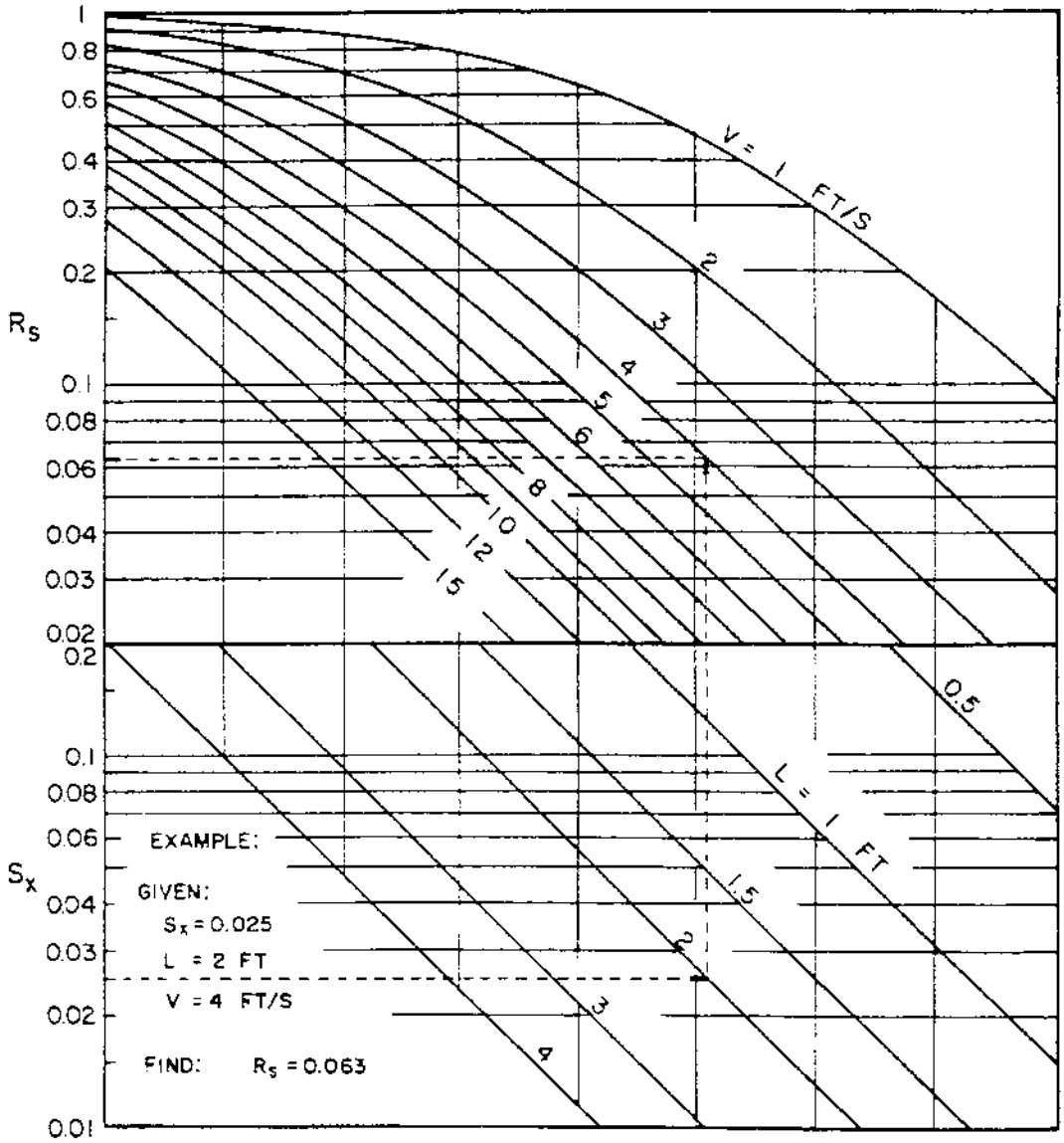


Figure 3.4.2-2

Grate Inlet Side Flow Interception Efficiency

Source: HEC-12



V = 3.1 ft/s Gutter depression = 2 in

Find: Interception capacity of:

A curved vane grate, and

A reticulin grate 2-ft long and 2-ft wide

Solution:

From Figure 3.4.2-1 for Curved Van Grate, $R_f = 1.0$

From Figure 3.4.2-1 for Reticulin Grate, $R_f = 1.0$

From Figure 3.4.2-2 $R_S = 0.1$ for both grates.

From Equation 3.4.2-6:

$$Q_i = 3.0[1.0X\ 0.69 + 0.1\ (1\text{-}0.69)] = 2.2 \text{ cfs}$$

For this example the interception capacity of a curved vane grate is the same as that for a reticulin grate for the sited conditions.

3.4.3 Grate Inlets In Sag

A grate inlet in a sag operates as a weir up to a certain depth dependent on the bar configuration and size of the grate and as an orifice at greater depths. For standard gutter inlet grate, weir operation continues to a depth of about 0.4 foot above the top of grate and when depth of water exceeds about 1.4 feet, the grate begins to operate as a orifice. Between depths of about 0.4 foot and about 1.4 feet, a transition from weir to orifice flow occurs.

The capacity of grate inlets operating as a weir is:

$$Q_i = CPd1.5 \qquad \textbf{(Eq. 3.4.3-1)}$$

Where:

P = perimeter of grate excluding bar widths and the side against the curb, ft

C = 3.0

d = depth of water above grate, ft and as an orifice is:

$$Q_i = CA(2gd)0.5 \qquad \textbf{(Eq 3.4.3-2)}$$

Where:

C = 0.67 orifice coefficient

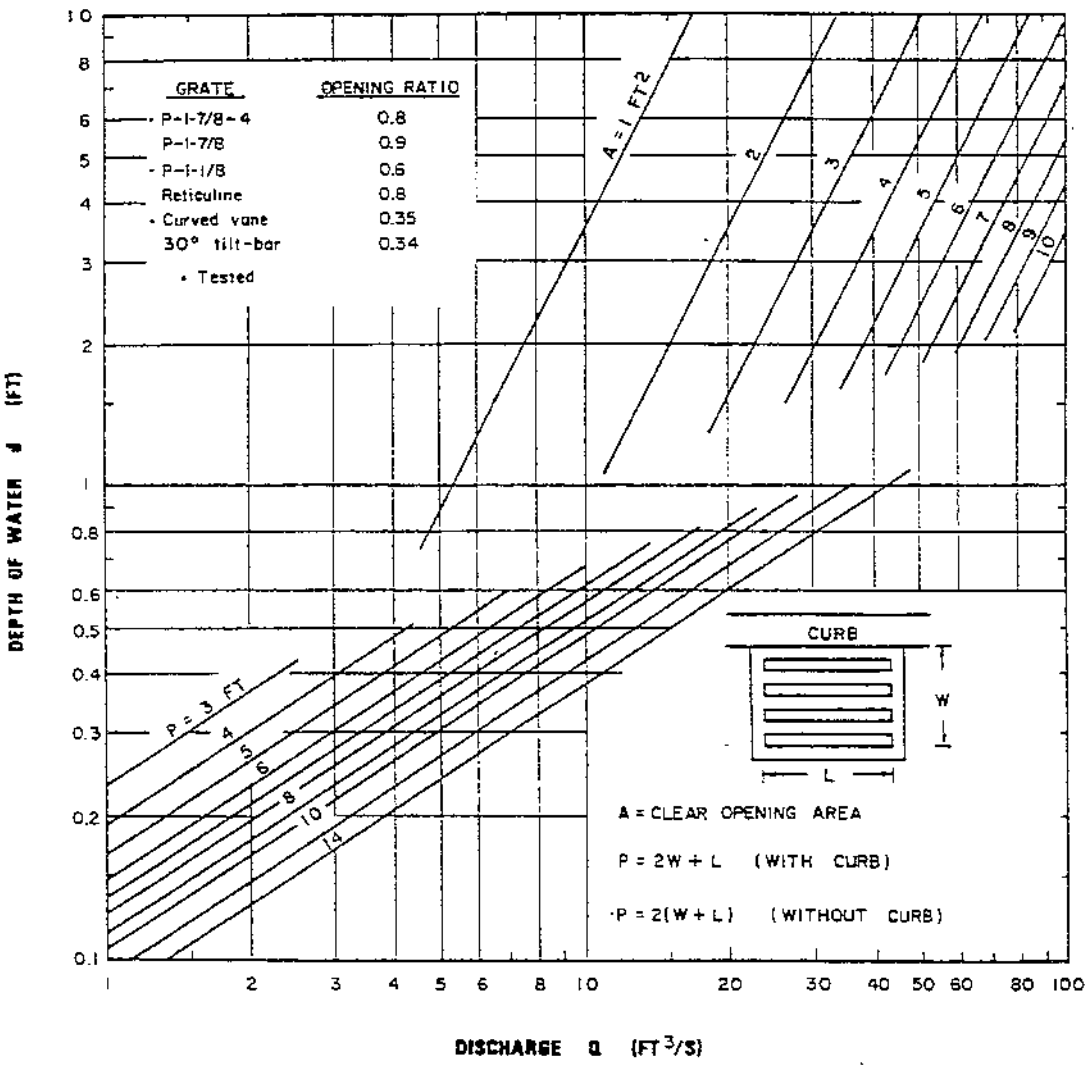
A = clear opening area of the grate, ft^2

g = 32.2 ft/s^2

Figure 3.4.3-1

Grate Inlet Capacity In Sump Conditions

Source: HEC-12



Reference: USDOT, FHWA, HEC-12 (1984).

Figure 3.4.3-1 is a plot of equations 3.4.3-1 and 3.4.3-2 for various grate sizes. The effects if grate size on the depth at which a grate operates as an orifice is apparent from the chart. Transition from weir to orifice flow results in interception capacity less than that computed by either weir or the orifice equation. This capacity can be approximated by drawing in a curve between the lines representing the perimeter and net area of the rate to be used.

The following example illustrates the use of figure 3.4.3-1

.

Given: A symmetrical sag vertical curve with equal bypass from inlets upgrade of the low point; allow for 50% clogging of the grate

Q_b = 3.6 cfs

Q = 8 cfs, 10-year storm

T = 10 ft, design

S_X = 0.05 ft/ft

d = TS_X = 0.5 ft

Find: Grate size for design Q. Check spread at S = 0.003 on approaches to the low point.

Solution: From Figure 3.4.3-1, a grate must have a perimeter of 8 ft to intercept 3 cfs at a depth of 0.5 ft.

Some assumptions must be made regarding the nature of the clogging in order to compute the capacity of a partially clogged grate. If the area of a grate is 50 percent covered by debris so that the debris-covered portion does not contribute to interception, the effective perimeter will be reduced by a lesser amount than 50 percent. For example if a 2-ft x 4-ft grate is clogged so that the effective width is 1-ft, then the perimeter, P = 1 + 4 + 1 = 6 ft, than 8 ft, the total perimeter, or 4 ft, half of the total perimeter. The area of the opening would be reduced by 50 percent and the perimeter by 25 percent.

Therefore, assuming 50 percent clogging along the length of the grate, a 4 x 4, a 2 x 6, or a 3 x 5 grate would meet requirements of an 8-ft perimeter 50 percent clogged.

Assuming that the installation chosen to meet design conditions is a double 2 x 3 ft grate, for 50 percent clogged conditions: P = 1 + 6 + 1 = 8 ft

For 10-year flow: d = 0.5 ft (from Figure 3.4.3-1)

The American Society of State Highway and Transportation Officials (AASHTO) geometric policy recommends a gradient of 0.3 percent within 50 ft of the level point in a sag vertical curve.

Check T at S = 0.003 for the design and check flow:

Q = 3.6 ft^3/s, T+ 8.2 ft (10-year storm, Figure 3.3.3-1)

Thus a double 2 x 3-ft grate 50 percent clogged is adequate to intercept the design flow at a spread which does not exceed design spread and spread on the approaches to the low point will not exceed design spread. However, the tendency of grate inlets to clog completely warrants consideration of a combination inlet, or curb-opening inlet in a sag where ponding can occur, and flanking inlets on the low gradient approaches.

END OF SECTION 3.4