### 6.7.1.2 Street Gutters and Inlets

Surface runoff from urban streets are typically routed to sewer pipes through street gutters and inlets. To facilitate drainage, urban roadways are designed with both cross-slopes and longitudinal slopes. The cross-slope directs the incident rainfall to the sides of the roadway, where the pavement intersects the curb and forms an open channel called a *gutter*. Longitudinal slopes direct the flow in the gutters to stormwater *inlets* that direct the flow into sewer pipes. Typical cross-slopes on urban roadways are in the range of 1.5% to 6%, depending on the type of pavement surface (Easa, 1995), and typical longitudinal slopes are in the range of 0.5% to 5%, depending on the topography. The spacing between stormwater inlets depends on several criteria, but it is usually controlled by the rate of flow and the allowable water spread toward the crown of the street.

The flowrate in a triangular curb gutter, illustrated in Figure 6.35, can be derived from the Manning equation (ASCE, 1992) as

$$\boxed{Q = 0.38\left(\frac{1}{nS_x}\right) d^{8/3} S_o^{1/2}} \tag{6.169}$$

where $S_x$ is the street cross-slope, $n$ is the Manning roughness coefficient, $S_o$ is the longitudinal slope of the street, and $d$ is the depth of flow at the curb. The conventional Manning equation has been modified in deriving Equation 6.169 because the hydraulic radius does not adequately describe the gutter cross-section, particularly when the top-width $T$ exceeds 40 times the depth at the curb (ASCE, 1992). The depth and top-width of gutter flow are related by

$$d = TS_x \tag{6.170}$$

Typical Manning $n$ values for street and pavement gutters are given in Table 6.31 (USFHWA, 1984b). To facilitate proper drainage, it is recommended that the gutter grade exceed 0.4% and the street cross-slope exceed 2% (ASCE, 1992). The gutter, together with a curb, should be at least 15 cm (6 in.) deep and 60 cm (2 ft) wide, with the deepest portion adjacent to the curb. The maximum allowable width of street flooding depends on the type of street and is usually specified separately for minor and major design runoff events. Typical guidelines for allowable pavement encroachment are given in Table 6.32. Allowable pavement encroachment is the basis for computing the street drainage capacity using the modified Manning equation.

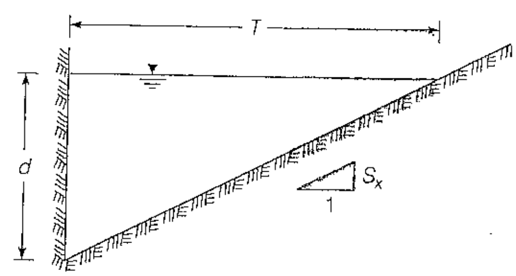

**Table 6.31**
Typical Manning $n$ Values for Street and Pavement Gutters

| Type of gutter or pavement | Manning $n$ |
|---|---|
| Concrete gutter, troweled finish | 0.012 |
| Asphalt pavement | |
| Smooth texture | 0.013 |
| Rough texture | 0.016 |
| Concrete gutter with asphalt pavement | |
| Smooth | 0.013 |
| Rough | 0.015 |
| Concrete pavement | |
| Float finish | 0.014 |
| Broom finish | 0.016 |

Source: USFHWA (1984b).

**Table 6.32**
Pavement Encroachment Guidelines

| Street type | Minor storm runoff | Major storm runoff |
|---|---|---|
| Local* | no curb overtopping†; flow may spread to crown of street | Residential dwellings, public, commercial and industrial buildings shall not be inundated at the ground line, unless buildings are flood-proofed. The depth of water over the gutter flow line shall not exceed an amount specified by local regulation, often 30 cm (12 in.). |
| Collector‡ | no curb overtopping†; flow spread must leave at least one lane free of water | Same as for local streets. |
| Arterial§ | no curb overtopping†; flow spread must leave at least one lane free of water in each direction | Residential dwellings, public, commercial, and industrial buildings shall not be inundated at the ground line, unless buildings are flood-proofed. Depth of water at the street crown shall not exceed 15 cm (6 in.) to allow operation of emergency vehicles. The depth of water over the gutter flow line shall not exceed a locally prescribed amount. |
| Freeway¶ | no encroachment allowed on any traffic lanes | Same as for arterial streets. |

Source: Denver Regional Urban Storm Drainage Criteria Manual (1984).

*A local street is a minor traffic carrier within a neighborhood characterized by one or two moving lanes and parking along curbs. Traffic control may be by stop or yield signs.

†Where no curb exists, encroachment onto adjacent property should not be permitted.

‡A collector street collects and distributes traffic between arterial and local streets. There may be two or four moving traffic lanes and parking may be allowed adjacent to curbs.

§An arterial street permits rapid and relatively unimpeded traffic movement. There may be four to six lanes of traffic, and parking adjacent to curbs may be prohibited. The arterial traffic normally has the right-of-way over collector streets. An arterial street will often include a median strip with traffic channelization and signals at numerous intersections.

¶Freeways permit rapid and unimpeded movement of traffic through and around a city. Access is normally controlled by interchanges at major arterial streets. There may be eight or more traffic lanes, frequently separated by a median strip.

## ▪ Example 6.39

A four-lane collector roadway is to be constructed with 3.66 m (12 ft) lanes, a cross-slope of 2%, a longitudinal slope of 0.5%, and pavement made of rough asphalt. If the (minor) roadway drainage system is to be designed for a rainfall intensity of 150 mm/h, determine the spacing of the inlets.

### Solution

For a collector street, Table 6.32 indicates that at least one lane must be free of water. However, since the roadway has four lanes, the drainage system must necessarily be designed to leave two lanes free of water (one on each side of the crown). Since each lane is 3.66 m wide, the allowable top width, $T$, is 3.66 m, with $n = 0.016$ (rough asphalt), $S_x = 0.02$, and $S_o = 0.005$. The maximum allowable depth of flow, $d$, at the curb is given by

$$d = TS_x = (3.66)(0.02) = 0.0732\ \text{m} = 7.32\ \text{cm}$$

and the maximum allowable flowrate, $Q$, in the gutter is given by the Manning equation (Equation 6.169) as

$$Q = 0.38\left[\frac{1}{nS_x}\right] d^{8/3} S_o^{1/2} = 0.38\left[\frac{1}{(0.016)(0.02)}\right](0.0732)^{8/3}(0.005)^{1/2} = 0.0787\ \text{m}^3/\text{s}$$

Since the design-rainfall intensity is 150 mm/h $= 4.17 \times 10^{-5}$ m/s, then the contributing area, $A$, required to produce a runoff of 0.0787 $\text{m}^3$/s is given by

$$A = \frac{0.0787}{4.17 \times 10^{-5}} = 1887\ \text{m}^2$$

The roadway has two lanes contributing runoff to each gutter. Therefore, the width of the contributing area is $2 \times 3.66 = 7.32$ m, and the length, $L$, of roadway required for a contributing area of 1,887 $\text{m}^2$ is given by

$$L = \frac{1887}{7.32} = 258\ \text{m}$$

The required spacing of inlets is therefore 258 m. This is a rather long spacing, and the required placement of inlets at roadway intersections may govern the location of inlets. ▪

Stormwater inlets can take many forms but are usually classified as curb inlets, gutter inlets, or slotted drains. The various inlet types are illustrated in Figure 6.36. These inlets are typically located at low points (sumps), directly upstream from intersections, or at intermediate locations. Municipalities sometimes specify the manufacturer and specific inlet types that are acceptable within their jurisdiction.

**Curb Inlets.** Curb inlets are vertical openings in the curb covered by a top slab. The capacity of a curb inlet depends on the amount of debris blockage, the amount of the total flow that can be intercepted by the inlet, whether the inlet throat is depressed, and whether deflectors are used. Details of the performance of curb inlets can be found in regulatory manuals such as the *Denver Regional Urban Storm Drainage Criteria Manual* (1984). According to ASCE (1992), curb inlets without local depressions are very inefficient, the final design should show roughly one 1.2-m long inlet for every 0.08 $\text{m}^3$/s on a street with a longitudinal slope of 2% or less, and opening heights should not exceed 15 cm (6 in.) to reduce risks to children. Curb openings act as weirs up to a depth equal

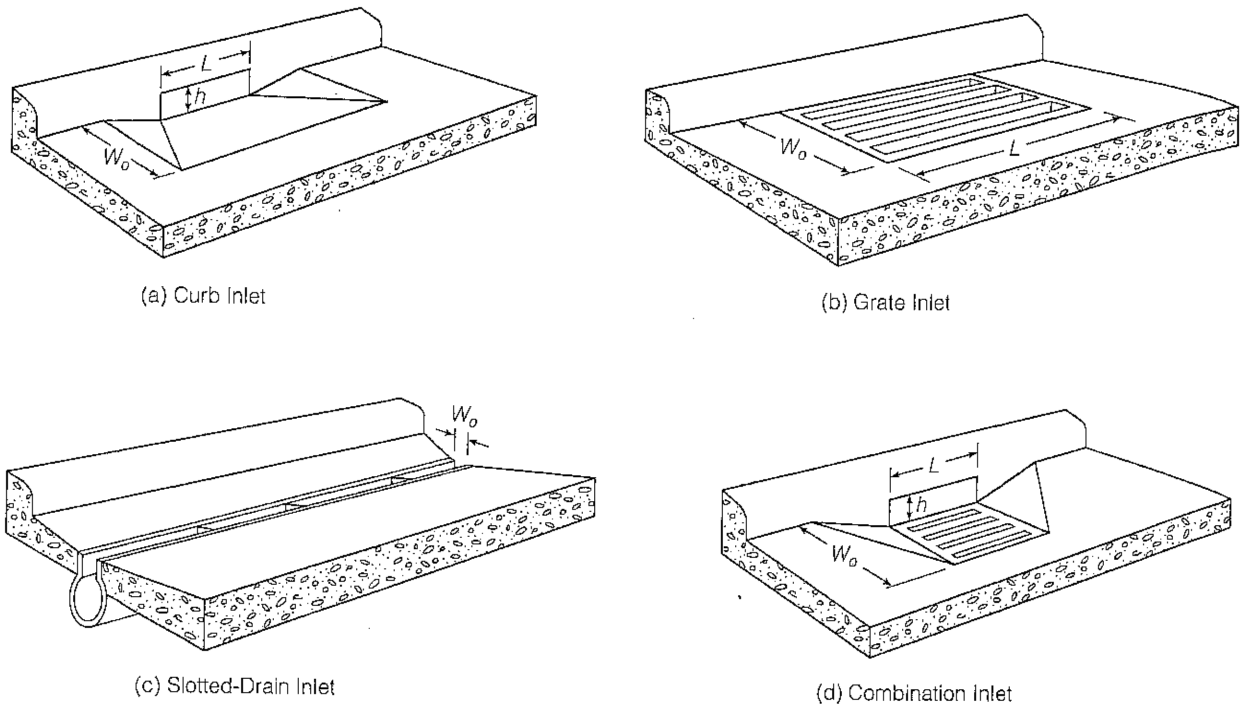


**Figure 6.36** ■ Stormwater Inlets
Source: FHWA (1984a).

to the opening height, and the inlet operates as an orifice when the water depth is greater than 1.4 times the opening height. The weir flow equation gives the flowrate, $Q_i$ (m$^3$/s), into the curb inlet as (Wanielista et al., 1997)

$$\boxed{Q_i = 1.27(L + 1.8W_o)d^{1.5}} \tag{6.171}$$

where $L$ is the length of the curb opening (m), $W_o$ is the width of the inlet depression (m), $d$ is the depth of flow at the curb, where $d$ is less than the depression depth and $h$ is the height of the curb opening. Without a depressed gutter, the inflow to a curb inlet is given by

$$\boxed{Q_i = 1.27Ld^{1.5} \qquad d \leq h} \tag{6.172}$$

When the flow depth, $d$, exceeds 1.4 times the opening height, the inflow to the curb inlet is given by the orifice equation

$$\boxed{Q_i = 0.67A\left[2g\left(d - \frac{h}{2}\right)\right]^{\frac{1}{2}}} \tag{6.173}$$

where $A$ is the area of the curb opening ($= hL$).

### ■ Example 6.40

A roadway has a maximum allowable flow depth at the curb of 8 cm and a corresponding flowrate in the gutter of 0.08 m$^3$/s. Determine the length of a 15-cm (6-in.) high curb inlet that is required to remove all the water from the gutter. Consider the cases where (a) the width of the inlet depression is 0.4 m, and (b) there is no inlet depression.

**Solution**

(a) Since the flow depth (8 cm) is less than the height of the inlet (15 cm), the curb inlet acts as a weir. In this case, $Q_i = 0.08\ \text{m}^3/\text{s}$, $W_o = 0.4$ m, $d = 0.08$ m, and the weir equation (Equation 6.171) can be put in the form

$$L = \frac{Q_i}{1.27d^{1.5}} - 1.8W_o$$

The required weir length, $L$, is therefore given by

$$L = \frac{0.08}{1.27(0.08)^{1.5}} - 1.8(0.4) = 2.06\ \text{m}$$

With an inlet depression, the length of the curb opening should be at least 2.06 m.

(b) In the case of no inlet depression, the inlet equation (Equation 6.172) can be put in the form

$$L = \frac{Q_i}{1.27d^{1.5}}$$

and the required weir length is given by

$$L = \frac{0.08}{1.27(0.08)^{1.5}} = 2.78\ \text{m}$$

The presence of an inlet depression reduces the required curb length from 2.78 m to 2.06 m, a reduction of 26%. ■

**Grate Inlets.** Grate inlets consist of an opening in the gutter covered by one or more grates. Grate inlets are flush mounted to the pavement and function best when located in a sump. The main disadvantage of using grated inlets is their interference with bicycles and the tendency for debris blockage. If clogging due to debris is not expected, then a grate or grate/curb combination type inlet will provide more capacity than a curb inlet. For depths of water not exceeding 12 cm, the following weir equation can be used to calculate the capacity, $Q_i$ ( $\text{m}^3/\text{s}$), of the grate inlet

$$\boxed{Q_i = 1.66Pd^{1.5}} \qquad (6.174)$$

where $P$ is the perimeter of the grate opening (m) and $d$ is the depth of flow above the grate (m). If the grate is adjacent to a curb, then that side of the grate is not counted in the perimeter. If the flow depth over the grate exceeds 43 cm, then the following orifice equation is used to compute the capacity, $Q_i$, of the grate inlet

$$\boxed{Q_i = 0.6A\sqrt{2gd}} \qquad (6.175)$$

where $A$ is the total area of the opening and $d$ is the depth of flow above the grate. For depths of flow between 12 cm and 43 cm, the capacity of the grate is somewhere between that calculated by Equations 6.174 and 6.175. The minimum length, $L$ (m), of clear opening parallel to the direction of flow to allow the flow to fall through the opening and clear the downstream end of the bars can be estimated by (ASCE, 1992)

$$\boxed{L = 0.91V(t+d)^{0.5}} \tag{6.176}$$

where $V$ is the average velocity of the water approaching the grate inlet (m/s), $d$ is the depth of flow above the grate (m), and $t$ is the thickness of the grate (m). In typical grated inlets, all of the frontal flow, and a portion of the side flow, is intercepted. The ratio, $R$, of the side flow intercepted to the total side flow is called the side flow interception efficiency, and can be estimated using

$$R = \frac{1}{1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}} \tag{6.177}$$

where $S_x$ is the cross-slope of the gutter. A more detailed discussion of the capacity calculation for grate inlets is given by the Federal Highway Administration (USFHWA, 1984a).

## ■ Example 6.41

A roadway has a cross-slope of 2%, a maximum allowable flow depth at the curb of 8 cm, and a corresponding flowrate in the gutter of 0.08 m$^3$/s. The gutter flow is to be removed by a 1.5-cm thick grate inlet that is mounted flush with the curb. Calculate the minimum dimensions of the grate inlet.

### Solution

Since the depth of flow is less than 12 cm, the inflow to the inlet is given by the weir equation (Equation 6.174), which can be put in the form

$$P = \frac{Q_i}{1.66d^{1.5}}$$

where $P$ is the grate-inlet perimeter not including the side adjacent to the curb, $Q_i = 0.08$ m$^3$/s, $d = 0.08$ m, and

$$P = \frac{0.08}{1.66(0.08)^{1.5}} = 2.13 \text{ m}$$

The minimum length, $L$, of the grate inlet is given by Equation 6.176, where $t = 0.015$ m, $d = 0.08$ m, and

$$V = \frac{Q_i}{A}$$

where $A$ is the flow area in the gutter, given by

$$A = \frac{1}{2}d\left(\frac{d}{S_x}\right) = \frac{1}{2}(0.08)\left(\frac{0.08}{0.02}\right) = 0.16 \text{ m}^2$$

The flow velocity, $V$, in the gutter is therefore given by

$$V = \frac{Q_i}{A} = \frac{0.08}{0.16} = 0.5 \text{ m/s}$$

and the minimum length of the grate inlet is

$$L = 0.91V(t+d)^{0.5} = 0.91(0.5)(0.015 + 0.08)^{0.5} = 0.14 \text{ m}$$

Therefore, the grate inlet must have a minimum length of 14 cm and a minimum perimeter of 213 cm. ■

**Slotted-Drain Inlets.** Slotted drains are used on both curbed and uncurbed roadways and function much like curb inlets, although they are generally much longer than curb inlets (Loganathan et al., 1996). For slotted-drain inlets with slot widths greater than 4.45 cm (1.75 in.), the length, $L$, of drain required to intercept a flow $Q_i$ is given by (Wanielista et al., 1997)

$$\boxed{L = 0.6Q_i^{0.42}S_o^{0.3}\left(\frac{1}{nS_x}\right)^{0.6}} \tag{6.178}$$

where $S_o$ is the longitudinal slope of the drain, $n$ is the Manning roughness coefficient of the drain pipe, and $S_x$ is the cross-slope of the gutter.

## ■ Example 6.42

A roadway has a cross-slope of 2.5%, a longitudinal slope of 1.5%, and a flowrate in the gutter of 0.1 m$^3$/s. The flow is to be removed by a slotted drain with a slot width of 5 cm, and a Manning $n$ quoted by the manufacturer as 0.015. Estimate the minimum length of slotted drain that can be used.

### Solution

From the given data, $Q_i = 0.1$ m$^3$/s, $S_o = 0.015$, $n = 0.015$, $S_x = 0.025$, and Equation 6.178 gives the length of the drain as

$$L = 0.6Q_i^{0.42}S_o^{0.3}\left[\frac{1}{nS_x}\right]^{0.6} = 0.6(0.1)^{0.42}(0.015)^{0.3}\left[\frac{1}{(0.015)(0.025)}\right]^{0.6} = 7.35 \text{ m}$$

Hence the slotted drain must be at least 7.35 m long to remove the gutter flow. ■