NASHVILLE STORMWATER MANAGEMENT MANUAL

VOLUME 3—THEORY

CHAPTER 6

Storm Sewer Hydraulics

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Chapter 6
STORM SEWER HYDRAULICS

SYNOPSIS

The sizing of a closed storm sewer system usually requires two major computations. The first is primarily a hydrologic problem and provides a determination of the peak runoff flow rate arriving at particular design points in the system. The second involves sizing the storm sewers for conveyance of these peak runoff rates and is primarily a hydraulic problem. This chapter presents a brief discussion of the hydrologic and hydraulic fundamentals associated with storm sewer systems. References include the American Society of Civil Engineers (1969), the American Concrete Pipe Association (1978, 1980), the American Iron and Steel Institute (1980), Yen et al. (1974), and Colyer and Pethick (1976).

6.1 HYDROLOGY

Hydrologic determination of a peak runoff rate for sizing a storm sewer system can be made using many of the procedures developed for estimating either peak runoff rates or runoff hydrographs, as presented in Chapter 2. In general, storm sewer systems are sized to carry stormwater intercepted by appropriate inlet facilities. However, if the intercepted runoff is transported through an extensive pipe network, channel storage occurring within the storm sewers can modify the peak runoff rate as it travels along the system. The evaluation of this peak flow modification can be accomplished using hydrologic channel routing procedures.

6.1.1 SUMMATION OF FLOWS METHOD

The hydrologic computations for this method of storm sewer design are performed exactly as its title suggests. The total peak runoff rate is estimated by adding the runoff intercepted by each inlet upstream of the design point. This sum is then used to size the conduit. Results of this method are more conservative than those of the other methods discussed in this section. This method is not acceptable for use in Nashville and Davidson County.

A situation where peak runoff from numerous inlets arrives at the design point at different points in time cannot be accounted for by the Summation of Flows Method. In addition, the method does not consider that the peak runoff rate for each inlet can be reduced by the influence of channel storage in the upstream portion of the storm sewer system. The Summation of Flows Method is not considered good engineering practice for large systems where the potential for reducing peak runoff by channel storage exists and where time of travel characteristics of the system warrant detailed study. Since attenuation is ignored, the method can over-estimate the peak runoff arriving at the lower portions of a complex storm sewer system.

6.1.2 RATIONAL METHOD

A peak runoff rate can be calculated for each design point in a storm sewer system by using the Rational Method. A different time of concentration, which should increase as the design proceeds in the downstream direction, is required for each design point. Thus, for large systems, the design rainfall intensity is decreased and the design flow rate will be lower than that obtained through use of the Summation of Flows Method.

Application of the Rational Method has a logical basis, and it indirectly accounts for situations in which peak runoff arrives at individual inlets at different points in time. However, this approach does not explicitly account for channel storage that may be important in the upstream portions of a storm sewer system.

There may be locations in a storm sewer system where only a portion of the area draining to that location will cause the peak discharge. This can happen for systems where a small part of the total area has a disproportionately long travel time. Thus, another larger portion of the contributing area with a shorter time of concentration (and, therefore, a higher average rainfall intensity) can cause a higher peak discharge at a given location.

6.1.3 INLET HYDROGRAPH METHOD

The Inlet Hydrograph Method uses the inlet and storm sewer travel times to adjust the intercepted peak runoff rate for each storm sewer segment. The composite peak runoff rate at the design point is then obtained by summing the ordinates of triangular hydrographs for each inlet. This is generally accomplished graphically by plotting triangular hydrographs on the same scale and using dividers to sum hydrograph ordinates. The procedure is detailed in Volume 2, based on the presention in Jens and McPherson (1964) and Kaltenbach (1963).

6.2 HYDRAULICS

The hydraulic evaluation of a storm sewer system should provide a balanced system in which all segments will be used to their full capacity consistent with the flood protection criteria for the project site. The hydraulic computations are based on the appropriate peak runoff rates, developed with the hydrologic procedures discussed above.

Two types of flow can occur in closed conduits. Gravity flow occurs when a free water surface is exposed to the atmosphere as a boundary (see Figure 6-1). When the conduit is flowing full, the pipe is considered to be flowing under pressure (see Figure 6-2).

6.2.1 ENERGY LOSSES

The two basic types of energy losses associated with flowing water in storm sewers are pipe friction losses, usually called major losses, and pipe form losses (minor losses). Pipe friction losses are generally evaluated by selecting an appropriate Manning's roughness coefficient, n, when pipe capacity calculations are performed. Pipe form losses require more complex calculations and depend on characteristics of the storm sewer configuration, such as changes in pipe size, branches, junctions, expansions, and contractions.

Pipe form losses are the result of fully developed turbulence, which can be evaluated using the general expression:

$$H_L = K\ (v^2/2g) \qquad (6\text{-}1)$$

where:

H_L = Head loss, in feet

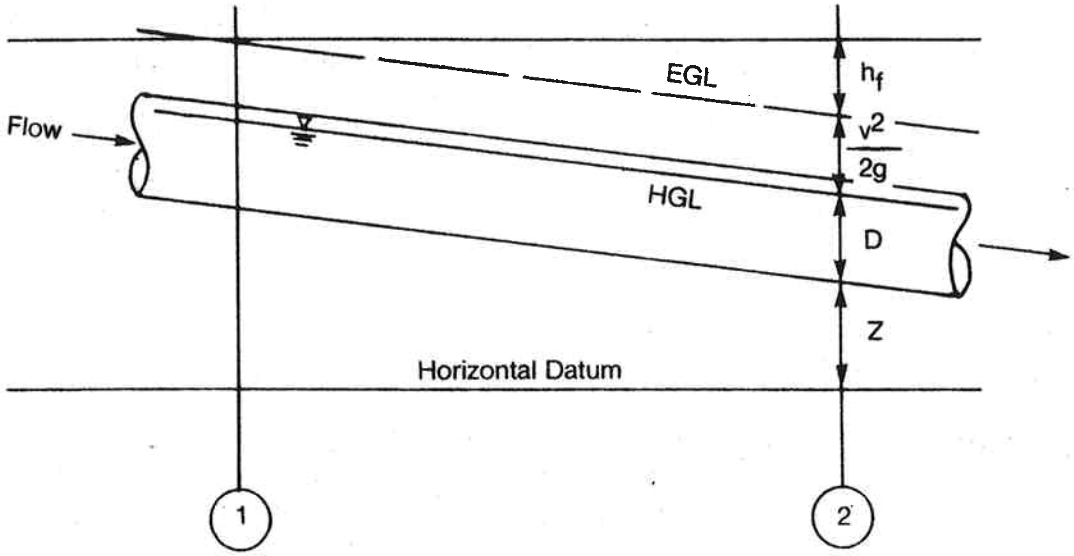

FIGURE 6-1
Open Channel Flow in a Closed Conduit

Z = Distance above horizontal datum
D = Depth of flow
P = Pressure head
$\frac{v^2}{2g}$ = Velocity head
h_f = Friction loss between Section 1 and Section 2
EGL = Energy grade line
HGL = Hydraulic grade line

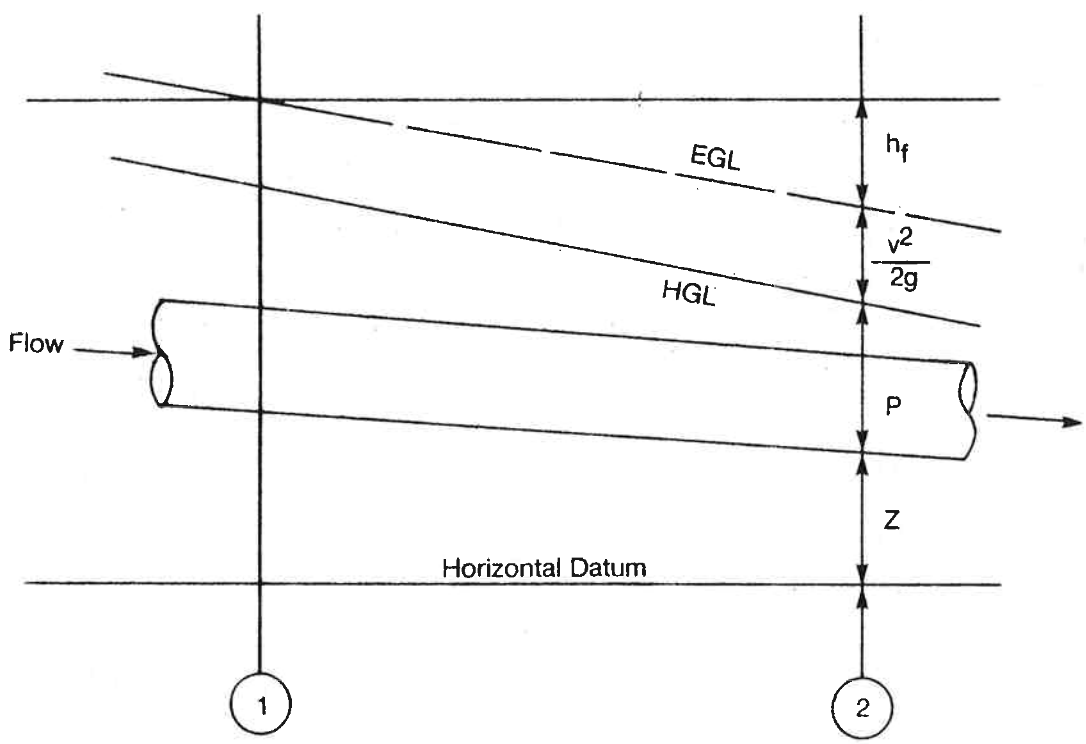

FIGURE 6-2
Pressure Flow in a Closed Conduit

K = Loss coefficient

v = Average velocity, in feet/second

g = Acceleration due to gravity, 32.2 feet/second^2

A few of the common types of pipe form losses encountered in storm sewer system design are defined below. Procedures for selecting the expansion loss coefficient for the various types of pipe form losses are presented in Volume 2. Standard references include publications by the University of Missouri (1958), the American Society of Civil Engineers (1969), and Marsalek (1985).

Expansion Losses. Expansion in a storm sewer conduit causes a shearing action between a high velocity jet from a smaller pipe and the boundary of a larger downstream pipe. As a result, much of the kinetic energy is dissipated by eddy currents and turbulence.

Contraction Losses. The reduction in cross-sectional area when flow passes from a large to a small pipe causes head losses, which are dependent on the amount of contraction and the type of entrance at the transition. Losses at contractions can be lowered by beveling the inlet edge at the contraction. This type of transition requires conversion of potential energy into kinetic energy to increase velocity.

Bend Losses. The bend loss coefficient used with Equation 6-1 has been found to be a function of the ratio of the radius of curvature of the bend to the width of the conduit; the deflection angle of the conduit; the geometry of the cross section of flow; and the Reynolds Number and relative roughness.

Junction and Manhole Losses. A junction occurs where one or more branch storm sewers enter a main storm sewer, usually at manholes. The hydraulic design of a junction is, in effect, the design of two or more transitions (e.g., expansions, contractions, and bends), one for each flow path. Allowances should be made for head loss caused by the impact at junctions.

6.2.2 GRAVITY FLOW

Under non-pressure or gravity flow conditions, the capacity of a closed conduit can be analyzed by applying Manning's Equation to evaluate frictional losses for uniform flow. As shown in Figure 6-1, the hydraulic grade line is the free water surface elevation and is parallel to the energy grade line under uniform flow conditions. For circular conduits flowing full, Manning's Equation can be expressed as:

$$v = \frac{0.592}{n} d_s^{2/3} S_o^{1/2} \quad (6\text{-}2)$$

or

$$Q = \frac{0.465}{n} d_s^{8/3} S_o^{1/2} \quad (6\text{-}3)$$

where:

v = Full flow velocity, in feet/second

Q = Design discharge, in cfs

n = Manning's roughness coefficient

d_s = Diameter of the circular conduit, in feet

S_o = Pipe slope, in feet/foot

Non-circular and non-full flow conditions can be evaluated using the standard form of Manning's Equation discussed in Chapter 3.

Given the appropriate peak runoff rate for the design point in question, the conduit is sized to carry this peak rate as gravity flow, using Manning's Equation. For a condition in which pressure is allowed to develop in storm sewers with a design based on gravity flow conditions, the design capacity of the system will be greater than that determined using Equation 6-3, and can be evaluated as discussed below.

6.2.3 PRESSURE FLOW

If the hydraulic grade line, as illustrated in Figure 6-2, can be increased above the crown of the pipe, pressure flow occurs. Theoretically, pressure flow can be evaluated using appropriate forms of the energy and continuity equations. In practice, pressure flow can be evaluated using the nomographs developed for culvert flow that are discussed in Chapter 5 of this volume and presented in Volume 2. Pressure flow calculations for complex or critical systems should be performed using computer programs.