

CHAPTER 3

STORM DRAINAGE SYSTEMS

3.7 Storm Drains

3.7.1 Introduction

After the tentative locations of inlets, drain pipes, and outfalls with tail-waters have been determined and the inlets sized, the next logical step is the computation of the rate of discharge to be carried by each drain pipe and the determination of the size and gradient of pipe required to care for this discharge. This is done by proceeding in steps from upstream of a line to downstream to the point at which the line connects with other lines or the outfall, whichever is applicable. The discharge for a run is calculated, the drain pipe serving that discharge is sized, and the process is repeated for the next run downstream. It should be recognized that the rate of discharge to be carried by any particular section of drain pipe is not necessarily the sum of the inlet design discharge rates of all inlets above that section of pipe, but as a general rule is somewhat less than this total. It is useful to understand that the time of concentration is most influential and as the time of concentration grows larger, the proper rainfall intensity to be used in the design grows smaller.

For ordinary conditions, drain pipes should be sized on the assumption that they will flow full or practically full under the design discharge but will not be placed under pressure head. The Manning Formula is recommended for capacity calculations.

3.7.2 Design Criteria

The standard recommended maximum and minimum slopes for storm drains should conform to the following criteria:

- 3.7.1.1 The maximum hydraulic gradient should not produce a velocity that exceeds 15 feet per second.
- 3.7.1.2 The minimum desirable physical slope should be 0.5 percent or the slope which will produce a velocity of 2.5 feet per second when the storm sewer is flowing full, whichever is greater.

For hydraulic calculations, minor losses should be considered. If the potential water surface elevation exceeds one foot below ground elevation for the design flow (25-year for lateral and 100-year for cross drainage systems), the top of the pipe, or the gutter flow line, whichever is lowest, adjustments are needed in the system to reduce the elevation of the hydraulic grade line.

3.7.3 Capacity

Formulas for Gravity and Pressure Flow

The most widely used formula for determining the hydraulic capacity of storm drain pipes for gravity and pressure flows is the Manning Formula and it is expressed by the following equation:

$$V = [1.486R^{(2/3)}S^{(1/2)}]/n \quad \text{(Eq 3.7.3-1)}$$

Where:

V = Mean velocity of flow (ft/s)

R = The hydraulic radius (ft) – defined as the area of flow divided by the wetted flow surface or wetted perimeter (A/WP)

S = The slope of hydraulic grade line (ft/ft)

n = Manning's roughness coefficient

In terms of discharge, the above formula becomes:

$$Q = [1.486AR^{(2/3)}S^{(1/2)}]/n \quad \text{(Eq 3.7.3-2)}$$

Where:

Q = Rate of flow (cfs)

A = Cross sectional area of flow (ft²)

For pipes flowing full, the above equations become:

$$V = [0.590D^{(2/3)}S^{(1/2)}]/n \quad \text{(Eq 3.7.3-3)}$$

$$Q = [0.463D^{(8/3)}S^{(1/2)}]/n \quad \text{(Eq 3.7.3-4)}$$

Where:

D = Diameter of pipe (ft)

The Manning's equation can be written to determine friction losses for storm drain pipes as:

$$H_f = [2.87n^2V^2L]/[S^{(4/3)}] \quad \text{(Eq 3.7.3-5)}$$

$$H_f = [29n^2LV^2]/[(R^{(4/3)})(2g)] \quad \text{(Eq 3.7.3-6)}$$

Where:

H_f = Total head loss due to friction (ft)

n = Manning's roughness coefficient

D = Diameter of pipe (ft)

L = Length of pipe (ft)

V = Mean velocity (ft/s)

R = Hydraulic radius (ft)

g = Acceleration of gravity = 32.2 ft/sec²

3.7.4 Nomographs and Table

The nomograph solution of Manning's formula for full flow in circular storm drain pipes is shown in Figures 3.7.4-1 – 3.7.4-2 and 3.7.4-3. Figure 3.7.4-4 has been provided to solve the Manning's equation for part full flow in storm drains.

Figure 3.7.4-1

Nomograph For Solution For Solution Of Manning's

Formula For Flow in Storm Sewers

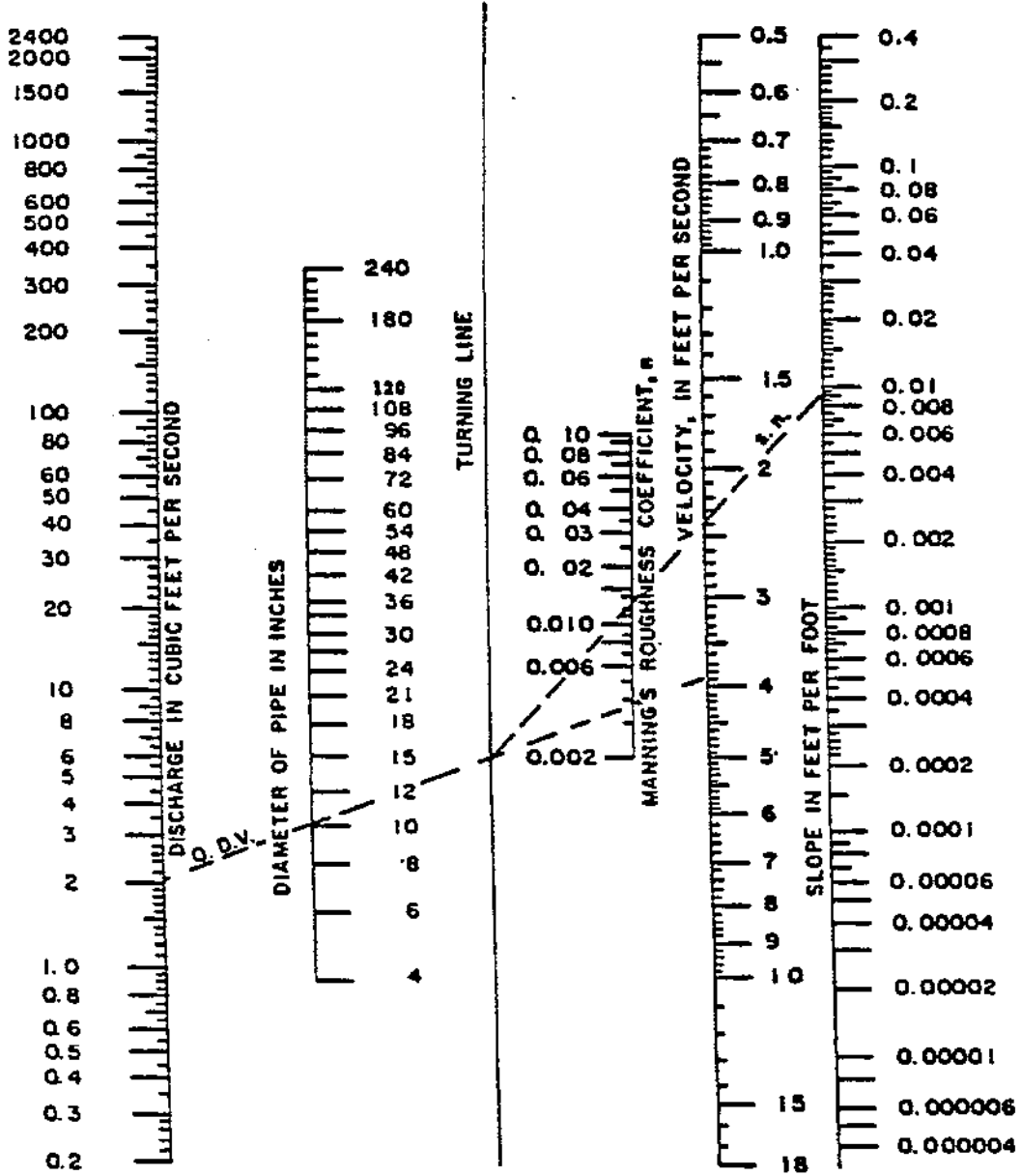


Figure 3.7.4-2

Nomograph For Computing Required Size Of Circular Drain, Flowing Full

$n=0.013$ or 0.015

*Example:- Given discharge $Q=4.4$ c.f.s.
friction factor $n=0.015$
slope of $0.0060'$ per foot
Find diameter 15 inches and
velocity of 3.5 ft.per second,
by following dashed line.*

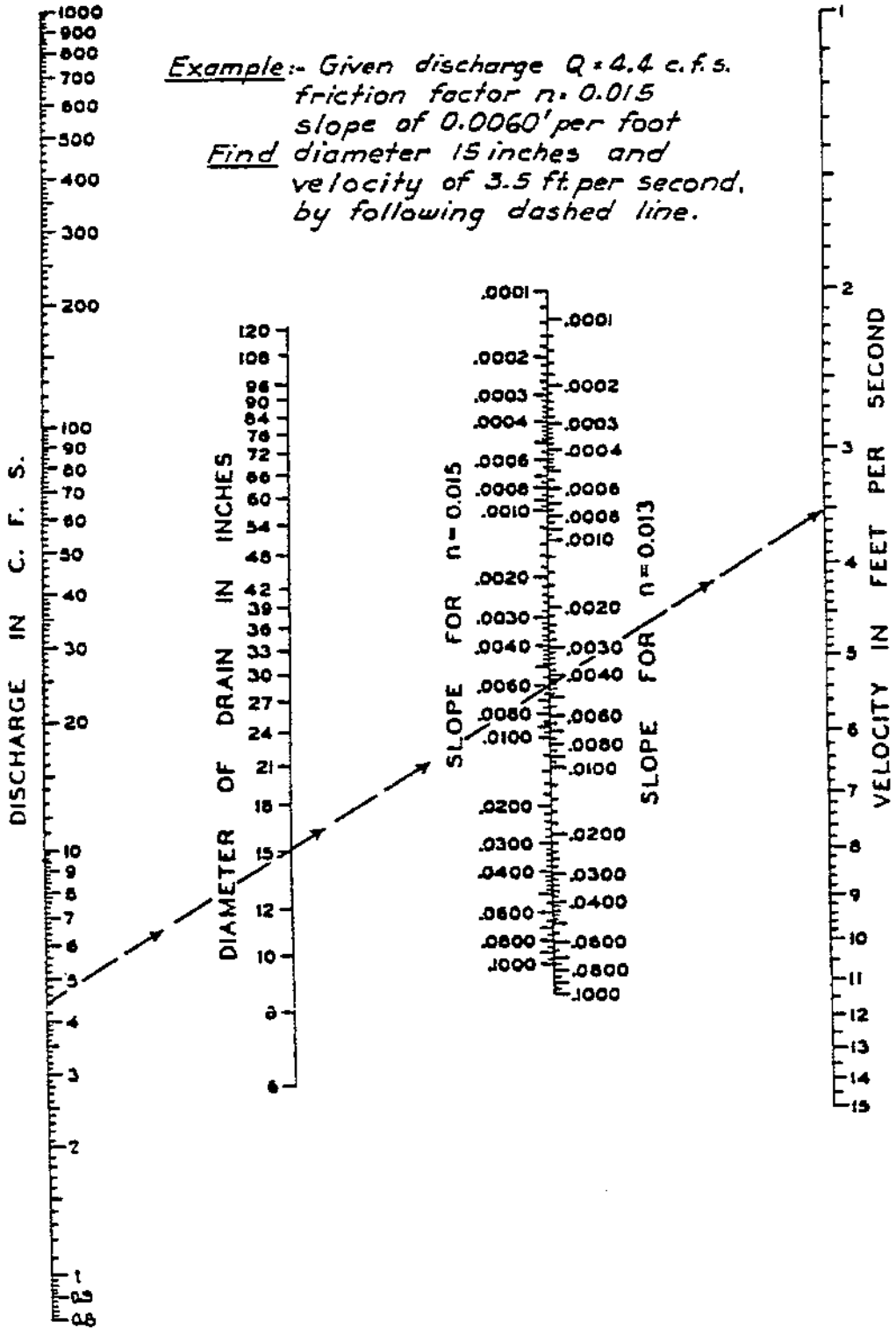


Figure 3.7.4-3

Concrete Pipe Flow Nomograph

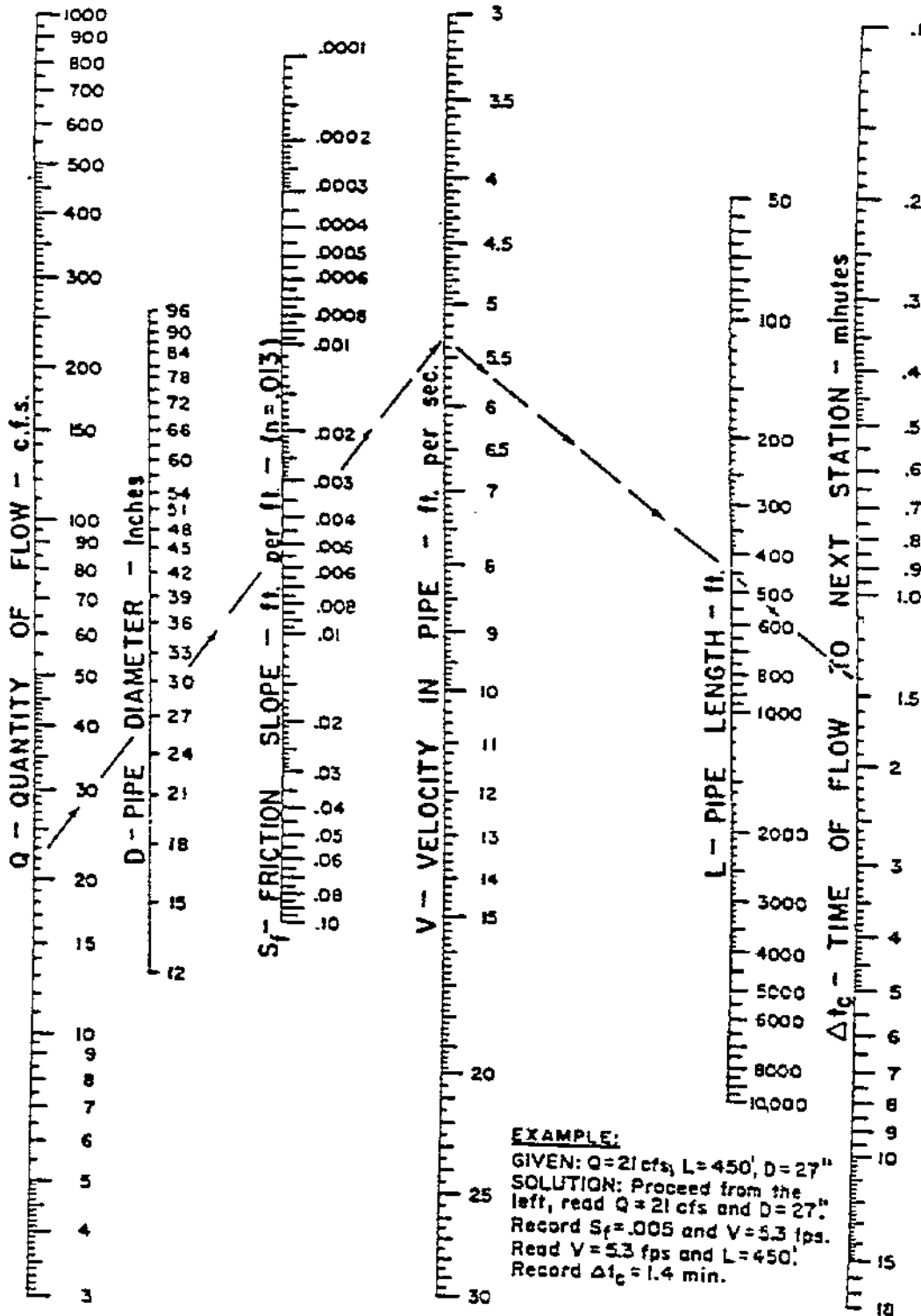
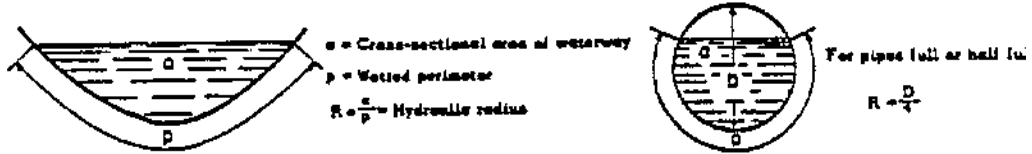


Figure 3.7.4-4

Values Of Various Elements Of Circular Section for Various Depths Of Flow

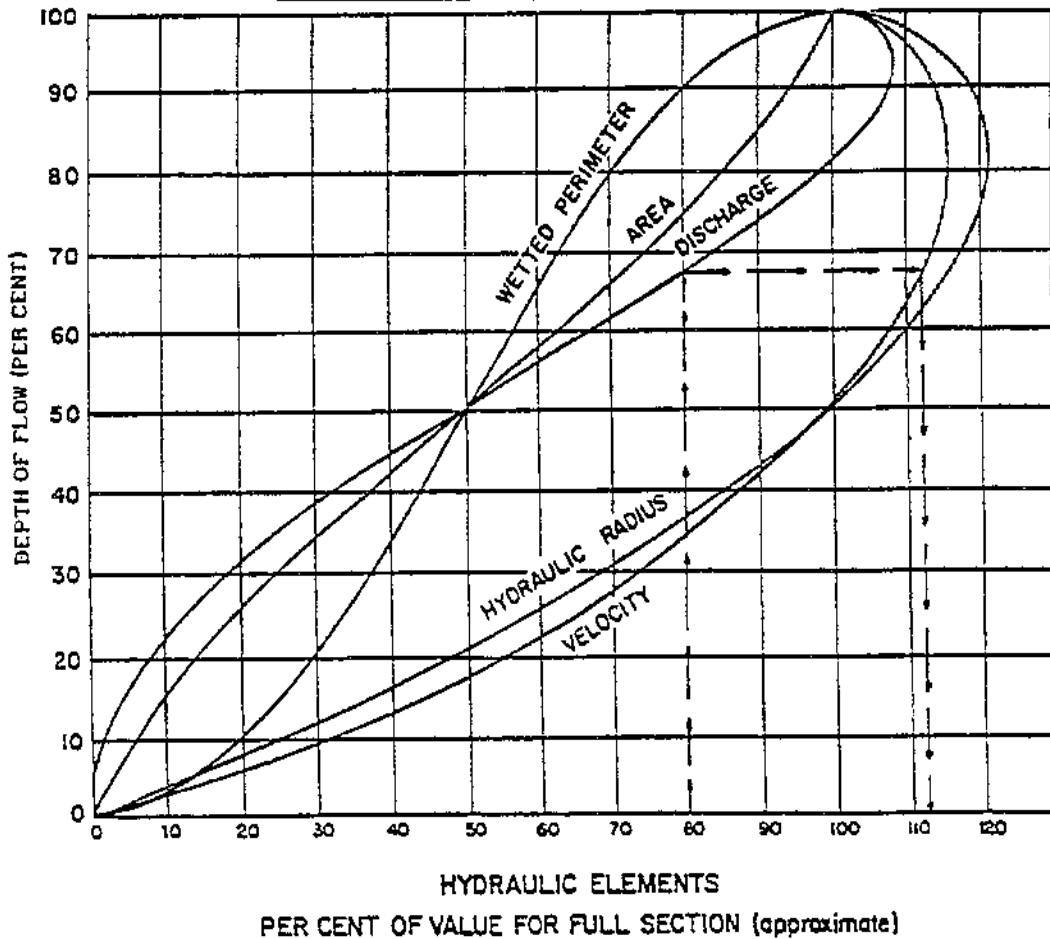


SECTION OF ANY CHANNEL

SECTION OF CIRCULAR PIPE

- V = Average or mean velocity in feet per second
- Q = aV = Discharge at pipe or channel in cubic feet per second (cfs)
- 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



3.7.5 Hydraulic Grade Lines

All head losses in a storm sewer system are considered in computing the hydraulic grade line to determine the water surface elevations, under design conditions in the various inlet, catch basins, manholes, junction boxes, etc.

Hydraulic control is a set water surface elevation from which the hydraulic calculations are begun. All hydraulic controls along the alignment are established. If the control is at a main line upstream inlet (inlet control), the hydraulic grade line is the water surface elevation minus the entrance loss minus the difference in velocity head. If the control is at the outlet, the water surface is the outlet pipe hydraulic grade line.

Design Procedure – Outlet Control

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 3.7.5-1 using the following procedure:

- 3.7.5.1 Enter in Column 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.
- 3.7.5.2 Enter in Column 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.
- 3.7.5.3 Enter in Column 3 the diameter (D_o) of the outflow pipe.
- 3.7.5.4 Enter in Column 4 the design discharge (Q_o) for the outflow pipe.
- 3.7.5.5 Enter in Column 5 the length (L_o) of the outflow pipe.
- 3.7.5.6 Enter in Column 6 the friction slope (S_f) in ft/ft of the outflow pipe. This can be determined by using the following formula:

$$S_f = (Q^2) / K \text{ or } (Q / K)^2 \quad \text{(3.7.5-1)}$$

Where:

S_f = Friction slope

K = $[1.486 AR^{2/3}] / n$

V = Average of mean velocity in feet per second

Q = Discharge of pipe or channel in cubic feet per second

S = Slope of hydraulic grade line

Multiply the friction slope (S_f) in Column 6 by the length (L_o) in Column 5 and enter the friction loss (H_f) in Column 7. On curved alignments, calculate curve losses by using the formula:

$$H_c = 0.002 (\Delta)(V_o^2/2g), \quad (3.7.5-2)$$

where

Δ = angle of curvature in degrees and add to the friction loss.

- 3.7.5.7 Enter in Column 8 the velocity of the flow (V_o) of the outflow pipe.
- 3.7.5.8 Enter in Column 9 the contraction loss (H_o) by using the formula $H_o = [0.25 V_o^2]/2g$, where $g = 32.2 \text{ ft/s}^2$.
- 3.7.5.9 Enter in Column 10 the design discharge (Q_i) for each pipe flowing into the junction. Neglect lateral pipes with inflows of less than ten percent of the mainline outflow. Inflow must be adjusted to the mainline outflow duration time before a comparison is made.
- 3.7.5.10 Enter in Column 11 the velocity of flow (V_i) for each pipe flowing into the junction (for exception see Step 10).
- 3.7.5.11 Enter in Column 12 the product of $Q_i \times V_i$ for each inflowing pipe. When several pipes inflow into a junction, the line producing the greatest $Q_i \times V_i$ product is the one that should be used for expansion loss calculations.
- 3.7.5.12 Enter in Column 13 the controlling expansion loss (H_i) using the formula $H_i = [0.35 (V_i^2)]/2g$.
- 3.7.5.13 Enter in Column 14 the angle of skew of each inflowing pipe to the outflow pipe (for exception, see Step 10).
- 3.7.5.14 Enter in Column 15 the greatest bend loss (H) calculated by using the formula $H = [KV_i^2]/2g$ where K = the bend loss coefficient corresponding to the various angles of skew of the inflowing pipes.
- 3.7.5.15 Enter in Column 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)

- 3.7.5.16 If the junction 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 Column 17.
- 3.7.5.17 If the junction incorporates full diameter inlet shaping, such as standard manholes, reduce the value of H_t by 50 percent and enter the adjusted value in Column 18.
- 3.7.5.18 Enter in Column 19 the FINAL H, the sum of H_f and H_t , is the final adjusted value of the H_t .
- 3.7.5.19 Enter in Column 20 the sum of the elevation on Col. 2 and the Final H in Col. 19. This elevation is the potential water surface elevation for the junction under design conditions.
- 3.7.5.20 Enter in Column 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 one foot below ground elevation for the design flow, the top of the pipe or the gutter flow line, whichever is lowest, adjustments are needed in the system to reduce the elevation of the H. G. L.
- 3.7.5.21 Repeat the procedure starting with Step 1 for the next junction upstream.
- 3.7.5.22 At last upstream entrance, add $V_1^2/2g$ to get upstream water surface elevation.

3.7.6 Minimum Grade

All storm drains should be designed such that velocities of flow will not be less than 2.5 feet per second at design flow or lower, with a minimum slope of 0.5 percent for concrete, and 1.0 percent for CMP. For very flat flow lines the general practice is to design components so that flow velocities will increase progressively throughout the length of the pipe system. Upper reaches of a storm drain system should have flatter slopes than slopes of lower reaches. Progressively increasing slopes keep solids moving toward the outlet and deters settling of particles due to steadily increasing flow streams.

The minimum slopes are calculated by the modified Manning formula:

$$S = [(nV)^2]/[2.208 R^{(4/3)}] \quad \text{(Eq. previously defined)}$$

3.7.7 Storm Drain Storage

If downstream drainage facilities are undersized for the design flow, an above- or below- ground detention structure may be needed to reduce the possibility of flooding. The required storage volume can be provided by using larger than needed storm drain pipes sizes and restrictors to control the release rates at manholes and/or junction boxes in the storm drain system. The same design criteria for sizing the detention basin is used to determine the storage volume required in the system.

3.7.8 Design Procedures

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

- 3.7.8.1 The first step is the determination of inlet location and spacing as outlined earlier in this chapter.
- 3.7.8.2 The second step is the preparation of a plan layout of the storm sewer drainage system establishing the following design data:
 - 3.7.8.2-1 Location of storm drains.
 - 3.7.8.2-2 Direction of flow.
 - 3.7.8.2-3 Location of manholes.
 - 3.7.8.2-4 Location of existing facilities such as water, gas, or underground cables.
- 3.7.8.3 The design of the storm drain system is then accomplished by determining drainage areas, computing runoff by rational method, and computing the hydraulic capacity by Manning equation.
- 3.7.8.4 The storm drain design computation sheet (Figure 3.7.8.4-1) can be used to summarize the hydrologic, hydraulic and design computations.

Figure 3.7.8.4-1

Storm Sewer Computation Form

<u>Inlet^a</u>	<u>Drainage Area (acres)</u>	<u>Time of Concentration (minutes)</u>	<u>Rainfall Intensity (inches/hr)</u>	<u>Runoff Coefficient</u>	<u>Inlet Flow Rate^b (cfs)</u>
1	2.0	8	6.3	.9	11.3
2	3.0	10	5.9	.9	15.8
3	2.5	9	6.1	.9	13.6
4	2.5	9	6.1	.9	13.6
5	2.0	8	6.3	.9	11.3
6	2.5	9	6.1	.9	13.6
7	2.0	8	6.3	.9	11.3

^a Inlet and storm drain system configuration are shown in Figure 3-18
^b Calculated using the Ration Equation (see Hydrology Chapter).

3.7.8.5 Examine all assumptions to determine if any adjustments are needed to the final design.

3.7.9 Rational Method Example

The following example will illustrate the hydrologic calculations needed for storm drain design using the rational formula (see Hydrology chapter for Rational method description and procedures).

<u>Inlet^a</u>	<u>Drainage Area (acres)</u>	<u>Time of Concentration (minutes)</u>	<u>Rainfall Intensity (inches/hr)</u>	<u>Runoff Coefficient</u>	<u>Inlet Flow Rate^b (cfs)</u>
I ₁ -M ¹	2.0	8	6.3	.9	11.3
I ₂ -M ₁	3.0	10	5.9	.9	15.8
M ₁ -M ₂	5.0	10.5	5.8	.9	25.9
I ₃ -M ₂	2.5	9	6.1	.9	13.6
I ₄ -M ₂	2.5	9	6.1	.9	13.6
M ₂ -M ₃	10.0	11.5	5.6	.9	50.2
I ₅ -M ₃	2.0	8	6.3	.9	11.3
I ₆ -M ₃	2.5	9	6.1	.9	13.6
M ₃ -M ₄	14.5	13.5	5.3	.9	68.6
I ₇ -M ₄	2.0	8	6.3	.9	11.3
M ₄ -O	16.5	14.7	5.1	.9	75.4

Figure 3.7.9-1
Hypothetical Storm Drain System Layout

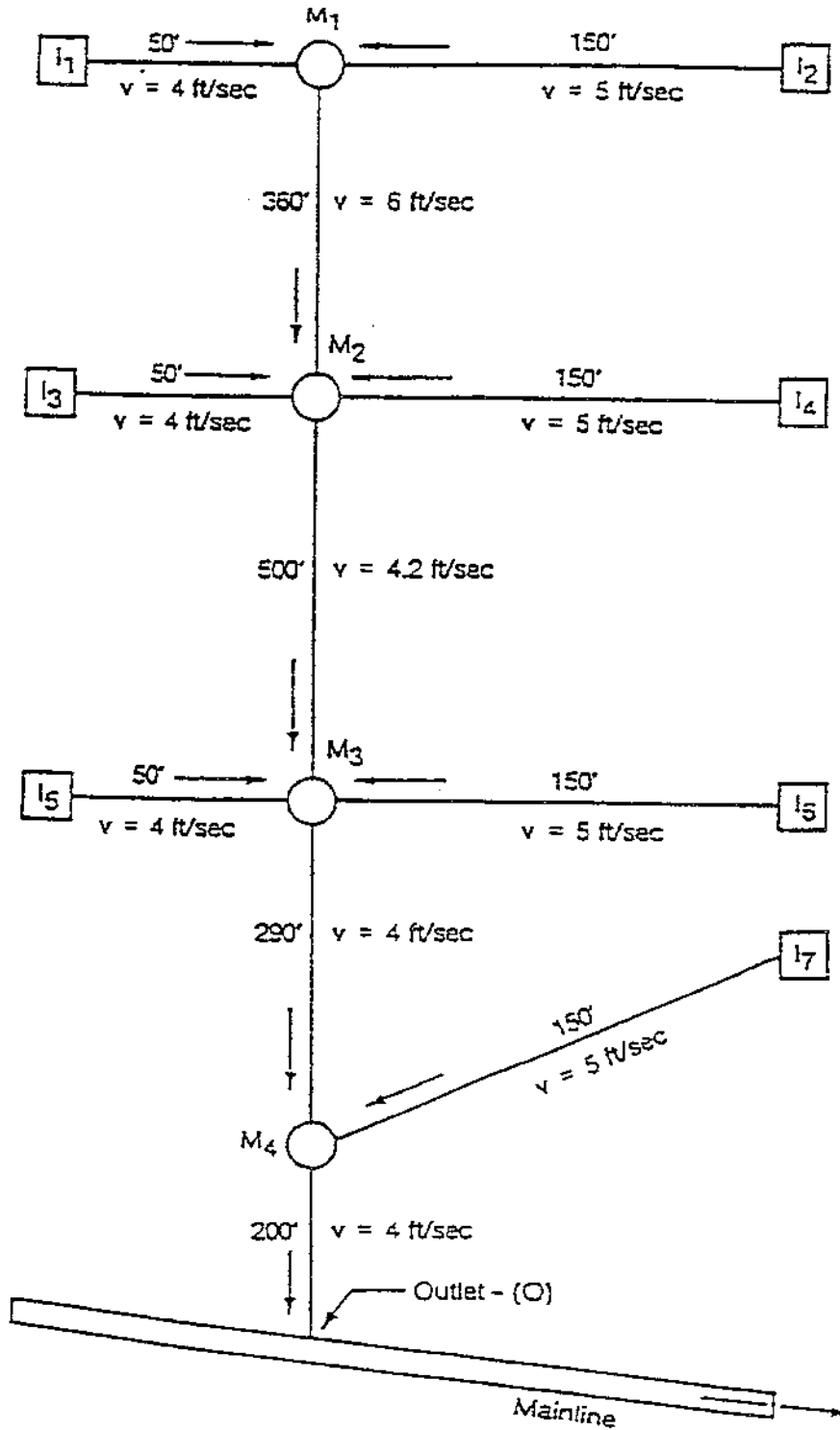


Figure 3.7.9-1 shows a hypothetical storm drain system that will be used in this example. Table 3.7.9-1 shows the tabulation of the data needed to be used in the rational equation to calculate inlet flow rate for the seven inlets shown in the system layout of Figure 3.7.9-1

END OF SECTION 3.7