Highway Hydraulics - Closed Channel Flow

Course Number: CE-02-707

PDH: 4

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7 Closed-Conduit Flow

7.1 TYPES OF FLOW IN CLOSED CONDUITS

Flow conditions in a closed conduit can occur as open-channel flow, gravity full flow or pressure flow. In open-channel flow the water surface is exposed to the atmosphere, which can occur in either an open conduit or a partially full closed conduit. Analysis of open- channel flow in a closed conduit is no different than any other type of open-channel flow, and all the concepts and principles discussed in Chapter 4 are applicable. Gravity full flow occurs at that condition where the conduit is flowing full, but not yet under any pressure. Pressure flow occurs when the conduit is flowing full and under pressure.

Due to the additional wetted perimeter and increased friction that occurs in a gravity full pipe, a partially full pipe will actually carry greater flow. For a circular conduit the peak flow occurs at 93 percent of the height of the pipe, and the average velocity flowing one-half full is the same as gravity full flow (Figure 7.1).

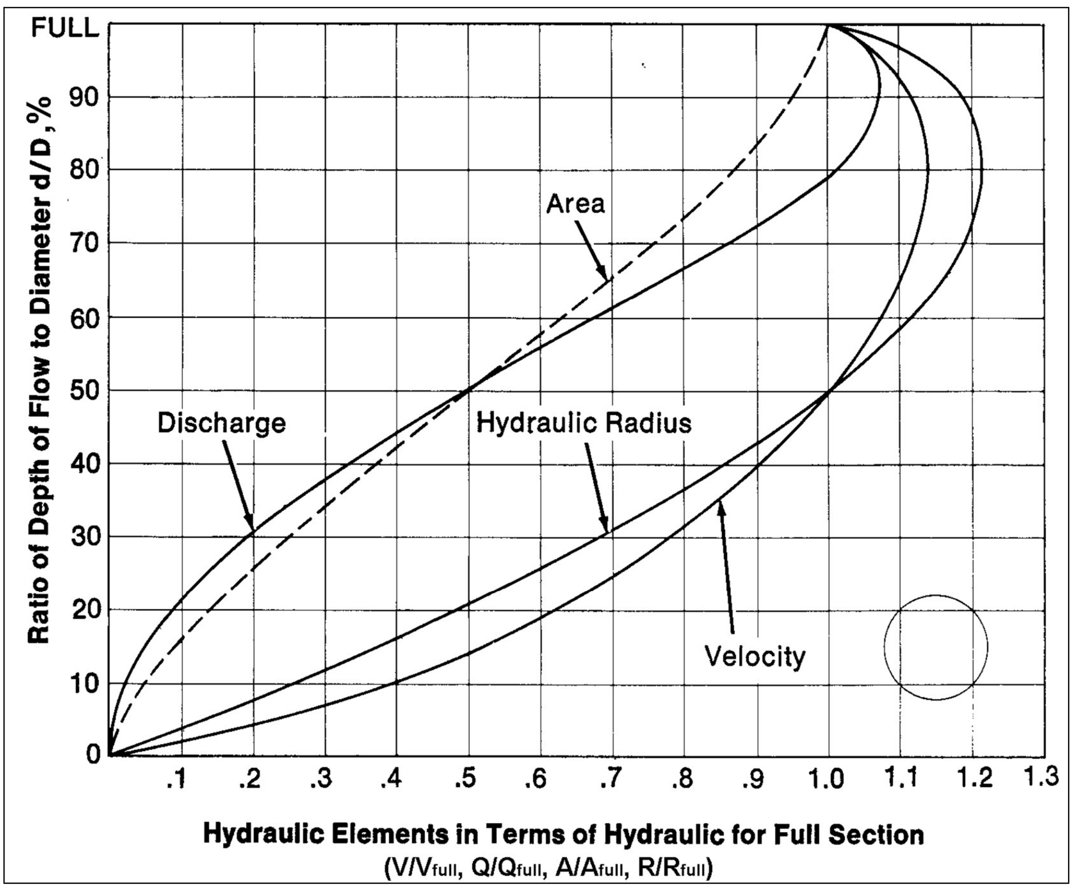


Figure 7.1. Part-full flow relationships for circular pipes.

Gravity full flow condition is usually assumed for purposes of storm drain design. Manning's equation (Equation 4.5) for circular section flowing full can be rewritten as:

$$Q = (K_u/n)\, D^{8/3}\, S^{1/2} \tag{7.1}$$

where:

Q	=	Discharge, m^3/s (ft^3/s)
n	=	Manning's coefficient
D	=	Pipe diameter, m (ft)
S	=	Slope, m/m (ft/ft)
K_u	=	0.312 (0.46)

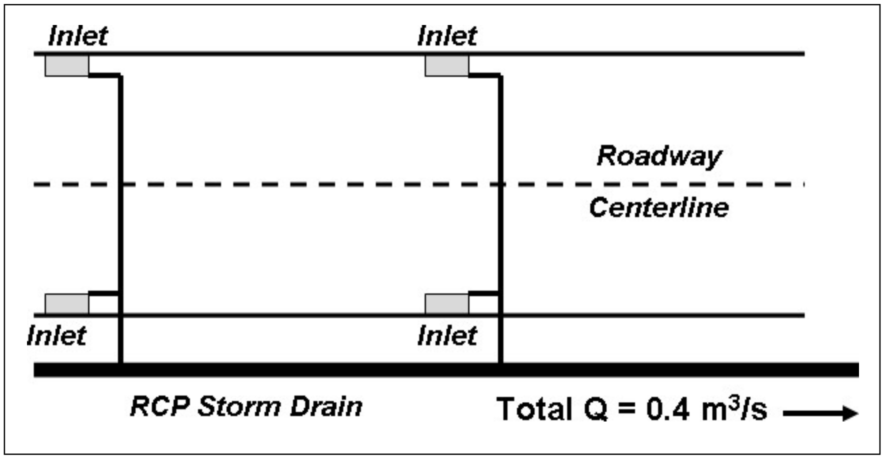
This equation allows for a direct computation of the required pipe diameter. Note that the computed diameter must be increased in size to a larger nominal dimension in order to carry the design discharge without creating pressure flow. The standard SI nominal sizes based on current English unit nominal sizes are given in Table 7.1.

Table 7.1. Nominal Pipe Sizes.

Nominal Size as Manufactured in English Units		Nominal Size Converted to SI Metric Units
Pipe Diameter		Pipe Diameter (mm)
Inches	Feet	
18	1.5	450
24	2.0	600
30	2.5	750
36	3.0	900
42	3.5	1,050
48	4.0	1,200
54	4.5	1,350
60	5.0	1,500
66	5.5	1,650
72	6.0	1,800
78	6.5	1,950
84	7.0	2,100
90	7.5	2,250
96	8.0	2,400
102	8.5	2,550
108	9.0	2,700
114	9.5	2,850
120	10.0	3,000
126	10.5	3,150
132	11.0	3,300
138	11.5	3,450
144	12.0	3,600

EXAMPLE PROBLEM 7.1 (SI Units)

Given: Pavement runoff is collected by a series of combination inlets. During the design event, the total discharge intercepted by all inlets is 0.4 m^3/s. A concrete storm drain pipe (n = 0.013) is to be placed on a grade parallel to the roadway grade, which is 0.005 m/m.



Find: The required storm drain pipe diameter and the full flow velocity.

1. Use the full flow equation (which gives pipe diameter in m)

   $Q = (K_u/n)\ D^{8/3}\ S^{1/2}$ where $K_u = 0.312$ for SI units

   $0.4 = (0.312/0.013)\ (D^{8/3})\ (0.005)^{1/2}$

   $D^{8/3} = 0.236$

   $D = 0.58$ m or 580 mm

2. Based on Table 7.1, the next larger nominal pipe size is 600 mm.

3. Under our design conditions, a 600 mm would be flowing slightly less than full. Based on the part-full flow relationships (Figure 7.1) the velocity does not change significantly from half-full to full. However, for tc calculation, the part-full velocity should be used.

   To calculate the part-full velocity, nomographs or trial-and-error solution can be used. Alternatively, the part-full flow relationships can be used. The full-flow discharge and velocity of a 600-mm concrete pipe are:

   $Q = (0.312/0.013)\ (0.60)^{8/3}\ (0.005)^{1/2} = 0.43\ m^3/s$

   $V = Q / A = 0.43 / \{[\pi\ (0.6)^2] / 4\} = 1.52$ m/s

   The ratio of part-full to full-flow discharge is

   $Q / Q_f = 0.40 / 0.43 = 0.93$

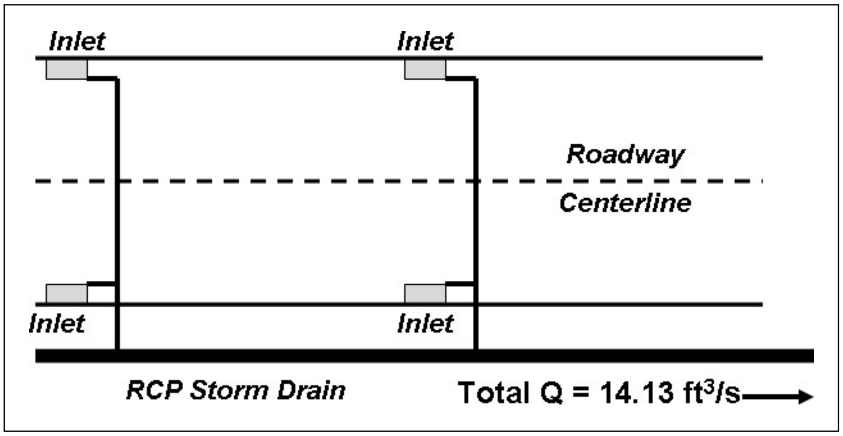
   The corresponding velocity ratio is 1.13 (Figure 7.1).

   Therefore;

   $V / V_f = 1.13$ and $V = 1.13\ (1.52) = 1.72$ m/s

EXAMPLE PROBLEM 7.1 (English Units)

Given: Pavement runoff is collected by a series of combination inlets. During the design event, the total discharge intercepted by all inlets is 14.13 ft^3/s. A concrete storm drain pipe (n = 0.013) is to be placed on a grade parallel to the roadway grade, which is 0.005 ft/ft.



Find: The required storm drain pipe diameter and the full flow velocity.

1. Use the full flow equation (which gives pipe diameter in ft)

$$Q = (K_u/n)\, D^{8/3}\, S^{1/2} \quad \text{where } K_u = 0.46$$

$$14.13 = (0.46/0.013)\,(D^{8/3})\,(0.005)^{1/2}$$

$$D^{8/3} = 5.64$$

$$D = 1.91 \text{ ft}$$

2. Based on Table 7.1, the next larger nominal pipe size is 24 inches or 2 ft.

3. Under our design conditions, a 24 inch would be flowing slightly less than full. Based on the part-full flow relationships (Figure 7.1) the velocity does not change significantly from half-full to full. However, for tc calculation, the part-full velocity should be used.

   To calculate the part-full velocity, nomographs or trial-and-error solution can be used. Alternatively, the part-full flow relationships can be used. The full-flow discharge and velocity of a 24-inch concrete pipe is:

$$Q = (0.46/0.013)\,(2)^{8/3}\,(0.005)^{1/2} = 15.89 \text{ ft}^3/\text{s}$$

$$V = Q / A = 15.89 / 3.14 = 5.06 \text{ ft/s}$$

   The ratio of part-full to full-flow discharge is:

$$Q / Q_f = 14.13 / 15.89 = 0.89$$