Module 7:
Hydraulic Design of Sewers and Storm Water Drains

Lecture 8:
Hydraulic Design of Sewers and Storm Water Drains (Contd.)

7.8 Effect of Flow Variations on Velocities in a Sewer

The discharge flowing through sewers varies considerably from time to time. Hence, there occur variation in depth of flow and thus, variation in Hydraulic Mean Depth (H.M.D.). Due to change in H.M.D. there occur changes in flow velocity, because it is proportional to $(\text{H.M.D.})^{2/3}$. Therefore, it is necessary to check the sewer for minimum velocity of about 0.45 m/sec at the time of minimum flow (1/3 of average flow) and the velocity of about 0.9 to 1.2 m/sec should be developed at a time of average flow. The velocity should also be checked for limiting velocity i.e. non-scouring velocity at the maximum discharge.

For flat ground sewers are designed for self-cleansing velocity at maximum discharge. This will permit flatter gradient for sewers. For mild slopping ground, the condition of developing self-cleansing velocity at average flow may be economical. Whereas, in hilly areas, sewers can be designed for self-cleansing velocity at minimum discharge, but the design must be checked for non-scouring velocity at maximum discharge.

Example: 1

Design a sewer for a maximum discharge of 650 L/s running half full. Consider Manning's rugosity coefficient of n = 0.012, and gradient of sewer S = 0.0001.

Solution

$Q \quad = A.V$

$0.65 \quad = (\pi D^2/8)\,(1/n)\,R^{2/3}\,S^{1/2}$

$R = A/P$

Solving for half full sewer, $R = D/4$

Substituting in above equation and solving we get D = 1.82 m.

Comments: If the pipe is partially full it is not easy to solve this equation and it is time consuming.

7.9 Hydraulic Characteristics of Circular Sewer Running Full or Partially Full

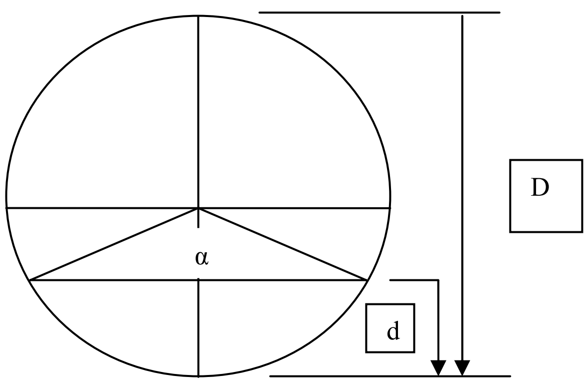


Figure 7.1 Section of a circular sewer running partially full

a) Depth at Partial flow

$$d = \left[\frac{D}{2} - \frac{D}{2}\cos\left(\frac{\alpha}{2}\right)\right]$$

b) Therefore proportionate depth

$$\frac{d}{D} = \frac{1}{2}\left[1 - \cos\left(\frac{\alpha}{2}\right)\right]$$

c) Proportionate area

$$\frac{a}{A} = \left[\frac{\alpha}{360} - \frac{Sin\alpha}{2\pi}\right]$$

d) Proportionate perimeter: $\frac{p}{P} = \frac{\alpha}{360}$

e) Proportionate Hydraulic Mean Depth

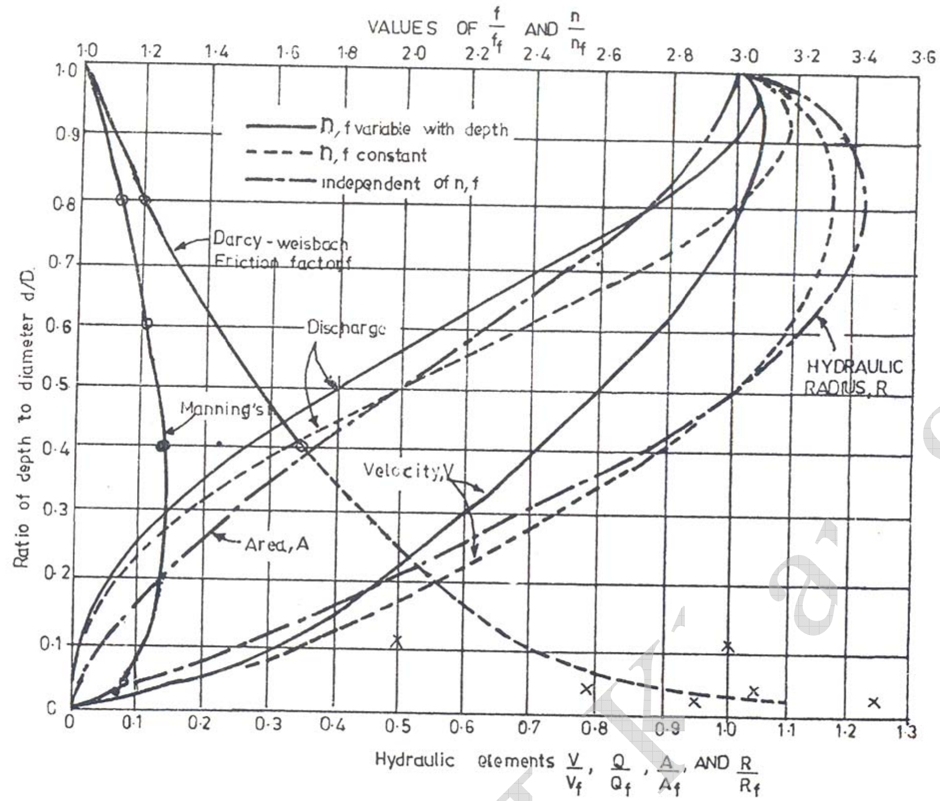
$$\frac{r}{R} = \left[1 - \frac{360 Sin\alpha}{2\pi\alpha}\right]$$

f) Proportionate velocity = $\frac{v}{V} = \frac{N}{n}\frac{r^{2/3}}{R^{2/3}}$

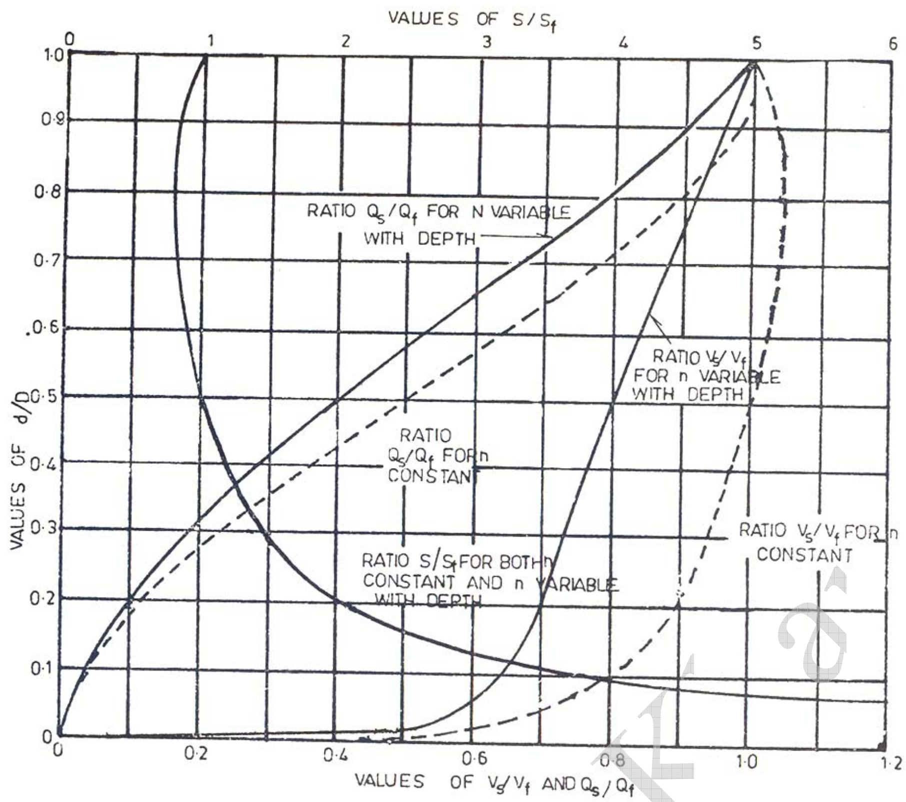
In all above equations except 'α' every thing is constant. Hence, for different values of 'α', all the proportionate elements can be easily calculated. These values of the hydraulic elements can be obtained from the proportionate graph prepared for different values of d/D (Figure 7.2). The value of Manning's n can be considered constant for all depths. In reality it varies with the depth of flow and it may be considered variable with depth and accordingly the hydraulic elements values can be read from the graph for different depth ratio of flow.

From the plot it is evident that the velocities in partially filled circular sewer sections can exceed those in full section and it is maximum at d/D of 0.8. Similarly, the discharge obtained is not maximum at flow full condition, but it is maximum when the depth is about 0.95 times the full depth.

The sewers flowing with depths between 50% and 80% full need not to be placed on steeper gradients to be as self cleansing as sewers flowing full. The reason is that velocity and discharge are function of tractive force intensity which depends upon friction coefficient as well as flow velocity generated by gradient of the sewer. Using subscript 's' denoting self cleansing equivalent to that obtained in full section, the required ratios v_s/V, q_s/Q and s_s/S can be computed as stated below:



(a) Hydraulic elements for circular sewer



(b) Hydraulic elements of circular sewer possessing equal selfcleansing properties at all depths

Figure 7.2 Proportionate graph for circular sewer section (CPHEEO Manual, 1993)

Consider a layer of sediment of unit length, unit width and thickness ‘t’ is deposited at the invert of the sewer. Let the slope of the sewer is θ degree with horizontal. The drag force or the intensity of tractive force (ι) exerted by the flowing water on a channel is given by:

$$\iota = \gamma_w \,.\, R.\, S$$

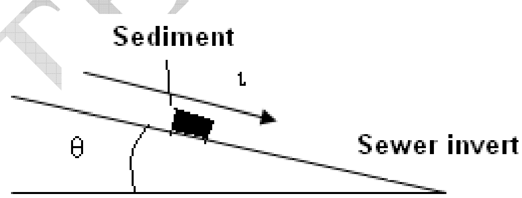


Figure 7.3 A sediment particle moving on the sewer invert

Where,

γ_w = unit weight of water

R = Hydraulic mean depth

S = slope of the invert of the sewer per unit length

With the assumption that the equality of tractive force intensity implies equality of cleansing, i.e., for sewers to be same selfcleansing at partial depth as full depth:

ι = T

Therefore,

$\gamma_w . r. s_s = \gamma_w . R. S$

Hence,

$s_s = (R/r) S$

Or $\frac{s_s}{S} = \frac{R}{r}$

Therefore,

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{s_s}{S}\right)^{1/2}$$

OR, by substituting $r/R = S/s_s$

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$$

And

$$\frac{q_s}{Q} = \frac{N}{n}\frac{a}{A}\left(\frac{r}{R}\right)^{1/6}$$

Example: 2

A 300 mm diameter sewer is to flow at 0.3 depth on a grade ensuring a degree of self cleansing equivalent to that obtained at full depth at a velocity of 0.9 m/sec. Find the required grade and associated velocity and rate of discharge at this depth. Assume Manning's rugosity coefficient n = 0.013. The variation of n with depth may be neglected.

Solution:

Manning's formula for partial depth

$$v = \frac{1}{n} r^{2/3} s^{1/2}$$

For full depth

$$V = \frac{1}{N} R^{2/3} S^{1/2}$$

Using V = 0.90 m/sec, N = n = 0.013 and R = D/4 = 75 mm = 0.075 m

$$0.90 = \frac{1}{0.013} 0.075^{2/3} S^{1/2}$$

S = 0.0043 This is the gradient required for full depth.

and, $Q = A.V = \pi/4\,(0.3)^2 \times 0.90 = 0.064\ m^3/s$

At depth d = 0.3D, (i.e., for d/D = 0.3) we have a/A = 0.252 and r/R = 0.684 (neglecting variation of n)

Now for the sewer to be same self cleansing at 0.3 m depth as it will be at full depth, we have the gradient (s_s) required as $s_s = (R/r)S$

Therefore, $s_s = S / 0.684$

$= 0.0043 / 0.0684 = 0.0063$

Now, the velocity v_s generated at this gradient is given by

$$v_s = V \frac{N}{n} \left(\frac{r}{R} \right)^{1/6}$$

$= 1 \times (0.684)^{1/6} \times 0.9$

$= 0.846$ m/s

The discharge q_s is given by

$$q_s = Q \frac{N}{n} \frac{a}{A} \left(\frac{r}{R} \right)^{1/6}$$

$q_s = 1 \times (0.258) \times (0.939) \times (0.064)$

$= 0.015\ m^3/s$