MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT

HYDRAULIC ELEMENT OF SEWER

- MODULE 2A

Camp Shield formula:

$$V = \sqrt{\frac{8\beta(S-1)gd}{f}}$$

where,

V=self cleansing velocity

β=dimensionless constant whose value depends upon the characteristics of sediments present in the Weisbach friction factor;

S=Specific gravity of sediments;

g=acceleration due to gravity;

d=diameter of solid particles

Minimum Velocity:

- Also known as self-cleansing velocity.
- It is the velocity at which solid particles will remain in suspension.
- Criteria for determining minimum velocity:
- For combined system, self cleansing velocity is 0.75m/s.

According to Badwin Latham self-cleansing velocity depends upon the diameter of sewers.

Table 3.1 Self cleansing velocities

Diameter(cm)	Velocity (m/s)
15-25	1.0
30-6	0.7
>60	0.6

Maximum Velocity:

- ✓ Also known as Limiting Velocity
- ✓ Velocity above which scouring or erosion of inner surface will occur
- ✓ Scouring mainly due to abrasive action of harder materials like sand, girt, gravel etc
- ✓ Limiting velocity depends upon the material of sewer

Sewer materials	Limiting velocities
Vetrified tiles	4.5-5.5
Cast iron	3.5-4.5
Stoneware	3.0-4.0
Cement concrete	2.5-3.0
Ordinary brick lined	1.5-2.5
Earthen channels	0.6-1.2

Hydraulic formulae:

1. Chezy's formula:

$$V = C\sqrt{RS}$$

where,

V= velocity if flow;

C= Chezy's coefficient;

R= Hydraulic mean depth;

S= Slope or gradient of sewer

- Different formulae for the calculation of Chezy's coefficient:

a) Kutter's expression:

$$C = \frac{23 + \frac{0.00155}{S} + \frac{1}{n}}{1 + \frac{\left(23 + \frac{0.00155}{S}\right)n}{\sqrt{R}}}$$

where, n=roughness coefficient

b) Bazin's formula:

$$C = \frac{157.6}{1.81 + \frac{m}{\sqrt{R}}}$$

where,

m is Bazin's coefficient

2. Hazen-Williams Formula

$$V = 0.849\, C_H R^{0.63} S^{0.54}$$

where,

C_H is the Hazen- William's coefficient

3. Manning's formula:

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

where,

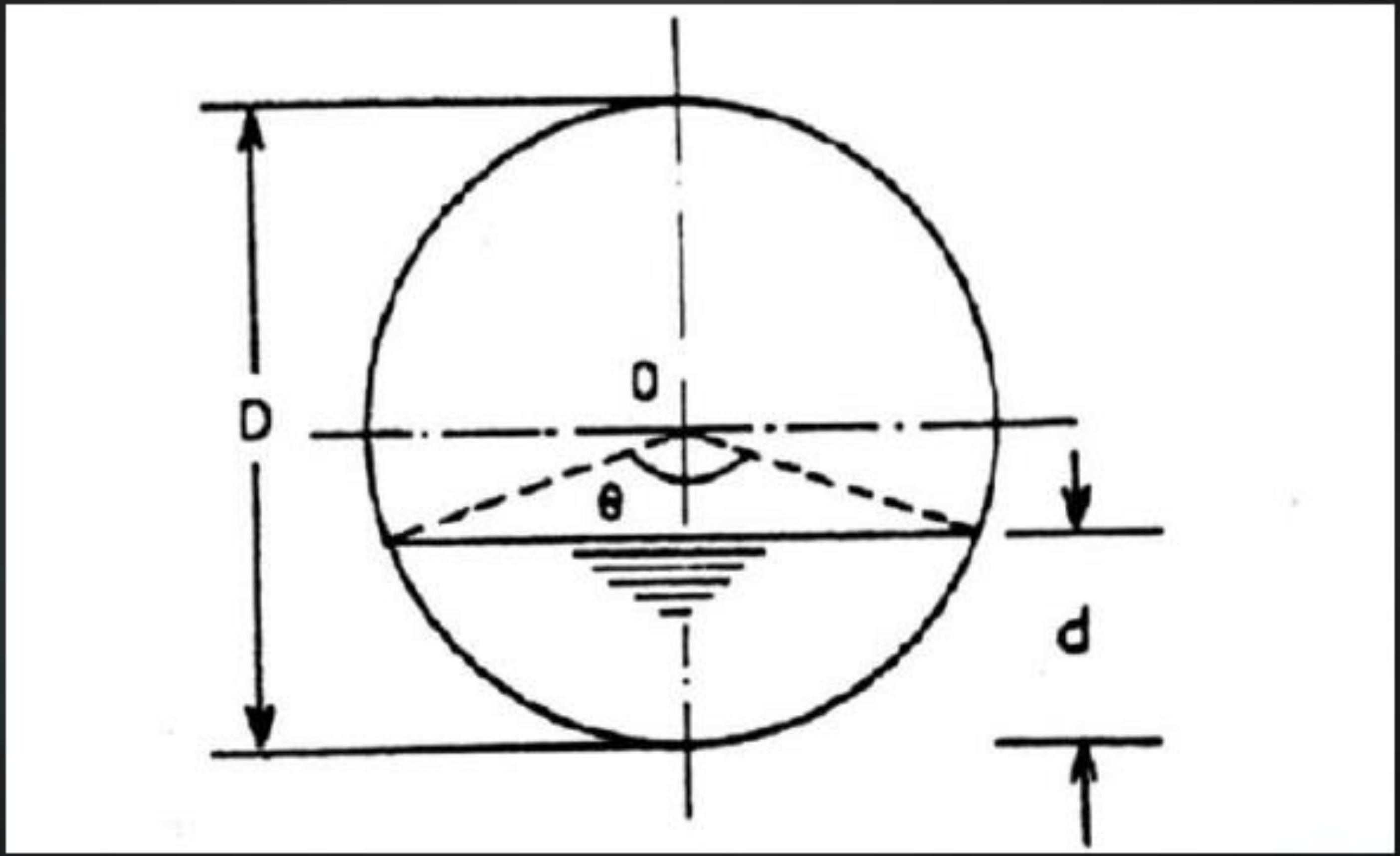
5. Crimp and Bruge's formula:

$$V = 83.47R^{2/3}S^{1/2}$$

Table 3.4 Manning's coefficient n

Conduit material	**Condition of interior surface**	
	Good	Fair
Salt glazed stoneware	0.012	0.014
Cement Concrete	0.013	0.015
Cast iron	0.012	0.013
Brick unglazed	0.013	0.015
Asbestos cement	0.011	0.012
Plastic smooth	0.011	0.011

- **Hydraulic elements of sewers:**
- Most commonly used sewers are circular.
- Hydraulic elements for different flow conditions are presented below:



Circular sewers running full:

Area of flow section $A = \frac{\pi}{4} D^2$

Wetted perimeter $P = \pi D$

Hydraulic mean depth $R = \frac{A}{P} = \frac{D}{4}$

Manning's formula:

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

Discharge $Q = A.V = \frac{A}{N} R^{2/3} S^{1/2}$

$$= \frac{0.3116}{N} D^{8/3} S^{1/2}$$

ii. Circular sewers running partially full:

Central angle θ is given by $cos\frac{\theta}{2} = \left(1 - \frac{2d}{D}\right)$

1. Depth $d = \frac{D}{2} - \frac{D}{2}\cos\frac{\theta}{2} = \frac{D}{2}\left(1 - \cos\frac{\theta}{2}\right)$

   Proportional depth $= \frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\theta}{2}\right)$

2. Area $a = \frac{\pi}{4}D^2 \times \frac{\theta}{360} - \frac{D}{2}\cos\frac{\theta}{2}\frac{D}{2}\sin\frac{\theta}{2}$

$$= \frac{\pi}{4}D^2\left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right]$$

   Proportional area $= \frac{a}{A} = \left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right]$

3. Wetted perimeter p= $\pi D \frac{\theta}{360}$

Proportional perimeter= $\frac{p}{P} = \frac{\theta}{360}$

4. Hydraulic mean depth $r = \frac{a}{p} = \frac{\frac{\pi}{4} D^2 \left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right]}{\pi D \frac{\theta}{360}}$

$$= \frac{D}{4}\left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]$$

Proportional hydraulic mean depth

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

5. Velocity of flow $v = \frac{1}{N} R^{2/3} S^{1/2}$

Proportional velocity $= \frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}$

Taking $\frac{N}{n} = 1,$

$$\frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = \left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{2/3}$$

6. Discharge $q = a \times v = \frac{1}{n} r^{2/3} S^{1/2}$

Taking $\frac{N}{n} = 1$,

Proportional discharge $= \frac{q}{Q} = \left(\frac{a}{A}\right)\left(\frac{v}{V}\right)$

$$= \left(\frac{a}{A}\right)\left(\frac{r}{R}\right)^{2/3}$$

$$= \frac{\theta}{360}\left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{5/3}$$

❑ Partial flow Diagram:

- Flow fluctuation occurs in sewer line so it is always designed for partial flow.
- Crimp and Berges have developed the following diagram for the calculation of hydraulic elements of sewers known as partial flow diagram.

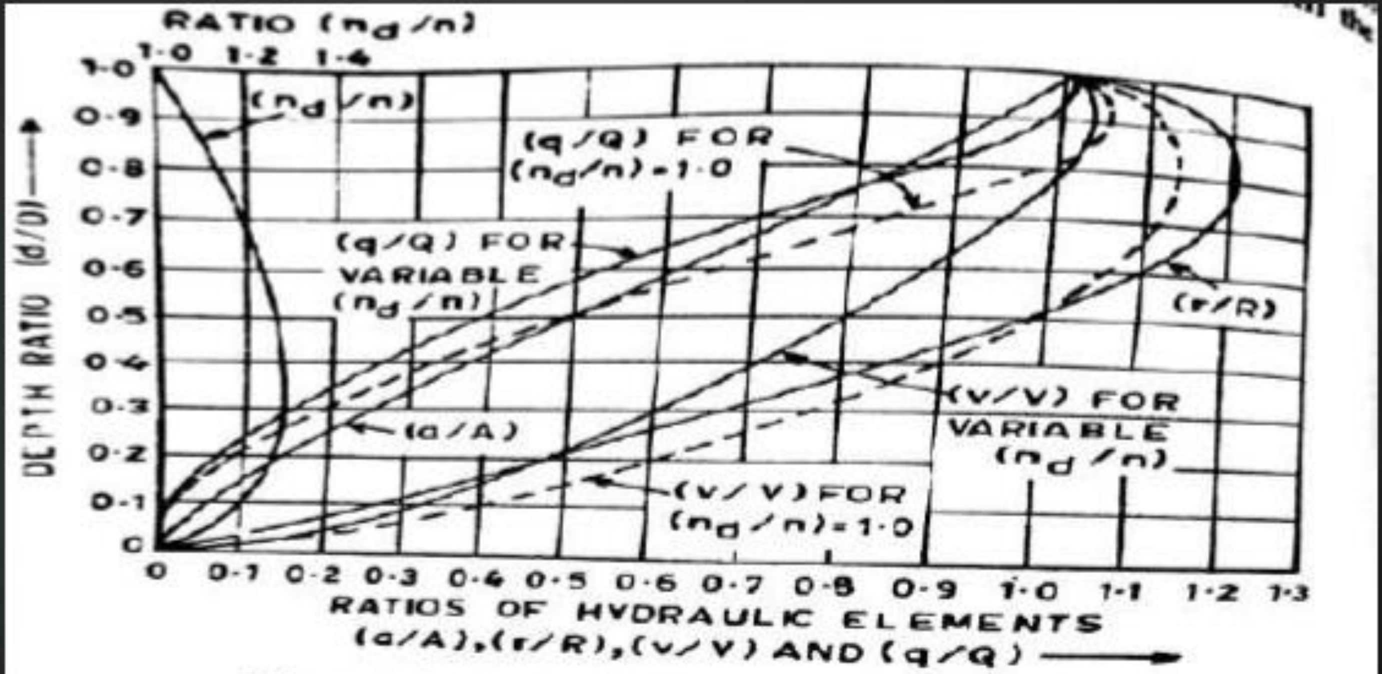


Figure 3-1 Partial Flow diagram

Source:Modi, 2001

TABLE 4.8 HYDRAULIC ELEMENTS OF CIRCULAR SEWERS RUNNING PARTIALLY FULL

$\frac{d}{D}$	$\frac{a}{A}$	$\frac{p}{P}$	$\frac{r}{R}$	For $N/n = 1.0$		$\frac{N}{n}$	For variable N/n	
				v/V	q/Q		v/V	q/Q
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.00	1.000	1.000	1.000	1.000	1.000	1.00	1.000	1.000
0.90	0.949	0.795	1.192	1.124	1.066	0.94	1.057	1.002
0.80	0.858	0.705	1.217	1.140	0.988	0.88	1.003	0.869
0.70	0.748	0.631	1.185	1.120	0.838	0.85	0.952	0.712
0.60	0.626	0.564	1.110	1.072	0.671	0.83	0.890	0.557
0.50	0.500	0.500	1.000	1.000	0.500	0.81	0.810	0.405
0.40	0.373	0.436	0.857	0.902	0.337	0.79	0.713	0.266
0.30	0.252	0.369	0.684	0.776	0.196	0.78	0.605	0.153
0.20	0.143	0.295	0.482	0.615	0.088	0.79	0.486	0.070
0.10	0.052	0.205	0.254	0.401	0.021	0.82	0.329	0.017
0.00	0.000	—	—	—	0.000	—	—	—

Source:B.C Punima,1998

Design the section of combined circular sewer from the data given below:
Area to be served is 150 hectares
Population of locality is 1,00,000
Maximum permissible velocity 3.2 m/s
Time of entry is 5 minutes
Time of flow is 20 minutes
Rate of water supply is 270 lpcd
Runoff coefficient is 0.45
Assume suitable data if necessary.

Solution:

Assuming 80% of the water supplied will be reaching the sewers as sanitary sewage ,quantity of sanitary sewage produced;

Average quantity of sanitary sewage flow (DWF)

=1,00,000 x 270 x 0.8 lit/day

=(100000x270x0.80) / (1000x24x60x60) m^3/s

=0.25 m^3/s

Maximum or peak quantity of sanitary sewage
=Peak factor x DWF (Assuming peak factor = 2)
=2 x 0.25 m^3/s
=0.5 m^3/s
$T_c = T_e + T_f$
where T_c= time of concentration
T_e = time of entry
T_f = time of travel or flow
The quantity of storm water will be maximum when storm duration is equal to time of concentration.
Thus, $t = t_c$= 25 minutes

$$i = \frac{1020}{t+20}$$

$i = \frac{1020}{25+20}$ = 22.67 mm/hr
The storm water runoff is given by rational formula ,as
$Q = \frac{CiA}{360}$, where C=0.45, i=22.67 mm/hr , A=150 hectare
=4.25 m^3/s

Therefore, combined discharge (Q) = 0.5+4.25

= 4.75 m^3/s

Now, $A = \frac{Q}{V} = \frac{4.75}{3.2}$ = 1.48 m^2

All velocities must lie between (0.75-3.2) m/s . Hence, 3.2 m/s is assumed.

Diameter of sewer , $D = \frac{\sqrt{4A}}{\pi}$

=1.374 m

Adopting commercially available size 1.4 m,

$$A = \frac{\pi D^2}{4}$$

$= \frac{\pi x\ (1.4)2}{4}$ = 1.54 m^2

$V = \frac{Q}{A} = \frac{4.75}{1.54} = 3.08\ m/s$<3.2 m/s. Hence,ok.

Check for cleansing velocity during dry weather flow

$$\frac{q}{Q} = \frac{0.25}{4.75} = \frac{1}{19} = 0.0526$$

$$\frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{5/3}$$

$$\left[\frac{18.94}{\theta}\right]^{3/5} + \frac{360 sin\theta}{2\pi\theta} - 1 = 0$$

Solving, θ = 93°

$$\frac{\vartheta}{V} = \left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{2/3}$$

Or, v= 3.08 x 0.529 = 1.629 m/s

0.75 m/s < 1.629 m/s < 3.2 m/s Hence,ok.

Check for self cleansing velocity during minimum flow

Assume Q_{min} = 1/2 of DWF

$$\frac{q}{Q} = 0.0263$$

$$\frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{5/3}$$

Solving, θ = 78.077°

$$\frac{\vartheta}{V} = \left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{2/3}$$

Or, v= 3.08 x 0.43 = 1.32 m/s

0.75 m/s < 1.32 m/s < 3.2 m/s Hence , ok.

Calculate the diameter and velocity of a circular sewer at a slope of 1in 150 when it is running just full at a discharge of 1.05 m^3/s. The value of n in Manning's formula is 0.011. What will be the discharge and velocity when flowing 0.75 depth of pipe for the same slope.

Solution:

Using Manning's equation,we have

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

Q = 1.05 m^3/s , n=0.11, s=1/150

Thus, by substitution , we get

$$1.05 = \left(\frac{1}{0.11}\right) x \left(\frac{\pi}{4} D2\right) x \left(\frac{D}{4}\right)^{2/3} x \left(\frac{1}{400}\right)^{1/2}$$

or, D= 0.7436 m

$$\text{Velocity (v)} = \frac{1}{n} R^{2/3} S^{1/2}$$

$$= \frac{1}{0.011} \left(\frac{0.7436}{4}\right)^{2/3} \left(\frac{1}{150}\right)^{1/2}$$

= 2.42 m/s

When flowing depth of pipe = 0.75m

$$\frac{d}{D} = 0.75$$

Central angle (θ) is given by , $\cos\frac{\theta}{2} = (1 - \frac{2d}{D})$

$= (1- 2 \times 0.75)$

$\theta = 240^{o}$

$$\frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{5/3}$$

Discharge(Q) = 1.05 m^3/s

Therefore, q = 0.9575 m^3/s

Now,

$$\frac{\vartheta}{V} = \left[1 - \frac{360 sin\theta}{2\pi\theta}\right]^{2/3}$$

Velocity (v) = 2.42 m/s

Therefore , ϑ = 2.74 m/s

1. Calculate the velocity of flow in a sewer of circular section having diameter of **1**m, laid at gradient of **1** in **600**. Use Manning's equation taking n=**0.012**

Solution:

For sewer running half full,

$A=\frac{\pi D^2}{8}$; $P=\frac{\pi D}{2}$

$R=\frac{A}{P}=\frac{D}{4}$

Hydraulic Radius(R)=0.25m

$A=\frac{\pi D^2}{8}=0.3627m^2$

Using Manning's equation;

$Velocity(V)=\frac{1}{n} R^{\frac{2}{3}}S^{\frac{1}{2}}=1.35$ m/sec

Discharge(Q)=AV=0.3927 * 1.35 =0.053 m^3/sec

2. Design a sewer to serve a population of 120000; the daily per capita water supply allowance being 180 litres, of which 80% find its way into the sewer. The permissible sewer slope is 1 in 1000, peak factor=2 and take Manning's n=0.012

Solution :

$$\text{Average flow (DWF)} = 0.80 \times 1{,}20{,}000 \times 180 \text{ liters/day}$$

$$= \frac{120000 \times 180 \times 0.80}{1000 \times 24 \times 60 \times 60} \ m^3/sec$$

$$= 0.20 \ m^3/sec$$

Maximum or peak quantity of sanitary sewage

$$= \text{Peak factor} \times DWF = 2 \times 0.20 = 0.40 \ m^3/sec$$

The sewer is designed for maximum discharge.

Thus using Manning's equation, we have

$$Q = \frac{A}{n} R^{2/3} S^{1/2}$$

$$n = 0.012, \quad s = \frac{1}{1000}$$

If D is the diameter of the sewer, then

$$A = \frac{\pi}{4}D^2, \qquad P = \pi D, \qquad R = \frac{A}{P} = \frac{D}{4}$$

Thus by substitution, we get

$$0.40 = \frac{1}{0.012} \times \left(\frac{\pi}{4}D^2\right) \times \left(\frac{D}{4}\right)^{2/3} \times \left(\frac{1}{1000}\right)^{1/2}$$

or, $D^{8/3} = 0.487$

or, $D = 0.763\text{m}$

Adopt commercially available size 0.8 m

Check for self cleansing velocity at maximum flow

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

$$V = 0.9 \text{ m/sec}$$

Which is 0.6 m/sec < 0.9 m/sec < 3 m/sec

Check for self cleansing velocity at dry weather flow

$$\frac{q}{Q} = \frac{0.2}{0.4} = \frac{1}{2} = 0.5$$

$$\therefore \frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{5/3}$$

Or, $\left[\left[\frac{180}{\theta}\right]^{3/5} + \frac{360 \sin\theta}{2\pi\theta}\right] - 1 = 0$

Solving, $\theta = 180^\circ$

$$\frac{v}{V} = \left[1 - \frac{360\sin\theta}{2\pi\theta}\right]^{2/3}$$

Or, $v = 0.9 \times 1 = 0.9$ m/sec

Which is 0.6 m/sec < 0.9 m/sec < 3 m/sec

Hence OK.

Check for self cleansing velocity during minimum flow;

Assume Q_{min} = 1/2 of DWF

$$\frac{q}{Q} = 0.25$$

$$\therefore \frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360\sin\theta}{2\pi\theta}\right]^{5/3}$$

Or, $$\left[\left[\frac{45}{\theta}\right]^{3/5} + \frac{360\sin\theta}{2\pi\theta}\right] - 1 = 0$$

Solving, $\theta = 117^\circ$

$$\frac{v}{V} = \left[1 - \frac{360\sin\theta}{2\pi\theta}\right]^{2/3}$$

Or, $v = 0.9 \times 0.682 = 0.61$ m/sec

Which is 0.6 m/sec < 0.61 m/sec < 3 m/sec

Hence OK.

3. Calculate the diameter of a sewer to serve an area of 20 square kilometer with a population density of 250 persons per hectare. The average rate of sewage flow is 350 lpcd. The maximum flow is 50% in excess of average together with the rainfall equivalent of 15 mm in 24 hrs, all of which are runoff, take the Vmax as 3m/sec.

Solution:

Total population of the area;

$$= 250 \times \left(\frac{20 \times 10^6}{10^4}\right) = 500000 \text{ persons}$$

Average sewage flow;

$$= \left(\frac{500000 \times 350 \times 10^{-3}}{24 \times 3600}\right) \text{m}^3/\text{sec} = 2.025 \text{ m}^3/\text{sec}$$

Peak or maximum flow;

$$= 1.5 \times 2.025 \text{ m}^3/\text{sec} \qquad (Q_{max.} = 1.5 \text{ times average flow})$$

$$= 3.038 \text{ m}^3/\text{sec}$$

Storm sewage;

$$Q = \frac{CiA}{360}$$

[Where, $C = 1$, $i = 0.625$ mm/hr, $A = 2000$ hactare]

$$= 3.472 \text{ m}^3/\text{sec}$$

Total flow for the combined sewer

$$= 3.038 + 3.472 = 6.51 \text{m}^3/\text{sec}$$

$$A = \frac{Q}{V} = \frac{6.51}{3} = 2.17 \text{ m}^2$$

Diameter of sewer, $D = \sqrt{\frac{4A}{\pi}} = 1.662$ m

4.Calculate the diameter of combined circular sewer with the following data:

Rate of water supply=100 lpcd

Population density=100 persons/hec

Peak factor=2.7

Area=35 hectares

Rainfall intensity=15 mm/hr

Slope=1 in 750

Rugosity coefficient=0.011

Runoff Coefficient=0.4

The sewer should run 0.6 full during peak flow

Solution:

Assume 80% of supplied water converted as wastewater,

Average flow (DWF) = 0.80×3500×100 liters/day

$$= \frac{3500\times100\times0.80\times10^{-3}}{24\times3600} \text{ m}^3/\text{sec}$$

$$= 0.00324 \text{ m}^3/\text{sec}$$

Maximum or peak quantity of sanitary sewage

$$= \text{Peak factor} \times DWF = 2.7 \times 0.00324 = 0.00875 \text{ m}^3/\text{sec}$$

Quantity of storm sewage;

$$Q = \frac{CiA}{360}$$ Where, C = 0.4, i = 15 mm/hr, A = 35 hectare

$$= 0.5833 \text{ m}^3/\text{sec}$$

Therefore, combined discharge (q) = 0.592 m^3/sec

$$\frac{d}{D} = 0.6$$

Central angle (θ) is given by expression $\cos\frac{\theta}{2} = \left(1 - 2\frac{d}{D}\right)$

$$= (1 - 2\times0.6)$$

$$\theta = 203.07^\circ$$

$$\therefore \frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360\sin\theta}{2\pi\theta}\right]^{5/3}$$

In full flow condition (Q) = 0.88116 m^3/sec

Using Manning's formula;

$$Q = \frac{A}{n} R^{2/3} S^{1/2}$$

$$n = 0.011, \quad s = 1/750$$

If D is the diameter of the sewer, then

$$A = \frac{\pi}{4}D^2, \quad P = \pi D, \quad R = \frac{A}{P} = \frac{D}{4}$$

$$0.88116 = \left(\frac{1}{0.011}\right)\times\left(\frac{\pi}{4}D^2\right)\times\left(\frac{D}{4}\right)^{2/3}\times\left(\frac{1}{750}\right)^{1/2}$$

D = 1 meter

5. A city has a population of 1 lakh with a per capita water supply of 200 lpcd. Design sewer running 0.7 times full at maximum discharge. Take n=0.013, slope=1 in 600 and peak factor=2.25. Assume 80% of w/s contibutes for sewage.

Solution:

$$\text{Quantity of water supplied} = \frac{100000 \times 200 \times 10^{-3}}{24 \times 3600} = 0.2315\ m^3/sec$$

Average quantity of sanitary sewage (DWF) = 0.8 X 0.2315

= 0.1852 m^3/sec

Peak discharge = pf X DWF = 0.4167 m^3/sec

$$\frac{d}{D} = 0.75$$

Central angle (θ) is given by expression $\cos\frac{\theta}{2} = \left(1 - \frac{2d}{D}\right)$

$$= (1 - 2 \times 0.75)$$

$$\theta = 227.16^\circ$$

$$a = \frac{\pi D^2}{4}\left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right] = 0.5872\ D^2$$

$$p = \pi D \frac{\theta}{360} = 1.9262\ D$$

$$r = \frac{a}{p} = 0.2962\ D$$

Using Manning's formula;

$$Q = \frac{a}{n}\ r^{2/3}\ S^{1/2}$$

(n = 0.013, s = 1/600)

$$0.4167 = \left(\frac{1}{0.013}\right) \times \left(0.5872 D^2\right) \times (0.2962\ D)^{2/3} \times \left(\frac{1}{600}\right)^{1/2}$$

D = 776 mm

Adopt commercially available size 0.8 m

Check Velocity;

$$V = \left(\frac{1}{0.013}\right) \times (0.23696)^{2/3} \times \left(\frac{1}{600}\right)^{1/2}$$

= 1.20 m/sec (0.6 to 3 m/sec OK)

Check self cleansing velocity for DWF;

$$\frac{q}{Q} = \frac{1}{2.25}$$

$$\therefore \frac{q}{Q} = \frac{\theta}{360}\left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{5/3}$$

Or, $\left[\left[\frac{160}{\theta}\right]^{3/5} + \frac{360 \sin\theta}{2\pi\theta}\right] - 1 = 0$

Solving, $\theta = 172.42°$

$$\frac{v}{V} = \left[1 - \frac{360 \sin\theta}{2\pi\theta}\right]^{2/3} = 0.97$$

Or, v = 0.97 × 1.20 = 1.166 m/sec

Similarly, Velocity during minimum flow can be obtained as minimum flow is one third of average flow.

$V_{min.}$ = 0.845 m/sec

As flow drops to minimum the self cleansing velocity will be maintained in the sewer. Hence, design is OK.

Design of Sewers

- The hydraulic design of sewers and drains, means finding out their sections and gradients, is generally carried out on the same lines as that of the water supply pipes.
- However, there are two major differences between characteristics of flows in sewers and water supply pipes.
- The sewage contain particles in suspension, the heavier of which may settle down at the bottom of the sewers, as and when the flow velocity reduces, resulting in the clogging of sewers
- To avoid silting of sewers, it is necessary that the sewer pipes be laid at such a gradient, as to generate self cleansing velocities at different possible discharges.
- The sewer pipes carry sewage as gravity conduits, and are therefore laid at a continuous gradient in the downward direction up to the outfall point, from where it will be lifted up, treated and disposed off.

Hydraulic formulae

1. Chezy's formula

$$v = C\sqrt{Ri},$$

where
V= is the mean velocity [m/s],
C= is the Chézy coefficient [m½/s],
R= is the hydraulic radius (~ water depth) [m],
i= is the bottom slope[m/m].

- Constant (C) is very complex. Depends on size, shape and smoother roughness of the channel, the mean depth etc.
- C can be calculated by using Bazin's formula.

2. Bazin's formula

$$C = \frac{157.6}{[1.81 + (K/R^{1/2})]}$$

Where,
K= Bazin's constant
R= hydraulic radius

Sr. No.	Inside nature of the sewer	K values
1.	Very smooth	0.109
2.	Smooth: bricks & concrete	0.290
3.	Smooth: rubble masonry	0.833
4.	Good, earthen material	1.540
5.	Rough: bricks & concrete	0.500
6.	Rough earthen material	3.170

3. Manning's formula

$$V = \frac{k}{n} R_h^{2/3} \cdot S^{1/2}$$

V = velocity of flow (m/s)

k = conversion factor of 1.486 $(ft/m)^{1/3}$

n = Manning coefficient

R_h = hydraulic radius (m)

S = slope of the water surface

* The value of "n" is calculated by kutter's formula

4. Kutter's formula

$$C = \frac{k_1 + \frac{k_2}{S} + \frac{k_3}{n}}{1 + \frac{n}{\sqrt{R}} \cdot \left(k_1 + \frac{k_2}{S}\right)}$$

Where

- C = Chézy's roughness coefficient
- S = Friction slope
- R = Hydraulic radius (m,)
- n = Kutter's roughness (unit less)
- k_1 = Constant (23.0 SI,)
- k_2 = Constant (0.00155 SI,)
- k_3 = Constant (1.0 SI,)

5. Hazen – William's formula

$$V = k\,C\,R^{0.63}\,S^{0.54}$$

where:

- V is velocity
- k is a conversion factor for the unit system k = 0.849 for SI units)
- C is a roughness coefficient
- R is the hydraulic radius
- S is the slope of the energy line (head loss per length of pipe)

6. Crimp and Burge's formula

$$V = 83.47\,R^{2/3}\,S^{1/2}$$

Where,

V = velocity of flow (m/s)

R = hydraulic radius (m)

S = slope of the water surface

Minimum Velocity

- The flow velocity in the sewers should be such that the suspended materials in sewage do not get silted up; i.e. the velocity should be such as to cause automatic self- cleansing effect.
- The generation of such a minimum self cleansing velocity in the sewer, at least once a day, is important, because if certain deposition takes place and is not removed, it will obstruct free flow, causing further deposition and finally leading to the complete blocking of the sewer.

Maximum Velocity

- The smooth interior surface of a sewer pipe gets scoured due to continuous abrasion caused by the suspended solids present in sewage.
- It is, therefore, necessary to limit the maximum velocity in the sewer pipe. This limiting or non- scouring velocity will mainly depend upon the material of the sewer.

Self clearing velocity

- To calculate minimum velocity of flow following formula is used.

$$V = \sqrt{(8k/f)\ (es - e)/e\ g.ds}$$

where,

V= minimum velocity of flow in m/s.

k= size of solids in sewage varying between 0.06mm

f= Darcy's coefficient of friction (normally 0.03)

es= specific gravity of solid material flowing in sewage, varies between 1.2 to 2.65

e= specific gravity of liquid in sewage (generally 1)

g= gravitational acceleration cont.

ds= dia of solid particles in mm

Effects of Flow Variation on Velocity in a Sewer

- Due to variation in discharge, the depth of flow varies, and hence the hydraulic mean depth (r) varies.
- Due to the change in the hydraulic mean depth, the flow velocity gets affected from time to time.
- It is necessary to check the sewer for maintaining a minimum velocity of about 0.45 m/s at the time of minimum flow (assumed to be 1/3rd of average flow).
- The designer should also ensure that a velocity of 0.9 m/s is developed at least at the time of maximum flow and preferably during the average flow periods also.
- Moreover, care should be taken to see that at the time of maximum flow, the velocity generated does not exceed the scouring value.

(1) **Circular section running full :**

Here Area of C/S, $A = \frac{\pi}{4}(D^2)$, D = dia of sewer

Wetted Perimeter $P = \pi D$

$$\therefore R = \frac{A}{P} = \frac{\frac{\pi}{4}(D^2)}{\pi D} = \frac{D}{4}$$

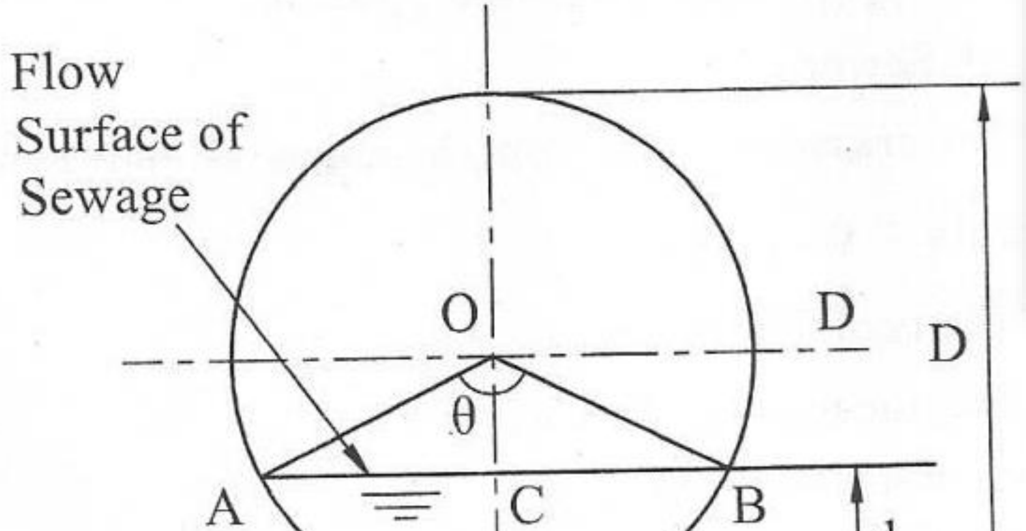
(2) **Circular section running partially full (Refer fig**

Let a = area of cross - section

b = wetted perimeter

r = H.M.D. (Hydraulic Mean Depth)

v = velocity of flow



(1) **Depth** $d = \frac{D}{2} - \frac{D}{2}\cos\frac{\theta}{2} = \frac{D}{2}(1 - \cos\theta/2)$

Proportional depth $\frac{d}{D} = \frac{1}{2}(1 - \cos\theta/2)$

(2) **Area** $a = \frac{\pi}{4}D^2 \times \frac{\theta}{360^\circ} - \frac{D}{2}\cos\frac{\theta}{2} \cdot \frac{D}{2}\sin\frac{\theta}{2}$

$$a = \frac{\pi}{4}D^2\left[\frac{\theta}{360^\circ} - \frac{\sin\theta}{2\pi}\right]$$

$\therefore$ Proportional Area $= \frac{a}{A}\left[\frac{\theta}{360^\circ} - \frac{\sin\theta}{2\pi}\right]$

(3) **Wetted perimeter :**

$$p = \pi D \cdot \frac{\theta}{360^\circ}$$

$\therefore$ Proportional wetted perimeter :

$$\frac{p}{P} = \frac{\theta}{360^\circ}$$

(4) H.M.D. :

$$r = \frac{a}{p} = \frac{\frac{\pi D^2}{4}\left[\frac{\theta}{360^\circ} - \frac{\sin\theta}{2\pi}\right]}{\pi D \frac{\theta}{360^\circ}}$$

$$\therefore \quad r = \frac{D}{4}\left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]$$

$$\text{Proportionate HMD} = \frac{r}{R} = \frac{\frac{D}{4}\left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]}{\frac{D}{4}}$$

$$= \left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]$$

(5) Velocity of flow :

$$v = \frac{1}{n} r^{2/3} S^{1/2} \text{ (Manning's)}$$

where =Manning's rougosity coefficient applicable for partial fl

$$\therefore \text{ Proportional velocity, } \frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}$$

$$\text{If } \frac{N}{n} = 1, \frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = \left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]$$

(6) Discharge :

$$q = a \times v \text{ Taking } \frac{N}{n} = 1.0, \text{ we get}$$

$$\text{Proportional discharge} = \frac{q}{Q} = \frac{a.v}{AV} = \frac{a}{A} \times \left(\frac{r}{R}\right)^{2/3}$$

$$\therefore \frac{q}{Q} = \left[\frac{\theta}{360^\circ} - \frac{\sin\theta}{2\pi}\right]\left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]$$

$$= \frac{\theta}{360^\circ}\left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]^{-5/3}$$

$$\text{For variable value of } \frac{N}{n}, \text{ we get}$$

$$\frac{q}{Q} = \frac{N}{n}\left(\frac{a}{A}\right)\left(\frac{r}{R}\right)^{2/3}$$

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

$$\tau = T$$

Therefore, $\gamma_w \cdot r \cdot s_s = \gamma_w \cdot R \cdot S$ (13)

Hence, $s_s = (R/r)\, S$

Or $$\frac{s_s}{S} = \frac{R}{r}$$ (14)

Therefore,

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{2/3}\left(\frac{s_s}{S}\right)^{1/2}$$ (15)

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

$$\frac{v_s}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$$ (16)

And

$$\frac{q_s}{Q} = \frac{N}{n}\frac{a}{A}\left(\frac{r}{R}\right)^{1/6}$$ (17)

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 = π/4 $(0.3)^2$ x 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 x $(0.684)^{1/6}$ x 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 x (0.258) x (0.939) x (0.064)

= 0.015 m^3/s

Example: 3

A combined sewer was designed to serve an area of 60 sq. km with an average population density of 185 persons/hectare. The average rate of sewage flow is 350 L/Capita/day. The maximum flow is 50% in excess of the average sewage flow. The rainfall equivalent of 12 mm in 24 h can be considered for design, all of which is contributing to surface runoff. What will be the discharge in the sewer? Find the diameter of the sewer if running full at maximum discharge.

Solution:

Total population of the area = population density x area

$= 185 \times 60 \times 10^2$

$= 1110 \times 10^3$ persons

Average sewage flow $= 350 \times 11.1 \times 10^5$ Liters/day

$= 388.5 \times 10^6$ L/day

$= 4.5\ m^3/sec$

Storm water flow $= 60 \times 10^6 \times (12/1000) \times [1/(24 \times 60 \times 60)]$

$= 8.33\ m^3/sec$

Maximum sewage flow $= 1.5 \times$ average sewage flow

$= 1.5 \times 4.5 = 6.75\ m^3/sec$

Total flow of the combined sewer = sewage flow + storm flow

$= 6.75 + 8.33 = 15.08\ m^3/sec$

Hence, the capacity of the sewer = $15.08\ m^3/sec$

Hence, diameter of the sewer required at the velocity of 0.9 m/s can be calculated as

$$\pi/4\ (D)^2 \times 0.90 = 15.08\ m^3/s$$

Hence, D = 4.62 m

Find the minimum velocity and gradient required to transport coarse sand through a sewer of 40 cm diameter with sand particles of 1.0 mm diameter and specific gravity 2.65, and organic matter of 5 mm average size with specific gravity 1.2. The friction factor for the sewer material may be assumed 0.03 and roughness coefficient of 0.012. Consider k = 0.04 for inorganic solids and 0.06 for organic solids.

Solution

Minimum velocity i.e. self cleansing velocity

$$Vs = \sqrt{\frac{8k}{f'}(Ss - 1)gd'}$$

$$Vs = \sqrt{\frac{8x0.04}{0.03}(2.65 - 1)x9.81x0.001}$$

$= 0.4155$ m/sec say 0.42 m/sec

Similarly, for organic solids this velocity will be 0.396 m/sec

Therefore, the minimum velocity in sewer = 0.42 m/sec

Now, Diameter of the sewer D = 0.4 m

Hydraulic Mean Depth = D/4 = 0.4/4 = 0.1 m

Using Manning's formula:

$V = 1/n\, R^{2/3}\, S^{1/2}$

$0.42 = (1/0.012) \times (0.1)^{2/3} \times S^{1/2}$

S = 1/1824.5

Example : 5

Design a sewer running 0.7 times full at maximum discharge for a town provided with the separate system, serving a population 80,000 persons. The water supplied from the water works to the town is at a rate of 190 LPCD. The manning's n = 0.013 for the pipe material and permissible slope is 1 in 600. Variation of n with depth may be neglected. Check for minimum and maximum velocity assuming minimum flow 1/3 of average flow and maximum flow as 3 times the average. (for d/D = 0.7, q/Q = 0.838, v/V = 1.12)

Solution

Average water supplied = 80000 x 190 x (1/24 x 60 x 60 x 1000) = 0.176 m^3/sec

Sewage production per day, (considering 80% of water supply) = 0.176 x 0.8 = 0.14 m^3/sec

Maximum sewage discharge = 3 x 0.14 = 0.42 m^3/sec

Now for d/D = 0.7, q/Q = 0.838, v/V = 1.12

Therefore, Q = 0.42/0.838 = 0.5 m^3/sec

Now

$$Q = \frac{1}{n}\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

$$Q = \frac{1}{0.013}\frac{\pi D^2}{4}\left(\frac{D}{4}\right)^{2/3}\left(\frac{1}{600}\right)^{1/2}$$

Therefore, D = 0.78 m

V = Q/A = 1.04 m/sec

Now, v/V = 1.12

Therefore v = 1.12 x 1.04 = 1.17 m/sec

This velocity is less than limiting velocity hence, OK

Check for minimum velocity

Now q_{min} = 0.14/3 = 0.047 m^3/sec

q_{min}/Q = 0.047/0.5 = 0.09

From proportional chart, for q/Q = 0.09, d/D = 0.23 and v/V = 0.65

Therefore, the velocity at minimum flow = 0.65 x 1.04 = 0.68 m/sec

This velocity is greater than self cleansing velocity, hence OK

d_{min} = 0.23 x 0.78 = 0.18 m

Questions

1. A 900 m long storm sewer collects water from a catchment area of 40 hectares, where 35% area is covered by roof (C=0.9), 20% area by pavements (C=0.8) and 45% area is covered by open plots (C=0.15). Determine the average intensity of rainfall and diameter of storm water drain. Assume the time of entry = 3 min; velocity at full flow = 1.45 m/sec; gradient of sewer = 0.001, and roughness coefficient = 0.013. The intensity of rainfall, cm/h = 75/(t + 5).
2. Explain the importance of considering minimum and maximum velocity while designing the sewers.
3. Explain 'Self-cleansing velocity'.
4. Explain important consideration while finalizing alignment and bed line of storm water drain.
5. Find the gradient required in sewer of 0.5 m diameter to maintain self cleansing velocity at flow full condition.
6. Write short notes on laying of sewer pipes. What hydraulic tests are conducted on the sewers?
7. Prepare notes on sewer maintenance.

Answers

Q. 1: Overall runoff coefficient = 0.5425; Average intensity of rainfall = 4.09 cm/h; Storm water quantity = 2.465 m^3/sec; and diameter of storm water drain = 1.556 m