MUNICIPAL & INDUSTRIAL WASTEWATER ENGINEERING

NUMERICAL PROBLEMS OF MODULE 1 & 2

Module 1 problems

DWF & WWF Calculation

- DWF= % of wastewater X water supply X Population X peak factor

DWF = [0.8 X w/s (lpcd) X popln X 3/(24X60X60)] m^3/s

WWF= AIR/360 m^3/s

A= Area in Hectare (ha)

I= Coefficient of rainfall/ impermeability factor

R= Rainfall intensity in mm/hr

Combined System= DWF+ WWF

Separate system= DWF & WWF

Partially combined System= DWF + portion of WWF

...This formula states that

$$Q_p = \left(\frac{1}{36}\right) K \cdot p_c \cdot A \qquad ...(3.1)$$

where Q_p = Peak rate of runoff in cumecs.

K = Coefficient of runoff.

A = The catchment area contributing to runoff at the considered point, in hectares.

p_c = Critical rainfall intensity of the design frequency *i.e.* the rainfall intensity during the critical rainfall duration equal to the time of concentration, in cm/hr.

Example 3.4. *A population of 30,000 is residing in a town having an area of 60 hectares. If the average coefficient of runoff for this area is 0.60, and the time of concentration of the design rain is 30 minutes, calculate the discharge for which the sewers of a proposed combined system will be designed for the town in question. Make suitable assumptions where needed.*

Solution. Let us first assume that the town is provided with a planned water supply from the water-works at an average per capita rate equal to 120 litres/day/person*. Also assume that 80% of this water supply will be reaching the sewers as sanitary sewage.

∴ Quantity of sanitary sewage produced per day

$$= \left(\frac{80}{100}\right) 120 \times 30{,}000 \text{ litres}$$

$$= 0.8 \times 120 \times 30 \text{ cu. m} = 2880 \text{ cu. m}$$

Quantity of sanitary sewage produced per second

$$= \frac{2880}{24 \times 60 \times 60} \text{ cumecs} = 0.033 \text{ cumecs}$$

∴ Average sewage discharge = 0.033 cumecs.

Assuming the maximum sewage discharge to be three times the average, we have

Max. sewage discharge

$$= 3 \times 0.033 = \mathbf{0.1\ cumecs.}$$

The storm water discharge can be computed by using Rational formula ; *i.e.*

$$Q_p = \frac{1}{36} K \cdot p_c \cdot A$$

Using $$p_c = \frac{100}{T + 20} \qquad (\textit{i.e.}\ \text{Eq. 3.8})$$

We have $$p_c = \frac{100}{30 + 20} = 2 \text{ cm/hr.}$$

$$\therefore \quad Q_p = \frac{1}{36} \times 0.60 \times 2 \times 60 \text{ cumecs} = \mathbf{2\ cumecs.}$$

Hence, the total peak discharge for which the sewers of the combined system should be designed

= Max. sewage discharge + Max. storm runoff

= 0.1 + 2.0 = **2.1 cumecs.** **Ans.**

Example 3.3. *The drainage area of one sector of a town is 12 hectares. The classification of the surface of this area is as follows :*

Percent of total surface area	*Type of surface*	*Coefficient of runoff*
20%	Hard pavement	0.85
20%	Roof surface	0.80
15%	Unpaved street	0.20
30%	Garden and Lawn	0.20
15%	Wooded area	0.15

If the time of concentration for the area is 30 minutes, find the maximum runoff.

Use the formula

$$R = \frac{900}{t + 60}.$$

Solution. If A represents the total area, then we have

$$K_1 A_1 = 0.85 \times 0.20\, A = 0.17\, A$$

$$K_2A_2 = 0.80 \times 0.20\,A = 0.16\,A$$
$$K_3A_3 = 0.20 \times 0.15\,A = 0.03\,A$$
$$K_4A_4 = 0.20 \times 0.30\,A = 0.06\,A$$
$$K_5A_5 = 0.15 \times 0.15\,A = 0.0225\,A$$
$$\Sigma = 0.4425\,A$$

$$K = \frac{\Sigma KA}{A} = \frac{0.4425\,A}{A}$$

or $$K = 0.4425$$

Now, in the formula of the type

$$R = \frac{900}{t + 60}$$

R is the rainfall intensity, gene
concentration time in minutes.

$\therefore$ R = rainfall intensity in mm/hr

$$= \frac{900}{30 + 60} = 10 \text{ mm/hr.} = 1 \text{ cm/hr.}$$

$\therefore$ P_c to be used in our Rational formula (Eq. 3.1)

$$= 1 \text{ cm/hr.}$$

Using Rational formula, we have

$$Q_p = \frac{1}{36} K.p_c.A$$
$$= \frac{1}{36} \times 0.4425 \times 1 \times 12 \text{ cumecs.}$$
$$= 0.1475 \text{ cumecs ; say } 0.148 \text{ cumecs.}$$

$\therefore$ Maximum rate of runoff expected from the area

= 0.148 cumecs. **Ans.**

Example 3.1. *Assuming that the surface on which the rain falls in a district is classified as follows :*

20% of the area consists of roof for which the runoff ratio is 0.9, 20% of the area consists of pavements for which the runoff ratio is 0.85, 5% of the area consists of paved yards of houses for which run off ratio is 0.80, 15% of area consists of macadam roads for which run off ratio is 0.40, 35% of the area consists of lawns, gardens and vegetable plants for which the runoff ratio is 0.10, and the remaining 5% of the area is wooded for which the runoff ratio is 0.05 ; determine the coefficient of runoff for the area.

If the total area of the district is 36 hectares and the maximum rain intensity is taken as 5 cm/hr ; what is the total runoff for the district ?

$$K = \frac{K_1A_1 + K_2A_2 + K_3A_3 + ... + K_nA_n}{A_1 + A_2 + A_3 + ... + A_n}$$

$$= \frac{\Sigma KA}{\Sigma A} = \frac{\Sigma KA}{A}$$

example, we have

$$K_1A_1 = \frac{20}{100} A(0.90) = 0.18\,A$$

$$K_2A_2 = \frac{20}{100} A(0.85) = 0.17\,A$$

$$K_3A_3 = \frac{5}{100} A(0.80) = 0.04\,A$$

$$K_4A_4 = \frac{15}{100} A(0.4) = 0.06\,A$$

$$K_5A_5 = \frac{35}{100} A(0.1) = 0.035\,A$$

$$K_6A_6 = \frac{5}{100} A(0.05) = 0.0025\,A.$$

$$\therefore \quad K = \frac{K_1A_1 + K_2A_2 + K_3A_3 + K_4A_4 + K_5A_5 + K_6A_6}{A}$$

$$= \frac{0.18A + 0.17A + 0.04A + 0.06A + 0.035A + 0.0025A}{A}$$

$$= 0.4875.$$

Hence, the runoff factor for the entire area

$= 0.4875.$ **Ans.**

The peak discharge from the area may be computed by using the rational formula given by Eq. (3.1) as

$$Q_p = \frac{1}{36} \cdot K.p_c.A$$

Here, we have

$K = 0.4875$

p_c = Critical rain intensity = 5.0 cm/hr (given)

A = 36 hectares

$$\therefore \quad Q_p = \frac{1}{36} (0.4875)(5.0)(36.0) = 2.4375 \text{ cumecs.}$$

Say 2.44 cumecs. **Ans.**

Example 3.2. *If in the above example, the density of population is 250 per hectare, and the quota of water supply per day is 225 litres ; calculate the quantity of*

(a) Sewage for which the sewers of a separate system, should be designed.

(b) Storm water for which the sewers of a partially separate system should be designed.

Solution. Area of district

$$= 36 \text{ hectares.}$$

Population density = 250 persons per hectare

$\therefore$ Population = 36 × 250 = 9000.

Average water supply per day

= 225 litres/person

$\therefore$ Average quantity of water supplied to the district per day

= 225 × 9000 litres = 20,25,000 litres = 2,025 cu. m.

$\therefore$ Rate of water supplied

$$= \frac{2025}{24 \times 60 \times 60} \text{ cumecs} = 0.0234 \text{ cumecs.}$$

Assuming the sewage discharge as 0.8 times the water supplied, we have

Average rate of sewage produced

$$= 0.8 \times 0.0234 = 0.0187 \text{ cumecs.}$$

Now assuming the peak rate of sewage as three times the average,we have

The peak rate of sewage flow

$$= 3 \times 0.0187 = 0.056 \text{ cumecs.} \quad \textbf{Ans.}$$

Case. (*b*) In case of partially separate system, the storm water from roofs and paved yards of houses will be allowed to enter the sewers. Now, from the previous example, we have

Area of roofs $= \frac{20}{100} \times 36$ hectares $= 7.2$ hectares.

Coefficient of runoff for roofs = 0.90

Area of pavements $= \frac{5}{100} \times 36 = 1.8$ hectares

Coefficient of runoff for pavements = 0.80.

∴ The discharge from roofs and pavements, as given by rational formula, using $p_c = 5$ cm/hr. is

$$= \left[\frac{1}{36} \times 0.90 \times 5.0 \times 7.2 + \frac{1}{36} \times 0.80 \times 5.0 \times 1.8\right] \text{ cumecs}$$

$$= 1.1 \text{ cumecs.}$$

Hence, the storm water which must pass through the sewers of a partially separate system = 1.1 cumecs. **Ans.**

Note. This is about 20 times the peak rate of sewage produced (*i.e.* 0.056 cumecs). Moreover, strictly speaking, the sewers of the partially separate system should be designed for carrying this storm water plus the sewage, *i.e.* for a discharge = 1.1. + 0.056 = 1.156 cumecs.

Module 2 problems

Full flow & partial flow designs

DESIGN OF SEWERS

FULL FLOW PROBLEMS

Example 4.7. *Calculate the velocity and discharge through a rectangular concrete lined smooth channel 2.4 m wide and 1.2 m deep built to a slope of 1 in 200, when running completely full. Use Bazin's coefficient in Chezy's formula as :*

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{r}}}$$

where K = 0.3 for smooth concrete lined surface.

(Engg. Services, 1968)

Solution. Area of channel

$$= A = 2.4 \text{ m} \times 1.2 \text{ m} = 2.88 \text{ sq. m.}$$

Wetted perimeter $= P = 2.4 + 1.2 + 1.2 + 2.4^{*} = 7.2$ m

$$\therefore \quad R = \frac{A}{P} = \frac{2.88}{7.2} = 0.40 \text{ m.}$$

Now, $C = \dfrac{157.6}{1.81 + \dfrac{0.3}{\sqrt{0.40}}} = \dfrac{157.6}{1.81 + 0.474} = \dfrac{157.6}{2.284} = 68.99$

Using, Chezy's formula, we have

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

$$= 68.99 \sqrt{0.40 \times \frac{1}{200}} = 68.99 \times 0.0447 = 3.08 \text{ m/sec.} \quad \textbf{Ans.}$$

Discharge $Q = A.V$

$$= 3.08 \times 2.88$$

$$= 8.88 \text{ cumecs.} \quad \textbf{Ans.}$$

Example 4.8. *Calculate the diameter and discharge of a circular sewer laid at a slope of 1 in 400 when it is running half full, and with a velocity of 1.9 m / sec. (n in Manning's formula = 0.012).*

(Engg. Services, 1969)

Solution. When pipe is running half full,

The area of section

$$a = \frac{\pi D^2}{8}$$

The wetted perimeter

$$p = \frac{\pi D}{2}$$

The H.M.D. $r = \frac{D}{4}$.

Using Manning's formula, we have

$$V = \frac{1}{n} \cdot r^{2/3} \cdot \sqrt{S}$$

$$\therefore \qquad 1.9 = \frac{1}{0.012}\left(\frac{D}{4}\right)^{2/3} \cdot \frac{1}{\sqrt{400}}$$

or $$D^{2/3} = 1.9 \times 0.012 \times 2.52 \times 20 = 1.15$$

or $$D = (1.15)^{\frac{3}{2} = 1.5} = 1.23 \text{ m.}$$

Hence, use 1.23 m dia sewer. **Ans.**

Discharge $Q = a.v$

$$= \frac{\pi(1.23)^2}{8} \times 1.9 \text{ m}^3/\text{sec}, = 1.13 \text{ cumecs.}$$ **Ans.**

Example 4.9. *Design a sewer to serve a population of 36,000 ; the daily per capita water supply allowance being 135 litres, of which 80 per cent finds its way into the sewer. The slope available for the sewer to be laid is 1 in 625 and the sewer should be designed to carry four times the dry weather flow when running full. What would be the velocity of flow in the sewer when running full ?*

Assume n = 0.012 in Manning's formula. *(Engg. Services, 1970)*

Solution. Population

= 36,000

Per capita water supply

= 135 litres/person/day

∴ Average water supplied daily

= 36,000 × 135 litres/day

Average water supplied in cumecs

$$= \frac{36{,}000 \times 135}{1000 \times 24 \times 60 \times 60} \text{ cumecs}$$

= 0.0562 cumecs.

Average sewage discharge

= 80% of water supplied

= 0.8 × 0.0562 cumecs = 0.045 cumecs.

∴ D.W.F. = 0.045 cumecs.

Maximum discharge for which sewer should be designed running full

= 4 × 0.045 cumec = 0.18 cumecs.

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

(Capital letters being used for running full)

$$\therefore \qquad 0.18 = \frac{1}{0.012}\left(\frac{\pi}{4}D^2\right)\left(\frac{D}{4}\right)^{2/3}\frac{1}{\sqrt{625}}$$

or $$\frac{0.18 \times 0.012 \times 4 \times 2.52 \times 52}{\pi} = D^{8/3}$$

or $$D^{8/3} = 0.173$$

or $$D = (0.173)^{\frac{3}{8} = 0.375} = 0.31 \text{ m}$$

Hence, use 0.31 m dia. sewer pipe. **Ans.**

Velocity of flow when running full

$$= V = \frac{Q}{A} = \frac{0.18}{\frac{\pi}{4}(0.31)^2} = 2.39 \text{ m/sec.}$$ **Ans.**

0.000...

Example 4.14. *A 25 cm diameter sewer with an invert slope of 1 in 400 is running full. Calculate the velocity and rate of flow in the sewer. Is it self cleansing ? Take n = 0.015.* *(Civil Services, 1993)*

Solution. D = dia of sewer = 25 cm = 0.25 m

Area of sewer when running full

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

$$= \frac{\pi}{4} \times (0.25)^2 \text{ m}^2 = 0.049 \text{ m}^2.$$

$$R = \frac{A}{P} = \frac{\frac{\pi}{4} \cdot D^2}{\pi D} = \frac{D}{4} = \frac{0.25}{4} = 0.0625 \text{ m}$$

$$S = \frac{1}{400}$$

$$N = 0.015$$

Using Manning's equation, we have

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

$$= \frac{1}{0.015} \times (0.0625)^{2/3} \cdot \frac{1}{\sqrt{400}} = 0.525 \text{ m/s.} \quad \textbf{Ans.}$$

$$Q = V.A = 0.525 \times 0.049 \text{ m}^3\text{/s} = 0.0257 \text{ m}^3\text{/s.} \quad \textbf{Ans.}$$

... which is slightly more than

Example 4.5. *Determine the size of a circular sewer for a discharge of 600 lp running half-full. Assume i = 0.0001 and n = 0.015.*

Solution. $d = 0.5\ D$

$$\frac{d}{D} = 0.5$$

$$q = 600 \text{ litres/sec.}$$
$$= 0.6 \text{ cumecs}$$
$$S = i = 0.0001$$
$$n = 0.015$$

From table 4.8, at $\frac{d}{D} = 0.5$

we have $\frac{q}{Q} = 0.5$

$$\therefore \quad Q = \frac{q}{0.5} = \frac{0.6}{0.5} = 1.2 \text{ cumecs.}$$

0.5 0.5

Assuming n not to vary with depth, we have by using Manning's formula,

$$Q = \frac{1}{N} . AR^{2/3} . \sqrt{S}$$

or $$1.2 = \frac{1}{0.015}\left(\frac{\pi}{4} . D^2\right)\left(\frac{D}{4}\right)^{2/3} . \sqrt{0.0001}$$

or $$\frac{1.2 \times 0.015 \times 4 \times 2.52 \times 100}{\pi} = D^{8/3}$$

or $$D^{8/3} = 5.78$$

or $$D = (5.78)^{3/8} = (5.78)^{0.375} = 1.93 \text{ m}$$

Hence, the diameter of the sewer required

$= 1.93$ m. **Ans.**

Example 4.4. *(a) A main combined sewer was designed to serve an area of 60 sq. km with an average population of 185 persons/hectare. The average rate of sewage flow is 350 litres/capita/day. The maximum flow is 50% in excess of the average together with the rainfall equivalent of 12 mm in 24 hours, all of which are run off. What should be the capacity of the sewer in cu. m/sec. ?*

(b) Find the minimum velocity and gradient required to transport coarse sand through a sewer of 40 cm dia with sand particles of 1 mm dia and specific gravity 2.65. Assume k for sand = 0.04. The Manning's roughness coefficient(n) for the sewer material may be assumed as 0.012.

Solution. Total population of the area

$= \text{Population density} \times \text{area}$

$= 185 \text{ p/ha} \times (60 \times 10^2) \text{ ha}$

$= 1110 \times 10^3$ persons

$= 11.1 \times 10^5$ persons

Average sewage flow = 350 litres/capita/day

$= 350 \times 11.1 \times 10^5$ litres/day

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

$$= \frac{388.5 \times 10^6}{10^3} \times \frac{1}{24 \times 60 \times 60} \text{ cu.m/sec}$$

$= 4.5$ cumecs.

$$\text{Storm water flow} = 60 \times 10^6 \times \left(\frac{12}{1000}\right) \frac{1}{24 \times 60 \times 60} \text{ cumecs.}$$

$$\left[i.e. \frac{\text{area in m}^2 \times \text{depth of S.R.O. in m}}{\text{Time of 24 hr. in sec.}} \right]$$

$= 8.33$ cumecs.

Maximum sewage flow

= 1.5 × average sewage flow

= 1.5 × 4.5 cumecs = 6.75 cumecs.

∴ Total maximum flow of the combined sewer

= Max. sewage flow + storm fl

= 6.75 + 8.33 = 15.08 cumecs.

Hence, the capacity of the sewer

= 15.08 cumec. **Ans.**

$$V_s = \frac{1}{n} \cdot r^{\frac{1}{6}} \sqrt{kd'(G-1)}$$

where, $n = 0.012$, $k = 0.04$, $G = 2.65$

d' = dia of grain = 1 mm

$$r = R = \frac{D}{4} = \frac{0.4 \text{ m}}{4} = 0.1 \text{ m}$$

$$V_s = \frac{1}{0.012} \times (0.1)^{1/6} \sqrt{0.04 \times \frac{1}{10 \times 100} \times (2.65 - 1)}$$

$= 56.77 \times (8.12 \times 10^{-3})$ m/s = 0.46 m/s

velocity required for the sewer to be self cleansing

= 0.46 m/sec. **Ans.**

Example 4.12. *A combined sewer of a circular section is to be laid to serve a particular area. Calculate the size of this sewer from the following data :*

Area to be served	= *120 hectares*
Population	= *1,00,000*
Maximum permissible flow velocity	= *3 m/sec.*
Time of entry for storm water	= *10 minutes*
Time of flow in channel	= *20 minutes*
Per capita water supply	= *250 litres/day/person*
Coefficient of run-off for the area	= *0.45*
Hourly, Maximum rainfall for the area at the design frequency	= *5 cm*

Assume any other data not given, and if needed.

Solution. *Sewage Discharge* (*i.e.* **D.W.F.**) *Computations*

Average water supplied

$$= 250 \times 1{,}00{,}000 \text{ litres/day}$$

$$= \frac{250 \times 1{,}00{,}000}{1000 \times 24 \times 60 \times 60} \text{ cumecs} = 0.289 \text{ cumecs}$$

Assuming that 80% of the water supplied appears as sewage, we have

Average sewage discharge

$$= 0.8 \times 0.289 = 0.23 \text{ cumecs}$$

$= 0.8 \times 0.289 = 0.23$ cumecs

Assuming the maximum sewage discharge to be 3 times the average discharge, we have

Maximum sewage discharge

$$= 3 \times 0.23 = 0.69 \text{ cumecs.}$$

Storm water discharge computations

Time of concentration

$$T_c = \text{Time of entry} + \text{Time of flow}$$

$$= (10 + 20) \text{ minutes} = 30 \text{ minutes.}$$

Now, maximum hourly rainfall for the area

$$= p_o = 5 \text{ cm/hr.}$$

$$p_c = p_o\left(\frac{2}{1+T_c}\right)$$

where T_c is the concentration time in hours

$$= \frac{30}{60} = 0.5 \text{ hour}$$

$$p_c = 5\left(\frac{2}{1+0.5}\right) = \frac{10}{1.5} = 6.67 \text{ cm/hr.}$$

Max. storm run off $= Q_p = \frac{1}{36} K.p_c.A$

$$= \frac{1}{36} \times 0.45 \times 6.67 \times 120 \text{ cumecs.}$$

$$= 10 \text{ cumecs.}$$

$\therefore$ The combined maximum discharge

$$= \text{Storm run-off} + \text{Sewage discharge}$$

$$= 10 + 0.69 = 10.69 \text{ cumecs.}$$

Now assuming the sewer to be running full at the maximum velocity of m/sec at the time of maximum flow, we have

$$\text{Area required} = \frac{Q}{V} = \frac{10.69}{3} \text{ m}^2 = 3.56 \text{ m}^2$$

$\therefore$ Dia of sewer pipe required

$$= \sqrt{\frac{4}{\pi} \cdot 3.56} = \sqrt{4.53} = 2.13 \text{ m.}$$

Hence, use a sewer pipe of 2.13 m dia. **Ans.**

DESIGN OF SEWERS

PARTIAL FLOW PROBLEMS

Example 4.1. *A 300 mm dia 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 0.90 m/sec. Find the required grade and associated velocity and rate of discharge at this depth. Assume Manning's rugosity coefficient n as 0.013. The variations of n with depth may be neglected.*

Solution. From Manning's formula, we have

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

At full depth, using capital letters, we have

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

Using $V = 0.90$ m/sec.

$N = 0.013$

$$R = \frac{D}{4} = \frac{300}{4} = 75 \text{ mm} = 0.075 \text{ m}$$

We have $0.90 = \frac{1}{0.013}(0.075)^{2/3}\sqrt{S}$

or $$\sqrt{S} = \frac{0.90 \times 0.013}{0.178} = 0.0657$$

or $$S = 0.0043 \quad (i.e.\ 4.3‰)^*$$

and $$Q = A.V.$$

$$= \frac{\pi}{4}(0.3)^2\ 0.90 \text{ cumecs} = \mathbf{0.064} \textbf{ cumecs}$$

Now, at a depth (d) equal to 0.3 times the full depth (D), we have

$$\frac{d}{D} = 0.3,$$

Using Table 4.8, we have for

$$\frac{d}{D} = 0.3$$ *(Variations of n to be neglected, as given)*

$$\frac{a}{A} = 0.252$$

$$\frac{r}{R} = 0.684$$

Now for the sewer to be the same self-cleansing at 0.3 depth (d), as it will be at full depth, we have the gradient (s_s) required from Eq. (4.25), as ;

$$s_s = \left(\frac{R}{r}\right) S$$

$$\therefore \qquad s_s = \frac{1}{0.684} S = \frac{1}{0.684} \times 0.0043$$

$$= 0.0063 \quad (i.e.\ 6.3‰). \quad \textbf{Ans.}$$

Now, the velocity v_s generated at this gradient is given by Eq. (4.26), as

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

$$= 1 \times (0.684)^{1/6} \times 0.9 \text{ m/sec} = 0.939 \times 0.9$$

$$= 0.846 \text{ m/sec.} \quad \textbf{Ans.}$$

The discharge q_s is given by Eq. (4.27) as

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

$$\therefore \qquad q_s = (1)(0.252)(0.684)^{1/6}(0.064) \text{ cumecs}$$

$$= 0.015 \text{ cumecs.} \quad \textbf{Ans.}$$

Example 4.2. *A 225 mm dia sewer is to discharge 0.005 cumecs at a velocity as self-cleansing as a sewer flowing full at 0.80 m/sec. Find the depth, velocity generated, and the required gradient. Use Manning's rugosity coefficient as 0.013. Also assume that the rugosity coefficient varies with depth. Standard chart of Fig. 4.4 can be used to compute the values of proportionate elements of self cleaning equivalent of full flow.*

0.8 m/sec, we have

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

$$\therefore \quad 0.8 = \frac{1}{0.013} \cdot \left(\frac{0.225}{4}\right)^{2/3} \sqrt{S}$$

$$\text{or} \quad \sqrt{S} = \frac{0.8 \times 0.013}{0.146} = 0.0712$$

$$\therefore \quad S = 0.0051 \quad (\textit{i.e. } 5.1‰).$$

Now $\quad Q = A.V.$

$$= \frac{\pi}{4} \cdot (0.225)^2 \times 0.8 \text{ cumecs.}$$

$$= 0.0397 \times 0.8$$

$$= 0.032 \text{ cumecs}$$

But $\quad q_s = 0.005$ cumecs (given)

$$\therefore \quad \frac{q_s}{Q} = \frac{0.005}{0.032} = 0.156.$$

Now, from Fig. 4.4 for $\frac{N}{n}$ variable and $\frac{q_s}{Q} = 0.156$, we have

$$\frac{d_s}{D} = 0.26$$

$$\frac{v_s}{V} = 0.72$$

and $$\frac{s_s}{S} = 1.7.$$

Hence, d_s = depth at equivalent self-cleansing
= 0.26 times full depth
= 0.26 × 0.225 m. = 0.058 m = 58 mm. **Ans.**

v_s = velocity at equivalent self-cleansing
= 0.72 V = 0.72 × 0.8 m/sec.
= 0.58 m/sec. **Ans.**

and v_s = slope at equivalent self-cleansing
= 1.7 × 5.1‰ = 8.6‰. **Ans.**

Example 4.3. *A 350 mm dia sewer is to flow at 0.35 depth on a grade ensuring a degree of self-cleansing equivalent to that obtained at full depth at a velocity of 0.8 m / sec. Find :*

(i) the required grade

(ii) associated velocity

(iii) the rate of discharge at this depth.

Given :

(i) Manning's rugosity coefficient = 0.014

(ii) Proportionate area = 0.315

(iii) Proportionate wetted perimeter = 0.472

(iv) Proportionate HMD (r / R) = 0.7705.

Solution. At full depth, $V = 0.8$ m/sec, $D = 350$ mm $= 0.35$ m, $N = 0.014$.

At 0.35 depth, $\frac{d}{D} = 0.35$, $\frac{a}{A} = 0.315$, $\frac{p}{P} = 0.472$, $\frac{r}{R} = 0.7705$.

$\therefore$ *At full depth*

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

$$0.8 = \frac{1}{0.014} \cdot \left(\frac{0.35}{4}\right)^{2/3} \cdot \sqrt{S}$$

$$\sqrt{S} = 0.0568.$$

$$S = 3.234 \times 10^{-3}$$

Now, for a sewer to be the same self-cleansing at 0.35 depth as it will be at full depth, we have the gradient (s_s) required from equation (4.25) as

$$s_s = \left(\frac{R}{r}\right) S$$

$$= \frac{1}{0.7705} \times 3.234 \times 10^{-3} \qquad \left[\because \frac{r}{R} = 0.7705 \text{ given}\right]$$

$$= 4.2 \times 10^{-3}$$

i.e. $= 4.2‰$.

(*i*) Hence, the reqd. grade = **4.2‰. Ans.**

(*ii*) The velocity generated at this gradient at 0.35 depth, is given by equation (4.26), as

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

$$= 1 \times (0.7705)^{1/6} . 0.8 = \mathbf{0.765 \text{ m/sec.}} \quad \textbf{Ans.}$$

(*iii*) The discharge q_s, is then given by

$$q_s = a.v_s$$

$$= 0.315 . \frac{\pi}{4} \times (0.35)^2 \times 0.765$$

$$= \mathbf{0.023 \text{ cumecs.}} \quad \textbf{Ans.}$$

... lined sewer was designed to serve an area

The velocity in sewer, however, is calculated by Manning's formula as :

$$v = \frac{1}{n} r^{2/3} . s^{1/2} \qquad (i.e., \quad \text{Eq. } 4.4)$$

Now, assuming the sewer is designed to be running full, we have

$$n = N = 0.012$$

$$r = R = \frac{D}{4} = 0.1 \text{ m}$$

$$\therefore \qquad 0.46 = \frac{1}{0.012} (0.1)^{2/3} . S^{1/2}$$

or

$$S = \frac{1}{1523}$$

Hence, the required gradient for the sewer to be self cleansing is 1 in 1523. **Ans.**

Example 4.6. *Design a sewer running 0.7 times full at maximum discharge for a town provided with the separate system, serving a population of 80,000 persons. The water supplied from the water- works to the town is at a rate of 190 litres/person/day. The sewer is made up of brick work plastered smooth with cement mortar (n = 0.013) and the permissible slope is 1 in 600. The variations of n with depth may be neglected. Assume any other data not given and needed.*

Solution.

Population = 80,000

Rate of water supplied

= 190 litres/person/day

Average rate of daily water supplied to the town

= 80,000 × 190 litres/day

Average water supplied (in cumecs)

$$= \frac{80{,}000 \times 190}{24 \times 60 \times 60 \times 1000} \text{ cumecs} = 0.176 \text{ cumecs}$$

Assuming that 80% of water supplied to the town appears as sewage, we have

The average discharge of sewage produced

$$= 0.176 \times 0.8 \text{ cumecs} = \mathbf{0.14 \text{ cumecs.}}$$

Assuming the maximum flow to be three times the average, we have

The maximum sewage discharge

$$= 3 \times 0.14 = 0.42 \text{ cumecs.}$$

Now since the sewer is to be designed as running 0.7 times the full depth at maximum discharge, we have from Table 4.8, for a value of $\frac{d}{D} = 0.7$,

$$\frac{q}{Q} = 0.838$$

Here $\quad q = 0.42$ cumecs

$\therefore \quad Q = \frac{0.42}{0.838} = 0.5$ cumecs.

Now using Manning's nomogram at full flow and $n = 0.013$ (Fig. 4.5), for known values of

$Q = 0.5$ cumecs (500 litres/sec.)

and $\quad S = \frac{1}{600}$;

we read the other unknown factors, as

$$D = 0.78 \text{ m}$$

and $$V = 1.04 \text{ m/sec.}$$

Then from Table 4.8, for $\frac{d}{D} = 0.7$;

we have $$\frac{v}{V} = 1.12$$

$$\therefore \quad v = 1.12\,V$$

$$= 1.12 \times 1.04 \text{ m/sec.} = 1.17 \text{ m/sec.}$$

Which is more than the self-cleansing velocity, and hence satisfactory.

Check for minimum flow

Assuming the minimum flow in the sewer to be $\frac{1}{3}$ time the average flow, we have, the minimum flow as

$$q_{\min} = \frac{0.14}{3} = 0.047 \text{ cumecs.}$$

From curves of Fig. 4.3, for a discharge ratio of $\frac{q_{\min}}{Q}$ as $= \frac{0.42}{0.047} = 0.11$, and $n = N$ as given, we have

$$\text{Depth ratio} = \frac{d_{\min}}{D} = 0.23$$

and velocity ratio for this depth ratio is given by

$$\text{Velocity ratio} = \frac{v_{\min}}{V} = 0.65$$