Wastewater Collection System

(Math Prob)

Description of flow	Ratio to average
Maximum daily	2.5 to 1
Maximum hourly	3 to 1
Minimum daily	0.67 to 1
Minimum hourly	0.33 to 1

Problem 1. Estimate the maximum **hourly, average daily and minimum hourly residential sewage flows** from an area occupied by 750 people having average per capita sewage flow of 59 gpcd. Consider the length of the sewer and house connections to be 1.3 miles and infiltration to be 30,000 gpd per miles.

Solution

Design Flows:

Qav (san) = 100 % of water use (60 –80% for developed country)

Qav (design) = Qav (san) + Infiltration + Storm Inflow

Qmax (design) = 3 Qav (san) + Infiltration + Storm Inflow

Qmin (design) = 0.33 Qav (san) + Infiltration + Storm Inflow

No of people to be served = 750

Average sanitary sewage flow, Qavg (san) = 750 × 59 = 44250 g/d = 1843.75 g/h

Infiltration = 30000 × 1.3 = 39000 g/d = 1625 g/h

Qav (daily) (design) = Qav (san) + Infiltration = 44250 + 39000 = **83250 g/d**

Qmax (hourly) (design) = 3 Qav (san) + Infiltration = 3× 1843.75 + 1625 = **7156.25 g/h**

Qmin (hourly) (design) = 0.33 Qav (san) + Infiltration = 0.33× 1843.75 + 1625 = **2233.44 g/h**

Problem 2. A drainage area, having rain falls during four months of the year only, has an area of 15 ha, with 30 houses/ha. The area has the following surface characteristics:

(i) The average area of the roof is 80 m^2/house, with runoff coefficient of 0.9.

(ii) The roads occupy 25% of total area. The main roads are tarred and interior ones are of water bound macadam. Impermeability factor for these roads could be taken as 0.6.

(iii) The remaining area is open space whose coefficient of runoff may be taken as 0.12.

If the rainfall records show that the intensity of an ordinary rainstorm is 4.5 cm/h, what will be the discharge from this district? Determine the dry weather flow from the area if the population is 300 persons/ha and the rate of water supply is 250 lpcd. Also find the ratio of storm sewage to dry weather flow and indicate the suitability of separate sewerage scheme in the area in preference to combined sewerage scheme.

Solution

For the area of 1 ha,

Roof area, A1 = 30 × 80 = 2400 m^2

Equivalent roof area, A1 C1 = 2400 × 0.9 = 2160 m^2

Road area, A2 = 0.25 × 1 = 0.25 ha = 2500 m^2

Equivalent road area, A2 C2 = 2500 × 0.6 = 1500 m^2

Open space area, A3 = (10000 – (2400 + 2500) = 5100 m^2

Equivalent open space area, A3 C3 = 5100 × 0.12 = 612 m^2

$$\text{Now, } C = \frac{A_1C_1 + A_2C_2 + A_3C_3}{A_1 + A_2 + A_3}$$

$$C = \frac{2160 + 1500 + 612}{10000} = 0.43$$

Q = FCIA = 27.8 ×0.43 × 4.5 × 15 = 807 l/s

Total population to be served = 300 persons / ha = 300 × 15 = 4500 persons

Average daily sewage contribution = 80% of average water supply = 0.8 × 250 × 4500

= 900000 l/d = 10.42 l/s

Assuming that the sewer is a branch/ lateral sewer, the maximum discharge of dry weather flow,

Q max = 2.5 × 10.42 = 26.05 l/s

Now, ratio of storm sewage to max dry weather flow = 807/26.05 = 31

From this problem, it is clear that if a combined sewer is adopted for the given area, the sewer would carry only **1/ 31 th** of total discharge for about 8 months of a year. Thus, a separate sewerage scheme is most suitable for the area given in this problem. However, the modern trend for well-planned cities is to adopt combined schemes for their overall merits over separate sewerage schemes.

Storm Sewer

Determine the peak discharge for use in the design of a highway crossing a canal. The catchment has the following characteristics:

Mainstream length	L	=	3.0 km
Catch area	A	=	7.5 km^2
Mainstream slope	S	=	5.0 m/km
Catchment type:	medium soil, (C = 0.48)		

A recurrence interval of 5 years is assumed to be suitable for the crossing.

Solution: The time of concentration,

$$t_c = \frac{FL}{A^{0.1}\ S^{0.2}}$$

$$= \frac{58.5 \times 3.0}{(7.5)^{0.1} \times (5.0)^{0.2}} = \frac{58.5 \times 3.0}{1.22 \times 1.38} = 104 \text{ mins or } 1.7 \text{ hrs}$$

The design rainfall intensity for a duration of 104 minutes and recurrence interval of 5 years in an area located close to the crossing is

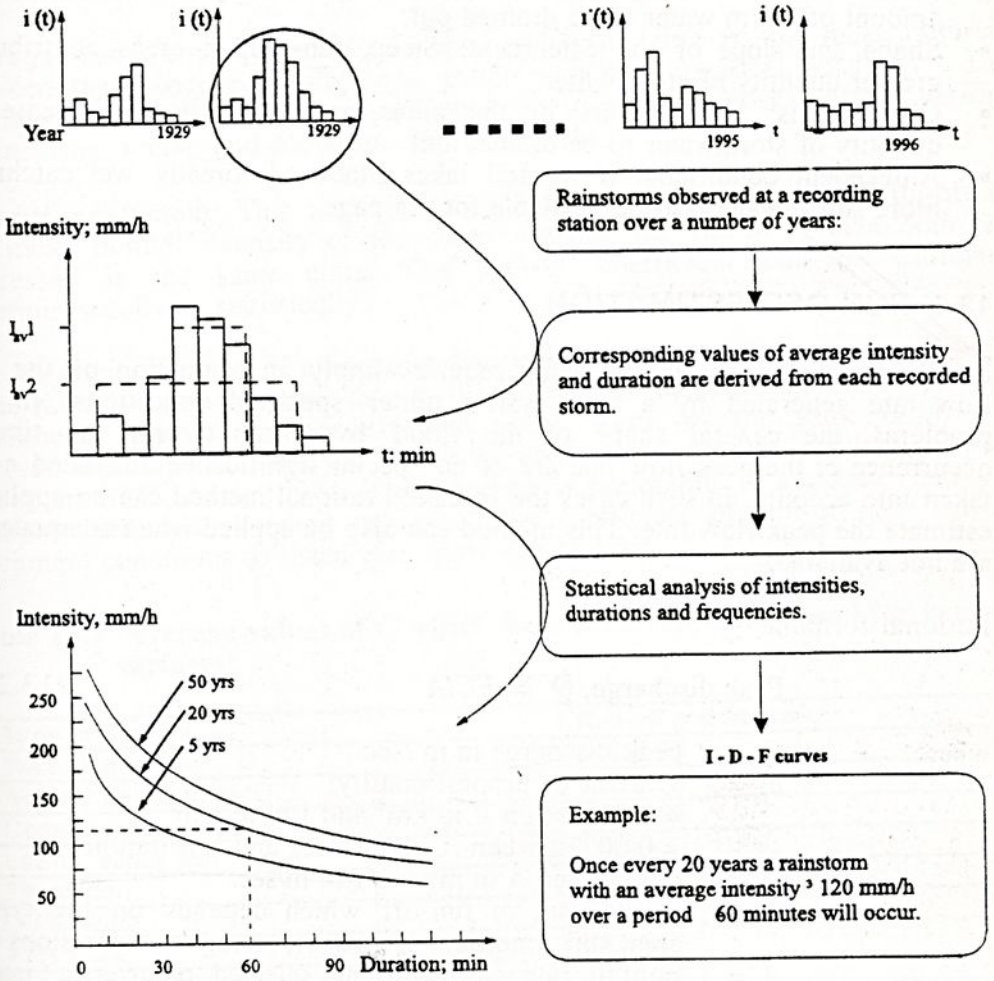
I = 70 mm/hrs [from intensity - duration - frequency curve]

The peak discharge can be found by using the rational formula,

$$Q = FCIA$$
$$= 0.278 \times 0.48 \times 70 \times 7.5$$
$$= 70.0 \text{ m}^3/\text{sec}$$

$$t_c = \frac{FL}{A^{0.1} S^{0.2}}$$

where t_c = time of concentration in minutes
F = factor of proportionality,
58.5 when A in km^2,
92.7 when A in hectares
L = mainstream length (km)
A = catchment area
S = mainstream slope (m/km)



IDF Curve

Example 2

Also determine the diameter of the storm sewer crossing the highway, for the above example, with sewer material having $n = 0.013$ and laid at a slope of 0.001. The velocity at full flow should be less than 3.0 m/sec.

Solution:

Discharge $Q = AV$

$$= \frac{\pi D^2}{4} (1/n\ R^{2/3}\ S^{1/2}) \quad \text{[using Manning's equation]}$$

$$\text{or,} \quad 70.0 = \frac{\pi D^2}{4} \times \frac{1}{0.013} (D/4)^{2/3}\ (0.001)^{1/2}$$

$$= D^2 . D^{2/3} . \pi/4 \times 1/0.013 \times (1/4)^{2/3} \times (0.001)^{1/2}$$

$$= D^{8/3} \times 0.76$$

$$\therefore \quad D^{8/3} = 70/0.76 = 92.10$$

$$\therefore \quad D = 5.5 \text{ m}$$

Use 5500 mm diameter storm sewer.

Check for velocity:

$$V = Q/A = \frac{70.0 \times 4}{\pi \times 5.5 \times 5.5}$$

$$= 2.95 \text{ m/sec. } 3.0 \text{ m/sec. Hence the velocity is o.k.}$$

Example:

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

$= 4.5$ m^3/sec

$= 388.5 \times 10^5$ L/day

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

Example:

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)

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

Hence,

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

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

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

$r / R = (1 - 360 \sin \theta / 2\pi\, \theta)$

$a/A = (\theta/360 - \sin\theta/2\pi)$

Now for the sewer to be same self cleansing at 0.3 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

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

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:

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.

Solution

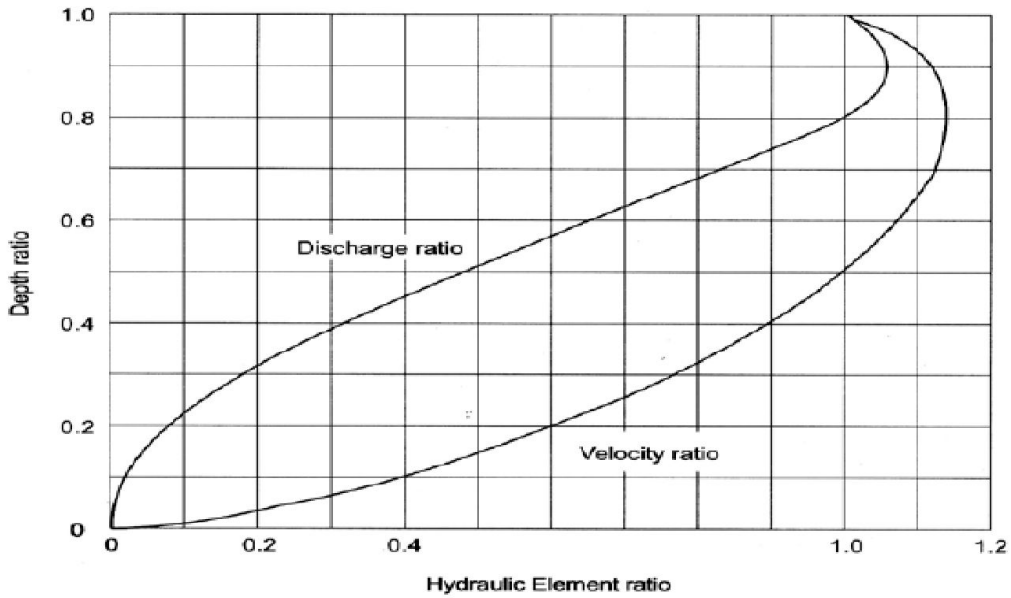
Average water supplied = 80000 x 190 x (1/24 x 60 x 60 x 1000) = 0.176 m^3/sec

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

Check for maximum velocity

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 **3 m/s** 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 **0.6 m/s** hence OK

Assignment: Solve the above problem with population 100000 persons and pipe flowing 0.75 full at maximum discharge. The rate of water supply is 150 LPCD, n = 0.013, and permissible S = 1 in 600.

Problems to Solve:

1. An 18 inch sewer with n=0.013 is laid on a slope of 0.015.
   a) What is the capacity when flowing half full?
   b) What will be the velocity when the depth of flow is 4.5 inch.

Problem: Determine the rate of discharge and discharge velocity in a 30 cm circular sewer with n = 0.013, slope = 0.004 and depth of flow equal to 7.5 cm, using both of the Nomograms and Partial flow diagram, given below.

Solution

From the nomograms –

for slope =0 .004 (m/m) = 4m/ 1000 m and diameter, D = 30 cm,

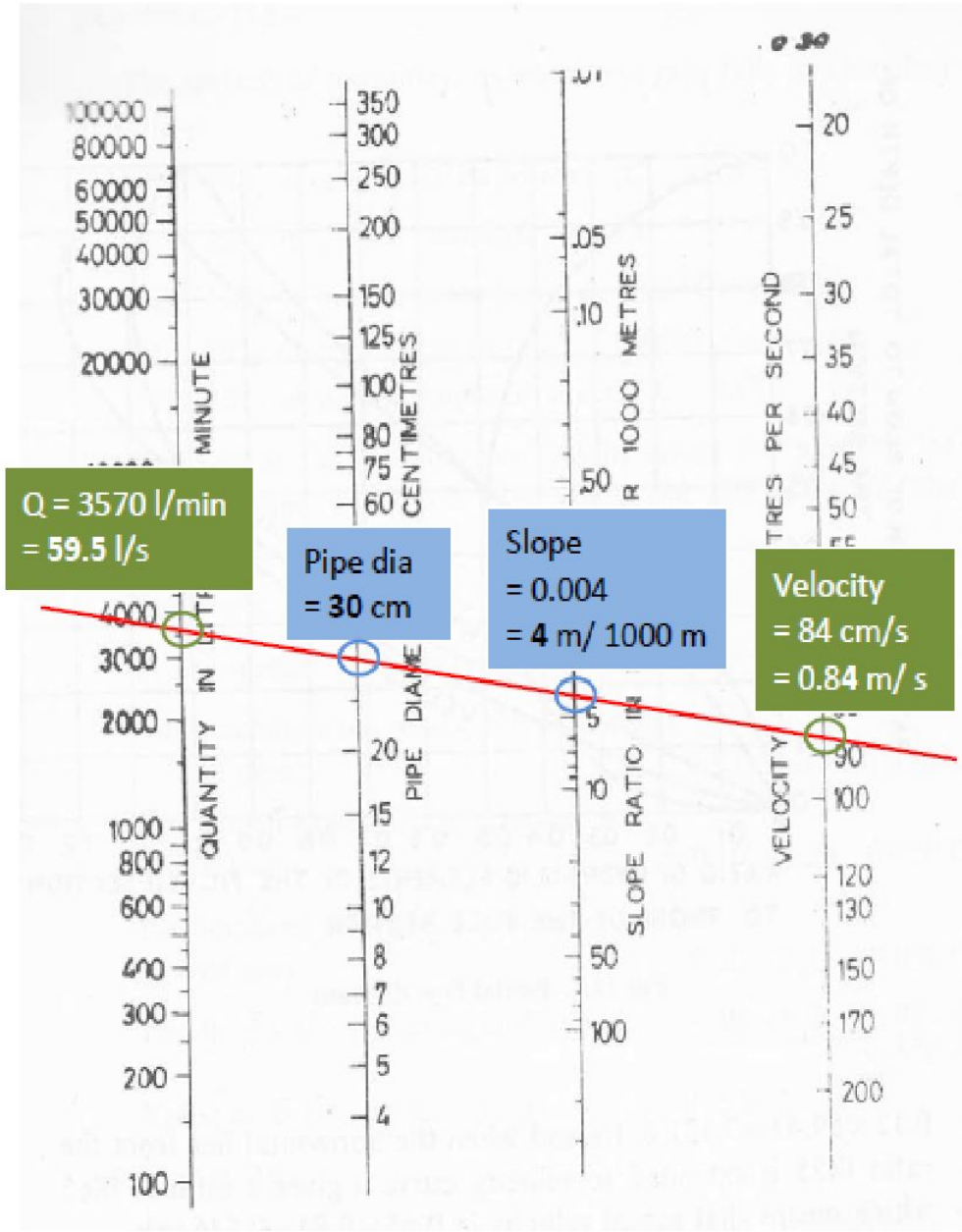
Discharge, Q = 3570 l/min = 59.5 l/s and Velocity, V = 84 cm/s = 0.84 m/s

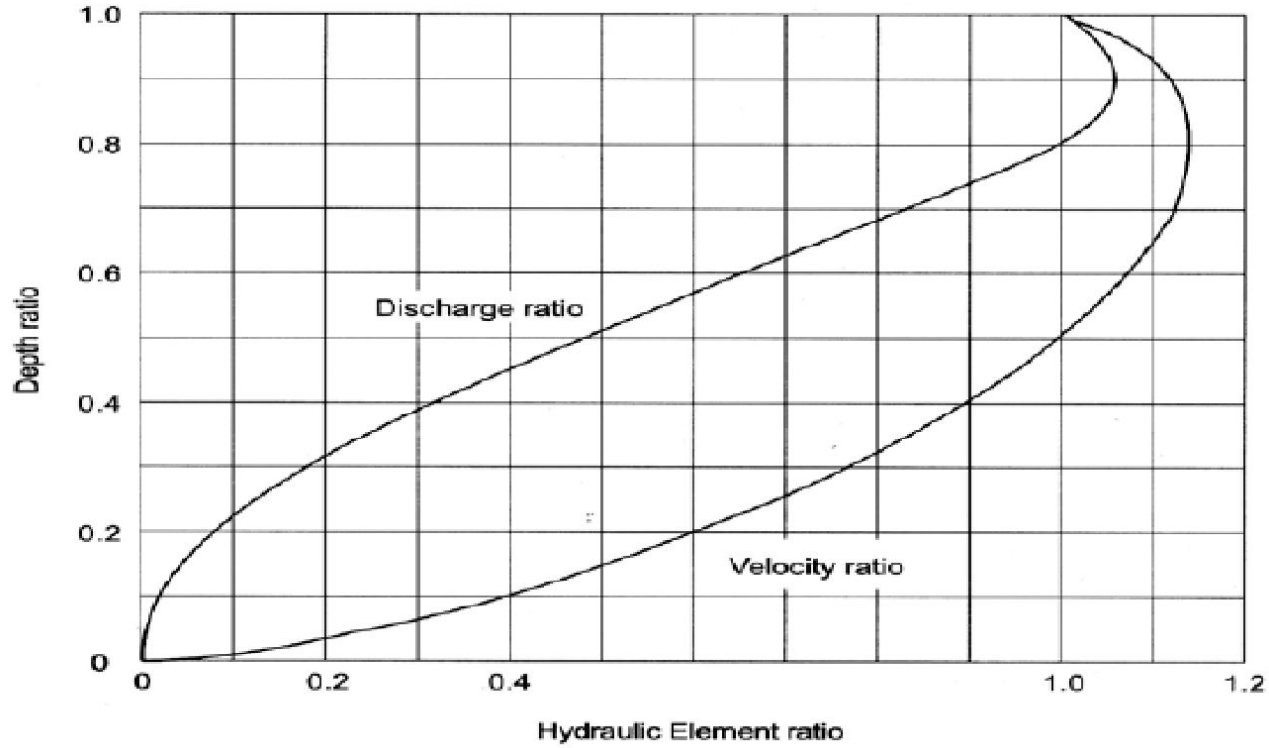
Now, depth ratio, d/D = 7.5 / 30 = 0.25

From the partial flow diagram, q/Q = 0.12

Therefore, q = 0.12 × 59.5 = **7.14 l/s**

Again, v = 0.65 × 0.84= **0.55 m/s**


Q = 3570 l/min
= 59.5 l/s
Pipe dia
= 30 cm
Slope
= 0.004
= 4 m/ 1000 m
Velocity
= 84 cm/s
= 0.84 m/ s
QUANTITY IN LITRES PER MINUTE
PIPE DIAMETER IN CENTIMETRES
SLOPE RATIO IN 1000 METRES
VELOCITY IN METRES PER SECOND


Depth ratio
Discharge ratio
Velocity ratio
Hydraulic Element ratio
0
0.2
0.4
0.6
0.8
1.0
1.2



Infiltration



Inflow

I & I

Problem: A trunk sewer is to be sized for a 25 km^2 (2,500 ha) city with a naturally sloped towards the major river with a gradient of 1 in 1000. It will be 60% residential, 30% commercial, and 10% industrial. The residential area will have 40% large lots, 55% small single family lots, and 5% multi-story apartments. The average domestic wastewater flow rate is 800 L/d/capita (9.26×10^{-6} m^3/sec/person), the average commercial flow rate is 25,000 L/D/ha ($2.89 \times I0^{-4}$ m^3/sec/ha), and the average industrial flow rate is 40,000 L/d/ha ($4.63 \times I0^{-4}$ m^3/sec/ha). I & I is 1,000 L/d/ha for the entire area. Estimate the peak and minimum flows to be handled by the trunk sewer. Given: $Q_{peak}/Q_{avg} = 5.5/(p^{0.18})$ and $Q_{min}/Q_{avg} = 0.2(p^{0.16})$,where *'p' is the total city* population in thousands. Also design the sewer based on the estimated flow and the saturation densities for the residential areas given in the table below:

Type of area	**Density (Persons/ha)**
Large lots	5-7
Small lots, single-family	75
Small lots, two-family	125
Multistory apartments	2,500

Type	Area(ha)	Density (persons/ha)	Population	Flow (m^3/s)
Large lots	0.4(1500)= 600	6	3,600	0.03
Small single family lots	0.55(1500) = 825	75	61,875	0.57
Multistory apartments	0.05(1500) = 75	2500	187,500	1.74
Total			**252,975**	**2.34**

Commercial sector = 30% of 2500 ha = 750 ha
Average flow from commercial sector = 750x25,000 L/d= 0.22 m^3/s

Industrial sector = 10 % of 2500 ha = 250 ha
Average flow from industrial sector = 250x40,000 L/d = 0.12 m^3/s
Thus,
Average wastewater flow (excluding I/I) = 2.34+0.22+0.12 = 2.68 m^3/s
Assuming total population is equal to residential population, i.e.

P= 252,975

Then,

$$\frac{Q_{peak}}{Q_{ave}} = \frac{5.5}{(P/1000)^{0.18}} = \frac{5.5}{(252.975)^{0.18}} = 2.0$$

$$\frac{Q_{\min}}{Q_{ave}} = 0.2(P/1000)^{0.16} = 0.2(252.975)^{0.16} = 0.48$$

Hence,

Peak flow = Peak factor x wastewater + I/I = 2.0(2.68)+0.03= 5.39 m^3/s

Minimum flow = 0.48(2.68) + 0.03 = 1.32 m^3/s

Using Manning's Equation for a full-flowing pipe (n=0.013 for concrete) at a gradient S=0.001

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

$$D = \left(\frac{5.39 \cdot 0.013}{0.3117 \cdot \sqrt{0.001}} \right)^{3/8}$$

$$D = \left(\frac{0.07007}{0.009857} \right)^{3/8} \approx 2.278 \text{ m}$$

Velocity Check:

It is essential to ensure the flow velocity (V) is within the self-cleansing range (typically 0.6 m/s to 3.0 m/s)

$$V = \frac{Q}{A} = \frac{5.39}{\frac{\pi \cdot 2.28^2}{4}} \approx 1.32 \text{ m/s}$$

Since 1.32 m/s is greater than 0.6 m/s and less than 3.0 m/s the design is hydraulically stable.

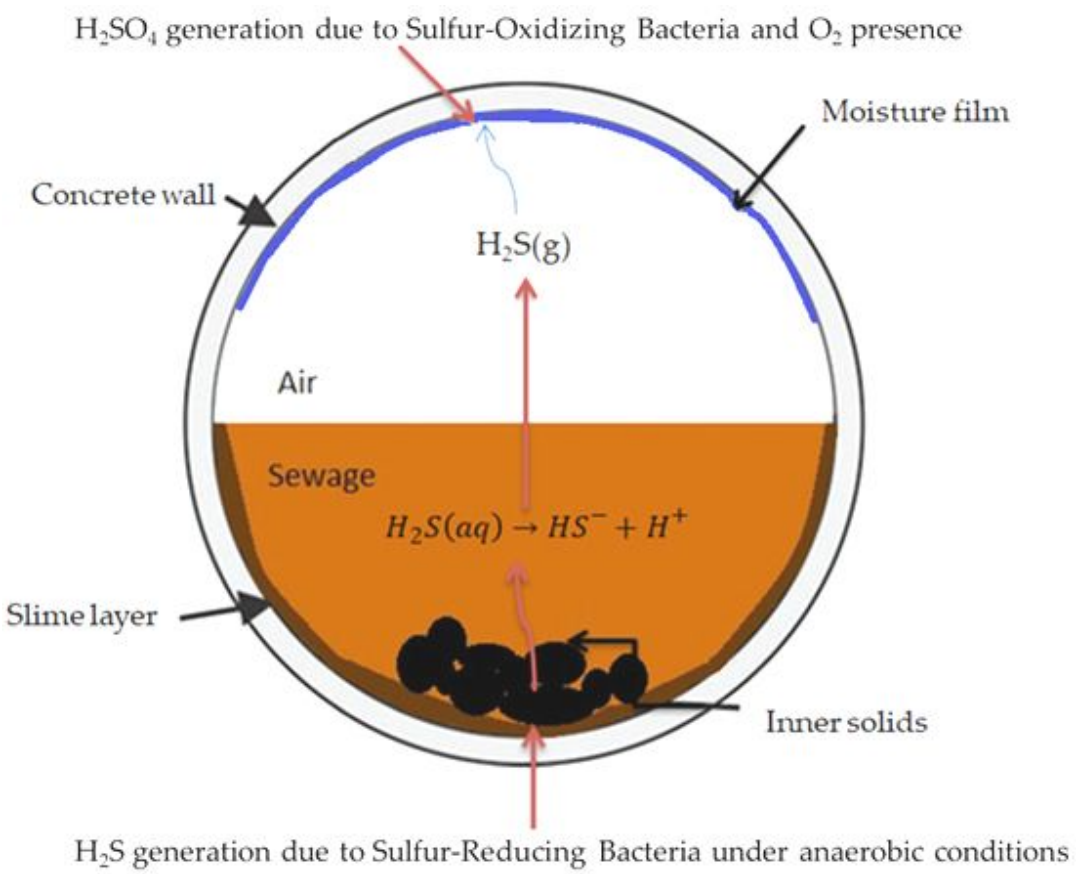
The design requires a sewer pipe with a diameter of **2.28 meters** (or the nearest standard commercial size, such as 2300 mm)

Why does H_2S form in sewers?

H_2S is formed by anaerobic processes in the thin slime layer that develops on the inside of the sewer walls as organic material in the sewage breaks down.

The formation of H_2S in wastewater mainly depends on:

- Flow (velocity) of sewage in pipes
- Slope of the pipe
- Ratio of wetted perimeter of the pipe wall to surface width of the stream
- Temperature of the sewage
- Biochemical oxygen demand (BOD)



Sulfide Generation

$$Z = 0.308 \frac{EBOD}{S_0^{0.5} Q^{0.33}} \times \frac{P}{B}$$

$$EBOD = BOD \times 1.07^{T-20}$$

$BOD =$ 5-day biochemical oxygen demand

$S_0 =$ Slope of the pipe

$Q =$ Discharge through the pipe

$P, B =$ Wetted perimeter and top width of the flow, respectively

$$P = \frac{D\theta}{2}$$

Top Width, B= D sin (θ/2)

Z values	Sulfide Condition
$Z < 5{,}000$	Sulfide rarely generated
$5{,}000 < Z < 10{,}000$	Marginal condition for sulfide generation
$Z > 10{,}000$	Sulfide generation common

Problem: A 2000 mm dia. RCC pipe is laid with a slope of 0.0015 for a design flow of 0.6 m^3/sec when flowing partially full having a width of 1.414m at the top. The sewer pipe provided is designed to carry domestic sewage having BOD_5 of 200 mg/L and a maximum temperature of 30°C. Determine the potential for Sulfide Generation (Z).

Step 1: Calculate the Effective BOD ($EBOD$)

The Effective BOD accounts for the increased biological activity at higher temperatures. It is calculated using the formula:

$$EBOD = BOD_5 \cdot 1.07^{(T-20)}$$

Given,

BOD_5=200 mg/L, T=30^0C

$$EBOD = 200 \cdot 1.07^{(30-20)} = 393.43 \text{ mg/L}$$

Step 2: Determine Geometric Parameters

For a circular pipe with diameter

D=2000 mm =2.0 m

R=1.0 m and a top width of flow B=1.414 m

Find the central angle

B=2Rsin (θ/2)

1.414=2(1.0) sin (θ/2) $\Rightarrow$sin (θ/2)=0.707$\Rightarrow\theta$/2=45^0

θ=90^0 (or π/2 radians).

Find the wetted perimeter

$P=R\cdot\theta$=1.0$\cdot\pi$/2≈1.571 m

Calculate the ratio

P/B =1.571/1.414≈1.111

Step 3: Calculate the Z-index

The Z-index formula is defined as:

$$Z = 0.308 \frac{EBOD}{S_0^{0.5} Q^{0.33}} \times \frac{P}{B}$$

Substitute the given values (S=0.0015, Q=0.6 m^3/sec)

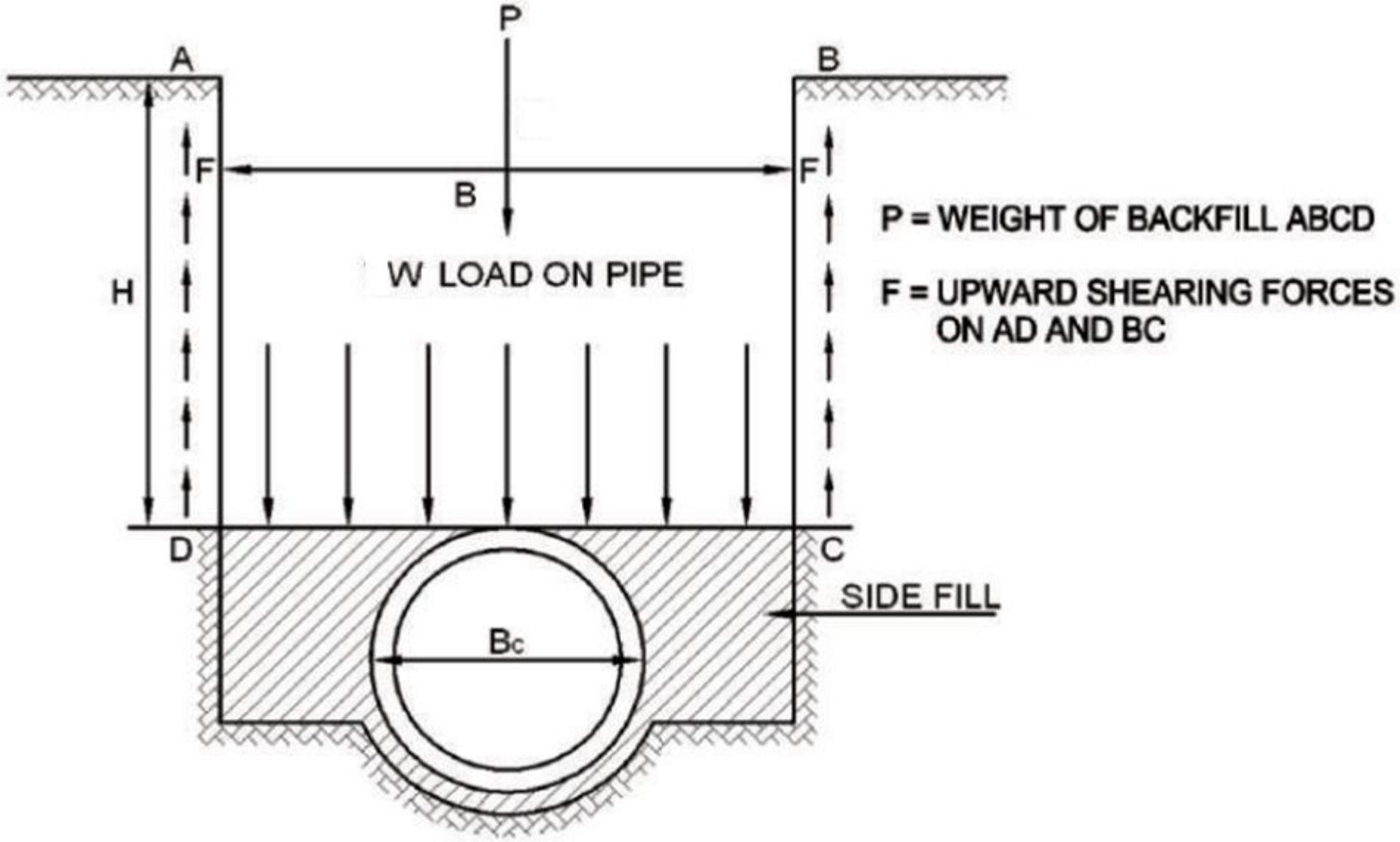
Z = 0.308 (393.43x1.111)/ $(0.0015)^{1/2}$x $(0.6)^{1/3}$

Z= 0.308 (393.43 x 1.111)/(0.03873 x 0.8434) ≈ 134.63/ 0.03266 ≈ 4,122

The potential for Sulfide Generation (Z) is 4,122. Since this value is less than 5,000, sulfide generation is **likely** not to occur.

Loads on Sewer

- In a buried sewer, stresses are induced by external loads and by internal pressure in case of a pressure main.
- The external loads are of two categories viz., load due to backfill material known as backfill load and superimposed load, which again is of two types viz. concentrated load and distributed load.
- The load on a buried conduit is equal to the weight of the prism of earth directly over the conduit, called the interior prism of earth plus or minus the frictional shearing forces transferred to the prism by the adjacent prism of earth.


P
A
B
F
F
B
W LOAD ON PIPE
H
P = WEIGHT OF BACKFILL ABCD
F = UPWARD SHEARING FORCES
ON AD AND BC
D
C
SIDE FILL
Bc

Loads on Sewer

The general form of Marston's formula is

$$W = C\,w B^2$$

Where,

W : Load on the pipe in kg/m

w : Unit weight of backfill soil in kg/m^3

B : Width of trench at the top of the pipe in m and

C : Load coefficient which is a function of a ratio of height of fill to width of trench (H/B) and of the friction coefficient between the backfill and the sides of the trench.