Chapter 3

HYDRAULIC DESIGNS
OF
SEWERS

2020

3.1 INTRODUCTION

- Sewerage system is designed to remove entire sewage effectively and efficiently from the houses to the point of disposal.
- 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.
- The Following aspects should be considered while designing the system.
  - ✓The sewers provided should be adequate in size to avoid overflow and possible health hazards.
  - ✓For evaluating proper diameter of the sewer, correct estimation of sewage discharge is necessary.
  - ✓The flow velocity inside the sewer should neither be so large, nor should be so small causing scouring and silting of the solid in the sewers.

- ✓ The sewers should be laid below the ground at least 2 to 3 m deep to carry sewage from basement.
- ✓ The sewage should flow under gravity with 0.5 to 0.8 full at designed discharge, i.e. at the maximum estimated discharge.
- ✓ The sewage is conveyed to the point usually located at low-lying area, where the treatment plant is located.
- ✓ Treatment plant should be designed taking into consideration the quality of raw sewage expected and to meet the discharge standards.

3.2. Design Period for d/t components of sewerage system

Design period should not be too long and short, it should not exceed the useful life of the component structures.

Guides for fixing design period:

- ✓ Useful life of component structures
- ✓ Easy and difficulty of expansion (need higher value of design period)
- ✓ Amount and availability Fund : limited(small)- short design period
- ✓ Rate of interest on borrowing: high- short the design period; small- high the design period will be
- ✓ Population growth: high - short the design period; low - long the design period will be.

- The following design periods are often used in designing the different components of a sewerage scheme.

Type of structure	Characteristics	Design period
Lateral sewers, less than 15cm diameter	Requirements may change faster in limited area	Full development
Branches, mains, and trunk sewers	Difficult and costly to enlarge	40-50
Treatment units	Growth and interest rates being high to moderate	15-20
Pumping plant	The additional pumps can be installed in future, very easily	5-10

❖ Difference in the Design of Water Supply Pipes and Sewerage Pipes

- There are two major differences between the characteristics of flows in sewers and water supply pipes
  - ✓ The water supply pipes carry pure water without containing any kind of solid particles, either organic or inorganic in nature. The sewer pipes, on the other hand, does contain such particles in suspension; and the heavier of these particles may settle down at the bottom of the sewer
  - ✓ The water supply pipes carry water under pressure, and hence, within certain limits, they may be carried up and down the hills and the valleys whereas, the sewer pipes carry sewage as gravity, conduit (or open channels)

Water Supply Pipes	**Sewer Pipes**
It carries pure water.	It carries contaminated water containing organic or inorganic solids which may settle in the pipe. It can cause corrosion of the pipe material.
Velocity higher than self-cleansing is not essential, because of solids are not present in suspension.	To avoid deposition of solids in the pipes self-cleansing velocity is necessary at all possible discharge.
It carries water under pressure. Hence, the pipe can be laid up and down the hills and the valleys within certain limits.	It carries sewage under gravity. Therefore it is required to be laid at a continuous falling gradient in the downward direction towards outfall point.
These pipes are flowing full under pressure.	Sewers are design to run partial full at maximum discharge. This extra space ensures non-pressure gravity flow. This will minimize the leakage from sewer, from the faulty joints or crack, if any.

Provision of Freeboard in Sewers and Storm Water drain

For Sanitary sewers:

Freeboard: act as a factor of safety to counteract against factors, such as:

- ✓ Low estimates of the average and maximum flows, made due to some wrong data obtained.
- ✓ Large scale infiltration of storm water
- ✓ Unforeseen increase in population or water consumption and the consequent increase in sewage production.

- Sewers with diameter less than 0.4 m are designed to run half full at maximum discharge, and sewers with diameter greater than 0.4 m are designed to flow 2/3 to ¾ full at maximum discharge.
- The extra space provided in the sewers provides factor of safety to counteract against the above factors.

For Storm Water Drains

- ✓ The over-flowing of drains is not so much harmful, as is the overflowing of sewers, mainly because sanitary sewage is highly polluted as compared to the storm water.
- ✓ The storm water drains are, therefore, provided with nominal provisions of freeboard above their designed full supply lines.

Peak discharge in the drain for which designed, in cumecs	Freeboard to be left in meters
Below 0.3	0.3
0.3-1.0	0.4
1-5	0.5
5-10	0.6
10-30	0.75
30-150	0.90
More than 150	1.0

3. 3. Hydraulic Formulas for determining Flow Velocities in Sewers and Drains

A. Chezy's Formula

This formula was evolved by Chezy in 1775, and states that

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

Where ,

V= velocity of flow in the channel in m/sec

R = hydraulic mean radius of channel, i.e. A/P Where A is the area of channel and p is the wetted perimeter of the channel

S = hydraulic gradient, equal to the ground slope for uniform flows,

C = a constant, called Chezy’s constant

continued

- The Chezy's constant c depends upon various factors, such as:

✓the size and the shape of the channel,

✓roughness of the channel surface,

✓ hydraulic Characteristics of the channel, etc.

The value of c can be obtained by using either the Kutter's formula or the Bazin's formula, as given below.

- ***Kutter's formula***

$$c = \frac{\left(23 + \frac{0.00155}{s}\right) + \frac{1}{n}}{\left(23 + \frac{0.00155}{s}\right) * \frac{n}{\sqrt{r}} + 1}$$

continued

Where ;

n = Rugosity coefficient depending upon the type of the channel surface.

S = Bed slope of the sewer

r = Hydraulic mean depth = a/p

S.No	Pipe material	Value of n at full depth	
		good surface interior	Fair interior surface
1	Salt glazed stone ware pipes	0.012	0.014
2	Cement concrete pipes	0.013	0.015
3	Cast iron pipes	0.012	0.013
4	Brick unglazed sewers/Drains	0.013	0.015
5	Asbestos cement	0.011	0.012
6	Plastic(smooth) pipes	0.011	0.011

➢ ***Bazin's formula***

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

Where,

r = Hydraulic mean depth of channel

K = Bazin’s constant

S. no	Types of the inside surface of the sewer or drain	Value of K
1	Very smooth surface	0.11
2	Smooth brick and concrete surface	0.29
3	Rough brick and concrete surface	0.5
4	Smooth rubber and masonry surface	0.83
5	Good earthen channel	1.54
6	Rough earthen channel	3.17

B. Manning's Formula

- ✓ Robert Manning, in 1885 Developed Manning formula used for open channel flow conditions.
- ✓ This is most commonly used for design of sewers.

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

Where,

v = velocity of flow, m/s

R = hydraulic radius, m

S = slope /hydraulic gradient

n = a roughness coefficient

C. William-Hazen's Formula

- ✓ This formula is generally used for flows under pressure for designing water supply pipes, and is seldom used for designing sewers.

$$V = 0.85 C_H * r^{0.63} * s^{0.54}$$

The value of coefficient C_H may be taken from the table

S. No	Type of pipe material	Value of CH for	
		New pipes	Design purpose
1	Concrete and R.C.C pipes	140	110
2	Cast iron pipes	130	100
3	Galvanized iron pipes	120	100
4	Steel pipes with welded joints	140	100
5	Steel pipes with riveted joints	110	95
6	Steel pipes with welded joints lined with cements for bituminous enamel	140	110
7	Asbestos cement pipes	150	120
8	Plastic pipes	150	120

Flow Velocity

- ✓ Minimum velocity of 0.6 m/sec with flow at ½ full or full depth this velocity is called self cleansing velocity.
- ✓ Sewers for domestic sewage should be designed that the velocity of flow does not go below 0.6 m/sec but in general velocity of 0.9 m/sec is desirable
- ✓ A self-cleansing velocity may be defined as that velocity at which the solid particles will remain in suspension, without setting at the bottom of the sewer.

Minimum and maximum Velocity

- **Besides transportation certain minimum velocity should be kept for:**
  - ✓ Economical reasons since very low velocities require greater cross-sectional area for a particular flow.
  - ✓ Hygienic and economical reasons since slow velocity implies longer time for the sewage to reach sewer outfall this makes the sewage stale and highly septic affecting sewer material and staff in handling.
- **Larger velocities are required** to ensure that as soon as sewage is developed it reaches the outfall point within the shortest time possible while it is Fresh – which is easy to handle.

continued

- ✓Recommended maximum average velocities of flow is 2.5-3.0 m/sec at design depth of flow.
- ✓Higher value can also be considered based on the surface characteristics of the sewer material. The maximum allowable velocity should be non-scouring velocity.
- ✓If the velocity of flow exceeds this velocity, the smooth interior surface of the pipe gets scoured to the continuous abrasion caused by the suspended solids present in the sewage.

3.4. Hydraulic characteristics of circular sewer

✓circular section is most widely adopted for sewer pipes

Hydraulic Elements of Circular Sewers :

(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. 8.6),**

Let a = area of cross - section

b = wetted perimeter

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

v = velocity of flow

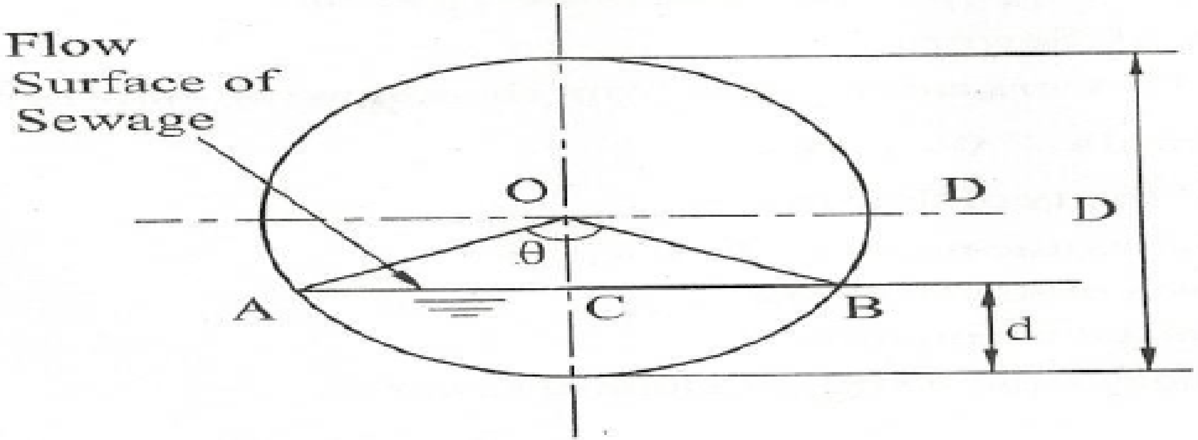


Fig. 8.6

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

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

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

$\therefore$ 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 flow condition

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

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** :

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

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

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

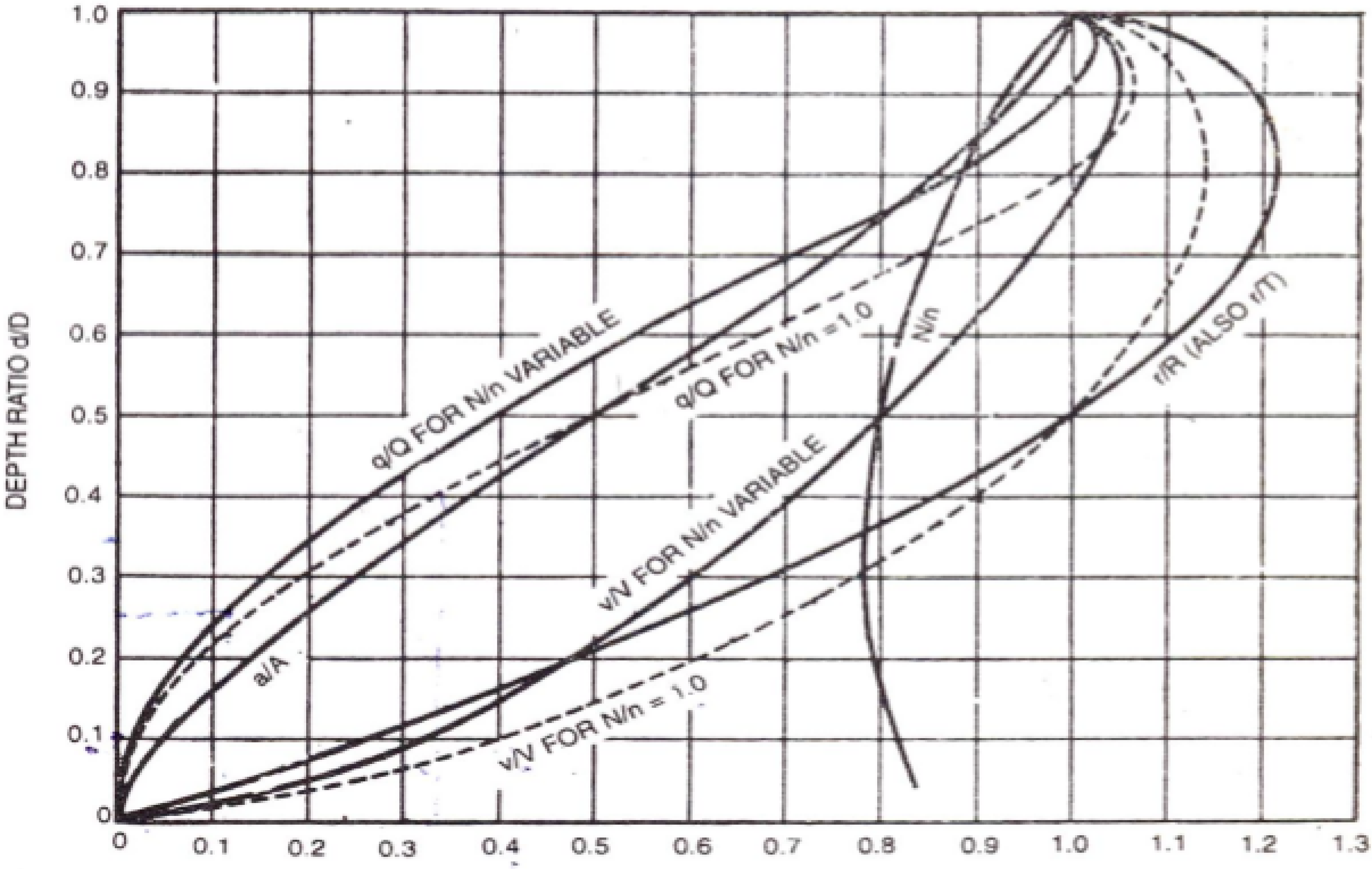
$$= \frac{\theta}{360^\circ}\left[1 - \frac{360^\circ \sin\theta}{2\pi\theta}\right]^{-5/3}$$

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

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

Hydraulic Elements of circular sewer Running Partially full								
d/D	a/A	p/p	r/R	For N/n = 1.0		N/n	For Variation N/n	
				v/V	q/Q		v/V	q/Q
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1	1	1	1	1	1	1	1
0.9	0.949	0.795	1.192	1.124	1.61	0.94	1.057	1.002
0.8	0.858	0.705	1.217	1.14	0.988	0.88	1.003	0.869
0.7	0.748	0.631	1.185	1.12	0.838	0.85	0.952	0.712
0.6	0.626	0.564	1.11	1.072	0.671	0.83	0.89	0.557
0.5	0.5	0.5	1	1	0.5	0.81	0.81	0.405
0.4	0.373	0.436	0.857	0.902	0.337	0.79	0.713	0.266
0.3	0.252	0.369	0.684	0.776	0.196	0.78	0.605	0.153
0.2	0.143	0.295	0.482	0.625	0.088	0.79	0.486	0.07
0.1	0.052	0.205	0.254	0.401	0.021	0.82	0.329	0.017
0	0				0			

proportionate graph



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)

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

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

$= 1 \times (0.684)^{2/3} \times 0.9$

$= 0.699 m/s$

The discharge q_s is given by

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

$q_s \quad = 0.064*1*0.252*0.776$

$= 0.013 m3/s$

problems

1 : Calulate the velocity of flow and corresponding discharge in a sewer of circular section having diameter $= 1.2$ m, laid at a gradient 1 in 400. The sewer runs at 0.7 depth. Use Manning's formula taking $N = 0.018$

2 : Determine the size of a circular sewer for a discharge of 450 lit/s running half-full Assume $s = 1/4500$ and $N = 0.016$.

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.

3.5. Sewer appurtenance

- ✓ Sewer system require various types of appurtenances for their proper functioning and maintenances.
- ✓ If sewerage system will not be provided and maintained properly, salt, ashes, fats, oils and greasy matters etc will choke the sewer line.
- ✓ Therefore, for the proper operation and maintenance of sewerage system various devices are essential:

1. Manholes
2. Drop manholes
3. Lamp holes
4. Clean-outs
5. Street inlets called Gullies
6. Catch basins
7. Flushing tanks
8. Grease and Oil traps
9. Inverted siphons
10. Storm regulators.

1. Manholes

Manholes are constructed from masonry or R.C.C. thus, help in joining sewer lengths, and also help in their inspection, cleaning and maintenance.

Location and Spacing of Manhole:

- ✓ The manholes are generally provided (**location**) at every bend, junction, change of gradient, or change of sewer diameter.
- ✓ The **spacing** between the manholes, depends mainly upon the size of the sewer line. The larger is the diameter of the sewer, the greater will be the spacing between the manholes.

- The manhole spacing, generally adopted, on straight sewer reaches, is given below:

Size of the Sewer	Recommended Spacing of Manholes on straight reaches of sewer lines as per IS
Up to 0.3m	45m
Up to 0.6m	75m
Up to 0.9m	90m
Up to 1.2m	120m
Up to 1.5m	250m
Greater than 1.5m	300m

Classification of Manholes

Depending upon their depth, the manholes may be classified as:

i. Shallow manholes

ii. Normal manholes

iii. Deep manholes.

A. shallow manhole: is about 0.7 to 0.9 m in depth, and is constructed at the start of a branch sewer or at places, which are not subjected to heavy traffic.

B. normal or medium manhole: is about 1.5 m in depth and is constructed either square (1 m x 1 m) or rectangular (1.2 m x 1 m) in cross section. Its section is not changed with depth, as is done in a deep manhole.

- ✓ is provided with a heavy cover at its top.

C. A deep manhole:

- ✓ having depth more than 1.5 m and provided with a heavy cover at its top.

Component Parts of a Manhole

i. Access Shaft: The upper portion of a deep manhole is called access shaft.

Its minimum size for a rectangular manhole is about 0.75* 0.6m; and for a circular manhole, the minimum diameter is about 0.6 to 0.75m.

ii. Working chamber: the lower portion of the manhole is known as the working chamber, as it provides a working space for inspecting and cleaning-operations.

- ✓ Its minimum size for a rectangular manhole is about 1.2m*0.9 m; and for a circular manhole, the minimum diameter is about 1.2m.
- ✓ The height of this chamber should generally be not less than 1.8 m or so.

continued

iii. **The Benching**

- the Bottom or invert portion of manhole.
- The bottom portion of the manhole is constructed in cement concrete.
- A semicircular or a V-shaped channel is generally constructed, and the sides are made to slope towards it

iv. **The side walls**

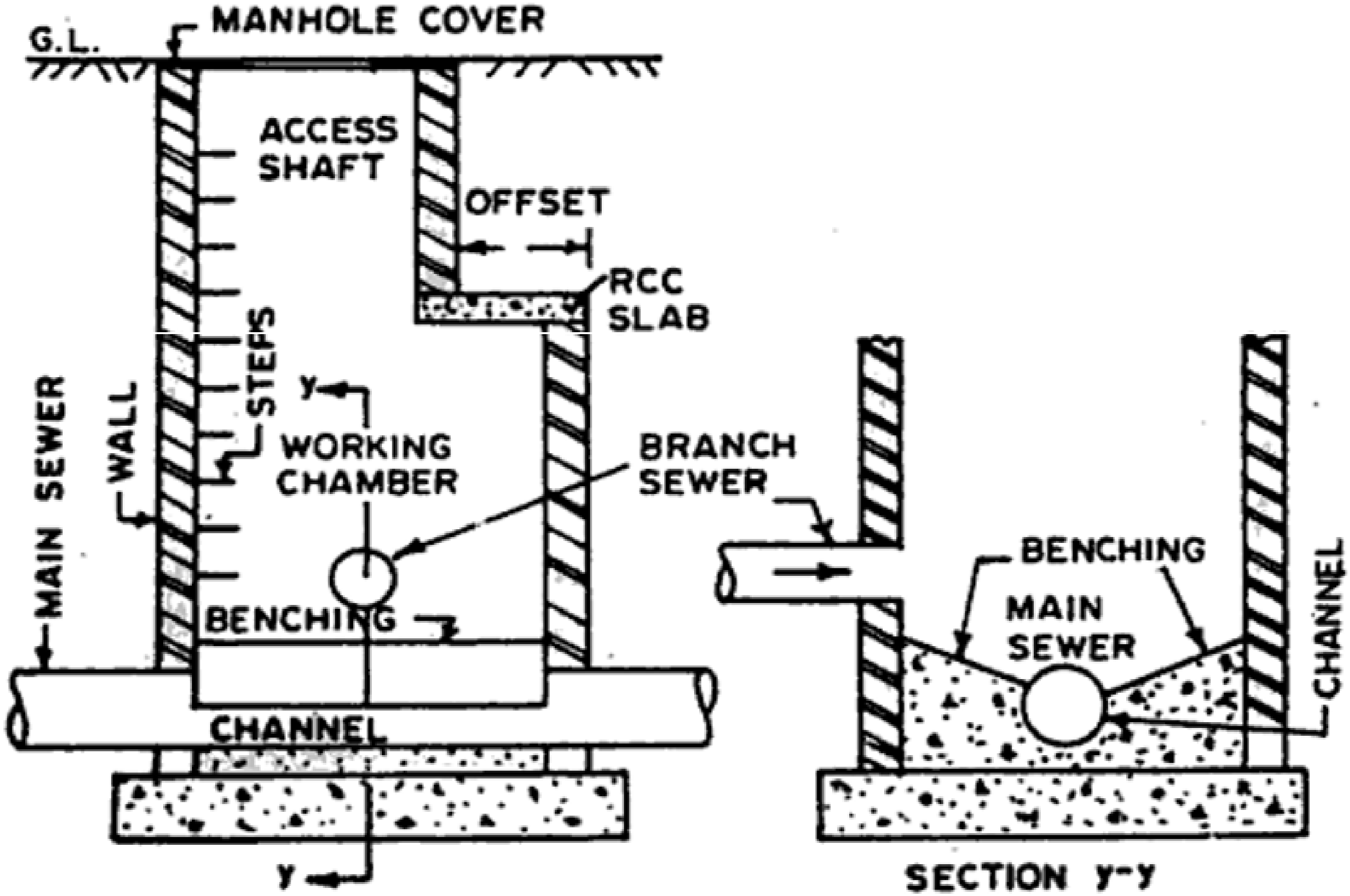
- The side walls of the manhole are made of brick or stone masonry or RC.C.
- The brick masonry walls are simple to construct, and are common adopted.
- The minimum thickness of the brick walls should be 22.5cm

v. Steps or Ladders

- ✓Steps are generally provided for entering into the manhole.
- ✓For deeper manholes, ladders are provided in place of steps.
- ✓The ladder will give a high sense of security to the laborers when they enter into the manhole.

vi. Cover and Frame

- ✓The manhole is provided with a cast iron cover and, a cast iron frame at its top.
- ✓The thickness of the frame is about 20 to 25cm,and its base is about 10cm wide.
- ✓The manhole cover may be rectangular or circular;
- ✓The size of a rectangular cover is about 0.6m*0.45m, and that of a circular cover being 0.5 to 0.6m in diameter.



MANHOLE COVER
G.L.
ACCESS SHAFT
OFFSET
RCC SLAB
STEPS
WALL
MAIN SEWER
Y
WORKING CHAMBER
BRANCH SEWER
BENCHING
CHANNEL
Y
BRANCH SEWER
BENCHING
MAIN SEWER
CHANNEL
SECTION Y-Y

continued

2. Drop Manholes

- ✓When a branch sewer enters a manhole by more than 0.5 to 0.6m above the main sewer, the sewage is generally not allowed to fall directly into the manhole, but is brought into it through a down pipe taken from the branch sewer to the bottom of the manhole.
- ✓If the drop is only a few meters the down pipe can be kept sloping (at 45° to the ground), and if the drop is more, a vertical pipe is found to be economical.
- ✓The manhole, in which a vertical pipe is used, is called a drop manhole; whereas, the one using an inclined pipe is called a ramp

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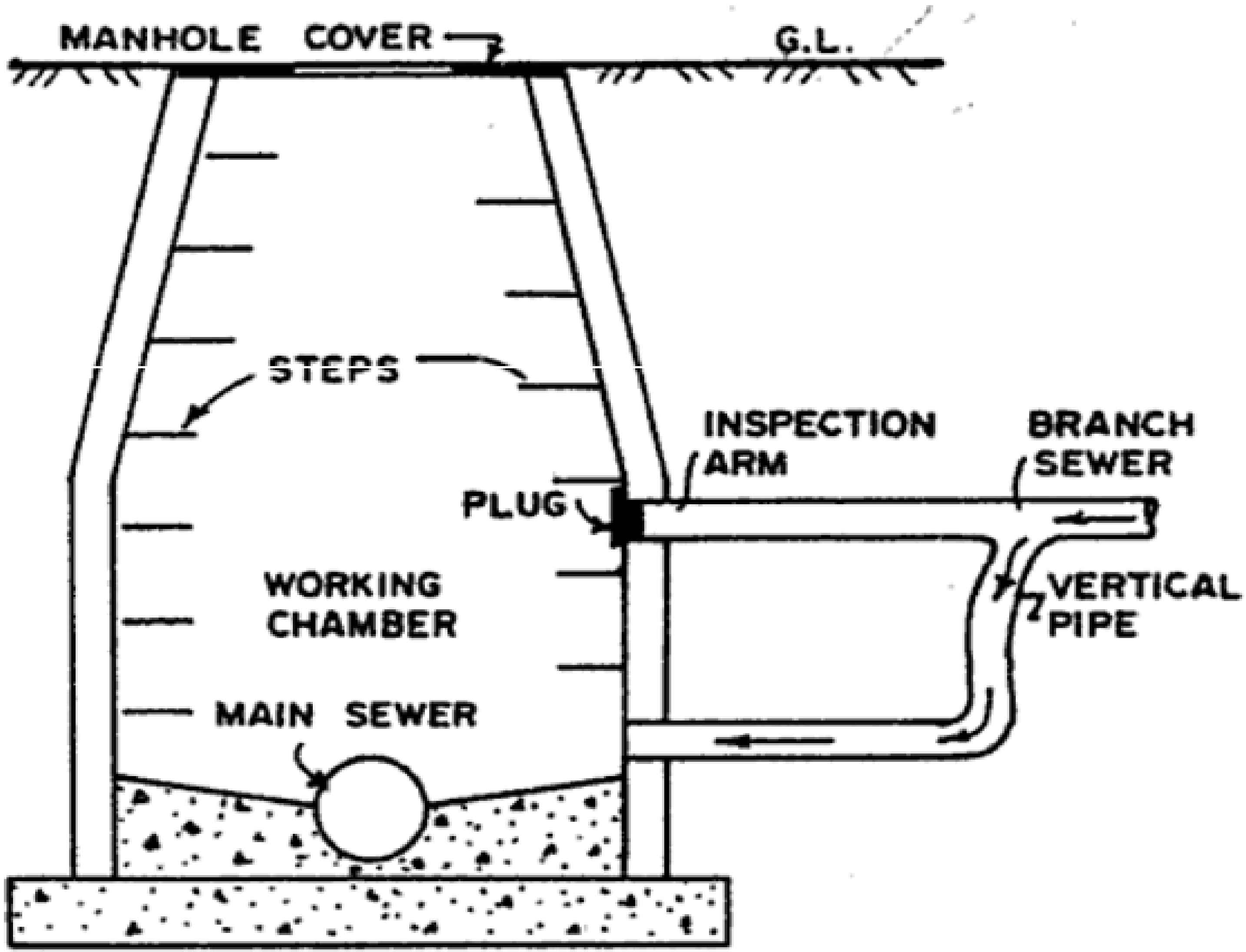
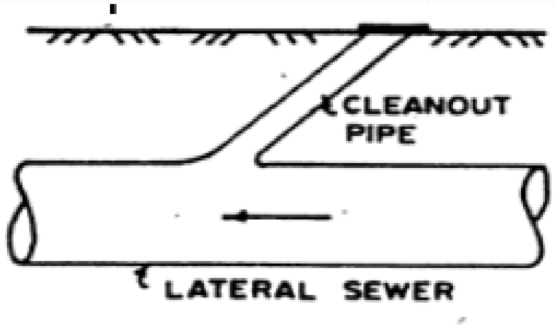

MANHOLE COVER
G.L.
STEPS
INSPECTION
ARM
BRANCH
SEWER
PLUG
WORKING
CHAMBER
VERTICAL
PIPE
MAIN SEWER

3. Clean-outs

- ✓ A clean-out is an inclined pipe extending from the ground and connected to the under-ground sewer.
- ✓ A cleanout is used for cleaning sewer pipes.
- ✓ A clean-out is generally provided at the upper ends of lateral sewers in place of manholes. The functioning of a clean-out is very simple, and consists in removing the top cover and forcing water through the clean-out pipe to lateral sewers to remove obstacles in the sewer line.
- ✓ If obstructions are large enough , a flexible rod may be inserted through the clean out pipe and pushed forward and backward to remove such obstacles.

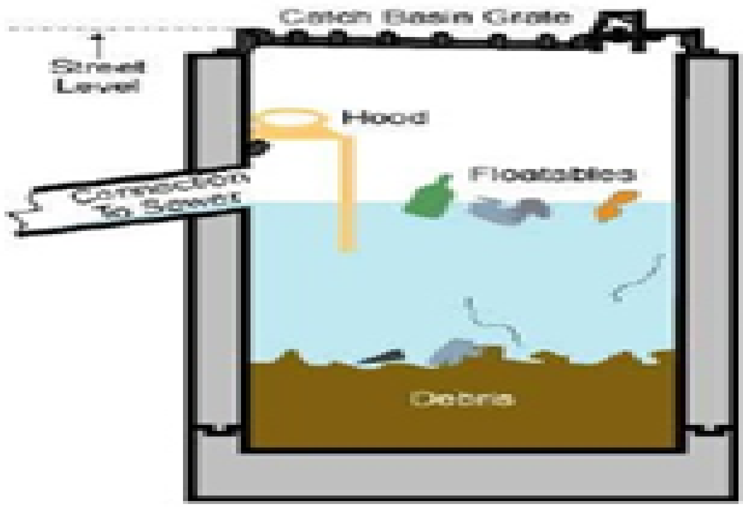


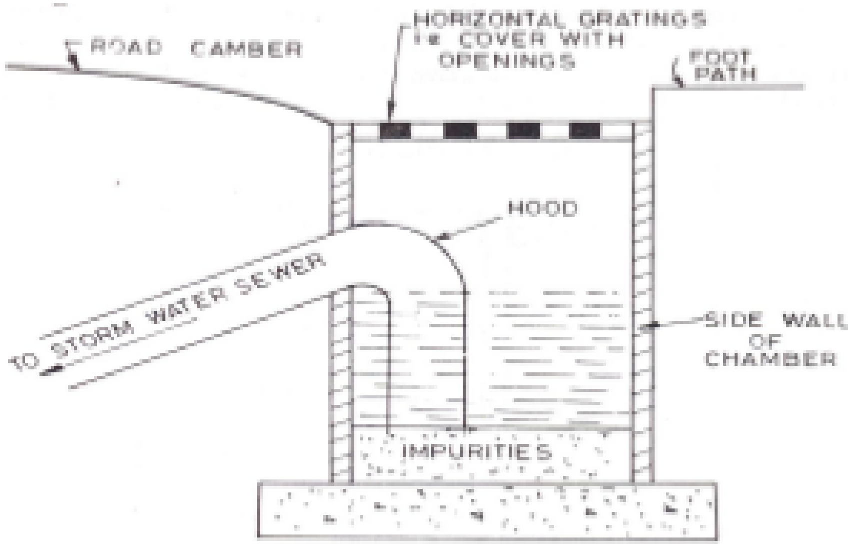
4. Street Inlets or Gullies

- ✓Inlets are gullies or openings on the road surface at the lowest point for draining rainwater from roads, and admitting it into the underground storm water sewers (drains) or combined sewers.
- ✓These inlets are, therefore, located along road sides on straight roads at an interval of 30m to 60m.

5. Catch Basins or Catch Pits

- ✓ Catch basins are street inlets provided with additional small settling basins.
- ✓ Grit, sand, debris, etc., do settle in these basins, and their entry into the sewer is thus prevented.
- ✓ Catch basins need periodical cleaning, as otherwise, the settled organic matter may decompose, producing foul odors, and may also become a breeding place for mosquitoes.



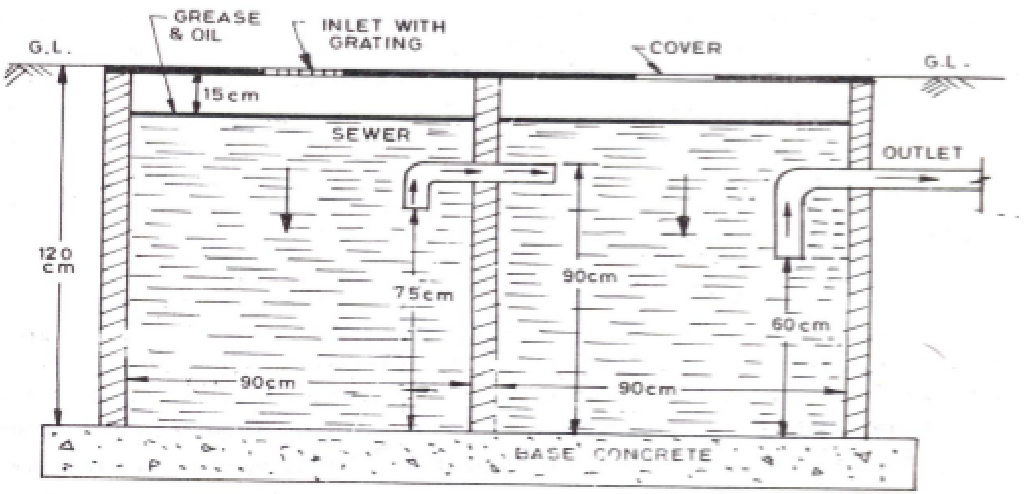


6. Flushing Tanks

- ✓Near the dead end points of sewers, flush devices are installed.
- ✓These devices store water temporarily, throw it into the sewer for the purpose of flushing and cleaning sewer.
- ✓Flushing tanks should have a capacity to store enough water which may prove to be sufficient for cleaning the sewer line
- ✓The capacity is generally kept equal to about one tenth of the cubical contents of the sewer line served by it.

7. Grease and Oil Traps

- Grease and oil traps are those trap chambers which are constructed in a sewerage system to remove oil and grease from the sewage before it enters into the sewer line.
- Such traps are located near the sources contributing grease and oil to the sewage.
- They are generally located at places, such as, automobile repair workshops, garages, kitchens of hotel, oil and grease industries, etc



8. Inverted Siphons

- ✓ Whenever a sewer pipe has to be dropped below the hydraulic gradient line for passing it beneath a valley, a road, a railway, a stream, or any other depression in the earth's surface or where it passes beneath some other obstructions in its path.
- ✓ The sewage through such a pipe line will be flowing under pressure.
- ✓ An inverted siphon is thus a sewer section constructed lower than the adjacent sewer sections, and it runs full under gravity with pressure greater.
- ✓ Inverted siphon laid between the inlet and the outlet chambers consists of two sloping pipe lengths joined by a flat pipe length.

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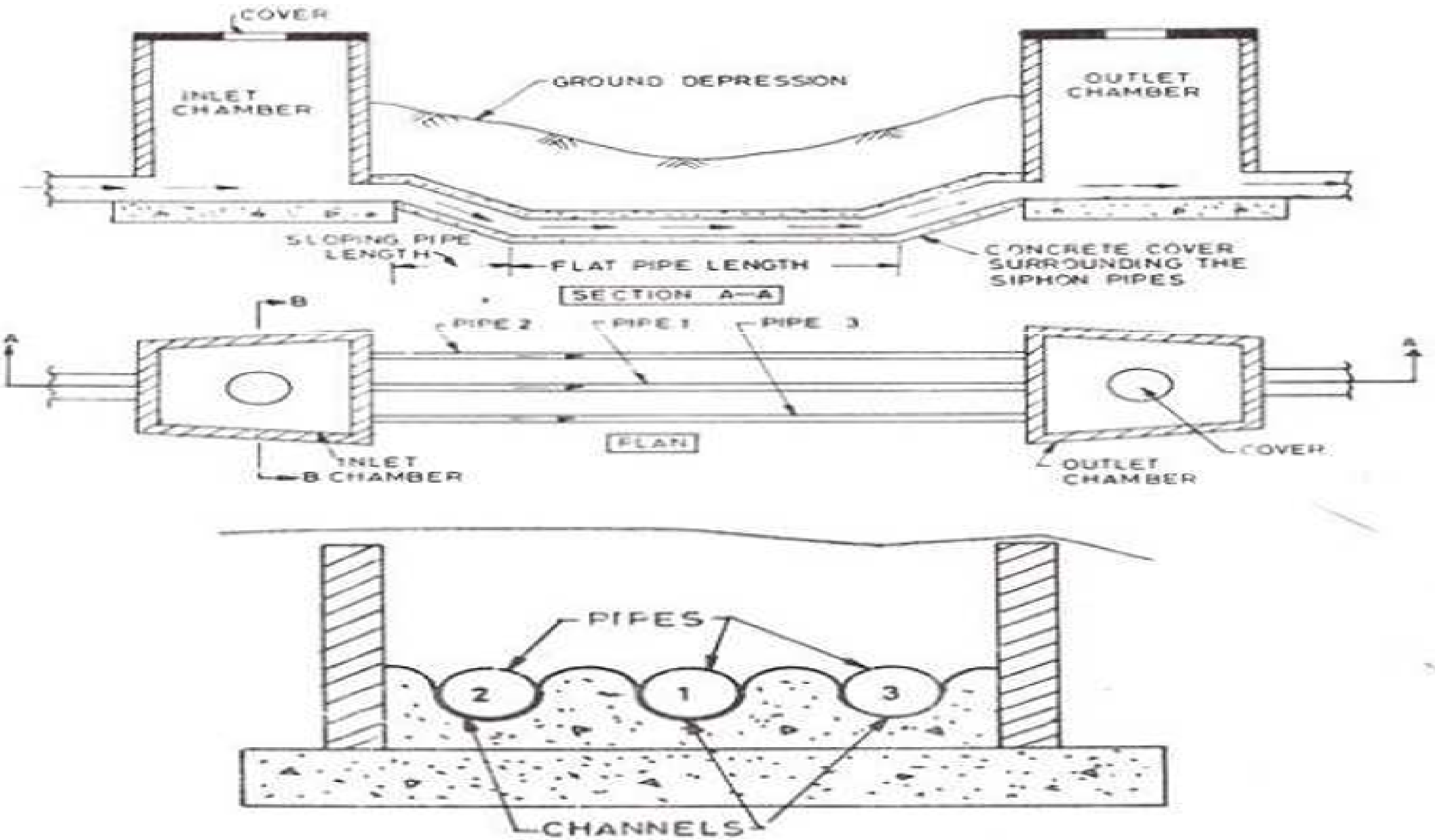

Section B—B (on enlarged scale)

3.6. Sewer Material

- The following factors are to be carefully considered while selecting materials.
  - ✓ Resistance to abrasion
  - ✓ Strength and durability
  - ✓ Light weight
  - ✓ Imperviousness
  - ✓ The economy and cost
  - ✓ Hydraulically efficient (Smooth) of sewer.
  - ✓ Resistance to corrosion

- The following are the various materials, which are used for sewers.

- ✓ Cast and ductile iron,
- ✓ PVC (polyvinyl chloride),
- ✓ Concrete, asbestos cement,
- ✓ HDPE (high density polyethylene),
- ✓ Brick, and vitrified clay

Most sewer pipes are made of concrete.

End of chapter three