CHAPTER 04

Design of Sewerage System and Sewer Appurtenances

INTRODUCTION

Providing an adequate sewer system for an area is an art that requires careful engineering. It should be properly and skillfully, planned and designed so as to transport the entire sewage effectively and efficiently from the houses and up to the point of disposal. The sewer must be adequate in size or they will overflow and causes property damage, danger to health and nuisance. Adequacy in size of sewer calls for correct estimation of the amount of sewage and use of hydraulics to determine proper size and grades of sewers, which will permit reasonable velocity of flow. This flow should neither be too large as to require heavy excavations and high lift pumping nor should it be too small to cause deposition of solids in sewer bottom with accompanying odours and stoppages.

4.1 Difference in the Design of Water Supply Pipes and Sewer Pipes

The hydraulic design of sewers and drains, which means finding out their sections and gradients, is generally carried out on the same lines as that of the water supply pipes. There are two major differences between the characteristics of flows in sewers and water supply pipes.

(i) 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 conduits and they must, therefore, be 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.

(ii) Water supply pipes carry pure water without containing any kind of solid particles, either organic or inorganic in nature. The sewage, on the other hand, does contain such particles in suspension and the heavier of these particles may settle down at the bottom of the sewers as and when the flow velocity reduces, thus ultimately resulting in the clogging of the sewers. In order to avoid such clogging or silting of sewers, it is necessary that the sewer pipes be of such a size and laid at such a gradient as to generate self-cleansing velocities at different possible discharges. The sewer materials must also be capable of resisting the wear and tear caused due to abrasion of the solid particles present in the sewage, with the interior of the pipe.

4.2 Sewer Materials

Vitrified clay (or stone ware), cement concrete, asbestos cement and cast iron are the most common materials used for construction sewer pipes. While selecting a particular material for construction sewer pipes, the important factors which must be considered are:

(i) **Resistance to corrosion:** The sewer pipes are likely to be acted upon by sewer gases, and thus get corroded, due to the presence of acids and other impurities in sewage.

(ii) **Resistance to abrasion:** When the sewage contains a lot of grit and sand particles, moving at a high velocity at the sewer invert, a log of wear and tear of the sewer material may be caused due to abrasion. To avoid this erosion or wear and tear of the sewer pipes, the sewer material must be strong enough, so as to withstand such possible abrasions.

(iii) **Strength and durability:** The sewer pipes should be strong enough to withstand all the forces that are likely to come on them. Since they are laid well below the ground level, they are subjected to considerable external loads.

(iv) **Light weight:** The material used for sewers should be light, so that the sewers can be easily handled and transported.

(v) **Imperviousness:** The sewer material should be impervious as not to allow any seepage of the sewage from the sewer.

(vi) **The economy and cost:** The sewer material must be cheaper and less costly as to cause overall economy in their construction.

(vii) **Hydraulically efficient:** The sewer material should be such as to provide a smooth interior surface (with Manning's N as low as possible) so as to provide an hydraulically efficient surface.

Besides cement concrete, asbestos cement and vitrified clay which are the commonly used materials, other materials which may also be used for sewer constructions are bricks, cast iron and plastics. The sewers of different possible materials and their comparative utilities are described below:

1. **Asbestos cement sewers:** Asbestos cement pipes are manufactured from a mixture of asbestos fibre, silica and cement, converted under pressure to a dense homogeneous materials, possessing considerable strength, called asbestos cement. The asbestos fibre which is thoroughly mixed with cement serves as reinforcement, and provides a strong material. These pipe are normally available in sizes say from 10 to 90 cm in diameter and 4 metres in length.

   Joining: These pipes can be easily assembled without skilled labour, with the help of a special coupling (called Ring Tie coupling or Simplex joint) as shown in fig. 4.1. The assembly consists of a pipe sleeve and two rubber rings, which are compressed between the pipe and the interior of the sleeve. The joint is as resistant to corrosion as the pipe itself, and is flexible enough as to permit as much as 12° deflection, while laying the pipes around curves (in plan)

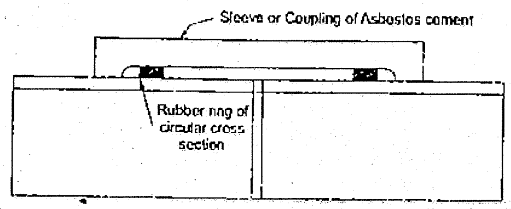


Fig.4.1 Simplex joint for AC pipes

The advantages of AC pipes are:

(i) They are light in weight and hence easy to transport.

(ii) They can be easily cut and assembled without skilled labour.

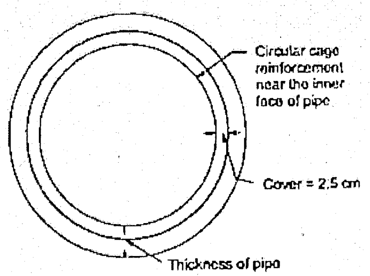
(iii) Their interior surface is exceptionally smooth (with Manning's N = 0.011), thus providing an excellent hydraulically efficient sewer.

The disadvantages of AC pipe are:

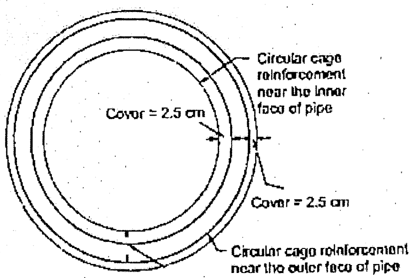
(i) They are structually not strong enough to bear the huge compressive stresses induced by the heavy external loads to which the deeply buried sewers may be subjected to.

(ii) They are susceptible to corrosion by sulphuric acid from hydrogen sulphide gas generated in sanitary waste water or by some industrial chemicals. The sulphide corrosion of asbestos cement as well as cement concrete pipes is a big problem in areas where the sewage is strong, stale and very warm, because under such conditions the bacterial activity responsible for producing hydrogen sulphide gas gets accelerated. Hence in all such cases, vitrified clay (popularly called stone ware) pipes should be used for sewers of less than 1 m in diameter, and cement concrete pipes with cast insitu plastic linings may be used for larger diameter sewers.

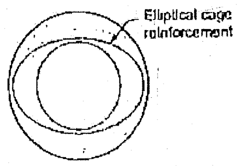
2. **Plain cement concrete and reinforced cement concrete sewers:** Plain cement concrete pipes are manufactured in small sizes, while they are reinforced with steel reinforcement for larger diameter pipes. RCC pipes are easily available in sizes up to diameters say 1.8 metres, and may be got manufactured for larger diameters say upto about 4.5 meters, on special orders. These pipes may either be prepared at site by transporting ingredients (i.e., cement, steel aggregates, water, etc.) or can be manufactured in factories, and then transported to site.



(a) Single cage reinforced pipes (only main circumferential reinforcement shown)



(b) Double cage reinforced pipes (only main circumferential reinforcement shown)



(c) Elliptical cage reinforced pipes (only main circumferential reinforcement shown)

Fig. 4.2

They are known as cast in situ pipes in the former case, and precast pipes in the latter case. Cast insitu pipes are useful when the site conditions are difficult and where it may be difficult to carry the pipes. But since such pipes are cast at site, lesser supervision and check is possible as compared to the case of precast pipes which are cast in the factories and thus subjected to greater quality control and supervision.

Reinforcement concrete (RCC) pipes are those concrete pipes which are provided with circumference reinforcement to carry internal or external stresses, and a nominal longitudinal reinforcement equal to 0.25% of the cross-sectional area of concrete. The circumferential reinforcement is generally provided in three different ways, as shown in fig. 4.2 (a), (b) and (c).

The non-pressure RCC pipes are classified according to IS 458 : 1988 into the following three categories:

(i) **NP2 pipes:** They are light duty RCC non-pressure pipes, normally used for drainage and irrigation use, for culverts carrying light traffic. The thickness of NP2 pipes vary from 25 mm for 8 cm dia. pipe to 110 mm for 2.2 m dia. pipe.

(ii) **NP3 pipes:** They are medium duty no-pressure pipes, normally used for drainage and irrigation use, for culverts carrying medium traffic. The thickness of NP3 pipes very from 25 mm for 8 cm dia pipe to 215 mm for 2.6 m dia. pipe.

(iii) **NP4 pipes:** They are heavy duty non-pressure pipes, normally used for drainage and irrigation use, for culverts carrying heavy traffic, such as railway loading.

The unreinforced as well as reinforced concrete pipes shall be capable of withstanding a test pressure of 7 m head of water.

RCC pressure pipes, classified as P1, P2 and P3 pipes, are generally used for carrying water supplies under pressure and are usually not used as sewers which are designed as gravity conduits:

RCC pipes can be manufactured in three different ways, viz.:

(a) Pipes having bar and mesh reinforcement, and concrete poured by usual ordinary methods or concrete pouring and tamped.

(b) Pipes made by rotating the mould or the form, rapidly about the pipe axis. The mould contains concrete and fabricated reinforcement. The centrifugal force throw of the concrete, which then spreads in a uniform layer over the internal surface of the mould and embed the reinforcement thus providing a high density water watertight concrete surface. This type is known as centrifugal type.

(c) The third type of pipes are made by lining thin cylindrical steel shells, both internally and externally, with rich cement concrete. These are stronger and more watertight than the first two. They are known as cylinder type.

Hume steel pipes are also the RCC pipes patented under this name, and consist of thin steel shells coated from inside with cement mortar by centrifugal process. The thickness of the inside coating varies from 12 mm to 30 mm depending upon the size of the pipe. They are also coated from outside, so as to protect the steel shell from external weather or soil action.

Advantages of concrete pipes are given below:

(i) All these different forms of cement concrete pipes are quite strong in tension (for withstanding internal pressures) as well as in compression (for withstanding external loads).

(ii) They are quite resistant to erosion and abrasion.

(iii) They can be easily moulded and manufactured either at site or in the factory.

(iv) They can be made of any desired strength by proper design and proportioning of concrete mixes.

(v) Their cast-insitu forms may be easily used at places where, owing to ground water or running sand conditions, brick sewers or cast at site concrete sewers can not be used.

(vi) They prove economical in medium and large sizes, and hence, widely adopted for branch and main sewers.

The biggest drawback of the concrete sewers, however, is the fact that they easily get corroded and pitted by the action of sulphuric acid produced from hydrogen sulphide gas (evolved from the stale sewage) or from such other chemicals present in sewage. This not only reduces the life span of the sewers but also reduces their carrying capacities with time. Besides corrosion, they are also susceptible to erosion by sewage containing too much silt and grit.

The concrete sewers can be protected from such actions by lining their interiors with vitrified clay linings, as shown in fig. 4.3. The blocks of vitrified clay, for this purpose, are provided with projections, which project and enter the cement concrete as shown. The joint between adjacent blocks are filled either with rich cement mortar or with bituminous compounds.

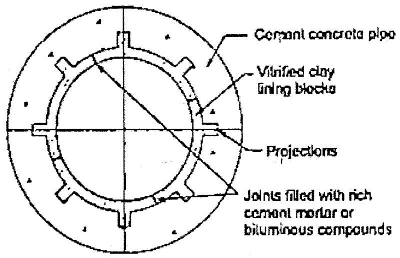


Fig. 4.3 Cement concrete pipe, lined inside with vitrified clay lining

Other methods of protecting concrete sewers from hydrogen sulphide corrosion are:

(i) Prohibiting the entry of wastes containing sulphides.

(ii) Reducing the sulphate contents by pretreating the sewage.

(iii) Aerating and chlorinating the sewage.

(iv) By adequately ventilating the sewers.

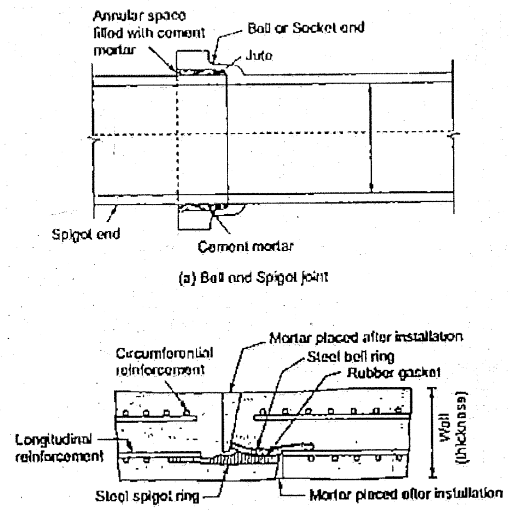
(v) By making the sewers to run full.

(vi) By adding such chemicals to sewage as may neutralise the already present sulphur compounds.

In view of its merits and drawbacks, the unlined cement concrete sewers are widely used for carrying storm water, which is comparatively free from organic impurities responsible for generating hydrogen sulphide gas. They may, however, be used for branch sewers bringing sewage free from industrial wastes. With protective linings, they are used for almost all the branch and main sewers.

Joining: The concrete pipe lengths, flowing under gravity, can be easily joined with a mortar caulked bell and spigot joint, such as shown in fig. 4.4 (a).

For such gravity flow, This pipe has been developed in size of 0.6 m to 1.8 m in diameter. A special pipe laying machine with a slip form is used. This No-joint pipe though not reinforced, is yet found to have a good life. For high pressure pipes, a lock joint such as shown in fig. 4.4 (b) may be needed. For heads above 30 m or so, a welded steel cylinder is often cast in the pipe for water tightness.



(a) Ball and Spigot joint

(b) Joint for concrete pressure pipe

Fig. 4.4

The RCC pipe lengths are joined by placing the protruding end bars of different lengths butting against one another and welding them, and finally filling the gap with rich cement concrete, so as to provide a watertight joint.

3. **Vitrified clay or stone ware or salt glazed sewers:** Vitrified clay pipes are widely used for carrying sewage and drainage, as house connections as well as lateral sewers. They are available in size of 5 cm increments from 10 to 30 cm, and in 7.5 cm increments from 30 cm to 90 cm. They are, however, rarely made in sizes bigger than 90 cm diameter.

These pipes are manufactured from clays and shales of special qualities, which are, first of all, pulverized and mixed thoroughly with water. This mixture is then used for casting standard pipe sections in a pipe press at a pressure of about 8.5 kg/cm^2. These moulded pipe sections are dried in warm air, and then burnt in hot kilns under controlled temperatures. The temperatures of the kiln is maintained at about 150°C, in the beginning for several hours, and then raised to about 700°C, and finally to about 1200°C, when fusion or vitrification of clay takes place. This makes it very dense and hard. Near the end of the burning period, sodium chloride (i.e., common salt) is placed in the kiln. The intensive heat causes the salt to vaporise, which reacts with the clay, forming a thin smooth, hard, and a waterproof glazed layer on the pipe surfaces. These pipes are joined by a bell and a spigot flexible compression joint, in which the precision mated surfaces are in tight contact with one another. These pipe lengths are, therefore, cast with having bell and spigot ends, in lengths of about 0.9 to 1.2 m. The interior surface of the socket end and the exterior surface the spigot end, are, however, not glazed so as to make a watertight joint.

The advantages of these pipes are:

(i) The stoneware pipes offer the maximum advantages of being highly resistant to sulphide corrosion, and therefore, preferred for carrying polluted sewage and industrial wastes.

(ii) Their interior are very smooth and they are hydraulically very efficient.

(iii) They are highly impervious and do not allow any sewage to very efficient.

(iv) They are, though weak in tension, yet quite strong in compression, and hence they are quite suitable for withstanding compressive stresses caused by traffic and back fills.
They, however, can withstand only very small tensile stresses caused by internal pressures. Hence, they can, through withstand slight tensile stresses caused by some chancy surcharge of gravity sewers, yet cannot be used as sewers flowing under pressure.

(v) These pipes are quite cheap, durable, easily available, and can be easily laid and joint.

(vi) They are made, non absorbent, so as not to absorb water more than 5% of their own weight, after kept immersed in water for 24 hours.

The disadvantages of these pipes are:

(i) They are heavy, bulky, and brittle, and, therefore, difficult to transport. Due to this reason, they are cast only in smaller sizes and smaller lengths. Due to their shorter lengths, numerous joints are required in laying such pipes, and due to smaller sizes, they cannot be utilized as branch or main sewers.

(ii) They cannot be used are pressure pipes, because they are weak in tension.

4. **Brick sewers:** Bricks had been used as sewer material since ancient days. They, however, have now-a-days been almost replaced by cement concrete sewers. However, they may still be used at places where the sewers are required to the constructed at the site and ingredients required for cement concreting may not be easily available. They may also be preferred for constructing large sized combined sewers, or particularly for storm water drains.
Brick sewers are generally plastered on their outer surfaces so as to prevent the entry of tree roots and ground water through the brick joints; and are lined inside with stone ware or ceramic block so as to render them smooth and hydraulically efficient. The stoneware or ceramic coating also helps in resisting sulphide corrosion which is not possible with the ordinary cement plaster as the same is easily attacked by sewer gases like hydrogen sulphide.

5. **Cast iron sewers:** Cast iron pipes are structurally stronger and capable of withstanding greater tensile, compressive, as well as bending stresses, but are costlier, compared to cement concrete or stone ware pipes. They are therefore, used as sewers, only under special circumstances, such as:

(i) For outfall sewers, for rising mains of pumping stations, or for inverted siphons, all running under pressure.

(ii) For sewers to be laid below heavy traffic loads, such as those laid below highways or railways.

(iii) For sewers which are to be 100% leak proof, so as to avoid possible contamination of under ground water supplies.

Cast iron pipes are through structurally quite stronger and durable, yet can not withstand the corrosive action of gases and other acids present in sewage; and hence generally lined from inside with cement concrete, or painted with coal tar, etc. Although the sewer pipes are not subjected to high pressures, but still they are made as heavy or even heavier than the water pipes, so as the resist the corrosive action of sewage.

6. **Lead sewers:** The lead pipes are smooth, soft, and can be easily bent to take odd shapes. They are also not affected by acid or alkaline sewage discharges, and can resist sulphide corrosion. They are, however, very costly.
The lead pipes are occasionally used in smaller sizes (3 to 4 cm diameter) and in smaller lengths in the toilets. The may be used as a downtake pipes of flushing cisterns, or as waste pipes from stall urinals and wash basins, or for geyser connections.

7. **Plastic sewers:** The use of plastics for non-pressure sewer pipes is of comparatively recent origin, and is still in the experimental stages. Yet however, certain countries like Netherlands, Scandinavia, France, etc. have already started using plastic pipes for sewers of 250 mm dia and above, on a moderate to large scale (15% to 25% or so). Their use in Germany and U.K. is hardly 5-7%, and in India, practically no plastic pipes are used for sewers, although of course, they are, finding increasing use in internal water supply and drainage fittings.

4.3 Laying of Sewer Pipes

All the sewer pipes are generally laid starting from their outfall ends, towards their starting ends. The advantage gained in starting from the tail end, (i.e. outfall end) is the utilisation of the tail length even during the initial period of its construction, thus ensuring that the functioning of the sewerage scheme has not to wait till the completion of the entire scheme.

The laying of the sewer pipes is, therefore, started from the outfall end and proceeded upward by locating the different points along the proposed alignment on the ground. It is common practice, to first locate the points where manholes are required to be constructed and then laying the sewer pipe between the two manholes.

The laying of the sewer consists of the followings steps:

4.3.1 Marking of the Alignment

The alignment of the sewer is marked along the road with a theodolite and invar tape. The centre line may be marked according to the following two methods:

(a) By Reference Line

(b) By Sight Rail

(a) **By Reference Line:** In Reference Line method, a reference line is marked along any side of the busy roads by theodolite and invar tape. The points F_1F_2...... are on the reference line. The starting point (P_1) of the centre line is marked with a peg. Then the distance F_1P_1 is measured by tape. Now the other points P_2, P_3, P_4 ..... etc. are marked pegs by taking as $F_1P_1 = F_2P_2 = F_3P_3$ .... etc. Thus, the points P_1, P_2, P_3 ..... etc. will represent the centre line of the sewer. This centre line may be checked by the theodolite. (Fig. 4.5)

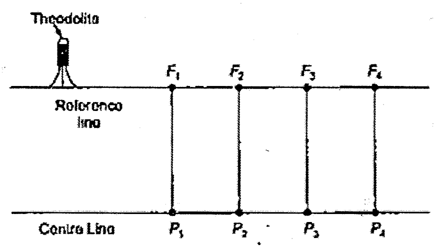


Fig. 4.5 Reference Line

(b) **By Sight Rail :** In Sight Rail method, two vertical posts are driven at suitable distance apart. Then by ranging through a theodolite the centre line is marked with nail on a sight rail which is fixed on the vertical posts. The sight rail should be fixed in such a way so that its upper edge just coincides with the line of sight. The centre line of the sewer is transferred to the ground by plumb bob with respect to the nail.

The distance between the upper edge of sight rail and the invert level is determined and noted on the sight rail for finding the exact invert level by boning rod. The length of boning rod is adjusted according to the height as noted in sight rail. The crosshead is levelled with the upper edge of sight rail and the bottom edge indicates the invert level.

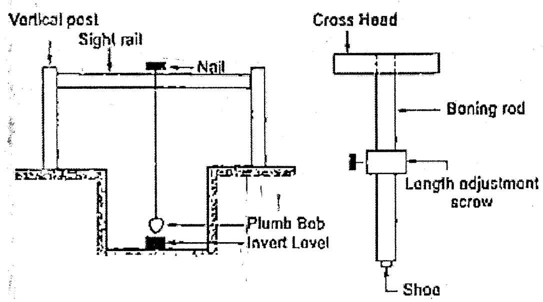


Fig. 4.6 Sight rail

4.3.2 Excavation of Trench

- The width of excavation of any level will depend upon the width of the trench at the bottom and the additions due to side slopes and due to timbering etc.
- The trench is excavated between two manholes, and the sewer is laid between them.
- Further excavations are carried out for laying the pipes between the next consecutive manholes.
- The process is continued from the outfall end of the sewer towards the uphill, till the entire sewer is laid out.

4.3.3 Bracing of the Trench

- The braces are the cross wooden pieces extending from one side of the trench to the other side and may also be called struts.
- The bracing will absorb the soil pressure and prevent it from collapsing.

4.3.4 Dewatering of Trench

- While excavating a trench, the ground water may appear, if the watertable happen to be high or if the sewer happens to be laid very deep. This ground water will create problems in further excavations.
- The ground water may be removed through an open jointed drain constructed below the sewer trench, which discharges into an independent water course either by gravity or pumping.

4.3.5 Laying of Pipes

After the bedding concrete has been laid in the required alignment and levels, the sewer pipes are lowered down in to the trench. (Fig. 4.7)

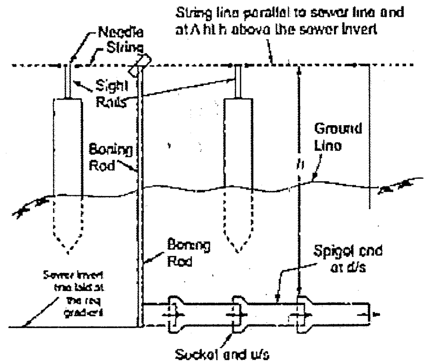


Fig. 4.7 Laying of sewer (L-section)

NOTE: The sewer pipe lengths are usually laid from the lowest point with their socket ends facing upstream.

- The spigot of each, is inserted in the socket of the laid pipe
- After fitting the socket, spigot joining is done with lead caulking or cement mortar.

4.3.6 Testing of the Sewer Pipes

The sewers after being laid and jointed are tested for water tight joints, and also for correct straight alignment, as described below:

4.3.6.1 Test for Leakage called Water Test

The sewers are tested, so as to ensure 'no leakage' through their joints after giving a sufficient time to these joints to set in. The sewer pipe sections are tested between manhole to manhole under a test pressure of about 1.5 m of water head.

In order to carry out this test on a sewer line between two manholes, the lower end (i.e. downstream end) of the sewer is first of all, plugged. The water is now filled in the manhole at the upper end, and is allowed to flow through the sewer line. The depth of water in the manhole is maintained to the testing head about 1.5 m. The sewer line is watched by moving along the trench, and the joints which leak or sweat are repaired.

4.3.6.2 Test for Straightness of Alignment and Obstruction

The straightness of the sewer pipe can be tested by placing a mirror at one end of the sewer line and a lamp at other end. If the pipe line is straight, the full circle of light will be observed. However, if the pipe line is not straight, this would be apparent, and the mirror will also indicate any obstruction in the pipe barrel.

4.3.6.3 By Air Test

The Air Test is carried out for large diameter sewer. The pipe ends of both the manholes are plugged. An air compressor is connected to the plug the upper manhole and pressure gauge is attached with the plug of lower manhole. The pressure exerted by the compressed air is recorded in the pressure gauge. It is left for few hours. If the pressure drops below the permissible limit, then it is an indication of leakage. The exact point of leakage is found out by applying soap solution which will show bubbles at the point of leakage. If leakage is detected, it should be removed immediately.

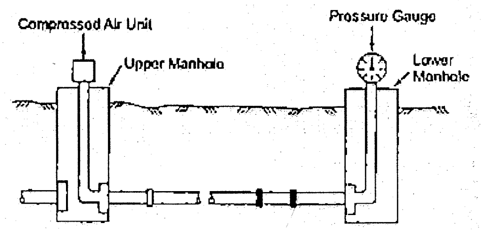


Fig. 4.8 Air Test

4.4 Types of Collection System

For the transport of entire sewage effectively and efficiently from the houses and upto the point of disposal, sewer should be designed not to flow full under gravity because reserve space in the sewer safeguards against fluctuations in sewage flow.

The three types of collection systems are:

4.4.1 Sanitary Sewer

- In sanitary sewer system, lateral sewer collects discharges from houses and carry them to another branch sewer, and has no tributary sewer lines (Fig. 4.9).

- Branches or sub-main lines receive waste-water from laterals and convey it to large mains.
- The main sewer, also known as trunk or outfall sewer, carries the discharge from large areas to the treatment plant.
- Manholes are provided at intersection of sewer lines and also at regular intervals to facilitate regular inspection and cleaning.
- They are designed to carry domestic wastes originating from the sanitary conveniences of dwellings, business buildings, factories or institutions including industrial wastes produced in the area.

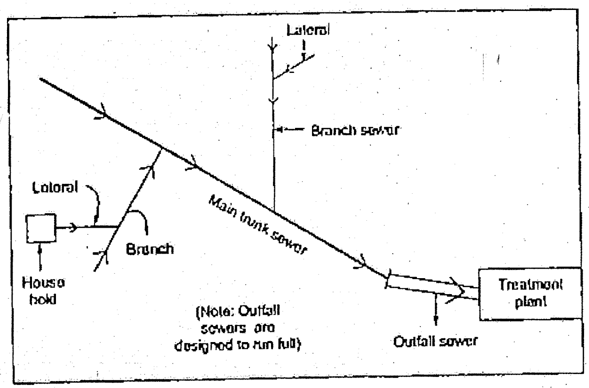


Fig. 4.9 A typical sanitary sewer layout

4.4.2 Storm Sewer

- Storm sewers carry surface runoff developed during or following the period of rainfall over concerned area including street wash.
- Surface water enters a storm drainage system through inlets located in street gutters that collect natural drainage.
- Since no house connection is required, the storm sewers may not depend upon the individual lots, and this may permit them to be run by shorter routes than that of sanitary sewers.
- Storm sewer pipes are set shallower as compared to sanitary sewers as far as possible.

NOTE

Major difference in design of sanitary and storm sewer:

(i) In sanitary and storm sewers the latter are assumed to surcharge and overflow periodically. Sanitary sewer are designed and constructed to prevent surcharging.

(ii) Second difference between sanitary and storm sewers is the pipe size that are needed to serve a given area. Storm drains are larger than the pipe collecting domestic waste water.

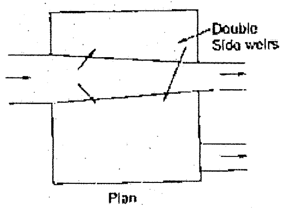


Fig. 4.10 Storm Water Overflow and Sewerage System

4.4.3 Combined Sewer System

- When the drainage is taken along with sewage, it is called Combined Sewer System.
- This system consists of a single sewer line of large diameter through which the sewage and storm water are allowed to flow and are carried to the treatment plant.

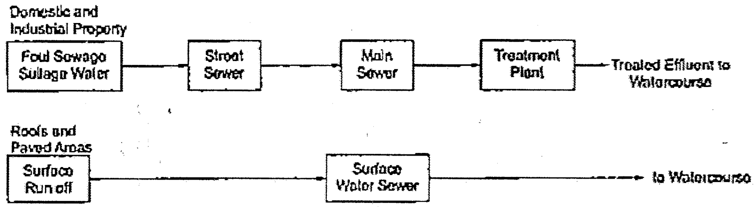


Fig. 4.11 Separate Sewerage System

- The storm water dilutes the sewage and hence its strength is reduced
- In this way, self-cleaning velocity is easily achieved
- As the single sewer line serves the double function, it becomes economical.

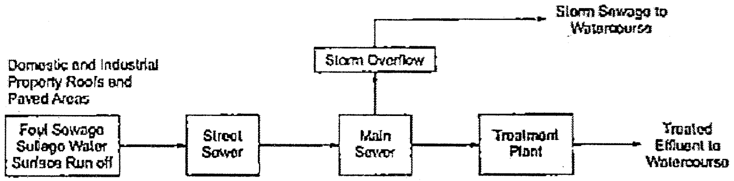


Fig. 4.12 Combined Sewerage System

Types of Sewer in a Typical Collection System

The types and sizes of sewer used will vary with size of the collection system and the location of the waste water- treatment facilities. The principal types of sewers found in most collection system are described by function in table, and illustrated graphically.

Table: 4.1 Types of sewers in a typical collection system

Type of Sewer	Purpose
Building	Building sewers, sometimes called building connections, connect to the building plumbing and are used to convey wastewater from the building to lateral or branch sewers, or any other sewer except another building sewer. Building sewers normally begin outside the building foundation. The distance from the foundation wall to where the sewer begins depends on the local building regulations.
Lateral or branch	Lateral sewers form the first element of a wastewater collection system and are usually in streets or special easements. They are used to collect wastewater from one or more building sewers and convey it to a main sewer.
Main	Main sewers are used to convey wastewater from one or more lateral sewers to trunk sewers or to intercepting sewers.
Trunk	Trunk sewers are large sewers that are used to convey wastewater from main sewers to treatment or other disposal facilities or to large intercepting sewers.
Intercepting	Intercepting sewers are larger sewers that are used to intercept a number of main or trunk sewers and convey the wastewater to treatment or other disposal facilities

Do you know? Combined sewer are generally not circular because of generating non-sufficient self cleaning velocity except rainy season. They are egg shaped sewers.

4.5 Assumptions in Sewer Design

Following assumptions are made for the purpose of hydraulic design of Sewer:

- The flow of waste water in sewer is steady and uniform. The unsteady and nonuniform waste water flow characteristics are accounted in the design by proper sizing of man holes.
- The available head in waste water lines is utilized in overcoming surface resistance and, in small part in attaining kinetic energy for the flow.
- The design of sewers are based on peak flow discharge.

Flow Formula:

- Manning's formula is used for open channel flow
- William-Hazen formula is used for closed conduit or pressure flow.

Manning's Formula:

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

where, V = velocity in meters/sec
n = Manning's coefficient of roughness
R = Hydraulic radius in meters
S = Slope of hydraulic gradient

William-Hazens Formula:

$$V = 0.849 \times C \times R^{0.63} \times S^{0.54}$$

where, C = William Hazen's coefficient

Table : 4.2 Values of C_H for William Hazen's formula

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

Crimp and Burge's Formula:

$$V = 83.5 \times R^{2/3} \times S^{0.54}$$

This formula is comparable to Manning's formula having $\frac{1}{n} = 83.5$ or $n = 0.012$

Chezy's Formula

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

where, C = Chezy's constant depends upon various factors, such as the size and the shape of the channel, roughness of the channel surface, the hydraulic characteristics of the channel. The value of C can be obtained by using either Kutter's formula or Bazin's formula.

(a) **Kutter's Formula**

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

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

Table : 4.3 Mannings or Kutter's Rugosity Coefficients (n)

S. No.	Pipe Material	Values of n at full depth for	
		Good interior surface condition	Fair interior surface condition
(1)	(2)	(3)	(4)
1.	Salt glazed stoneware 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/dains	0.013	0.015
5.	Asbestos cement	0.011	0.012
6.	Plastic (smooth) pipes	0.011	0.011

(b) **Bazin's Formula**

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

where, k = Bazin's constant

Table : 4.4 Bazin's Constant (K)

S. No.	Type of the inside surface of the sewer or drain	Value of K
(1)	(2)	(3)
1.	Very smooth surfaces.	0.11
2.	Smooth brick and concrete surfaces	0.29
3.	Rough brick and concrete surfaces.	0.50
4.	Smooth rubble and masonry surfaces.	0.83
5.	Good earthen channels.	1.54
6.	Rough earthen channels.	3.17

4.6 Design Data

- Sanitary sewers are design to run partially full (flow under gravity)
- Sewer should be designed to carry peak discharge i.e. maximum hourly discharge, and should be checked to ensure that at minimum discharge, (i.e. minimum hourly discharge) velocity generated should be greater than self cleansing velocity.

- Self cleansing velocity is the minimum velocity at which not any solids get deposited at the bottom of sewer.
- Self cleansing velocity is given by shield's formula

Table 4.5	
Pipe Size	Maximum discharge condition
D < 0.4 m	$\frac{1}{2}$ full at maximum discharge
0.4 ≤ D ≤ 0.9 m	$\frac{2}{3}$ full at maximum discharge
D ≥ 0.9 m	$\frac{3}{4}$ full at maximum discharge

$$V = \frac{1}{n} R^{1/6}\left[K_s (G_s - 1) d_p\right]^{1/2}$$

where, G_s = Special gravity of particle

d_p = particle size

k_s = a dimension less constant with a value of about 0.04 to start motion of granular particle and about 0.8 for adequate self cleansing of sewer.

R = hydraulic radius of sewer

n = Manning coefficient

Ensuring self cleansing velocity at minimum flow ensures that no solid is deposited even at minimum flow. However, sometimes design is done in such a way that although solid silting may occur at minimum flow, the same should be flushed out at a peak flow.

It is assumed that almost 75%-80% of accounted water supply goes into sewage.

NOTE

(i) The inorganic sand particles of diameter 1 mm and specific gravity of 2.65 can be removed with a minimum velocity of about 0.45 m/sec.

(ii) Organic particle of 5 mm diameter can also be removed with same minimum velocity.

4.7 Maximum Velocity

- The maximum velocity helps in
  (i) keeping the sewer size under control.
  (ii) preventing the sewage from getting stale and decomposed by moving it faster, thereby preventing evolution of foul gases.
- To avoid erosion of pipe surface maximum velocity should be limited as follows.

Table : 4.6 Non-scouring Limiting Velocities in Sewers and Drains

S.No.	Sewer Material	Limiting velocity in m/sec
1.	Vitrified tiles and glazed bricks	4.5 – 5.5
2.	Cast iron sewers	3.5 – 4.5
3.	Stone ware sewers	3.0 – 4.0
4.	Cement concrete sewers	2.5 – 3.0
5.	Ordinary brick - lined sewers	1.5 – 2.5
6.	Earthen channels	0.6 – 1.2

- Slope of sewer should be designed for minimum permissible velocity at minimum flow.

Hydraulic Characteristics of Circular Sewer Sections Running Full or Partially Full

The circular section is most widely adopted for sewer pipes. They may however, sometimes be of 'egg shape' or 'horse shoe shape' or 'rectangular shape'. The circular sewers may sometimes run full or may run partially full. When they run full, their hydraulic properties will be as given below:

Area of cross section

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

where D is dia of the pipe

welled perimeter

$$P = \pi D$$

∴ Hydraulic mean depth

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

When the sewer run partially full, at a depth, say d, as shown in figure 4.13, the hydraulic elements can be worked out as given below.

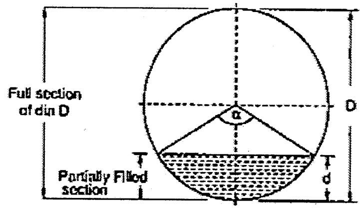


Fig. 4.13 Partially filled circular sewer section

The depth at partial flow

$$= d = \frac{D}{2} - \frac{D}{2}\cos\frac{\alpha}{2}$$

where α is the central angle in degrees as shown in figure.

∴ Proportionate depth

$$= \frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\alpha}{2}\right) \quad \text{...(i)}$$

Area of cross-section while running partially full

$$= a = \frac{\pi D^2}{4} \times \frac{\alpha}{360°} - \frac{D}{2}\cos\frac{\alpha}{2}\frac{D}{2}\sin\frac{\alpha}{2}$$

$$= \frac{\pi D^2}{4}\left[\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right] \quad \text{...(ii)}$$

∴ Proportionate area $= \frac{a}{A} = \left[\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right]$ ...(iii)

welted perimeter, while running partially full

$$= p = \pi D \cdot \frac{\alpha}{360} \quad \text{...(iv)}$$

∴ Proportionate perimeter $= \frac{p}{P} = \frac{\alpha}{360°}$ ...(v)

Hydraulic mean depth (H.M.D), which running partially full

$$= r = \frac{a}{p} = \frac{D}{4}\left[1 - \frac{360° \sin\alpha}{2\pi\alpha}\right] \quad \text{...(vi)}$$

∴ Proportionate H.M.D $= \frac{r}{R} = \left[1 - \frac{360° \sin\alpha}{2\pi\alpha}\right]$ ...(vii)

velocity of flow is given by Manning's formula, as

v = velocity at partial flow

$$= \frac{1}{n} r^{2/3} \sqrt{S_0}$$

[∵ $S = S_0$ i.e. bed slope]

∴ V = velocity, when running full

$$= \frac{1}{N} R^{2/3} \sqrt{S_0}$$

[Bed slope $S = S_0$ remains constant whether pipe runs full or partially full]

$\therefore$ Proportionate velocity $= \frac{v}{V} = \frac{N}{n} \cdot \frac{r^{2/3}}{R^{2/3}}$ ...(viii)

Assuming that roughness coefficient n does not vary with depth,

we have $n = N$

$\therefore$ Proportionate velocity $= \frac{v}{V} = \frac{r^{2/3}}{R^{2/3}} = \left[1 - \frac{360° \sin\alpha}{2\pi\alpha}\right]^{\frac{2}{3}}$ ...(ix)

Since, discharge is given by a.v, therefore

Discharge when pipe is running partially full

$= q = av$ ...(x)

Discharge when pipe is running full

$= Q = AV$ ...(xi)

$\therefore$ Proportionate discharge $= \boxed{\frac{q}{Q} = \frac{av}{AV} = \frac{a}{A} \cdot \frac{v}{V}} = \boxed{\frac{q}{Q} = \left[\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right]\left[1 - \frac{360° \sin\alpha}{2\pi\alpha}\right]^{2/3}}$ ...(xii)

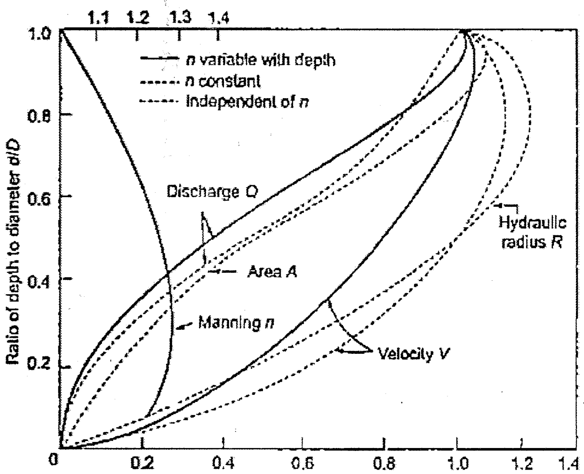


Fig. 4.14 Hydraulic elements for circular sewers

By knowing the conditions under which sewer runs full and by knowing two ratios by hydraulic elements under partial and full flow conditions, third can be calculated analytically or by using partial flow diagram.

Remember

- If Manning's coefficient 'n' is assumed constant with depth then $\frac{v}{V} = \left(\frac{r}{R}\right)^{2/3}$
- For constant 'n', velocity of flow is maximum when $\frac{d}{D} = 0.81$ and this V_{max} is 12.5% greater than when running full.
- For constant 'n', discharge is maximum when $\frac{d}{D} = 0.95$ and this q_{max} is 7% greater than the discharge at running full.
- $\frac{v}{V}$ decreases less sharply than $\frac{q}{Q}$ below $\frac{1}{2}$ full depth (for constant n)
- As $\frac{d}{D} < 0.5$, the decline in velocities is not so sharp as the decline in discharges, because the area (on which discharge depends) reduces much faster as compared to the hydraulic mean depth (on which velocity depends).
- $\frac{q}{Q} = \frac{1}{2}$ at $\frac{1}{2}$ full flow (n = constant)
- If $\frac{q}{Q} \to 0.5$ then $\frac{v}{V} \geq 1$ (for n = constant)
- For most efficient system, design should be done for 3 times of average and self cleaning velocity should be checked for $\frac{1}{3}$rd of daily discharge.

Example 4.1. **Design a sewer to serve a population of 36000. Daily water supply per capita = 135 l of which 80% goes into the sewer. Slope, $S = \frac{1}{625}$ and the sewer would be designed to carry 4 times the average discharge under design condition. What would be the velocity generated if $n = 0.012$ and it is assumed to be constant.**

Solution:

$$Q_{design} = 4 \times \left[0.8 \times 135 \times 36000 \frac{10^{-3}}{86400}\right] = 0.18 \text{ m}^3/\text{s}$$

$$S = \frac{1}{625}$$

Assume $\frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\alpha}{2}\right) = 0.66$

$$\alpha = 217.325°$$

$$\frac{q}{Q} = \left(\frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}\right)\left(1 - \frac{360 \sin\alpha}{2\pi\alpha}\right)^{2/3} = (0.804)(1.206)^{2/3} = 0.7727$$

$\Rightarrow$ $Q = 0.2329 \text{ m}^3/\text{sec}$

$$Q = \frac{1}{0.012} \times \left(\frac{D}{4}\right)^{2/3} \times \left(\frac{1}{625}\right)^{1/2} \times \frac{\pi D^2}{4} = 0.2329 \text{ m}^3/\text{s}$$

$\Rightarrow$ $D = 570$ mm

$$V = \frac{0.2329}{\frac{\pi}{4}(0.57)^2} = 0.912 \text{ m/sec}$$

$$\frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = (1.1039)^{2/3}$$

$\Rightarrow$ $v = 1$ m/sec

As the velocity is greater than 0.8 m/s at design flow it will ensure that at minimum flow, the velocity generated will be more than self cleansing velocity.

Example 4.2 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, $V = \frac{1}{N} R^{2/3} \cdot \sqrt{S}$

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

or $\sqrt{S} = 0.0568$

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

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 as

$$S_S = \left(\frac{R}{r}\right) S = \frac{1}{0.7705} \times 3.234 \times 10^{-3} \left[\because \frac{r}{R} = 0.7705 \text{ given}\right] = 4.2 \times 10^{-3}$$

i.e. $= 4.2\ \%$

(i) Hence, the reqd. grade = 4.2%

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

$$v_s = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6} \cdot V = 1 \times (0.7705)^{1/6} \cdot 0.8 = 0.765 \text{ m/sec.}$$

(iii) The discharge q_s, is then given by

$$q_s = a.v_s$$

$$= 0.315 \frac{\pi}{4} \times (0.35)^2 \times 0.765 = 0.023 \text{ cumecs.}$$

4.8 Equal Degree of Self cleansing

4.8.1 Shield's expression for self-cleansing velocity

Self cleansing velocity which is necessary to cause scouring and suspension of solid particles can be determined as follows:

Consider a layer of sediment of unit width and unit length and of thickness t deposited at the invert of a sewer of gradient θ. Let γ_{sub} is the submerged unit weight of sediment considered. Fig. 4.15.

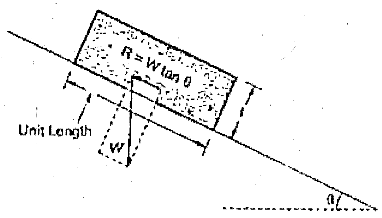


Fig. 4.15

Weight of sediment considered,

$$W = \gamma_{sub} (1)(1) t$$

But $\gamma_{sub} = \gamma_w \left(\frac{S_s - 1}{1 + e}\right)$ where, γ_w = unit weight of the water

S_s = specific gravity of the sediment

e = void ratio of sediment

But the porosity of sediment

$n = \left(\frac{e}{1+e}\right)$ where, n = porosity of sediment

$\therefore \quad 1 - n = \frac{1}{1+e}$

$\therefore \quad \gamma_{sub} = \gamma_w (S_s - 1)(1 - n)$

$\therefore \quad W = \gamma_w (S_s - 1)(1 - n) t$ ...(1)

It is necessary that the drag force (τ) exerted by the flowing water on the surface of the channel equals the frictional resistance R, i.e τ = R.

But, $R = W \tan \theta$

and for smaller value of θ,

$\tan \theta = \sin \theta$

$\therefore \quad R = W \sin \theta$

or $\tau = R = W \sin \theta$ ...(2)

or $\tau = \gamma_w (G - 1)(1 - n) t \sin \theta$ ...(3)

But we know that the drag force or the intensity of tractive force (τ) which is exerted by the flowing water on a channel of hydraulic mean depth r is given by

$\tau = \gamma_w \times r \times S$ when τ = drag force ...(4)

r = hydraulic mean depth of the channel

s = bed slope of the channel

equating equation (3) and (4), we have

$\gamma_w (G - 1)(1 - n) t \sin \theta = \gamma_w r s$

using $(1 - n) \sin \theta = K'$ (a constant), we get

$$(G - 1) K' \cdot t = r s \quad \text{or} \quad s = \frac{K'}{r}(G - 1) t$$

For single grains, the volume per unit area (i.e t) becomes a function of the diameter of the grain d' as an inverse measure of the surface area of the individual grains exposed to drag as friction

$$s \propto \frac{K'}{r}(G - 1) d' \quad \text{(for self cleansing)}$$

or $$s = \frac{k}{r}(G - 1) d'$$

Hence, the self cleansing invert slope (s) is given by

$$\boxed{s = \frac{k}{r}(G - 1) d'} \quad ...(5)$$

Where k is a dimensional constant, indicating an important characteristic of sediment present in sewage. Its value usually varies from 0.04 (minimum) applicable to start of scouring of clean grit to about 0.8 applicable for full removal of sticky grit. For relatively clean inorganic and organic matters present in sewage, its values are taken as 0.04 and 0.06 respectively. The actual value of k, should, however be determined only by experiments for different materials.

Hence, the invert slope at which the sewer will be self cleansing is given by equation (5).

Now from Chezy's formula, the velocity

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

∴ Self cleansing velocity $(V_s) = C\sqrt{r}\sqrt{\frac{K}{r}(G-1)d'}$ ...(6)

The Chezy's constant (C) in the above equation can be equated to $\sqrt{\frac{8g}{f'}}$ by comparing Chezy's formula and Darcy Weisbach formula.

$$\boxed{V_s = \sqrt{\frac{8g}{f'}kd'(G-1)}}$$

The usual value of f' for server pipe is 0.03. Similarly by equating Chery's formula with Manning's formula $\left(\text{i.e } V = \frac{1}{n}r^{2/3}\sqrt{s}\right)$. We can get $C = \frac{1}{n}r^{1/6}$. Then equation (6) becomes

$$\boxed{V_s = \frac{1}{n}\cdot r^{1/6}\sqrt{kd'(G-1)}} \quad ...(8)$$

From equation (4)

$$\gamma_w \cdot r \cdot s = \gamma_w \cdot R \cdot S \qquad \text{where } S = S_s$$

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

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

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

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

Remember: When minimum velocity requirement in a sewer is not satisfied option is to
(a) Increase the slope (b) Increase the dia of sewer

4.9 Egg Shaped Sewer

- Circular sewer sections are mostly used for separate sewage system.
- The circular sections are generally preferred to all other shapes because of their following advantages:
  - (i) They can be manufactured most easily and conveniently.
  - (ii) A circular sewer provides the maximum area for a given perimeter and thus providing the maximum hydraulic mean depth when running full or half full, and is therefore, the most efficient section of these flow conditions.

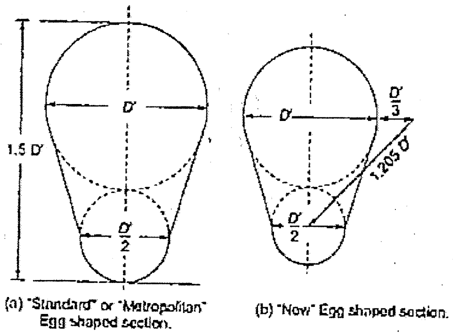


Fig.4.16 Typical view of Egg Shaped Section

  - (iii) Circular section utilizes the minimum quantities of materials and is therefore the cheapest and most economical.
  - (iv) A circular section, being of uniform curvature all round, offers less opportunities for deposits.
- All these advantages of circular sections are obtained only when the sections runs at least half full. When the depth goes below half depth the velocity reduces considerably.
- If a circular sewer is used for combined system it will be effective only during maximum rain water flow but during dry weather flow, velocity generated would be very less. Thus to take advantage of a circular sewer, two such circular sewer are assumed to be combined into one to form an "egg shaped sewer" in which smaller circular portion will be effective during dry weather and full section is effective during maximum rain water flow.
- Two sewers of different shapes are said to be hydraulically equivalent when they discharge at the same rate, while flowing full, on the same grade.
- The egg shaped sewer of an equivalent section, whose top diameter $D' = 0.84$ D, when D = diameter of circular sewer of same cross-section are obtained for passing the requisite discharge.
- Their disadvantage over circular sewer are:
  - (i) They are more difficult to construct.
  - (ii) Since the smaller base has to support the weight of the upper boarder section, they are less stable.
  - (iii) They require more material and are, therefore, more costly.

NOTE
In combined sewers, the variation in discharge could be as large as 20 to 25 times. Egg shaped sewer produces 2 to 15% higher velocity than that provided by hydraulically equivalent circular sewer.

4.10 Storm Water Drainage

- Design of storm water drainage requires the estimation of peak runoff rate for design.
- Peak runoff depends on the intensity of rainfall.
- The intensity of rainfall depends on recurrence interval and duration of rainfall.

NOTE
Rain of larger recurrence interval will have higher intensity. Hence 5 year recurrence interval rain is chosen for design, then it may lead to flooding in every 5-year (because the rainfall has a probability of exceeding the adopted value every 5-years and drainage has not been designed for this large rainfall). If larger frequency of rainfall is adopted in design, larger sewer will be required to carry the runoff safely.

4.10.1 Computing the peak drainage discharge by the use of Rational Formula

4.10.1.1 Time of Concentration

- If a rainfall is applied to an impervious surface at a constant rate, the resultant runoff from the surface would finally reach a rate equal to the rainfall. In the beginning, only a certain amount of water will reach the outlet, but after sometime the water will start reaching the outlet from the entire area, and in this case, the runoff rate would become equal to the rate of rainfall. "The period after which the entire area will start contributing to the runoff is called the Time of concentration"

- The time of concentration for a given storm water drain generally consist of two parts.
  1. The inlet time or overland flow time or time of equilibrium (T_i). The time taken by the water to flow overland from the critical point upto the point when it enters the drain mouth.

$$T_i = \left(0.885\frac{L^3}{H}\right)^{0.385}$$

where, T_i = Inlet time in hours

L = length of overland flow in km from the critical point to the mouth of the drain.

H = Total fall of level from the critical point to the mouth of the drain in meters.

  2. The channel flow time or gutter flow time (T_f) i.e. the time taken by the water to flow in the drain channel from the mouth to the considered point. This may be obtained by dividing the length of the drain by the flow velocity in the drain.

$$T_f = \frac{\text{Length of the drain}}{\text{Velocity in the drain}}$$

The total time of concentration (T_c) = $T_i + T_f$

4.10.1.2 Rain Fall Intensity

The intensity of rainfall during this much of time (for the given design frequency) can be easily obtained from the standard intensity duration curves or DAD curves.

The value of intensity so obtained is still the rainfall intensity at the rain gauge station and is called the "point rainfall intensity". In order to make it effective over the entire catchment area, it is necessary to multiply it by a factor called dispersion factor or areal distribution factor. Fig. 4.17

Thus design rainfall intensity = (point rainfall intensity) × (area dispersion factor)

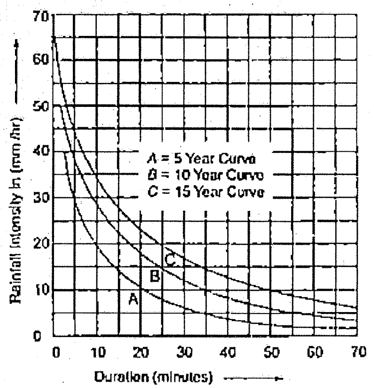


Fig. 4.17 Typical Intensity Duration Curves

- In absence of standard intensity duration curves, the value of design rainfall intensity (p_c)

$$p_c = p_0\left(\frac{2}{1+T_c}\right)$$

p_0 = (point rainfall intensity of a particular frequency) × (area dispersion factors)

This point rainfall intensity is obtained from contour map or maximum rainfall of a particular frequency.

p_0 is in cm/hr

p_c is in cm/hr

T_c in hr = Time of concentration

- The design rainfall can also be obtained from the formula.

$$p = \frac{a}{T+b}$$

where, p = Rain intensity in cm/hr

T = Time in minutes

a and b = Constants

$$p = \frac{75}{T_c+10} \quad \text{(for } T \text{ varying between 5 to 20 minute)}$$

and

$$p = \frac{100}{T_c+20} \quad \text{(for } T \text{ varying between 20 to 100 minutes)}$$

4.10.2 Rational Formula

$$Q = C \cdot p \cdot A$$

where, Q = Peak rate of runoff (m^3/s)

p = Runoff coefficient $\frac{\text{runoff}}{\text{rain flow}}$

i = intensity of rainfall (m/s)

A = drainage basin area-catchment area (m^2)

The coefficient of Runoff (C) is in fact, the impervious factor of runoff, representing the ratio of precipitation to runoff. Runoff coefficient value increase as imperiousness of catchment increases. When several different types of surfaces comprise the catchment than weighted average value of runoff coefficient is adopted.

$$C_{av} = \frac{C_1A_1 + C_2A_2 + C_3A_3 + \ldots\ldots}{A_1 + A_2 + A_3 + \ldots\ldots}$$

A_1 area has runoff coefficient = C_1

A_2 area has runoff coefficient = C_2

A_3 area has runoff coefficient = C_3 etc.

NOTE

1. Rainfall intensity depends on the storm recurrence interval and the storm duration.
2. In intensity duration curves, if 15 hr recurrence interval rain is to be adopted and time of concentration is 25 minutes then rain fall intensity to be adopted will be 25 mm/hr.

Example 4.3 The surface water from airport road side is drained to the longitudinal side drain from across one half of a bituminous pavement surface of total width 7.0 m, shoulder and adjoining land of width 8.0 m on one side of the drain. On other side of the drain, water flows across from reserve land with average turf and 2% cross slope towards the side drain, the width of the strip of land being 25 m. The inlet time may be assumed to be 10 min for these conditions. The runoff coefficients of the pavement, shoulder and reserve land with turf are 0.8, 0.25 and 0.35 respectively. The length of the stretch of land parallel to the road from where the water is expected to flow to the side drain is 400 m. Estimate the quantity of runoff flowing in the drain assuming 10 year frequency. The side drain will pass through clayey soil with allowable velocity of flow as 1.33 m/s. Intensity duration chart for 10 year frequency is

Duration (minutes)	5	10	15	20	30
Intensity (mm/hr)	160	150	125	110	95

Solution: Average runoff factor K for the entire area contributing discharge

$$K = \frac{K_1A_1 + K_2A_2 + K_3A_3}{A_1 + A_2 + A_3} = \frac{0.8\times(7\times400)+0.25\times(8\times400)+0.35\times(25\times400)}{(7\times400)+(8\times400)+(25\times400)}$$

$$= \frac{6540}{2800+3200+10000} = 0.40875$$

Total area = $16000\ m^2$ = 1.6 ha

Time of concentration

$$T_C = T_i + T_f$$

$$T_f = \text{channel flow time in drain} = \frac{400}{1.33} = 300 \text{ sec} = 5 \text{ min}$$

$$\therefore \quad T_C = 10 + 5 = 15 \text{ min}$$

Corresponding of T_C, rainfall intensity = 125 mm/hr

$$\Rightarrow \quad P_C = 12.5 \text{ cm/hr}$$

$$\text{Peak discharge } Q_P = \frac{1}{36} K P_C A = \frac{1}{36} \times 0.40875 \times 12.5 \times 1.6 = 0.227 \text{ m}^3/\text{s}$$

Example 4.4 : 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 strom 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 $= 250 \times 1{,}00{,}000$ litres/day

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

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

Average sewage discharge $= 0.8 \times 0.289 = 0.23$ cumecs

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

Maximum sewage discharge $= 3 \times 0.23 = 0.69$ cumecs

Storm water discharge computations

Time of concentration T_c = Time of entry + Time of flow = (10 + 20) minutes = 30 minutes

Now, maximum hourly rainfall for the area = p_o = 5 cm/hr.

$$P_C = P_o\left(\frac{2}{1+T_c}\right)$$

where T_C is the concentration time in hours $= \frac{30}{60} = 0.5$ hour

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

Now, using rational formula, we have

$$\text{Max. storm run off} = Q_P = \frac{1}{36} \times 0.45 \times 6.67 \times 120 \text{ cumecs} = 10 \text{ cumecs}$$

$\therefore$ The combined maximum discharge

= Storm run-off + Sewage discharge

= 10 + 0.69 = 10.69 cumecs.

Now assuming the sewer to be running full at the maximum velocity of 3 m/sec at the time of maximum flow, we have

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

$$\therefore \quad \text{Dia of sewer pipe required} = \sqrt{\frac{4}{\pi} \times 3.56} = \sqrt{4.53} = 2.13 \text{m}$$

Hence, use a sewer pipe of 2.13 m dia.

4.11 Sewer Appurtenances

Sewer appurtenances are those structures which are constructed at suitable intervals along a sewerage system and help in its efficient operation and maintenance. These devices include:

1. Manholes
2. Drop manholes
3. Lampholes
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

4.11.1 Manholes

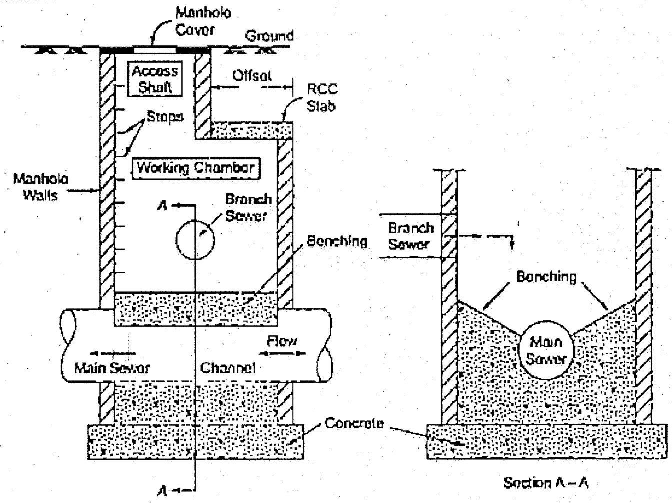


Fig. 4.18 Deep Manhole

- Manholes are masonary or R.C.C chambers, constructed at suitable intervals along the sewer lines for providing access into them. Thus it help in joining sewer lengths, in their inspection, cleaning and maintenance.

- The manholes are provided at every bend, junction, change of gradient or change of sewer dia.
- The larger is the diameter of the sewer, the greater will be the spacing between the manhole.
- Depending upon their depth the manholes are classified as
  (i) Shallow manholes (ii) Normal manholes (iii) Deep manholes
  Component of Manhole:

4.11.1.1 Access Shaft

- The upper portion of a deep manhole is called access shaft.
- Its minimum size for a rectangular manhole is about 0.75 × 0.6 m and for a circular manhole, the minimum diameter is about 0.6 to 0.75 m.

4.11.1.2 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.
- Height of chamber 1.8 m or more
  Minimum size of Rectangular manholes $\simeq$ 1.2 m × 0.9 m
  Minimum size of circular manhole diameter $\simeq$ 1.2 m

4.11.1.3 The Benching

- The bottom portion of the manhole is constructed in cement concrete.
- A semicircular or a U-shaped channel is generally constructed and the sides are made to slope towards it.
- The concreting is known as benching and facilitates the entry of sewage into the main sewer.

4.11.1.4 The Side Walls

- The side walls of the manhole are made of brick or stone masonry or R.C.C.
- The minimum thickness of the bricks walls should be 22.5 cm
- $t = 10 + 4d$ (for brick wall)
  where t = thickness of wall in cm
  d = Depth of excavation in meters.

4.11.1.5 Steps or Ladders

- Steps are generally provided for descending into the manhole.
- The steps are made of cast iron and are placed staggered at a horizontal distance of about 20 cm and at a vertical centre to centre distance of about 30 cm.

4.11.1.6 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 25 cm and its base is about 10 cm wide.

Do you know? Sewer cover is always circular because it can never drop down in sewer.

4.11.2 Drop Manhole

- When the branch sewer enters a manhole by more than 0.5 to 0.6 m above the main sewer, the sewage is not allowed to fall directly, but brought into it through a down pipe.
- If the drop is only a few meters, the down pipe can be kept sloping (at 45° to the ground), and if 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, where as, the one using an inclined pipe is called a ramp.
- The drop manhole serve the following purposes.
  (i) It avoid a lot of earth work excavation
  (ii) The sewage trickling into the manhole from the directly placed branch sewer is likely to fall on persons working in the manhole. This is avoided in drop manholes.

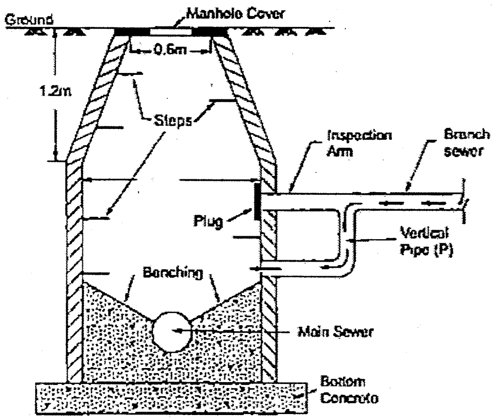


Fig. 4.19 A typical section of circular drop manhole

- A plug is provided at the point where branch sewer, if taken straight, intersects the wall of the manhole. The length of the branch sewer between the vertical pipe and the plug is known as inspection arm and can be used for inspecting and cleaning the branch sewer after opening the plug.

4.11.3 Lamp Holes

- Lamp holes are the small openings on sewer to permit the insertion of a lamp into the sewer. The lamp light is then viewed from the upstream as well as downstream manholes. The obstructed light confirms the obstructions in the sewers.
- It consists of a vertical cast iron or stone ware pipe (20 to 30 min dia) extending from the ground and connected to the sewer line through a T-junction. The vertical pipe is surrounded by concrete to make it stable.
- The lampholes are adopted when
  (i) a bend in sewer is necessary
  (ii) construction of manholes is difficult
  (iii) the spacing of manholes is more than the usual
- Besides its principal use as an inspection device, a lamphole can be used as flushing device and if its cover is kept perforated it can be used for ventilation of sewer, in which case lamp hole is known as a fresh air inlet.

4.11.4 Clean-Outs

- A clean-out is an inclined pipe extending from the ground and connected to the under ground sewer. A clean-out is used for cleaning sewer pipes.
- A clean-out is provided at the upper ends of lateral sewers in place of manholes.

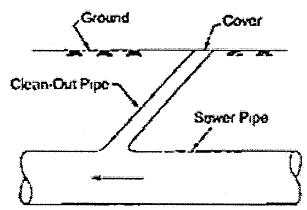


Fig. 4.20 Clean-out

- A clean-out consists of a removing the top cover and forcing water through the clean out pipe to lateral sewers to remove obstacles in the sewer pipe.

4.11.5 Street Inlets or Gullies

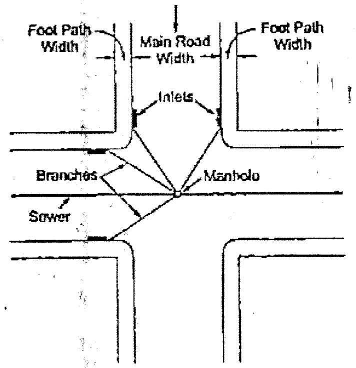


Fig. 4.21 Showing the locations of storm sewer inlets at street intersections.

- Inlets are gullies or openings on the road surface at the lowest point for draining rain water from roads and admitting it into the under ground storm water sewers (drains) or combined sewers.
- These inlets are located along road sides at an interval of 30 m to 60 m.
- A street inlet is a concrete box having gratings or openings in vertical or horizontal direction. Former is called vertical inlet or the curb inlet and latter is called horizontal inlet.

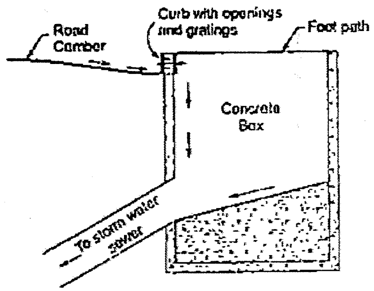


Fig. 4.22 Vertical inlet or curb inlet

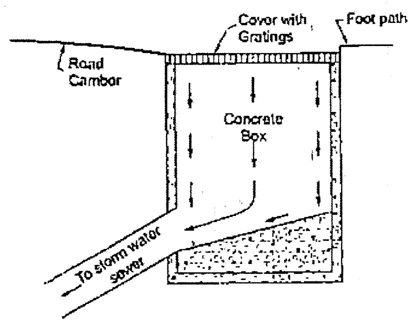


Fig. 4.23 Horizontal inlet

4.11.6 Catch Basins or Catch Pits

- Catch Basins are nothing but 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.
- Hood, is also provided, which prevents the escape of foul gases through the sewer line.
- It requires periodical cleaning, otherwise, the settled organic matter may decompose, producing foul smell.

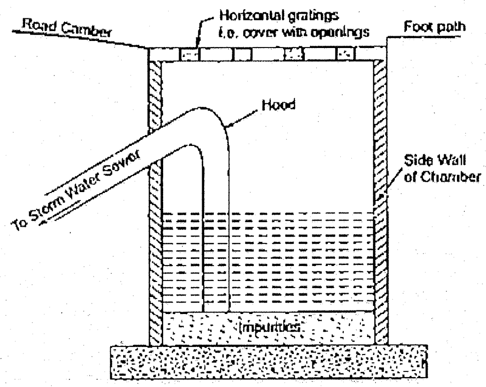


Fig. 4.24 Catch basins or catch pits

4.11.7 Flushing Tanks

- Flushing devices are installed to prevent blockage of sewer pipes, in the case of sewer laid on flat gradients not producing self cleansing velocities or near the dead end points of sewer.
- These devices store water temporarily, and throw it into the sewer for the purpose of flushing and cleaning the sewer.
- The capacity of flushing tank is equal to about one tenth of cubical contents of the sewer line served by it.
- Two types of flushing operations are normally used:
  - (i) Flushing operation using automatic flushing tank
  - (ii) Hand operated flushing operation

(i) Automatic Flushing Tanks

- Flushing operation is carried out automatically at regular intervals (Fig.4.25).
- The entry of water is regulated according to the period equal to the flushing interval.

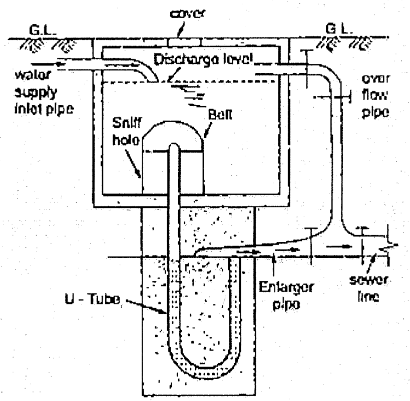


Fig. 4.25 Automatic flushing tank

(ii) Hand Operated Flushing Operations: The flushing and cleaning of sewers can be carried out at suitable intervals by means of manual labour.

4.11.8 Grease and Oil Traps

- These trap chamber are constructed in a sewerage system to remove oil and grease from the sewage before it enters into the sewer line.
- They are located near sources contributing grease and oil to the sewage.
- The removal of oil and grease are necessary because of the following reasons:
  - (i) The grease and oil will stick to the sewer sides and thus reducing the sewer capacity.
  - (ii) The suspended matter flown along with the sewage also sticks to the side of the sewer, due to sticky nature of oil and grease, thus further reducing sewer capacity.
  - (iii) The presence of oil and grease in the sewage adds to the possibilities of explosions in the sewers.

(iv) The presence of oil and grease in sewage makes the sewage treatment difficult as their presence adversely affects the biochemical reactions

- The grease and oil being lighter in weight, float on the top surface of the sewage. Hence, if an outlet draws the sewage from lower level, grease and oil will excluded.

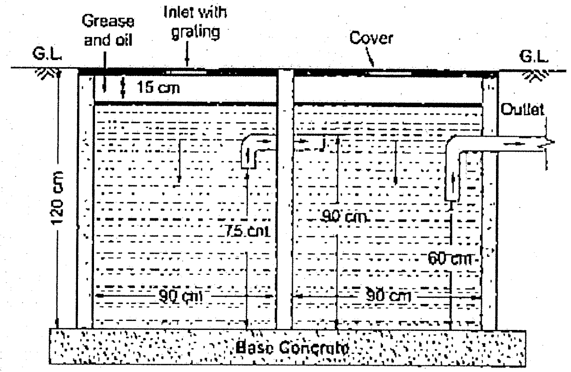


Fig. 4.26 Grease and oil trap

4.11.9 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, a tidal estuary or any other depression in the earth's surface or where it passes beneath some other obstruction in its path, it will be known as an inverted siphon or depressed sewer or a sag pipe.
- The sewage through such a pipe line will not flow under gravity, but will be flowing under pressure (as in the case of water pipe lines).

NOTE

- An inverted siphon is thus a sewer section constructed lower than the adjacent sewer sections, and it runs full under gravity with pressure greater than the atmosphere.
- An inverted siphon is usually made of siphon tubes or pipes made of cast iron or concrete. These pipes are laid between the inlet and the outlet chambers (usually at same elevation).
- The pipes between these ends are depressed for passing below obstructions like roads, railways, river or any other ground depressions. The inverted siphon laid between the inlet and the outlet chambers consist of two sloping pipe lengths joined by a flat pipe length.

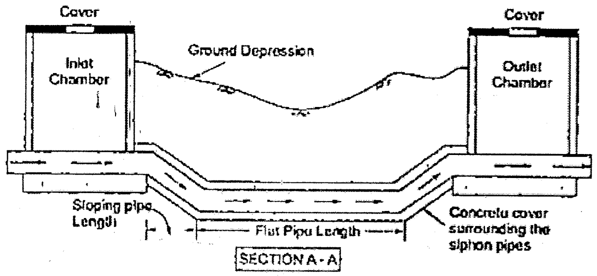
4.11.9.1 Design of an Inverted Siphon

- The proper design of siphons is very important; as otherwise, they are likely to be clogged and become inefficient.
- The siphon should, therefore, be designed to develop a self cleansing velocity of about 0.9 m/sec even during minimum discharge.
- For this purpose, the inverted siphon is usually made of three pipe sections laid side by side. One of these channels is meant for carrying minimum sanitary sewage, the other one for maximum sanitary sewage, the third one for carrying combined flow during monsoons.
- The inlet chamber inlet contains three channels one for each pipe section. When channel no 1 overflows, the sewage enters channels no 2 and pipe no 2 starts functioning. Similarly, when channel no 2 overflows, the sewage enters channel no 3 and pipe no 3 starts functioning.
- Three channels are provided for combined sewers. For sanitary sewers only two pipe sections will be required one for minimum dry weather flow, and the other for maximum dry weather flow.
- Additional points must be kept in mind while designing these inverted siphons.
  (i) If the length of the siphon is more hatch boxes at interval of about 100 m should be provided for facility of rodding.
  (ii) The changes of direction of inverted siphons should be easy and gradual.
  (iii) The design of siphons should be made on the basis of pipes running full under pressure. It is therefore necessary to know the maximum available head. The greater is this available head, the better self cleansing of the siphon will occur. Also the losses including the loss of head due to friction, losses due to bends and losses at the entry should be properly calculated.
  (iv) The inlet chamber should be provided with screens, so as to remove the coarser silt, debris, grit etc. from the sewage before it enters the siphon pipes.
  (v) The minimum diameter of the siphon pipe is taken as 15 to 20 cm.
  (vi) Manholes should be provided at each end of the siphon to enable barrels to be cleaned.
  (vii) It is advisable to provide a diversion for the siphon. Hence when the siphon either gets choked, or overflows due to surcharge, the flow of sewage can be diverted.

NOTE: There should be no vacuum anywhere in the siphon i.e. the pipes should run full, although due to wide fluctuations in sewage flow, the same is very difficult to achieve.

4.11.9.2 Demerits of Inverted Siphon

(i) It is most likely to get silted, as the down gradient is not continuous, when once it gets silted up, it becomes very difficult to clean it up.
(ii) If the inlet chamber is not properly designed, the floating matter present in the sewage will separate out and will accumulate in this chamber thus seriously affecting the proper working of this chamber.
(iii) It is not possible to give side connections to the inverted siphons.



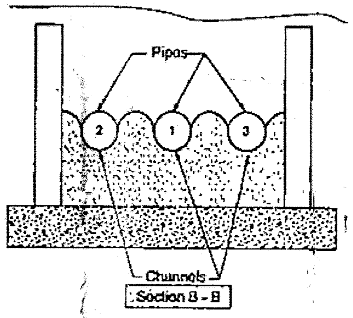


Fig. 4.27 Inverted siphon

4.11.10 Storm Water Regulators or Storm Relief Works

- Storm water regulators are constructed in the combined sewage system and permit the diversion of excess storm water into nearby stream.
- These are used for preventing over loading of sewers pumping station, treatment plants by diverting the excess flow to relief sewers.

Storm regulators may be of the following three types :

(I) Leaping Weir: The leaping weir arrangement consist of an opening in the invert of the storm drain (or combined sewer) through which the normal storm flow is diverted into the intercepting sewer and the excess flow leaps over the combined sewer to flow into the nearby stream.

When the sewage discharge is small the sewage will fall directly into the intercepting sewer through the opening. But, however, when the discharge exceeds certain limit, the excess sewage leaps or jumps across the weir and it is carried to the natural stream.

The leaping weir is a good regulator, but in heavy storm, most of the flow may leap over the combined sewer and only small quantity maybe left in the sewer, which may result in low velocity and thus creating silting problems.

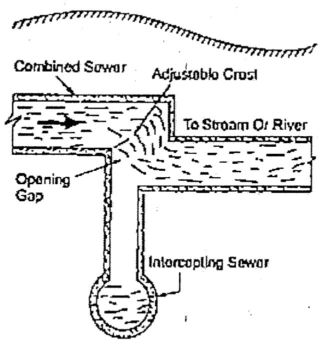


Fig. 4.28 Leaping weir

(II) Overflow Weir : In this type of arrangement, the excess sewage is allowed to overflow the combined sewer in the manholes, from where it enters into a channel carrying it into a storm water drain or directly into a stream.

In order to prevent the escape of the floating matter from the combined sewer, adjustable plates may be used.

In another type of arrangement, opening at suitable height above the invert of the sewer are provided at suitable intervals along the length of the combined sewer.

These opening are then joined to a storm water drain, which is laid near the combined sewer.

The excess sewage above this fixed height is thus diverted and conveyed to the natural stream or the river, through the stream water drain.

(III) Siphon Spillway : The siphon spillway arrangement is used for diverting excess sewage discharge form the combined sewer.

This method provides the most effective type of a storm relief work.

It is an automatic process and works on the principle of shiphonic action. The shiphonic action starts when the sewage in the combined sewer rises above a fixed level (i.e. crest level of siphon) and stops as soon as the sewage falls below this level.

The level of the crest of the siphon is generally kept at the level reached by the flow in the combined sewer during the period of maximum dry weather flow.

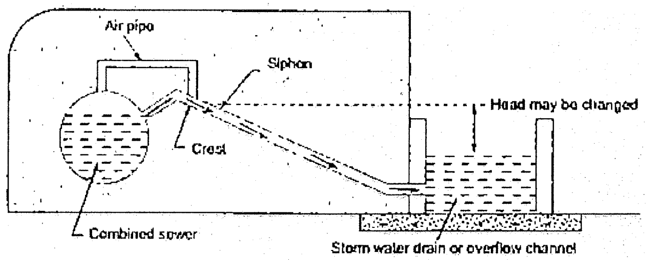


Fig. 4.29 Siphon spillway type of storm regulator

Maintenance, Cleaning and Ventilation of Sewer

Ventilation of Sewer: The sewers must be properly ventilated for the following reasons.

- The decomposition and putrefaction of sewage inside the sewers may result in the production of various sewer gases such as H_2S, CO_2, CH_4, CO, NH_3, N_2.
- These gases are disposed of into the atmosphere by exposing the sewage to the outside atmosphere by suitable methods of ventilation.
- Methane gas being highly explosive, if not removed may even blow off the manhole covers and thus have a tendency to interfere with flow of sewage.
- Another reason for ventilating sewer is to ensure a continues flow of sewage inside the sewer is achieved by ventilation by keeping the surface of sewage in contact with free air and thus preventing the formation of air locks in these sewage.

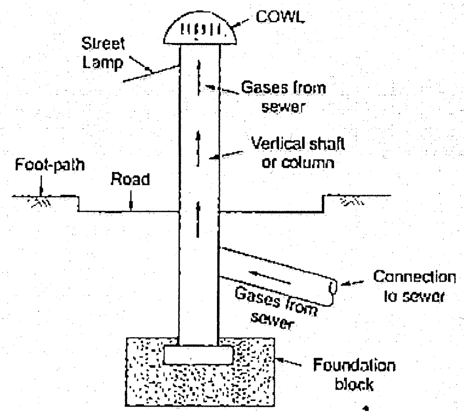


Fig. 4.30 Ventilating column

4.12 Shape of Sewer Pipes

(a) Circular shaped sewer: Most widely used for all type of sewer.

(b) Standard egg shaped sewer: Preferred for combined sewer.

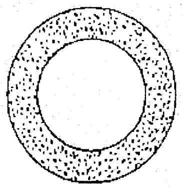


Fig. 4.31 Circular Shaped Sewer

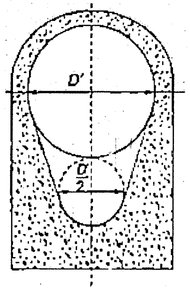


Fig. 4.32 Standard Egg-Shaped Sewer

(c) Horse shoe shaped sewer: Used for large sewers with heavy discharges, such as trunk and outfall sewers.

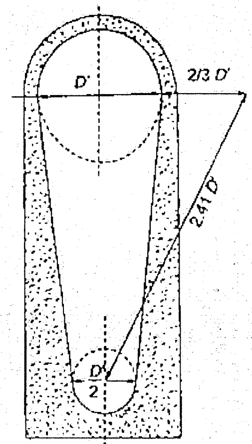


Fig. 4.33 New Egg-shaped sewer (may be preferred for combined sewers)

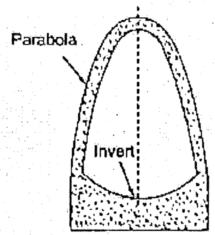


Fig. 4.34 Parabolic shaped sewer (may be used for carrying comparatively smaller quantities of sewage)

(d) Parabolic shaped sewer: Used for carrying comparatively smaller quantities of sewage (Fig. 4.34) Available size ranges and description of commonly used pipe for gravity flow sewer.

Table: 4.7 Available size ranges and descriptions of commonly useed pipe for gravity flow sewers

Type of Pipe	Available Size range, mm/inch	Description
Asbestos cement (AC)	100 - 900 (4 - 36)	Weighs less than other commonly rigid pipes. May be susceptible to acid corrosion and hydrogen sulfide attack, but if properly cured with steam at high pressure (autoclave process), may be used even in environments with moderately aggressive waters or soil with high sulfate content.
Ductile iron (DI)	100 - 1350 (4 - 54)	Often used for river crossings and were the pipe must support unusually high loads, where an unusually leak proof sewer is required, or where unusual root problems are likely to develop. Ductile-iron pipes are susceptible to acid corrosion and hydrogen sulfide attack, and therefore should not be used where the groundwater is brackish, unless suitable protective measures are taken.
Reinforced concrete (RC)	300 - 3600 (12 - 144)	Readily available in most localities. Susceptible to corrosion of interior if the atmosphere over wastewater contains hydrogen sulfide, or from outside if buried in an acid of high-sulfide environment.
Prestressed concrete (PC)	400 - 3600 (16 - 144)	Especially suited to long transmission mains without building connections and where precautions against leakage are required. Susceptibility to corrosion (the same as reinforced concrete)
Polyvinyl chloride (PVC)	100 - 375 (4 - 15)	A plastic pipe used for sewers as an alternative to asbestos cement and vitrified-clay pipe. Lightweight but strong. Highly resistant to corrosion.
Vitrified clay (VC)	100 - 900 (4 - 36)	For many years the most widely used pipe for gravity sewers, still widely used in small and medium sizes. Resistant to corrosion by both acids and alkalies. Not susceptible to damage from hydrogen sulfide, but is brittle and susceptible to breakage.

4.13 Corrosion of Concrete Sewers Due to Biological Reaction

- H_2S in sewer is usually produced by bacteriological reduction of sulphates.
- H_2S gas by itself is not injurious to cement concrete. It gets readily oxidsed by dissolved oxygen or by several bacterial species.
- In the presence of air, H_2S gets oxidised to H_2SO_4 and this sulphuric acids reacts with the cement constituents of concrete.
- Actually, it reacts with the lime in the cement concrete to form $CaSO_4$ which in turn, reacts with the calcium aluminates in the cement to form calcium sulpho-aluminates which occupy a greater volume than the compound they replace. This leads to expansion and disruption of concrete sewer.

Remember

(i) Stoneware pipes are highly resistant to sulphide corrosion, and therefore, preferred for carrying polluted sewage and industrial wastes.

(ii) The usual practice is to use vitrified clay (or stone ware or slab-glazed sewers) pipes of smaller diameter and cement concrete for larger diameter for carrying sewage.

4.14 Methods of Ventilation

Following methods are adopted for ventilating the sewers:

(i) Use of ventilating columns:

- The ventilating columns or shafts are placed at intervals of 150 to 300 m along the sewer lines. They are also provided at the upper end of every branch sewer, and also at every change in the size of the sewers.
- The ventilating columns are generally designed to serve two purposes together; one for ventilating the sewer and other for working as a support for street lamps, sign boards etc.
- The diameter of the ventilating column is kept equal to one third of the dia of the sewer served by it.

(ii) Use of Ventilating Manhole Covers:

- The manhole covers are some times provided with perforations through which the sewers gets exposed to the atmosphere. But it will cause more nuisance, as the bad smells continue to erupt from them.
- The openings of the manhole cover will permit admitting large quantities of storm water and other road dust etc.
- It has no practical utility except that it may be adopted in very isolated places.

(iii) Proper Design of Sewers:

- The sewers should be properly designed as running half or two third full, thus reserving the top space for the sewer gases.
- The velocity in the sewer should be self cleansing so that sewage does not stay at one point for longer periods.

(iv) Use of Mechanical Devices:

- Forced draught is sometimes provided by exhaust fans to expel out the foul gases from the sewers.

(v) Unobstructed Outlets:

- In the case of storm water drains or sewers, they can also act as partial ventilation.

(vi) House vent and Soil Pipes:

- They may directly help in ventilating house drains and public sewers, where interceptors are not provided on the sewers connecting houses and buildings.

4.15 Maintenance of Sewer

- Sewer maintenance involves their cleaning to keep them free from any clogging and to carry out the repairs to the damaged portions.
- Sewer maintenance generally includes their frequent inspection and supervision, measuring the rate of flow, cleansing and flushing, repairing the leaking joints or any other damaged portions.

4.16 Cleaning of Sewers

- Sewers should be periodically cleaned so as to avoid their complete clogging.
- For cleaning small sewers which can not be entered into by manual labour, flushing operations are essential.
- Medium sized sewers are generally cleaned by using scraping instrument, which are dragged through the sewer. Crane rod is used for this purpose.

4.16.1 Precautions to be taken while entering sewers

- Various poisonous and explosive gases are found present in sewer are: H_2S, CO_2 and CH_4 along with petrol vapours. These gases are largely produced when the sewage gets stale and septic.
- Following precautions should be taken while allowing the workers to enter the sewers.

(i) Open the manhole at least half an hour in advance. This will help in obtaining some ventilation and exposure of the sewer to the atmospheric oxygen.

(ii) Tests should be carried out to detect the presence of any hazardous gases inside the sewer. The following tests may be carried out to detect their presence:

(a) H_2S gas may be detected by exposing a sheet of paper moistened with lead acetate for 5 minute near the sewer entry. If the paper turns black, the presence of H_2S gas is indicated.

(b) Presence of CO_2 gas may be detected by lowering a minors safety lamp near the level of sewage in the manhole. If the flame extinguishes within 5 minutes, the presence of CO_2 gas is indicated.

(c) The presence of methane (CH_4) gas may be detected by lowering the minor's safety lamp in the upper layers of sewer, methane, being lighter than air is generally present in the upper layers of sewer.

(iii) If the hazardous gases are absent, a lighted lantern may be lowered down the manhole, so as to test the presence of oxygen. If it burns brilliantly, the sewer can be safe to enter.

(iv) In any case, the workers going down for inspection must be tied with ropes to their waists and they may be held fast by the person on top, so that they may be immediately pulled up in case of any risks.

(v) Any smoking or carrying of naked lights inside the sewers are strictly prohibited.

(vi) Necessary waring signals should be erected.

Illustrative Examples

Example 4.5 A town has a population of 100,000 persons with a per capita water supply of 200 litre/day. Design a sewer running 0.7 times full at maximum discharge. Take a constant value of $n = 0.013$ at all depths of flow. The sewer is to be laid at a slope of 1 in 500. Take a peak factor of 3. (Take self cleansing velocity = 60cm/s) and adopt.

$\frac{q}{Q}$	$\frac{v}{V}$
0.196	0.776
0.088	0.615

Solution:

Total Water supplied $= 100{,}000 \times 200 = 20 \times 10^6$ litres/day

$$= \frac{20 \times 10^6}{10^3 \times 24 \times 3600} = 0.2315 \text{ cumecs}$$

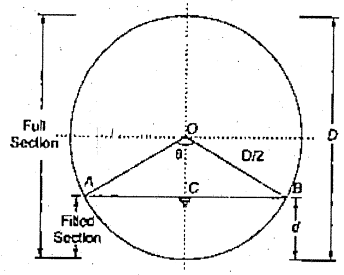
Assuming that 80% of the water supplied to the town appears as sewage, we have average discharge in the sewer

$$= 0.8 \times 0.2315 = 0.185 \text{ cumecs}$$

At a peak factor of 3

Maximum discharge $= 3 \times 0.185 = 0.556$ cumecs

Since the sewer is to be designed as running 0.7 times the full depth,



$$\frac{d}{D} = 0.7 \text{ and}$$

$$q = 0.556 \text{ cumecs}$$

For a sewer running partially full

$$\cos\frac{\theta}{2} = 1 - 2\frac{d}{D}$$

$$= 1 - 2 \times 0.7 = -0.4$$

$\therefore$

$$\frac{\theta}{2} = 113.58°;$$

$$\theta = 227.16°$$

$$\sin\theta = -0.7332$$

$$a = \frac{\pi}{4}D^2\left[\frac{\theta}{360} - \frac{\sin\theta}{2\pi}\right] = \frac{\pi}{4}D^2\left[\frac{227.16}{360} + \frac{0.7332}{2\pi}\right] = 0.587\,D^2 \quad \text{...(i)}$$

Perimeter, $$p = \pi D\frac{\theta}{360} = \pi D\frac{227.16}{360} = 1.982\,D$$

Hydraulic radius, $$r = \frac{a}{p} = \frac{0.587\,D^2}{1.982\,D} = 0.296\,D$$

Now, $$q = \frac{1}{n}ar^{2/3}S^{1/2}$$

$\therefore$ $$0.556 = \frac{1}{0.013} \times 0.587\,D^2(0.296\,D)^{2/3}\left(\frac{1}{500}\right)^{1/2}$$

or $$D^{8/3} = 0.6190$$

From which $$D = 0.835 \text{ m}$$

Check for self cleansing velocity at maximum discharge

$$r = 0.296\,D = 0.296 \times 0.835 = 0.247 \text{ m}$$

$\therefore$ $$v = \frac{1}{n}r^{2/3}S^{1/2} = \frac{1}{0.013}(0.247)^{2/3}\left(\frac{1}{500}\right)^{1/2} = 1.356 \text{ m/s}$$

This is much more than the self cleansing velocity of 60 cm/sec

Check for self cleansing velocity at minimum discharge.

Now assuming that minimum flow equal to $\frac{1}{3}$ times the average flow.

$\therefore$ $$q_{min} = \left(\frac{1}{3}\right) \times 0.185 = 0.0617 \text{ m}^3\text{/s}$$

$$\text{Full flow discharge} = \frac{1}{n}\left(\frac{D}{4}\right)^{2/3}S^{1/2}.\frac{\pi D^2}{4}$$

$$= \frac{1}{0.013}\left(\frac{0.835}{4}\right)^{2/3}\left(\frac{1}{500}\right)^{1/2} \times \frac{\pi}{4}(0.835)^2 = 0.6625 \text{ m}^3\text{/s}$$

$$\frac{q_{min}}{Q} = \frac{0.185}{3 \times 0.6625} = 0.093$$

$$V_{full} = \frac{0.6625}{\frac{\pi}{4}(0.835)^2} = 1.21 \text{ m/s}$$

For $$\frac{q}{Q} = 0.093$$

$$\frac{v}{V} = 0.622$$

$$v = 0.753 \text{ m/s} > 0.6 \text{ m/s}$$

Example 4.6 **A combined sewer of circular section is to be designed in a sewage system for a city with a population of 100000 in an area of 100 hectares. The mean flow of sewage from the city is 250 litre/capita/day. The rainfall intensity in the area is 4 cm/hr. The coefficient of runoff of the area is 0.48. The ratio of peak to average sewage flow is 2.0. The Manning's roughness coefficient is 0.012 and the Hazen-William's coefficient is 85. Using Manning's equation and Hazen-William's expression, determine the gradient of the sewer to carry the peak flow with a velocity of 1.2 m/s.**

Solution:

Given

Population = 100000

$\therefore$ Area = 100 ha

Mean flow of sewage = 250 l/c/day

Rainfall intensity i = 4 cm/hr

K = 0.48

n = 0.012

Ratio of peak to average sewage flow = 2

$$\text{Discharge } Q_r = \frac{1}{36}KiA = \frac{1}{36} \times 0.48 \times 4 \times 100 = 5.33 \text{ m}^3\text{/s}$$

$$\text{Average sewage discharge} = \frac{100000 \times 250}{86400} = 0.29 \text{ m}^3\text{/s}$$

Peak sewage discharge = $2 \times 0.29 = 0.58$ m³/s

Total average discharge = $(5.33 + 0.58)$ m³/s

Peak velocity = 1.2 m/s

$$\text{Area of sewer} = \frac{5.91}{1.2} = 4.925 \text{ m}^2$$

Let dia of sewer is D

$\therefore$ Area, $$\frac{\pi}{4}D^2 = 4.925 \text{ m}^2$$

$$D = 2.505 \text{ m}$$

According to Manning's formula

Flow velocity, $$V = \frac{1}{n}\left(\frac{D}{4}\right)^{2/3}S^{1/2}$$

$$1.2 = \frac{1}{0.012}\left(\frac{2.505}{4}\right)^{2/3} S^{1/2}$$

$\therefore$ $S = 3.869 \times 10^{-4}$

According to William Hazen's formula,

$$V = 0.85\, C_H \times r^{0.63}\, S^{0.54}$$

$\Rightarrow$ $S = 8.739 \times 10^{-4}$

Example 4.7 A combined sewer of circular section is to be laid to serve an area of 100 ha with a population of 90,000 supplied with water at 200 litres per day. Assuming an impermeability factor of 0.50 and time of concentration of rainfall 't' as 20 minutes. Calculate the size of the sewer when it has to run full with a velocity of 0.3 m/s. Assume suitable coefficients for 'a' and 'b' in the equation for R, intensity of rainfall relating to 't', the time of concentration.

Solution:

Given,

Population = 90,000

Area = 100 ha

Water supply = 200 litres per day

$K = 0.50$

Time of concentration = 20 minutes

Full velocity = 0.3 m/s

Let critical rainfall intensity $= \dfrac{a}{b + T_C}$

$a = 75$ and $b = 10$

$\therefore$ $R = \dfrac{75}{T_C + 10} = \dfrac{75}{20 + 10}$

$\therefore$ $R = 2.5$ cm/hr

Peak discharge, $Q_C = \dfrac{1}{36} kiA = \dfrac{1}{36} \times 0.50 \times 2.5 \times 100 = 3.47$ m³/sec

Average water discharge $= \dfrac{90000 \times 200}{86400} \times 10^{-3} = 0.2083$ m³/s

Average sewage discharge = 0.8 × 0.2083 = 0.1666 m³/sec

Peak sewage discharge = 3 × 0.166 m³/s = 0.5 m³/s

Total discharge = 3.47 + 0.5 = 3.97 m³/sec

Given full velocity = 0.3 m/s

$\therefore$ Area of sewer $= \dfrac{3.97}{0.3} = 13.24$ m²

Take sewer as circular $\dfrac{\pi}{4} D^2 = 13.233$

$\therefore$ $D = 4.1$ m

Example 4.8 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

Solution:

Area of channel = A = 2.4 m × 1.2 m = 2.88 sq. m.

Wetted perimeter = P = 2.4 + 1.2 + 1.2 + 2.4 = 7.2 m ...(Running full)

$\therefore$ $R = \dfrac{A}{P} = \dfrac{2.88}{7.2} = 0.40$ m

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

Using, Chezy's formula, we have

$$V = C \cdot \sqrt{RS} = 68.99\sqrt{0.40 \times \frac{1}{200}} = 68.99 \times 0.0447 = 3.08 \text{ m/sec}$$

Discharge $Q = A.V = 3.08 \times 2.88 = 8.88$ cumecs

Example 4.9 Design an outfall circular sewer of the separate system for a town with a population of 1,00,000 persons generating sewage at the rate of 180 litres per head per day. The sewer can be laid at a slope of 10 in 10,000 with n = 0.012. A self-cleansing velocity of 0.75 m/sec is to be developed. The dry weather flow may be taken as 1/3 of the maximum discharge. Given the following table.

Proportionate Depth	Proportionate Velocity	Proportionate Discharge
0.31	0.7901	0.2086
0.35	0.8430	0.2629
0.37	0.8675	0.2981
0.39	0.8909	0.3217
0.40	0.9022	0.3370
0.42	0.9299	0.3682

Solution:

Population = 1,00,000

Average rate of water supply = 180 litres/person/day

$\therefore$ Average rate of water supplied per day = 1,00,000 × 180 litres

$\therefore$ Average rate of water supplied in cumecs $= \dfrac{1,00,000 \times 180}{1,000 \times 24 \times 60 \times 60}$ cumecs = 0.208 cumecs

$\therefore$ D.W.F = 0.208 cumecs

$\therefore$ Maximum discharge = 3 × 0.208 cumecs = 0.624 cumecs

Let us design the sewer as running full at maximum discharge

Using Manning's formula, we have

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

Assuming that the sewer is laid at the available slope of 10 in 10,000 *i.e.* 1 in 1,000, we have

$$S = \frac{1}{1000}$$

Putting the values in Manning's equation, we have

$$0.624 = \frac{1}{0.012}\left(\frac{\pi}{4}D^2\right)\left(\frac{D}{4}\right)^{2/3}\frac{1}{\sqrt{1000}}$$

or $\quad D^{8/3} = 0.758$

or $\quad D = (0.758)^{3/8} = 0.915\text{ m}$

Now, velocity of flow at full flow

$$V = \frac{Q}{A} = \frac{0.625}{\frac{\pi}{4}(0.915)^2} = 0.95\text{ m/sec}$$

This is more than 0.75 m/sec, and hence satisfactory.

Let us check for the velocity at D.W.F.

At D.W.F. $\quad \frac{q}{Q} = \frac{1}{3} = 0.333$

From the given table, corresponding to this discharge ratio, we find

Depth ratio $\quad \frac{d}{D} = 0.40$

Velocity ratio $\quad \frac{v}{V} = 0.9022$ (given)

Hence, the velocity developed at D.W.F = 0.9022 × 0.95 m/sec = 0.855 m/sec

This is more than 0.75 m/sec and, therefore, satisfactory.

NOTE: If the velocity at D.W.F. works out to be less than 0.75 m/sec, then increase the design slope or try with increase dia of sewer.

Important Expressions

1. Manning's formula, $\boxed{V = \frac{1}{n}R^{2/3}\cdot S^{1/2}}$ where, V = Velocity of flow
   R = Hydraulics Radius
   S = Slope of sewer

2. Shield's formula, $\boxed{V = \frac{1}{n}R^{1/6}\left[k_s(G_s - 1)d_p\right]^{1/2}}$ where, G_s = specific gravity
   d_p = Particle size
   k_s = dimension size constant

3. In partial flow of circular sewers

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

R = hydraulic radius
n = manning coefficient

$$\rightarrow \quad \frac{a}{A} = \frac{\alpha}{360} - \frac{\sin\alpha}{2\pi}$$

$$\rightarrow \quad \frac{r}{R} = \frac{a/A}{p/P} = 1 - \frac{360\sin\alpha}{2\pi\alpha}$$

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

$$\rightarrow \quad \frac{q}{Q} = \frac{v}{V} \times \frac{a}{A}$$

NOTE: Small letter represent hydraulic elements under partial flow and capital letter represents the hydraulics elements under full flow conditions.

4. Equal degree of self cleansing, $\frac{v}{V} = \frac{N}{n}\left(\frac{r}{R}\right)^{1/6}$

5. Runoff coefficient or Impermeability Factor, $C_{av} = \frac{C_1A_1 + C_2A_2 + C_3A_3 + \ldots\ldots}{A_1 + A_2 + A_3 + \ldots\ldots}$

6. Rational formula for discharge, $Q = CiA$
   C = Runoff coefficient, $\quad Q$ = Peak rate of runoff
   i = Intensity of rainfall, $\quad A$ = Catchment area

7. Rainfall Intensity

$$i = i_0\left(\frac{2}{1 + T_c}\right) \qquad T_c = \text{Time of concentration}$$

$$i = \frac{75}{T_c + 10} \qquad \text{for,} \quad 5 \le T_c \le 20$$

$$i = \frac{100}{T_c + 20} \qquad \text{for,} \quad 20 < T_c < 100$$

Summary

- The alignment of the sewer is marked along the road with a theodolite and invar tape.
- In combined sewer system, storm water dilutes the sewage and hence its strength is reduced and also self-cleansing velocity is easily achieved.
- Design of sewer is based on peak flow discharge, however at least once in a day, self cleansing velocity must be achieved.
- Slope of sewer should be designed for minimum permissible velocity at minimum flow.
- When minimum velocity requirement in a sewer is not sufficient, option is to increase the slope or increase the diameter of sewer.
- The siphon spillway arrangement is used for diverting excess sewage discharge from the combined sewer.

Objective Brain Teasers

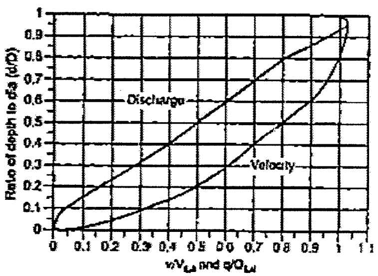
Q.1 A combined sewer is one which transports
(a) domestic sewage and storm water
(b) domestic sewage and industrial wastes
(c) domestic sewage and over head flow
(d) domestic sewage, industrial wastes and storm water

Q.2 A 20 cm diameter sewer is laid at a slope of 0.004 and is designed to carry a discharge at a depth of 10 cm with Manning's n = 0.014, the design discharge is ______ litre/sec.

Q.3 The drop manholes are provided in sewerage system when there is
(a) change in alignment of sewer line
(b) change in size of sewers
(c) change in the elevation of ground level
(d) change from gravity system to pressure system

Q.4 At the same mean velocity, the ratio of head loss per unit length for a sewer pipe flowing full to that for the same pipe flowing half full would be
(a) 2.0 (b) 1.63
(c) 1.00 (d) 0.61

Q.5 An existing 300 mm diameter circular sewer is laid at a slope of 1 : 280 and carries a peak discharge of 1728 m^3/d. Use the partial flow diagram shown in the given figure and assume Manning's n = 0.015.



Partial flow diagram for circular sewer

At the peak discharge, the depth of flow and the velocity are, respectively,
(a) 45 mm and 0.28 m/s
(b) 120 mm and 0.50 m/s
(c) 150 mm and 0.57 m/s
(d) 300 mm and 0.71 m/s

Q.6 In transition of sewers from smaller diameter sewers to larger diameter sewers, the continuity of sewers is maintained at the
(a) bottom of the concrete bed of sewers
(b) inverts of the sewers
(c) crowns of the sewers
(d) hydraulic gradients of the sewers

Q.7 The slope of a 1.0 m diameter concrete sewer laid at a slope of 1 in 1000, develops a velocity of 1 m/s, when flowing full. When it is flowing half-full, the velocity of flow through the sewer will be
(a) 0.5 m/s (b) 1.0 m/s
(c) 2 m/s (d) 2.0 m/s

Q.8 Self-cleansing velocity is
(a) the minimum velocity of flow required to maintain a certain amount of solids in the flow
(b) the maximum velocity of flow required to maintain a certain amount of solids in the flow
(c) such flow velocity as would be sufficient to flush out any deposited solids in the sewer
(d) such flow velocity as would be sufficient to ensure that sewage does not remain in the sewer

Q.9 The following steps are involved in laying a sewer in a trench:
1. Transferring the centre line of the sewer to the bottom of a trench.
2. Setting sight rails over the trench.
3. Driving pegs to the level of the invert line of the sewer.
4. Placing the sewer in the trench.

The correct sequence of these steps is
(a) 1, 2, 3, 4 (b) 2, 3, 4, 1
(c) 4, 2, 3, 1 (d) 2, 3, 1, 4

Q.10 In the design of storm sewers, "time of concentration" is relevant to determine the
(a) rainfall intensity
(b) velocity in the sewer
(c) time of travel
(d) area served by the sewer

Q.11 The maximum flow occurs in an egg shaped sewer when the ratio of depth of flow to vertical diameter is
(a) 0.33 (b) 0.50
(c) 0.95 (d) 1.00

Q.12 A circular sewer of diameter 1 m carries storm water to a depth of 0.75 m. The hydraulic radius is approximately
(a) 0.3 m (b) 0.4 m
(c) 0.5 m (d) 0.6 m

Q.13 For the design of a storm sewer in a drainage area, if the time of concentration is 20 minutes, then the duration of rainfall will be taken as
(a) 10 min (b) 20 min
(c) 30 min (d) 40 min

Q.14 A sewer is commonly designed to attain self-cleansing velocity at
(a) peak hourly rate of flow
(b) average hourly rate of flow
(c) minimum hourly rate of flow
(d) sewer running half full

Q.15 Consider the following statements:
1. The velocity of flow in the rising main should be less than 0.8 m/s at any time.
2. Maximum velocity of flow is generally limited to 1.8 m/s and never allowed to exceed 3.0 m/s.

In the design of large sewage pumping stations, which of the above conditions must be satisfied?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

Q.16 If a sewer X is to be designed to generate equivalent self-cleansing action as in sewer Y, then
(a) velocity in sewer X must be equal to velocity in sewer Y
(b) slope of sewer X must be equal to slope of sewer Y
(c) tractive force intensity generated in sewer X must be same as that in sewer Y
(d) the roughness coefficient of X sewer material should be same as that of Y sewer material

Q.17 Consider the following statement regarding building manholes:
1. They must be provided at every change of alignment, gradient or diameter.
2. They must be provided at the head of all sewers.
3. They must be provided at every junction of two or more sewers.
4. They must be provided at every 100 m along straight runs of sewers.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 3 (d) 2 and 4

Q.18 In the design consideration of sewerage system, the sewers must have which one of the following?
(a) Maximum velocity of flow
(b) Only 50 per cent of maximum velocity of flow
(c) Minimum velocity of not less than cleansing velocity of flow
(d) High pressure at all times

Q.19 A sewer of 400 mm diameter and slope 1 in 400, running half-full, has a flow velocity of 0.82 m/sec. What velocity of flow will be obtained if the slope is made 1 in 100?
(a) 3.28 m/s (b) 1.64 m/s
(c) 0.82 m/s (d) 0.41 m/s

Q.20 A sewer has a diameter of 300 mm and slope of 1 in 400. While running full it has a mean velocity of 0.7 m/s. If both the diameter and slope are doubled (to respectively be 600 mm and 1 in 200), what will be the changed mean velocity when running half-full ? Use Manning's formula.

(a) 1.59 m/s (b) 2.80 m/s
(c) 0.90 m/s (d) 1.00 m/s

Q.21 The self-cleansing velocity in a sewer depends on:

1. BOD (soluble)
2. Slope of the sewer
3. Ratio of depth of flow sewage to sewer diameter ratio

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

Q.22 One sewer has a dia. of 300 mm and another one has a dia. of 600 mm. When both run half-full, what will be the ratio of velocities in the two pipes if the slope of both pipes is the same?

(a) 1 (b) $\frac{1}{2}$
(c) $\left(\frac{1}{2}\right)^{2/3}$ (d) $\left(\frac{1}{2}\right)^{3/2}$

Q.23 Consider the following statements:
Ventilation of sewer lines is necessary to

1. avoid building up of sewer gases
2. ensure atmospheric pressure in the waste water surface
3. ensure the safety of sewer maintenance people
4. provide oxidation facility to sewage

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 3

Directions: The following items consists of two statements; one labelled as 'Statement (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.24 Assertion (A): The crown of the outgoing larger diameter sewer is always matched with the crown of incoming smaller diameter sewer.
Reason (R): It eliminates backing up of sewage in the incoming smaller diameter sewer.

Q.25 Assertion (R) : At a manhole, the crown of the outgoing sever should not be higher than the crown of the incoming sewer.
Reason (R) : Transition from a larger diameter incoming sewer to a smaller diameter outgoing sewer at a manhole should not be made.

Q.26 Assertion (A): While laying a sewer line, the socket end of a sewer is kept facing the downward slope in the trench.
Reason (R): The socket end being heavy will slide down the slope if it faces the downward slope.

Q.27 Assertion (A): Sewers are not allowed to flow full.
Reason (R): Reserve space in the sewer takes care of fluctuations in the sewage flow.

Q.28 Assertion (A): The design of all non-circular sections is based upon getting a "hydraulically equivalent section".
Reason (R): The chart of hydraulic elements is very useful in sewer design.

Q.29 Assertion (A): Most important activity in sewer line construction is to start constructing it from the tail end and to check levels with a boning rod.
Reason (R): Construction of sewer line from tail end is recommended because required number of pumping stations may be incorporated in sewer network design.

Q.30 Assertion (A): Laterals of minimum specified diameter in sewerage system have to be laid at slopes designed for self-cleansing velocity.
Reason (R): For the specified minimum lateral diameter at specified slopes, a minimum flow rate is not essential to maintain self-cleansing velocity.

Answers

1. (d)	2. (9.626)	3. (c)	4. (c)	5. (a)
6. (b)	7. (b)	8. (c)	9. (d)	10. (a)
11. (c)	12. (a)	13. (b)	14. (c)	15. (b)
16. (c)	17. (a)	18. (c)	19. (b)	20. (a)
21. (c)	22. (c)	23. (d)	24. (a)	25. (b)
26. (d)	27. (a)	28. (b)	29. (c)	30. (b)

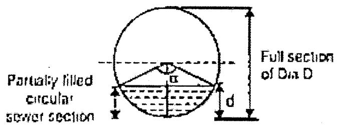
Hints and Explanations:

Ans.2 (9.626)
Given, depth of partial flow, $d = 0.10$ m

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

$$\Rightarrow \quad 0.10 = \frac{0.20}{2}\left(1 - \cos\frac{\alpha}{2}\right)$$

$$\therefore \quad \alpha = 180°$$



Area of partially filled circular Sewer section,

$$a = A\left(\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right)$$

$$= \frac{\pi D^2}{4}\left(\frac{\alpha}{360°} - \frac{\sin\alpha}{2\pi}\right)$$

$$= \frac{\pi(0.20)^2}{4}\left(\frac{180°}{360°} - \frac{\sin 180}{2\pi}\right)$$

$$= \frac{\pi(0.20)^2}{4} \times \frac{1}{2} = 0.0157$$

$\therefore$ Design discharge,

$$q = av = a \cdot \frac{1}{n} \cdot (r)^{2/3} (s)^{1/2} \quad \text{...(iii)}$$

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

$$\Rightarrow \quad r = R\left[1 - \frac{360° \sin 180°}{2\pi \times 180°}\right]$$

$$= R = \frac{D}{4} = \frac{0.20}{4} = 0.05$$

$\therefore$ Design discharge,

$$q = av = a \cdot \frac{1}{n} \cdot (r)^{2/3} \cdot (s)^{1/2}$$

$$\therefore \quad q = 0.0157 \times \frac{1}{0.014}(0.05)^{2/3}(0.004)^{1/2}$$

$= 9.626 \times 10^{-3}$ m^3/sec
$= 9.626$ lit/sec

Ans.4 (c)
Head loss per unit length is independent of sewer running full or half full condition.

Ans.5 (a)

$$q = 1728 \text{ m}^3/\text{d} = 0.02 \text{ m}^3/\text{s}$$

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

$$= 0.05 \text{ m}^3/\text{s}$$

$$\frac{q}{Q} = 0.4$$

$$\Rightarrow \quad \frac{d}{D} = 0.15$$

$$d = 0.045 \text{ m} = 45 \text{ mm}$$

Also, $\frac{v}{V} = 0.4$

$$V = \frac{Q}{A} = 0.7085 \text{ m/s}$$

$$\Rightarrow \quad v = 0.28 \text{ m/s}$$

Ans.7 (b)

For $\frac{d}{D} = 0.5$; $\frac{v}{V} = 1.0$

where, d is depth of flow
v is flow velocity at depth d
D is diameter of sewer
V is flow velocity at full flow

$\therefore \quad v = 1.0$ m/s

Ans.9 (d)

First sight rails are set over the trench. Then pegs can be driven to the level of invert line and centre line of the sewer marked on sight rails can be transferred to the bottom of the trench. Finally, sewers should be placed in the trench.

Ans.10 (a)

Time of concentration (t_c) is the time taken by water droplet to reach the catchment outlet from farthest part. So whole catchment contributes to runoff only when the time of rainfall is greater than 't_c'. It is used to determine critical rainfall intensity.

Ans.12 (a)

Hydraulic radius of sewer flowing full

$$R = \frac{D}{4} = \frac{1}{4} = 0.25\,m$$

At 0.75 m depth of flow

$$\frac{r}{R} = 1.2$$

$$\therefore \quad r = 1.2 \times 0.25 = 0.3\,m$$

At 0.5m depth of flow

$$\frac{r}{R} = 1.0$$

$$\therefore \quad r = 0.25\,m$$

Ans.13 (b)

Maximum runoff will be obtained from the rain having a duration equal to the time of concentration, and this is called the critical rainfall duration. Therefore duration of rainfall should be 20 min.

Ans.15 (b)

Rising main may be of cast iron or asbestos cement pressure pipe. The velocity of flow in the rising main should not be less than 0.75 m/s at any time of flow to avoid settling of particles. The maximum velocity limitation is due to continuous abrasion caused by the suspended particles.

Ans.16 (c)

Velocity and discharge are functions of tractive force intensity which depends upon friction coefficient as well as flow velocity. For equal self cleansing tractive force intensity should be same in both sewers.

Ans.18 (c)

The velocity which will even scour the deposited particles of a given size, must be developed in the sewers, at least once a day, so as not to allow any deposition in the sewers is called self-cleansing velocity. 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.

Ans.19 (b)

Velocity of flow is given by Manning's formula

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

$$\therefore \quad v \propto S^{1/2}$$

$$\therefore \quad v_1 = \frac{1}{n}(R)^{2/3}\left(\frac{1}{400}\right)^{1/2}$$

$$v_2 = \frac{1}{n}(R)^{2/3} \times \left(\frac{1}{100}\right)^{1/2}$$

$$\therefore \quad \frac{v_2}{v_1} = \left(\frac{400}{100}\right)^{1/2}$$

$$\therefore \quad v_2 = 2 \times 0.82 = 1.64\ m/s$$

Ans.20 (a)

According to Manning's formula

$$V_1 = \frac{1}{n}(R_1)^{2/3}(S_1)^{1/2} = 0.7\ m/s$$

$$\Rightarrow \quad V_1 = \frac{1}{n}\left(\frac{D_1}{4}\right)^{2/3}(S_1)^{1/2} = 0.7 m/s$$

Now, $D_2 = 2D_1;\ S_2 = 2S_1$

$$\therefore \quad V_2 = \frac{1}{n}\left(\frac{2D_1}{4}\right)^{2/3}(2S_1)^{1/2}$$

$$\therefore \quad V_2 = 2.24\,V_1 = 1.57\ m/s \cong 1.59\ m/s$$

Ans.21 (c)

Self-cleaning velocity does not depend on BOD.

Ans.22 (c)

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

$$\frac{V_1}{V_2} = \left(\frac{R_1}{R_2}\right)^{2/3}$$

$$= \frac{(A_1/P_1)}{(A_2/P_2)}^{2/3} = \left[\frac{\frac{\pi}{8}D_1^2 \Big/ \frac{\pi D_1}{2}}{\frac{\pi}{8}D_2^2 \Big/ \frac{\pi D_2}{2}}\right]^{2/3}$$

$$= \left(\frac{D_1}{D_2}\right)^{2/3} = \left(\frac{1}{2}\right)^{2/3} \qquad [\because D_2 = 2D_1]$$

Ans.23 (d)

Ventilation in sewers is needed to avoid:

(i) the danger of asphyxiation of sewer maintenance employees

(ii) the buildup of odourous gases such as hydrogen sulphide, ammonia etc.

(iii) the development of explosive mixture of sewer gases principally methane and oxygen

Another reason for ventilating sewers is to ensure a continuous flow of sewage inside the sewer.

Ans.26 (d)

Socket end face upstream slope.

Ans.27 (a)

Sewers generally run half to three-fourth full at peak flow, so that fluctuations in flow can be accommodated.

Ans.28 (b)

Hydraulically equivalent section means that two sections can carry same discharge, while flowing full, on the same grade.

Ans.29 (c)

The construction of sewer line is started from the tail end so that sewers of tail length may be utilized even during the initial periods of its construction, thus ensuring that the functioning of sewerage scheme need not to wait till the completion of entire scheme.

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