Design of Water and Wastewater Treatment Systems

Sewer Systems

Sewer Systems

DEFINITIONS

Sewage

Combination of various types of liquid wastes conducted away from residence, buildings and institutions, industrial establishment.

Sewer

Sewer an artificial conduit, usually underground, for carrying off waste water and refuse, as in a town or city.

Sullage

Discharge of kitchens, bathrooms wash basins etc. excluding discharge from hospitals, operation theatre and slaughter houses.

Sewerage Systems

A sewerage system, or wastewater collection system, is a network of pipes, pumping stations, and appurtenances that convey sewage from its points of origin to a point of treatment and disposal.

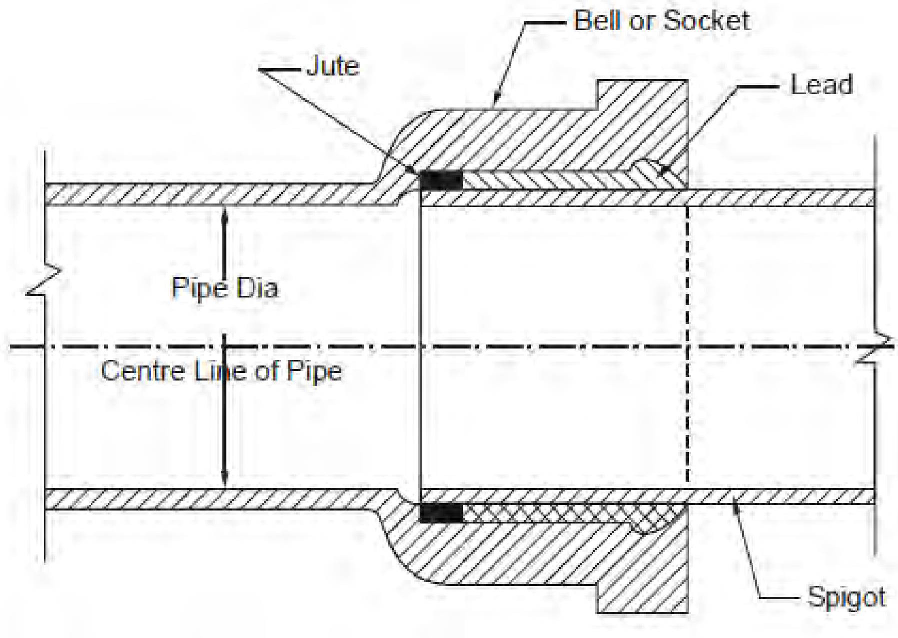
JOINTS IN WATER SUPPLY PIPES

Joints used for connecting water main or sub-main may be classified as:

- spigot and socket joint.
- flanged joint.
- expansion joint, and
- collared joint.

Spigot and Socket Joint

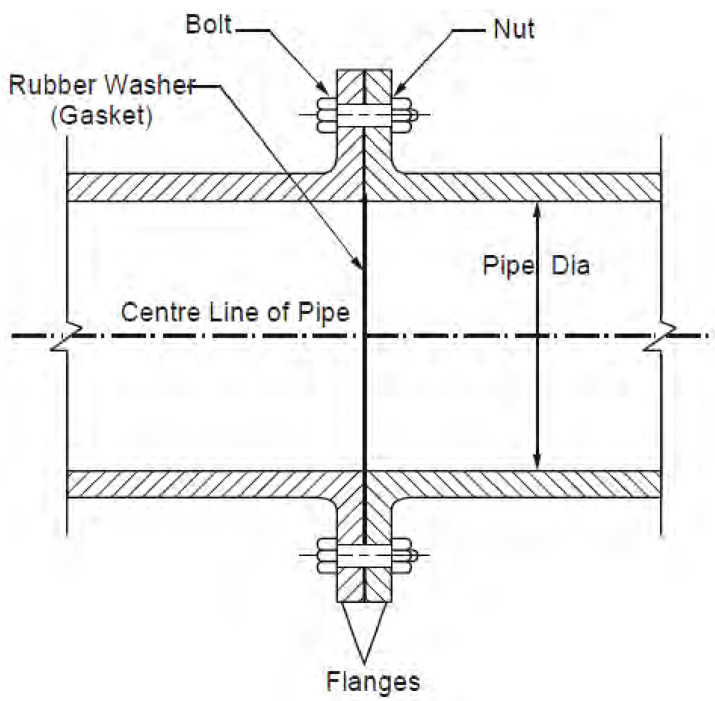
The joint is also called bell and spigot joint. The enlarged end is called "socket' or "bell" whereas the normal end is called spigot. The normal end. i.e. spigot is fitted into the socket and proper alignment is done. The joint is made by caulking in spun yarn (jute) and then filling the remainder of the joint space by molten lead and then thoroughly caulking the lead. The molten lead solidifies quickly and makes the joint water tight.



The joint is somewhat flexible and allows the pipe to be laid on flat curves without the use of special mountings. Mostly mains and sub-mains of cast iron, spun iron or steel are joined with this type of joint.

Flanged Joint

Flanged joints are generally used at locations where it becomes necessary to disjoint the pipe off and on. such as at pumping stations, filter plants etc. Cast iron pipes which are to be joined with flanged joints are cast with heavy flanges at both ends whereas in case of steel pipes, flanges are separately cast and screwed or welded at both ends of the pipe length.

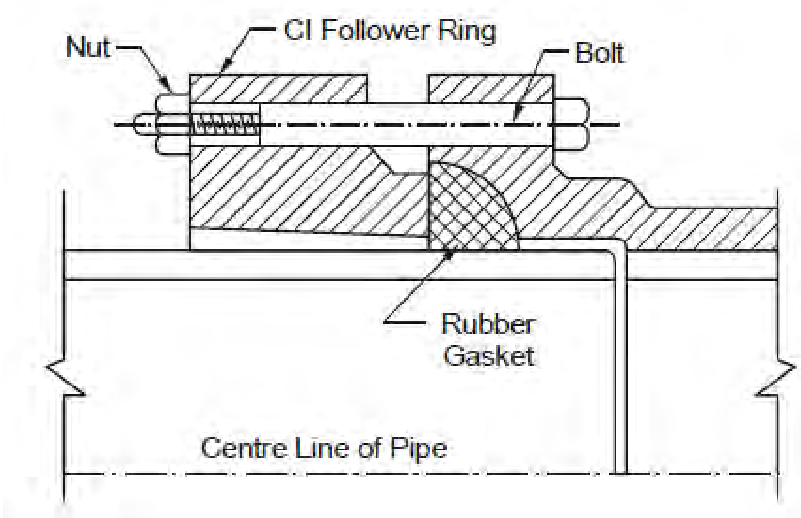


The flanges are put together and a rubber washer known as gasket is kept between flanges and fixed by means of nuts and bolts. The gasket is not less than 1.5 mm thick.

The joints are strong, rigid and easy to repair.

Expansion Joint

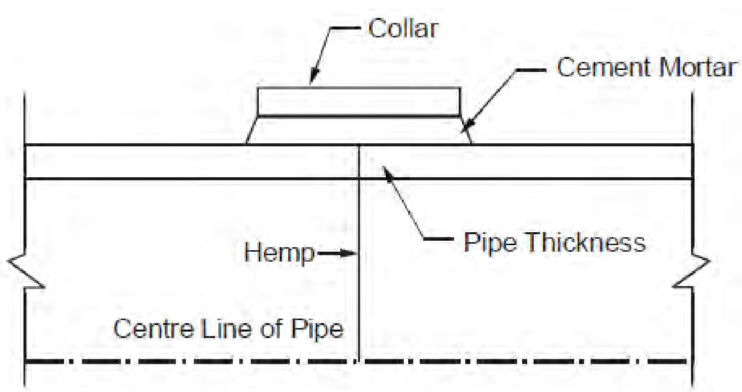
Expansion joints are provided in metal pipe lines at suitable intervals to take into account the change in pipe lengths due to temperature variations. The socket end is connected rigidly to an angular ring which slides freely over the spigot end.



A small gap is kept between the face of the spigot and inner face of the socket. A rubber gasket is provided between the socket and spigot and finally they are tightened with nut and bolt.

Collared Joint

Concrete pipes are mostly joined by collared joints. Pipes are having spigot at one end and socket at the other and jointed by a gasket or hemp and clean cement. It is further strengthened by providing a concrete collar wide enough to cover the overlap of the joint. Pipes of bigger diameters are joined with collared joints. Pipes without sockets are put butting together and joined with collar.



Since Welding techniques have developed to a great extent, now-a-days practice is developing to join pipes by welding. Specially, metal pipes are most suitable for welding.

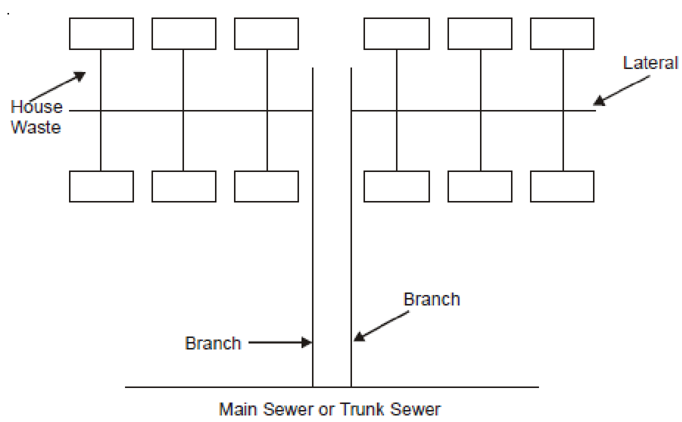
CLASSIFICATION OF SEWERS

Classification 1: With respect to their use

- **Sanitary sewers**. A sewer which carries sewage from residence, commercial buildings and institutions and to which storm, surface and ground water are not internally admitted also refer to as separate sanitary sewer or separate sewer.
- **Storm sewer**. A sewer which carries storm water and surface water, street wash and other wash water as drainage, but excludes other sewage and industrial waste. This sewer is also called Storm drain.
- **Combine sewer**. A sewer receiving both surface run off and sewerage is called the Combined Sewer'.
- **Storm over flow sewer**. A sewer used to carry the excess of storm flow from a main or intercepting sewer to an independent outlet generally in connection with a combined sewer system having limited main or intercepting sewer capacity.
- **Relive or auxiliary sewer**. A sewer built to carry the flows in excess of the capacity of an existing sewer.

Classification 2: According to their positions

- **Building sewer**. The extension from a building drain to the public sewer or other places of disposal, also called the house sewer or house connection.



- **Lateral sewer**. A sewer which discharges into a branch or other sewer and has only building sewer tributary tn it.
- **Branch sewer**. A sewer which receives sewage from a relatively small area and discharges into a main sewer.
- **Sub-main sewer.** An arbitrary term used for relatively large branch sewer.

- **Main sewer.** A sewer to which one or more branch sewers are tributary and which serves a large territory, also called trunk sewer.
- **Intercepting sewer**. A sewer which receives dry weather flow from a number of transverse sewers or outlets and frequently additional predetermined quantities of storm water (if from a combined system) and conduct such water to a point for treatment or disposal.
- **Outfall sewer.** A sewer which receives sewage from a collecting system and carries it to a point of final discharge.

Classification 3: System as a whole

- **Separate system**. A sewer system comprised exclusively a sanitary only sewage and to which storm water, surface water and ground water are not intentionally admitted also refer to as sanitary system or separate sanitary system.
- **Storm sewer system**. A system composed only o£ sewer carrying storm water, surface water, street wash and other wash waters or drainage and from which sewage and industrial waste are excluded.
- **Combined sewer system**. A system of sewers receiving both surface run off and sewage.

CLASSIFICATION OF SEWAGE

- **Sanitary sewage**. Sewage derives from dwelling, business building, public institution etc. also called *Domestic sewage*.
- **Storm sewage**. Surface run off caused by rainfall which is conveyed through sewer are called '*Storm sewage'*.
- **Industrial sewage**. Liquid wastes from industry7 such as dying, paper making etc. are called Industrial sewage'.
- **Combined sewage**. Combination of sanitary and storm sewage with or without the industrial waste is called the Combined sewage'.

SEWAGE DESIGN PARAMETERS

Design Period

1. For collection system that is Sewerage – 40 years

2. Pumping plant – 10 years

3. Sewage treatment plant – 15 to 20 years.

Quantity of Storm Sewage

Rational method : Q = AIR

where Q = rate of flow

A = area drained

I = run off co-efficient

R = average rainfall intensity during a period t where t = duration of storm

DESIGN OF SEWER SYSTEM

We now know that sanitary sewers 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 that these serve. Whereas storm sewers carry surface runoff developed during or following the period of rainfall over concerned area including street wash.

In sanitary sewer system, *lateral* sewer collects discharges from houses and carries them to another *branch* sewer, and has no tributary sewer lines. Branches or *sub-main lines* receive waste-water from laterals and convey it to large mains. A main sewer, also called 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.

Surface waters enter a storm drainage system through inlets located in street gutters or depressed areas that collect natural drainage. Catch basins under street inlets are connected to the main storm sewer located in the street right-of-way. often along the centre line, by short pipelines. Since no house connections are 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. Pipelines gradients follow the general slope of the ground surface such that water entering can flow downhill to a convenient point for discharge. Storm sewer pipes are set shallower as compared to sanitary sewers as far as possible.

Flow Formulae

Hydraulic grade line coincides with the surface of the flowing water.

Pressure flow. Flow in sewer occurs under a pressure above or below the atmospheric pressure. Most sewer are designed as open channel. In inverted siphons and discharge line from pumps flow occurs under pressure.

Flow formula for open channel (Chezei's formula)

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

where V = Velocity of flow in m/sec

R = Hydraulic mean depth in m

S = Slope of the hydraulic grade line

C = Co-efficient depending on the nature of the surface, hydraulic depth, velocity, and slope of hydraulic grade line.

C is given by Kutter's formula,

Manning's Formula

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

where

S = Slope of hydraulic gradient.

R = Hydraulic radius (hydraulic mean depth) in metre.

V= Velocity in metre per seconds, and

n = Manning's coefficient of roughness.

A circular sewer may run either full or partially full.

Circular section running full

Let D be the internal diameter of circular sewer.

Area of cross-section $A = (\pi/4)D^2$

Wetted perimeter $P = \pi D$

Hydraulic mean depth $R = A/P = D/4$

Circular sewer running partially full

$$A = \frac{a}{A}\left[\frac{\theta}{360^0} - \frac{\sin\theta}{2\pi}\right]$$

$$p = \pi D.\frac{\theta}{360^0}$$

Hydraulic mean depth

$$= \frac{A = \frac{\pi D^2}{4}\left[\frac{\theta}{360^0} - \frac{\sin\theta}{2\pi}\right]}{\pi D.\frac{\theta}{360^0}}$$

Hazen's William's formula

$$V = 0.85 C R^{0.63} S^{0.54}$$

where V = Velocity in m/sec

R = Hydraulic mean depth in m

S = Slope in hydraulic grade line

C = Co-efficient depend on pipe material.

Velocities

At the time of design it is to be ensured that a minimum velocity is maintained in the sewers during minimum flow conditions so that no solid gets deposited in the sewer and at the same time the velocity should not be excessive to cause erosion in sewer pipes.

Velocity at Minimum Flow

In order to prevent settlement of sewage solids, the sewers are designed for minimum flow velocity. The minimum velocity at which no solid gets deposited at the bottom of sewer is called **self cleansing velocity**. The self cleansing velocity in sewer is determined by *Shields formula:*

$$V = R^{2/3}[K_s(S_s - 1)d_p]^{1/2}$$

where

S_s = Specific gravity of particle.

d_p = Particle size.

K_s = A dimensionless constant with a value of about 0.04 to start motion of granular particles and about 0.8 for adequate self cleansing of sewers.

R = Hydraulic mean radius (HMD) of the sewer, and

n = Manning's coefficient.

Limiting Velocity (Non scouring velocity)

Excessive velocity of flow may cause erosion of sewer pipe. Therefore, it is usually limited to 3.0 metre per second.

Depth of Flow

From considerations of ventilation in wastewater flow, sewers are designed to flow 0.8 full at ultimate peak flow.

Example

Calculate the velocity of flow, and discharge in a sewer of circular section having diameter of 1 m, laid at a gradient of 1 in 500. Use Manning’s formula taking N = 0.011 Assume that the sewer is running half full.

Solution

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

n = 0.012

where V is the velocity of flow and R is the H.M.D. when the sewer is running half full (i.e., d/D = 0.5)

For d = 0.5 D, $\theta = 180^0$

$$p = \pi D.\frac{\theta}{360} = \pi D.\frac{180}{360} = \frac{\pi D}{2}$$

$$r = \frac{a}{p} = \frac{\pi}{8}D^2.\frac{2}{\pi D} = 0.25\,m$$

$$v = \frac{1}{0.012}(0.25)^{2/3}(1/500)^{1/2} = 1.479\,m/s$$

Problem

A stone-ware sewer, 30 cm in diameter is laid at a gradient of I in 100. Using N=0.013 in Manning's formula, calculate the velocity and discharge when the sewer is running full.

Answer: 1.368 m/s; 0.0967 cumecs

Example

A sewer is to be designed to receive flow from 100 ha of a community, where the population density is estimated to average 25 people/ha. The average per capita sewage flow is estimated to be 400 l/d. Compute the design flow, assuming peak flow is to be four times the average flow.

Solution

Total population = 25 x 100 = 2500 persons

Qty. of water/per day = population x per capita flow

= 2500 x 400

= 1000,000 l/day

= 1000 m^3/day

Assuming that 80% of this water appears as sewage, we have the quantity of sewage per day

= 0.80 x 1000 = 8000 m^3/day

Peak flow = 400 x 4 = 1600 l/day = 1.6 m^3/day

Design flow = 800/1.6 = 500 m^3/day

DESIGN CONSIDERATION OF SEWERS

- Average flow of sanitary sewage is taken to be the same as average rate of water supply.
- Design period is about 25 years.
- Design rate of sewage flow in sanitary sewers is 400% at the average flow for lateral and sub mains and 250% for mains and trunks.
- Sewers in combined system should be capable of carrying at least two times the **Dry Weather Flow (D.W.F.)** in addition to storm water.

- Sewers are normally designed to flow full when discharging the max. flow.
- Sanitary sewers should be designed for self creating velocity of at least 60 cm/sec and combined sewers for a velocity of 75 to 90 cm/sec.
- Minimum size of sewers to be used is 15 cm.
- Manholes should be provided at intersections at changes of direction of gradient and at interval not exceeding 120 m of straight length.
- A deep of about 12 mm is given in manhole where only direction changes.
- At points where size changes crowns are kept at same elevation.

DESIGN STEPS OF SEWER SYSTEM

The following steps are followed in the design of sewer system:

Preliminary investigation

A map of the city or a position of the city to be surveyed is to be obtained. If a map is not available, then a survey must be done. The map should show the built up areas street and topographical features such as contours etc.

Preliminary investigation will include.

- Present and future areas to be served.
- Present and future population to be served.
- Expected amount of sewage to be handled.
- Character of sewage.
- Proposed size for sewage treatment plant.

Detail survey

This is done mainly as the underground survey. This includes the underground services, such as presence and location o£ existing sewers if any. water main, gauge line, telephone and telegraph conduct, foundation of structure, position and location of underground rock, depth of water table etc.

Layout of the system

A tentative layout of sewer is made on the map by drawing lines. Considering the usual slope of the ground and other topographical and underground consideration.

Actual design

This includes determination of grades, sizes, location of sewer lines, design of pumping plant, design of other sewer appurtenance.

Preparation of final maps, plans, profiles and specification etc.

After the design a final plan is drawn for each street showing the position of sewers and appurtenance. A provision of each street is also showing position of sewers, of their size, grade, elevation and other appurtenance.

SEWER CONSTRUCTION

It consists of the following works

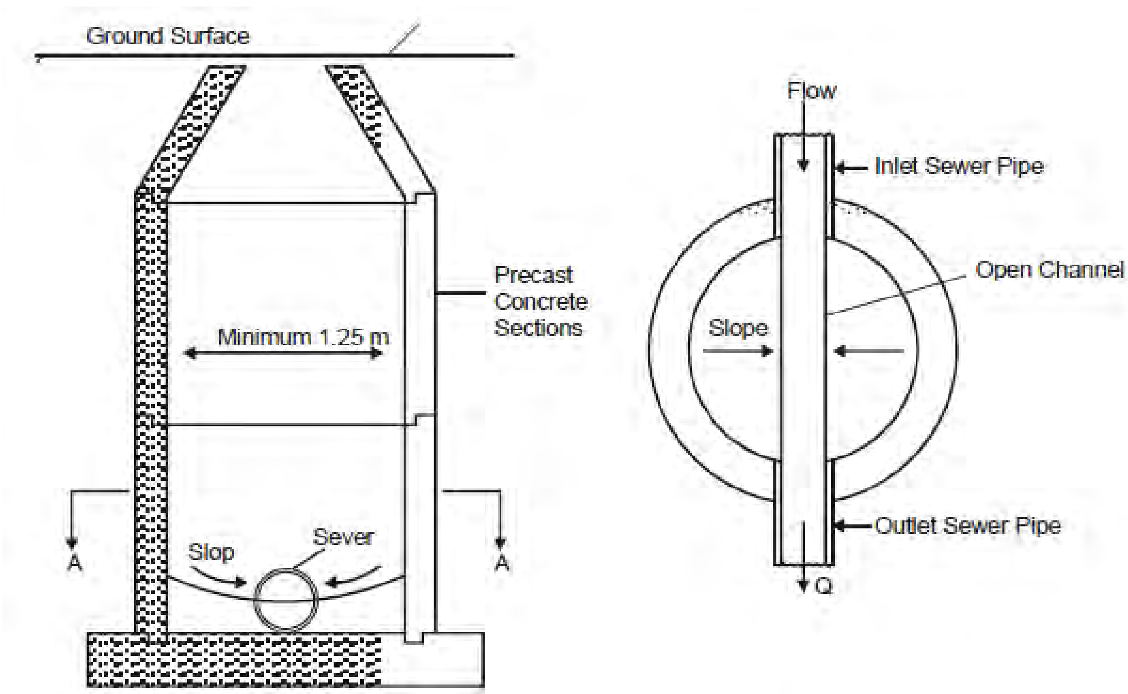
- Excavation and preparation of trenches.
- Sheeting and bracing if needed.
- Dewatering.
- Pipe laying.
- Jointing.
- Backfilling.
- Construction of appurtenance.

SEWER APPURTENANCES

Sewer appurtenances are devices which are essential for proper operation of the system.

Manholes

A manhole is an opening constructed on the alignment of a sewer to facilitate access into the sewer. A typical manhole for a lateral sewer is shown in given figure.



Their principal purpose is to permit inspection (including sampling and flow measurement), cleaning, repair and removal of any obstructions. Manholes are located over the pipe centreline under the circumstances :

- when there is a change in the pipeline diameter.
- when there is a change in pipeline slope.
- when there is a change in pipeline direction.
- at all pipe intersections, and
- at the uppermost end of each lateral.

Manholes are directly constructed over the central line of the sewer. They are circular, rectangular or square in shape. Circular manholes are stronger and provide easier access as compared with other types of manholes and hence generally preferred. The inside dimension should be sufficient to perform the necessary operations regarding inspection and cleaning without difficulty.

Straight-through Manholes

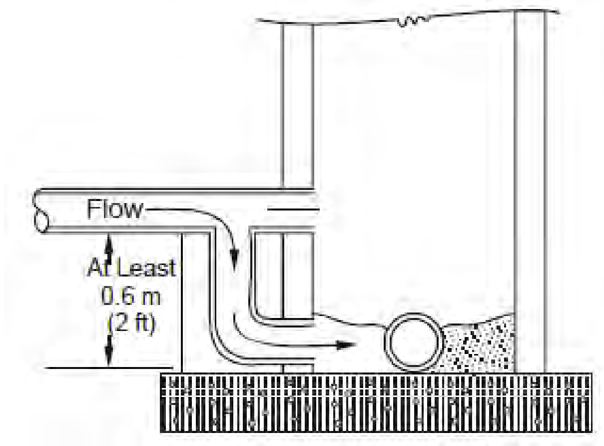
The simplest type of manhole is that built on a straight run of sewer with no side junctions. Where there is a change in the size of sewer, the crown level of the two sewers should be the same, except where special conditions require otherwise.

Junction Manholes

A manhole should be built at every junction of two or more sewers, and the curved portions of the inverts of tributary sewers should be formed within the manhole.

Drop Manholes

When a sewer connects with another sewer, where the difference in level between water lines (peak flow levels) of main line and the invert level of branch line is more than 600 nun or a drop of more than 600 nun is required to be given in the same sewer line a drop manhole shall be provided. The outside connection is provided for the protection of man entering the manhole and resulting structure is known as drop manhole. Therefore, sometimes when a lateral sewer joins deeper, sub-main sewer, the use of a drop manhole will reduce the amount of excavation needed by allowing the lateral to maintain a shallow slope (see figure). The wastewater drops into the lower sewer through the vertical pipe at the manhole.



Flushing Manholes

Where it is not possible to achieve self-cleansing velocities due to the flatness of the gradient especially at the top ends of the branch sewers, which receive very little flow, it is essential that some form of flushing device be incorporated in the system. This can be done by providing an overhead water tank from which connections are made through pipes and flushing hydrants to rush water to the sewers. Flushing can also be accomplished by the use of a fire hydrant or tanker and hose.

Catch Basins

Catch basins are used to interrupt the flow of sewage before it enters the sewer, causing deposition of suspended grit and sludge and the detention of floating rubbish, which could enter and clog the sewer. A separate catch basin may be used for each inlet or. to save expense, the pipes from several inlets at a comer may discharge into the same catch basin. Various types of catch basins are successfully used - some holding water in a trap and others discharging directly into the sewer. The construction of the catch and its cover follows the principles given for the construction of manholes. In unusual situations it may be necessary to install a larger basin, but too large a catch basin is undesirable because of the probable production of bad odour.

Silt Basins

Basins to interrupt the flow of sewage may be installed on storm sewers to provide a place for the deposition of grit particularly on sewers where there are no catch basins. In order to promote the deposition of grit the velocity of flow should not be greater than 0.6m/s. and to prevent the deposition of organic matter it should not be less than 0.3 m/s. Silt basins are undesirable on separate or on combined sewers because of the inevitable collection of organic matter.

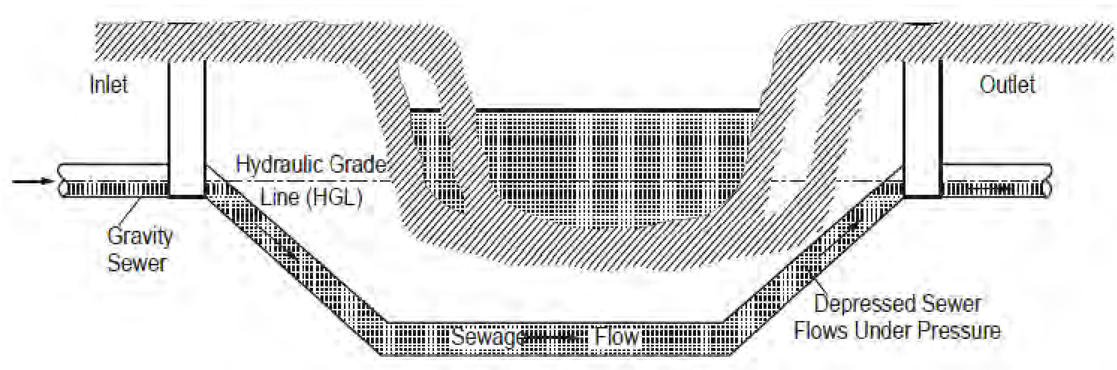
Grease and oil Traps

Grease in sewers results in the formation of incrustations that are difficult to remove and cause a substantial loss in the capacity of the sewer. Some cities have a basin for the removal of these substances at the sewerage-treatment works.

A general feature of grease and oil traps is the provision of a channel, which forces the sewage to flow downwards, beneath a free surface, while passing through the trap. Floating grease and oil rise to the surface on the inlet side of the trap, from which they may be cleaned through removable covers on the structures. It is essential that the cover be tightly sealed to avoid the escape of odours into the building: and it is preferable that the trap, if large, be placed outside the building itself The capacity of trap should be about double that of the fixtures draining into it.

Inverted Siphons

Ail inverted siphon or depressed sewer is a sewer that runs full under gravity flow at a pressure above atmosphere in the sewer. Special features of inverted siphon is that its profile is depressed below the hydraulic grade line. This is very useful when a sewer line has to be laid across a stream, a highway cut. or any other similar obstruction. When the profile laid below the ground, that portion of the sewer is known as inverted siphon (or. a depressed sewer) (see figure).

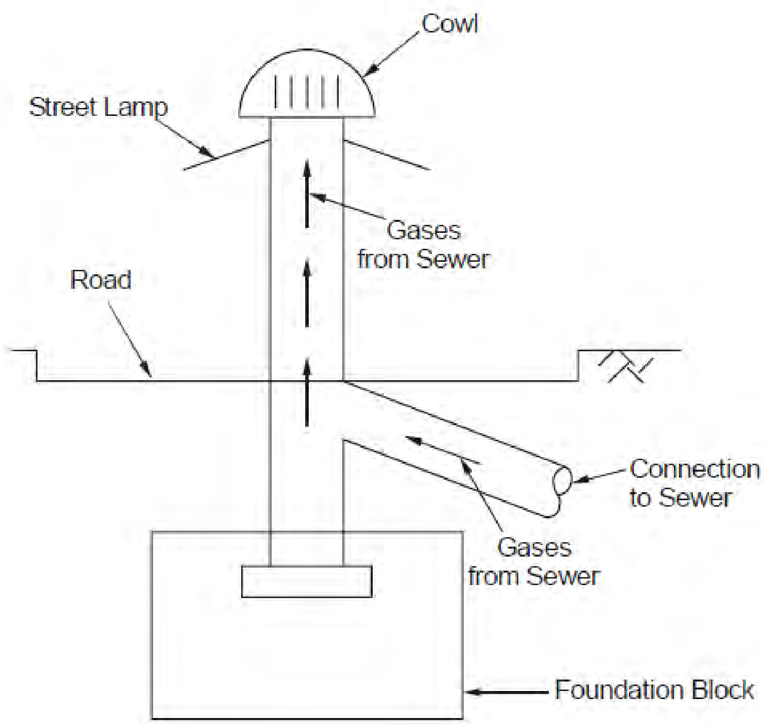


It is obvious that this section of sewer lies below the hydraulic grade line, flowing full and under pressure. In order to maintain appropriately higher velocities to disallow solids settling down in the sewer pipe, generally two or Three different sizes of parallel pipes are provided to carry the minimum, average and peak flows. Since the siphon is subject to pressure, while flowing, ductile iron pipes or concrete encasement is provided in order to prevent leakage. The siphon may be constructed as a [/with vertical or inclined legs.

True siphons are also used in sewerage practices depending upon the ground profile (topography). A true siphon is a sewer that flows full with the flow line above the hydraulic grade line, the pressure in the sewer being less than atmospheric.

Ventilation of Sewers

The ventilation of sewers (see figure) is desirable to prevent the accumulation of dangerous explosive or corrosive gases: the concentration of unpleasant odours that may escape to cause a nuisance in the environment; accumulation of hydrogen sulphide, which corrodes concrete and metal exposed to it in the sewer and in the plumbing: and, the creation of pressures (above or below atmospheric) that may break water seal in plumbing traps.



Pressures in the system are developed by the wind blowing up the outlet: and. also by the trapping of air due to surcharge of sewer: and due to other causes as well.

Example

Design an inverted syphon of a total length of 80 m, to he provided for a 100 cm diameter sewer. The discharges which it has to carry are 0.72 cu.m./sec., 0.31 cu. m./sec. and 0.093 cu. m./sec., for maximum, average and minimum discharges respectively. The difference in levels between the inverts of the inlet and outlet manholes is 0.60 m. Adopt suitable self-cleaning velocity.

Solution

Outline

Three separate sewers shall be designed to carry the discharge in the following way:

- One pipe shall be designed to carry the minimum flow = 0.093 cu.m./sec.
- One pipe shall be designed to carry the remaining of average flow = 0.310 – 0.093 = 0.217 cu.m./sec.
- One pipe shall be designed to carry the remaining of the max. flow. = 0.72-0.31 =0.41 cu.m./sec.

The inclined length of each of the pipes shall be = $\sqrt{(80^2 + 0.55^2)}$ = 80 m

Adopting self-cleaning velocity = 100 m/sec.

Sizes of pipes for minimum flow

The sizes of the various pipes shall be determined as follows:

Q = A. V.

A = Q/V

$A_1 = Q_1/V = 0.093/1.00 = 0.093$ sq. m.

Or $\pi d^2/4 = 0.093$

$d_1 = \sqrt{0.093/0.785} = 0.3442$

Provide pipe of 30.0 cm diameter pipe. Ans.

Then the developed velocity = $0.093/(\pi/4) \times (0.3)^2 = 1.316$ m/sec. Safe.

Sizes of pipes for average flow

$$A_2 = \frac{Q_2}{V} = \frac{0.217}{1.00} = 0.217\, sq.m$$

or $$\frac{\pi}{4} d_2{}^2 = 0.217$$

∴ $d_2 = 0.5257$ m

∴ Provide sewer of 50 cm diameter.

Then developed velocity will be

$$\frac{0.217}{(\pi/4)(2.5)^2} = 1.105\, m/\sec \text{ (safe)}$$

Sizes of pipes for maximum flow

$$A_3 = \frac{Q_3}{V} = \frac{0.41}{1.00} = 0.41 sq.m$$

or $$\frac{\pi}{4} d_3{}^2 = 0.41$$

∴ $d_3 = 0.7227$

Provide sewer of 70 cm diameter.

Developed velocity = $\frac{0.41}{(\pi/4)(0.7)^2} = 10.66$ m/s (safe)

Head loss

Total head loss in smallest sewer

= head loss due to entrance + due to friction + due to bends + due to outlet

$$= \frac{1}{2}.\frac{v^2}{2g} + \frac{flv^2}{2gd_1} + \frac{v^2}{2g}$$

$$= \frac{flv^2}{2gd_1} + \frac{1.5v^2}{2g}$$

$$= \frac{0.02x80x1.316^2}{2x9.81x0.3} + \frac{1.5x1.316^2}{2x9.81} = 0.602\,m$$

Invert level

The outlet invert level should be lower than the inlet by the amount equal to the total head loss during the, flow in the smallest pipe i.e.: 60 cm Therefore, the difference already kept is the same i.e. 60 cm. Hence the design is O.K.

ASSIGNMENT

Q.1. (AMIE S19, 4 marks): Explain the meaning of the terms: (i) sewage (ii) sewer (iii) sewerage system (iv) sullage.

Q.2. (AMIE S17, 7 marks): List the factors to be considered in designing of sewers.

Q.3.(AMIE W15, 19, S19, 7 marks): Why is it necessary to provide sewer appurtenances in sewer lines? Show any five items on diagram.

Q.4. (AMIE S15, 8 marks): Describe different types of sewers used in sewerage system.

Q.5. (AMIE S16, 7 marks): Write an explanatory note on "self cleansing velocity" in sewers.

Q.6.(AMIE W17, 20 marks): Describe with neat sketches various types of sewer appurtenances used in sewer system.

Q.7. (AMIE S19, 6 marks): Design an inverted syphon of length 50 m which is to carry a maximum discharge of 0.75 ml/s, an average flow of 0.3 m^3/s and a minimum discharge of 0.065 ml/s. The velocity of flow is to be maintained at 1 m/s.

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