Chapter 10

WASTEWATER COLLECTION AND TRANSPORTATION

Introduction/Conventional sewerage system/ Small bore sewerage system/Simplified sewerage system/Non-sewered transportation of wastewater

10.1 INTRODUCTION

Most on-site sanitation systems are built relying on the infiltration capacity of soils. However, as the population density increases and the per capita water consumption rises due to improvements in the water supply, particularly in the urban centres, on-site systems often fail because of insufficient land area required for infiltration. Moreover, soil's capacity to absorb wastewater with a high organic content also decreases. Consequently the overflow of the pit latrines or the septic tanks ends up in surface water drainage networks causing considerable pollution in the natural streams and rivers. On-site sanitation systems are also likely to pollute the groundwater system when the groundwater table is high.

The obvious alternative to on-site sanitation in such situations is waterborne sewerage. Widely termed as conventional sewerage system, it consists of a series of underground pipes collecting and transporting waterborne excreta and other household wastewater to a distant place. Some degree of treatment is provided to the wastewater before final disposal into natural watercourses or in some cases onto land.

Unfortunately, conventional sewerage, as currently practiced, is very expensive and is only applicable to cities, commercial, residential and industrial areas which can afford it. Developing countries rarely have sufficient funds to invest in the large number of sewerage schemes required, and the communities most in need are too poor to be able to repay the capital and running costs. This has led to search for new alternatives for solving the acute sanitation problems of densely populated low-income urban communities in the developing countries.

The recent developments are the so-called small bore sewerage systems (also termed as settled sewerage) and simplified sewerage systems (also called shallow sewerage) which have been successfully implemented in many parts of the world including Australia, USA and Brazil. These systems offer similar benefits as conventional sewerage systems but the costs are far less.

This chapter includes only a brief discussion on these lower-cost sewerage systems and the detailed design procedures of these systems can be found elsewhere (Mara, 1996). It is also not the intention of this chapter to include a complete description of the conventional sewerage system, which can be found in any standard textbook. However, the chapter begins with a cursory discussion on the conventional sewerage systems, which would help readers better appreciate the important aspects of the recently developed lower-cost sewerage systems.

10.2 CONVENTIONAL SEWERAGE SYSTEM

The basic functional elements of a conventional sewerage system include the house connections for collection of household or institutional wastewater, a network of sewer systems for collection and conveying the wastewater, a treatment plant for processing the wastewater, and the receiving environment (water or land) for disposal of the treated wastewater. Of the total system, the major investment is made in the collection and conveyance of wastewater through a network of reticulation sewers. This section will briefly consider this element of the conventional sewerage system.

Important terms

Wastewater: is the liquid waste conveyed by a sewer and may include domestic and industrial discharges as well as storm sewage, infiltration, and inflow.

Domestic (Sanitary) sewage is the liquid waste which originates in the sanitary conveniences, e.g., water closets (wc), urinals, baths, sinks etc. of dwellings, commercial or industrial facilities, and institutions. This is sometimes also referred to as black water.

Industrial wastewater includes the liquid discharges from spent water in different industrial processes such as manufacturing and food processing.

Sullage is the liquid discharge from kitchens, wash basins etc. and excludes discharge from WCs and urinals. Sullage, also known as grey water, is less foul than domestic sewage and can be discharged through open surface drains in unsewered areas.

Storm water is the surface runoff obtained during and immediately after the rainfall, which enters sewers through inlets. Storm water is not as foul as sanitary or industrial sewage and hence can be carried through open drains or channels and disposed of in natural rivers or streams without any treatment.

Infiltration is the water which enters the sewers from the ground through leaks or faulty joints.

Sewer is a pipe or conduit, generally closed, but normally not flowing full, which carries sewage.

Sanitary sewer carries sanitary sewage and is designed to exclude storm sewage, infiltration, and surface inflow. Industrial waste may be carried in sanitary sewers, depending upon its characteristics.

Storm sewer carries storm sewage and any other waste which may be discharged into the streets or onto the surface of the ground.

Sewerage refers to the entire system of collection, treatment and disposal of sewage through a system of reticulation sewers.

The essential elements of a sewerage system include:
- collection and conveyance;
- treatment;
- disposal.

Collection refers to the collection of sewage from different points of generation and conveying sewage to any desired points through a network of sewers. Sewage treatment includes any process which may be used to favourably modify the characteristics of sewage. Sewage disposal refers to the discharge of liquid wastes to the environment. Normally, but not always, disposal implies some degree of treatment prior to discharge.

Types of collection systems

There are three different sewage collection systems:

Separate sewerage system: In this system sanitary sewage and storm waste are collected and conveyed separately through two different systems
Advantages of separate sewerage system are:
- sewers are of smaller sizes;
- only sanitary sewage is treated;
- storm water can be discharged without treatment;
- sewage lifting is less costly because of less volume.

Disadvantages of separate systems are:
- two sets of sewers may prove costly;
- smaller sewers may be difficult to clean.

Combined sewerage system: In this system both sanitary sewage and storm water are collected and carried together through a single set of sewers.

Advantages of combined systems are:
- only one set of sewers might prove economical;
- larger sewers are easy to clean;
- strength of sewage diluted with stormwater.

Disadvantages of combined system are:
- increased load on treatment plant;
- larger volume requires to be lifted;
- heavy rains may cause overflow and thus create a nuisance;
- storm water is polluted unnecessarily;
- more difficult to properly treat the wastewater to high quality standards;
- flow during the dry period may cause difficulties in maintaining minimum flow.

Partially combined or partially separate system: In this system only one set of sewers is laid to carry sanitary sewage as well as storm water during low rainfall. During heavy rainfall excess storm water is carried separately e.g., through open drains to natural channels.

Advantages of this system include:
- sizes of sewers is not very large;
- advantages of both separate and combined systems;
- minimal solids deposition problem;
- problems of storm water discharges from homes is simplified.

Disadvantages are:
- velocity of flow may be low during the dry period;
- increased load on pumps & treatment unit.

Suitable conditions for a separate system:
- In flat areas a separate system is economical as deep excavations are not required.
- When sufficient funds are not available for two sets of sewer systems; only a sanitary sewerage system may be installed.
- Where rainfall is not uniform throughout the year a separate system is suitable.
- In areas near rivers or streams, only a sanitary system may be installed; storm water may be disposed of into rivers untreated, through open drains.
- Where pumping is required at short intervals.
- In rocky areas where large combined systems may be difficult to install.
- If sewers are to be laid before actual development of the area, a separate system is desirable.

Suitable conditions for combined system:
- Where rainfall is uniform throughout the year, a combined system is economical.
- Where pumping is required for both sanitary sewage and storm water.
- Where sufficient space is not available for two separate sets of sewer systems.

Types of sewers

The types and sizes of sewers vary with size of the collection system and the location of the wastewater treatment facilities. The principal types of sewers found in most collection systems (Figure 10.1) are as follows:

Building sewers: Also called house connections, are used to convey wastewater from the buildings to lateral or branch sewers, or any other sewer except another building sewer. Building sewers normally begin outside the building foundation.

Lateral or branch sewer: Lateral sewers form the first element of a community sewage collection system and are usually in streets. They are used to collect sewage from one or more building sewers and convey it to a main sewer.

Main sewer: Main sewers are used to convey sewage from one or more lateral sewers to trunk sewers or to interceptor sewers.

Trunk sewers: These are large sewers that are used to convey sewage from main sewers to treatment plants or other disposal facilities or to larger intercepting sewers.

Intercepting sewers: These 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.

Outfall sewer: These are the segments of main or trunk or interceptor sewers which lie between connections and the final point of disposal or treatment plant.

Design of sanitary sewer system

The important objectives of the design of a sanitary sewer system are:
- to ensure ease of operation;
- to minimize maintenance requirements.

Two major factors to be considered in the design of a sewer system are
- the quantity of wastewater flow;
- the flow hydraulics.

Estimation of 'design flow' is important in that it ultimately determines the sizes of sewers to be provided. These must be of adequate capacity to handle the waste flow at the end of the design period. Wastewater flows are highly variable and contain floating and suspended solids. Consideration of flow hydraulics in

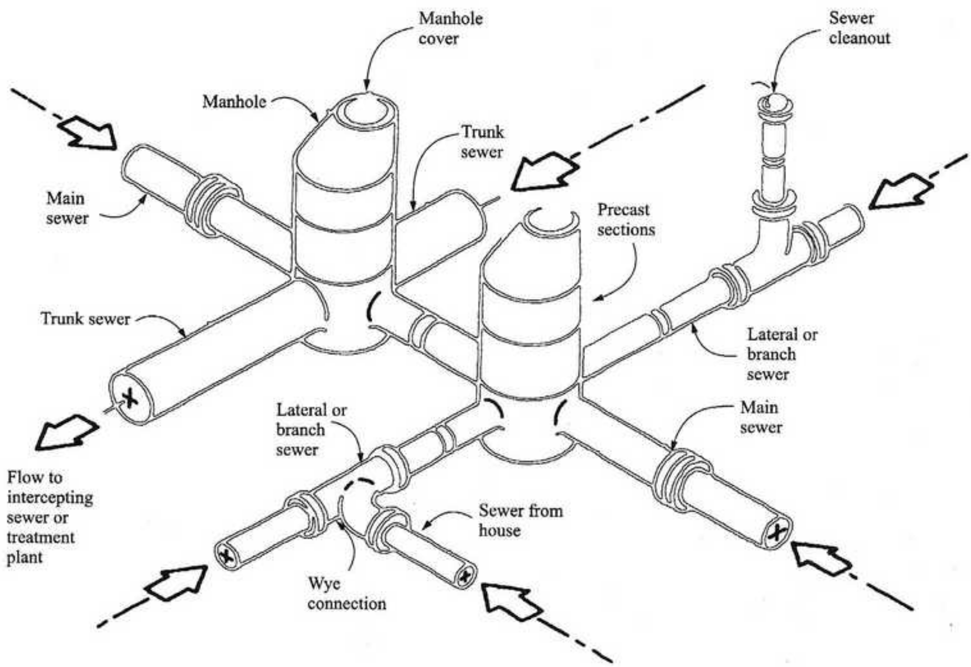

Figure 10.1 Definition sketch of different types of sewers (peavy et al. 1986)

sewer design is, therefore, important in minimizing solids deposition in sewers, thereby minimizing maintenance requirements.

Estimation of wastewater flows

A sanitary sewer system is designed as a separate system, which is intended to receive domestic wastewater, commercial and industrial wastewater and groundwater infiltration. The quantity of wastewater in sanitary sewer systems is influenced by the following factors:

- population estimate
- rate of water supply
- type of area served
- groundwater infiltration.

Population Estimates: The population that may be expected to live within an area at some future date will determine the quantity of wastewater flow from that area. It is therefore important to make an assessment of the future population before it is possible to estimate the probable wastewater flow. There is no exact method of predicting the future population in a particular catchment area, nor is there any way of determining the direction that the future development may follow. Some guiding factors affecting population growth may, however, be considered in estimating future population:

- Past records of the population trends of the locality or similar areas will enable a population growth rate to be determined from which the future population can be estimated.
- A study of the locality may identify areas likely to be preferred for different activities e.g., residential, commercial, industrial or recreational. Such a study may be used to determine the probable future development of an area.
- Government control either by legislation, incentives or a Town Planning Authority may affect the direction and rate of future growth.
- Availability of transport and road systems, power and water supplies will also affect future development of an area.

Evaluation of such factors for a particular region leads to an estimate of the design population, which is essential for determining wastewater quantities. Population estimates are often made using the following simple equation:

$$P_n = P_o [1 + r]^n$$

Where, P_n = future population after n years
P_o = present population
r = population growth rate (as decimal)

Relation to water use: Sanitary sewage and industrial wastes are derived principally from the water supply. It is fairly common to assume that the average rate of sewage flow is equal to the average rate of water consumption. But this should be done only after careful consideration of the actual nature of the community. Such an estimate would be too high for a residential community in an area with hot, dry summers, and too low for a community containing industries, or commercial institutions with private water supplies.

The quantity of sewage will also be affected by factors affecting water use, such as:

- characteristics (economic level) of the population (50-380 lpcd);
- metering of water supply;
- other factors (e.g., climate, quality, pressure, and conservation programs).

Groundwater infiltration: The presence of a high groundwater table results in leakage into the sewers and in an increase in the quantity of wastewater. The rate and quantity of infiltration depends on a number of factors:

- depth of sewer invert below the groundwater table;
- sewer size;
- materials of the sewers;
- length of sewer below groundwater table;
- nature and types of soils;
- types of joints;
- workmanship during sewer laying.

Quantity of infiltration can be expressed in one of the following ways:

- litres/hectare of area/day
- litres/km length of sewer/day
- litres/cm (inch) diameter/km length/widely.

Groundwater infiltration rate may vary widely e.g., from 3,000 litres/hectare/day to 50,000 litres/hectare/day depending on age of the sewers, sewer materials, type of area and level of the groundwater table.

Components of design flows: The unit quantities of wastewater for which the sewer sizes have to be designed are called the design flows and consist of the dry weather flow and the wet weather flow.

Also, the wastewater flow is not uniform throughout the day and throughout the year. It varies during the day due to the varying use of water for domestic, commercial and industrial purposes. Variations throughout the year is due to seasonal variation of rainfall and rainfall intensity.
Due to such variations in wastewater flow, the following terms are used:

- Average Dry Weather Flow (ADWF)
- Peak Dry Weather Flow (PDWF)
- Peak Wet Weather Flow (PWWF)

ADWF: is the average of the daily dry weather flow to the sewer system when not affected by storm infiltration and reflects the wastewater discharges from domestic, industrial and commercial fixtures.

PDWF: the wastewater flow during the day is not uniform. During normal daily flows, two distinct peaks usually occur - the morning peak and the evening peak.

The ratio of peak to average dry weather flow is termed as the "peak factor" and is a variable and depends greatly on population size and density. Generally, the ratio will fall as the number of contributors increases.

PWWF: is the maximum flow to be considered in designing the capacity of sewers and is the sum of the maximum peak dry weather flow plus the storm contribution during wet weather period.

Storm contribution is made up of direct entry of storm water through flooded manholes, illegal connections of storm runoff, and also by infiltration of groundwater through defective or fractured sewers and fittings.

The daily variation of wastewater flow is shown by the hydrographs in Figure 10.2. As can be seen from the figure, minimum flow occurs during early morning when the water consumption is lowest. The first peak flow generally occurs just after the peak late-morning water use. A second peak flow generally occurs in the early evening.

Design Flow Estimation

The procedure of estimating design flow presented here is based on a rational approach followed by the Melbourne and Metropolitan Board of Works (MMBW, 1981). The design flow consists of the sum of the PDWF plus wet weather additive and may be expressed as:

$$Q = \sum D.d + \sum I.i \quad (10.1)$$

Where $\sum D$ = is the sum of all dry weather flow components
d = peak dry weather factor
$\sum I$ = basic wet weather additive
i = appropriate infiltration factor.

Sewers are usually designed to have a capacity $\geq Q$.

The average daily dry weather flow is calculated as the sum of the flows from the different types of land use from all individual parts of the catchment.

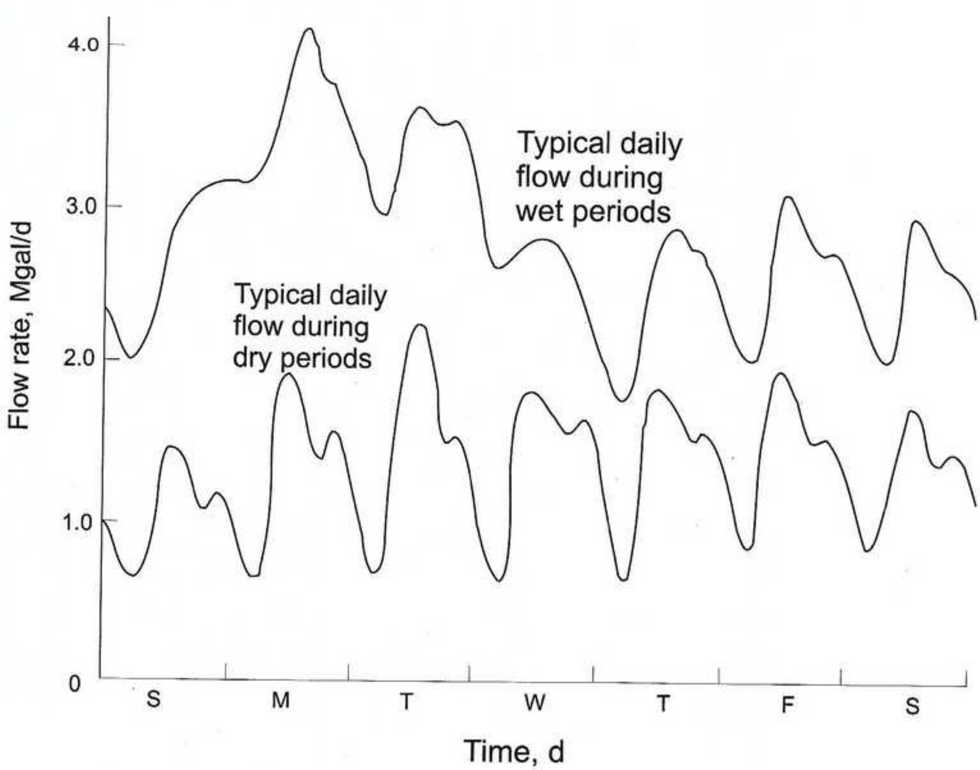

Figure 10.2 Typical dry and wet weather hydrographs

$$\Sigma D = P.q_r + A_c.q_c + A_i.q_i \quad (10.2)$$

where P = population
q_r = residential discharge rate (say, 100-400 lpcd)
A_c = commercial area
q_c = commercial discharge rate (say, 0.25-1.5 l/sec/ha for sub- urban business areas but may be up to 8.0 l/sec/ha in high- rise business area)
A_i = industrial area
q_i = industrial discharge rate. (depends on industry type, e.g., 0.25-0.35 l/sec/ha.)

Values of 'd' may vary from 3.0 for small areas to 1.7 for larger areas.

The basic wet weather additive may be expressed as:

$$\Sigma I = A_r.K + A_c.K/4 + A_i.K/4 \quad (10.3)$$

where A_r = residential area
A_c = commercial area
A_i = industrial area.
K = ground constant

The infiltration factor or the wet weather flow factor, i, varies from 1.0 for small areas to 0.5 for large areas in a manner similar to the decrease in rainfall intensity with increasing area.

The ground constant, *K* depends on many factors. It varies with different ground types: higher values, for clayey soils and lower values for sandy soils. It also varies with density of residential areas (i.e., number of connections), type of sewer joints (low values for good joints), and different types of land use (e.g., residential, commercial and industrial). For industrial and commercial areas the values are reduced to a quarter. The values of K will vary from place to place and should be determined from observations over many years.

Self-cleaning velocity requirements

Considering the large variation in wastewater flow, sewer design must be such that deposition of organic and other solid materials is minimized to avoid sewer blockages. As such sewers are graded to attain self-cleansing velocity within the sewer to avoid deposition.

The usual practice for the hydraulic design of circular sewers is to maintain a minimum velocity for achieving the self-cleaning action and in general a minimum velocity of 0.6 m/sec., when flowing full is considered adequate for sanitary sewers.

The basis of the minimum velocity approach is that the mean tractive force (shear) between the flowing wastewater and the pipe wall must, at least once per day, be as great as the tractive force on a similar size pipe graded to run full at 0.6 m/sec. It is on this basis that the design of sewers relies on the peak dry weather flow at least once a day.

Because of the fluctuations in wastewater flows, it is not possible to maintain self-cleansing velocity at all times, and during minimum flow conditions the velocity will be much less. It is recommended that sewers be graded to provide a velocity of at least 0.6 m/sec at an estimated maximum flow and velocities of not less than 0.4 m/sec during low flows.

Non-scouring velocity

In design of sewers, the maximum velocity of flow has also to be considered. If the velocity of flow exceeds a certain limit, the solid particles in the wastewater may damage the surface of the sewers by scouring action.

The maximum permissible velocity at which no such scouring action takes place is known as non-scouring velocity. This velocity mainly depends on sewer materials. Recommended non-scouring velocities are:
2.5-3.0 m/sec for concrete sewers
3.0-3.5 m/sec for vitrified sewers
2.0-2.5 m/sec for brick sewers
3.5-4.0 m/sec for cast iron sewers

Hydraulic design of sewers

Sewers are designed for gravity flow of wastewaters. There are various empirical formulae which are used in the design of sewers, e.g., Chezy's formula, Manning's formula, Bazin's formula, Crimp's & Burge's formula, Hazen & William's formula and so on. However, Manning's equation is the most commonly used formula in the design of sewers. Manning's most widely used equation for velocity determination is:

$$V = 1/n\ R^{2/3}\ S^{1/2} \qquad (10.4)$$

where V = velocity m/sec
n = friction factor or Manningês roughness coefficient.

See handout for further detail and Math

$$R_{\text{hydraulic radius}} = \frac{\text{X-sectional area of flow}}{\text{wetted perimeter}}$$

S = slope of the energy grade line.

- Assuming uniform flow conditions, this slope is considered equivalent to the slope of the sewer bottom.
- In general, n-values varying from 0.013 to 0.015 are used in sewer design depending on the roughness of the sewer surface.

- Furthermore, n values are assumed to be constant for all depths of flow, although it has been shown experimentally that n values are greater in partially filled sewers than in sewers flowing full.

Sewers flowing partly full

In general, sewers are design to flow full only under maximum flow conditions. However, it is also necessary to estimate the velocity and/or discharge under flow conditions. This is particularly important to ensure minimum velocity during low flow in order to avoid solids deposition in sewers.

The relationships between various hydraulic elements for flow at full depth and at other depths in circular sewers can be determined from simple trigonometric functions. A circular sewer running partly full is considered in Figure 10.3.

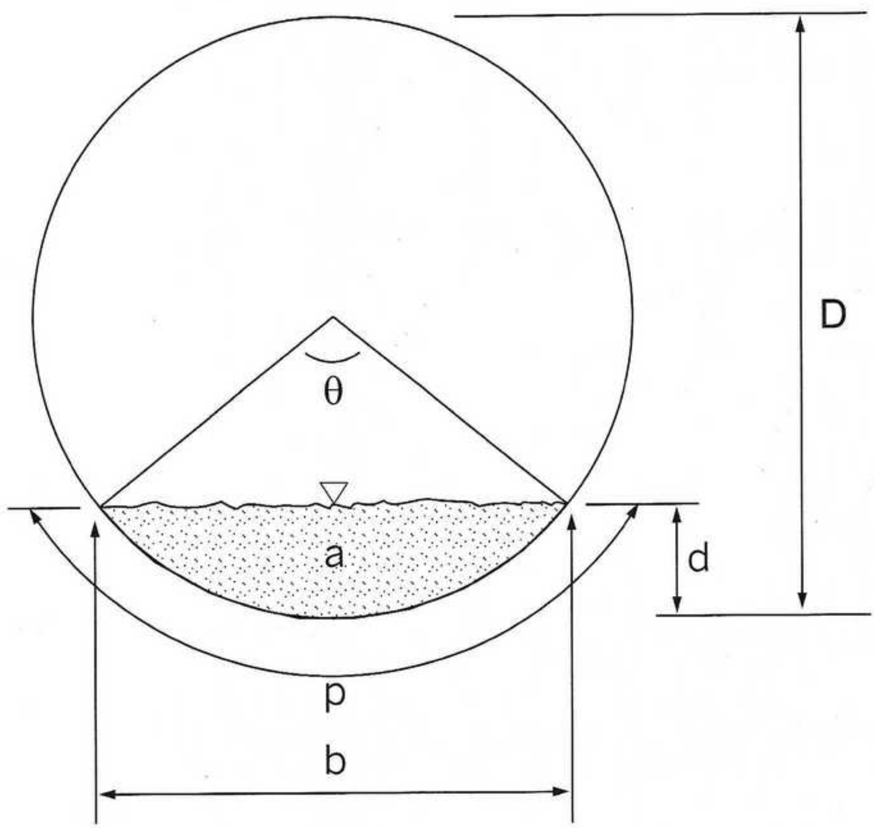

Figure 10.3 Circular sewer section flowing partially full

When the sewer is flowing full, let,

D	=	full depth (i.e., sewer diameter)
A	=	cross-sectional area, $\pi D^2/4$
P	=	perimeter, πD
V	=	velocity of flow
Q	=	average discharge while flowing full

When the sewer is flowing partially full, let

d	=	depth of flow
a	=	X-sectional area of flow
p	=	wetted perimeter
v	=	velocity of flow
q	=	average discharge of partial flow.

(Units of respective parameters are the same for both cases)

It is now possible to determine the proportionate velocity, v/V, proportionate flow,q/Q, proportionate area, a/A, proportionate hydraulic radius, r/R from simple trigonometric relationships. Values of v, q, a and r at a given depth ratio can then be computed based on corresponding values of V, Q, A and R for full flow condition.

Relationships between hydraulic elements for flow at full depth and at other depths in circular sewers have been developed using Manning's equation. The relationships commonly known as the "hydraulic elements diagram for circular sewers" are normally used for the design of sewers under partial flow conditions. The diagram (Figure.10.4) is prepared from calculations of various hydraulic elements of a circular sewer considering the diameter (or the full depth of flow) to be uniform, with standard values of n and slope, s.

- A hydraulic elements diagram is useful for obtaining all other elements if any one of them is known for a partly filled sewer.
- The first step is to determine the area, velocity or discharge for the sewer flowing full and also the ratio of the depth of flow to the diameter of the sewer.
- The necessary multiplier for the partly full sewer is then read from the diagram.
- The diagram is also useful when the capacity of a full sewer is known, and it is required to find the depth of flow, and the velocity corresponding to a smaller discharge.

Several important points can be observed from the hydraulic elements diagram of Figure10.4.

- velocities under full flow conditions and half full conditions are equal, i.e., $v = V$ at both $d/D = 0.5$ and $d/D = 1$;

- the maximum velocity occurs at $d/D = 0.81$ and is given by $v/V = 1.14$;
- the maximum flow occurs at $d/D = 0.94$ and is given by $q/Q = 1.07$.

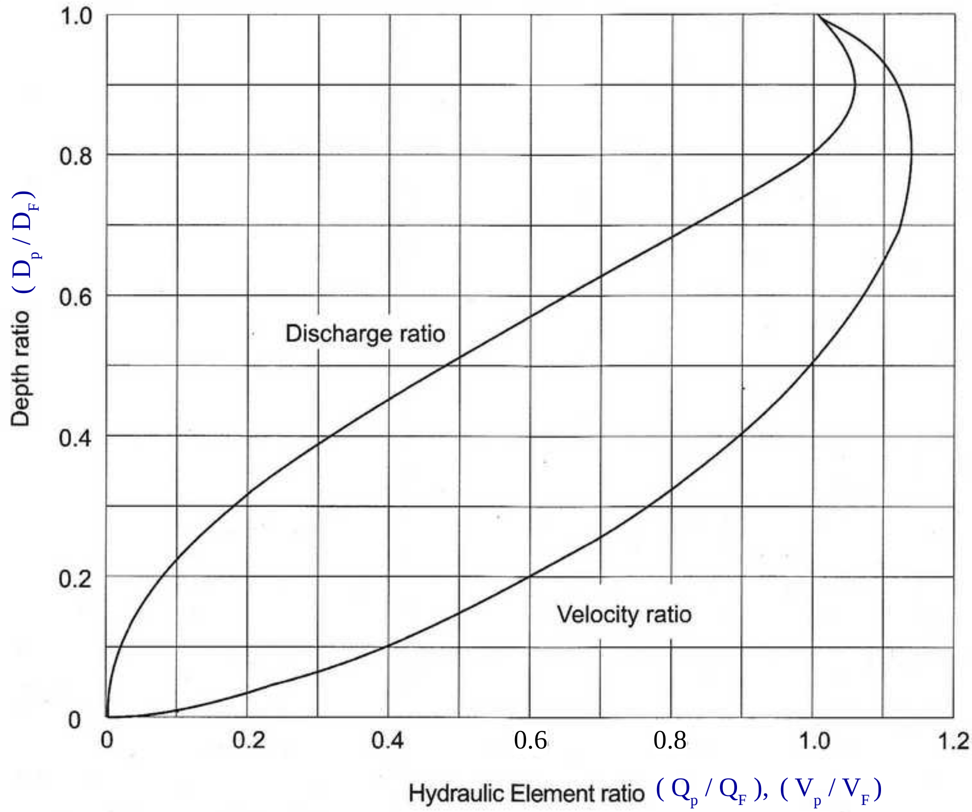

Figure 10.4 Hydraulic elements diagram for circular sewers

Construction methods and materials

Before the construction of sewers, it is essential that the design and detail working drawings are complete. The detail working drawing should include the following:

- size and alignment of sewers;
- position of manholes and other appurtenances;
- invert levels and grades at different positions;
- depth and width of trenches;
- the nature and type of bedding.

The various steps to be followed for the construction of sewers are as follows:

1. marking of alignment before starting excavation;
2. setting benchmarks as reference points for maintaining accurate sewer invert level.;

3. establishing grade lines by installing sight rails for determining reduced levels of excavations, bedding and sewer invert;
4. excavating the trench with or without shoring (timbering) depending on soil condition and depth of trenches;
5. dewatering of trenches when excavating below groundwater table;
6. providing bedding for surface of uniform and required grading;
7. laying of sewers in a proper fashion and jointing of pipes using appropriate jointing materials;
8. testing of sewers against leakage before backfilling of trenches;
9. backfilling of trenches in layers and properly compacting by ramming and watering.

Operation and maintenance

Operation and maintenance of sewerage systems include mainly the removal of blockages, cleaning of sewers, ventilation of sewer gases and repair of sewers and appurtenances when required.

Manholes are installed on main sewers usually at intervals of 40 to 80 metres for the purpose of cleaning. Sewers can be cleaned manually or by water jet hosing.

Safety measures should be taken to avoid hydrogen sulphide poisoning during cleaning operations. Sewers, manholes and pumping stations should be monitored more frequently with increasing age to ensure that rehabilitation is done before the system collapses.

Experiences in Bangladesh

Conventional sewerage systems in Bangladesh exist only in parts of Dhaka city. The only sewage treatment plant at Pagla employs waste stabilization methods of sewage treatment and discharges treated waste into the river Buriganga. Storm water in Dhaka is collected by a separate drainage system, which discharges without treatment into various water bodies through a number of outlets.

Dhaka Water and Sewerage Authority (DWASA) is responsible for construction as well as operation and maintenance of waterborne sewerage system in Dhaka city. O&M of sewage lift stations and the treatment plant at Pagla constitute major regular tasks for DWASA.

Dhaka's sewerage system is characterized by unauthorized connections, particularly by industries, resulting in huge revenue loss and adding unanticipated volumes to collection and treatment capacity.

The present status of urban sanitation in Bangladesh reflects the lack of financial resources for providing conventional sewerage in urban areas of the country. The high cost of conventional sewerage is clearly not affordable for a developing country like Bangladesh when it is seen that the per capita annual income of people is only US $ 240.

10.3 SMALL BORE SEWERAGE SYSTEM

In the face of limited global and national resources, the high cost of traditional waterborne sewerage has stimulated interest in alternative low-cost proposals in order to extend adequate sanitation services to medium and low-income communities. One such proposal is the so-called "small bore sewerage" (SBS) system. This is a recent sanitation technology that offers all the advantages of conventional waterborne sewerage systems but at a much lower cost than the conventional ones. The technology is relatively little known, but has been used extensively in Australia and to some degree in the USA.

SBS system elements

There are three basic elements to a small bore sewerage system. These are:

- septic tanks;
- small bore sewer network;
- treatment plant.

The SBS system (Figure10.5) collects wastewater discharges from all the fixtures in households (or other premises) in a similar fashion to the conventional sewerage system. The basic difference between the two systems is the incorporation of septic tanks within the individual premises as part of the SBS system. The wastewater collected in the septic tank is then transported under gravity through a network of reticulation sewers to a treatment plant comprising a series of stabilisation lagoons.

In the case of an existing septic tank system the sewer installation commences immediately downstream of the existing septic tank, and new developments must install septic tanks to be able to connect to the SBS system.

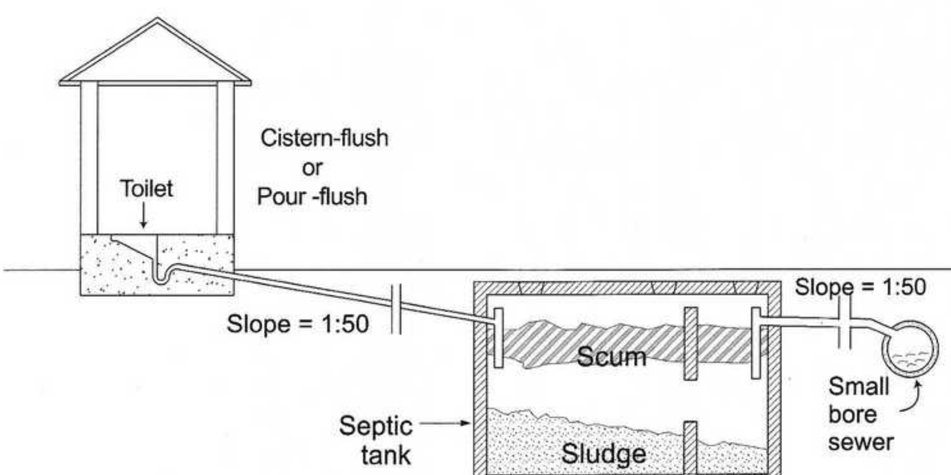

Figure 10.5 Elements of small bore sewerage system

Septic tanks

Septic tanks or interceptors are required to be installed within individual premises to receive wastewater from toilets, baths, laundry and kitchens. These are designed with a view to achieve the following fundamental functions:

- sedimentation of undissolved, settleable solids in the wastewater thus requiring sufficient retention time;
- storage of sludge and scum for at least three to five years or more, thus requiring sufficient volume;
- reduction of the biochemical oxygen demand (BOD) of the wastewater through anaerobic decomposition of the organic matter contained in the wastewater; and
- substantial attenuation of peak flows, which is a function of the liquid surface area of the tank.

Literature (Viraraghavan, 1976) suggests that, in septic tanks, suspended solids are reduced gravitationally and by microbial action by about 18 to 70% and the BOD is reduced by about 46 to 60% depending on the design and performance of the septic tanks.

The wastwater flows which reach the small bore sewers are markedly attenuated in the septic/interceptor tank from the rate at which they are discharged by the users. The extent of attenuation is a function of the tank liquid surface area and the length of time over which the wastewater is discharged to the tank. It is reported (Otis and Mara, 1985) that peak discharges are attenuated by about 64% in septic tanks. Field experience suggest that the maximum discharge from septic tanks can be about 25% of the peak input.

The important point to be mentioned here is that all the above functions of septic tanks lead to significant changes in the design criteria of the SBS system compared to the conventional system. Some of these design differences are discussed in the following sections.

SBS sewer reticulation

The important parameters that bring significant changes in the design criteria of the SBS collection system, due to the presence of septic tanks in individual premises, are the design flow, sewer sizes, minimum velocity, sewer grades and manholes.

Design flows: Estimation of the wastewater flow is an important factor in the overall design of a sewerage system. Over-estimation of the flow usually results in the sewerage system being over-designed, whereas under-estimation may result in system failure. Considerable care has therefore to be exercised in estimating the design flow.

It is the general tendency of the home users to use the same amount of water for various household purposes such as shower, laundry, sink, toilets etc., wherever a reticulated water supply is available. Thus the average discharges into the sewerage system would be relatively independent of the presence of a septic tank. However, in the SBS system, it is desirable that the average dry weather flow be less than the respective values generally quoted for conventional systems. This can be achieved by using water-saving plumbing fixtures such as low volume toilet flushing cisterns.

It is not uncommon to assume wastewater flows of the order of 200 lpcd for the design of conventional sewerage systems, even for the low- to middle-income communities in developing countries This results in unjustifiably expensive, and hence unaffordable solutions. Otis and Mara, (1985) suggest that the design flow to be considered feasible in conjunction with the SBS systems should be in the range of 40-80 lpcd with yard tap supplies and form 80-20 lpcd with multiple tap in-house supplies.

The wastewater flows which reach the SBS sewer network are attenuated significantly in the septic tank. Hence the design flow peak factor will also be less in the case of an SBS system. There are very few data on the magnitude of peak flows in small bore sewers. However, in the absence of more field data Otis and Mara (1985) suggest that a design flow peak factor of 2 should be adopted.

In addition to wastewater flows, estimates of groundwater infiltration and surface water inflow are also considered in the design of conventional sewerage systems. It is, however, intended that in the SBS system infiltration be eliminated by using solvent jointed UPVC as sewer materials. The flow figures quoted above for the SBS system, however, are not stringent design criteria. Rather they should be assessed individually for different areas considering their population growth, living standard, availability and type of water supply, and household water usage pattern.

Sewer diameter: In the SBS system sewer sizes are smaller because of low average flow and because of attenuation of peak flow in the septic tank, thereby reducing the required sewer capacity. Since most of the settleable solids are retained in the septic tank, the possibility of solids deposition and blockage in the sewer is minimized. Elimination of storm water infiltration will also reduce the required sewer capacity.

The minimum size of sewer most commonly used in the conventional system is 150 mm, while the SBS system can employ a minimum sewer size of as low as 50 mm. The Australian practice uses a minimum size of 100 mm sewer. As soon as design flows indicate that the sewer will flow more than 60% of full capacity at full development then the next higher size should be adopted.

In developing countries however, where the specialised equipment for cleaning smaller diameter sewers is not generally available, a minimum diameter of 100 mm may be recommended.

Sewer gradients: The grades of conventional sewers are established to produce self-cleansing velocities in order to avoid solids deposition in the sewer. The usual practice for the hydraulic design of circular sewers is to maintain a minimum velocity for achieving the self-cleaning action. In the SBS system, since the settleable solids in the wastewater are retained and the suspended solids are reduced significantly in the septic tank, it is not necessary to maintain a self-cleansing velocity in the sewer reticulation system. As a result the grades can be substantially reduced thereby reducing the volume of excavation to a great extent.

Manholes and flushing points: The SBS system requires less maintenance due to minimal solids content of the wastewater. Therefore, a fewer number of manholes are installed. Flushing points are used in the system at locations where the manholes would otherwise exist. These points consist of a 100 mm PVC riser with a removable screw-cap under a concrete cover at the surface to provide access for flushing. Flushing points are preferable to manholes because they are less costly and can be more tightly sealed to eliminate most infiltration and grit which commonly enter through the lids and walls of manholes.

Wastewater treatment

In the SBS system, treatment of wastewater is performed in two stages, firstly, on-site treatment in the septic tanks and secondly, off-site secondary treatment in a series of stabilisation lagoons. In the septic tanks the larger particles and the settleable solids are retained, and the BOD and the suspended solids are significantly reduced. To attain a certain effluent quality, the primary effluent from the septic tanks is treated in a series of stabilisation lagoons.

Treatment in stabilization lagoons is simple, effective and low-cost. Both conventional and SBS systems can adopt lagoon treatment processes if sufficient land area is available and the climatic conditions are favourable. The major difference with the SBS system is that the septic tanks reduce the organic loading of the wastewater. As indicated earlier, about 46 to 60% BOD is removed in the septic tank. Consequently, the cost of treatment in the lagoons will be reduced due to the lesser land area required for the SBS system.

Technical advantages

The small bore sewerage system has specific technical advantages over the conventional sewerage system as listed below.

- Sewer sizes can be reduced because each septic tank tends to act as a balancing tank, largely eliminating surge.
- Since the wastewater contains minimum solids, self-cleansing velocities are not necessary and hence sewer grades can be substantially reduced.
- Sewer blockages are minimal as septic tanks retain most of the solids content.
- Volume of excavation is considerable reduced because of smaller sewers and lower sewer grades.
- Solids handling at the secondary treatment site is minimum.

- Rapid construction is possible because of lesser volume of excavation and fewer number of manholes to be constructed.

However, due consideration must be given to the following factors when evaluating SBS system with respect to conventional sewerage systems.
- With a conventional sewerage system there are no septic tanks to be inspected or desludged within the individual premises. However, a community might not have a sewerage system for a long time due to financial constraints.
- Septic tank installation is mandatory for new homes to be able to connect to the SBS systems.

Economic considerations

Although the basic principles of both the SBS system and the conventional sewerage system are similar, there will be differences in the initial capital costs and the annual maintenance costs between the two systems. This is because of changes in the design criteria brought about by the presence of the septic tank in the SBS system.

The differences in the initial capital costs between the systems are a result of the following factors.

A reduction in the capital costs in the SBS system due to:
- reduction in the sewer sizes;
- reduction in minimum grades, thereby reducing the volume of excavations;
- reduction in the number of manholes;
- reduction in hydraulic and organic loading of wastewater due to the existence of the septic tank, thereby reducing the treatment plant area;
- less costly pumps with minimal solids handling required.

An increase in the capital costs in the SBS system due to:
- installation of septic tanks (however, if use is made of existing septic tanks then it will be an added cost advantage for the SBS system);
- installation of flushing points.

The differences in the annual maintenance costs between the two systems are a result of the following factors.

A reduction in the maintenance costs in the SBS system due to:
- fewer manholes;
- less frequent cleaning of sewers because the possibility of blockage due to solids deposition is minimum;
- no sludge handling is required at the treatment site.

An increase in the maintenance costs in the SBS system due to:
- desludging of septic tanks 3 to 5 times per year;
- regular flushing of sewers.

The SBS system, as it appears from the above discussions, holds significant promise economically and can be considered as a viable alternative to the conventional sewerage system. It is particularly suitable in areas where septic tanks are already in existence and where the future growth potential is minimal. For newly developed areas with high growth potential the SBS system may be marginally cheaper because of the high cost of septic tank installations. It is important however, that emphasis be given to assess relative costs on a case by case basis, as both the SBS and the conventional sewerage system's costs are sensitive to local conditions.

SBS system design

The design procedure for small bore sewerage systems is similar to that of conventional sewerage systems, which have been discussed in a previous section. The additional component to be designed in case of SBS systems is the interceptor tank, which is again the same as conventional septic tank design.

Peak flow estimation is done taking a substantial attenuation in the interceptor tank into consideration . In the hydraulic design of an SBS sewer network, separate analysis is done for each sewer section using Manning's equation and the hydraulic elements diagram.

Since the flow in the SBS sewers is free of solids, theoretically it is possible to lay the sewers on a "rolling grade", i.e., following the slope of the land. Some sections can even have a negative or upward gradient, provided that there is enough overall slope to carry the maximum flow.

However, considering that the interceptor tanks/septic tanks will not perform as efficiently as designed for, there will always be some solids over-run through the septic tank outlets which will then tend to settle in SBS sewers. It is therefore recommended that SBS sewers be designed for uniform gradient and partial flow conditions as in the case of conventional sewers. The minimum grade and velocity would, however, be much less than those for conventional sewerage and should be varied considering local conditions.

Applicability in Bangladesh

In the absence of expensive conventional sewerage systems, septic tanks and pour-flush sanitation systems are largely used in the urban centres, including the major cities of Bangladesh. However, septic tank effluent disposal has generally been very poor. It is not uncommon to see, particularly in the country townships, septic tank effluents being discharged into open ditches without awareness of the effluent quality and their detrimental effects on the living environment. Even in parts of large cities, due to adverse ground conditions (e.g., low soil permeability, shallow rock) and high groundwater table particularly during wet periods, septic tank effluent cannot be disposed of properly. Furthermore, improper installation and poor operation and maintenance of pit latrines as well as septic tank effluent soakage constitute active sources of groundwater pollution.

Small bore sewerage systems are particularly suitable in such situations. Particular advantages can be drawn from sewering existing pour-flush and septic tank systems. When an existing septic tank system fails, commonly due to soil becoming unable to absorb increased wastewater flows resulting from improvements in water supply, or from increased housing densities, the septic tank effluent is best discharged into a small bore sewer system. This is always less expensive than abandoning the septic tank and installing a conventional sewer network.

Application of small bore sewerage systems has recently been initiated in Bangladesh. Several SBS schemes have been installed in low-income housing areas at Mirpur in Dhaka. These schemes, however, collect effluents from medium to large communal septic tanks and discharge them into nearby low-lying areas without treatment. The first signs of SBS systems use in Bangladesh is certainly encouraging. However, the important aspects that require careful consideration for successful application of SBS system are:

- proper design and construction of interceptor tanks and sewer network;
- regular desludging of interceptor tanks;
- prohibition of illegal connections to the SBS sewer network.
- Proper treatment of collected effluent before final disposal.

10.4 SIMPLIFIED SEWERAGE SYSTEM

Simplified sewerage, also called shallow sewerage, is a low-cost sanitation technology particularly suited to high-density, low-income urban areas in developing countries. Simplified sewerage is designed to receive all household wastewater without settlement in solids interceptor tanks or septic tanks as is done in the case of small bore sewerage systems. It is essentially similar to conventional sewerage, but without any of the later' s conservative design features. Small diameter sewers used to convey the sewage are laid at shallow gradients. These sewers are often laid inside housing blocks, where the system is known as condominial sewerage. They may also be laid outside the housing block, usually under sidewalks rather than in the middle of the road, as is the case with conventional sewerage.

The system is the outcome of critical review of the justification for conventional sewerage design standards. This review led to sweeping changes in conventional sewer design standards for minimum diameters, minimum slopes, minimum depths, and the spacing and location of manholes. The changes were based on findings of research in hydraulics, satisfactory experience and redundancy, which ultimately led to the development of a lower-cost sewerage system with smaller, flatter and shallower sewers with fewer and simpler manholes.

In addition, the system makes use of design periods that are considerably shorter than those used in conventional sewerage. Although it is claimed (Otis et al., in Mara, 1996) that the simplified sewerage system was developed in Brazil, the basic concept of the system was adopted by the New South Wales PWD

(Brady et al., 1983) at about the same time. A model layout of a simplified sewerage scheme is shown in Figure 10.6.

Design principles

Sewer design must be such that deposition of organics and other materials is minimized to avoid blockages of the sewer line. As such, sewers are graded to attain self-cleansing velocity to avoid deposition. The usual practice for the hydraulic design of circular sewers is to maintain a minimum velocity for achieving the self-cleaning action. In general a minimum velocity of 0.6 m/sec when flowing full is considered adequate for sanitary sewers.

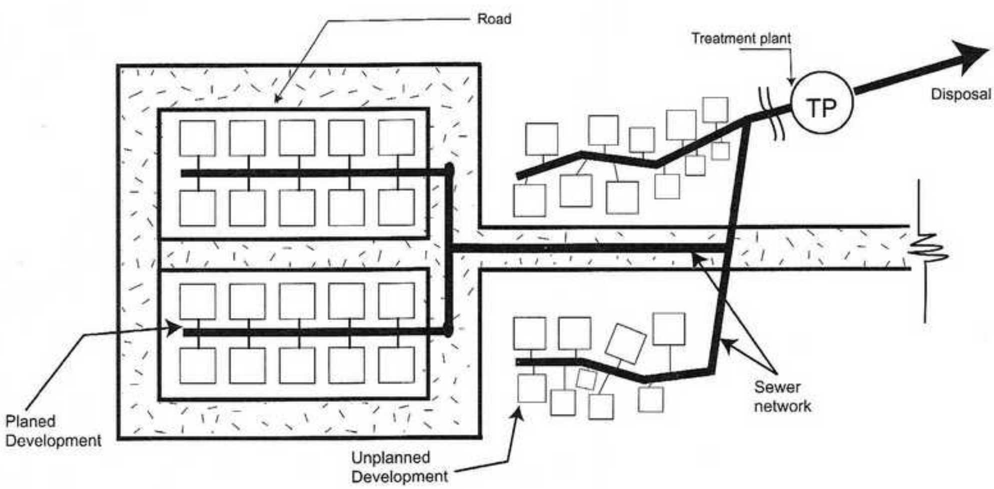

Figure 10.6 Model layout of a small simplified sewerage scheme

A recent trend is to apply a critical shear stress (tractive tension) approach instead of minimum velocity theory in the hydraulic design of sewers (Yao, 1974). The critical shear stress of sediment particles is considered as the minimum shear stress necessary for the initiation of motion of the particle. Its magnitude depends on a number of factors including the densities of the particle and the fluid, the size of the particle and the viscosity of the fluid.

The minimum velocity theory, established in 1942 by the Boston Society of Civil Engineers, states that at least once a day the mean tractive force (shear) between the flowing sewage and the pipe wall must be as great as the tractive force on a similar size pipe graded to run full at 0.6 m/sec. However, Yao (1974) indicated that this minimum velocity is not independent of sewer size, and the practice of using a constant minimum velocity for all sewer sizes tends to either underdesign larger sewers or overdesign smaller sewers. The shear stress attained under a constant minimum velocity varies considerably with varying sewer sizes, being lower for larger sewers.

The recent minimum tractive tension approach of hydraulic design is to ensure self-cleansing of sewers by attaining sufficient shear stress on the critical area of the wetted perimeter. The New South Wales PWD revised design practice (Brady et al., 1983) recommends that the average shear stress over the critical area of the wetted perimeter must be equal to or greater than 1.47 N/m^2. Previously the NSW PWD had been designing on the basis of the minimum velocity theory and the recent revision of this criterion, i.e., adopting this critical shear stress approach has resulted in the flattening of the grades at which smaller size sewers (up to 300 mm) are laid. Although larger size sewers are required to be graded more steeply than was the case with previous design, the flattening of smaller size sewers has resulted in substantial reductions in overall costs for the sewerage of small country towns.

The design of simplified sewerage in Brazil is based on a minimum tractive tension of 1 N/m^2 and a minimum flow depth of 0.2 relative to the sewer diameter. The design slope is thus determined by:

$$I_{min} = 0.0056\, Q_i^{-6/13} \qquad (10.5)$$

where,
I_{min} = minimum sewer slope, m/m
Q_i = initial wastewater flow, litres/sec.

Based on this minimum sewer grade, the diameter of the sewer is determined using the projected final flow and limiting the ratio of depth of flow to sewer diameter, $d/D \leq 0.8$. In simplified sewerage, the usual limits for d/D is $0.2 < d/D < 0.8$ (Mara, 1996).

A hydraulic design chart (table 10.1) for simplified sewers based on Manning's equation, simplifies the determination of sewer diameter by relating d/D to $Q_f/I_{min}^{0.5}$ and $V/I_{min}^{0.5}$, where Q_f is the final flow in m^3. The exact or a nearer value of $Q_f/I_{min}^{0.5}$ is located in this design chart where d/D does not exceed 0.80. The final velocity V_f is computed from the corresponding $V/I_{min}^{0.5}$ value in the chart. A derivation of this method can be found elsewhere (Mara, 1996).

Operation and maintenance

Simplified sewerage systems have been widely adopted in Brazil and subsequently applied in Bolivia, Colombia and Cuba (Otis et al., in Mara, 1996). Information on operational problems, however, is not yet readily available. Experience in Brazil suggests that occurrence of obstructions in sewers is insignificant and this supports the policy of reducing the number of manholes for maintenance purposes.

Manholes in simplified sewers are similar to conventional manholes, but they are smaller because there is no need for maintenance personnel to enter the manholes due to shallower depths and the availability of modern cleaning equipment. Engineers in Brazil are in favour of installing a fewer number of manholes initially, with the intention of constructing additional ones if the need arises due to blockages.

Cost

Simplified sewerage systems have proven to be substantially cheaper than conventional sewerage system. Cost savings ranging from 20 to 50 % have been reported (Otis et al., in Mara 1996). The initial projects in Brazil have shown a cost reduction of about 40%. The cost of simplified sewerage, however, varies from place to place depending on the varying design standards and criteria.

Suitability

Simplified sewerage systems offer a new cost saving approach primarily based on rational changes in long-standing traditional conservative sewer design standards. One important consideration is that the safety factors, which have been embedded in many design criteria e.g., design flow, minimum diameter, depth etc. need not be the same everywhere in all situations.

For example, there is no valid basis to apply the same conservative design standards in busy city areas where breakdowns could create heavy losses and great inconvenience, as in the outskirts of a city where breakdowns might have less severe impacts. Experiences in Brazil and other countries have shown that:

- simplified sewerage could be a viable lower-cost alternative to conventional sewerage systems particularly for the developing countries;
- design modifications in simplified sewerage are based on sound engineering principles without jeopardizing the level of service;
- costs could be 30 to 50 % less than conventional sewerage, thus allowing service coverage to be expanded.

10.5 NON-SEWERED TRANSPORTATION OF WASTEWATER

Bucket latrine system

The bucket latrine system is one of the oldest and least hygienic systems, and though generally not recommended, existed for centuries all over the world. A squatting slab or seat is placed immediately above a bucket placed for collection of excreta (Figure10.7). The bucket of an average family fills up with excreta within a few days. A collector empties the bucket typically once or twice a week and it is transported by a push cart/animal cart to a specified dumping place. The bucket is positioned adjacent to an outside wall with a door and is accessible from the street or lane. Removal is sometimes called 'nightsoil collection' because it is often carried out during the night.

The act of emptying the bucket into the cart typically involves spillage and the area becomes heavily contaminated. The same occurs at the depot where the contents of the carts are emptied for transportation in trucks or for treatment,

Table 10.1 Design chart for simplified sewers based on Manning's equation with n = 0.013, and v in m/s, I in m/m, q in m^3/s and the sewer diameter D in mm.

d/D	D=100		D=150		D=225		D=300	
	$V/I^{1/2}$	$Q/I^{1/2}$	$V/I^{1/2}$	$Q/I^{1/2}$	$V/I^{1/2}$	$Q/I^{1/2}$	$V/I^{1/2}$	$Q/I^{1/2}$
0.02	0.9260	0.0000	1.2135	0.0001	1.5901	0.0003	1.9262	0.0006
0.04	1.4607	0.0002	1.9140	0.0005	2.5081	0.0013	3.0383	0.0029
0.06	1.9017	0.0004	2.4920	0.0011	3.2654	0.0032	3.9558	0.0068
0.08	2.2888	0.0007	2.9992	0.0020	3.9300	0.0059	4.7609	0.0126
0.10	2.6383	0.0011	3.4572	0.0032	4.5302	0.0094	5.4880	0.0202
0.12	2.9593	0.0016	3.8778	0.0047	5.0814	0.0137	6.1557	0.0296
0.14	3.2573	0.0022	4.2683	0.0064	5.5930	0.0189	6.7754	0.0408
0.16	3.5359	0.0029	4.6334	0.0085	6.0714	0.0249	7.3550	0.0537
0.18	3.7979	0.0037	4.9766	0.0108	6.5212	0.0317	7.8999	0.0684
0.20	4.0451	0.0045	5.3006	0.0133	6.9458	0.0393	8.4142	0.0847
0.22	4.2792	0.0055	5.6074	0.0162	7.3477	0.0477	8.9012	0.1026
0.24	4.5013	0.0065	5.8984	0.0192	7.7291	0.0567	9.3631	0.1221
0.26	4.7124	0.0076	6.1750	0.0225	8.0915	0.0665	9.8022	0.1431
0.28	4.9132	0.0088	6.4382	0.0261	8.4364	0.0769	10.2200	0.1656
0.30	5.1045	0.0101	6.6888	0.0298	8.7648	0.0879	10.6178	0.1894
0.32	5.2867	0.0115	6.9276	0.0338	9.0777	0.0996	10.9968	0.2144
0.34	5.4604	0.0129	7.1551	0.0379	9.3759	0.1118	11.3580	0.2407
0.36	5.6258	0.0143	7.3719	0.0422	9.6599	0.1245	11.7022	0.2681
0.38	5.7834	0.0158	7.5784	0.0467	9.9305	0.1377	12.0300	0.2965
0.40	5.9334	0.0174	7.7750	0.0513	10.1881	0.1513	12.3420	0.3259
0.42	6.0761	0.0190	7.9619	0.0561	10.4331	0.1653	12.6388	0.3561
0.44	6.2116	0.0207	8.1395	0.0610	10.6658	0.1797	12.9206	0.3870
0.46	6.3401	0.0224	8.3079	0.0659	10.8865	0.1944	13.1880	0.4187
0.48	6.4618	0.0241	8.4674	0.0717	11.0955	0.2094	13.4412	0.4509
0.50	6.5768	0.0258	8.6181	0.0761	11.2929	0.2245	13.6804	0.4835
0.52	6.6852	0.0276	8.7601	0.0813	11.4789	0.2398	13.9057	0.5165
0.54	6.7870	0.0294	8.8934	0.0866	11.6537	0.2553	14.1174	0.5497
0.56	6.8822	0.0311	9.0182	0.0918	11.8172	0.2707	14.3155	0.5831
0.58	6.9709	0.0329	9.1345	0.0971	11.9696	0.2862	14.5001	0.6164
0.60	7.0531	0.0347	9.2422	0.1023	12.1107	0.3017	14.6711	0.6497
0.62	7.1288	0.0365	9.3414	0.1075	12.2407	0.3170	14.8285	0.6827
0.64	7.1979	0.0382	9.4319	0.1127	12.3593	0.3321	14.9722	0.7153
0.66	7.2603	0.0399	9.5137	0.1177	12.4664	0.3471	15.1020	0.7474
0.68	7.3159	0.0416	9.5865	0.1227	12.5619	0.3617	15.2177	0.7789
0.70	7.3646	0.0432	9.6503	0.1275	12.6455	0.3759	15.3189	0.8096
0.72	7.4061	0.0448	9.7048	0.1322	12.7169	0.3897	15.4054	0.8393
0.74	7.4404	0.0464	9.7497	0.1367	12.7757	0.4030	15.4766	0.8680
0.76	7.4670	0.0478	9.7845	0.1410	12.8214	0.4157	15.5320	0.8953
0.78	7.4856	0.0492	9.8090	0.1451	12.8534	0.4277	15.5708	0.9211
0.80	7.4959	0.0505	9.8224	0.1489	12.8710	0.4389	15.5921	0.9452
0.82	7.4972	0.0517	9.8241	0.1524	12.8732	0.4492	15.5947	0.9674
0.84	7.4888	0.0527	9.8131	0.1555	12.8588	0.4585	15.5773	0.9874
0.86	7.4698	0.0537	9.7882	0.1583	12.8261	0.4666	15.5377	1.0048
0.88	7.4389	0.0545	9.7477	0.1605	12.7731	0.4733	15.4735	1.0194
0.90	7.3944	0.0551	9.6894	0.1623	12.6967	0.4786	15.3810	1.0306
0.92	7.3336	0.0554	9.6098	0.1635	12.5923	0.4819	15.2545	1.0379
0.94	7.2522	0.0556	9.5031	0.1638	12.4526	0.4830	15.0852	1.0402
0.96	7.1421	0.0553	9.3588	0.1632	12.2634	0.4811	14.8561	1.0360
0.98	6.9830	0.0546	9.1504	0.1609	11.9904	0.4745	14.5253	1.0218
1.00	6.5768	0.0517	8.6181	0.1523	11.2929	0.4490	13.6804	0.9670

Source: Mara, (1996)

composting or agriculture. Consequently the bucket latrine system is being phased out in most countries where it is still practised. The system is discouraged because the work involved is unpleasant and socially unacceptable, and particularly because the collectors and the people in the neighbourhood are exposed to excreta-related diseases.

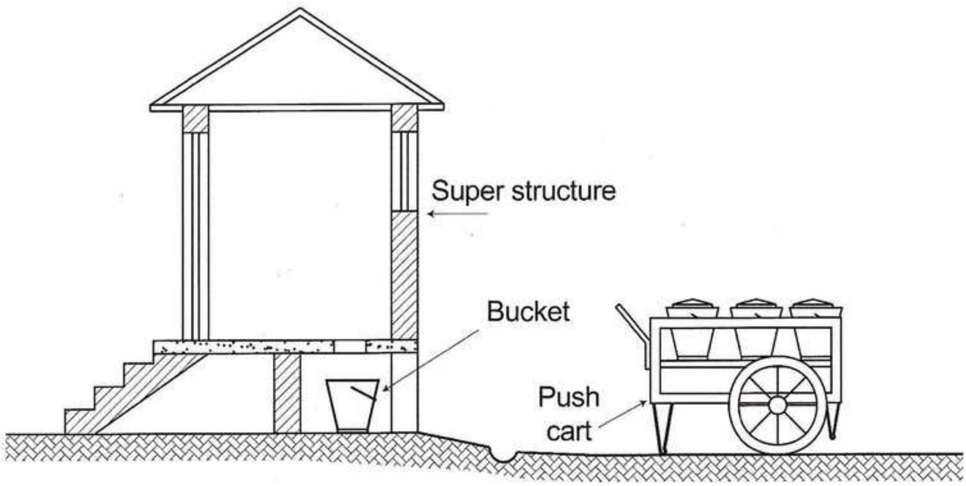

Figure 10.7 Essential features of a bucket latrine system

In Bangladesh, the municipal authorities have recently abandoned the system, but there are many households in different parts of the country that are still served by the bucket latrine system. The collection and disposal of most of these systems are organized informally. There were, however, many well-organized collection systems until the 1960s. Ideally, buckets should be properly sealed and replaced with new disinfected buckets before carrying the sealed buckets to the depot. The buckets should then be emptied, thoroughly washed and properly disinfected before their next use.

Advantages and disadvantages

The advantages of the bucket latrine system are as follows:

- The bucket latrine system is considered to be one of the lowest-cost options though generally not recommended for hygienic reasons.
- The system may be suitable for densely populated urban slums where space is not available for on-site disposal, provided excreta are collected and transported in a proper manner.

The disadvantages are as follows:

- The system's activities are unpleasant and in most instances socially unacceptable.
- The collectors and the people in the neighbourhood are exposed to excreta-related diseases.
- The system requires frequent/daily removal of excreta.

- Use of water for anal cleansing may overload the system.
- Separate sullage disposal facilities must to be installed.
- Spillage of excreta results in flies and odour nuisance.

Abandoning the bucket latrine systems allows for upgrading to other acceptable options. For instance, these can be upgraded to vault systems and can be improved further by introducing water seal pans and mechanised emptying and transportation employing vacuum tankers. However, if the bucket latrine system is to be continued for some reason it should work under situations of tight institutional control, where all operations are carefully supervised.

Vault-vacuum tanker system

The vault latrine system is similar to pour-flush latrines except that the pit or the vault is impermeable and emptied by an electro-mechanically or manually powered pump and tanker at regular intervals of about two to six weeks. The vault may be built immediately below the squatting plate, or displaced from it and connected to it by a short length of pipe (Figure10.8). The advantage of the latter option is that adjacent houses may share the vault with some savings in construction and collection costs.

The collection truck is equipped with vacuum tubing, which may be as long as 100 metres to allow access to houses distant from a road or lane. The excreta thus collected are transported to a distant place for treatment prior to disposal.

Vault systems are suitable for densely populated urban areas where on-site sanitation systems cannot be used and water-borne sewerage is too expensive to install, and where institutional ability to organize and maintain a collection system suitable for vault toilets exists. The vault and tanker system is widely used in Japan and other countries of East Asia.

It is reported that in the 1990s, about a third of the people of Japan used this system (Kitawaki et al. 1994). In the urban areas of Korea, the annual cost of conventional sewerage systems was found to be more than five times greater than the existing vault system (Bradley and Raucher, 1988). Health benefits and the total pollution load to the environment are about the same if separate sullage treatment is installed and the vault emptying system is efficiently operated.

Design and construction

The vault may be constructed from concrete or brick but has to be watertight because loss of water may cause pumping problems. The required working or effective volume of the vault is calculated from the following formula:

$$V = NQD / K \qquad (10.6)$$

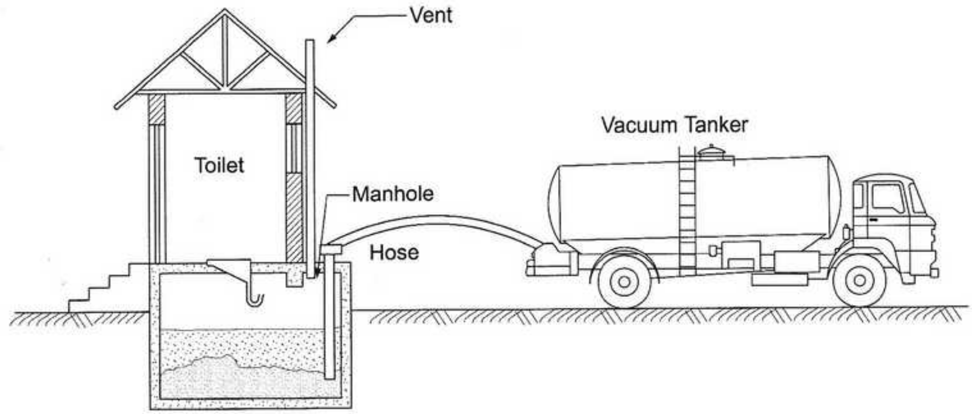

Figure 10.8 Typical vault-vacuum tanker sanitation system

where, V = vault working volume in litres
N = number of users
Q = average volume of excreta plus flushing water (litres/person/day)
D = time interval between successive emptying of vault in days
K = vault volume under-utilization factor

The average combined excreta and flush water contribution (Q) is generally less than 10 litres/person/day. The emptying cycle is usually once every 14-28 days. The vault volume under utilization factor, K, is introduced since the vault will normally be emptied before it is full. For well-maintained and organized collection vehicles, K may be as high as 0.85. Often K is assumed to be as low as 0.5 to allow for twice the planned filling time.

The vault need not be very large. For example, for a family of six using 10 litres per capita daily with a pour-flush system that is being emptied every two weeks, and with K taken as 0.5, the required vault volume is only 1.68 m^3. From the above equation it is evident that the vault volume and the emptying period are proportional to each other. Once vault construction and emptying costs are known, it is possible to minimize the total cost by optimizing the combination of vault size and emptying period.

Collection vehicles

Vaults can be emptied manually but this is unhygienic because of likely spillage, and therefore not recommended. Emptying should be done mechanically wherever possible. The usual type of vehicle is a truck-mounted tanker equipped with a vacuum pump. Hand-drawn smaller vehicles with handoperated diaphragm pumps can be used to service vaults located off narrow lanes. These small tankers can then bring the excreta to conventional vacuum tankers or to a transfer station for collection by larger vehicles.

Treatment and disposal

The collected excreta can be handled in several ways. It can be treated in sewage treatment works or waste stabilization ponds. The excreta can also be safely reused as a soil conditioner after treatment through composting.

Organization

In most developing countries, organization will be the limiting factor for running vault systems. The vault toilets should therefore not be introduced unless sufficient institutional skills are available to run the system. Close supervision is necessary to ensure that standards of hygiene are maintained, and the service remains available to all users.

Maintenance

Maintenance of the fleet of collection vehicles is a critical factor in operation of vault systems. There must be adequate workshop facilities, sufficiently trained mechanics, and sufficient stock of spare parts available to service the vehicles.

Advantages and disadvantages

The main advantages of a vault – vacuum sanitation system are listed below.

- Vault toilets are suitable for densely populated urban areas where they can be conveniently located inside the houses.
- Excreta can be used in agriculture after it has been treated.
- Compared with other wet sanitation systems having tanks such as the septic tank or aqua-privy, the initial costs are lower since the vault is smaller.
- Water requirements are minimal as the user is conscious of saving vault-emptying charges.

The disadvantages are as follows:

- A high degree of organizational set-up is necessary to run vault collection services efficiently and hygienically.
- Any breakdown in the collection timetable can quickly produce risks to public health.
- Vaults are hygienic to users, but they can pose health risks to the workers if they collect excreta manually.
- Vault systems have high operating costs.
- Separate provisions must be made for sullage disposal.

Questions

1. What are the basic elements of a conventional sewerage system? Under what circumstances may conventional sewerage system be considered as an appropriate sanitation technology?

2. Compare the merits and demerits of separate and combined sewerage systems for wastewater collection. Briefly discuss the suitability of each system. Which system do you think would be suitable for urban areas of Bangladesh?

3. Briefly discuss the factors that influence the estimation of wastewater flows for the design of sanitary sewer systems. Define the various components of design flow and outline the procedure of estimating design wastewater flow.

4. Explain the significance of self-cleansing velocity in the hydraulic design of sewers. What is the basis of providing a minimum velocity for achieving self-cleaning action in sewers?

5. What are the important functions of a septic tank that lead to significant changes in the design of a small bore sewer network? Why is self-cleansing velocity not required in small bore sewer systems?

6. What are the technical advantages of small bore sewerage systems over a conventional sewerage system? What factors bring in significant cost savings in small bore sewerage systems? Comment on the applicability of small bore sewerage systems in Bangladesh.

7. Define simplified sewerage systems. What is the basic difference between small bore and simplified sewerage systems? Discuss the design principles of simplified sewerage systems.

8. How could simplified sewerage be a lower-cost alternative to conventional sewerage system, particularly for the developing countries? Discuss its suitability in Bangladesh.