3.1 GENERAL

Once used for its intended purposes, the water supply of a community is considered to be wastewater. The individual conduits used to collect and transport wastewater to the treatment facilities or to the point of disposal are called sewers.

There are three types of sewers: sanitary, storm, and combined. Sanitary sewers are designed to carry wastewater from residential, commercial, and industrial areas, and a certain amount of infiltration inflow that may enter the system due to deteriorated conditions of sewers and manholes. Storm sewers are exclusively designed to carry the storm water. Combined sewers are designed to carry both the sanitary and the storm flows.

The network of sewers used to collect wastewater from a community is known as wastewater collection system. The purpose of this chapter is to define the types of sewers used in the collection systems, types of wastewater collection systems that are used, the appurtenances used in conjunction with sewers, the flow in sewers, the design of sewers, and the construction and maintenance of sewers.

3.2 MUNICIPAL SEWERAGE SYSTEM

3.2.1 Types of Sewers

The types and sizes of sewers used in municipal collection system will vary with size of the collection system and the location of the wastewater treatment facilities. The municipal or the community sewerage system consists of (1) building sewers (also called house connections), (2) laterals or branch sewers, (3) main and submain sewers, (4) trunk sewers, and (5) intercepting sewers.

House sewers connect the building plumbing to the laterals or to any other sewer lines mentioned above. Laterals or branch sewers convey the wastewater to the main sewers. Several main sewers connect to the trunk sewers that convey the wastewater to large intercepting sewers or the treatment plant. The types of sewers usually used in wastewater collection system are shown in Figure 3.1 (Qasim, 1985).

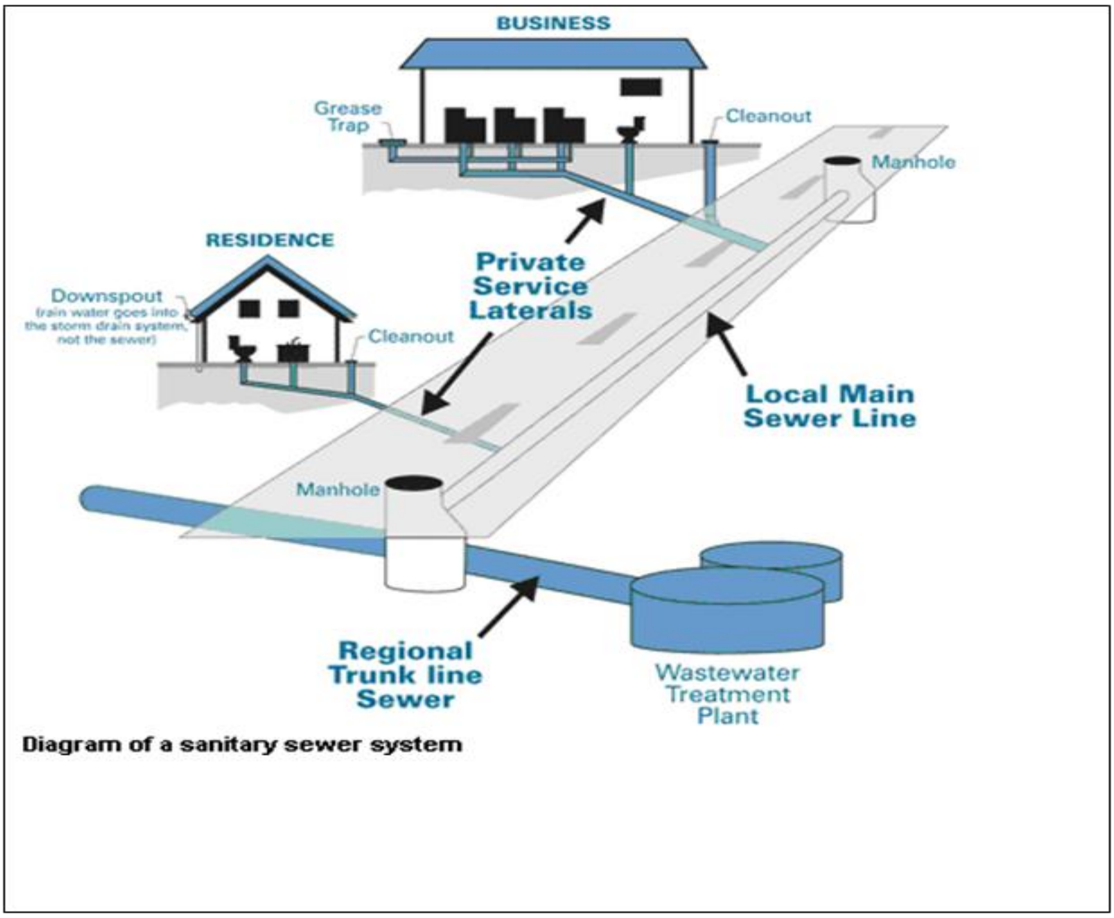

Figure (3.1): Types Of Sewers Used In Wastewater Collection System

The diameter of a sewer line is generally determined from the peak flow that the line must carry and the local sewer regulations, concerning the minimum sizes of the laterals and house connections. The minimum size recommended for gravity sewer is 200 mm (8 in).

3.2.2 Sewer Materials

Sewers are made from concrete, reinforced concrete, vitrified clay, asbestos cement, brick masonry, cast iron, ductile iron, corrugated steel, sheet steel, and plastic or polyvinyl chloride (PVC) or ultra polyuinyl chloride (uPVC). Concrete and ultra polyvinyl chlorides are the most common materials for sewer construction.

3.3 TYPES OF WASTEWATER COLLECTION SYSTEMS

3.3.1 Gravity Sewer System

Collecting both wastewater and storm water in one conduit (combined system) or in separate conduits (separate system). In this system, the sewers are partially filled. A typical characteristic is that the gradients of the sewers must be sufficient to create self-cleansing velocities for the transportation of sediment. These velocities are 0.6 to 0.7 m/s when sewers are flowing full or half-full. Manholes are provided at regular intervals for the cleaning of sewers.

3.3.2 Pressure Type System

Collecting wastewater only. The system, which is entirely kept under pressure, can be compared with a water distribution system. Sewage from an individual house connection, which is collected in manhole on the site of the premises, is pumped into the pressure system. There are no requirements with regard to the gradients of the sewers.

3.3.3 Vacuum Type System

Collecting wastewater only in an airtight system. A vacuum of 5-7 m is maintained in the system for the collection and transportation of the wastewater. There is no special requirement for the gradients of the sewers.

Pressure and vacuum–types systems require a comparatively high degree of mechanization, automation and skilled manpower. They are often more economical than gravity system, when applied in low population density and unstable soil conditions. Piping with flexible joints has to be used in areas with expansive soils.

3.4 SEWER APPURTENANCES

3.4.1 Manholes

Manholes should be of durable structure, provide easy access to the sewers for maintenance, and cause minimum interference to the sewage flow. Manholes should be located at the start and at the end of the line, at the intersections of sewers, at changes in grade, size and alignment except in curved sewers, and at intervals of 90-180 m in straight lines.

The general shapes of the manholes are square, rectangular or circular in plan, the latter is common. Manholes for small sewers are generally 1.0-1.2 m in diameter. For larger sewers larger manhole bases are provided. The maximum spacing of manholes is 90-180 m depending on the size of sewer and available size of sewer cleaning equipment (Qasim,1985).

Standard manholes consist of base, risers, top, frame and cover, manhole benching, and step-iron. The construction materials of the manholes are usually precast concrete sections, cast in place concrete or brick. Frame and cover usually made of cast iron and they should have adequate strength and weight.

Drop Manholes

Adrop manhole is used where an incoming sewer, generally a lateral, enters the manhole at a point more than about 0.6 m above the outgoing sewer. The drop pipe permits workmen to enter the manhole without fear of being wetted, avoid the splashing of sewage and corrosion of manhole bottom.

3.4.2 House Connections

The house sewers are generally 10-15 cm in diameter and constructed on a slop of 0.02 m/m. house connections are also called, service laterals, or service connections. Service connections are generally provided in the municipal sewers during construction. While the sewer line is under construction, the connections are conveniently located in the form of wyes or tees, and plugged tightly until service connections are made. In deep sewers, a vertical pipe encased in concrete is provided for house connections (Qasim, 1985).

3.4.3 Inlets

Inlets are structures through which storm water enters the sewers. Their design and location require consideration of how far water will be permitted to extend into the

Street under various conditions. The permissible depth of water in the gutter is limited to 150 mm on residential streets and to that depth, which will leave two lanes, clear of standing water on arterials and one lane on major streets (Mc Ghee, 1991).

3.4.4 Inverted Siphons

An inverted siphon is a section of sewer, which is dropped below the hydraulic grade line in order to avoid an obstacle such as a railway or highway cut, a subway, or a stream. Such sewers will flow full and will be under some pressure; hence they must

be designed to resist low internal pressures as well as external loads. It is also important that the velocity be kept relatively high (at least 0.9 m/s) to prevent deposition of solids in locations, which would be very difficult or impossible to clean (Mc Ghee, 1991).

Since sewage flow is subject to large variation, a single pipe will not serve adequately in this application. If it is small enough to maintain a velocity of 0.9 m/s at minimum flow, the velocity at peak flow will produce very high head losses and may actually damage the pipe. Inverted siphons normally include multiple pipes and an entrance structure designed to divide the flow among them so that the velocity in those pipes in use will be adequate to prevent deposition of solids (Mc Ghee, 1991).

3.4.5 Sewer Outlets and Outfalls

Storm water and treated wastewater may be discharged to surface drainage or to bodies of water such as lakes, estuaries, or the ocean. Outlets to small streams are similar to the outlets of high way culverts, consisting of simple concrete headwall and apron to prevent erosion. Some wastewater treatment plants are located at elevations, which might be flooded. Present regulations require that sewage treatment works be protected against a 100-year flood, which may require levees around low-lying installations and pumping of the treated flow when stream levels are high. Gravity discharge line in such circumstances must be protected by flap gates or other automatically closed valves, which will prevent the stream flow from backing up into the plant (Mc Ghee, 1991).

Sewers discharging into large bodies of water are usually extended beyond the banks into fairly deep water where dispersion and diffusion will aid in mixing the discharge with the surrounding water. The outfall lines are constructed of either iron or reinforced concrete and may be placed from barges or joined by divers. Iron is generally preferred for outfall 610 mm in diameter or less. In bodies of water which are sufficiently large to permit heavy wave action. The outfall may be protected by being placed in a dredged trench or by being supported on pile bents. Subsurface discharges normally employ multiple outlets to aid in distribution and dilution of the wastewater (Mc Ghee, 1991).

3.4.6 Pumping of Sewer

There are many communities in which it is possible to convey all the sewage to a central treatment location or point of discharge in only a gravity system. In other areas with flat terrain, more than one drainage area, low-lying sections, or similar complications, pumping may be required. Pumping may also be required at or within sewage treatment plants, in the basements of buildings which are below the grade of the sewer, and to discharge treated wastewater to streams which are above the elevation of the treatment plant (Mc Ghee, 1991).

Pumping of untreated sanitary sewage requires special designs, since sewage often contains large solids. Nonclog pumps have impellers, which are usually closed and have, at most, two or three vanes. The clearance between the vanes is sufficiently large that anything, which will clear the pump suction, will pass through the pump. A bladeless impeller, sometimes used as a fish pump, has also been applied to this service. For a specified capacity, bladeless impellers are larger and less efficient than vaned designs (Mc Ghee, 1991).

Sewage pumping stations within the collection system include a wet well, which serves to equalize the incoming flow, which is always variable. Although pumps that can operate at variable speed are available, their cost and the complexity of their control systems generally make them an expensive alternative. Ordinary constant-speed pumps with standard motors should not be turned on and off too frequently since this can cause them to overheat. In small pumping stations there may be only two pumps, each of which must be able to deliver the maximum anticipated flow. Lower flows are allowed to accumulate in the wet well until a sufficient volume has been accumulated to run the pump for about 2 min. The wet well may also be sized to ensure that the pump will not start more often than once in about 5 minutes. The specific values of running time and cycle time depends upon the characteristics of the motor used and must be obtained from the manufacturers (Mc Ghee, 1991).

3.5 HYDRAULICS OF SEWER DESIGN

3.5.1 Introduction

Wastewater systems are usually designed as open channels except where lift stations are required to overcome topographic barriers. The hydraulic problems associated with these flows are complicated in some cases by the quality of the fluid, the highly variable nature of the flows, and the fact that an unconfined or free surface exists. The driving force for open-channel flow and sewer flow is gravity. For the hydraulic calculations of sewers, it is usually assumed uniform flow in which the velocity of flow is constant, and steady flow condition in which the rate discharge at any point of a sewer remains constant (Metcalf,1982).

3.5.2 Flow Formulas

In principle all open channel flow formulas can be used in hydraulic design of sewer pipes through Manning's formula. The following are the most important formulas:

1. Chezy formula: Using the Chezy equation, the velocity of flow in sewers can be determined according to

$$V = C\sqrt{RS} \qquad (3.1)$$

Where V is the velocity of flow, C is the Chezy coefficient ($C = 100\,R/(m+\sqrt{R})$, where m = 0.35 for concrete pipe or 0.25 for vitrified clay pipe), R is the hydraulic radius, and S is the slope of the sewer pipe.

2. Darcy-Weisbach formula: It is not widely used in wastewater collection design and evaluation because a trial and error solution is required to determine pipe size for a given flow and head loss, since the friction factor is based on the relative roughness which involves the pipe diameter, making it complicated. Darcy-Weishbach formula states that

$$H = \lambda\, L*V^2/(D*2g) \qquad (3.2)$$

Where H is the pressure head loss in mwc, L is the length of pipe, D is the diameter of pipe, λ is the dimensionless friction factor generally varying between 0.02-0.075.

3. The Manning formula: Manning's formula, though generally used for gravity conduits like open channel, it is also applicable to turbulent flow in pressure conduits and yields good results, provided the roughness coefficient n is accurately estimated. Head loss, according to Manning's equation is given by

$$V = 1/n\, R^{2/3}\, S^{1/2} \qquad (3.3)$$

Where n is the Manning coefficient ($1/n = 75\ m/s^{1/3}$), R is the hydraulic radius = area /wetted perimeter (circular pipe flowing full, R= D/4).
Coefficient of roughness depends on the material and age of the conduit. Commonly used values of n for different materials are given in Table 3.1.

Table 3.1:Common Values of Roughness Coefficient Used in the Manning Equation

Commonly Used Values of n	**Material**
0.013 and 0.015	Concrete
0.013 and 0.015	Vitrified clay
0.013 and 0.015	Cast iron
0.015 and 0.017	Brick
0.022 and 0.025	Corrugated metal pipe
0.013 and 0.015	Asbestos cement
0.025 and 0.003	Earthen channels

3.5.3 Hydraulics of Partially Filled Sections

The filling rate of a sewer is an important consideration, as sewers are seldom running full, so sanitary sewers designed for 40% or 50% running full, that is means only 40 % to 50 % of the pipe capacity should be utilized to carry the peak flow.

Partially filled sewers are calculated by using partial flow diagram and tables indicating the relation between water depth, velocity of flow and rate flow .The hydraulic characteristics are similar as for open channels, but the velocity of flow is reduced by increased air friction in the pipe with increasing water level, particularly near the top of the pipe. The velocity of flow and the flow rate are reduced at filling rates between 60% and 100%; the water level in the pipe is unstable at filling rates above 90% or 95%.

3.6 DESIGN SYSTEM AND CONSTRUCTION

COMMUNITY SEWERAGE SYSTEM

Designing a community sewerage system is not a simple task. It requires considerable experience and a great deal of information to make proper decisions concerning the layout, sizing, and construction of a sewer network that is efficient and cost-effective. The design engineer needs to generally undertake the following tasks (Qasim,1985, Peavy,1985):

1- Define the service area.
2- Conduct preliminary investigations.
3- Develop preliminary layout plan and profile.
4- Selection of design parameters.
5- Review construction considerations.
6- Conduct field investigation and complete design and final profiles.
7- Prepare contract drawing and specifications.

3.6.1 Service Area

Service area is defined as the total area that will eventually be served by the sewage system. The service area may be based on natural drainage or political boundaries, or both. It is generally a part of the area wide waste management plan.

3.6.2 Preliminary Investigations

The design engineer must conduct the preliminary investigations to develop a layout plan of the sewerage system. Site visits and contacts with the city and local planning agencies and state officials should be made to determine the land use plans, zoning regulations, and probable future changes that may affect both the developed and undeveloped land. Data must be developed on topography, geology, hydrology, climate, ecological elements, and social and economic conditions. Topographic maps with existing and proposed streets and other utility lines provide the most important information for preliminary flow routing (Qasim, 1985).

If reliable topographic maps are not available, field investigations must be conducted to prepare the contours, place bench marks, locate building, utility lines, drainage ditches, low and high areas, stream, and the like. All these factors influence the sewer layout.

3.6.3 Layout Plan

Proper sewer layout plan and profiles must be completed before design flows can be established. The following is a list of basic rules that must be followed in developing a sewer plan and profile (Qasim, 1985):

1. Select the site for the wastewater treatment plant. For gravity system, the best site is generally the lowest elevation of the entire drainage area.
2. The preliminary layout of sewers is made from the topographic maps. In general, sewers are located on streets, or on available right-of-way; and sloped in the same direction as the slope of the natural ground surface.
3. The trunk sewers are commonly located in valleys. Each line is started from the intercepting sewer and extended uphill until the edge of the drainage area is reached, and further extension is not possible without working downhill.
4. Main sewers are started from the trunk line and extended uphill intercepting the laterals.
5. All laterals or branch lines are located in the same manner as the main sewers. Building sewers are directly connected to the laterals.
6. Preliminary layout and routing of sewage flow is done by considering several feasible alternatives. In each alternative, factors such as total length of sewers; and cost of construction of laying deeper lines versus cost of construction, operation, and maintenance of lift station, should be evaluated to arrive at a cost-effective sewerage system.
7. Sewers should not be located near water mains. State and local regulations must be consulted for appropriate separation distance between the sewers and water lines.

8. After the preliminary sewer layout plan is prepared, the street profiles are drawn. These profiles should show the street elevations, existing sewer lines, and manholes. These profiles are used to design the proposed lines.

3.6.4 Selection of Design Parameters

Many design factors must be investigated before sewer design can be completed. Factors such as design period; peak, average, and minimum flows; sewer slopes and minimum velocities; design equations; etc. are all important in developing sewer design. Many of the factors are briefly discussed below.

1. **Design Period:** Design period should be based on ultimate tributary population. It is not uncommon to design sewers for a design period of 25-50 years or more.

2. **Design Population:** Population projections must be made for the population at the end of the design year. Discussion on population projection can be found in chapter four.

3. **Design Flow Rate:** Sanitary sewers should be designed to carry peak residential, commercial, and industrial flows, and the normal infiltration and inflow where unfavorable conditions exist.

4. **Minimum Size:** As mentioned earlier, minimum sewer size recommended is 20 cm (8 in). Many countries allow 15 cm (6 in) lateral sewers.

5. **Minimum and Maximum Velocities:** In sanitary sewers, solids tend to settle under low-velocity conditions. Self-cleaning velocities must be developed regularly to flush out the solids. Most countries specify minimum velocity in the sewers under low flow conditions. A good practice is to maintain velocity above 0.3 m/s under low flow conditions. Under peak dry weather condition, the lines must attain velocity greater than 0.6 m/s. This way the lines will be flushed out at least once or twice a day. In depressed sewers self-cleaning velocities of 1.0 m/s must be developed to prevent accumulation of solids. Velocities higher than 3

m/s should be avoided as erosion and damage may occur to the sewers or manholes.

6. Slope: Flat sewer slopes encourage solids deposition and production of hydrogen sulfide and methane. Hydrogen sulfide gas is odorous and causes serious pipe corrosion. Methane gas has caused explosions. The minimum slopes are such that a velocity of 0.6 m/s is reached when flowing full and n =0.013. Minimum sewer slopes for different diameter lines are summarized in Table 3.2.

Table 3.2: Minimum Recommended Slopes of Sanitary Sewer.

slope	**Diameter**	
mm	**mm**	**inch**
0.006	150	6
0.004	200	8
0.0028	250	10
0.0022	310	12
0.0017	360	14
0.0015	380	15
0.0014	410	16
0.0012	460	18
0.0008	610	24
0.00067	690	27
0.00058	760	30
0.00046	910	36
0.00038	1050	42
0.00032	1200	48
0.00026	1370	54

7. Depth: The depth of sewers is generally 1-2 m below the ground surface. Depth depends on the water table, lowest point to be served, topography, and the freeze depth.

8. Appurtenances: Sewer appurtenances include manholes, building connections, inlets, inverted siphons, outlets and outfall, and others. These are discussed briefly in section 3.4. Appropriate sewer appurtenances must be selected in design of sanitary sewers. Manholes for small sewers are generally 1.2 m in diameter. For larger sewers larger manhole bases are provided. The maximum spacing of manholes is 90-180 m.

9. Design Equations and Procedures: Sanitary sewers are mostly designed to flow partially full. Once the peak, average, and minimum flow estimates and made general layout and topographic features for each line are established, the design engineer begins to size the sewers. Design equations proposed by Manning, Chezy, Gangullet, Kutter, and Scobey have been used for designing sewers and drains. The Manning equation, however, has received most widespread application. This equation in various forms is expressed below:

$$V = 1/n\ R^{2/3}\ S^{1/2} \qquad (3.3)$$

$$Q = (0.312\ /n)\ D^{8/3}\ S^{1/2} \quad \text{(circular pipe flowing full)} \qquad (3.4)$$

Where Q is the flow rate.

Various types of nomographs have been developed for solution of problems involving sewers flowing full. Nomographs based on Manning's equation for circular pipe flowing full and variable n values are provided in Figure 3.2. Hydraulic elements of circular pipes under part-full flow conditions are provided in Figure 3.3. It may be noted that the value of n decreases with the depth of flows Figure 3.2. However, in most designs n is assumed constant for all flow depths. Also, it is a common practice to use d, v, and q notations for depth of flow, velocity, and discharge under partial flow condition while D, V, Q notations for diameter, velocity, and discharge for sewer flowing full. Use of equations 3.3 and 3.4 and Figures 3.2 and 3.3 are shown in the design calculation in chapter four (Qasim, 1985).

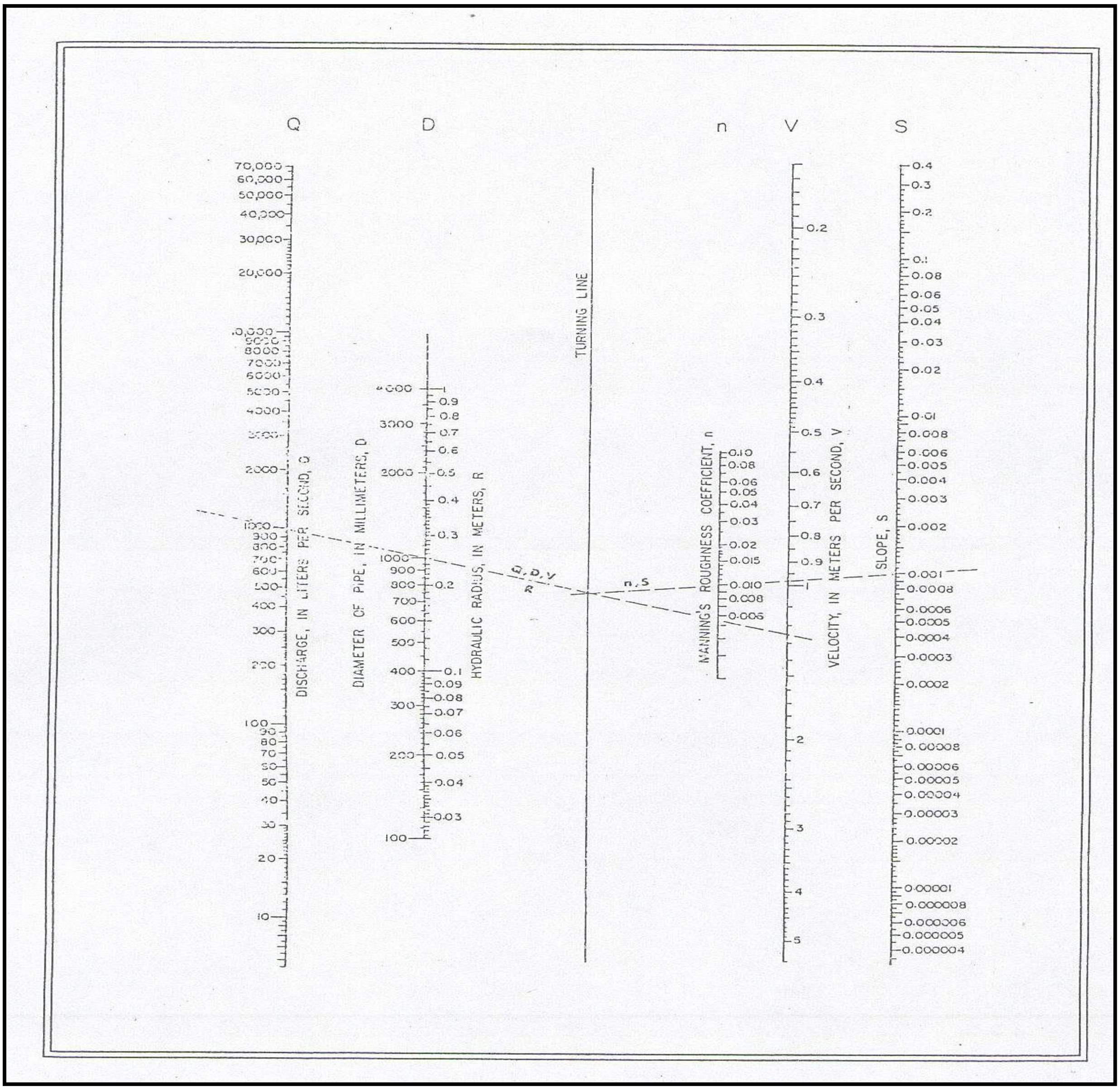

Figure (3.2) Nomograph for solution of manning formula

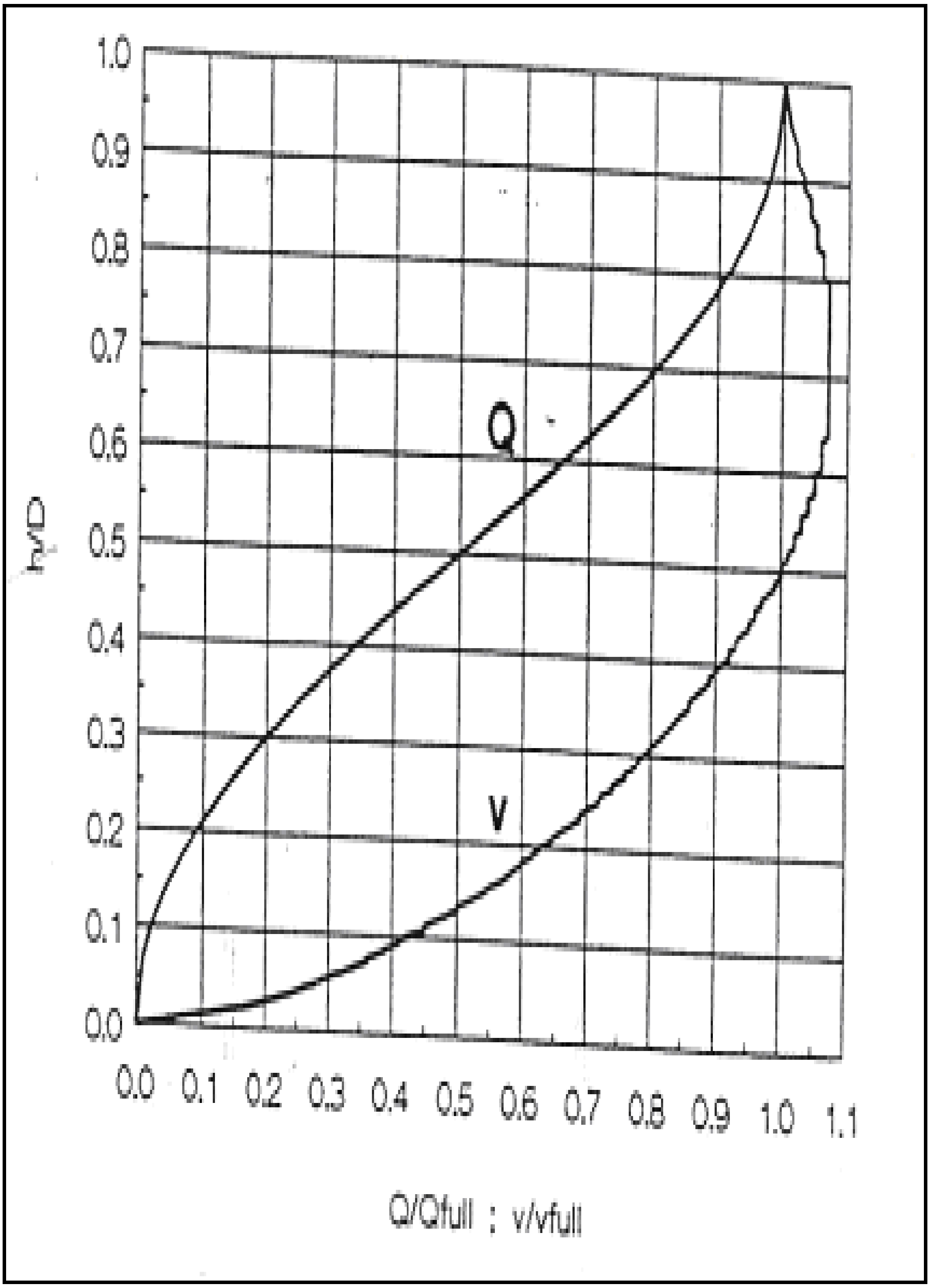

Figure (3.3) Hydraulic properties of circular sewer

After the preliminary sewer layout plan and profile are prepared, the design computations are accomplished. Design computations for sewers are repetitious and therefore, are best performed in a tabular format.

3.6.5 Construction Consideration

1. **Construction Materials:** As mention earlier, sewers are made from concrete, reinforced concrete, vitrified clay, asbestos cement, brick masonry, cast iron, corrugated steel, sheet steel, and plastic. Important factors in selection of sewer material include the following:

- Chemical characteristics of wastewater and degree of resistance to corrosion against acid, base, gases, solvent, etc.
- Resistance to scour and flow.
- External forces and internal pressure
- Soil conditions.
- Type of backfill and bedding material to be used.
- Useful life.
- Strength and water tightness of joints required, and effective control of infiltration and inflow.
- Availability in diameter, length, and ease of installation.
- Cost of construction and maintenance.

2. Joints and Infiltration: The method of making joints should be fully covered in the specifications. Joints should be designed to make sewers water-tight, root-resistant, flexible, and durable. A leakage test should be specified. The leakage shall not exceed 0.5 m^3 per day per cm of pipe diameter per Km. It has been experimentally demonstrated that joints made from rubber gasket and hot-poured bituminous material produced almost no infiltration, whereas cement mortar joints cause excessive infiltration.

3. Sewer Construction: Sewer construction involves excavation, sheeting and bracing of trenches, pipe installation, and backfilling. Each of these construction steps is discussed briefly below (Qasim,1985).

- **Excavation**: After the sewer alignment is marked on the ground, the trench excavation being. Machinery such as backhoe, clamshell, dragline, front-end loader or other specialized equipment is used. Hand excavation may be possible only for short distances. Hard rocks may be broken by drilling; explosives may also be used where situations permit.
- **Sheeting and Bracing**: Trenches in unstable soil condition require sheeting and bracing to prevent caving. Sheeting is placing planks in actual contact with the trench sides. Bracing is placing crosspieces extending from one side of the trench to the other. Sheeting and bracing may be of various types depending on the depth and width of the trenches and the type of soils supported. Common types are stay bracing, poling boards, box sheeting, vertical sheeting, and skeleton sheeting. In many situations pumping may be necessary to dewater the trenches.

- **Sewer Installation**: after the trench is completed, the bottom of the trench is checked for elevation and slope. In firm, cohesive soils the trench bottom is shaped to fit the pipe barrel and projecting collars. Often granular material such as crushed stones; slag, gravel, and sand are used to provide uniform bedding of the pipe. The pipes are inspected and lowered with particular attention being given to the joints. The pipe lengths are placed on line and grade with joints pressing together with a level or winch. The joints are then filled per specifications.

- **Backfilling:** The trenches are filled immediately after the pipes are laid. The fill should be carefully compacted in layers of 15 cm deep around, under the over the pipe. After completion of the filling, the surface is then finished.

3.6.6 Field Investigations and Completion of Design

Fieldwork should be conducted to establish benchmarks on all streets that will have sewer lines. Soil borings should be conducted to develop subsurface data needed for trenching and excavation. The depth of boring should be at least equal to the estimated depth of the sewer lines. Detailed plans should be drawn showing the following: (1) contours at 0.5 m intervals in map with scale 1 cm equal to 6 m, (2) existing and proposed streets, (3) streets elevations, (4) railroads, building, culverts, drainage ditches, etc, (5) existing conduits and other utility lines, and (6) existing and proposed sewer lines and manholes. The sewer profiles should also be developed showing ground surface and sewer elevations, slop, pipe size and type, and location of special structures and the appurtenances.

3.6.7 Preparation of Contract Drawings and Specifications

It is important that the detailed drawings be prepared and specifications completed before the bide can be requested. The contract drawings should show (1) surface features, (2) depth and character of material to be excavated, (3) the existing structures that are likely to be encountered, and (4) the details of sewer and appurtenances to be constructed.

The specifications should be prepared by writing clearly and completely all work requirements and conditions affecting the contracts. As an example, technical specifications should cover items such as site preparation, excavation and backfill, concrete work, sewer materials and pipe laying, jointing, appurtenances, and acceptance tests (Qasim, 1985).

3.7 INFORMATION CHECKLIST FOR THE DESIGN OF SANITARY SEWER

Design of sanitary sewers involves preliminary investigations, a detailed field survey, design calculations, and field drawings. The design engineer should be familiar with the service area, the local and state design criteria, and the design procedures. Adherence to a carefully planned sequence of activities to develop sewer design minimizes project delays and expenditures. A checklist of design activities is presented below. These activities are listed somewhat in their order of performance.

However, in many cases separate tasks can be performed concurrently or even out of the order given below.

1. Develop a sewer plan showing existing and proposed streets and sewers, topographic features with contour of 0.5 m, elevations of street intersections, and location of permanent structures and existing utility lines. Mark the proposed sewer lines and tentative slopes.

2- Locate manholes and number them in accordance with a convenient numbering system.

3- Prepare vertical profile showing ground surface, manhole location, and elevation at the surface of each manhole.

4- Determine total land surface area that will be eventually served by different sewer lines.

5- Determine expected saturation population densities and average per capita wastewater flow rate.

6- Estimate peak design flow, peak, average, and minimum initial flows.

7- Reviews design equations and develop hydraulic properties of the conduits.

8- Obtain state standards, sewer codes, or any design and maintenance criteria established by the concerned regulatory agencies.

SUMMARY

In this chapter, municipal sewage collection systems in general have been described. The various types of wastewater collection systems have been narrated. Some literature on the sewer appurtenances has been reviewed. The flow equations of sewer pipes have been brought out. The design and construction of community sewage system has been briefly discussed. Finally the information checklist for the design of sanitary sewers has been pointed out.