Design of Sanitary Sewers, Course #404 Presented by:

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I. INTRODUCTION

Sewer systems are essential for the public health and welfare in all areas of concentrated population and development. Every community produces water-borne wastes of domestic, commercial, and industrial origin. Sewers perform the virtually needed functions of collecting these wastes and conveying them to points of discharge or disposal.

1.1. Classification of sewers

Sewer is a pipe or conduit that carries wastewater and classified as follows:

Sanitary sewer – A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants and institutions.

Relief sewer – A sewer built to carry the flows in excess of the capacity of an existing sewer.

Building sewer – The pipe connecting the building drain with the public sewer or other places of disposal. It is also called house connection.

Lateral sewer – A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it.

Branch sewer – A sewer that receives wastewater from a relatively small area and discharges into a main sewer serving more than one branch-sewer area.

Sub-main sewer – A sewer into which the wastewater from two or more lateral sewers is discharged and which subsequently discharges into a main sewer.

Main sewer – In large systems, the principal sewer to which branch sewers and sub-mains are tributary. It is also called a trunk sewer.

Intercepting sewer – A sewer that receives flow from a number of transverse sewers or outlets and conducts the flow to a point for treatment or disposal.

Outfall sewer – A sewer that receives wastewater from a collection system or a treatment plant and carries it to a point of final discharge.

1.2. **Phases of project development**

The following phases comprise the development of a typical sewer project:

1. Preliminary or investigative phase.
2. Design phase.
3. Construction phase, and
4. Operation phase.

1.3. Parties involved in sewer projects:

The following parties are involved in a typical sewer project:

1. Owner.
2. Engineer.
3. Contractor.
4. Legal counsel.
5. Financial consultant, and
6. Regulatory agencies.

II. <u>SURVEYS AND INVESTIGATIONS</u>

Surveys and investigations produce the basic data necessary for a sewer project. "Survey" refers to the process of collecting and compiling information necessary to develop a project. "Investigation" usually refers to assimilation and analysis of the data produced by surveys for arriving at engineering decisions.

II.1. Types of information required.

The following types of information are generally required for a sewer project:

II.1.1. Physical – Includes Topography, surface conditions, details of paving to be disturbed, underground structures, subsoil conditions, water table details, details of existing system to which a proposed sewer may connect, location of streets, alleys or unusual obstructions, required rights-of-way and pertinent information relative to possible future extension of the proposed project by annexation or service agreements with adjacent communities or areas.

II.1.2. Developmental – Includes population trends and density in area to be served, type of development such as residential, commercial or industrial, quantity and strength of wastes from industrial contributors, water use data, location of future roads, airports, industrial areas that may affect the routing and location of sewers and capacity and condition of existing sewer system.

II.1.3. Political –Includes present political boundaries and probability of annexation of adjacent areas, possible service agreements with adjacent communities, existence and effectiveness of industrial waste ordinances, and effectiveness and adequacy of present political subdivision to undertake the project.

II.1.4. Financial – Includes information relative to existing policies, obligations, or commitments bearing on financing of proposed sewers, amounts and retirement schedule of outstanding bonds, availability of federal or state grants or loans, schedule of existing sewer service rates with revenues, property plats as required for sewer assessments, and local construction and operating conditions affecting cost.

II.2. Source of information

Possible sources of the different types of information sought by surveys for sewer projects include:

II.2.1. Physical – Existing maps and system plans, city plats and topographic maps, state highway plans and maps, US Geological Survey topographic maps, local utility records and plans, aerial photographs, and boring and test pits to indicate sub soil conditions.

II.2.2. Developmental – Includes census reports, planning and zoning reports, sampling data in existing sewers to establish flow characteristics from similar areas, records of water use, design basis with operational characteristics of existing sewers from system records, and criteria of regulatory agencies.

II.2.3. Political – Includes municipal and state laws, conferences with owner as well as other officials, comprehensive plans established by planning agencies, and local area meeting reports.

II.2.4. Financial – Includes pertinent records of the owner's fiscal officer, auditor's records for tax levies, ordinances for outstanding bonds, tax maps showing subdivisions and ownership of property to be affected by special assessments, and methods used for assessment of previous projects.

III. <u>QUANTITY OF SANITARY SEWAGE</u>

Sanitary sewers are provided to carry the spent water supply of a community, including industrial wastes, to a point of treatment or ultimate disposal. Connection of roof, yard, and foundation drains to the sanitary sewers must be strictly prohibited. The sewer capacity to be provided must be determined from careful analysis of the present and probable future quantities of domestic and industrial wastewaters, and ground water infiltration.

III.1. Design period – The design period is defined as the length of time throughout which the capacity of the sewer will be adequate. For large sewers, past and future trends in population, water use, and existing wastewater flows must be studied to establish the design period. It must be established prior to the design of the sewer. Once established, consideration must be given to the quantity of wastewater to be handled. Because the flow is largely a function of population served, population density, and water consumption, lateral and sub main sewers must be designed for peak flows corresponding to the population at saturation density as set forth in the community's master plan or otherwise predicted. Anticipated maximum water-use rates and population density may be used as a guide in determining maximum sewage flows. Trunk sewers, interceptors, and outfalls are commonly designed for the peak flow expected at least 25 to 50 years in the future.

III.2. Population estimates – It is customary to multiply the future tributary population by the probable per capita sewage contribution. So the accuracy of the population estimate is extremely important in this computation. In addition to their immediate value in estimating flows, future population estimates influence the choice of the design period. Future population trends depend on many factors as shown below:

1. Location with respect to transportation facilities.
2. Raw materials and manufactured products.
3. Possible expansion of present industries.
4. Availability of sites for residential, commercial, or industrial development.
5. Civic interest in community growth.
6. Availability of other utility services at reasonable rates, and
7. Real estate values.

The most widely employed mathematical or graphical methods for extending past municipal population data are:

1. Arithmetical progression or uniform growth rate.
2. Constant- percentage growth rate.
3. Decreasing rate of increase.
4. Graphical comparison with the growth rates of similar and larger cities.

5. The use of mathematical trends such as the logistic curves.

III.2.1. Arithmetical progression – This method of estimation is based on a constant increment of increase and may be stated as follows:

$$\frac{dy}{dx} = K_u$$

where Y = population

t = time (usually years)

K_u = uniform growth-rate constant

If Y_1 represents the population at the census preceding the last census (time t_1), and Y_2 represents the population at the last census (time t_2), then

$$\int_{y1}^{y2} dY = Ku \int_{t1}^{t2} dt$$

Integrating and inserting the limits, the following equation is obtained

$$Y_2 - Y_1 = K_u (t_2 - t_1)$$

Therefore,

$$K_u = \frac{Y_2 - Y_1}{t_2 - t_1}$$

Using the above equation the expression to estimate the population at the end of the forecast period t is

$$Y = Y_2 + \frac{(Y_2 - Y_1)}{(t_2 - t_1)} (t - t_2)$$

III.2.2. Constant-percentage growth rate – For equal periods of time this procedure assumes constant growth percentages. If the population increased from 90,000 to 100,000 in the past 10 years, the increase is 11 %. It is assumed that the same percentage increase will prevail in the ensuing decade. Hence, the growth in the ensuing decade is estimated to be 100,000 + 0.11 x 100,000 or 111,000. Mathematically, this may be formulated as percent increase per unit time. Integrating the expression and setting the limits, yields

$$K_p = \frac{\log_e Y_2 - \log_e Y_1}{t_2 - t_1}$$ and the population estimate is given by

$$\log_e Y = \log_e Y_2 + K_p (t - t_2)$$

Logarithm to base 10 may be also used in the above equations.

III.2.3. Decreasing rate of increase – Estimates made on the basis of a decreasing rate of increase assume a variable rate of change. Mathematically, the decreasing rate of increase may be formulated as

$\frac{dY}{dt}$ = $K_D(Z - Y)$ where K_D represents a constant percentage of a decrease per unit time

Z represents the saturation or limiting value that must be estimated and the other variables are as defined in paragraph III.2.2, above.

Then,

$$\int_{y1}^{y2} \frac{dY}{Z - Y} = K_p \int_{t1}^{t2} dt$$ and upon integration,

$$-\log_e \frac{Z - Y2}{Z - Y1} = K_D (t_2 - t_1)$$

Rearranging yields

$$Z - Y_2 = (Z - Y_1) e^{-KD\Delta t}$$

Then subtracting both sides of the equation from $(Z - Y_1)$,

$$(Z - Y_1) - (Z - Y_2) - (Z - Y_1) = (Z - Y_1)(1 - e^{-KD\Delta t}) \text{ and}$$

$$Y_2 - Y_1 = (Z - Y_1)(1 - e^{(-KD\Delta) t})$$

The above equation may be used to make estimates in the limiting reason.

III.2.4. Graphical comparison with other cities - The population-time curve of a given community can be extrapolated on the basis of trends experienced by similar communities. Population trends are plotted such that all the curves are coincident at the present population value of the city being considered. See Figure III.1

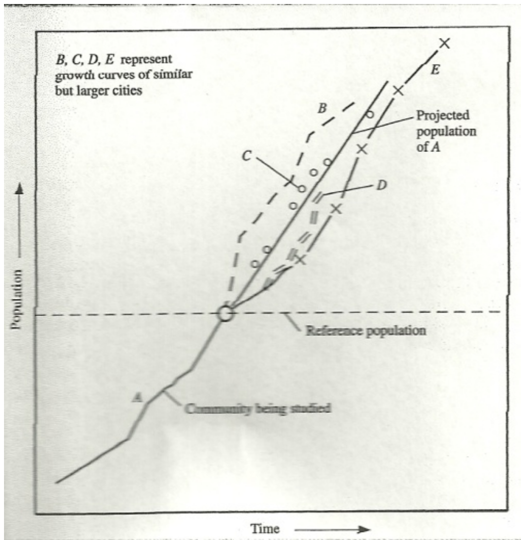

Figure III.1 Graphical Comparison With Other Cities

The cities selected for comparison should not have reached the reference population value too far in the past since the historical periods involved may be considerably different. With the exercise of due caution, this method should give reasonable results.

III.2.5. Mathematical trends using logistic curves –Mathematical curve fitting using Logistic curve has its greatest utility for establishing population trends of communities. This curve is S-shaped and has upper and lower asymptotes, with the lower asymptote being equal to zero. The logistic in its simplest form is

$$Y_c = K/(1 + 10^{a+bx})$$

Where

Y_c is ordinate of the curve
X is the time period in years
K,a,b are constants

To fit this curve, three years, represented by X_0, X_1, and X_2, each equidistant from the other in succession, must be selected. These years are chosen so that one will be near the earliest recorded population for the area, one near the middle, and one near the end of the available record. The fitted curve will pass through the values of Y_0, Y_1, and Y_2 which are associated with X_0, X_1, and X_2. The origin on the X axis is at the year indicated by X_0. The number of years from X_0 to X_1, or from X_1 to X_2 is designated as *n*.

The constants are then obtained by using the following equations:

$$K = \frac{2Y_0Y_1Y_2 - Y_1^2(Y_0 + Y_2)}{Y_0Y_2 - Y_1^2}$$

$$a = \log\{(K - Y_0)/Y_0\}$$

$$b = 1/n[\log\{Y_0(K - Y_1)/Y_1(K - Y_0)\}]$$

Substitution of these values in the equation above permits determination of Y_c for any desired value of X

III.3. Design flows –A sanitary sewer has two main functions: (1) to carry the peak discharge for which it is designed, and (2) to transport suspended solids so that deposits in the sewer are kept to a minimum. The following flows are important:

(a) Daily maximum and minimum.
(b) Daily mean and the peak.

The daily mean flow is derived from analysis of a full year's operating data whenever possible. This information also may aid in estimating minimum, maximum, and peak flows, where they cannot be measured. The peak flow is defined as the mean rate during the maximum 15 min for every 12-month period and it varies from 1.3 to 3.3 of the average daily flow. The daily minimum and maximum discharges for the initial and final years of the design period are of value in determining treatment plant capacities. Peak flow established for the end of the design period determines the hydraulic capacity of sewers. Minimum flows established for the initial and final years of design govern the design of sewers to insure proper self-cleansing velocities.

III.3.1. Per capita sewage flow – The per capita sewage flow is less than the per capita water consumption because water is lost through leakage, lawn sprinkling, car washing, swimming pools etc. In arid regions the mean sewage flow may be as little as 40 percent of the average water consumption. On the other hand, industrial wastes or sewage from users of individual water supplies may result in average sewage quantities greater than measured per capita water usage. Consideration also must be given to changes in water use habits and new household appliances, such as garbage grinders, dishwashers, and automatic clothes washers, in arriving at probable future per capita sewage contributions. The per capita sewage flow varies from 50 to 140 gallons per day (GPD) and where industrial flows are included it could be as high as 160 GPD. A value of 100 gallons per capita per day (GPCD) is found to be a reasonable average flow not including commercial and industrial flows. When these flows are also included an average GPCD of 125 may be used. These rates do not make any allowance for flows from foundation drains, roof or yard drains, none of which should be connected to sanitary sewers. In addition, sanitary sewers must be designed to carry unavoidable amounts of groundwater infiltration or seepage. Ground water gains entrance to sewers through pipe joints, broken pipe, cracks or openings in man holes and defective wye branches. It is a common practice to allow capacity for infiltration at about 30,000 GPD/mile of sewer and house connection concurrently with the peak design rate of flow of sanitary sewage. Many state regulatory agencies have set 400 GPCD for laterals and 250 GPCD for trunk sanitary sewers as the minimum acceptable design flow rates.

IV. HYDRAULICS OF SEWERS

Having established the basic design flows, hydraulic computations must be made with care. It is common practice to design sewers for uniform flow conditions with a free water surface, laid to slopes which will insure adequate self cleaning velocities, thus the flow in a sewer is considered as open channel flow. The flow in sewers is in a true sense unsteady flow. In order to simplify the hydraulic design, however, it is necessary to assume steady flow conditions. Flow is said to be steady if the rate of discharge at a point in a conduit remains constant with time. Steady flow is said to be uniform flow when the velocity and depth are the same from point to point along the conduit. Hydraulic designs are computed at the estimated peak capacity flows and at minimum flows to determine the effectiveness of scour.

The total energy per pound of water at any point along a stream line in a flowing conduit, based on the invert as the datum, is given by Bernoulli's theorem, as follows:

$$H = z + h + (v^2/2g)$$

Where H = specific energy head
z = height above bottom or potential energy, and
$v^2/2g$ = kinetic energy per pound or the velocity head of the stream line

Figure IV.1 illustrates the hydraulic profile of uniform flow in open channel.

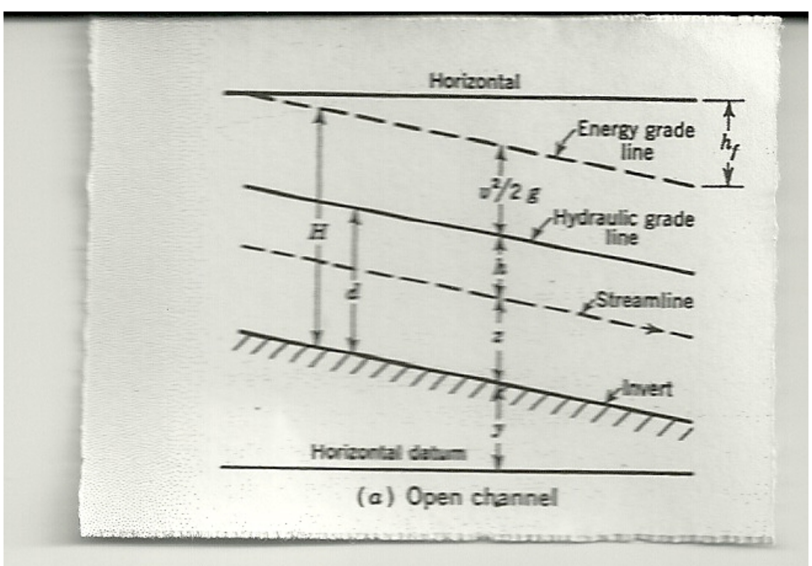

Figure IV.1 Uniform Flow Hydraulic Profile in Open Channel

It is important to note from Figure IV.1, that the energy grade line will be at the same location regardless of where the datum is taken. The velocity varies over a cross section from zero at the walls to a maximum in the middle of the channel and so the total energy is not the same for each stream line. However for hydraulic computations, it is conveniently assumed that the velocity is the same for each stream line and is equal to the mean velocity or the rate of discharge divided by the cross sectional area. Then Bernoulli's equation applies to any and all stream lines in an open channel, and therefore to the channel as a whole. For uniform flow in open channel, the slope of the energy grade line and the hydraulic grade line will be the same as the slope of the invert, and the depth of flow will adjust itself to produce a velocity commensurate with the friction losses in the channel.

In the case of a pressure conduit, the slope of the energy grade line and the slope of the hydraulic grade line are independent of the slope of the conduit itself, as shown in Figure IV.2 below.

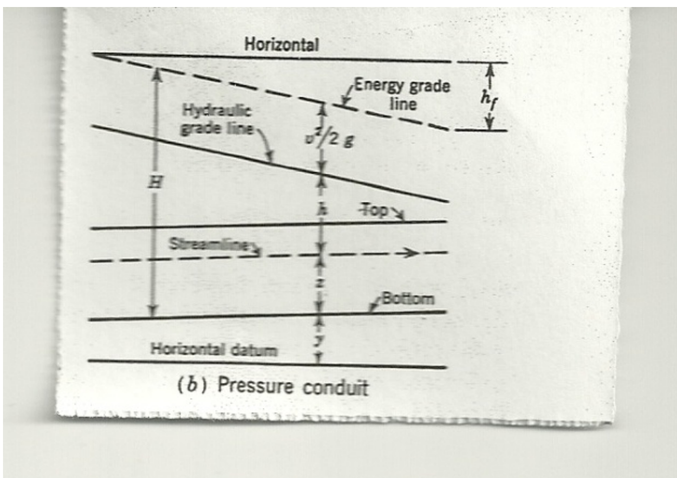

Figure IV.2. Uniform Flow Hydraulic Profile in Pressure Conduit

Their slopes are determined by the rate at which the head is lost by friction in the flowing stream. The energy grade line is a more convenient datum on which to base the hydraulic computations than is the invert of the conduit.

IV.1. Pipe friction formulas –(1) Kutter's formula. This formula is more commonly used in the solution of problems involving open-channel flow in sewers. The formula is as shown below:

$$v = [\{(1.81/n) + 41.67 + (0.0028/s)\}/\ 1 + n/\sqrt{r}\ \{(41.67 + (0.00028/s)\}]$$

where v = mean velocity of flow, ft/sec.

r = hydraulic radius, ft (equal to area/wetted perimeter).

s = slope of the energy grade line, and

n = coefficient of roughness.

(2) Manning's formula. This formula has come into more general use. This is simpler and its 'n'-value is substantially equal to Kutter's 'n' for types of pipes commonly used in sewer construction. The Manning's formula is as shown below:

$$V = (1.486/n)\ r^{2/3} s^{1/2}$$

where the nomenclature is the same as in Kutter's formula.

Table IV.1. Suggested values of 'n' for Manning's formula

Kind of pipe	Use in Designing	
	From	To
Cement-lined cast iron pipe	0.012	0.015
Dirty or tuberculated cast-iron pipe	0.015	0.035
Concrete pipe	0.012	0.015
Asbestos-cement pipe	0.012	0.015
Vitrified sewer pipe	0.012	0.015
Corrugated steel:		
Uncoated, ½-in. corrugations	0.024	0.026
Asphalt coated and 25% paved	0.021	0.023
Smooth asphaltic lining	0.012	0.015

[a]Suggested ranges of values are for sewage—the lower values are suggested for clear water.

Figure IV.3 is an alignment chart for the solution of the Manning's formula for circular pipes flowing full.

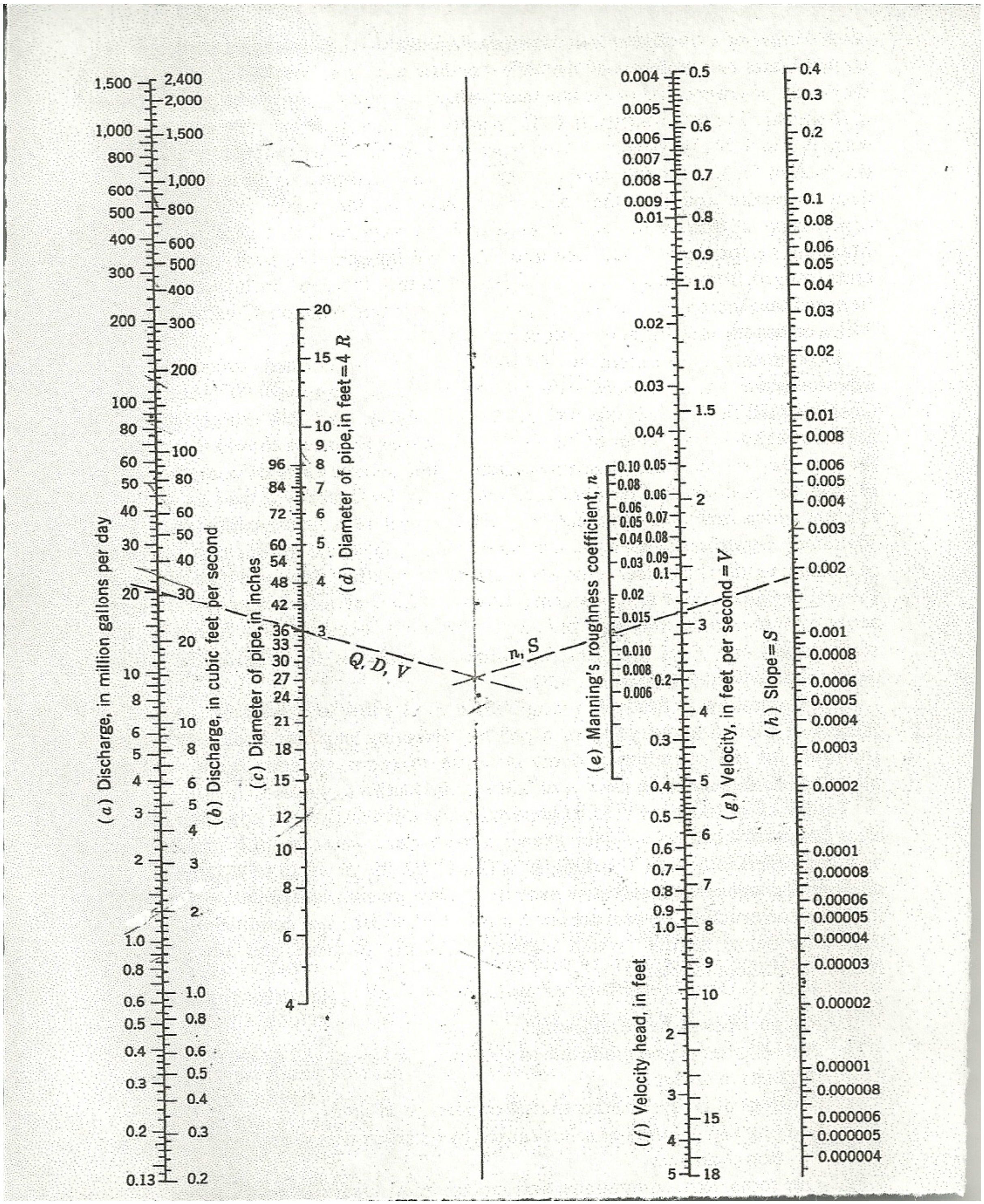

Figure IV.3. Alignment Chart for Flow in Pipes (Manning's formula)

The use of the chart for Manning's formula is demonstrated by the following numerical example:

<u>Example</u>

Given:

Sewage flow = 20 MGD

Pipe diameter = 36 in

Manning's roughness coefficient ,'n' = 0.012

Find:

Velocity of flow

Slope of the line

Procedure:

1. Connect 20 on the discharge line and 36 on the diameter line and extend the same until it cuts the center pivot line.
2. Connect this point on the pivot line and 0.012 on the Manning's 'n' line and extend the same such that it cuts the velocity and slope lines.
3. Read these values as 2.9 ft/sec and 0.0019 respectively.

The solution for the above numerical example is shown in dotted line in Figure IV.3

For sewers flowing partially full, Figure IV.4, a hydraulic-elements graph, is used. This graph is prepared for both 'n' constant and variable values.

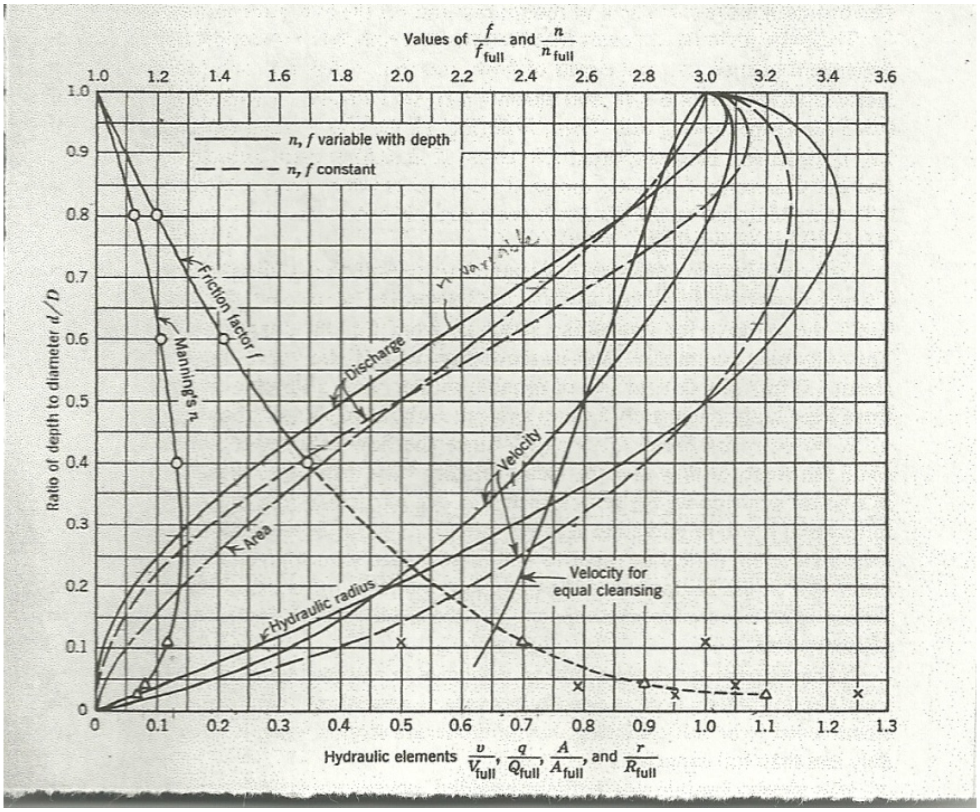

Figure IV.4. Hydraulic-Elements for Circular Sewers

The method of using the hydraulic elements graph is illustrated by the following example:

Example

Given:

Diameter of sewer = 12 in.

Slope = 3 ft per 1000 ft.

Manning's roughness coefficient = 0.013.

Sewer flows 0.4 full (d/D ratio).

Find:

Velocity and discharge for 0.4 full flow.

Procedure:

- Using Figure IV.3,as in the previous example, find Discharge full (Q_f) and Velocity full(v_f) as

  2.0 cu ft/sec, and 2.5 ft/sec respectively.

- Using Figure IV.4, for a d/D ratio of 0.4, find the discharge ratio, q/Q as 2.7 and the velocity ratio, v/V as 0.71.

- Required discharge q = 0.27 x 2.0 = 0.54 cu ft/sec and v = 0.71 x 2.5 = 1.78 ft/sec.

When sewage flows in a conduit under pressure, closed channel flow occurs. For problems involving the flow of sewage in a closed channel is given by Hazen–Williams formula which is shown below:

$$V = 1.318\ Cr^{0.63}s^{0.54}$$

in which the nomenclature is same as that used in Manning's formula and C is the friction coefficient or coefficient of roughness.

Table IV.2 Suggested Values of 'C' for Hazen-Williams Formula

Kind of pipe	Use in Designing	
	From	To
Smooth pipes ………………………………………………………………………	130	140
Tuberculated cast iron pipes ………………………………………………..	40	40
Cement-lined concrete pipes ……………………………………………..	100	120

Figure IV.5 is an alignment chart for the solution of Hazen-Williams formula for closed –channel flow in circular conduits.

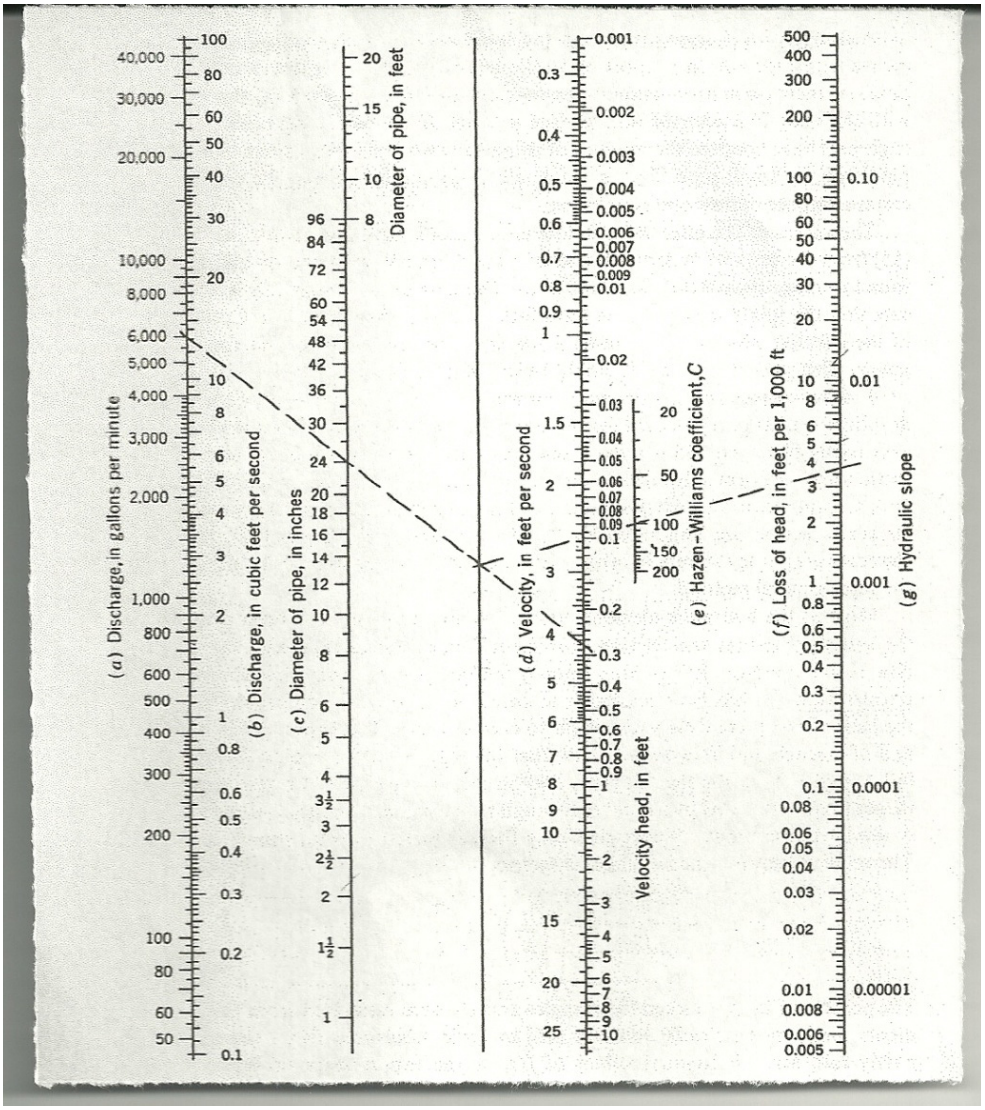

Figure IV.5. Alignment Chart for Flow in Pipes (Hazen-Williams Formula)

In order to avoid the danger of deposits in sanitary sewers, it is desirable to estimate beforehand the probable minimum flows which will obtain in the pipe during the early years of use and to select a slope which will permit self-cleansing at these flows. Sanitary sewers laid at slopes which will produce full velocities of 2 ft/sec seldom give trouble from deposits. Most state health departments require a minimum full velocity of 2 ft/sec. Based on an 'n' value of 0.013 and a full velocity of 2 ft/sec, the following minimum slopes result.

Diameter of pipe, inches ………………	6	8	10	12	15	18	21	24
Slope, ft/1000 ft …………………………	6.3	4.0	2.8	2.2	1.6	1.2	1.0	0.8

To prevent erosion of sewer inverts, the limiting velocity is often taken at about 10 ft/sec.

V. DESIGN OF SEWER SYSTEMS

The sewer must be deep enough to receive the flow from its sources. The material from which it is made should be resistant to corrosive action and scour, and the structural strength should be sufficient to carry the backfill, impact, and live loads satisfactorily. The size and slope or gradient of a sewer must be adequate for the flow to be carried. The slope must be adequate to avoid deposition of solids. The sewer joint material must be selected to meet the conditions of use. Economy of maintenance, safety to personnel and the public also must be considered.

V.1. Layout of system -The design of sanitary sewers involves the layout of a system or part of a sewer system. Preliminary layouts can be made largely from maps, provided they show adequate contours and other pertinent information. In general the sewers will slope in the direction of the slope of the street, or ground surface, and will be connected together by sub-main and trunk sewers. A sewer system may discharge to a treatment plant, a water course, or to a trunk or intercepting sewer. The most common location for sanitary sewers is at or near the center of the street. A sewer must often be located in a right of way or easement acquired for that purpose when there is no street. It is general practice to lay sewers in straight lines between manholes in sizes up to and including 2 1/2 to 3 ft in diameter. In large sewers curves may be used as desired. Manholes are located at the junctions of sewers, and also at changes in alignment or grade, except in curved sewers as noted earlier. A spacing of 300 ft is considered a maximum for the smaller-sized and medium-sized sewers. When the size is large enough to permit walking in the sewer, spacing of more than 500 ft may be used.

V.2. Selecting the type of conduit – It is necessary to consider shape and type of conduit to be used. Precast reinforced-concrete sewer pipe is widely available in circular cross sections up to 12 ft in diameter. It is a common practice to use circular cross sections for all sewer sizes up to about 8 ft in diameter provided depth and head limitations do not exist. For reinforced-concrete, cast-in-place sewers, sections like horseshoe-shape or semi elliptical shape may be used. Vitrified-clay pipe and concrete pipe of circular cross section are the most widely used type of sewer for sizes up to and including about 24 in. If the sewer is laid below ground water and in order to minimize infiltration, cast iron pipe or cement-asbestos pipe may be used. Sewer locations near public water supplies should be avoided whenever possible. When such locations cannot be avoided, cast-iron or concrete pressure pipe may be used. Sewers should not be laid in the same trench with water mains. Tees or wyes should be provided for all house connections. The practice of breaking a hole into the side of a sewer and cementing a branch into it for a house connection should be avoided. The type of material to use for small sewers is sometimes dictated by excessive trench loads and superimposed traffic loads. Extra-strength clay, concrete or asbestos cement pipe may be used to gain added strength where needed and in some cases cradles are also necessary.

V.3. Ventilation – Air normally is drawn down sanitary sewers by the flow of sewage and there is also an exchange of air due to rise and fall of sewage. Manholes and building vents generally allow adequate access of air and thus maintain ventilation in sewers. The reasons for ventilation of sanitary sewers are as follows:

1. To remove any odorous air for satisfactory disposal. Otherwise, it may tend to escape from sewer pipes in some places.
2. To maintain a sewer atmosphere where oxygen is not depleted below 90% of normal.
3. To dry out walls of structures and reduce corrosion where sulfide is present in the sewage, and
4. To reduce explosive atmosphere in case flammable gases and liquids are present in sewers.

V.4 Sulfides in sewers – Sewers must be designed such that the menace of hydrogen sulfide gas does not occur. The amount of sulfide produced varies with the strength of sewage, temperature, diameter of pipe, and detention time. In most cases serious sulfide production will not occur if the detention time is less than 15 minutes. If velocities of flow are low, sulfide build-up is likely to occur. If the sewage is quite dilute and temperatures are low, a velocity as low as 1 ft/sec might be sufficient to prevent sulfide build-up. Of course this velocity is unsatisfactory from the stand point of solids transportation. If the sewage is strong and the temperature is relatively high, a velocity of more than 3 ft/sec is necessary.

The following should be considered in sewer design:

- Provide velocities that will prevent sulfide build-up.
- Minimize points of high turbulence.
- Minimize the length of force mains.
- Provide for injection of air into force main.
- Design pump stations such that it will not be necessary to back sewage up into the tributary sewers.
- Provide forced-draft ventilation if there is a place where air may stagnate to the point of serious depletion of its oxygen content.

If substantial concentrations of sulfide prevail, the following control measures must be considered:

- Provide chlorination which is satisfactory for immediate and complete destruction of sulfide.
- Add nitrates, and salts of iron and zinc.
- Dilute the sewage with water where it is available. This will also take care of the low velocity problem in the initial years operation of the system.
- Clean the sewer with a ball at intervals of 1 to 5 years.
- Treat the sewer with lime (dosage: 5,000 to 10,000 PPM) once or twice a week for a period of one hour.
- Inject compressed air into pressure sewers.
- Use ammonia in the atmosphere of structures where there is much turbulence.

V.5. Depth – The depth of the sewers must be such as to provide an adequate outlet for all connections and to prevent freezing. Several rules are practiced in choosing the depth of sewers. One rule is to keep the top of the sewer not less than 3 ft below the basement floor. Another rule is to place the invert of the sewer not less than 1 ft below the top of the house foundation. The determination of minimum depth should take into consideration the length and slope of the house connection and the cost of sewer construction. Where houses have no basements, sewers may be built in shallower depths.

V.6. Slopes – Ideally, the slope of the sewer must be kept nearly parallel to the surface of the ground. This may not be possible in all cases. It is common practice to use slopes which will produce minimum velocity of 2 ft/sec when flowing full. In the initial years, full flow will not occur and hence the self-cleaning velocity of 2 ft/sec will not be obtainable. For this situation, it is desirable to estimate beforehand the probable minimum flow during the early years of use and to select a slope which will produce self-cleaning velocity. There are two objectives in establishing minimum slopes, one of which is to avoid nuisance from deposits of putrescible organic matter and the second of which is to reduce the necessity for frequent cleaning. The maximum slope to be used is determined from the consideration of erosion which may be caused by high velocities. The erosion is caused primarily by the grit or other inorganic solids which are transported along the invert when the velocity of flow is high. It is common practice to limit the velocity to about 10 ft/sec.

V.7. Depth of flow – It is general practice to design small sanitary sewers up to 12 to 15 inches in diameter with flows not more than one-half full at peak design flow. Large sanitary sewers, 30 inches and larger, are designed to flow from more than half full at the peak design flow up to about seven-tenths of the diameter. It is desirable to avoid the condition of sanitary sewers flowing full for ventilation reasons.

V.8. Other conditions – Consideration must be given to the following conditions in sewer design:

- Open cut: consideration in design must be given to the load on a sewer in open cut which is a function of the bedding, the trench width, the backfill material, and the superimposed load on the ground surface. The trench width is secured by practical construction methods. The bedding design should be such that the maximum resistance to the loads on the pipe will be secured compatible with economy of construction. A careful determination should be made of the load caused by the backfill material.
- Tunnel: since tunnel construction is usually at greater depths than open-cut construction, the loads on the sewer will generally be greater and the sewer must be designed with this in mind.
- Sewers built in rock: special attention must be given to proper bedding of the sewer to avoid damage thereto due to contact with rock. Granular bedding or a concrete cradle is normally provided. The backfilling material well over the top of the sewer should be free of rocks or stones.
- Exposed sewers: in case the sewers have to be built above the ground surface, they will be carried on supports or on fill material.

- Special foundation: unstable foundations may be encountered in the form of silt, peat log, quick-sand, or other soft material. Obtaining satisfactory construction in these unstable soils is necessary. The trench bottom may be stabilized by placing a layer of crushed stone or gravel below the pipe. Concrete or wooden cradles often suffice to spread the load in wet or moderately soft conditions. Depending upon load-bearing characteristics of the foundation, pile bents, timber platforms supported on piles may be used.
- Sewers on steep slopes: attention must be given to selecting materials to resist erosion. It may be necessary to provide some means of anchorage to prevent movement of the pipe.
- Force mains: force mains are required to deliver the sewage discharged from a pumping station to its destination which may be a treatment plant, a receiving stream or a high point in the sewerage system. Force mains are usually constructed of cast-iron pipe, steel pipe, reinforced concrete pressure pipe, or asbestos-cement pressure pipe. Velocities in force mains normally falls within a range of 3 to 5 ft/sec. Force mains are a major source of sulfide problems in sewers. Injection of compressed air, chlorine or other chemicals into force mains on the discharge side of the pump has been used successfully for sulfide control. When high points in a sewage force main are necessary, they should be equipped with means for venting. Manually controlled vents or vertical riser pipes or a special type of air-release valve may be used for this purpose. Blow off or flushing arrangements are desirable at low points in the force main if disposable facilities are available, and should be installed in manholes or valve chambers for easy accessibility. Anchors of sufficient size to withstand the thrust should be installed at bends.

V.9. Relief sewers – A relief sewer is constructed more or less parallel to an existing sewer when the capacity of the existing sewer is exceeded. They are also called supplementary sewers. In designing a relief sewer, it must be decided whether the proposed sewer is to share with its mate all rates of flow or is to take all flows in excess of some pre-determined amount. The topography and available head may dictate which of these alternates is to be adopted. Consideration must be given to the slope and corresponding velocities in the two sewers. The hydraulic design of inlet chambers for relief sewers must be done cautiously in order to obtain the desired flow conditions. Regulators, overflow weirs, and other devices may be used to divide the flow as required.

V.10. Organization of computations – To start the hydraulic design of a sewer system, a map is required showing the location of all the required sewers and from which the area tributary to each point can be measured. Preliminary profiles of the ground surface along each line are also required. These profiles should show the critical elevations which will establish the sewer grades, such as the basements of low-lying houses and other buildings, existing sewers which must be intercepted, and high-water elevations in the receiving body of water or receiving trunk sewer, together with other details of the sewers to be intercepted and the receiving sewers. Several trial designs may be required to determine the one which will properly distribute the available head. Sewer design computations, being repetitious, must be done on tabular forms, with regular headings.

Table V.1 below shows a typical form for tabulating the results of computations for the design of sanitary sewers.

<u>Table V.1. Typical Computation Form for Design of Sanitary Sewers</u>

TABLE 17.—TYPICAL COMPUTATION FORM FOR DESIGN OF SANITARY SEWERS

Line No.	Location	Manhole No.		Length, ft	Area, Acres		Maximum Discharge Total				Minimum Discharge Total				Slope of sewer, %	Diameter, D, in.	Capacity full, cfs	Velocity full, fps	Minimum velocity, fps	Maximum velocity, fps	Maximum depth, ft	Maximum velocity head, ft	Maximum energy, H, ft	Manhole loss, ft; transition + curve + junction	Manhole invert drop, ft	Fall in sewer, ft	Sewer Invert Elevation		Ground Surface Elevation	
		From	To		Increment	Total	Infiltration, mgd	Sewage, mgd	Sewage and Infiltration		Infiltration, mgd	Sewage, mgd	Sewage and Infiltration														Upper end	Lower end	Upper end	Lower end
									Mgd	Cfs			Mgd	Cfs																
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)

VI. APPURTENANCES AND SPECIAL STRUCTURES

Certain appurtenances are essential in the proper functioning of any complete sanitary sewer system. These appurtenances may include manholes, terminal cleanouts, house sewers, inverted siphons, junction chambers, and other structures or devices of special design. The following discussion is limited to a general description of each of the various appurtenances, with special emphasis upon the features considered essential to good design.

- Manholes – manholes are among the most common appurtenances found in sewerage systems. Their main purpose is to permit the inspection and cleaning of the sewers and the removal of obstruction. Most manholes are circular in shape, with the inside dimension sufficient to perform inspecting and cleaning operations without difficulty. A minimum inside diameter of 4 ft has been widely used. When the width of the sewer does not exceed the width of the manhole, the manhole is usually constructed directly over the center line of the sewer. For larger sewers, the manhole is preferably constructed tangent to the side of the sewer for better accessibility. Consideration must be given to the need for introduction of cleaning equipment into the sewer. The opening into the manhole must enable a man to gain access to the interior without difficulty. Figures VI.1 to VI.3 below show different type of manholes in use:

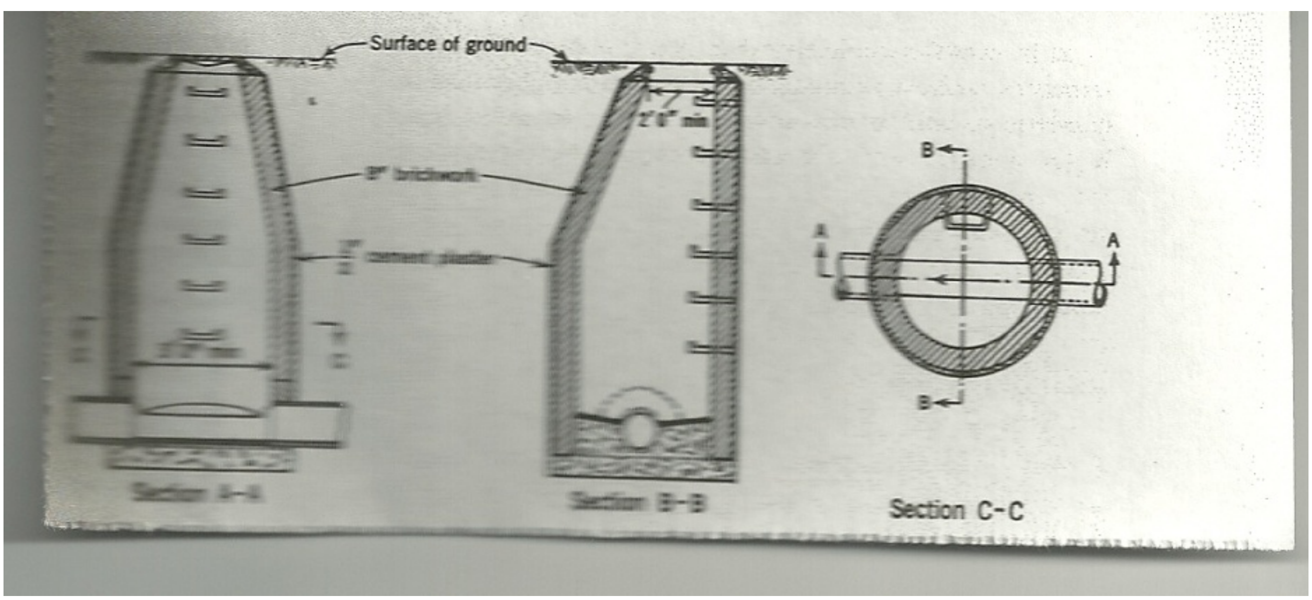

Figure VI.1. Typical Manhole, Type A

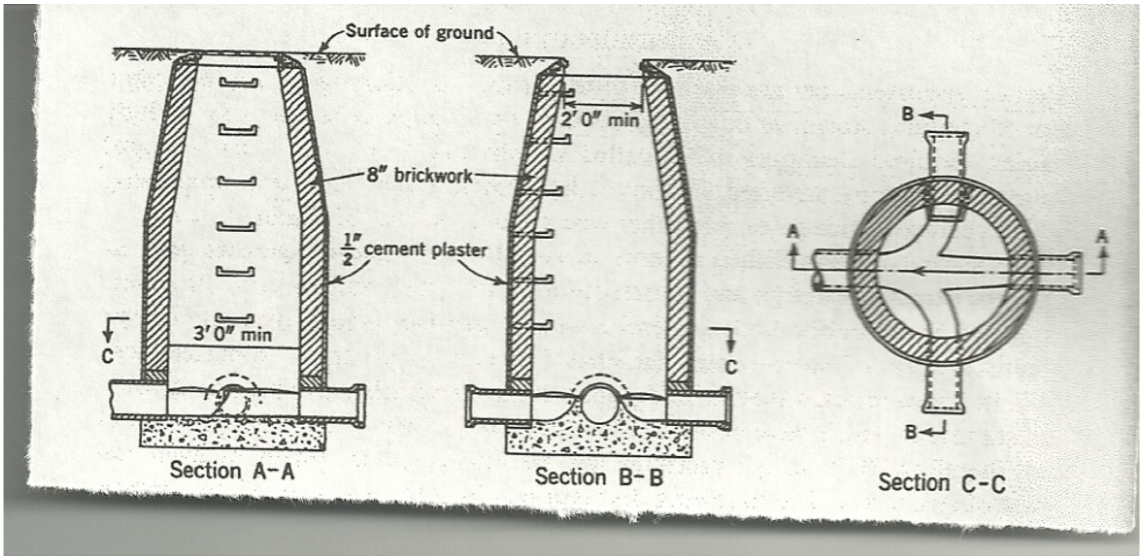

Figure VI.2. Typical Manhole, Type B

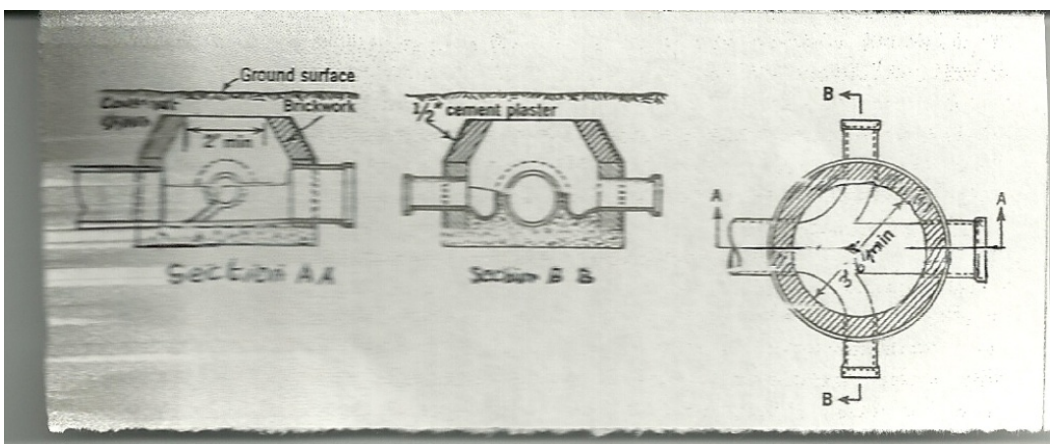

Figure VI.3. Shallow Manhole

A base slab of concrete at least 8 in thick should be provided on smaller sewers to support the walls of the manhole and to prevent the entrance of ground water. All sanitary flow should be carried in smoothly constructed **U** shaped channels which may be formed integrally with the concrete base or may be constructed separately of concrete or brick. The side height of the channel should be1/2 to 3/4the diameter of the sewer. Adjacent floor areas should be sloped to drain to the channel with a slope of 1 in./ft. Where the sewer changes direction or size in a manhole, or a branch sewer enters a manhole, the invert should be sloped to allow for the sewer height increase.

The materials commonly used for the construction of manhole walls include brick, poured concrete, precast rings, and solid segmental block. The following considerations must be taken into account while choosing the material:

1. Cost in place, including material, labor, and equipment.
2. Durability under all reasonable conditions of service.
3. Adaptability of the material to meet field conditions.
4. Depth of manhole and character of surrounding material.

Brick walls are normally constructed of 8 in. thick. The outside of the wall must be plastered with at least 1/2 in. thick cement mortar. Plain poured concrete walls can be somewhat less thick than brick walls. Reinforced concrete walls may be necessary sometimes. Precast concrete walls are available in circular sections of various heights and are usually reinforced to reduce the thickness and weight.

- Manhole frames, covers, and steps – manhole frames and covers are invariably of close-grained gray cast iron. The combined weight for the frame and cover varies from 400 to 600 lbs. Solid covers are preferable to the perforated type to diminish objectionable odors and to prevent entrance of surface waters. Locked or special bolted-down covers may be used to prevent theft, vandalism, or unauthorized entrance. Steps or ladder rungs with a minimum thickness of 1 in are provided as a means of access. Steps should be heavy cast iron, wrought iron, or stainless steel and should be spaced at about 12 to 15 in. vertically. They may also be staggered. The use of portable ladders in lieu of steps is also in practice.

- <u>Drop manholes</u> – Differences of elevations of incoming and outgoing sewers which would result in stranding of solids or in nuisance to maintenance personnel should be avoided. When the difference between the sewers is appreciable, the incoming sewer must be dropped which is done by means of an outside connection as shown in Figure VI.4

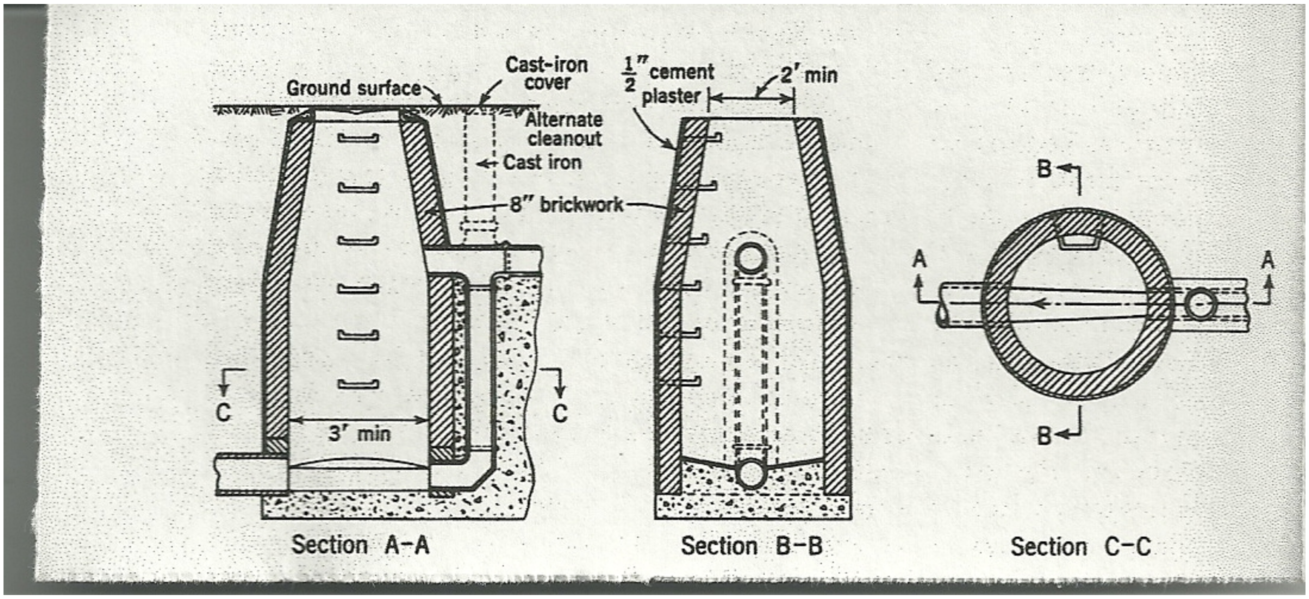

Figure VI.4. Drop Manhole

Sound judgment must be exercised to determine where the difference in elevation warrants using an outside drop instead of lowering the upstream or branch sewer. Encasement of the entire outside drop in concrete or brick masonry is needed to protect it against damage during backfilling of the trench.

- Terminal cleanout structures – these are sometimes used at the ends of branches or lateral sewers. Their purpose is to provide means for inserting cleaning tools, for flushing, or for inserting an inspection light into the sewer. A terminal cleanout amounts to an upturned pipe coming to the surface of the ground. The turn should be made with bends so flexible that cleaning rods can be passed through it. The diameter should be same as that of the sewer. The cleanout is capped with a cast iron frame and cover. Figure VI.5 shows details of a cleanout. Terminal cleanouts are limited in usefulness and should never be used as a substitute for a manhole.

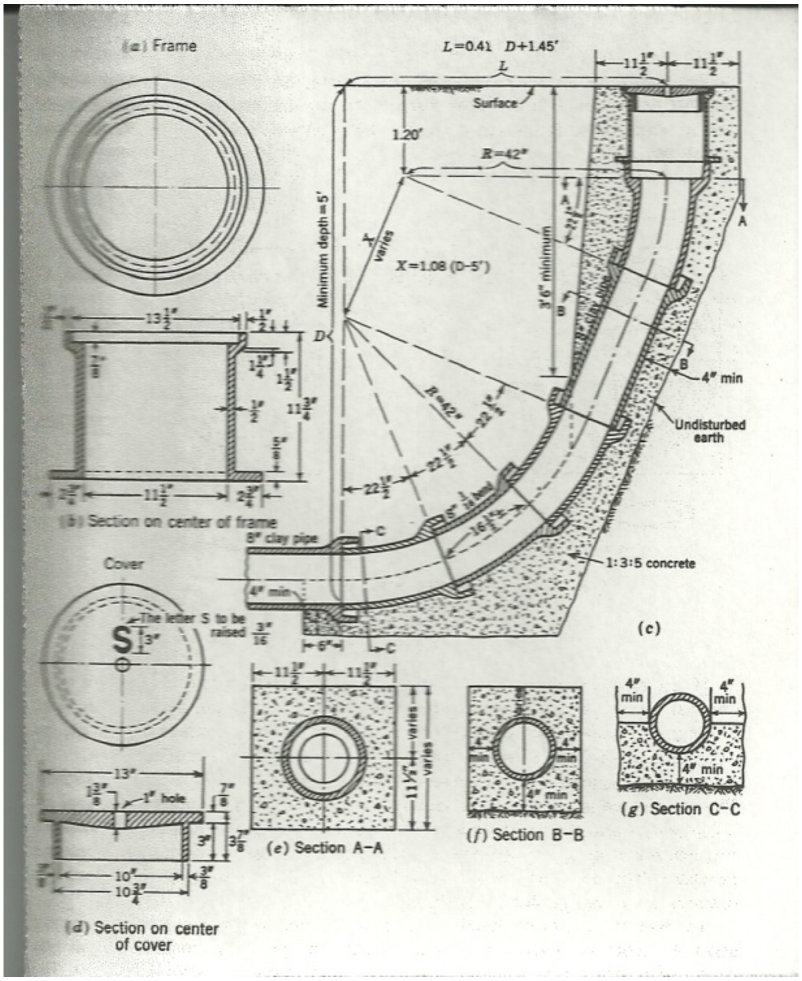

Figure VI.5. Terminal Cleanout Structure

- Junction chambers – intersection of large sewers is usually made by means of a brick or concrete structure known as a junction chamber. Each junction chamber presents a special design problem which must be given careful structural and hydraulic consideration. The principal objective in the design should be to provide a safe and economical structure which will combine the flow smoothly without decreasing the velocities appreciably and without causing backwater conditions in the sewers that enter the chamber. A typical junction chamber is shown in Figure VI.6

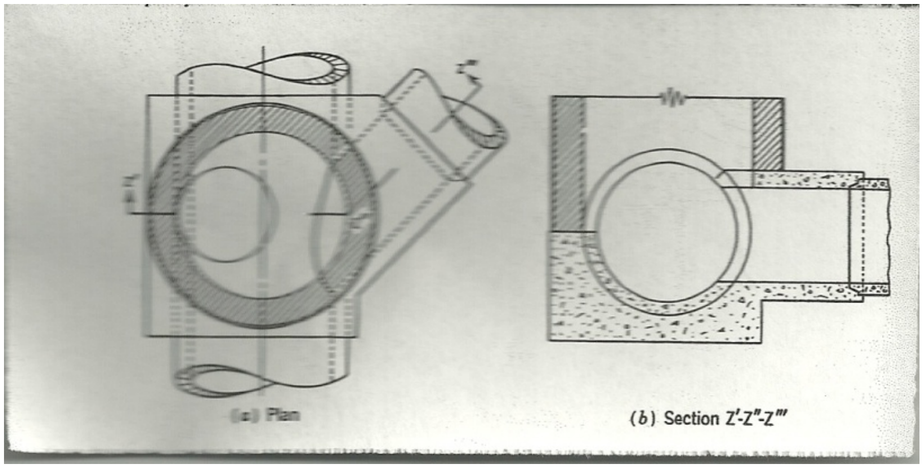

Figure VI.6. Junction Manhole

- House sewers – these should not be less than 6 in. in diameter and are laid to a straight line and grade with a minimum slope of 1/4 in. per foot. Materials, joints, and workmanship should be equal to those of the street sewer to minimize infiltration and root penetration. Connection to the main sewer should be made with a wye or tee branches. The wye or tee may be installed with the branch turned about 45^0 from the horizontal, so back-flooding of the house connection will not occur when the collecting sewer flows full. The upper or free end of the service lines or branches should be closed with a carefully fitted stopper when service lines are not completed to buildings or when immediate connections are not made to wye or tee branches.
  Figure VI.7 shows details of a service connection.

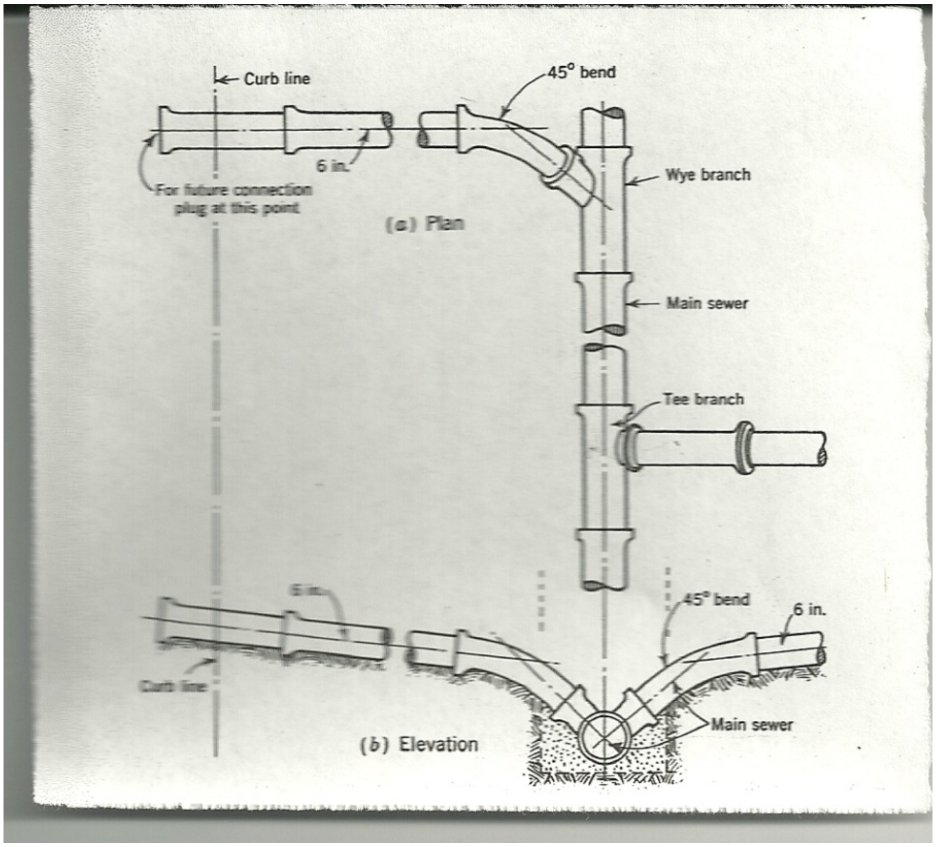

Figure VI.7. Service Connection Details

- Inverted siphons – the term "inverted siphon" refers to a depressed sewer which flows full under pressure. The purpose is to carry the flow under an obstruction such as a stream or a depressed highway and to regain as much elevation as possible. Manholes or access chambers must be provided at both the inlet and outlet for cleaning purpose and for control of the flow. These chambers should be large enough to permit a man to work with cleaning equipment. Where practical, it is advisable to provide a means for flushing the siphon at fairly frequent intervals. A blow-off may be installed at the low point if feasible. Smooth curves should be used for changes of slope in the siphon pipes so cleaning equipment can be run through them. The rise out of the siphon for small pipes should be on a moderate slope. Vertical riser outlets with restricted cross section can be used for larger-diameter siphons. The inlet and outlet elevations of the siphon should be established in such a way as to avoid excessive surcharging of the gravity sewers under peak flow conditions. For large inverted siphons, provision must be made for a high stack for the purpose of ventilating the inlet structure.

- Sewer outfalls – communities adjacent to the sea coast can consider the discharge of their sanitary sewage directly into the ocean. The acceptability and effectiveness of the ocean outfall are dependent on:

1. The dilution and diffusion of the sewage into the ocean water.
2. The dilution and diffusion of the sewage into the ocean water.
3. Current patterns at point of discharge and travel time to shore.
4. Ocean floor materials and bottom topography.
5. Treatment prior to discharge, and
6. Shore use and condition to be maintained.

The design of a submarine sewer outfall requires experience and judgment. Outfalls to discharge sewage in oceans, lakes, or other large bodies of water must have tight joints to prevent escape of the polluting sewage before the suitable location has been reached. Cast iron, steel, or reinforced-concrete pipes have been used with bolted, welded, calked, or non-rigid rubber-gasketed joints made by a driver. Entrance of sea water may be prevented by tide gates at the end of outfalls. Sewer outfalls which are frequently above the receiving waters are quite often provided with masonry or concrete head walls and wing walls.

- Flow-measuring devices – flows may be computed using the proper open-channel flow formula if the slope, diameter, and the roughness coefficient of the sewer pipe are known. Velocity of flow can be computed or measured by the use of dyes, floats, current meters, or radio- active tracers if data on slope and roughness of the pipe are not available. The following measuring devices are generally used:

1. V-notch weir.
2. Rectangular weir.
3. Magnetic flow meter.
4. Parshall flume, and
5. Palmer-Bowlus flume.

VII. <u>MTERIALS FOR SEWER CONSTRUCTION</u>

The following factors must be considered in the selection of materials for sewer construction:

1. Flow characteristics.
2. Life expectancy and use.
3. Resistance to scour.
4. Resistance to chemicals.
5. Ease of handling and installation including fittings and connections.
6. Strength to resist structural failure.
7. Type of joint.
8. Availability, and
9. Cost of materials, handling, and installation.

The following materials have been used for sewer construction:

- <u>Asbestos-cement pipe</u> – pipe of asbestos fiber and cement, in sizes 4 through 36 in. in diameter is available and is used in sewerage systems. Jointing is accomplished by compressing rubber rings between pipe ends and sleeves. Asbestos-cement or cast-iron fittings are used. The advantages of using this pipe are light weight and ease of handling long laying lengths, tight joints, rapidity of installation, and corrosion resistance to most natural soil conditions. When specifying the pipe, the pipe diameter, class or strength, and type of joint should be specified. The pipe should conform to standard specifications of American Water Works Association (AWWA) or American Society for Testing Materials (ASTM).

- <u>Brick masonry</u> – brick masonry had been used for large diameter sewers in the past. Due to high cost, lack of durability, and other factors, brick is now used only in special applications.

- <u>Cast-iron pipe</u> – cast-iron pipe is available from 4 through 48 in. in diameter with a variety of jointing methods. They are used in gravity sewers where absolutely tight joints are essential. The advantages of cast-iron pipe are long laying lengths with tight joints, ability to withstand high internal pressure and external load and, corrosion resistance in most natural soils. When specifying cast-iron pipe, it is necessary to give the pipe class, the joint type, the type of lining, and the type of exterior coating. Cast-iron pipe and fittings must conform to the specifications of American Standards Association (ASA) or AWWA specifications.

- Concrete pipe – unreinforced-concrete pipe in sizes 4 to 24 in. in diameter and reinforced concrete pipe in sizes 8 to 120 in. in diameter are generally available for gravity sewers. A number of joint designs are available depending on the degree of water tightness required. Gasketed tongue-and- groove joints can be used when infiltration is a problem. Protective linings should be used where excessive corrosion is likely to occur. The advantages of concrete pipe are the relative ease with which the required strength may be provided, the wide range of pipe sizes, the long laying lengths, and the rapidity with which the trench can be opened and backfilled. When specifying concrete pipe, it is necessary to give the pipe diameter, class or strength, the method of jointing, the type of protective coating and lining if any, and any other special requirements for concrete. The pipe should conform to the standards of AWWA or ASTM

- Cast-in-Place reinforced concrete – sewers are constructed of cast-in-place reinforced concrete when the required size is more economical than concrete pipe, when a special shape is required and, when headroom and working space are limited. Forms for concrete sewers should be unyielding and tight, and should produce a smooth sewer interior. Reinforcing steel, concrete aggregates, and portland cement must conform to standard specifications of the ASTM. Methods for resisting corrosion are the same as those for concrete pipe.

- Steel pipe – the flexibility of galvanized corrugated steel permits the fabrication of a variety of conduit shapes with a choice of protective coatings. Available sizes and shapes include: circular in sizes 8 to 96 in. in diameter, pipe arches equivalent in area to circular pipe of 15 to 60 in. in diameter, structural-plate structures of 60 to 180 in. in diameter, and structural-plate arches from 5 to 25 ft in span. Pipe sections are generally furnished up to 20 ft in length in multiples of 2 ft. The sections are jointed by coupling bands which may be single piece, two pieces or an internal expanding type used in lining work. To increase durability and to resist corrosion, galvanized pipe can be coated with bituminous material. Tees, wyes. elbows, and manholes may be fabricated from the same material. The advantages of steel pipe are light weight, long laying lengths, ease of shipping, adaptable to stacking methods, flexibility, strong mechanical joints, and ability to adjust to trench-loading conditions. Materials and fabrication should conform to the specifications of American Association of State Highway and Transportation Officials (AASHTO). When specifying concrete pipe, it is necessary to include: size, shape, gage of metal, assembly of sections, coatings, and couplings.

- Vitrified-Clay pipe – this type of pipe is manufactured in sizes 4 to 36 in. in diameter. The pipe may be unglazed, salt-glazed, or interior ceramic-glazed. The laying length varies from 3 to 6 ft. The pipe is manufactured in standard and extra strength to provide for varying trench depths. When specifying, the pipe diameter and deviations from standard specification references must be stated. It may be necessary to provide special bedding or concrete-cradling to obtain structural stability. The pipe should conform to the specifications of ASTM. Standard pipe fittings of vitrified clay are available to meet most requirements.

- Joints – The characteristics of a good joint include: water tightness, resistance to root penetration, resistance to corrosion, a reasonable degree of flexibility, and durability. There are several type of joints. For small size concrete pipes made with bell-and-spigot ends, the joints may be similar to those used on vitrified clay pipe. For larger size concrete pipe with tongue-and-groove ends, joints can be made with mortar or bituminous compounds or with rubber gaskets. For asbestos-cement pipe, the joint consists of a collar or coupling and a pair of rubber rings. For bell-and-spigot concrete pipe, cement mortar is used to pack against the hemp, or jute calked in to the annular space of the pipe, and to butter around the pipe joint forming a 45^0 bevel. For a pipe with a tongue-and-groove joint, cement mortar is used to pack the interior joint space and is packed or floated in to the exterior joint space. For vitrified clay pipe, mortar or bituminous compounds may be used. Bituminous compounds may be hot-poured or applied cold. Dry or un-oiled jute or similar material is used to calk in to the annular space of the bell-and-spigot pipe to center the joint, and to prevent the jointing material from flowing or being forced into the pipe interior.

VIII. STRUCTURAL REQUIREMENTS

The structural design of a sewer requires that the supporting strength of the conduit as installed, divided by a suitable factor of safety, must equal or exceed the loads imposed on it by the weight of earth and any superimposed loads. The supporting strength of buried conduits is a function of installation conditions as well as the inherent strength of pipe itself. Since installation conditions have such an important effect on both load and supporting strength, a satisfactory sewer construction project requires attainment of design conditions in the field.

VIII.1. Load on sewers due to gravity earth forces – Anson Marston developed methods for determining the vertical load on buried conduits due to gravity earth forces in all of the most commonly encountered construction conditions. His methods are based on a theory which states that the load on a buried conduit is equal to the weight of the prism of earth directly over the conduit, called the interior prism, plus or minus the frictional shearing forces transferred to that prism by the adjacent prisms of earth. The magnitude and direction of these frictional forces depend upon the relative settlement between the interior and adjacent earth prisms. The theory makes the following assumptions:

1. The calculated load is the load which will develop when ultimate settlement has taken place.
2. The magnitude of the lateral pressures, which induce the shearing forces between the interior and adjacent earth prisms, is computed in accordance with Rankine's theory.
3. Cohesion is negligible except for tunnel conditions.

The general form of Marston's equation is as follows:

$$W = CwB^2$$

Where W = vertical load per unit length acting on the conduit due to gravity earth loads

w = weight of earth per unit volume

B = trench width depending on installation conditions

C = a constant that measures the effect of

1. Ratio of the height of fill to width of trench
2. Shearing forces between interior and adjacent earth prisms
3. Direction and amount of relative settlement between interior and adjacent earth prisms for embankment conditions.

VIII.2. Types of loading conditions – The accepted system of classification is shown in Figure VIII.1 below:

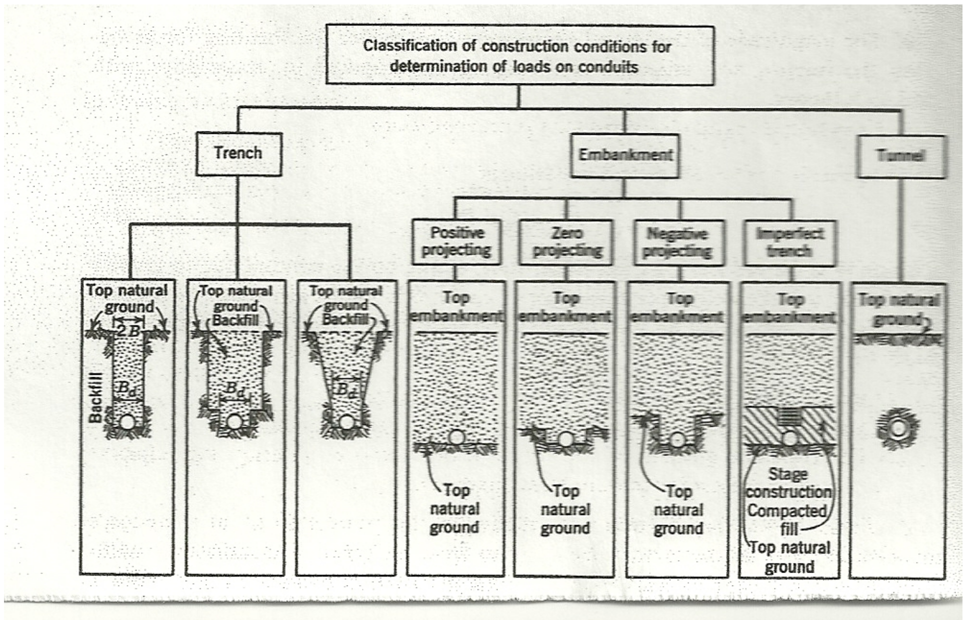

Figure VIII.1. Classification of Construction Conditions

Trench conditions are defined as those in which the conduit is installed in a relatively narrow trench cut in undisturbed ground and covered with earth backfill to the original ground surface. See Figure VIII.1.

Embank conditions are defined as those in which the conduit is covered with fill above the original ground surface or when a trench in undisturbed ground is so wide that trench wall friction does not affect the load on the pipe. This classification is further subdivided into (a) positive projection and (b) negative projection. Positive projection exists when the top of the conduit is above the adjacent original ground surface. Negative projection exists when the top of the pipe is below the adjacent original ground surface in a trench which is narrow with respect to the size of pipe and depth of cover and when the native material is of sufficient strength that the trench shape can be maintained dependably during the placing of the embankment.

VIII.3. Loads on trench conditions – The vertical load on a sewer pipe is the resultant of the weight of the prism of soil within the trench and above the top of the pipe and the friction or shearing forces generated between the prism of soil in the trench and the sides of the trench. The backfill has a tendency to settle in relation to the undisturbed soil in which trench is excavated. This tendency for movement induces upward shearing forces which support a part of the weight of the backfill. So the resultant load on the horizontal plane at the top of the pipe within the trench is equal to the weight of the backfill minus the upward shearing forces as indicated in Figure VIII.2

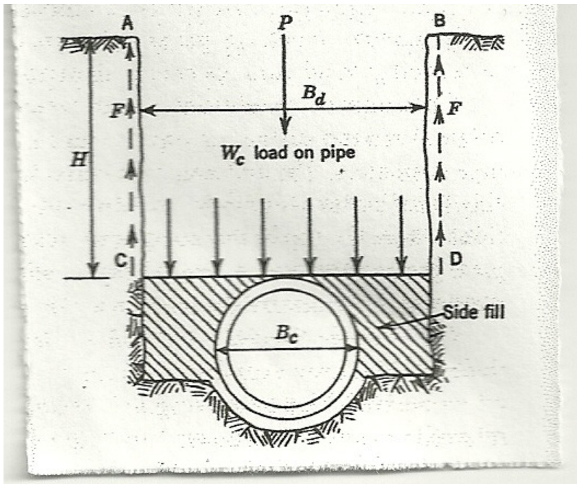

Figure VIII.2. Load- producing Forces

The width of the trench and the unit weight of the backfill soil have direct influence on the load on the pipe. So the width should be kept to an absolute minimum with the provision of sufficient working space at the sides of the pipe to calk joints properly, to insert and strip form, and to compact backfill. The load is also influenced by the coefficient friction between the backfill and the sides of the trench and by the coefficient of internal friction of the backfill soil.

Marston's formula for loads on rigid conduits in trench condition is as shown below:

$$W_c = C_d w B_d^2$$

Where W_c = load on the pipe, lb/ft

- w = unit weight of backfill soil, lb/cu ft
- B_d = width of trench at the top of the pipe, ft
- C_d = a constant (depends upon the ratio of height of fill to width of trench and the friction coefficient between the backfill and the sides of the trench). The value of C_d can be obtained from FigureVIII.3 which contains five curves, A, B, C, D, and E. Curve A represents granular material without cohesion; curve B represents sand and gravel; curve C represents saturated top soil; curve D represents ordinary clay; and curve E represents saturated clay.

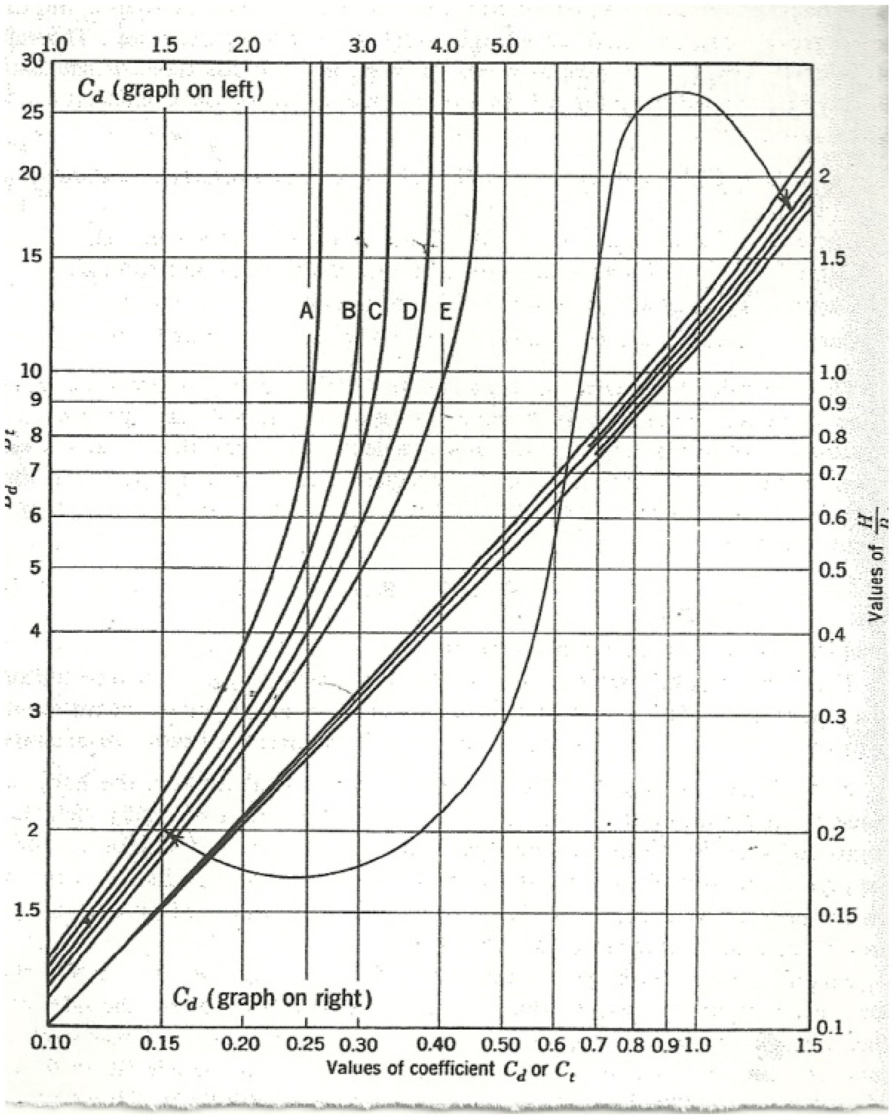

Figure VIII.3. Computation Diagram for Earth Loads

Legend for Figure VIII.3:

Curve A represents granular material without cohesion
Curve B represents sand and gravel
Curve C represents saturated top soil
Curve D represents ordinary clay
Curve E represents saturated clay

Application of the above formula is shown in the following numerical example.

Example: Determine the load on a 24-in diameter rigid pipe under 14 ft of saturated top soil in trench conditions. The side fill is 1 ft wide on each side. Assume the pipe wall thickness as 2 in.

B_c = 24 + 4 = 28 in. = 2.33 ft
B_d = 2.33 + 2.00 = 4.33ft
w = 120 lb/cu ft for saturated top soil
H/B_d = 14/4.33 = 3.24
C_d from Figure VIII.2 = 2.1
Applying the above values in formula

$$W_c = C_d w B_d^2$$
$$= 2.1 \text{x} 120 \text{ x } 4.33^2$$
$$= 4{,}720 \text{ lb/ ft}$$

If the pipe is flexible and the soil at the sides is compacted to the extent that it will deform under vertical load the same amount as the pipe itself, the side fills may be expected to carry their proportional share of the total load. For a situation of this kind, the trench load formula is given below:

$$W_c = C_d w B_c B_d$$

Where B_c = outside width of the pipe, ft
B_d = width of the trench at the top of the pipe, ft
w = unit weight of backfill soil, lb/cu ft
W_c = load on the pipe, lb/ft
C_d = a constant from Figure VIII.3

Application of the above formula is shown in the following numerical example.

Example: Determine the load on a 30-in. diameter flexible conduit, with a wall thickness of 2 in., installed in a trench 4 ft 6 in. wide at a depth of 12 ft. The trench is cut in ordinary clay having a unit weight of 120 lb/cu ft.

H = 12 ft
B_d = 4.5 ft
B_c = 30 + 4 = 34 in. = 2.83 ft
H/B_d = 12/4.5 = 2.67
C_d from Figure VIII.2 = 1.9 and applying the above values in formula
$W_c = C_d w B_c B_d$ = 1.9 x 120 x 4.5 x 2.83 = 2,903.6 lb/ft

VIII.4. Loads on sewers due to superimposed loads – Two types of superimposed loads are encountered commonly in the structural design of sewers. These two types are: (1) concentrated load, and (2) distributed load.

VIII.4.1. Concentrated load – the formula for load due to superimposed concentrated load, such as a truck wheel, as shown in Figure VIII.3 below, is given by the following formula:

$$W_{sc} = C_s(PF/L)$$

Where W_{sc} = the load on the conduit, lb/unit length

P = the concentrated load, lb

F = the impact factor

L = the effective length of the conduit, ft

C_s = the load coefficient (see Table VIII.1). It depends upon $B_c/2H$ and $L/2H$ where

H = the height of fill from the top of conduit to ground surface ,ft

B_c = width of conduit, ft

The effective length of a conduit is defined as the length over which the average load due to surface traffic units produces the same stress in the conduit wall as does the actual load which varies in intensity from point to point. It is general practice to use an effective length of 3 ft for conduits greater than 3 ft long and the actual length for shorter conduits.

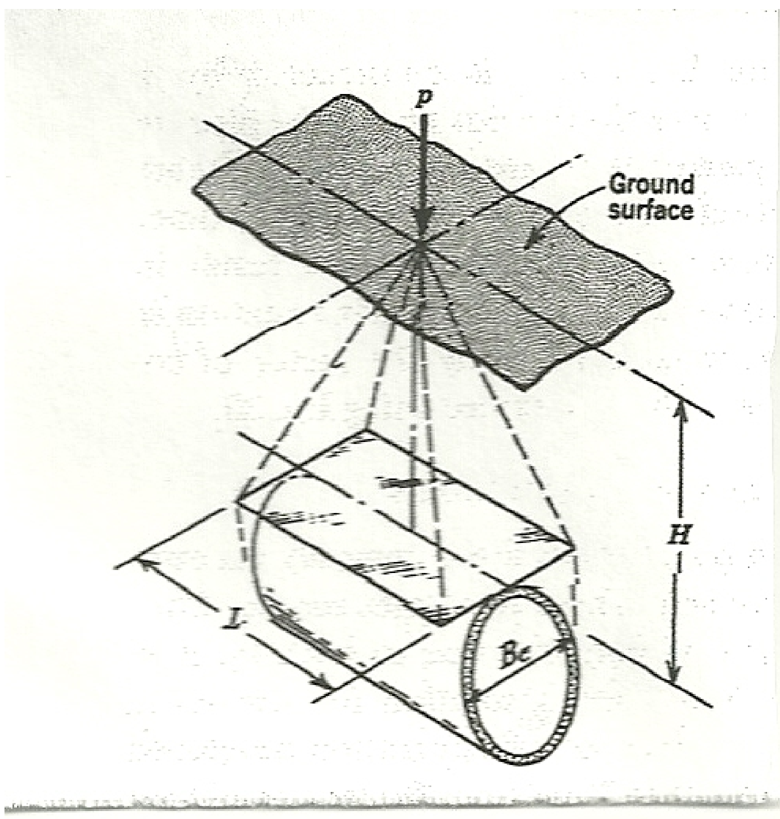

Figure VIII.4. Concentrated Superimposed Load

Table VIII.1. Values of Load Coefficients

$\frac{D}{2H}$ or $\frac{B_c}{2H}$	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

The dynamic loads caused by traffic produce an impact and this must be considered in load computations. The following impact factors are recommended:

Highway traffic ………………………………… 1.50
Railway traffic ………………………………… 1.75
Airfield runways……………………………… 1.00
Airfield taxiways, aprons, hard stands…… …1.50

The following numerical example shows the load computation due to a super- imposed concentrated load:

Example: Determine the load on a 24-in diameter pipe under 3 ft of cover caused by a 10,000-lb truck wheel applied directly above the center of the pipe.
Assume the pipe section is 2.5 ft long; the wall thickness is 2 in.; and the impact factor is 1.5

B_c = 24+4 = 28 in. = 2.33 ft
L = 2.5 ft
H = 3.0 ft
B_c/2H = 2.33/6 = 0.39
L/2H = 2.5/6 = 0.41
From Table VIII.1, for B_c/2H of 0.39 and L/2H of 0.41, the load coefficient = 0.240
Substituting the above values in equation $W_{sc} = C_s(PF/L)$
W_{sc} = 0.24 x {(10,000x1.5)/2.5} = 1,440 lb/ft

VIII.4.2. Distributed loads – In the case of a superimposed load distributed over an area of considerable extent, as shown in Figure VIII.5 below, the following formula is used for load computation:

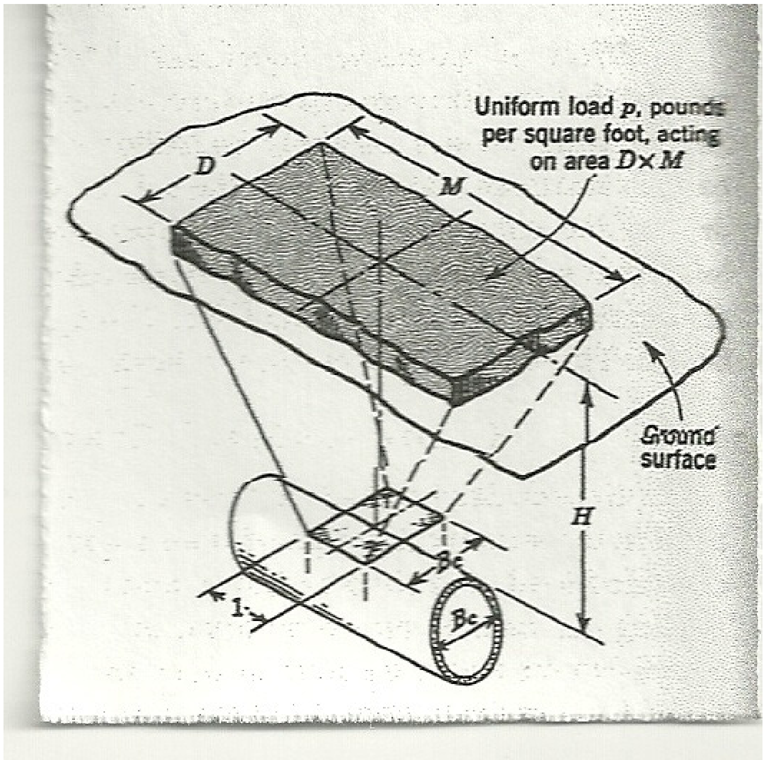

Figure VIII.5. Distributed Superimposed Load

$W_{sd} = C_s p F B_c$

where W_{sd} = load on conduit, lb/unit length

p = intensity of distributed load , lb/sq ft

F = impact factor

B_c = width of the conduit, ft

C_s = load coefficient, depends upon D/2H and M/2H (refer to Table VIII.1) where

H = height from the top of the conduit to the ground surface, ft

D and M = width and length, respectively, of the area over which the distributed load acts, ft

VIII.5. Pipe bedding – the contact between the pipe and the foundation on which it rests is the pipe bedding. This has an important influence on the distribution of the reaction against the bottom of the pipe and hence influences the supporting strength of the pipe as installed. Pipe bedding falls into the following classes:

- **Class A –** concrete cradle. The pipe is embedded in a monolithic cradle of plain or reinforced concrete having a minimum thickness of ¼ the inside diameter or a minimum of 4 in. under the barrel and extending up the sides for a height equal to ¼ the outside diameter. The width is at least equal to the outside diameter of the pipe barrel plus 8 in. The load factor is 2.2 to 2.8 depending upon the tamped backfill and up to 3.4 for reinforced concrete.

- **Class A –** concrete arch. The pipe is embedded in compacted granular material with a minimum thickness of ¼ outside diameter between barrel and bottom of trench excavation and extending half way up the sides of the pipe. The top half of the pipe shall be covered with a monolithic plain or reinforced concrete arch having a minimum thickness of ¼ the inside diameter at the crown with a minimum width equal to the outside pipe diameter plus 8 in. The load factor is 2.8 for plain concrete and up to 3.4 for reinforced concrete.

- **Class B – First-class bedding –** Class B bedding may be achieved by two types: (1) shaped bottom with tamped backfill, and (2) compacted granular bedding with tamped backfill. In the first type, the bottom of the trench excavation is shaped to conform to a cylindrical surface with a radius at least 2 in. greater than the radius to the outside of the pipe **a**nd with a width sufficient to allow 6/10 of the width of the pipe barrel to be bedded in fine granular fill placed in the shaped excavation. Carefully compacted backfill is placed at the sides of the pipe to a thickness of at least 12 in. above the top of the pipe. In the second type, the pipe is bedded in compacted granular material placed on a flat trench bottom. The granular bedding has a minimum thickness of ¼ the outside pipe diameter and extends halfway up the pipe barrel at the sides. The reminder of the sides and a minimum depth of 12 in. over the top of the pipe is filled with carefully compacted material.

- **Class C – Ordinary bedding -** This bedding is achieved by either a shaped bottom or with a compacted granular bedding with tamped backfill. In the former, the pipe is bedded in an earth foundation formed in the trench bottom by a shaped excavation which fits the pipe barrel for a width of at least 50 % of the outside pipe diameter. The sides and area over the pipe to a minimum depth of 6 in. above the top of the pipe is filled with lightly compacted fill. This bedding is not recommended for pipe line construction due to its cost and impracticality. In the latter, the pipe is bedded in compacted granular material placed on a flat trench bottom. The granular bedding has a minimum thickness of 4 in. under the barrel and extends 1/10 to 1/6 of the outside diameter up the pipe barrel at the sides. The reminder of the sides and to a minimum depth of 6 in. over the top of the pipe is filled with lightly compacted backfill. The load factor is 1.5.

- **Class D – Flat bottom trench –** In this type of bedding, the bottom of the trench is left flat, and no care is taken to secure compaction of backfill at the sides and immediately over the pipe.

The load factor is 1.1. This type of bedding is not recommended for sewer construction. Only Class B or Class C (with compacted granular bedding) is recommended for practical and economic reasons.

Figure VIII.6 shows the different kinds of bedding for conduits in trench

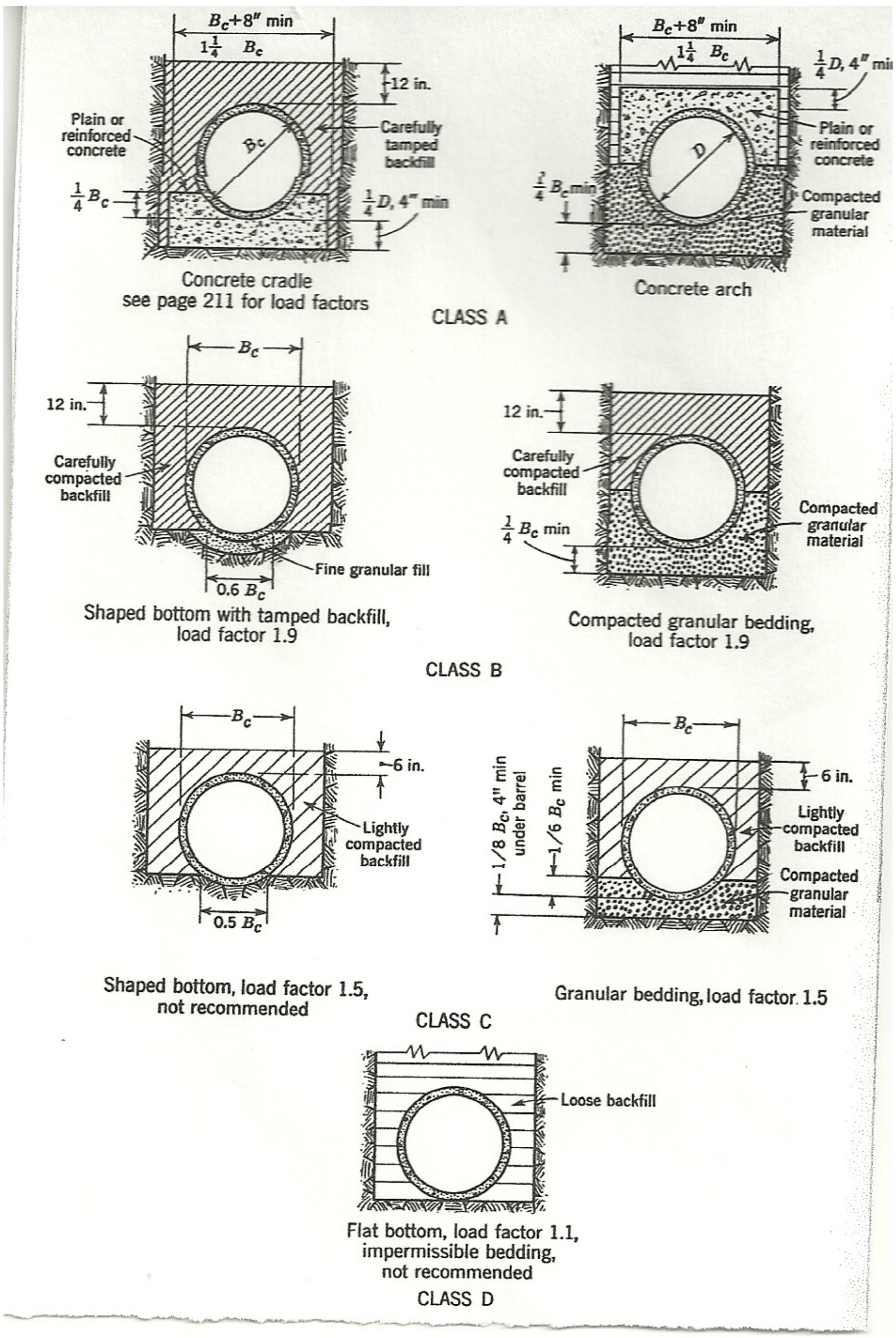

Figure VIII.6. Classes of Bedding for Conduits in Trench