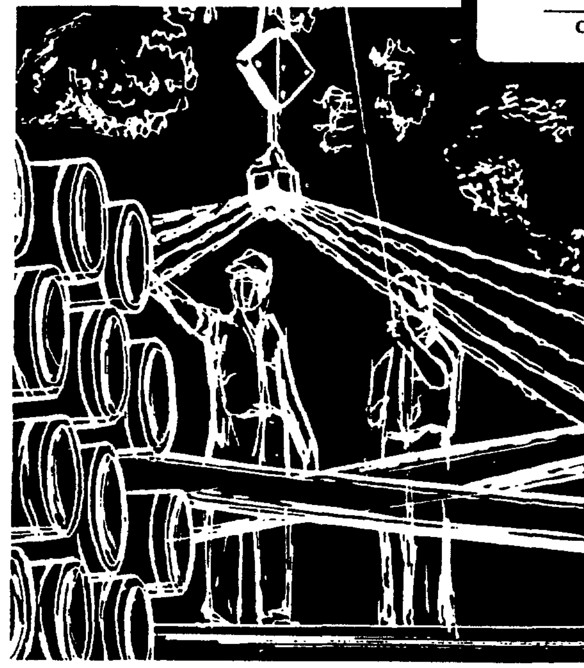

WASTEWATER SYSTEMS

pipes and piping

water and wastes engineering / MANUAL OF PRACTICE NUMBER THREE

PART 1/SYSTEM DESIGN

PART 2/MATERIALS

PART 3/INSTALLATION PRACTICES

PART 4/MAINTENANCE

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CONTENTS

FOREWORD

THIS MANUAL OF PRACTICE, the third in a projected series to be published by WATER AND WASTES ENGINEERING, is devoted to pipes and piping systems used in wastewater disposal operations.

This manual is a sequel to Manual of Practice No. 2, which covered pipes and piping systems in water supply operations. The purpose of these manuals is to provide ready, concise, and basic information. Manual of Practice No. 3 is particularly intended for persons interested or involved in the design, management, supervision, operation, and maintenance of municipal or industrial wastewater disposal systems.

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PART 1 / SYSTEM DESIGN

Introduction

PIPING SYSTEMS in wastewater disposal, commonly called sewers, have two basic functions: to collect and to transport domestic sewage and/or industrial wastes. Throughout this manual, the term sewer will refer to collection systems that transport wastewater from point of origin to point of treatment or ultimate disposal.

Sewers and piping that operate under pressure are generally termed force mains. The term inplant piping is commonly applied to piping systems within a treatment plant, regardless of the system's particular use.

According to Babbitt,[1] there is archeological evidence of sewers in Nippur, India (3750 BC) and Bagdad (2500 BC). The Cloaca Maxima, an arched sewer constructed in the 1st century AD to drain the Roman Forum, is still in existence. Modern sewer systems date from the early 19th century. Table 1 briefly traces the history of sewer systems.

The importance of sewer systems in the United States is indicated by the fact that, in spite of the large number of communities already sewered, the money currently being spent for sewer systems is approximately 62 percent of the total annual put-in-place construction cost for wastewater disposal facilities.

Unlike water mains, sewers seldom contain valves, except overflow gates, but do have a number of appurtenances, including: catch basins, flow measuring devices, flushing systems, inlets, junction chambers, lift stations, manholes, overflows, regulators, siphons, ventilators, and weirs.

Sewers contain no moving parts and therefore operation, so-called, is largely a matter of cleaning and maintenance. The principal role of sewers is to provide a water-tight passage through which wastewater can be transported quickly, with a minimum of decomposition and without odor production, stoppage, or overflow.

If the transportation of wastewater through a sewer is disrupted or impeded, problems may occur in treatment plant operations. It is important, therefore, for operating personnel in wastewater treatment plants to understand the most common sewer problems: exfiltration, grease, grit, or trash accumulation, infiltration, organic matter decomposition, root penetration, solids stranding, unevenness of sewer grades, and potential danger from flammable liquids.

Insofar as possible, within the available space, this manual will deal with different types of sewers, their design, materials used for construction, installation procedures, appurtenances, and maintenance.

Section 1—Sewer System Types

Sewers and sewer systems may be classified in four ways, according to: character of wastewater carried, relative position in the system (or service), design configuration, and materials of construction.

Tables 2 and 3 show the basis of classification of the different types of sewers in each of the first two categories.

Sewers may be classified according to the design configuration: barrel, basket-handle, catenary, circular, egg-shaped, horseshoe, ovoid, rectangular, or semi-elliptical.

Classification of sewers is also based on the material of construction (see Part 2).

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TABLE 1—HISTORICAL DEVELOPMENTS IN SEWER SYSTEMS

Approx. year	Event
1803	Concrete sewer installed in New London, Conn.
1805	New York City's first large sewer installed
1815	Excreta admitted to London sewers
1833	Construction of Paris sewers begun
1843	First full-scale sewer system for sanitary sewage installed in Hamburg, Germany[2]
1857–58	Sewer systems designed for Brooklyn (N.Y.) and Chicago
1880	Separate sewer system installed in Memphis, Tenn.[1]
1915	Last comprehensive sewer system for a large city completed in Baltimore
1962	11,420 municipal sewer systems in United States reported by U. S. Public Health Service[3]

TABLE 2—CLASSIFICATION OF SEWER BY TYPE OF WASTE CARRIED

Type of sewer	Character of wastewater carried
Sanitary	Domestic or sanitary sewage from households, commercial buildings, or industrial establishments
Storm	Storm water runoff from streets and land
Combined	Both sanitary sewage and storm water
Separate	Either storm water or sewage and industrial wastes, but not both
Industrial wastes	Wastewater from wet manufacturing or process industries; sanitary sewage may or may not be included
Cooling water	Water used for cooling purposes and discharged essentially unaffected by use

TABLE 3—CLASSIFICATION OF SEWER BY LOCATION IN SYSTEM OR PURPOSE

Type of sewer	Location in system or purpose
House	Receives household wastes from building plumbing drainage system and carries them to the street sewer
Lateral	Carries wastewater into another sewer (branch); has no other common sewer tributary to it
Branch	Receives wastewater from laterals and carries it to a main or trunk sewer
Main (also called trunk)	Receives wastewater from many tributary branches or laterals; serves a large area
Relief	Receives flow (overflow) above the capacity of an existing sewer
Interceptor	Receives dry-weather flow, and often storm water up to 5 × DWF, from a number of transverse (main or trunk) sewers. Interceptors are usually large, flow parallel to a natural drainage channel, and discharge to a treatment plant or to a receiving body of water
Force main	A sewer through which wastewater (or sludge) is pumped under pressure from one level to a higher level or from one plant to another
Influent	Sewer or interceptor leading into a treatment plant
Outfall (also called effluent sewer)	Sewer or pipe leading from an interceptor or treatment plant to or into a receiving body of water

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Section 2—Preliminary Considerations in Design

Except in small unsewered communities, the need to design a complete municipal sewer system has rarely arisen in the last 50 years. (There are exceptions, however, where new communities have been built, e.g., Levittown, L.I., Levittown, Pa., and Foster City, Calif.) Most sewer design projects today pertain to the sewering of newly developed residential areas within a city, construction of intercepting and/or storm sewers, separation of sanitary and storm sewers, replacement of undersized, overloaded, or collapsed sewers, and construction of sewers for the transportation of municipal and/or industrial wastes to wastewater treatment plants.

Preliminary report

Many municipalities have sewer departments employing engineering staffs to design necessary sewer systems; other communities utilize the services of consulting engineers. In both cases, the designer must make a number of decisions and carry out several operations before the final engineering design can be undertaken and construction begun. Generally a preliminary engineering report on a proposed sewer system reviews the needs of the community, estimated cost, financing methods, means for obtaining public support, and pertinent ordinances.

Engineering report

Once the preliminary report has been accepted and approved and arrangements or contracts have been made for the work to proceed, a full scale engineering report expanding on all phases of the preliminary report is usually prepared, and actual design begins. Sometimes, only the detailed engineering report and plans are prepared. Among the more important items included are layout, cost estimates, financing methods, sewer ordinances, and public relations efforts.

LAYOUT

The basic map of the area to be sewered should show locations of pertinent existing buildings, utilities, and drains. The basic map and engineering data should also include the following information:

System layout for the entire tributary area, with route alternatives, if necessary;
Estimated future growth of the area;
Estimated current and future flows from tributary areas;
Indicated pipe sizes, elevations, and grades;
Topographic contour lines;
Preferable materials of construction.

A concise review of the method of developing a sewer system layout has been published by the National Clay Pipe Institute.[4] Figure 1 shows a typical layout map for sewers.[4]

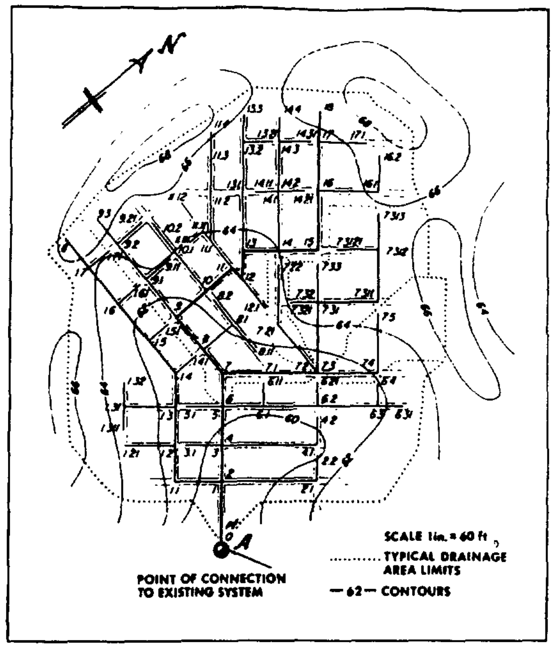


Fig. 1. Typical layout for sewer system.[4]

COST ESTIMATES

Babbitt and Baumann[5] recommend that the engineer's estimates of costs be grouped and divided among the following categories:

Labor	Contingencies	Legal expense
Materials	Profit	Land acquisition
Overhead	Engineering and Inspection	Extra work

In addition to the above categories, these authors[5] suggest that estimates of sewer costs be stated on a per-linear-foot basis, with the following detailed items:

Excavation, rock (per cu yd)	Repaving
Excavation, earth (per cu yd)	Flushing systems
Backfill (per cu yd)	Special sections
Manholes	Testing
Catch basins	

FINANCING METHODS

The engineering report should contain an evaluation of the possible methods of financing, with recommendations as to the preferable method. The common methods to be evaluated are:

General obligation bonds	Sewer service charges
General taxation	Special industrial waste charges
Government grants and loans	Combinations of the above methods
Private capital	
Revenue bonds	

The choice of financing methods often depends on the local situation, and each method has its proponents. With the passage of PL 89-234, The Water Quality Act of 1965, and of PL 89-753, The Clean Waters Restoration Act of 1966, the use of federal grants and funds has become one of the most important methods of financing sewer facilities.

Modern practice also favors the use of sewer service charges and special charges to industry for treating industrial wastes. Special industrial waste charges were proposed more than 40 years ago, but the first such industrial waste charge formula was developed and instituted by Symons and Crane in Buffalo in 1943.[6] A number of different formulas have since been used elsewhere. A definitive review of the most important formulas was published in 1954.[7]

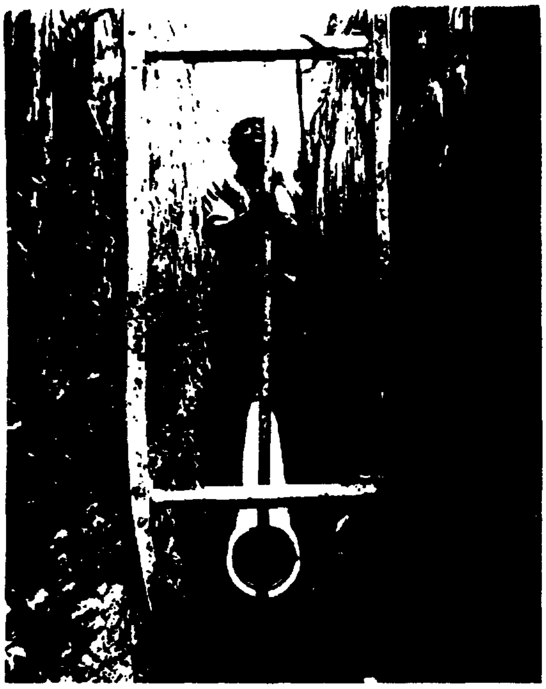
SEWER ORDINANCES

Where municipal ordinances do not provide adequate control of the wastes discharged into sewer systems, it is often desirable that the engineering report cover this matter and include basic recommendations for development of adequate ordinances.

A guide to the development of sound municipal sewer ordinances is contained in WPCF Manual of Practice No. 3, "Municipal Sewer Ordinances."[8]

PUBLIC RELATIONS

In any effort to obtain public support for financing sewer construction projects, both the engineers and municipal officials must make full use of all means of informing the



Asbestos-cement sewer pipe laid in trench that needed no sheeting.

public. These efforts will include newspaper, radio, and television publicity, talks before service clubs, etc.

Materials to aid a community in its public relations efforts are available from a number of sources. The Water Pollution Control Federation has published several relevant pamphlets, including one titled, "Public Relations for Water Pollution Control;" other pamphlets and bulletins are available from federal government agencies. Films for public showing have been prepared by many manufacturers. A book by M. M. Cohn,[2] contains information and suggestions for public relations projects related to sewers. Some manufacturers' associations and companies have published guides on community relations with respect to water supply systems. The principles in these bulletins are also applicable to sewer system projects.

Section 3—Sanitary Sewers

The design of a sewer system depends on several factors, including type (sanitary, storm, or combined sewer), location, capacity required, grade, depth, and trench load.

Generally sanitary sewers are more desirable than combined sewers and should be installed when the following situations exist:[10]

Sanitary sewage collection needs are immediate, but storm flow collection needs are not immediate;

Conditions favor overground transmission of storm waters for long distances;

Disposal of combined flow would require pumping, but storm flow pumping would not be necessary;

Treatment of storm waters is not necessary.

When the capacity of an existing system is sufficient for sanitary sewage flow but not storm water, a separate storm sewer should be constructed.

Combined sewers should be installed only when an evaluation of the above factors indicates that a combined system is more applicable than separate systems.

Many states require plans for sewer systems to be approved by the state health department before the start of construction. These plans should include:[5]

General map of municipality or sewer district, with drainage areas and location of sewers and appurtenances shown in detail;

Detailed plans and profiles of sewers;

Details of appurtenances;

Comprehensive report on proposed system;

Specifications.

Location

In locating sewers, the following factors should be considered: costs, grade, soil conditions, safety during construction, future expansion, etc. The best route may not necessarily be the shortest one.

GENERAL CONSIDERATIONS

The sewer route chosen determines the layout, which should be shown in the layout map (Fig. 1). This map should contain present and future street locations; contour lines of the area (at the smallest feasible intervals); present, currently proposed, and future sewers; elevations, sizes, and grades of sewer lines.

Generally, sewers should be laid in the streets, or in alleys between property lines, but not, for several reasons, on easements on property. Location in grassy areas in or along wide streets or boulevards is desirable to avoid disturbing the pavement. Sewers should usually be laid in straight lines, particularly between manholes; in housing developments where streets are curved, the sewer line will usually curve accordingly. Curved sewers with radii of 100 ft or more have generally given satisfactory service.

Wherever possible, lateral sewers should be laid within 50 ft of every lot or should provide for the shortest possible house connections; the location should also provide for proper cellar drainage of all property, without pumping. A manual published by The American Society of Civil Engineers[11] provides a standard practice for locating sanitary and storm sewers.

The sewer system layout will generally fit into one of two classifications: perpendicular or fan-shaped. Where the topography of a community is characterized by different levels, or by ridges and valleys, the sewer system layout may involve combinations of perpendicular and fan configurations, with or without lift stations and interceptors.

PROCEDURAL STEPS

One reference work[4] suggests the following steps in developing the layout of a new or expanded sewer system.

Trunk sewers. Begin at the point of discharge or outlet of the trunk sewer (i.e., at the lowest elevation) for the area under consideration and work uphill along the route of minimum slope. The line must eventually reach the edge of the drainage area or ridge line between drainage areas.

Location map. Revise the tentative layout to produce the shortest possible route. If possible, avoid layouts that require a sewer slope opposite to the ground surface slope. The final trunk line location should have a minimum length, require a minimum amount of excavation, and provide for drainage downward from both sides of the line for the entire area.

Branch sewers. Follow the same basic procedure as for trunk sewers, making each branch provide complete drainage of its own subdrainage area using the shortest possible length and minimum excavation.

Laterals. Locate the laterals from branch sewers in streets, using the same principles and procedures as for trunk sewers, i.e., minimum excavation and length, complete service to area, etc.

Service areas. Add to the location map the division lines that show the areas served by each trunk sewer, branch, or lateral. Each district should consist of all the acreage within which the flow is toward the point where the sewer crosses the boundary line of the area. Sub-areas on laterals should generally be no more than two blocks long.

Tributary load. After completion of the area location map, the acreage and expected tributary flow for each area should be calculated and tabulated in a cumulative manner that will show, at any particular point on the sewer, the sewer length, acreage, and flow tributary to the point.

Capacity

The required sewer size (diameter) depends on the volume of wastes to be handled in a period of time and on the hydraulic characteristics (grade, etc.) of the sewer.

The volume of flow to be handled depends on population tributary, waste discharge per capita, amount of water entering the sewer from the soil outside (infiltration) and the leakage from the sewer (exfiltration).

It is difficult and expensive to expand or increase the capacity of a sewer system once it is installed. There are only two means for doing so: digging up the sewer and replacing it with a larger size, or installing a parallel system. Both methods are costly. Therefore, it is good practice to make predictions of future population and flow on the best possible basis. Unfortunately, even the best estimates may be in error.

POPULATION TRIBUTARY

The prediction of population trends is complicated by a variety of technical, physical, social, political, economic, and other factors, including the strong trend to urbanization in this country.

Prediction methods. The designer must choose the best possible method and use his judgment in arriving at the most likely future population. Two groups of methods are available: mathematical and logical.

Mathematical methods. These methods include arithmetical and geometrical progression, decreasing rate of increase, and differential plot. All are subject to criticism for failure to give more than a poor guess. The mathematical approach is based on the assumption that a city, or area, in its early or "young" stages will increase in population geometrically, possibly by some fixed percentage for each interval of time; that later, for a certain time interval, the population will increase at a more or less uniform rate (i.e., by some fixed number for each time interval), and that, eventually, the rate of increase will taper off until some limit is reached, after which there will be no further increase. The problem is to determine which stage currently exists, and the percentage or fixed-number increase to be used. Population trends since 1950 have changed considerably because community growth has been influenced by local conditions, such as development of industry, transportation, changes in population age distribution, and other social and political trends. The mathematical approach is more unreliable today than in the years before 1940.

Mathematical methods also include the graphical extension of plotted data, graphical comparison with other cities, and application of the Verhulst theory. Graphical extension of plotted data or graphical comparisons with other cities involve the plotting of census data against time. Figure 2 shows the plotting of population records of the United States and several states and cities to 1950. Current growth patterns are different from those before 1950.

Graphical comparisons with other cities will only be as good as the designer's judgment in interpreting the plots. This judgment must include consideration of all of the factors mentioned above.

The Verhulst theory utilizes the principle that the population in any area increases only to a saturation limit.[12]

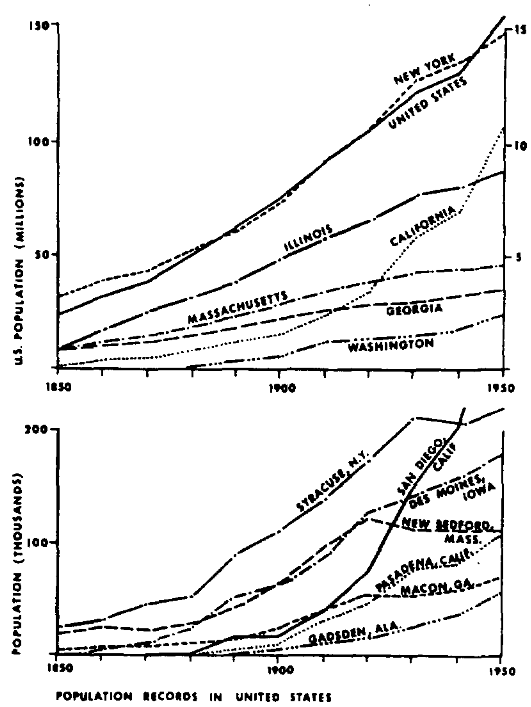


Fig. 2. Population trends in the United States.

Logical methods. These methods include the component method, the cohort survival method, and the ratio method. The first method involves the use of birth and death rates and expected future migration trends. The second method involves the computation of data on each age group for the entire projection period. The ratio method consists of three steps: determination of the ratio of the population in the area under study to the population of a larger area; extrapolation of that ratio to the terminal year of the prediction period; and conversion of the extrapolated ratio back to the predicted population for the smaller area.

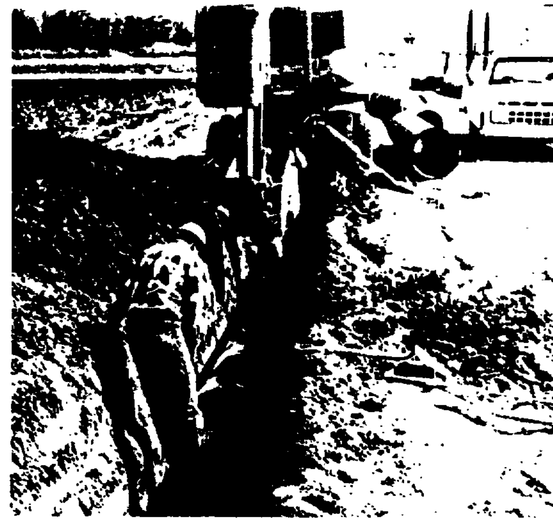
Prediction period. The period for which a population prediction applicable to main sewers and interceptors is to be made should be selected according to the local situation. It may be as short as 10 years or as long as 50 years. The selection of the period will be affected by many factors, such as legal limits on bond issues, economy, available funds, predicted population level, and the relative importance assigned to each factor by the designer. Bond issues frequently have a life span of only 20 to 30 years, but it is often desirable to predict population growth for longer periods. Some compromise between the bond life and the longer period desired may be the best solution so that the succeeding generation is not burdened with the cost of facilities for current use. Population predictions to be used in the design of lateral sewers should be based on full development of the area served and not on any specific length of time.

Population data sources. Information on population trends may be obtained from the U. S. Bureau of Census, the Population Reference Bureau in Washington, D. C., and state and regional agencies. Local telephone and power companies usually have excellent data on local area growth.

FLOW CAPACITY

The estimation of the volume of liquid to be carried in a sewer system and the selection of the necessary pipe size

Large diameter plastic pipe entering manhole location.



Ductile iron 24-in. force main at Creve Couer, Mo.

must take into account the current tributary domestic, industrial, and commercial waste load, infiltration, and exfiltration. In-making estimates of flow, many factors must be considered, the most important of which are discussed below:

Flow rates. For the design of sewer systems, it is necessary to know the total amount of liquid to be handled during various periods of time and, also, different instantaneous rates of flow. Inasmuch as sewage flows more or less continuously, any expression of amount is meaningless unless the time period involved is known.

The amounts of wastewater may be expressed in terms of rate of flow or discharge per unit time. The total volume for any day is the average of the variable instantaneous rates of flow throughout a particular day.

It need not be confusing to express both total flow and instantaneous flow rates in the same terms (gpd or mgd). In fact, it is convenient to do so when making future predictions or estimates. Flow data expressed in gallons per day may be converted easily to data expressed as cubic feet per second for use in standard hydraulic formulas, or as gallons per minute for use with printed charts or graphs.

Flow data may also be expressed in terms of gallons per capita per day. In this way, flows from different areas or cities may be compared. Flow data expressed as gallons per capita per day are often used as the basis for making future quantitative estimates. Per capita flow data may also be useful for other predictions.

The term "per capita" does not have a single meaning. For example, the per capita flow for an entire city may be the total flow divided by the total population, or it may be the total flow divided by the sewer-connected population. The two may be quite different. Also, the sewage flow for business, commercial, and industrial discharges may be reported on a per capita basis, and the value may be determined on four different bases. The total flow may be divided by: (1) total number of persons in the city; (2) the sewer-connected population; (3) the number of persons residing within the business, commercial, or industrial area under study; or (4) the number of persons working within the area under study. The values will differ markedly.

Generally the choice of method for determining per capita flows is immaterial, providing it is stated and understood. However, when the total per capita flow for a community is computed by adding the per capita flows for domestic, business, commercial, and industrial areas, then it is important to use the same basis for calculating each category.

Average flows. The total sewage quantity consists of the individual flows from the various area categories (residential, business, commercial, and industrial). This total flow will bear some relation to the public water supply use of the community, but this relation varies from city to city, depending on the amount of unaccounted-for water, the amount of water used for public purposes and for lawn sprinkling, the number of individual water supply wells in the community, infiltration and exfiltration in the sewers, and the extent to which storm water and roof drainage is kept out of the sewers.

Where good estimates of these various factors are not available, actual measurement of the flow in sewers is the

TABLE 4—WATER USE AND SEWAGE FLOW IN VARIOUS CITIES

City	Average quantity (gpcd)	
	Water*	Sewage**
Akron, Ohio	121	190
Ann Arbor, Mich.	116	110
Auburn, N. Y.	187	136
Aurora, Ill.	81	132
Buffalo, N. Y.	202	242
Cleveland, Ohio	165	130
Detroit, Mich.	141	141
Fitchburg, Mass.	183	82
Galesburg, Ill.	96	159
Gary, Ind.	98	195
Green Bay, Wis.	83	188
Indianapolis, Ind.	109	147
Kenosha, Wis.	141	205
Marion, Ind.	139	153
Marshalltown, Iowa	112	170
Minneapolis, Minn.	93	141
Niagara Falls, N. Y.	394	670
Oshkosh, Wis.	64	125
Pasadena, Calif.	150	70
Phoenix, Ariz.	253	142
Racine, Wis.	174	202
Rochester, N. Y.	118	134
Toledo, Ohio	147	126
Urbana, Ill.	87	93
Washington, D. C.	165	147
Worcester, Mass.	103	138

* From "A Survey of Operating Data for Water Works in 1945" *JAWWA* 40: 165 (1948).
** From operator's reports, mostly 1945, others between 1943 and 1947.

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best method of obtaining the desired data. The wide variation between water use and wastewater flow in a number of cities is shown in Table 4. Although these data were collected some time ago, they indicate the possible variations between water supply quantities and wastewater flow.

Water use records of a number of metered water supplies plus careful sewer gagings indicate that the average domestic sewage flow may vary from 15 to 70 gpcd, depending on type of dwelling and economic level of people served. For example, the following rates may apply in communities where the water service is completely metered:

Dwelling type	Flow (gpcd)
Apartment house	65±
First class	55±
Middle class	40±
Lower class	25±

Where water supply charges are based on flat rates, flow values will be higher, and, in the lowest class dwellings, may be twice the above figure. For design purposes, it is advisable to select a value of 50 gpcd or more for calculations of domestic sanitary sewage flow.

Waste flow from business and commercial districts is generally related to the amount of contributing floor space; a common estimate is 300 gpd per 1000 sq ft of floor area.

Industrial wastes vary widely in volume depending on the type of industry, inplant treatment or disposal, and the use of cooling water. Only a careful study of industrial sewer gaging can indicate the extent of the industrial load.

When selecting the estimated flow rate values to be used for design purposes, it must be remembered that the estimate is for future conditions and that the per capita average flow is more likely to increase than to decrease.

One simple means of estimating sewage flow rates, often used for preliminary estimates, can be illustrated by the following hypothetical example:

Item	Calculation	Flow rate (mgd)
Domestic sewage	100 gpcd × 12,000 pop.	1.2
Business and commercial wastes	10,000 gpcd × 64 acres	0.64
Industrial wastes	By measurement	0.27
Infiltration	5000 gpd/mile × 23 miles	0.11
Total avg. flow		2.02

Infiltration and exfiltration. Ground water may leak into a sewer (infiltration) or wastewater may leak out of a sewer (exfiltration). Such leakage may occur through poor joints or cracks in the pipe or manholes, which may result from poor construction, settlement after construction, or deterioration of materials.

Most of the time, a sewer pipe carries only a portion of its maximum capacity, and the tendency for water to leak out is small. On the other hand, the ground water level, either normally or after rains, may be well above the top of the sewer, and an appreciable amount of water may enter the sewer. Both modern pipe and modern joints have contributed greatly to eliminating or minimizing infiltration. Extraneous water in sewers is likely to come from illegal connections from roof drainage, surface runoff through manhole covers, and forgotten or unrecorded street inlets.

The resulting infiltration may be expressed in gallons per day per acre of area served, in gallons per day per mile of sewer line, or in gallons per day per inch diameter per mile of sewer. The last method is the most logical, and a common value for design purposes is 200 gpd per in. diam. per

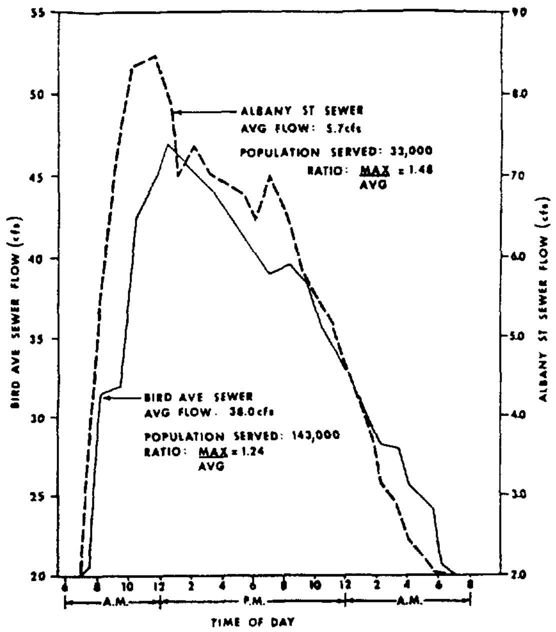

Fig. 3. Hourly sewage flows in two Buffalo, N. Y., sewers.

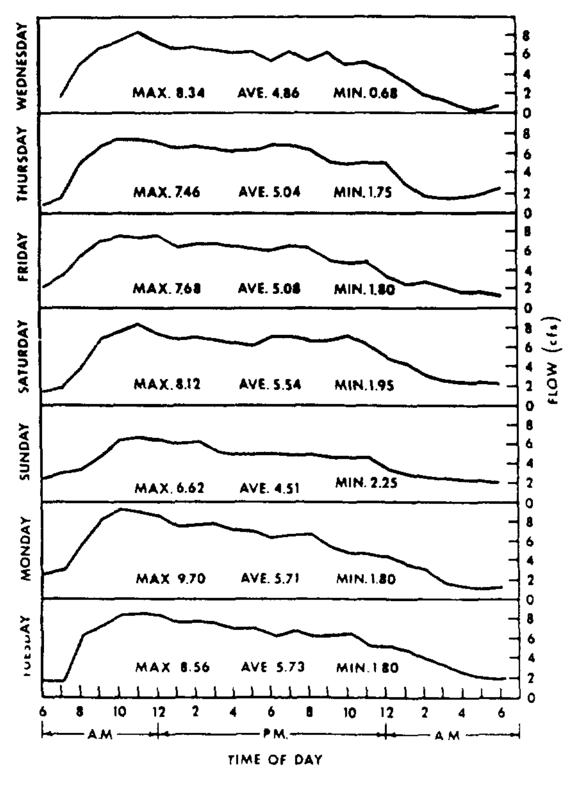

Fig. 4. Variations in daily and hourly flow in Albany St. sewer, Buffalo, N. Y.; tributary population—33,000.

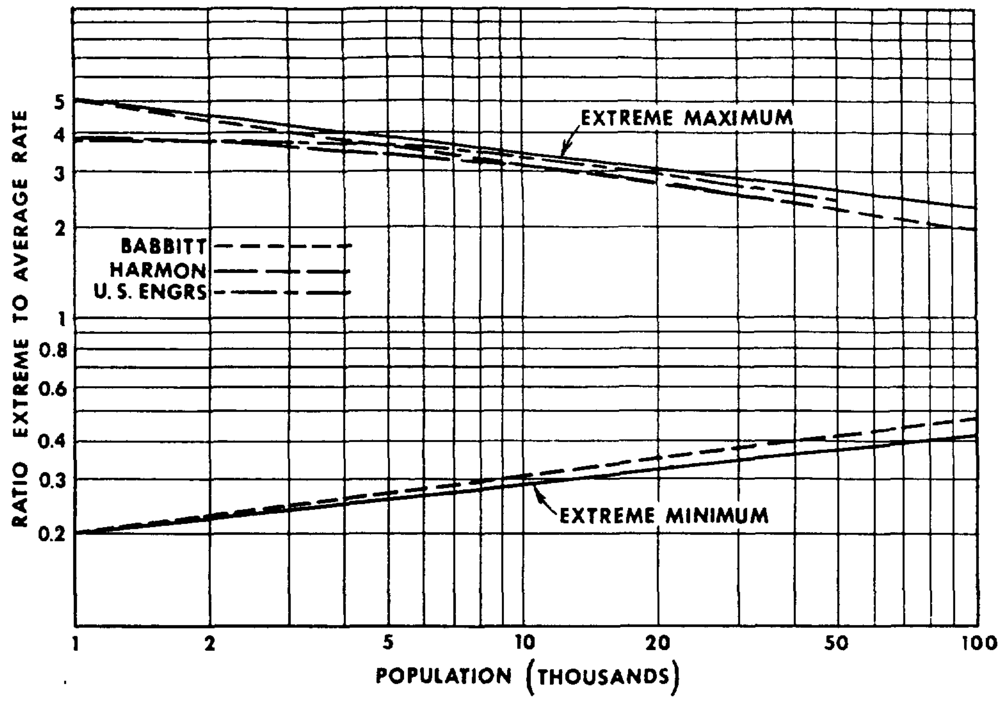

Fig. 5. Extreme flow rates as a function of population.[5,13]

mile. However, when making estimates for design purposes, the sewer size is not known, so other values may be used: 5000 gpd per mile, or 200 gpd per acre. Extreme conditions may halve or double these values. The prediction of infiltration rates may also be expressed on a per capita basis, in which case values between 10 and 40 gpcd are often used.

Infiltration rates vary, depending on sewer construction, type of soil, elevation of water table, manhole leakage, roof drainage, etc. (See discussion of flow variations.) When predicting extreme maximum rates of flow for design purposes, it is usually desirable to consider infiltration rates separately. Relatively few data are available on measured rates; they indicate a wide range of values.

Velzy and Sprague[13] reported in 1955 on the infiltration specifications set by 11 consulting engineers and 13 cities. The ranges of these specifications are shown in Table 5. These specifications are outdated today for new sewer construction because pipes and pipe joints have been greatly improved in the past 10 to 20 years. Current specifications should be much stricter. These data are included here for reference purposes only.

TABLE 5—INFILTRATION SPECIFICATIONS[13]

Allowable infiltration (gpd/mile)	Consulting engineers	Cities
Per in. diam.		
Min.	175	145**
Max.	875*	1500**
8-in pipe		
Min.	1400	1160
Max.	7000	12,000
24-in pipe		
Min.	4200	3480
Max.	21,000	36,000

*Some engineers used higher values for wet pervious ground and short sections.
**One city used 10,000 gpd per mile of pipe regardless of pipe size.

Exfiltration is seldom considered in determining design capacity of sewers. It is a condition that is highly undesirable, and all efforts should be made in design and construction to prevent such leakage.

Variations in flow rate. Average daily volumes or rates of flow, as discussed above, represent the average of all variations during the day. These variations range from a maximum during the morning hours to a minimum after midnight. Between these rates, the variation depends on the character of the community, its work habits, and other factors.

Not only will flow rates vary throughout the day, but they will differ from day to day (see Figs. 3 and 4), and from season to season.

It is obvious from the data in Table 4 and from Figs. 3 and 4 that the average flow varies widely, hence it is advisable to compare and predict data on a per capita basis. To make comparisons of variable rates of flow, it is common practice to compare the ratios of various flow rates to the average flow. Such a ratio may be used to compare any stated flows, such as maximum and minimum. Use of this ratio is of value not only in making comparisons, but also in predicting the magnitude of flows for design purposes.

Extreme flow rates. The relation of extreme flow rates to the average flow is influenced by a number of factors, including the character and work pattern of the neighborhood. The smaller the area, the more pronounced is the change in the ratio of extremes to average flow (see Fig 3). In other words, the ratio of extreme maximum flow to average flow is inversely proportional to the population served. Furthermore, the peak sewage flow will follow the peak water use load, and vice versa.

Other water uses and wastewater sources have compensating effects. Infiltration can vary with the season, as does

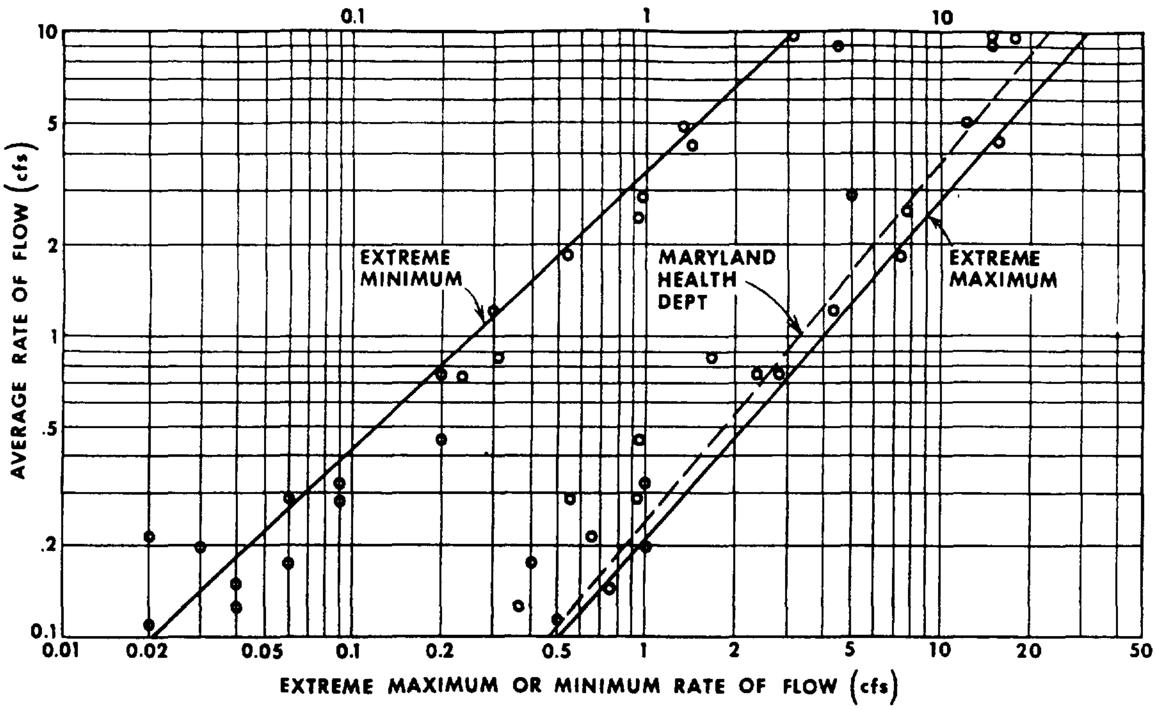

Fig. 6. Extreme flow rates as a function of average flow.[14]

the amount of public water supply used for lawn sprinkling, etc. Both affect the ratio of maximum to average flow, but to some extent they are compensating factors.

Extreme flow rates may be related either to population or to average flow rates. Figure 5 shows the recommended values of several authorities for extreme variations in sewage flow with respect to contributing population, and Fig. 6 shows comparable data on the basis of average flows. The equations for Fig. 5 are:

$$Q_{max.} = Q_{avg.} \times \frac{5}{P\ 1/6} \qquad \text{Eq. 1}$$

$$Q_{min.} = Q_{avg.} \times \frac{P\ 1/6}{5} \qquad \text{Eq. 2}$$

where:

Q = flow rate (cfs)
P = population (thousands)

The equations for Fig. 6 are:

$$Q_{max.} = 4 \times Q^{0.9} \qquad \text{Eq. 3}$$

$$Q_{min.} = 0.25 \times Q^{1.1} \qquad \text{Eq. 4}$$

These equations are empirical and are applicable only over a certain range. If the lines on the graphs were extended, maximum and minimum lines would intersect at some large population or large average flow rate. This is impossible, and these equations should therefore not be used for populations greater than 100,000 or average flows greater than 10 mgd.

Patterns of flow rate variation for business, commercial, and industrial areas differ somewhat from pattern of variation of domestic sanitary sewage flow variations. The ratio of maximum or minimum to average flow rate is generally smaller than for domestic sewage. Some designers use a constant value based on total city population. Relating extreme flows to average flows, as in Fig. 6, is usually simpler and is satisfactory.

SIZING SEWERS

When the maximum flow rate has been determined and the ground surface profile has been established, the diameter, slope, and depth of the sewer, and manhole elevations must be determined.

The size and slope of a sewer depend on the maximum flow rate to be handled and on the hydraulics of wastewater flow. The subject of flow hydraulics and its importance in sewer design is discussed in Section 4.

Section 4—Hydraulics of Sewers*

In the design of a sewer system, the fundamentals of hydraulics are most important. As a basis for considering the hydraulics of sewers, the following principles apply: [4]

Sewage has the same flow characteristics as water because its solids content is not high enough to appreciably change its specific gravity from that of water.

The surface of flowing sewage will, under the influence of gravity, seek its own level in a sloping channel. This is termed gravity flow.

Constant discharge from free flowing sewers is termed steady state flow, but under normal sewage flow conditions, steady state does not exist.

Uniform flow in sewers requires successive sewer cross sections to be the same, and mean velocity, sewage volume, sewer slope, size, and alignment to be constant.

* This section on hydraulics is largely a contribution of the late Professor H. M. Gifft of Cornell University. Much of it was taken from the unfinished manuscript of a text book on sanitary engineering jointly authored by H. M. Gifft and George E. Symons. The untimely death of Professor Gifft halted the writing of that text book when it was half finished.

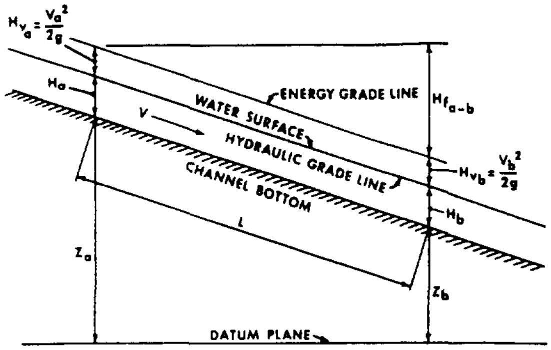

Fig. 7. Bernoulli's theorem—open channel flow.

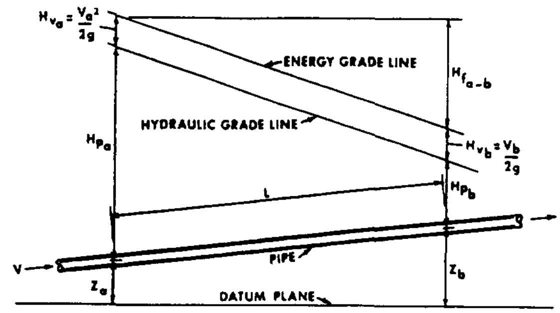

Fig. 8. Bernoulli's theorem—pipe flow.

The flow in partly full sewers is characterized as open channel flow. Sewers flowing full under pressure (siphons, force mains, and overloaded sewers) are surcharged.

Flow in pipes and conduits

Wastewater flowing in either an open or closed conduit has energy of position and of motion. Under conditions of steady flow, the total energies at any two points along the path of flow will be the same, except for loss of energy resulting from friction between the two points. In terms of difference in elevation, the principle, known as Bernoulli's theorem, is written as:

$$Z_a + H_a + \frac{V_a^2}{2g} = Z_b + H_b + \frac{V_b^2}{2g} + H_F \qquad \text{Eq. 5}$$

where:

- Z_a and Z_b = elevation of invert above datum plane at points a and b
- H_a and H_b = elevation of water surface above sewer invert at points a and b, or the hydraulic gradeline
- $\frac{V_a^2}{2g}$ and $\frac{V_b^2}{2g}$ = elevation of energy gradeline above hydraulic gradeline at points a and b
- H_F = elevation of energy gradeline at point a minus the elevation of the energy gradeline at point b

The explanation of these terms becomes apparent in Figs. 7 and 8. (L in these figures is the distance between points a and b.)

Under uniform flow conditions, the situation most often encountered in sewer systems, the velocity of flow is constant between points a and b, and, therefore, the hydraulic gradient is parallel to the energy gradient and to the invert. Because the slopes are equal, the terms are sometimes used interchangeably; more often, however, the term hydraulic gradient is used, and the energy gradient is ignored or forgotten.

For pipes flowing under pressure, the velocity head is quite small and, because it usually has a relatively constant value, may have little effect on the flow. There are times, however, when the value of the velocity head is a most important factor and cannot be ignored.

In open channel flow, as in sewer pipes, the velocity head can often be ignored because it does not change appreciably from point to point. The magnitude of velocity head, however, often is appreciable with respect to depth of flow, and therefore, may have an influence in junction chambers, manholes, and at points of change in sewer size and direction.

Flow formulas

Computations for sewer design are generally made on the basis of the sewer flowing full but not surcharged. Flow formulas have been developed for computing head losses resulting from friction along a length of pipe or channel. One of the earliest formulas, developed by Chezy, is:

$$V = C\sqrt{RS} \qquad \text{Eq. 6}$$

where:

- V = velocity of flow (fps)
- S = slope of energy gradient or ratio of H_F/L (see Figs. 7 and 8)
- R = hydraulic radius
- C = a coefficient

In Eq. 6, S is only approximately equal to the slope (see Figs. 7 and 8); R, the hydraulic radius (expressed in feet), is the area of a cross section divided by the "wetted perimeter." The coefficient, C, was originally thought to be a constant, dependent only on the roughness of the internal pipe surface.

Without delving into the relation of observed C values to Reynolds' numbers, it is sufficient to say that for normal conditions (Reynolds' numbers between 10^5 and 10^7), the deviation of C from a constant value may not be too great. It is, however, large enough to have suggested a more practical formula in which the coefficient was more nearly a constant and dependent only on the roughness of the conduit surface.

The most common method of improving the Chezy formula has been to replace the Chezy "C" by another expression containing some term as a measure of surface roughness.

Kutter proposed for Chezy's C, the expression:

$$C = \frac{41.67 + (0.0028/S) + (1.81/n)}{1 + [41.6 + (0.0028/S)]\,[n/\sqrt{R}]} \qquad \text{Eq. 7}$$

where R and S are the same as in Eq. 6, and n is the supposedly true roughness coefficient.

Manning proposed another formula for Chezy's C:

$$C = \frac{1.486}{n} R^{1/6} \qquad \text{Eq. 8}$$

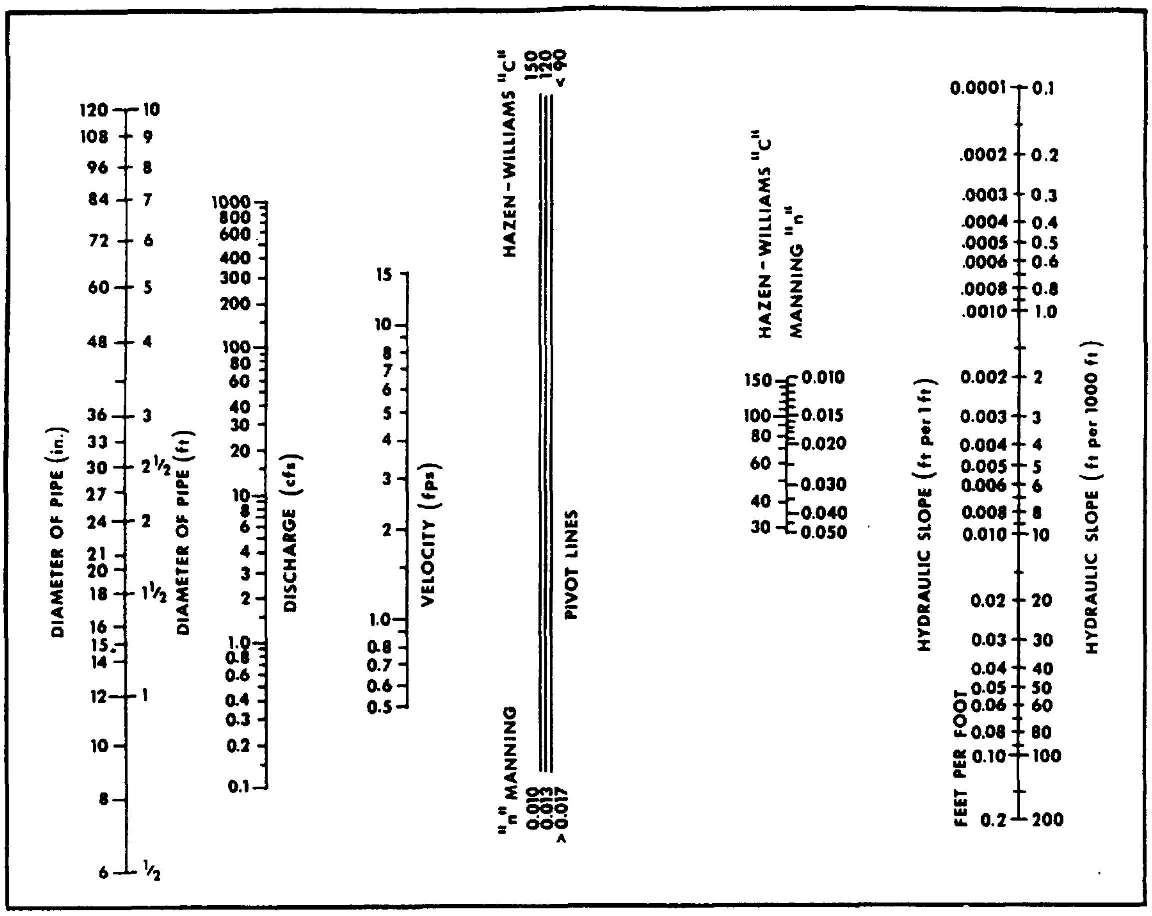

Fig. 9. Alignment chart for Manning's formula and Hanzen-William's formula for circular pipes flowing full.

where n is intended to be the same as in Kutter's formula. Hazen and Williams also proposed an equation as a measure of surface roughness, Chezy's C.

Hazen and Williams' C value has become the standard determination for comparing the roughness coefficient of pipelines in water systems; their formula is usually written as

$$V = 1.318 \times C \times R^{0.63} \times S^{0.54} \qquad \text{Eq. 9}$$

In the field of wastewater piping (sewers), either the Kutter or the Manning formula is used. The latter is the more common and is usually written as

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \qquad \text{Eq. 10}$$

Pipe flow chart

The Manning formula conforms to the fundamental laws of fluid flow in relatively rough pipes, and the Hazen-Williams formula is reasonably close for "smooth" pipes. Figure 9 is an alignment chart for the Manning and Hazen-Williams formulas. The relationship between n and C was determined by constructing the "hydraulic slope" scale so that the lines for n and C were coincidental.* The chart, therefore, is applicable in the solution of a number of equations of the form.

$$Q = AV = K D^x S^y \qquad \text{Eq. 11}$$

where:

- Q = flow (cfs)
- A = area of cross section (sq ft)
- V = velocity (fps)
- K = coefficient of roughness
- x = coefficient varying from 0.67 to 0.63
- y = coefficient varying from 0.50 to 0.54

The use of the chart is similar to that for standard pivot-type alignment charts except that the location of the pivot line is dependent on the roughness factor. Three of the five variables must be known, or assumed, and the other two may be found with a straightedge by one alignment and one pivot. Simultaneous values are always read on the same side of the pivot line.

Examples. A 10-in. diam. pipe is to carry a flow of 5 cfs; line is dependent on the roughness factor. Three of the five C = 90. If a straightedge is lined between 10 on the diameter scale and 5.0 on the discharge scale, the resulting velocity is 9.5 fps. To find the hydraulic slope, the straightedge is pivoted about the intersection with the pivot line labeled 90 to the mark 90 on the roughness scale. The resulting intersection in the hydraulic slope scale is 0.080 ft per ft. (Note: if the 150 pivot line had been used, the slope would have been incorrectly indicated to be 0.055 ft per ft.)

* Another approach to the correlation between Manning's "n" and Hazen and Williams' "C" values is described by R. G. Dittig on p. 100 of this issue.

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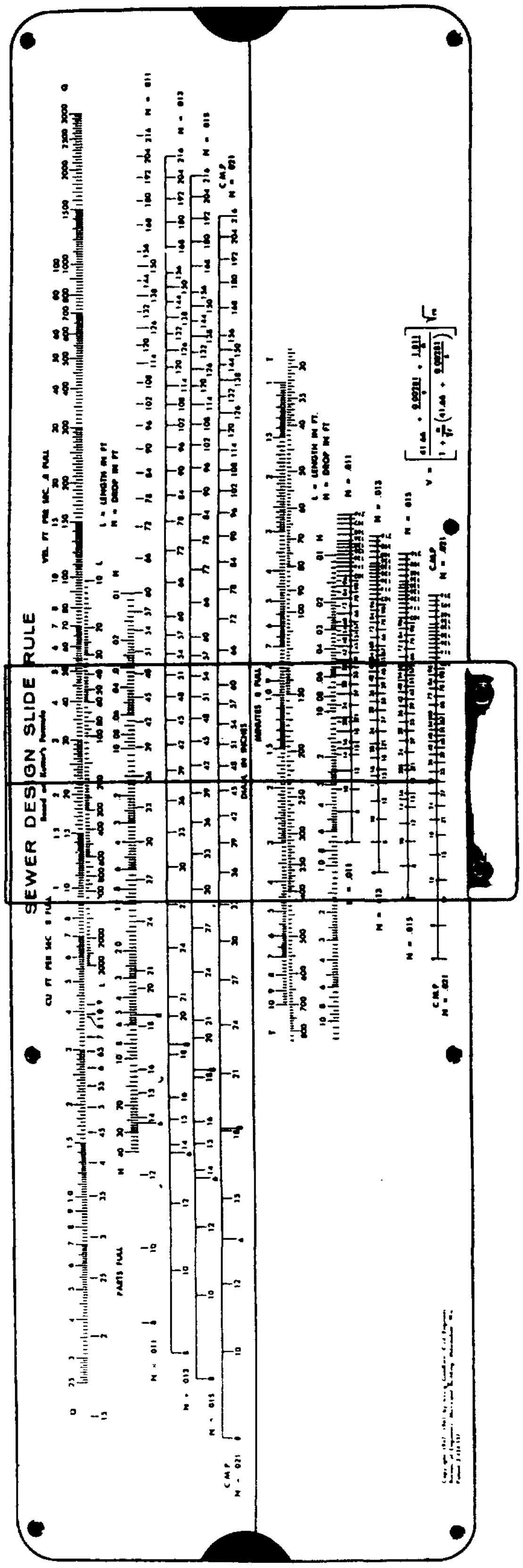


Fig. 10. Sewer design slide rule.[c]

A sewer pipe to be laid on a slope of 0.001 ft per ft is to carry a flow of 22.0 cfs; n = 0.013. A straightedge is lined between S = 0.001 and n = 0.013 to locate the point on the 0.013 pivot line. The straightedge is then pivoted about this point to Q = 22.0 and indicates the required diameter to be 36 in. and the velocity of 3.1 fps.

SEWER DESIGN SLIDE RULE

Another method of solving sewer design problems is to use a sewer design slide rule (see Fig. 10). This slide rule* has a wide range, is simple to operate, and is accurate. The device is based on the Chezy formula ($V = C\sqrt{RS}$) with Kutter's formula being used to determine the value of C. The slide rule includes scales for the following

Scale	Range
Q	0.25 to 3000 cfs
% full	10 to 100
L	10 to 3000 ft
H	0.1 to 40 ft
V	0.5 to 50 fps
n	0.011, 0.013, 0.015, 0.021
D	6 to 216 in.
T	0.1 to 10 min

VALUES OF C AND N

Hazen-Williams C values to indicate roughness coefficient are not the same as Chezy's values, which are seldom used today. Both Kutter's and Manning's formulas are in fairly common use, and both use an n value. For pipe diameters smaller than 3 ft, there are considerable discrepancies between the value of n in the two formulas. For pipe diameters larger than 3.0 ft, the values of n are practically the same for both formulas. Many engineers prefer to use the Manning formula for solving pipe flow problems. A formula developed by Scobey is often used for concrete pipe.

Table 6 shows Hazen-Williams C values and Manning's n values for various pipe materials. The C-values are the same as those given in Manual of Practice No. 2;[24] the n values given as ranges are the values recommended for design purposes by ASEC-WPCF Manual of Practice No. 9,[26] which does not cover a number of pipe materials listed in Table 6. It should be noted that tests on most of these

* Copyrighted 1947, by Irving Goldfein; U.S. patent no. 2,454,157. It is available from some pipe manufacturers or may be purchased from the designer.

TABLE 6—HAZEN-WILLIAMS' C AND MANNING'S N VALUES*

(For various pipe materials)

Pipe material	C value	n value**
Asbestos-cement	140+	0.011–0.015
Bituminized fiber	...	...
Brick	...	0.013–0.017
Cast iron		
New	140+	0.011–0.015
Cement lined	140+	0.011–0.015
Old, tuberculated	80–100	0.015–0.035
Clay		0.011–0.015
Concrete (quality pipe)	140+	0.011–0.015
Fiberglas reinforced resin	140+	...
Plastic and truss type plastic	140+	...
Steel (pressure pipe)	140+	...
Corrugated steel		
Unpaved	...	0.024–0.026
Coated and 1/4 paved	...	0.021–0.023
Smooth lining	...	0.011–0.015
Wrought Iron	140+	...

* C-values are those given in Manual of Practice No. 2[24] for water pipe and n-values are those given by WPCF Manual of Practice No. 9[26] (in revision), except as noted.
** The higher values are used for wastewater where quality of joint construction is poor, where settlement may occur, or where the construction is old; the lower values may be used for clear water.
Values supplied by materials manufacturers are less than those shown. Where no n values are shown, values stated by manufacturers are also less than any value shown in this table.

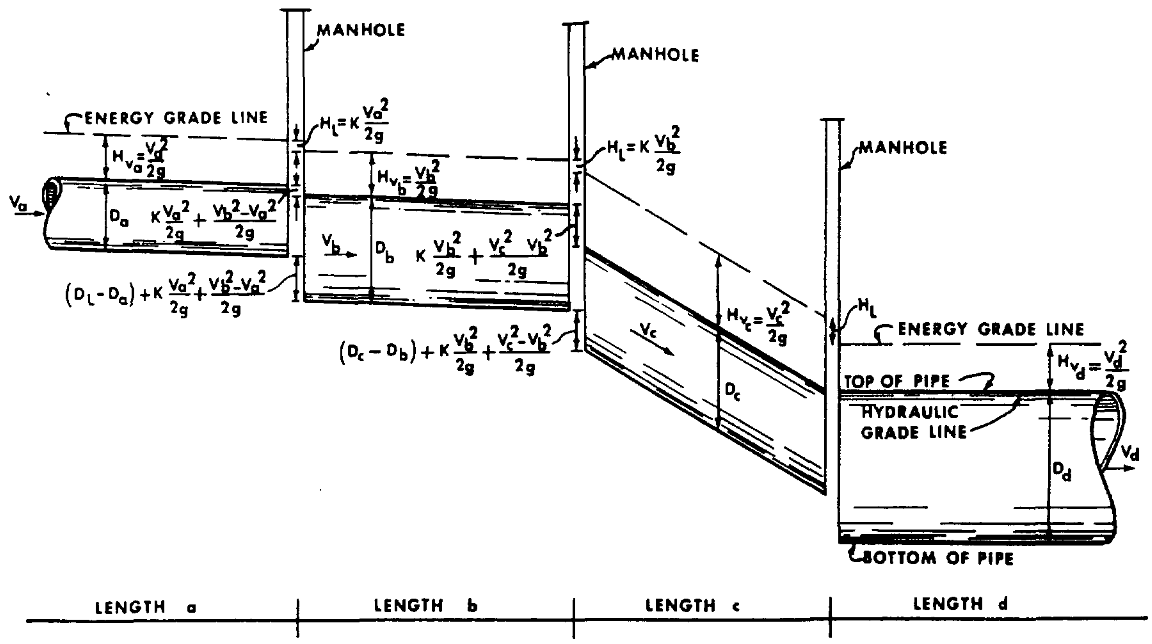


Fig. 11. Energy and hydraulic gradelines with respect to sewer elevations.

pipe materials indicate an n value of 0.010 or 0.011, and many design engineers use these lower values in preference to those listed in Table 6, except where state regulations do not allow the lower value.

Minor head losses

Although friction between the liquid and the pipe surface may account for most of the energy or head lost, other losses may also have to be considered. The estimation of minor losses in sewer lines is more difficult than in water pipelines, because the flow is not under pressure and the conversion back and forth between potential and kinetic energy (i.e., pressure head ⇄ velocity head) is less predictable. Furthermore, the change in elevation of the hydraulic gradeline owing to changes in velocity must also be taken into account because the crown of the sewer and the hydraulic gradeline are usually coincidental.

In general, the energy or head losses may be considered to be a function of the velocity above the point in question. That is

$$H_L = \frac{KV^2}{2g} \qquad \text{Eq. 12}$$

where:

H_L = head loss (ft)
V = velocity (fps)
g = gravity constant (32.2 fps^2)
K = constant

In addition, the change in hydraulic gradeline elevation is a function of the change in velocity at that point:

$$H = \frac{V_2^2 - V_1^2}{2g} \qquad \text{Eq. 13}$$

The value of K in Eq. 12 depends on the cause of the head loss; it may vary from 0.1 to 2.0 but is usually less than 1.0.

When the velocity is reduced, that is, when the sewer slope and the hydraulic gradient become less steep, an increase in elevation of the water surface occurs. Because of open channel conditions, it is likely that very little of the velocity head will be recovered; it is therefore customary to assume that there will be no increase in elevation of hydraulic gradient at such points. Figure 11 is an illustration of the relationship between the energy and hydraulic gradelines with respect to sewer pipe elevations.

PARTIALLY FULL SECTIONS

The hydraulic values for a conduit flowing less than full may be calculated by the usual formulas, but the computations are laborious. A simpler method is to use special diagrams. Figure 12 is a diagram for the solution of such problems in connection with circular sections.

The use of this chart is relatively simple for the solution of problems in terms of the relative values of the several variables. In Fig. 12, the values of the variables are shown in terms of full-flow conditions.

As can be seen from Fig. 12, it is possible for sewers to carry liquid at a higher rate when flowing partly full then when flowing full. In the design of sewers, it is not desirable to rely on this apparent anomaly as a design basis because the hydraulic conditions at maximum flow rate are unstable. For example, the sewer may suddenly run full at a

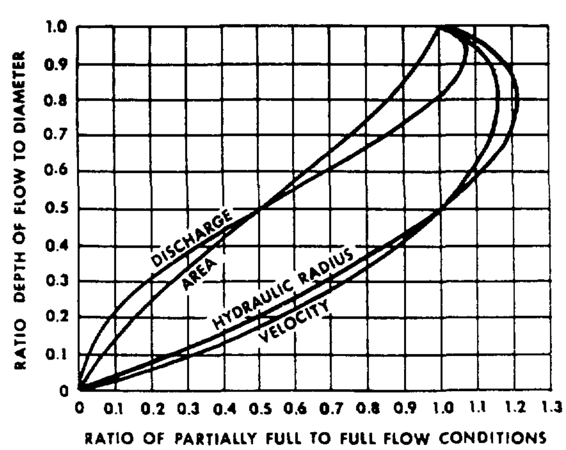
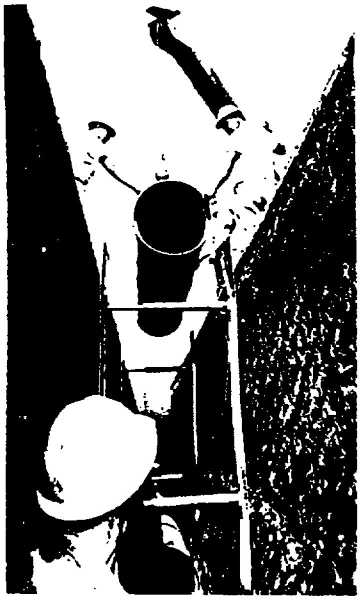
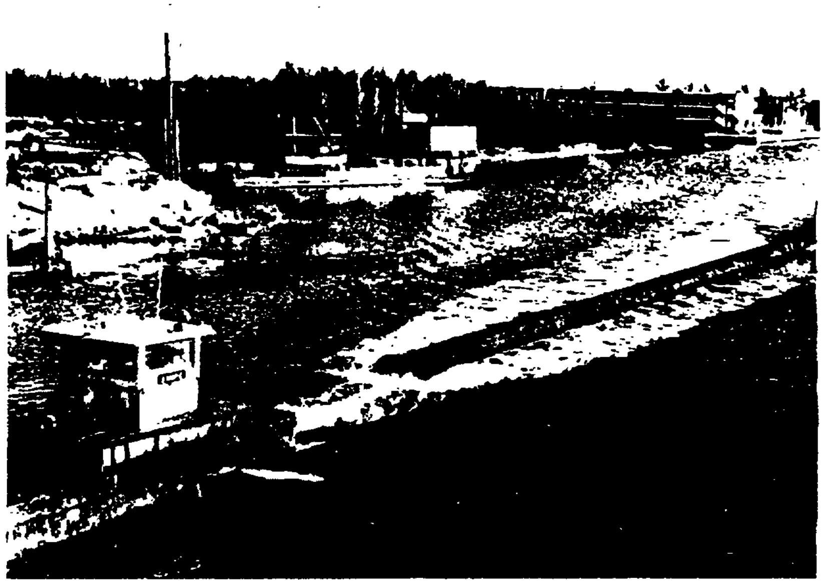


Fig. 12. Ratio of partially-full to full-flow conditions.



Reinforced plastic mortar sewer pipe; Los Altos, Calif.



Wrought iron (49-in. OD) outfall sewer for North Miami, Fla., being towed down Intracoastal Waterway.

decreased rate of flow or under pressure at the same maximum flow rate.

From Fig. 12, it can also be seen that the hydraulic elements of a sewer are: hydraulic radius (R), cross-sectional area of flowing stream (A), average velocity of flow (V), and rate of discharge (Q). The curves for R and A are the same for all diameters of pipe, but the curves for V and Q depend on the formula used in computations and on the assumed values of R, S, and n. These effects are so small, however, that within the limits of the accuracy of pipe flow formulas, this diagram is applicable to all diameters, surface roughness conditions, and slopes of hydraulic gradients.

Note that the solution of a specific problem involves four points, on four curves, all at the same relative depth, as for example

	Ratio to full pipe flow	
Characteristic	**Condition 1**	**Condition 2**
Rate of flow (Q)	0.33	0.97
Depth (D)	0.40	0.8
Area (A)	0.37	0.85
Hydraulic radius (R)	0.85	1.22
Velocity (V)	0.90	1ı14

CHANNEL FLOW CONDITIONS

There are other factors and conditions that must be taken into account in the computations involved in sewer design. These conditions will be mentioned here only by brief explanations of the meaning of the terms. For detailed discussions, the reader is referred to standard texts on the subject of hydraulics of sewers.[5,17]

Critical depth is the depth of flow when the specific energy of open channel flow is at a minimum. It is expressed as

$$E_s = d + \frac{V^2}{2g} \qquad \text{Eq. 14.}$$

where:

E_s = specific energy
d = depth or hydrostatic head
V = velocity

Under these conditions, the depth is critical, the velocity critical, and the hydraulic gradient is known as critical slope. Critical depth is a function of the channel discharge and channel cross-section and is independent of slope or other channel characteristics.

Control section is a point or cross-section where the slope of a channel changes; the critical depth occurs at that point, with the depth being greater above, and less below the point.

Dropdown curve is the curve in the surface upstream from a control section, under uniform flow conditions.

Backwater curve is the curve in the surface of a stream above an obstruction or sudden decrease in the slope of a channel when the velocity of flow is decreasing downstream and the slope of the invert is less than critical.

Hydraulic jump is defined as a sudden transition from stream low stage at less than critical depth to high stage above critical depth. A hydraulic jump will occur when the channel bottom slope changes suddenly from greater than critical to less than critical, or when a stream at less than critical depth flows into water with a depth greater than critical.

Standing wave is the term applied to a condition caused by an obstruction in a channel and resulting in a permanent rise of the surface level above normal for a short distance. Standing waves occur only when the velocity is greater than critical.

Hydraulic bore, also termed traveling wave, occurs when the open channel flow rate changes suddenly at some point or changes continuously along the channel in the direction of flow. An unsteady flow exists and the hydraulic bore is created. It may travel either upstream or downstream, depending on the immediate cause. A hydraulic bore traveling downstream is useful in sewer flushing.

SEWER DESIGN

Tables and diagrams[4,5,17] have been published to aid in the design of sewers and the computation of flow conditions, slopes, etc. Also useful is the sewer design slide rule mentioned previously. Information and diagrams are available on the discharge of circular sewer pipes running full at various n values in Kutter's formula. One available

TABLE 7—RECOMMENDED MINIMUM SEWER GRADES

Sewer size (in.)	Grade range (ft/100 ft)
8	0.33–0.40
10	0.25–0.28
12	0.19–0.22
15	0.14–0.16
18	0.11–0.12
21	0.9 –0.10
24	0.080
27	0.070
30	0.060
36	0.049

diagram[4] shows the discharge capacity of clay pipe sewers for n = 0.013 for various sizes of pipes, velocities, and slopes. Diagrams of similar nature for asbestos-cement pipe (with n values of 0.010 and 0.011) are available from several manufacturers. Also, diagrams similar to Fig. 12, but relating to sewers not circular in shape, have been published.[5] Many data tables are also available[17] for use in calculating sewer flow and design problems. All of these tools are useful to the designer.

Design principles. In designing a sewer, the following principles should be kept in mind:[4,5]

The wetted cross-sectional area of the sewer pipe must be sufficient to handle the flow at the designed velocity.

The design velocity must be sufficient to prevent stranding of solids in the sewer, but not high enough to cause excessive turbulence, scour, or thrust. For steep slopes, the depth of flow should be less than critical.

Hydraulic jumps and dropdown curves should be avoided where pipe sizes or discharge rates change. That is, the invert elevations should be such that the water surfaces match above and below the point of change.

The depth at which the sewer is laid should be sufficient to provide for drainage of all cellars of ordinary depth. If cellars are 5- to 7-ft deep, the depth of the street sewer should be such as to provide a slope of the house connection of 1.67 ft per 100 ft. An additional 12 in. should be allowed for vertical bends in house sewers and for the depth of house sewer beneath the basement floor.

In streets less than 80 ft wide, a minimum depth of 8 ft is recommended for invert of sewer laterals 24 in. or less in diameter. For larger sewers, the depth should be greater to prevent backup of sewage into basements.

Where possible, to avoid unnecessary excavation, sewers should be laid parallel to the ground surface, if the ground slope is sufficient, or on a flat, but not extremely flat, grade.

The slope or grade of sewers should be sufficient to provide a minimum flow velocity in excess of 1 fps under actual flow conditions, or 2 fps when flowing full. Maximum allowable flow velocity should be limited to 10 fps. Velocities greater than the hydraulic critical velocity should be avoided to prevent hydraulic jump and other problems resulting from nonuniform flow. Table 7 shows commonly recommended minimum sewer grades for pipe sizes from 8 to 36 in.; this particular table is based on Manning's formula with n = 0.10 and a flow velocity of 2 fps with the pipe running full,[2] but this n-value is lower than most states allow in sewer design.

Minimum pipe size should be 8 in. (some states allow 6 in.). Do not select a sewer larger than the calculated sewer size, except when the required size lies between two commercial sizes; in this case, use the larger size. House sewers should be no less than 4 in. in diameter, preferably larger.

Except under special design conditions, a sewer should never discharge into another sewer of smaller size even if the latter's capacity is larger because it has a steeper slope.

Profile map. As the diameter of pipe and necessary slope are computed for each area served, a profile map of the sewer in that area should be drawn. It should show the elevation and grade of the sewer line as well as the depth of cut required in excavating the soil. The depth of this cut is equal to the difference between the ground level elevation and the required elevation of the bottom of the trench. The profile map should also show "top of sill" elevations of residences to be served, if such data are available.

Shapes other than circular. The circular shape used for most sewers provides the maximum cross-sectional area for the amount of wall material required. Circular shapes are generally more convenient to manufacture, and they provide relatively good hydraulic qualities.

The previous discussion of the hydraulics of sewage flow was based on the use of circular sewers. Shapes other than circular are used frequently, however, for one or more reasons. For example: to provide greater strength and resistance to superimposed loads (i.e., for structural reasons); to reduce construction costs; to make construction easier; or to improve flow conditions during periods of low flow. Among the various noncircular shapes are basket handle, catenary, egg, horseshoe, ovoid, rectangular, and semi-elliptical. With one or two exceptions, shapes other than circular are not manufactured but are constructed in place.

Flow in noncircular sewers may be calculated by substituting the hydraulic elements of the channel in the desired formulas. One means of calculating flow in noncircular sewers utilizes the principle of hydraulic equivalents. Sewers are hydraulically equivalent when they discharge the same quantity at the same rate, when both are flowing full on the same hydraulic gradient. Tables of hydraulic equivalent data are available,[5,17] as are the formulas and examples of the required calculations.

Sewers built in place. Concrete pipe is available in diameters up to 144 in. Larger or smaller sewers may be constructed in place, and noncircular sewers of large size are always constructed in place. (Some manufactured noncircular shapes are available in sizes up to 108 in.) Materials for sewers built in place may be brick, concrete, or segmented tile block.

Brick is almost never used in current sewer construction. Its use declined because of cost and the scarcity of skilled bricklayers.

Concrete poured in place is used for large circular sewers and for nearly all noncircular shapes (except when manufactured noncircular shapes are available). The design of concrete, built-in-place sewers takes into account not only the size and flow capacity but also the shape and wall thickness necessary for the soil conditions and depth of cover. Formulas for the design of noncircular concrete sewers exist.[20] Their inclusion here is not really pertinent to this manual, which has as its principal aim the discussion of manufactured pipe.

Segmented blocks of vitrified tile are made with curved inner and outer faces. These blocks may be obtained for the construction of circular sewers from 30 to 108 in. in diameter. Use of segmented tile block has decreased.

Section 5—Storm and Combined Sewers

Storm sewers may be combined with sanitary systems or they may be constructed as separate systems. Usually, separate storm sewers are not as extensive as sanitary sewer systems. During the past 40 years or so, many storm sewers have been constructed to relieve the load on existing combined sewer systems. In these cases, the storm sewer has often been laid parallel to a trunk combined sewer or installed to drain the same area served by the combined sewer.

Until recently, storm water runoff has been considered to be relatively free of organic matter, although admittedly carrying suspended inorganic matter. Therefore, storm (relief) sewers usually discharged directly, without treatment, into the nearest water course. A more enlightened view,

Large diameter, long length clay sewer pipe in fully sheeted trench.

based on studies in the past several years, is that storm water carried a relatively large amount of organic matter, as well as inert solids, and that its discharge to water courses imposes an undesirable pollution load on the receiving water. Therefore, it is now thought that storm water should be treated before discharge.

Currently, considerable attention is being given to the controversy over whether or not existing combined sewer systems should be separated into two systems. If storm waters should be treated, as appears desirable, then separation of combined sewer systems is not the answer. Rather, it appears that where storm sewers are necessary to relieve flooding conditions, adequate storm water treatment should be provided. Other approaches have been suggested. One now under study proposes that sanitary wastes be transported under pressure through small lines laid in existing combined sewers.[18] In one variation of this idea currently in use, a gravity flow steel sanitary sewer is installed inside a larger storm sewer.

Planning

Whatever the future approach to solving the problem of storm waters, the planning and design of storm sewers is just as important as that of sanitary sewers, although the factors involved differ.

A sound approach to storm water sewers is a comprehensive general plan based on future needs. Without such a plan, the construction of storm sewers often will result in a final system that is haphazard in layout, duplicating in area transversed, and inadequate in many areas. When a stepwise comprehensive plan is followed, the most effective system should be produced at the least overall expense.

A storm water system, like a sanitary sewer system, requires a preliminary survey, including information on the location of underground utilities and a map showing all pertinent data about the area to be served. There are four principal steps in the design of a storm sewer system.[5] These are: Determination of the best location for inlets to the system; calculation of the required capacity from runoff data; computation of the required pipe size and slope; and drawing of the profile map.

Location and drainage areas

Generally, storm sewers should not be located in the center of paved streets, but their location is often dictated by the location of water mains, sanitary sewers, and other utilities. The location of storm sewers also depends to a great extent on the most advantageous sites for inlets (see Part 1, Section 6) and on the topography of the area to be drained.

The drainage area of a storm sewer is selected on the basis of topography rather than on the basis of an artificial boundary as used for an area to be served by sanitary sewers. True drainage lines are determined by the slope of paved streets, paved and unpaved property, downspout locations, and other factors.

Capacity

The design capacity of a storm sewer is dependent on the quantity of storm water to be handled (i.e., rainfall runoff). Any other factors, if they exist, may be disregarded. Actually, the rate of flow for which a storm sewer should be designed is dependent on the magnitude of runoff rate.[19]

There are three general methods for determining the quantity of storm water: by empirical formulas, by flow gaging, and by the rational method of computation.

Empirical formulas have been used to calculate storm runoff for relatively small city drainage areas, particularly when the data necessary for use in the rational method are not available. Empirical formulas may be used, also, for rough preliminary computations. The most common formulas used are the Bürkli-Ziegler formula and the McMath formula. Details may be found in standard texts.[5,10,17]

Flow gaging to measure storm runoff has several drawbacks. It requires a reasonably accurate determination of the cross-section at the point of measurement and particular attention to the characteristics of the storm being measured. The extrapolation of flow data for one storm to other conditions may produce misleading design bases.

The *rational method* for computation of flow from storm runoff involves the equation

$$Q = AIR$$

where:

Q = runoff (cfs)
A = area drained (acres)
I = runoff coefficient of area
R = rainfall rate (in./hr)

The runoff coefficient has been determined for various types of surfaces. Calculations are made for storm intensity and runoff with consideration of the maximum storm runoff to be handled and allowance for the effect of storage and time of concentration of the runoff.[19]

SIZING STORM SEWERS

The use of the rational method in determining storm quantities has been described by Gifft and Symons[19] and need not be presented in detail here. In storm sewer design, the size of storm (i.e., maximum runoff) for which the storm sewer is to be designed must be decided. The design of a sewer to handle a 100-year storm (i.e., a storm intensity that is likely to occur once in 100 years), may involve an expenditure that is too high and is unwarranted. It is considered good practice to limit the storm sewer size to a 10-year storm for residential areas and to a 25- or 30-year storm for commercial districts. One factor in this decision is the liability of a community for damage caused by floods.

The determination of the sewer size and slope is made from consideration of the hydraulics of the system necessary for the capacity required (see Section 4).

Combined sewers

As indicated previously, combined sewer systems should be discouraged, but when a combined sewer system is designed, the sizing and slope of the pipe are determined by the calculated capacity required to handle both the sanitary sewage and the storm flow. Thus, in theory, the capacity is the sum of the capacities required for sanitary sewage and storm flow, including the ground water infiltration factor. If the amount of sanitary sewage is quite small in relation to the storm flow, then the storm flow requirements will dictate the size of the combined sewer. If industrial wastes are discharged into the sewer, they must be considered in calculating the capacity required.

After the storm flow quantities have been calculated,[19] the pipe size and slope of combined sewers are determined by the method outlined for sanitary sewers in Section 4.

Section 6—Appurtenances

Sewer systems differ in several respects from water distribution systems; they operate under gravity (not pressure) conditions; they contain no valves; and they include a number of appurtenances not used in water systems.

Types of appurtenances

Appurtenances are those structures or devices (not pipe) in a sewer system that are essential to proper functioning. Appurtenances may include catch basins, flow measurement devices, flush tanks, foundations, house sewers, inlets, junction chambers, lampholes, manholes, outlets, overflow chambers, silt basins, siphons, storm water storage tanks, traps, underdrains, ventilators, weirs, and lift stations.

No attempt will be made here to delve into the details of design and construction of all of these devices. Such details may be found in a number of standard texts.[5,10,20] Lift stations were covered in Manual of Practice No. 1. General comments will be made, however, on some of the other major appurtenances, particularly with respect to their relation to the design of sewer systems.

CATCH BASINS

Catch basins are used to interrupt the flow of wastewater before it enters a sewer. The velocity of flow is reduced sufficiently to allow deposition of grit. The use of catch basins in sewer systems is decreasing because they need frequent cleaning, lead to development of odors, and provide breeding places for mosquitoes. If sewers are designed with slopes that prevent the settling of grit, the need for catch basins is eliminated.

FLUSH TANKS

A flush tank is a chamber or tank in which water, or sewage, is accumulated for discharge at intervals; the discharge is used for flushing the sewer. Flush tanks are used only in sanitary or combined sewers and only where flat sewer grades cause stranding of solids. Flush tanks generally are designed to operate automatically but may be designed for manual operation. Details of flush tank design may be found in standard reference works.[5,10,20]

HOUSE SEWERS

Lines that connect the street sewer to the house plumbing system are termed house sewers. House sewers are usually 4, 5, or 6 in. in diameter; but the 4-in. size is becoming less and less popular. It is good practice to standardize the house sewer size for a community. House sewers should never be connected to a street sewer of smaller size.

Connections between house sewers and street sewers may be by a wye-branch or a tee-branch. Some designers prefer wyes on street sewers less than 24 in. in diameter, and tees on larger sizes, but experience in Los Angeles and elsewhere has shown that tees sacrifice little in hydraulic characteristics while improving structural properties. The use of a 1/8 curve with a wye-branch does permit the house sewer to be laid more nearly at right angles to the street sewer.

The use of water-sealed traps for ventilation control at, or just inside, the house wall is generally frowned on. Where traps are used, proper ventilation to the air is necessary to prevent build-up of pressure within the sewer, which might lead to blowing of the seal.

INLETS

An inlet is an opening at the street surface designed to allow surface runoff into storm or combined sewers. Inlet locations should be chosen to provide for the satisfactory carrying away of surface runoff. Most storm inlets are in street gutters, and the best location is one that prevents overloading of the gutters, prevents runoff across streets and sidewalks, and provides service to largest possible area.

Large diameter, cement-lined steel pipe being installed in unsheeted trench.

One important factor in inlet design is the quantity of flow in the gutter. This factor may be determined by the use of Kutter's or Manning's formula. There are many other factors that must be taken into consideration,[5,10,20] but need not be discussed here.

JUNCTION CHAMBERS

A junction chamber is a converging section where the flow of one or more sewers is brought together for discharge into a larger or main trunk sewer or interceptor. Principles of junction chamber design include the following: inverts of the incoming sewers should be at elevations that ensure the same normal surface flow line in all sewers; the slope of the incoming sewers should be relatively steep to ensure that when one sewer is flowing deeper than others, the backup in the sewers with smaller flow will extend only a short distance; where possible, entering sewers should be constructed on long radius curves tangent to one another to prevent turbulence in the chamber; and flow into and out of the chamber should be at the same velocity because reduced velocity of the flow from the chamber could lead to turbulence, loss of head, odors, and sedimentation.

A design that will meet all of these requirements is sometimes difficult to obtain because of local conditions. Details of various designs of junction chambers (bell-mouth, flat-top, etc.) may be found in a number of reference works.[5,10,20,21]

MANHOLES

A manhole is a shaft or chamber through which access from the ground surface to a sewer may be obtained for inspection or cleaning.

Manholes should be placed at intervals of 300 to 500 ft, or at every point where a sewer changes in direction, size, grade, or shape. Sewers should run in straight lines between manholes.

Manholes may be constructed of brick, concrete block, corrugated metal, poured concrete, or precast concrete pipe.

Reinforced concrete sewer pipe (96 in.) with plastic liner in Los Angeles San Fernando Valley Project.

The size and shape of a manhole are often matters of individual preference.

Manhole covers. Manholes should be so constructed that they can be covered by a standard cast-iron manhole frame and cover; the frame opening is usually slightly less than 2 ft in diameter. The design of the cover usually depends on the traffic load it will receive. Iron-rung steps are usually placed at convenient spacings from the top to the bottom of the manhole. Rungs should be corrosion resistant.

Manhole bottoms. The bottom of a straight-line manhole is usually constructed with a half-round or split section of the sewer pipe as a channel continuation of the sewer; concrete is usually placed in the remainder of the manhole bottom, sloping upward slightly from the top of the split section to the wall of the manhole. Junction manholes are designed and constructed as the situation demands.

Drop manholes. Where lateral sewers join a main sewer located at a lower elevation, a drop manhole is installed; this allows the sewage to come in at one level and go out at a lower level. The actual design will depend on the particular local situation. Where the difference between the elevation of the two sewers is great, sewage may be allowed to fall freely from the higher to the lower sewer. This type of structure is known as a well-hole; it usually has a bottom located so as to provide a cushion of water into which the sewage may fall before it flows out in the lower sewer.

OVERFLOWS AND REGULATORS

An overflow is any device or structure that permits or causes excess flow (flow above the sewer capacity) to be diverted to a relief sewer or to an outlet discharging into a receiving body of water. Most overflows are a type of weir formed by an opening in the side of the sewer, at a point high enough to permit the excess flow to pass to the relief channel or outlet, while at the same time causing the dry-weather flow (DWF), or 2 to 5 times DWF, to continue flowing in the main sewer. This type of structure is used frequently in combined sewer systems. Sometimes overflows involve rather elaborate designs of concrete structures.

A regulator has a function similar to that of an overflow. It is a device that diverts sewage flow from one sewer to another, particularly in combined sewer systems or storm water sewers, to prevent the surcharging of a sewer, or to regulate the amount of flow to a wastewater treatment plant. Regulators usually begin to operate when the flow in the sewer reaches a predetermined level.

Regulators may be mechanical devices, leaping weirs, or side weirs; the last being essentially the same as an overflow weir.

The details of design of overflow and regulator structures or devices depend on the local conditions and the purpose of the device or structure.

OUTLETS

The design of sewer outlets or outfall structures must be determined entirely by local condition. The outlet may be a simple concrete headwall designed to prevent undercutting of the pipe by the discharging wastewater or by movement of the receiving body of water. It may be a complex underwater structure located some distance offshore at the bottom of the river, estuary, lake, or ocean, and designed to disperse the wastewater or treated effluent into the receiving body of water. If discharging into tidal waters or streams subject to flooding, the sewer outlet may be covered by a flap valve or automatic gate to prevent backflow into the sewer line when the water level above the outlet is higher than normal.

SIPHONS

A true siphon is a closed conduit, a section of which lies above the hydraulic gradeline. This condition results in a less-than-atmospheric pressure in the section above the gradeline and necessitates the use of a vacuum to start flow.

An inverted siphon (also termed "depressed sewer") is a section of sewer that is lower than adjacent sections. It is so constructed to pass under a valley, a water course, or other local obstruction. An inverted siphon runs full at greater-than-atmospheric pressure because the crown lies below the hydraulic gradeline. In general wastewater practice parlance, the term siphon is commonly used to mean an inverted siphon, not a true siphon, although true siphons may be used in the design of flushing tank systems.

Inverted siphons may be designed to meet one of three conditions: fixed elevation of inlet and outlet to provide a minimum loss of head in the siphon and to maintain a scouring velocity to prevent depositions; fixed elevation of inlet and outlet to maintain a fixed velocity; or fixed elevations of inlet and outlet with no limitations on head loss other than to provide a scouring velocity.

Good engineering practice dictates the use of twin siphons (i.e., two barrels), each with a pipe size of 6 in. or more. The details of design will depend on local conditions and, to some extent, on the designer's preference or judgment.

In some locations, the construction of inverted siphons may be eliminated if necessary by carrying the sewer on a light bridge across a depression. Sanitary sewers should not be carried on the floor of a highway bridge, regardless of the material of construction, because traffic vibration may weaken the joints, thereby allowing leakage. If there is no other way of solving the problem, a sewer may be carried under a bridge on hangers, or on a special truss between bridge piers.

STORM WATER TANKS

Storm water standby tanks are used to provide interim storage of a volume of storm water until such time as the sewer can handle it without being surcharged. The use of such structures is more common in combined sewer systems, where it is the intent to pass all storm water through the sewage treatment works and to avoid overflow of storm water into nearby bodies of water.

These tanks are generally designed to permit overflow from the sewers into the tanks at time of surcharge and to empty back into the sewers as the flow decreases to normal. Usually, they operate under gravity conditions, but, in some cases, the stored water may be pumped back into the sewer from which it overflowed.

Probably the largest storm water storage basin exists at Buffalo, N. Y.,[22] where runoff from certain areas is sent into an abandoned quarry during storms to prevent street flooding. After the flow in the sewers has subsided to normal, the stored water is pumped back into the sewer system and passes to the wastewater treatment plant. Cleaning of the quarry following the removal of the excess water is a regular maintenance operation, as it is in constructed storm water detention tanks. Boston is installing storm water tanks and Chicago is considering the idea.

TRAPS

Traps are structures or devices designed to capture and hold discrete particles of various substances that are undesirable in sewers or in treatment plants. Such devices may be used to keep grease, oil, sand, or silt out of sewer systems. These devices involve a stilling basin, where the velocity of the liquid flow is reduced sufficiently to permit separation of the unwanted material from the liquid.

The principles of flotation are involved in the removal of grease and oil. Such devices are usually designed with an outlet baffle or a submerged outlet pipe and sometimes with an inlet baffle or submerged inlet as well.

Silt basins operate on the principle of gravity separation of particles heavier than water (Stokes law). Such basins should be installed only in storm sewers and never in sanitary or combined sewers. They are usually designed to reduce the velocity of flow to a value between 1 and 2 fps. Velocities below 1 fps permit sedimentation of organic matter, and velocities above 2 fps do not permit effective separation of the silt or grit.

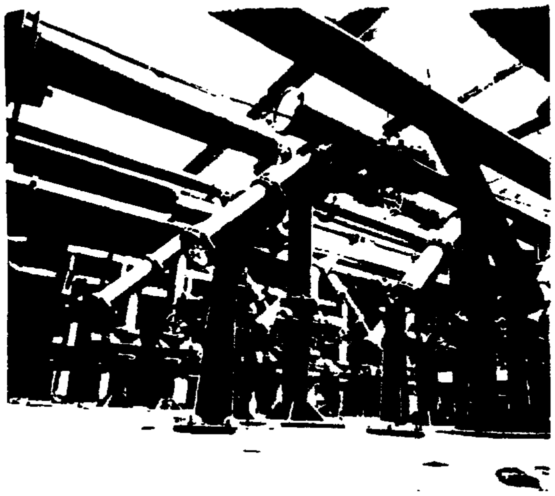
Design criteria. Design criteria for sewer appurtenances vary according to local conditions. Some basic guidelines used by the Engineering Facilities Command of the U. S. Navy are given in Table 8.[23]

Miscellaneous appurtenances. Other appurtenances may be designed into or as part of sewer systems, for example, lift stations. Lift stations are generally unattended and operate automatically where the flow is relatively small. Where the flow is from large areas, these stations are usually staffed and operated accordingly. The operation of lift stations is covered in some detail in Part 2, Section 4 of Manual of Practice No. 1.

Other miscellaneous appurtenances include foundations, flow measuring devices, lampholes, underdrains, and ventilators. A discussion of these appurtenances does not appear to be warranted in this manual.

TABLE 8—SUGGESTED DESIGN CRITERIA FOR SEWER APPURTENANCES[23]

Structure	Type	Where to use	Details: Pipe size (in.)	Details: Max. manhole spacing (ft)	Requirements
Manhole	Regular	Terminally on all lines, at all junctions and changes of direction	8	300	Lower invert through manhole a distance equal to loss of head in manhole
		At changes in invert elevation of slope	10–15 18–48	400 500	At changes in sewer size, lineup crowns
		Where not otherwise required according to spacing shown in details	48	600	Raise top of manhole above possible flooding level
	Drop	When difference between inlet and outlet inverts exceeds 2 ft			For difference less than 2 ft, increase sewer slope to match crowns
Siphons	Inverted	For carrying sewers under obstruction or waterways	Maintain velocity of 3 fps using multiple pipes as required Minimum pipe size—6 in. Provide overflow		Use ASCE Manual No. 37, Ch. 5 for hydraulic design
Intercepting sewers		Where discharge of existing sewers must be brought to a new concentration point	Where receiving combined sewage, design for velocity of 2.5 fps		Take special care against infiltration resulting from depth or proximity of surface water
Regulators		On combined systems	Set to divert all storm flows in excess of those for which pumping and treatment facilities are designed		
Traps and interceptors	Grease and oil	On all outlets from subsistence buildings, garages, mechanical shops, wash pits and other points where grease or oil can enter system	Displacement velocity, 0.05 fps. Grease removal—in absence of other data use 300–400 mg per L. Provide for storage of one week's grease production (one day if continuous removal is provided). Length = twice depth		



Inplant piping at New York City Newtown Creek Pollution Control Plant.

Section 7—Inplant Piping Systems

Inplant piping systems are used in lift and main pumping stations and treatment plants of all types.

Design

As in water treatment plants,[24] the selection and sizing of inplant piping systems must take into consideration the use or service for which the line is intended, the pressure at which it will operate, the required flow capacity, and the fluid to be carried. Material selection is discussed in Part 2, Section 14.

Layout and arrangement

Inplant piping systems in wastewater treatment plants include pump suction and discharge lines for raw wastes, treated wastes, and sludges of all kinds; gas, air, and oil lines; sampling lines; chemical feed lines; sludge processing equipment lines; heating, plumbing, ventilating, and potable water systems; yard and fire protection sprinkling systems; and hydraulic and pneumatic valve operating and instrumentation systems.

ARRANGEMENT

For any particular service, the piping should always be arranged so that any breakage or outage causes only a minimum interruption of operation. This consideration is particularly applicable to suction lines and discharge header lines in pumping systems.

Piping and valves should be arranged on a systematic basis and should conform to the placement of pumps and other equipment, with a minimum of fittings and bends, so that head loss will be at a minimum.

The arrangement of pipes should provide for easy access to pumps, valves, and other equipment not only for installation, but also for maintenance procedures. Suction piping on pumps should be carefully designed to avoid air pockets. Such lines should rise gradually to the pump, and eccentric reducers should be installed where necessary to prevent air pocket formation. Pipelines that may require repeated cleaning (e.g., raw sludge lines) should be arranged in such a way that cleaning tools can be inserted.

COLOR CODING

It is probably more important to color-code pipelines in a wastewater treatment plant than it is in a water treatment plant. The standard color-code of the U. S. A. Standards Institute may serve as a basis for the color coding system used in a wastewater treatment works. Whatever color coding system is adopted, the colors should be easily recognized in the available light at any particular location. The pipelines should also carry lettered labels and directional arrows at points where such information is desirable. Colors in bands may be used to indicate fluid being carried.

PART 2 / MATERIALS

Section 1—Selection Criteria

In selecting sewer pipe materials, the design engineer should base his decision on an evaluation of the comparative physical, chemical, hydraulic, and economic characteristics of the pipe or material.

PHYSICAL CHARACTERISTICS

There are seven principal physical characteristics to be evaluated.

Size. Sewer pipe is not available in all sizes in all materials. If the required pipe size is larger than available manufactured sizes of a particular material, then some other material must be selected, either a manufactured product or a material to be constructed in place.

Shape. Uniformity of shape for each segment (length) of pipe used is essential to ensure proper alignment, optimum hydraulic flow conditions, and ease of connection to other sections or other sewers. Sewers built in place also should have a uniform shape except where there is a change in size.

Strength. The structural strength of a pipe should be sufficient to resist failure or detrimental deformation under weights imposed on it by backfill overburden loads. The pipe must also have the strength to resist the shock of traffic loads, the ability to withstand temperature variations, and to conform to any other system design conditions.

Durability. Sewer pipe is nearly always installed underground, where it is not easily accessible. Also, sewers are designed for many years of service. For these reasons, as well as overall cost, sewer pipe should have a long life.

Surface. The internal surface of a sewer pipe or its lining should be able to withstand abrasion caused by scouring action of wastewater carrying gritty materials. The external surface or its coating also should be able to withstand damage during handling or during backfilling of trenches.

Imperviousness. Sewer pipe should be impervious, to prevent leakage of water through the material.

Joint characteristics. Joints should be of simple, rugged design, facilitating installation and ensuring a maximum degree of tightness, to prevent leakage in or out and to prevent the entrance of roots. Jointing materials likewise should have long life and should provide tightness.

CHEMICAL CHARACTERISTICS

Two chemical characteristics of pipe are important in the evaluation of sewer pipe material.

Corrosion resistance. The surface of the pipe material or its coating should be resistant to true corrosion or destruction by electrochemical action or by interaction with any chemicals present in the wastewater.

Solution resistance. Sewer pipe material should be resistant to the dissolving action of water.

HYDRAULIC CHARACTERISTICS

Sewer pipe should have a smooth bore, that is, it should have a low coefficient of surface roughness, so that it will provide the maximum flow capacity per inch of size with a minimum of friction loss.

ECONOMIC CHARACTERISTICS

The sewer pipe selected should be economical not only in original cost but also in cost of installation and maintenance. Length of life is another factor to be considered in the overall economic characteristics.

SPECIFICATIONS

Once the design of the sewer is completed and the pipe materials selected, the design engineer should prepare a set of specifications for the sewer pipe. Ordinarily, the standard specifications of the American Society for Testing Materials are used in specifying and testing materials, but when ASTM specifications do not apply, the engineer should develop the necessary specifications.

Section 2—Design Factors

Pipe used in gravity flow sewers is not subjected to internal pressure, except to a small degree under conditions of surcharge. Therefore, in the design of sewer pipe, internal pressure is not a significant factor. On the other hand, a sewer pipe installed in a backfilled trench carries the external static and live loads placed on it. Furthermore, sewer pipe is frequently laid at greater depths than water pipe. For these reasons, the factor of external load is very important in the design of sewer pipe, regardless of the material used.

In calculating loads on buried sewer pipes, the Marston load formula[24,25] is generally applied. The formula is based on the theory that the load on a sewer is equal to the weight of the prism of earth (interior prism) directly above it plus or minus the frictional shearing forces transferred to that prism by adjacent prisms of earth, the magnitude of these frictional forces being a function of the relative settlement between the interior and the adjacent prisms.[26] The Marston equation ($W = CwB^2$) is given and explained in Manual of Practice No. 2 (p. M11).[24]

Marston's equation is applicable to all types of installations, which are usually classified as: trench, embankment, or tunnel.

Trench loads

Trench installations are those in which the pipe is laid in a relatively narrow trench (generally less than two pipe diameters in width) cut in undisturbed ground, with the pipe covered by backfill to the original ground surface.

External loads on sewer pipe consist of two parts: backfill (gravity earth load) and surface load; the latter results from static and live conditions that transmit their effect or impact into the ground and onto the pipe.

Trench width is an important factor in the load exerted on the pipe; the wider the trench, the greater the load, until the transition point is reached. The trench width at the top of the pipe is the controlling factor, so this width should be kept at a minimum. Certainly, whenever possible, sewer pipe should be installed in a trench no wider than necessary to accomplish satisfactory bedding and jointing.

GRAVITY EARTH LOADS

External loads resulting from backfill are calculated by the Marston load formula as indicated previously. According to Spangler,[25] the portion of total load within a ditch that will be carried by the pipe depends on the relative rigidity of the pipe and the fill material that does not lie directly above the pipe (i.e., sidefill).

Rigid pipe, in a situation where the sidefill is relatively compressible, must carry practically all of the load. In the case of relatively flexible, thin-walled pipe, with the fill thoroughly tamped at the sides of the pipe, the sidefill will carry some of the load.

Table 9 shows trench loads calculated according to the Marston formula, assuming that the soil is granular without cohesion and that it weighs 100 lb per cu ft. For soils of other densities, these data should be multiplied by a proper factor; the factor depends on the weight and the cohesiveness of the soil.[26]

There are many cases where the trench load formula is less accurate than the positive projecting embankment formula (see below), because the transition point from trench to embankment is a function of the height of backfill to width of the ditch at the top of the pipe and the pipe diameter. The use of the trench load formula would lead to overdesign of the pipe for those cases where the actual width of trench is greater than the transition width. It might be more economical with respect to pipe class to use the embankment formula where it is applicable.

SUPERIMPOSED LOADS

Static superimposed loads are caused by structures supported on the soil above the pipe, such as streets, buildings,

TABLE 9—TRENCH LOADS (LB PER LIN FT) FOR DIFFERENT TRENCH WIDTHS AND DEPTHS*

Depth of top of pipe (ft)	Trench width at top of pipe (ft)						
	2	2-½	3	3-½	4	5	6
4	550	725	900	1015	1280	1875	2160
5	640	855	1060	1350	1440	2000	2600
6	700	935	1200	1530	1760	2250	2880
7	740	1030	1350	1650	2000	2500	3240
8	800	1130	1440	1840	2460	2950	3600
9	860	1160	1570	1960	2300	3120	3960
10	880	1250	1600	2080	2480	3380	4320
12	940	1370	1800	2230	2800	3750	4850
14	960	1440	1930	2450	2960	4120	5400
16	1000	1470	2020	2650	3200	4500	5950
18	1000	1500	2070	2750	3440	4750	6300
20	1020	1560	2120	2820	3510	5000	6500
22	1030	1560	2160	2880	3600	5250	7200
24	1040	1590	2250	2940	3600	5500	7200
26	1040	1590	2250	3000	3680	5620	7550
28	1040	1610	2250	3080	3840	5620	7900
30	1040	1620	2300	3060	3910	5750	7900

* Data are for granular soil without cohesion, weighing 100 lb per cu ft, based on broad fills.

etc. Live loads are caused by traffic. These superimposed loads may be calculated by the formula (also developed by Marston) that appears as Eq. 5 in Manual of Practice No. 2 (p. M11).[24]

This equation contains an impact factor for moving traffic. In the case of sewers, which are usually laid more than 6 ft deep, the calculation of live loads is generally not utilized in calculating the pipe design. Superimposed static loads and, where depth of cover is less than 6 ft, live loads should be calculated and included in the pipe design.

Embankment loads

A sewer may be constructed so that its top is at or near the natural ground surface, and then covered with an embankment.[26] When the top of the sewer is somewhat above the natural ground surface, it is termed a *positive projecting conduit*. A *negative projecting conduit* is one installed in a relatively shallow trench, with its top below the natural ground surface. The trench above the pipe is then backfilled and compacted and the embankment constructed to the finished grade by ordinary methods. This type of construction gives a greater depth of fill than a positive projecting conduit. This increased depth plus the compressibility of the loose fill ensures that the prism over the pipe will settle more than that of the adjacent prisms, thus creating upward shearing forces that relieve some of the load on the pipe.

An *imperfect ditch conduit* is constructed as follows: first, the pipe is installed as a positive projecting conduit; then an embankment is built to some height above the pipe and compacted as it is placed; next, a pipe-width trench is excavated directly above the pipe in the embankment down almost to the top of the pipe; and finally, the trench is filled with loose compressible material, and the balance of the embankment is completed in the normal manner.

Formulas for positive projecting, negative projecting, and imperfect ditch embankment installations and a discussion of tunnel installations are given in various design manuals.[20] As indicated previously, there may be cases where embankment type construction will result in economy, particularly with respect to the required class of pipe.

Supporting strength

The load carrying capacity or supporting strength of a sewer pipe depends on the pipe shape, pipe material, and type of bedding used. Three terms are used in connection with supporting strength, and they have different meanings and values. They are: "supporting strength" (the three-edge bearing test); "safe supporting strength," which depends on the type of bedding used in the trench; and "field supporting strength," which is the safe supporting strength multiplied by a safety factor.

THREE-EDGE BEARING TEST

As in the case of water pipes, the simplest, most easily performed, and most accurate test for determining supporting strength (crushing strength) of a pipe is the three-edge bearing test (see Manual of Practice No. 2, Fig. 5, p. M10).[24] There are three other methods for determining supporting strength, and if used, data from these tests may be converted to three-edge bearing test equivalents by dividing the observed results by appropriate factors. In all of these tests, the results are reported in terms of pounds per linear foot.

The results of the three-edge bearing test provide a basis for determining the resistance to crushing loads under standardized laboratory test procedures. When the pipe is installed, its supporting strength (resistance to crushing) is increased by virtue of the bedding on which it rests. Four types of bedding are shown in Fig. 13.[25]

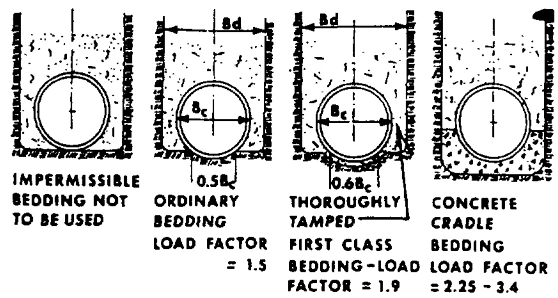


Fig. 13. Types of bedding for sewer pipe.[30]

Bedding conditions. These four bedding conditions have been designated as A, B, C, and D by the ASCE and WPCF Manual on Sewer Design.[26] That manual also contains a computation diagram for determining earth loads on buried pipes under the several conditions of bedding. The supporting strengths of sewer pipes under these bedding conditions are all greater than the three-edge bearing strength. The relative factors for comparing each to the three-edge bearing test are shown in Fig. 13 and below. Bedding types are described as follows.

Impermissible or flat bottom—Class D (load factor, 1.1). Little or no care is exercised to shape the foundation to fit the pipe. Secondy, little care is taken in backfilling to make sure that the material used is of good granular quality or is at least partially compacted under and around the pipe. Spangler[25] strongly discourages the use of this type of bedding.

Ordinary—Class C (load factor 1.5). Ordinary care is exercised to shape the foundation to fit the pipe reasonably well for a width of at least one half the pipe diameter. Backfill must be lightly tamped to a depth of 6 in. over the top of the pipe.

First class—Class B (load factor 1.9). Bedding consists of fine granular material (crushed stone or pea gravel) on an earth foundation carefully shaped to fit the pipe for at least 60 percent of its diameter, or compacted granular material with tamped backfill. The backfill must be tamped in two layers of 6 in. each over the top of the pipe.

Concrete cradle—Class A (load factor 2.25 to 3.4). Bedding consists of plain or reinforced concrete of suitable thickness placed under the pipe and extending upwards around it to some depth less than the pipe radius. Another Class A bedding consists of a concrete arch construction with a load factor of 2.8 to 4.8. (This type of construction is described in Part 2, Section 7.)

Concrete encasement (load factor greater than 1.0). In this type of bedding, sewer pipe is encased in concrete to a thickness of 2 in. or more. The supporting strength depends on the compressive strength and thickness of the concrete and on the size of the pipe; the load factor also depends on these factors.

SAFE SUPPORTING STRENGTH

As indicated, the actual load that a pipe will support depends on the type of bedding. The "safe supporting strength" is calculated from the load factors noted above. These safe supporting strengths are shown in Table 10. Although data are included on the impermissible bedding condition, the use of this type of flat bottom bedding is not recommended.

SAFETY FACTORS

It is good practice to include a safety factor in the engineer's specification of class of sewer pipe to be used on a particular installation. For rigid manufactured sewer pipe, a

TABLE 10—SUPPORTING STRENGTHS (LB PER LIN FT) OF SEWER PIPE FOR DIFFERENT BEDDING CONDITIONS

Three edge bearing strengths	Impermissible bedding (load factor 1.1)	Ordinary bedding (load factor 1.5)	First class bedding (load factor 1.9)	Concrete cradle bedding (load factor 2:25–3.4)
1100	1210	1650	2090	2475–3740
1300	1430	1950	2470	2925–4420
1400	1540	2100	2660	3150–4760
1500	1650	2250	2850	3375–5100
1750	1925	2625	3325	3938–5950
2000	2200	3000	3800	4500–6800
2200	2420	3300	4180	4950–7480
2400	2640	3600	4560	5400–8160
2750	3025	4125	5225	6190–9350
3200	3520	4800	6080	7200–10880
3500	3850	5250	6650	7875–11900
3900	4290	5850	7410	8775–13260
4000	4400	6000	7600	8800–13600
5000	5500	7500	9500	11,000–17,000

safety factor of 1.2 to 1.5 is recommended. That is, once the safe supporting strength is determined, it is multiplied by a factor of 1.2 to 1.5 to obtain the "field supporting strength," which serves as the basis for specifying the pipe class to be installed.

For reinforced concrete sewer and culvert pipes, it is customary to design on the basis of 80 percent of the ultimate load, or 100 percent of the load necessary to produce a 0.01-in. crack, whichever is less.

APPLICABILITY OF DATA

These data and comments on sewer pipe design are generally applicable to most types of manufactured pipe. Where differences from these design practices apply for specific pipe materials, the matter will be covered in the discussion of the particular material. Sewers constructed in place also have different design considerations, depending on size, shape, and material.

Section 3—Asbestos-Cement Pipe

The same materials, processes, and testing procedures are used in the manufacture of asbestos-cement nonpressure sewer pipe and building sewer pipe as in the manufacture of pressure pipe for water supply systems. The subject of manufacture is covered in Manual of Practice No. 2 (pages M10 to M13).[24]

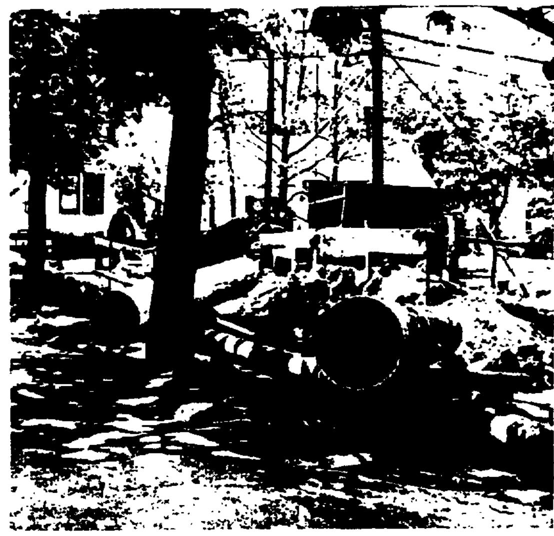
Pipe characteristics

There are three types of asbestos-cement pipe: building sewer pipe, gravity sewer pipe, and pressure sewer pipe. In the selection of pipe, the design engineer must consider, in addition to application, characteristics of the pipe material.

PHYSICAL CHARACTERISTICS

Asbestos-cement building sewer pipe is supplied in Class 1500. Nonpressure sewer pipe is generally available in Classes 1500, 2400, and 3300, and sometimes in Classes 4000 and 5000. These class designations are based on supporting strengths as determined by the three-edge bearing test. Pressure sewer pipe is available in Class 100, Class 150, and Class 200, based on the combined internal and external loading theory.[24]

Table 11 shows data on the available pipe diameters and lengths and the weight per foot in the different classes. These weights per foot are approximate and include the weight of one coupling attached to the pipe length. The weights given in Table 11 are approximate and may vary slightly from one manufacturer to another.



Well-point dewatering system along fully-sheeted trench for 24-in. asbestos-cement sewer pipe.

SURFACE CHARACTERISTICS

The need for a smooth bore in sewer pipe has been pointed out previously. Manufacturers of asbestos-cement sewer pipe meet this criterion through the method of manufacture, which utilizes a polished steel mandrel around which the pipe is formed. The resulting product has a Kutter or Manning n value of 0.010. After curing, the material has a low content of uncombined calcium hydroxide. The flow characteristics are relatively unaffected by continued use.

Linings

Asbestos-cement sewer pipe is normally unlined. An epoxy-lined pipe is available for use in special applications. This epoxy material is applied free of solvents, and the lining, therefore, has no holidays attributable to solvent evaporation. Pipe joints and fittings are also available with epoxy linings. The surface of epoxy-lined pipe has a roughness coefficient equal to or better than that of unlined pipe.

Joints and fittings

Nonpressure asbestos-cement sewer pipe and house and building sewer pipe use the same type of couplings, with flexible rubber rings, as does water pipe. These couplings provide a joint that is both leakproof and rootproof.

Fittings of all types and for all uses are available for joining asbestos-cement pipe to other sewers constructed of any material.

Specifications

In the preparation of specifications for asbestos-cement nonpressure sewer pipe, the design engineer should specify that the manufacture and material meet the requirements of the latest revision of the Federal Specification SS-P-331 and ASTM Specification C-428. Asbestos-cement pressure sewer pipe is specified by Federal Specification SSP351a, AWWA C-400-65, and ASTM Des. C-296-65T.

Manufacturers

Asbestos-cement sewer pipe is manufactured by the following companies:

Cement-Asbestos Product Co., Woodward, Ala.
Certain-teed Products Co., Ambler, Pa.
Flintkote Co. (Orangeburg Mfg. Div.), Orangeburg, N. Y.
Johns-Manville Corp., New York, N. Y.

TABLE 11—CHARACTERISTICS OF ASBESTOS-CEMENT PIPE

Size (in.)	Available lengths (ft)	Approximate weight per foot (lb)* (with coupling attached) Class 1500	Class 2400	Class 3300	Class 4000	Class 5000	Class 6000	Class 7000
				BUILDING AND HOUSE SEWERS				
4	5, 6-1/2, 10, 13	4.6–5.0	5.0–5.6	6.7				
5	5, 6-1/2, 10, 13	6.4–6.7	6.9–7.7	8.9–9.4				
6	5, 6-1/2, 10, 13	7.7–8.7	8.8–9.2	10.3–11.1				
				GRAVITY SEWERS				
6	5, 6-1/2, 10, 13	8.1	8.8	10.4				
8	5, 6-1/2, 10, 13	12.8–13.1	12.8–14.0	14.5–15.8				
10	6-1/2, 13	16.1–17.1	16.1–17.7	17.8–20.5	20.0–22.7	21.9–25.8		
12	6-1/2, 13	22.2–29.9	23.0–24.0	24.9–27.0	26.6–29.6	29.6–33.6		
14	6-1/2, 13	25.9–27.7	25.9–28.9	29.7–34.0	31.1–37.3	34.1–42.0		
15	6-1/2, 13	28.4	28.4	33.1	35.2	39.3		
16	6-1/2, 13	31.5–33.3	31.5–35.3	34.5–41.1	37.1–45.4	40.9–51.0		
18	6-1/2, 13		40.3–42.0	45.6–48.9	50.7–54.2	53.4–60.6		
20	6-1/2, 13		46.3–48.9	52.2–57.1	59.0–63.0	61.7–70.6		
21	6-1/2, 13		50.1	58.7	66.3	72.5		
24	13		56.1–64.3	70.8–74.5	78.9–82.3	81.4–92.2		
27	13			89.3	96.6	110.4		
30	13			104.8	115.9	128.9		
33	13				133.5	148.7		
36	13				152.2	169.8		
39	13					198.0	219.0	238
42	13					216.0	290.0	260

* Weight per foot will vary with pipe length because total weight includes attached coupling. Weight per foot also varies from one manufacturer to another; above ranges are from two manufacturers.

Section 4—Bituminized Fiber Pipe

Laminated-wall, bituminized-fiber drain and sewer pipe is designed to have a resistance to external loads, chemicals, heat, and water. It is manufactured in accordance with Federal Specifications SS-P345a and Commercial Standard CS 226-59. Homogeneous bituminized-fiber pipe is also manufactured in accordance with Commercial Standards CS116-54, but this type of pipe is not covered in this section.

Manufacture

The process of manufacturing laminated-wall bituminized fiber pipe consists of two major steps. The first step is the forming of the pipe as a multiple laminated or spiral fibrous structure of tough uniform fibers bonded with a special water resistant adhesive. The second step is impregnation of the formed pipe, under high pressure, with an especially compounded liquefied pitch. The result is a pipe with a dense wall and smooth interior surface, free from obstructions or rough flaky areas.

Testing

To ensure that the pipe as produced by the manufacturing process meets specifications, samples are tested to determine their strength with respect to crushing, axial-compression crushing, surge pressure, and hydrostatic pressure, and to determine their resistance to flattening pressures, chemicals, kerosene, hot water, and heat. Tests are also made to determine resistance to the absorption of water and to longitudinal permeability seepage. All tests are conducted with standardized equipment and controlled procedures.

MINIMUM TEST CRITERIA

Table 12 lists the minimum acceptable test criteria for physical strength characteristics.

In addition to the criteria in Table 12, laminated-wall, bituminized fiber pipe must have the following characteristics.

Chemical and kerosene resistance. Both pipe and fittings must be highly resistant to corrosive soils, acids, alkalies, salts, and petroleum wastes. After being subjected to the chemicals under test conditions, the crushing strength of the samples must not be less than the values indicated in Table 12. Tests are made by subjecting separate samples, for periods of 10 days at 70 to 80° F, to 0.1 *N* sulfuric acid, 0.1 *N* sodium carbonate, 0.1 *N* sodium sulfate, and kerosene. Then the test specimens are emptied, rinsed, wiped dry, and tested for crushing strength.

Flattening resistance. Both pipe and fittings must resist the combined flattening effects of earth loads and heat.

TABLE 12—MINIMUM REQUIRED PHYSICAL CHARACTERISTICS FOR BITUMINIZED-FIBER PIPE

Federal Specifications SS-P-345a

Pipe size* (in.)	Wall thickness (in.)	Physical strength tests: Axial crushing (lb/lin ft)	Beam (lb/lin ft)	Crushing (lb/lin ft)	Hydrostatic pressure (psi)	Surge pressure (psi)
2	0.25	6,000	1,000	1,500	350	600
3	0.28	10,000	1,000	1,500	350	600
4	0.32	13,000	2,200	1,500	350	600
5	0.41	20,000	4,200	1,500	350	600
6	0.46	30,000	4,400	1,500	300	500
8	0.57	39,000	7,000	1,800	300	500
10	0.61	60,000	7,500	1,800	200	350
12	0.61	72,000	8,500	1,800	150	350
15	0.67	98,000	10,000	1,800	150	250
18	0.71	125,000	11,500	1,800	100	250

* Nominal inside pipe diameter.

House sewer connection being set into 12-in. bituminized-fiber sewer pipe.

TABLE 13—CHARACTERISTICS OF SOME COMMERCIALLY AVAILABLE BITUMINIZED-FIBER PIPE*

Pipe size (in.)	Wall thickness (in.)	Length (ft)	Weight (lb/lin ft)	Crushing strength (lb/lin ft)
2	0.260	10	1.1	
3	0.29	10	1.9	
4	0.34	10	2.7	2100
6	0.29	20	3.7	
6	0.34	20	4.5	
6	0.39	20	5.0	
6	0.48	10	6.8	2900
8	0.34	20	6.0	
8	0.39	20	6.8	
8	0.44	20	7.7	
8	0.57	10	10.8	2650
8	0.57	15	10.8	
10	0.45	20	8.7	2000
12	0.54	20	12.9	1800
12	0.57	15	15.0	
15	0.56	20	16.8	1800
18	0.70	20	24.0	1900

* The data in this table do not necessarily apply to all commercially available pipe.

Tests are made by subjecting two 3-in. lengths to a dead-weight load at a temperature of 150 ± 2° F for 48 hr. The dead-weight loads differ for different pipe diameters, (110 lb per lin ft for pipe 2- to 4-in. diam., 130 lb per lin ft for 5- and 6-in. pipe, and 160 lb per lin ft for pipes of 8- to 18-in. diam.). After cooling to 75° F, the decrease in inside diameter may not be more than 2 percent.

Heat resistance. Specimens selected at random must show a resistance to heat, that is, after being subjected to a temperature of 180° F for 8 hr, while laid on a flat surface, the test specimens must show no appreciable exudation of bituminous material nor any flattening or other distortion.

Hot water resistance. Pipe specimens must be able to withstand the effects of boiling water. There must be no evidence of disintegration or separation into laminations during a 6-hr test. Inspection for such damage is performed after the specimens have been cooled in water at 70° F for 2 hr (or dried overnight at 70° F).

Longitudinal permeability. To test for longitudinal permeability, pipe samples with machined ends joined by a coupling are subjected to water pressure of 5 psi for 1 hr and are examined for movement of water into the pipe longitudinally through the pipe ends. Following the test, no appreciable amount of water should emerge from the ends of the pipe.

Water absorption. Weighed pipe samples, immersed in water at 75° F for 48 hr, then wiped clean and dry, should not increase in weight by more than 2 percent of the dry weight.

Surface characteristics

Laminated-wall, bituminized fiber pipe as produced for commercial use has a smooth bore. According to the manufacturers, calculations of flow capacity may be based on a Kutter or Manning n value of 0.010, but design engineers usually use an n value of 0.012 to 0.015.

Joints

Unless otherwise specified by the design engineer on a project, the ends of bituminized-fiber pipe are tapered to fit within couplings that are also tapered inside. Pipe lengths of more than 10 ft are usually furnished with plain ends. Joints with couplings are watertight. Couplings used for jointing are subjected to rigid testing for strength, etc. In addition to the standard coupling of bituminized fiber, couplings are also made of butyl rubber and neoprene.

Commercially available pipe

Table 13 lists the characteristics of typical commercially available pipe. Some commercial products have dimensions and properties that are well above the minimum values specified in Federal Specifications SS-P-345a.

Laminated-wall, bituminized-fiber pipe is also available in sizes between 18 and 48 in. in diameter. All sizes may be obtained as perforated pipe for use in septic tank drain fields (in small sizes) or for land drainage (in large sizes).

SHIPPING

Laminated-wall, bituminized-fiber pipe is crated and shipped by rail (minimum load weight, 36,000 lb), or by truck (minimum load weight, 30,000 lb).

Manufacturers

Laminated-wall, bituminized-fiber pipe may be obtained from the following manufacturers:

Kyova Pipe Co., Ironton, Ohio
Orangeburg Mfg. Co., Div. of Flintkote Co., Orangeburg, N. Y.
Robinson Clay Pipe Co., Akron, Ohio
Sonoco Products Co., Hartsville, S. C.

Section 5—Brick and Clay Blocks

Bricks and vitrified segmented tile blocks are manufactured by firing a clay mixture in a kiln under controlled conditions. The composition and method of manufacture affect the characteristics of the product.

Bricks and tile blocks currently are seldom used in sewer construction because of the high cost of skilled labor required for installation. In some instances, however, liner plates of vitrified clay are used to protect the invert of a concrete sewer against erosion. Brick is sometimes used in the construction of manholes, but in recent years, concrete has largely replaced brick for this application.

Where brick or segmented tile blocks are used, they are usually obtained from the nearest possible point of manufacture.

Because this manual is devoted principally to the subject of sewers constructed of manufactured pipe, the processes for manufacturing brick and tile blocks will not be covered.

Manufacturers

As brick sewers are built in place and do not utilize a manufactured pipe product, no listing of manufacturers is considered to be necessary.

Manufacturers of vitrified clay tile blocks and liner plates are generally the same companies that manufacture clay sewer pipe (see Section 7).

Section 6—Cast Iron Pipe

Cast iron pipe, manufactured in the same way as for water supply systems, is generally specified for installation where the sewer is to be exposed, where there is expected to be internal pressure (as in force mains) or unusual external load or settlement; or where tight joints are needed to limit infiltration (as in a stream crossing).

According to the Cast Iron Pipe Research Association,[27] the same general type of cast iron pipe is used for conveying sewage as for conveying water. Therefore, the same design procedure is applicable to both water and sewer pipe, except that in the case of gravity sewers, where there is no internal pressure, it is not necessary to use a factor of safety as high as that recommended for buried pressure pipelines. Cast iron pipe is also used in wastewater treatment plants. In all cases, the class designation is given in terms of the pressure to be encountered.

There is a nonpressure cast iron pipe, sometimes termed soil pipe, that is manufactured in small sizes for use in house sewer systems or building drains. The process of manufacture is essentially the same as for cast iron pressure pipe.

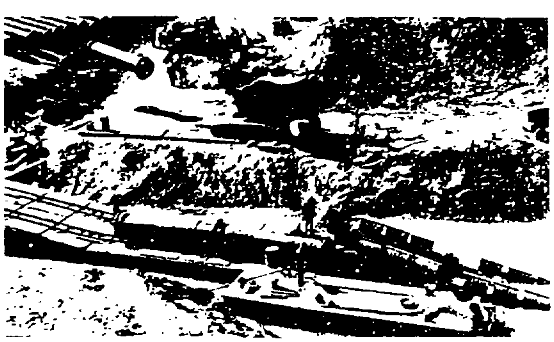
Because the design and manufacture of cast iron pipe is the same whether the pipe is used in a water distribution system or in a sewer, the discussion of these subjects will not be reviewed here. The subjects appear in sufficient detail in Manual of Practice No. 2 (pages M14 to M17).[24]

Manufacturers

Manufacturing companies that produce cast iron pipe include the following:

- Alabama Pipe Co., Div. Woodward Iron Co., Anniston, Ala.
- American Cast Iron Pipe Co., Birmingham, Ala.
- Buffalo Pipe & Foundry Corp., Buffalo, N. Y.
- James B. Clow & Sons, Inc., Chicago, Ill.
- Griffin Pipe Products Co., Oakbrook, Ill.
- Lynchburg Foundry Co., Lynchburg, Va.
- McWane Cast Iron Pipe Co., Birmingham, Ala.
- Shahmoon Industries, Inc., Warren Foundry & Pipe Div., New York, N. Y.
- Traverse City Iron Works, Traverse City, Mich.
- United States Pipe & Foundry Co., Birmingham, Ala.
- R. D. Wood Div., Griffin Pipe Products Co., Florence, N. J.

Twin force mains (36-in. ductile iron pipe) for river crossing at Kansas City, Kan.



Section 7—Clay Pipe

Clay pipe was probably first used to carry water and wastes in Babylon, more than 5000 years ago. Clay pipe drains were found in the ruins of an ancient palace built about 1400 B.C. on the Island of Crete. With the beginning of modern sanitary practices, in about the mid-1800's, clay pipe sewers became widely used in Europe and America.

The first clay sewer pipe in Boston was reportedly [28] laid prior to 1700; it was handmade. Probably the first factory-made clay pipe was hexagonal water pipe manufactured at Middlesbury, Ohio, in 1849. In the succeeding 50 years, although clay pipe was manufactured extensively in the United States, the clay pipe industry was concentrated in Ohio, Tennessee, and the Carolinas.[28] The use of clay sewer pipe grew as population increased and sewer systems were expanded.

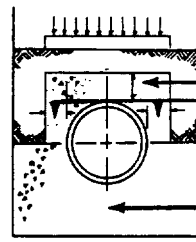


Fig. 14. Special method of laying clay pipe to increase supporting strength.

Design

In the early years of clay pipe manufacture, no consideration was given to the various design factors necessary to produce pipe that would withstand loads imposed on it. Now, however, as a result of continued research, the manufacturing processes are controlled to produce a product that will meet conditions of service. According to ASTM Des. C13-65T, clay sewer pipe may be either glazed or unglazed.

FACTORS OF DESIGN

Selection criteria, as previously presented in Part 2, Section 2, apply to clay pipe. So, too, do the design factors (trench loading, supporting strength, and safety factors) as presented in the same section.

These design factors are reflected in standards issued by ASTM, the United States of America Standards Institute (USASI), and the federal government. The National Clay Pipe Institute has prepared a list of these specifications (Table 14).

TABLE 14—CLAY PIPE STANDARDS AND SPECIFICATIONS[a]

Designation* ASTM	USASI	Title of specification
C-4		Specifications for clay drain tile
C-12	A 106.2	Recommended practice for installing vitrified clay pipe
C-13	A 106.3	Specifications for standard strength vitrified clay pipe
C-32	A 100.1	Sewer brick—clay or shale
C-200		Specifications for extra strength vitrified clay pipe
C-301	A 106.5	Testing of vitrified clay pipe
C-425		Specifications for jointing vitrified clay pipe

*ASTM = American Society for Testing Materials, 1916 Race St., Philadelphia, Pa.
USASI = United States of America Standards Institute, 70 E. 45th St., New York, N. Y. 10017.

TABLE 15 DESIGN CHARACTERISTICS OF CLAY PIPE

Pipe size (in.)	Crushing strength (lb/lin ft)**		Weight (lb/ft)		Hydraulic radius† (ft)
	Standard strength	Extra strength	Standard strength	Extra strength	
4	1200	2000	8.	10.	0.083
6	1200	2000	14.	15.5	0.125
8	1400	2200	21.5	24.	0.167
10	1600	2400	31.5	36.5	0.208
12	1800	2600	43.5	55.	0.250
15	2000	2900	67.5	90.	0.312
18	2200	3300	96.	116.	0.375
21	2400	3850	137.	180.	0.437
24	2600	4400	171.5	218.	0.500
27	2800	4700	225.5	256.	0.556
30	3300	5000	270.	334.	0.625
33	3600	5500	330.	424.	0.687
36	4000	6000	390.	504.	0.750

* ASTM Specification: standard strength—C13; extra strength—C200.
** Three-edge bearing test.
† Flowing full or half full.

External loads. Two types of clay pipes are available: standard strength and extra strength. The minimum crushing strength for each, as allowed under ASTM Specifications C-13 and C-200, is shown in Table 15.

As indicated previously, this minimum allowable crushing strength (three-edge bearing test) becomes the basis for the calculation of supporting strengths for the type of bedding used. For design purposes, supporting strength value should be multiplied by a safety factor of 1.2 to 1.5.

As an alternate to using extra-strength pipe to obtain greater supporting strengths, it is possible to use a special bedding method, termed arch encasement.[4] The method (see Fig. 14) consists of placing the pipe on a bed of 1/4 to 3/4-in. crushed stone, adding stone around the pipe up to the springline, and pouring a concrete arch cap over the pipe. Backfill should be carefully tamped, both at the sides and on top of the arch. With this type of bedding, the supporting strength of the encased pipe is 3.5 times the minimum three-edge bearing crushing strength. Even with poor underbedding, a load factor of 2.25 times the three-edge bearing test strengths may be obtained by arch encasement. The use of reinforcing bars in the concrete reduces the amount of concrete required.

Pipe characteristics

With respect to clay pipe, the characteristics that must be considered in selection include not only crushing strengths (Table 15) and physical measurements, but also several other characteristics, some of which are not covered by specifications.

Large diameter clay sewers laid in concrete cradle construction.

Allowable absorption. In the specified test for absorption, pipe is immersed in boiling water for 5 hr, then cooled and wiped dry. The maximum gain in weight caused by water absorption is limited to 8 percent.

Acid resistance. Where acid resistance of the pipe is a consideration, the acid-soluble material in the pipe is limited to 0.25 percent by weight.

Nonspecified characteristics. In addition to the characteristics covered by ASTM specifications, there are several other characteristics that should be considered by the design engineer.

Abrasion resistance is important in sewers carrying combined wastes and storm water. Many cities in this country have clay pipe sewer systems that have been in service more than 100 years. This long experience record attests to the abrasion resistance characteristics of this type of pipe.

Deformation resistance is related to pipe strength. Under design conditions, and in the three-edge bearing test, the change in pipe shape under load is negligible up to the point of pipe failure caused by loads in excess of the supporting strength of the pipe.

Long life is a characteristic attested to by the history of sewers both in ancient and modern installations.

PHYSICAL CHARACTERISTICS.

Physical measurement characteristics have been published in detail.[4] Pipe is commonly available in sizes from 4 to 42 in. in internal diameter (see Table 15); the nominal minimum length is 2 ft for pipe up to 12 in. in diameter, and 3 ft for pipe of larger size. Pipe is also generally available in 4, 5, and 6 ft lengths.

Barrel thickness may vary within allowable limits. For example, for 4-in. pipe, the nominal wall thickness is 1/2 in., but the minimum allowable thickness is 7/16 in.; for 36-in. pipe, the nominal wall thickness is specified at 2-3/4 in., but the allowable minimum is 2-5/8 in. The outside diameter of the pipe barrel may vary from 4-7/8 in. to 5-1/8 in. for 4-in. pipe, to 40-3/4 in. to 40-1/4 in. for 36-in. pipe. Limits are also placed on socket size and depth.

Straightness of pipe lengths is specified: maximum allowable deviation is 1/16 in. per ft of length.

Weights of clay pipe per foot of length increase with increases in pipe size; see Table 15.

Hydraulic characteristics of vitrified clay pipe are indicated by an n value of 0.013 (Kutter or Manning) generally used by design engineers for pipe of all sizes. Where clay sewer pipelines are laid with careful attention to grade, straightness, and best possible jointing, and where flow velocities provide self scouring at all times, n values as low as 0.011 have been used in calculations of flow capacity. Table

15 shows the hydraulic properties of clay sewer pipe of different sizes.

Manufacture

The manufacture of clay pipe begins with the selection and mining of clays having desirable composition and characteristics.[28]

MATERIALS

Three types of clay are considered acceptable by ASTM: surface clay, occurring at the earth's surface in an unconsolidated and unstratified condition; fire clay, a sedimentary clay of low flux content; and shale, a thinly stratified, consolidated, sedimentary clay, with well-marked cleavage parallel to the bedding. Clay pipe may be made from any one of these substances or from a combination of two or three of them. Approximately 2400 lb of clay is required to make 1 ton of clay pipe.

PROCESS

After mining and storage at the plant, the clays are ground to pass a screen of 10 to 16 mesh per in. The various clays are then blended to produce the desired quality pipe.

Tempering and mixing. The ground clays, when blended, are moistened and mixed (tempered) in a pugmill or similar mixer to produce a smooth, homogeneous mass having the consistency of modeling clay.

Pressing. "Green" pipe is formed by extruding the tempered clay through a die under pressures of 750 to 2000 psi. Any entrained air left after mixing is expelled in the pressing process. Removal of air ensures that blisters and laminations will be avoided in the steps that follow. The forming of the pipe is accomplished by steam-operated vertical presses or by horizontal extrusion presses. Today, all operations are automatic or semiautomatic.

Both the pipe barrel and bell are produced in the pressing or extrusion operation. The green pipe is an extremely dense mass composed of about 82 percent clay and 18 percent water, by weight. Formed green pipe is quite heavy in the larger sizes; for example, a 5-ft length of 36-in. pipe weighs 3500 lb in the green condition. The pipe is also larger than final desired size to allow for shrinking in later operations. Green pipe is strong enough to stand on end without slumping during its transfer from the pressing operation to curing. Following pressing, the pipe is cut to the desired length.

Vitrified clay pipe for use in sewers is made with bell and spigot ends, except on order for special conditions. Fittings, such as wyes, tees, saddles, elbows, slants, etc., are also made by an extrusion process. In addition to the usual bell and spigot type of joint, there is also an "O" ring joint available.

Curing. To reduce the moisture content of the green pipe to 3 percent or less, the pipe is dried (cured) in a warm, moisture-controlled curing room. This operation is necessary to prevent the formation of steam within the pipe during the firing process.

During curing, the pipe remains on end, with the bell up. Curing time depends on the pipe size; 4-in. pipe may dry in 1 to 3 days, while a 36-in pipe may require 1 to 3 weeks. In the drying process, the pipe shrinks to its final size. After it has been dried, the pipe is hard and firm and ready for the next step in the manufacturing process.

Firing. The final strength of clay pipe depends on a fusion of clay particles under extreme heat. This process, termed firing, takes place in either a beehive furnace or kiln (batch operation) or in a tunnel furnace (continuous operation).

For the first few hours of the operation, the furnace temperature is held at about 200° F to drive off residual moisture in the cured pipe. This part of the process is termed "water smoking."

When the pipe is thoroughly dried, the furnace temperature is increased to 900 to 1400° F, at which point organic matter and certain minerals in the clay are burned. This part of the process is termed "oxidation;" the gases formed in the burning are driven off before the pipe becomes too dense to permit their escape.

Following oxidation, the furnace temperature is raised quickly to 1900 to 2200° F, at which point the clay vitrifies. The final temperature used depends on the constituents of the clay.

During the vitrification process, particles with a high heat resistance form the skeleton structure of the pipe. Around this skeleton, materials of lower melting point flow to form a dense hard, coherent mass.

Cooling. After firing, the temperature of the furnace and the pipe is reduced slowly at controlled rates to prevent cracking of the pipe. The composition of the clays used is a factor in the cooling rate used.

TESTING

When the pipe is cool enough to handle, it is subjected to a series of tests. The first of these is the "hammer test," in which each length of pipe is tapped lightly with a hammer. If a pipe does not have a bell-like ring when tapped, it is rejected.

Other tests are made on random samples of each batch, in accordance with standard procedures set forth in ASTM specifications. (See Table 14 for name and number of specifications.) These tests include: crushing test (three-edge bearing test); acid resistance (48-hr immersion in nitric, sulfuric, hydrochloric, and acetic acids); water absorption (immersion in boiling water for 5 hr); and visual inspections for dimension and imperfections, i.e., blisters, chips.

STORAGE AND SHIPPING

Following production and testing, vitrified clay pipe is stored on end in yards. It is shipped, as ordered, by rail or truck.

Manufactures

Vitrified clay pipe and products may be obtained from the following manufacturers. The list is not all-inclusive.

American Vitrified Products Co., Cleveland, Ohio
Can-Tex Industries, Inc., Mineral Wells, Tex., and Connelton, Ohio
Denver Brick and Pipe Co., Denver, Colo.
Grand Ledge Clay Product Co., Grand Ledge, Mich.
International Pipe and Ceramics Corp., Parsippany, N. J.
Iowa Clay Pipe Co., Des Moines, Iowa
Lee Clay Products Co., Morehead, Ky.
Logan Clay Products Co., Logan, Ohio
Nalco Corp., Pittsburgh, Pa.
Oconee Clay Products Div., Milledgeville, Ga.
Pacific Clay Products Co., Los Angeles, Calif.
Pomono Pipe Products Co., Greensboro, N. C.
Robinson Clay Products Co., Akron, Ohio
Streater Div., Clow Corp., Wheaton, Ill.
United States Concrete Pipe Co., Cleveland, Ohio

Section 8—Concrete Pipe

Concrete, actually hand-tamped natural cement, was used in the construction of Rome's Cloaca Maxima, or main sewer, which was constructed more than 2000 years ago and is still in use. The earliest recorded installation in this country was in 1842 in Mohawk, N. Y.[29] Other installations were made more than 100 years ago in San Francisco, Calif., and Utica, N. Y. The Concrete Pipe Handbook[29] lists 99 cities with concrete sewer pipe systems more than 50 years old and 82 cities where the sewer systems contain more than 50 miles of concrete pipe of various sizes.

TABLE 16—DESIGN CHARACTERISTICS OF NONREINFORCED CONCRETE PIPE

Pipe size (in.)	Standard strength: Wall thickness (in.)	Standard strength: Crushing strength* (lb/lin ft)	Standard strength: Weight (lb/lin ft)	Extra strength: Wall thickness (in.)	Extra strength: Crushing strength* (lb/lin ft)	Extra strength: Weight (lb/lin ft)
4	9/16	1000	8.5	3/4		13
6	3/8	1100	17	3/4	2000	20
8	3/4	1300	27	7/8	2000	31
10	7/8	1400	37	1	2000	42
12	1	1500	50	1-3/8	2250	68
15	1-1/4	1750	78	1-5/8	2750	100
18	1-1/2	2000	105	2	3300	150
21	1-3/4	2250	159	2-1/2	3850	230
24	2-1/8	2400	203	3	4400	315

* Three-edge bearing test.

According to the design criteria of the U. S. Navy Engineering Facilities Command,[23] precast concrete pipe "may be used where there is an indicated savings because of its low cost, adequate strength, and good joint capabilities." Precast concrete sewer pipe may be obtained in several shapes, many sizes, and with several types of joints. The choice of a particular type, shape, or joint depends on the use to which the pipe is to be put, the location and conditions of installation and operation, and other engineering factors.[29]

Design

As is the case for all gravity-flow sewer pipe, internal pressure is not a design factor for concrete sewer pipe. With respect to external loads and supporting strengths, the design of concrete sewer pipe is based on consideration of trench loads and superimposed loads that are discussed in Part 2, Section 2 of this manual and in Manual of Practice No. 2.[24]

NONREINFORCED CONCRETE

Plain concrete is used in sewers up to 24-in. in diameter. Sometimes termed "bell end" concrete pipe, it is of the bell and spigot type. There are several means of making up this bell and spigot type joint (see later discussion). Nonreinforced concrete pipe is manufactured in two grades, standard strength and extra strength, in accordance with ASTM Des. C14-65.[30]

This type of pipe is available in 3-ft lengths for 4- to 24-in. pipe diameters and in 4-ft lengths for pipe diameters of 10 to 24 in. In 21 and 24 in. diam., lengths of 6 and 7-1/2 ft are available. ASTM specifications place limits on the allowable variation in dimensions of laying length, internal diameter, barrel thickness, and depth, diameter, and wall thickness of the socket. Table 16 lists some of the important physical characteristics of nonreinforced concrete sewer pipe.

Under some conditions, and for different pipe sizes and pipe classes, there are limitations on the depth at which nonreinforced concrete may be safely buried in backfilled trenches. In general, the published limitations[29] may be summarized as follows:

For soil weighing 130 lb per cu ft, there is no limit on depth of cover for any size of extra-strength pipe placed on ordinary, first-class, or concrete-cradle bedding or for standard strength pipe placed on first-class or concrete-cradle bedding. Standard strength pipe in sizes of 18, 21, and 24 in. should have covers no deeper than 31, 21, and 18 ft respectively.

For soil weighing 130 lb per cu ft, there is no limit on depth of cover for any size of extra-strength pipe laid on concrete cradles. For both strengths of pipe laid on ordinary or first class bedding, the allowable depth of cover for 130 lb per cu ft soil will vary with the pipe size and type; the better the bedding, the greater the allowable depth of cover, and usually, the larger the pipe diameter, the less the allowable depth of cover for the particular type of bedding. Data in published tables[29] are based on a trench width 16 in. greater than the outside diameter of the pipe.

REINFORCED CONCRETE PIPE

Reinforced concrete sewer pipe is manufactured in five classes, designated as I, II, III, IV, and V, in accordance with ASTM specifications. These classes have different strength requirements as indicated by the D-Load (Table 17), according to ASTM Des. C76-66T[31]. The strength test requirement under the three-edge bearing method may be expressed in terms of the D-load (test load in pounds per linear foot per foot of diameter) to produce a 0.01-in. crack, or in terms of this load and the D-load to produce the ultimate, multiplied by the internal diameter of the pipe in feet. Values for these strengths are shown in Table 17.

Pipe within each of these class designations is manufactured in different sizes and three wall thicknesses (A, B, C) and has different reinforcement requirements. Pipe lengths of 4, 5, 8, and 12 ft are manufactured; the length depending to some extent on pipe size and on the manufacturer. Table 17 is a condensed listing of reinforced concrete pipe characteristics. Three compressive strengths, 4000, 5000, and 6000 psi, are shown.

Reinforcement. Reinforcing steel is embedded in reinforced concrete pipe in such a manner that the concrete and the steel act together to give structural and supporting strength to the pipe. In some classes of pipe, for diameters less than 36 in., only one reinforcing cage is used (Fig. 15), the reinforcing being located 1 in. inside the inner surface of the pipe. In larger pipes of all classes, one of two methods of reinforcing may be used. In the first method, two reinforcing cages are used, one is 1 in. inside the inner surface, the other 1 in. beneath the outside surface of the pipe (Fig. 15).

As an alternative to the two-cage circular reinforcement design, a single elliptical reinforcing cage is placed within the circular pipe shell in such manner that the cage is no nearer the surface at any point than is specified. Pipe that is reinforced with an elliptical cage must be laid in such a position that the shorter axis of the ellipse is vertical, so that the pipe will provide its maximum supporting strength. A lifting hole is normally provided in the pipe to ensure that it will be laid in the proper position. Labels indicating "top"

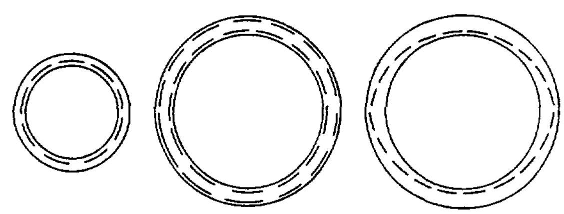


Fig. 15. Location of reinforcing steel in circular concrete sewer pipe left to right: single-cage, two-cage, elliptical.

TABLE 17—DESIGN CHARACTERISTICS OF REINFORCED CONCRETE PIPE

(Data given as minimum to maximum range)

	D load			Wall thickness (in.)			Weight (lb/ft)[a]		
	0.01 in. crack	Ultimate	Pipe size (in.)	Wall A	Wall B	Wall C	Wall A	Wall B	Wall C
Class I	800	1200							
Concrete strength 4000 psi			60–96	5–8	6–9	[b]			
Concrete strength 5000 psi			102–108	8-1/2–9	9-1/2–10		1064–2710	1295–3090	
Class II	1000	1500							
Concrete strength 4000 psi			12–96	1-3/4–8	2–9	4-3/4–9-3/4[c]	79–2710	93–3090	366–3020[d,f]
Concrete strength 5000 psi			102–108	8-1/2–9	9-1/2–10	10-1/4–10-3/4			
Class III	1350	2000							
Concrete strength 4000 psi			12–72	1-3/4–8	2–7	4-3/4–8-3/4[e]			
Concrete strength 5000 psi			78–108	6-1/2–9	8-1/2–10	9-1/4–10-3/4			
Class IV	2000	3000							
Concrete strength 4000 psi			12–66[i]	1-3/4–2-3/4[g]	2–5-1/2[h]	3-3/4–7-3/4[i]			
Concrete strength 50000 psi			60–84[j]		6–7[j]				
Class V	3000	3750							
Concrete strength 6000 psi			12–72[k]		2–5[k]	3-3/4–7-3/4[k]			

[a] Approximate; based on 150 lb per cu ft concrete. [b] Not manufactured. [c] Available only from 36- to 96-in. diam. [d] 24- to 90-in. diam. [e] Available only from 36- to 84-in. diam. [f] Modified or special designs above 30 in. for Wall A [g] Up to 30-in. diam. only. [h] Up to 54-in. diam. only. [i] Available only from 24- to 66-in. diam. [j] 60 to 72 in. diam. in Wall B; 72 to 84 in. in Wall C. [k] 12- to 48-in. diam. in Wall B; 24 to 78 in. in Wall C.

or "bottom" are sometimes used to show the short axis of the ellipse.

The amount of reinforcing steel required depends on pipe size and necessary supporting strength. ASTM Des. C76-66T[31] specifies the amounts of steel for each pipe size in each class of pipe and for each wall thickness.[29]

Pressure pipe. Where concrete pipe is to be used in sewage force mains or in siphons under pressure, the design engineer on the project may find it desirable to specify concrete pressure pipe as used in water supply systems. Information on this type of pipe was covered in considerable detail in Manual of Practice No. 2.[24]

SHAPES OTHER THAN CIRCULAR

Two pipe shapes other than circular are also manufactured; these are the arch-type and the elliptical.

Arch-type concrete pipe. The cross-sectional shape of arch-type concrete pipe is an arch. The dimensions vary according to pipe size and are specified by ASTM Des. C-506-63T. Arch-type pipe is made in Classes II, III and IV, with 4000 psi strength concrete, except for 72- and 84-in. Class III pipe, which requires 5000 psi concrete.

Table 18 shows the sizes available, with the accompanying rise and span. The size is given as the diameter of a circular pipe of equivalent cross-sectional a-ea. Arch-type pipe is used where an economical solution is desired for a limited head application. This type of pipe is available in only a limited number of states.

Elliptical pipe. Elliptically-shaped reinforced concrete pipe is manufactured in two types: horizontal-elliptical for low-head installations, and vertical-elliptical for high head applications. The horizontal-elliptical pipe is manufactured in Classes I to IV, the vertical-elliptical pipe in Classes II to VI. The latter type comes in compression strengths of 4000, 5000, and 6000 psi, depending on the pipe size. Both types are available in 4-, 6-, and 8-ft lengths; longer lengths may be obtained if specified.

Pipe sizes are expressed in terms of their equivalent circular pipe diameters. The following data indicate some of the pertinent physical measurements of the minimum and maximum sizes available. The minimum size pipe is equivalent in area (1.8 sq ft) to an 18-in. diam. circular pipe. It weighs approximately 200 lb per ft of length, and its rise versus span measurements are 14 × 23 in. for the horizontal-vertical pipe and 23 × 14 in. for the vertical-horizontal pipe. The maximum size pipe is equivalent in area (118.6 sq ft) to a 144-in. diam. circular pipe; it weighs approximately 7300 lb per ft. and it has a rise versus span of approximately 129 × 193 in. for the horizontal pipe and 193 × 129 in. for the vertical pipe. Wall thickness in the smallest pipe size is 2-3/4 in. and in the largest pipe size is 13 in.

Horizontal-elliptical pipe and vertical elliptical pipe of a given class have the same supporting strength as circular pipe of the same class. Calculation of hydraulic flow characteristics are generally based on a Manning's n value of 0.012. Charts, diagrams, and nomograms available from the Bureau of Public Roads[12] show capacity, headwater depth, and head for pipes flowing full. There are also charts available from manufacturers, for both vertical and horizontal types, showing the discharge in cubic feet per second for various grade slopes, n-values, and equivalent pipe sizes.

SAFETY FACTORS

In the previous general discussion of design factors (Part 2, Section 2), it was pointed out that when designing sewers and calculating supporting strength required, a safety factor of 1.2 to 1.5 should be used. Concrete pipe manufacturers generally believe that a safety factor of 1.0 (using a 0.001-in. crack load) is sufficient[20] for reinforced concrete pipe because the specified "D-load" is a minimum for test samples, whereas the D-load on installed pipe is always higher. Furthermore, concrete pipe strength increases with age, thus offering a built-in safety factor. For most designs, a factor of 1.0 for a 0.01-in. crack load, results in a factor of at least 1.5 for the ultimate load.

Characteristics

Concrete is composed of a mixture of portland cement and aggregates (sand, gravel, or broken stone); it sometimes includes fly ash or air-entraining material in varying amounts.

TABLE 18—DESIGN CHARACTERISTICS OF ARCH-TYPE REINFORCED CONCRETE PIPE

Equiv. size[a] (in.)	Water area (sq ft)	Wall thickness (in.)	Min. rise (in.)	Min. span (in.)
18	1.65	2-1/2	13-1/2	22
24	2.8	3	18	28-1/2
30	4.4	3-1/2	22-1/2	35-3/4
36	6.4	4	26-5/8	43-3/4
42	8.8	4-1/2	31-5/8	51-1/8
48	11.4	5	36	58-1/2
54	14.3	5-1/2	40	65
60	17.7	6	45	73
72	25.6	7	54	88
84	34.6	8	62	102
90	44.5	8-1/2	72	115
96	51.7	9	77-1/4	122
108	66.0	10	87-1/8	138

[a] Diameter of circular pipe with approximately equivalent cross sectional area.

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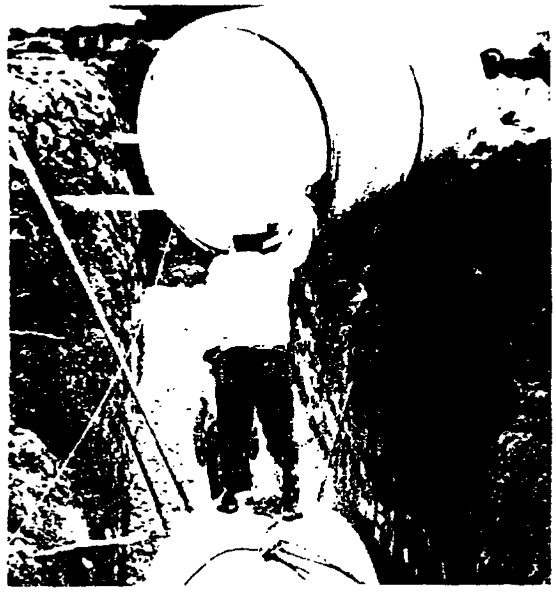


Large diameter concrete sewer laid on selected fill in unsheeted trench.

PHYSICAL CHARACTERISTICS

Concrete pipe has a number of physical characteristics that make it useful in a sewer system. It is hard and dense and weighs from 150 to 165 lb per cu ft. The high density obtained by the methods used in manufacture and control of the ingredients in the mix ensure a high compressive strength—4000, 5000, or 6000 psi after 28 days. Tensile strength is considered to be one-tenth of the compressive strength.

Abrasion resistance. Experience has shown that concrete pipe has long life, as witnessed by the number of communities with concrete sewer systems more than 50 years old. The durability evidenced by these case histories demonstrates the resistance of concrete pipe to the normal abrasive action of domestic wastewaters and storm waters.

Shrinkage and expansion. The shrinkage of good quality concrete stored in air ranges between 0.0002 and 0.0005 in. per in. Concrete stored in water will expand up to 0.002 in. per in. within a year. Thermal expansion is generally stated to be only 0.000006 in. per in. per degree Fahrenheit. This factor has no practical bearing on the installation of normal sewer systems.

Absorption and permeability. ASTM specifications limit water absorption to 8 percent of the dry weight of the concrete pipe. Concrete's permeability to water is very small, and pipe lengths that show any water passing through the walls are rejected. This characteristic prevents infiltration through the pipe walls. To meet the standards presented in Part 2, Section 2, the several jointing methods available (see later discussion) practically eliminate infiltration at connecting joints.

CHEMICAL CHARACTERISTICS

Concrete is an alkaline material that is unaffected by water of normal or high pH. Concrete will react, however, with acids, whether they are in the soil surrounding the pipe, carried in the wastewater, or produced from the oxidation of hydrogen sulfide within the sewers. When reasonable attention is given to protection against acid soil conditions, concrete pipe is durable in any type of soil. The denser the concrete, the more resistant it is to acidic soils.

With respect to possible attack by acids on the interior surface of a concrete sewer, consideration need be given only to three simple factors. The pH of the wastewater should be above 4.5; strongly acidic industrial wastes should be kept out of sewers; and conditions contributing to the production of hydrogen sulfide should be avoided.

In sewer systems, hydrogen sulfide may be converted to sulfuric acid by a biological oxidation process; the resulting acid attacks the sewer. (This acidic attack is not peculiar to concrete; some other sewer pipe materials are also attacked by acids in wastewaters.)

There are several ways in which the formation of hydrogen sulfide can be prevented.

By designing and installing the sewers to produce a velocity that will prevent stranding of solids on flat grades or sedimentation of organic matter in the sewers, and that will give the shortest possible flow time through the sewer;

By keeping high-temperature and high-sulfate-content wastes out of the sewer system;

By adding chemicals to the wastewater to prevent the growth of sulfate-splitting organisms;

By providing flushing systems for sewers laid on flat grades;

By installing ventilating systems to keep the concentration of hydrogen sulfide at a low value in the sewer atmosphere.

HYDRAULIC CHARACTERISTICS

According to the Concrete Pipe Handbook,[29] the Manning formula is generally used in making flow calculations for concrete pipe. The Handbook recommends that the n values be 0.013 for sanitary sewer pipes, and 0.010, 0.011, or 0.012 for concrete storm sewer pipe. The value for sanitary sewers is conservative and takes into account bends, wyes, tees, connections, and operating conditions. The storm sewer values are based on straight, well-graded pipe flowing full (0.010) and flowing partly full (0.011).

Manufacture

The project design engineer sometimes will specify the characteristics needed for the concrete in a particular sewer, but generally, the manufacturer is more familiar with local cements and is more qualified to select the materials and design the mix. All processes begin with the design of the mix or the combination of ingredients.

MATERIALS

As indicated previously, concrete pipe is made from "an extremely dry mix of cement, sand, and gravel or broken stone and water, with or without additions such as fly ash and/or air-entraining agents . . ."[29]

The design of the concrete mix is fairly standard, but individual manufacturers may adapt these designs to fit their own operations and product characteristics. Whatever the individual plant design mixes used, the final product depends on these factors: suitability of materials, accurate measurement of ingredients, thorough mixing, proper water-to-cement ratio, proper placement of mix in forms, and adequate curing and testing to ensure strength, durability, and impermeability of the resulting pipe.

According to the Portland Cement Association,[29] "Designing a concrete mix . . . consists of selecting the water-cement ratio that will produce concrete of the desired resistance to exposure and the required strength, and finding the most suitable combination of aggregates, which will give the necessary workability when mixed with portland cement and water in this ratio."

The design of the concrete mix is generally done by the manufacturer and not by the project design engineer.

PROCESSES

The four most common methods of concrete pipe manufacture are briefly described below.

Cast and vibrated pipe. Steel forms of a size to produce the desired inside pipe diameters and wall thickness are filled with the desired concrete mix, which is compacted by vibration (using either air or electric vibrators) applied both outside the form and to the concrete mix itself. The vibration expels all entrapped air, gives the concrete the desired density, and imparts a smooth finish to the inside and outside walls of the pipe. After vibration, the form is allowed to stand until the concrete sets. When the form is stripped away, the pipe is cured for the time specified to produce the strength class desired. This process can be used for both nonreinforced and reinforced sewer pipe.

Packerhead process. This method for manufacturing nonreinforced and reinforced concrete pipe utilizes a machine with a revolving "packerhead" that continuously packs the dry mix in the form from bottom to top as the form is filled with the mix. The mix is so dry and is packed under so much pressure that the green pipe can be removed from the form after the packing operation is completed. The green pipe is sent to curing immediately, where it is cured in the vertical position. The packerhead process produces the density and smooth surfaces desired in the final product.

Tamped pipe process. This method for manufacturing nonreinforced pipe utilizes a form in which the dry mix is tamped by wooded hammers fitted with steel shoes that strike the surface of the mix 500 to 600 times a minute as the mix is continuously added to the form. In this process, the inside core remains stationary while the outside form revolves. When the form is filled with the tamped mix, the green pipe is removed immediately and placed in the curing room. It is the tamping of the mix that ensures the desired density and smoothness of the inside wall. According to some manufacturers, this process is becoming obsolete.

Centrifugal process. Pipe manufacture by the centrifugal process involves forms rotating at high speed, with the concrete added in such a manner that it is compacted against the form, and the excess water is literally squeezed out. This method is used in the manufacture of reinforced concrete pipe. The mold consists of a steel cylinder in which the steel reinforcing cage is placed and secured.

The smoothness of the inside of the pipe is obtained by the high centrifugal force produced during the rotation of the form.

This is a simplifed description of the centrifugal process, of which there are a number of patented methods. The manufacture of centrifugally produced pressure pipe was described in Manual of Practice No. 2.[24]

Curing. Concrete sewer pipe may be cured by either the steam or water process or by a sealing membrane. These methods are described in Manual of Practice No 2.[24]

Testing

Possibly the most important factor in the production of concrete sewer pipe is the testing to which samples of production are subjected. Acceptance or rejection of pipe is based on the tests that are specified in ASTM Des. C-14 for nonreinforced pipe and ASTM Des. C-76 for reinforced concrete pipe. The properties of both types of pipe tested include: crushing strength (three-edge bearing test), absorption, sizes and dimensions, permeability, defects and imperfections, and finish of ends. Nonreinforced concrete pipe is subjected to a hydrostatic test of 10 psi for 10 min to determine leakage. The concrete in reinforced concrete pipe also must pass a compression test. All these tests are made in accordance with the appropriate ASTM specifications.

Liners and linings

Concrete sewer pipe that may be subjected to abnormal conditions in operation, such as acids, gritty material, or hydrogen sulfide, may be lined to protect the inside surface of the pipe.

A good lining should have the following characteristics: resistance to acids, chemicals, water, and abrasion; assured adherence to the pipe's interior surface; imperviousness; ample thickness; and resistance to attack by biological organisms. The major methods of applying such linings include integral lining, insertion of plastic liners, lining in place, and liquid application.

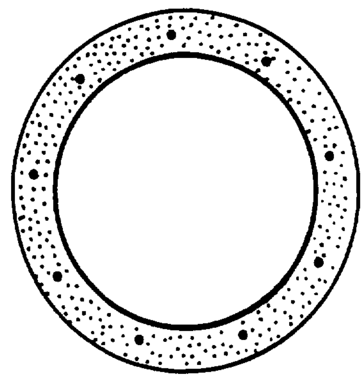


Fig. 16. Cross section, exaggerated, of integral-type epoxy lining in concrete pipe.

INTEGRAL COATING

In a patented process, an integral aggregate-filled coal tar epoxy lining is produced on the inner surface of the pipe.

The epoxy lining, containing selected silica aggregates, is applied to an average thickness of 100 mils on the interior of uncured, dry-mix, machine-made concrete pipe (18 to 72 in. up to 12 ft lengths) immediately after the pipe is manufactured. The pipe is cured after the application of the lining. During the curing process, the lining develops a physical-chemical molecular adhesion with the concrete surface to become an integral part of the concrete wall. An exagerated cross-section of lined pipe is shown in Fig. 16.

Laboratory tests indicate that this lining resists acids, abrasion, strong chemical solutions, and hydrogen sulfide. Manufacturing tests have been made of its adhesive qualities and its resistance to impact, hydrostatic pressure, and infiltration under pressures up to 50 psi. The process was developed in 1962, and pipe of this type has been installed in many sizes at a number of sites since that time.

PLASTIC LINER

A liner consisting of a high polymer vinyl chloride resin is molded under high temperature and pressure to form a dense and impervious material. This liner can be cast into any concrete pipe that is formed on an inner mold. Its design is shown in the exaggerated sketch in Fig. 17. Joints between sections of the liner, from pipe section to pipe section, are made by heat-welding the material to itself to obtain a continuous impermeable lining.

Another system employing a PVC sheet and a specially designed adhesive and application method, may be used on concrete pipe manufactured by any process.

FIELD APPLIED EPOXY

Epoxy material containing finely divided silica is applied to new pipe sections either in the field or after installation using a lining process similar to that used for cement lining of water mains in place. The method is described in some detail in Part 2, Section 13 of this manual.

LIQUID APPLICATION

The interior or exterior of concrete pipe may be painted with bitumastic, coal-tar epoxy, or other resistant substance, either at the manufacturing site or at the project site.

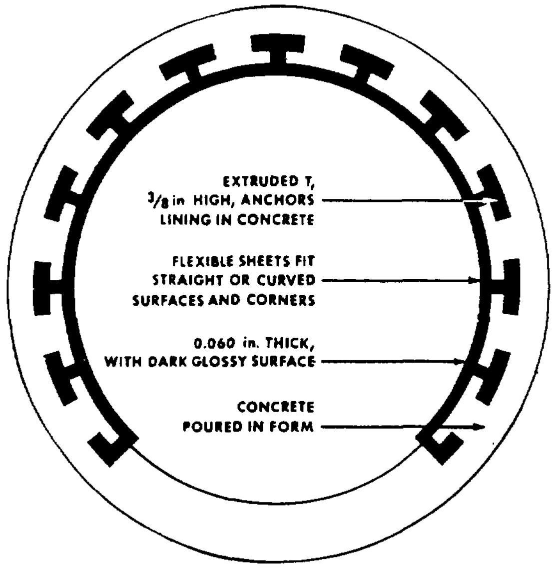


Fig. 17. Cross section, exaggerated, of plastic liner for concrete pipe.

Joints and fittings

Various types of joints are available for connecting concrete pipe sections, and the type of joint used often depends on the ground water conditions, pipe size, the manufacturer, and whether the pipe is reinforced or nonreinforced.

The principal types of joints are bell and spigot, tongue and groove, modified tongue and groove (with a reinforced modified bell), concrete collar, single rubber ring gasket, and external band. Methods of making joints will be discussed in Part 3 of this manual.

Fittings of all types, including bends, wyes, tees, connections, and specials, are available in all sizes.

Cast-in-place concrete pipe

Concrete sewers cast in-place involve engineering design formulas and calculations. Different shapes involve different engineering design approaches. Principles of design for such sewers may be found in standard reference texts[5,10,20,26] and will not be covered in this manual.

Manufacturers

Manufactured concrete pipe, joints, and fittings may be obtained from the following manufacturers; the list is not necessarily all-inclusive. For a complete list, consult the American Concrete Pipe Assn.

American Pipe & Construction Co., Monterey Park, Calif.
The Cretex Co., Inc., Elk River, Minn.
Gifford-Hill Pipe Co., Dallas, Tex.
Hydro Conduit Corp., Denver, Colo.
International Pipe & Ceramics Corp., Parsippany, N. J.
Price Brothers Co., Dayton, Ohio
United Concrete Pipe Corp., Birmingham, La.
United States Concrete Pipe Co., Cleveland, Ohio
Vulcan Materials Co., Atlanta, Ga.

Specially lined pipe, as described previously, or epoxy lining-in-place may be obtained from the following companies:

Epoxy lining-in-place; Centriline Corp., Div. of Raymond International, Inc., New York, N. Y.

Integral lining; U. S. Steel Chemicals, Div. of U. S. Steel Corp., Pittsburgh, Pa.

Plastic linings are manufactured by Amercoat Corp., Brea, Calif., but are applied by the pipe producer.

Section 9—Plastic and Plastic Lined Pipe

Until recently, the use of plastic pipe in sewer systems was limited to building sewers, house sewers, and force mains, primarily because the largest size available was 6 in. in diameter. In about 1965, a specially designed plastic pipe, termed truss pipe, was introduced in sizes of 8-, 10-, 12-, and 15-in. diam. In 1967, a British manufacturer announced the production of extruded polyvinyl chloride pipe (PVC) in diameters up to 16 in., with the future possibility of producing 20-, 24-, and 30-in. pipe. These developments undoubtedly will lead to the wider use of plastic pipe for sewers.

ABS, PE, and PVC pipe

The U. S. Department of Commerce has issued two commercial standards for plastic drain, waste, and vent pipe and fittings (CS 270-67 for ABS and 272-65 for PVC pipe) and one for sewer and drain pipe (CS 228-61 for styrene-rubber plastic). As the use of plastic pipe for sewers increases, there may be standards developed specifically for plastic sewer pipe of various compositions. Information on the design, specifications, manufacture, and testing of plastic pipe for water systems may be found in Manual of Practice No. 2.[24] Manufacture of plastic sewer pipe is similar.

In addition to the types of pipe used for water systems and/or drain, waste, and vent systems, there are two types of plastic pipe designed for wastewater use: styrene-rubber plastic pipe, and truss-type plastic pipe.

Styrene-rubber plastic pipe

This type of pipe is an extruded product and is available in 10-ft lengths. Four sizes are produced, each with a crushing strength of 1000 lb per lin ft. The dimensional characteristics of this type of pipe, as given in CS-228-61, are as follows:

Pipe size (in.)	Wall thickness (in.)	Weight (lb/ft)
2	0.073	0.25
3	0.100	0.49
4	0.125	0.78
6	0.183	0.67

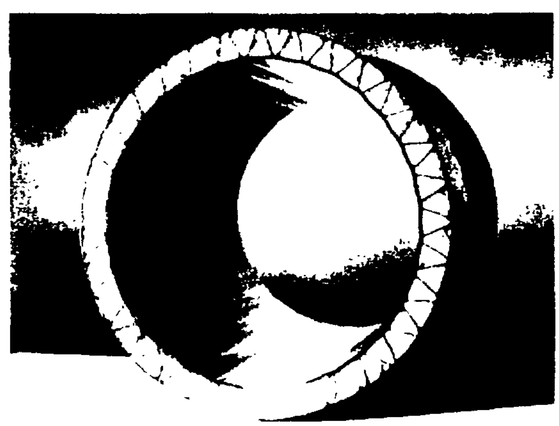


Fig. 18. Cross section of truss-type ABS plastic pipe.

CTD000610

TABLE 19—DATA ON TRUSS-TYPE PLASTIC PIPE

Pipe size			
Regular strength (in.)	Extra strength (in.)	Length (ft)	Weight (lb/lin ft)
...	4	6-1/4, 12-1/2	...
...	6	6-1/4, 12-1/2	...
8	...	6-1/4, 12-1/2	8
10	...	6-1/4, 12-1/2	11
12	...	6-1/4, 12-1/2	15
15	...	6-1/4, 12-1/2	26

The pipe has a tensile strength of 3100 psi, an impact strength of 3.2 ft-lb per in. notch, and an elongation of 17 percent. It is resistant to acids, detergents, caustics, and ordinary domestic wastewater.

Jointing is done by the solvent-weld method to form leakproof and rootproof joints. All types of fittings are available.

Plastic truss pipe

This type of plastic pipe (Fig. 18) consists of two interconnected walls of acrylonitrile-butadiene-styrene (ABS) resin tied together by a truss of the same material, with the voids filled with lightweight concrete.

DESIGN

The lightweight concrete in the voids of truss-type plastic pipe helps to carry the compressive load and provides lateral support for the truss members. Tensile stresses are carried by the pipe wall.

Either of two methods may be used in calculating the necessary resistance or supporting strength for backfill loading: the deflection design method or the ring compression method.[33] Tests using the latter design method indicate that the maximum backfill depth should be 48 ft, based on a given wall strength, a soil weight of 100 lb per cu ft, and a safety factor of 4.0.

The maximum recommended permissible design deflection is 5 percent in a period of 12 months. Field tests indicate that where bedding is good, the maximum deflection noted was 2 percent in 12 months.

CHARACTERISTICS

Truss-type plastic pipe is relatively light in weight and, because of its composition, is quite durable for sewer installations. It has a high resistance to abrasion, freezing, and thawing, and is not affected structurally at temperatures up to 130° F. Thermal expansion is not significant over normal installation ranges. This type of pipe is chemically resistant to hydrogen sulfide and acids in concentrations up to 5 percent.

Minimum specification (ASTM D-18617) for crushing strength is 1500 lb per lin ft, but tests on 8-in. pipe show that between 60 and 130° F, the crushing strength ranges from 2100 to 1650 lb per lin ft.

Good hydraulic flow characteristics result from the smooth surface of the interior wall of the pipe. As produced, this type of pipe is stated to have a Manning n value of 0.010.

MANUFACTURE AND TESTING

Truss-type plastic pipe is made by an extrusion process that forms both the walls and the truss arrangement simultaneously. Data on pipe sizes and weights are given in Table 19. Jointing is accomplished by chemical (solvent) welding to produce a sewer that is leakproof, and resists root penetration, and infiltration. All types of fittings are available

Plastic pipe (15-in.) for sewer line in New York State.

Laboratory tests made on pipe after manufacture include beam tests and impact tests. By specifications of the manufacturer, truss pipe must show no leakage after sustaining a 1-in. deflection for 24 hr with a 10-ft internal water head. The required spans for the flexural test are 82, 90, 96, and 110 in. for pipe diameters of 8, 10, 12, and 15 in., respectively. Beam tests on 8-in. pipe show deflections of 1, 2, or 3 in. in a 10-ft span, with respective loads of 870, 1460, and 1900 lb.

Plastic-lined pipe

Steel pipe that has a plastic lining may be considered as plastic lined steel pipe; it also may be considered as steel armored plastic pipe. In this manual, this type of pipe is termed plastic-lined pipe.

The greatest use of plastic-lined pipe is in handling corrosive chemicals. Currently, the most important application of plastic-lined pipe in the wastewater field is in the disposal of chemical wastes into underground wells.

DESIGN AND MANUFACTURE

Plastic-lined steel pipe is produced with three types of extruded liners, namely, saran, Penton, and polypropylene. These liners are tough and stabilized; they range in thickness from 5/32 to 9/32 in. They are locked in place on the inside of the steel pipe walls by a force of several thousand pounds per square inch. The result is a thick-walled pipe with a heavy steel shell, the two layers being virtually monolithic. The pipe thus produced is suitable for use at temperatures from −20 to 200° F or higher. Pipe is available in sizes from 1 to 8 in., weighing from 2.4 to 28.6 lb per ft; it is made in 10 ft lengths.

In another manufacturing process, a special polyethylene co-polymer is bonded to both the inside and outside of steel pipe. This type of pipe is produced in approximately 30-ft lengths, with coatings of plastic 30 mils thick. Pipe sizes (diameters) available include 2, 3, 4, 6, and 8 in. The weight of this pipe ranges from 1.73 to 10.7 lb per ft. Joints are couplings or flanges.

The method for lining concrete pipe with plastic was previously described (Part 2, Section 8).

Manufacturers

Companies that produce acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), polyvinyl chloride (PVC), or styrene rubber plastic sewer pipe include the following: (All the companies listed do not necessarily produce all types of plastic pipes.)

Anesite Div., Clow Corp., Chicago, Ill.
Can-Tex Industries, Inc., Mineral Wells, Tex.
Carlon Products Corp., Aurora, Ohio
Celanese Plastics Co., Columbus, Ohio
Dan-dee Products Corp., Union City, Calif.
Ethyl Corp., Visqueen Div., Baton Rouge, La.
Evanite Plastic Co., Carrolton, Ohio
Flintkote Corp., Orangeburg, N. Y.
Gering Plastics Co., Div. of Monsanto, Kenilworth, N. J.
Haveg Industries, Inc., Amco Pipe, Wilmington, Del.
Johns-Manville Corp., New York, N. Y.
U. S. Pipe & Foundry Co., Birmingham, Ala.

Companies that produce plastic-lined pipe or plastic liners include the following:

Amercoat Corp., Brea, Calif.
Dow Chemical Corp., Midland, Mich.
International Protected Metals, Inc., South Plainfield, N. J.

Companies that produce truss-type plastic pipe include:

Armco Steel Corp., Metal Products Div., Middletown, Ohio
Robinson Clay Product Co., Akron, Ohio

Section 10—Reinforced Resin Pipe

For the purposes of this manual, fiberglass reinforced pipe is not defined as plastic pipe because the composition and methods of manufacture differ from those of the plastic pipe discussed in the previous section. Commercial products on the market carry registered trade names that do not indicate the composition of the pipe. At least two major types of reinforced resin piper are available commercially.

Reinforced epoxy or polyester plastic

This type of pipe, sometimes termed simply GRP (glass-reinforced pipe), is composed of fiberglass reinforced epoxy resin or polyvinyl ester. At least one commercial product is available in three classes. When epoxy resin is used, it meets ASTM Spec. Des. 1763-63. The pipe is tested for various characteristics in accordance with several applicable ASTM specifications. Each grade of pipe has a different temperature range resistance; the thermal expansion coefficient of the pipe in diameters from 4 to 12 in. is approximately 9×10^{-6} in. per in. per degree F. The pipe has a low hydraulic-flow friction coefficient; the Hazen-Williams C-value being stated by one manufacturer as 150.

Glass-reinforced piping is available in 15 and 20 ft lengths and in diameters from 2 to 24 in., but larger diameters can be obtained for special applications. In one process of manufacture, the pipe is built up by laminations, as follows:

Inner surface—0.01 to 0.02 in. smooth resin-rich interior, reinforced with surfacing mat or veiling.

Next interior layer—0.1 in. (minimum) chemical-resistant layer, 25 to 30 percent glass by weight.

Remaining interior layers—varied thickness of glass and resin to obtain the required laminate strength.

Exterior surface—resin-rich surface, reinforced with a surfacing mat.

This type of pipe has high corrosion resistance but not necessarily abrasion resistance. The corrosion resistance is provided by the resin; the strength by the fiberglass. Best corrosion-resistance/strength characteristics are obtained with 25 to 40 percent glass and 75 to 60 percent resin. Coupling joints may be threaded, solvent-welded, or made with resin coatings.

This type of pipe has been found useful in industrial wastes systems, particularly for deep-well disposal of industrial wastes. Table 20 lists the characteristics of three classes of pipe produced by one manufacturer.

TABLE 20—DATA ON GLASS-REINFORCED PIPE*

	Class 2025	Class 2530	Class 3040
Size (in.)**	2–12	2–12	2–12
Wall thickness (in.)	0.2–0.25	0.25–0.3	0.3–0.4
Weight (lb/ft)	0.83–6.70	1.25–8.0	1.4–10.4
Collapse pressure at 80°F (psi)	225–6	350–10	400–25
Axial load pressure at 80°F (psi)	3000–18,000	4000–25,000	4500–37,000
Internal pressure resistance at 200°F (psi)	200–130	300–160	400–240

* Class 2025 is suitable for use at temperatures up to 200°F, Classes 2530 and 3040 at temperatures up to 300°F.
** Nominal inside pipe diameters available are: 2, 2-1/2, 3, 4, 6, 8, 10, and 12 in.

TABLE 21—DATA ON REINFORCED PLASTIC MORTAR PIPE

Pipe size (in.)	Weight (lb/ft) Low head (125 ft)	High head (200 ft)
8	5.5	5.5
10	7.0	7.0
12	9.5	9.0
15	13.0	10.5
18	15.5	15.0
21	19.0	20.0
24	23.0	22.0
27	28.0	25.5
30	35.5	31.0
33	43.0	37.5
36	47.5	44.5
39	60.0	52.5
42	69.5	61.0
48	90.5	80.0

Reinforced plastic-mortar pipe

Reinforced plastic mortar pipe has a composite structure (Fig. 19) of synthetic polyester and sand mortar reinforced with continuous glass fibers.

This type of pipe is manufactured in two classes: low head (125 ft), and high head (200 ft). Because the high head pipe will be subjected to higher internal pressures, it contains a larger percentage of reinforcing glass filaments and less sand filter; consequently it weighs less per foot (Table 21). Wall thickness for the low head pipe ranges from a nominal 0.2 in. for 8-in diam. pipe to about 0.4 in. for the 48-in. pipe size. The wall thickness of high head pipe is similar to that of low-head pipe but in some cases it may be slightly less. Nominal weights per foot are shown in Table 21.

This type of pipe is manufactured in standard 10 ft laying lengths, but 20 ft lengths may be obtained. No published data are available at this time on the pipe's supporting strength for backfill loads in trenches. The material in this type of pipe will not react with the acids and chemicals normally encountered in domestic or industrial wastewaters or with corrosive soils. It is also resistant to electrolytic or galvanic corrosion and hydrogen sulfide. The internal surface of this pipe is extremely smooth and for hydraulic flow design calculations, the manufacturer recommends a Manning's n value of 0.009.

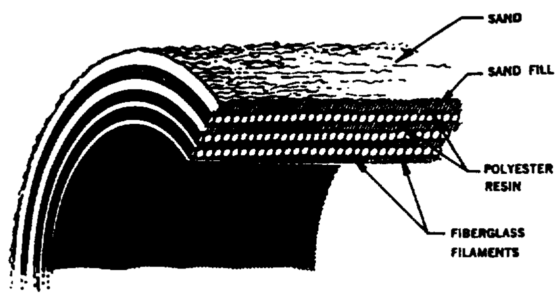


Fig. 19. Reinforced plastic mortar pipe composition.

Joints are of the bell and spigot type sealed with a fully contained round rubber gasket that produces joint tightness capable of preventing leakage and resisting root entrance.

This type of pipe has been used for new sewer lines and as a liner for deteriorated pipelines. When used as a liner, the reinforced plastic mortar pipe is pulled inside the old pipeline.

Manufacturers

Glass-reinforced pipe is manufactured by:
- Amercoat Corp., Brea, Calif.
- Ceilcote Co., Berea, Ohio
- Fibercast Co., Div. of Youngstown Sheet and Tube Co., Sand Springs, Okla.

Reinforced-plastic-mortar pipe is manufactured by:
- United Technology Center, Div. of United Aircraft Corp., Sunnyvale, Calif.

Section 11—Steel Pipe

Steel pipe is used for sewers in which its characteristics of lightness, imperviousness, flexibility, and resistance to internal and external pressures are applicable. It has found special application in locations where shock, ground movement, and external pressures may occur. Because of its flexibility, steel pipe will distribute deflection, buckling, or flattening loads in such a manner as to resist additional distortion without failing. Two types of steel pipe are available for use in sewer construction, smooth wall and corrugated.

Smooth-wall steel pipe

Smooth-wall steel pipe is used for above-ground installations, for force main or sewers operating under pressure, and for sewer lines suspended under bridges. In some instances, the pipe used for these applications is the same type as that used for water systems; in others, a pressure sewer pipe is used. The design, manufacture, lining, jointing, and testing of steel water pipe is covered in Manual of Practice No. 2.[24] A description of three major installations will serve here to show how such pipe is used in the wastewater field.

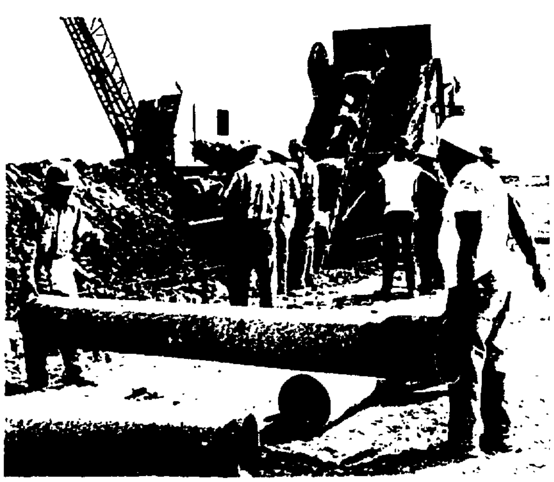
One notable example of a steel pipe used in a wastewater system is that which carries treated sewage from Baltimore, Md., to the Sparrows Point plant of the Bethlehem Steel Corp., where the activated sludge effluent is used as cooling water. A 60-in diam. steel line was constructed in 1942, and a 23,800-ft long, 96-in. diam. line in 1955. Total capacity of the two lines is 190 mgd. The larger line was laid in 40-ft sections welded together in the field. This pipe has wall thicknesses of 1/2, 9/16, and 5/8 in.; the three thicknesses being selected to meet the varying depth of cover conditions encountered. The pipe sections were coal-tar enameled, inside and out, and wrapped with 15 lb felt. Joints were coated and wrapped after welding.

Another notable steel pipe installation is the 10-mile long, 28-in. line that carries a treated industrial waste effluent from the Toms River Chemical Corp. in New Jersey to the Atlantic Ocean. The ocean outfall section is 3500 ft long.

The inside of this pipe is coated with coal-tar enamel 3/32 in. thick; the outside is also coal-tar-enamel coated and wrapped with felt. The outside of the outfall section was factory-coated with a 1/2-in. layer of asphalt. Before installation, the joints were welded and coated, and the ocean outfall section was wrapped with wire netting and sprayed with a 2-in. coating of high density concrete. As a further protection against electrolytic corrosion, a continuous zinc-ribbon anode was installed inside the entire pipe.

A third interesting steel pipe sewer is the 2-mile welded steel pipe, 18 to 36 in., installed as part of the influent sewer to the High Point, N. C., wastewater treatment works. Much of this pipe was installed on piers 8 to 35 ft above ground level.

Ten-foot section of reinforced plastic mortar pipe for sewer drain near Fresno, Calif.



Pressure sewer pipe

Pressure sewer pipe is a composite pipe consisting of smooth-wall welded steel pipe that is coated inside and outside and wrapped outside. It may be used when the project requires pressure sewer construction.

DESIGN

This type of pipe has been designed for various combinations of internal pressures and external backfill and live-load pressures. The internal pressure design is based on a unit stress in the pipe that does not exceed 50 percent of the minimum yield strength at maximum operating pressures (static head or gradient flow conditions, whichever is greater).[34] External load design is based on computed ring deflection that does not exceed 2 percent of diameter.[26]

CHARACTERISTICS

Steel pressure sewer pipe has characteristics of strength, resiliency, and ductility, which result from the composition of the metal. Careful lining and coating ensure a long life.

Physical characteristics. The product characteristics resulting from the design of the pipe cause this type of pipe to have a high beam strength. It is able to resist external loads caused by uneven bedding, unequal settling of fill, or accidental undermining of the pipe.

Both types of lining (coal-tar enamel and cement-mortar) have been shown by experience in Los Angeles, New Orleans, and elsewhere to have good resistance to abrasion and scour in force-main service.

Chemical characteristics. Coal-tar enamel linings in steel pressure sewer pipe are chemically inert and resistant to municipal and industrial wastes, hydrogen sulfide, acids and alkalies. Cement-mortar provides good protection for the

TABLE 22—DATA ON STEEL PRESSURE-SEWER PIPE

Cement-mortar lined

Nominal size (in.)	Thickness of mortar lining (in.)	Outside diam., (in.)	Pipe weight (lb/lin ft) Class 200	Class 225	Class 250	Class 275	Class 300	Class 325	Class 350	Class 375	Class 400
14	5/16	15.0	—	34.35	35.13	37.66	39.08	40.18	42.53	43.78	45.04
16	5/15	17.0	40.25	42.82	44.41	45.65	48.30	49.71	52.35	53.93	56.96
18	5/16	19.0	47.95	49.73	51.12	54.08	57.24	60.39	63.35	66.49	66.49
20	5/16	21.0	53.07	56.58	61.62	64.90	66.86	70.13	73.62	76.01	80.00
22	5/16	23.0	62.04	65.65	69.50	73.33	76.92	80.75	88.15	88.15	...
24	3/8	25.375	77.34	81.59	85.82	89.79	96.92	102.19	110.34	110.34	...
28	3/8	29.375	96.78	104.16	109.07	118.57	128.04	128.04	137.50	...	...
30	3/8	31.375	106.41	116.59	120.20	126.75	136.89	146.98	...	...	...
32	3/8	33.375	113.03	123.95	134.94	145.74	156.53	...	...	...	...
34	3/8	35.375	125.45	143.13	154.59	154.59	166.04	...	...	...	...
36	3/8	37.375	137.43	149.78	161.79	173.77	...	...	...	...	...

Note: Coal-tar enamel lined pipe is available in 8⅝ through 96-in. diam., in all required pressure classes, in lengths to meet design requirements up to 50 ft.

steel pipe against normal municipal and industrial wastewaters. It does not protect against attack by wastes of low pH, or by septic wastes, where hydrogen sulfide conditions develop. The outside coating and wrapping protect against acid soil conditions.

Hydraulic characteristics. Because steel pressure pipe is lined with coal-tar enamel or cement mortar, in accordance with the specifications for lining steel water pipe,[24] it has good hydraulic flow characteristics, with a Hazen-Williams C-value of 140+ for new pipe. In flow calculations, many designers use a C value of 135 for this type of pipe.

MANUFACTURE AND TESTING

Steel pressure sewer pipe is manufactured in the same manner as steel water pipe.[24] After the pipe lengths are produced, they are lined, either by centrifugally spun coal tar enamel or by centrifugally applied cement-mortar, to provide a dense lining for sewer service. Several layers make up the protective coatings. Table 22 shows data on dimensions and weights of available sizes of pressure-sewer pipe in different classes. The class numbers represent the working pressure (pounds per square inch) for which the pipe is designed, and the data for cement-mortar lined pipe. Sizes from 8-5/8 through 12-in. diam. are available only with coal tar enamel linings. Larger sizes are normally supplied with either cement-mortar linings or coal tar enamel linings. Regardless of the lining material used, the effective internal diameter is, for all practical purposes, equal to the nominal series given in Table 22.

JOINTS

Steel pressure-sewer pipe may be welded at the joints, if specifications require. For this type of jointing, the pipe ends may be square, beveled, or slip bell as specified. This type of pipe may also be joined by Dresser or other mechanical couplings.

Steel pressure-sewer pipe is generally furnished with an O-ring-type, rubber-gasketed bell and spigot joint that is self centering, flexible, and watertight under normal conditions of expansion, contraction, external live and earth load, settlement and vibration (see Fig. 20).

This joint, termed a stab-joint, is designed to withstand internal pressures up to 400 psi and external hydrostatic pressures of more than 100 ft head. Both bell and spigot ends are formed integrally during manufacture of the pipe.

This type of joint employs metal-to-metal contact of spigot against the inside of the barrel to provide support for the pipe barrel against imposed external loads. With this type of joint, a deflection of 3 degrees (depending on pipe size) is possible in laying.

If the project engineer desires to eliminate the discontinuity of pipe interior at the joint, the pipe can be lined in place in the field, with cement-mortar or cold applied mastics, either during or after assembly of the line.

Fittings that meet AWWA Standard C-208 are available for whatever purpose desired.

Corrugated steel pipe

Corrugated steel pipe is produced in two types: continuous seam and riveted. Riveted corrugated pipe is produced in two ways, depending on pipe size.

In smaller diameters, the pipe is formed from a metal sheet welded at one seam. In larger sizes, welded pipe is spiral welded. Large diameter riveted corrugated pipe is formed in the field by riveting together curved sheets to yield the desired diameter. This type of pipe is termed multiplate.

Corrugated pipe has found wide application for culverts and for drainage. Multiplate pipe in large sizes is used for this purpose. The usefulness of corrugated pipe for wastewater sewer installations is diminished by its relatively high roughness coefficient. Hydraulic flow characteristics may be improved either by lining the invert or lining the whole internal surface of the pipe. The pipe may also be lined in place, either with a cement-mortar or an epoxy lining. One interesting application of corrugated steel pipe is the placing of a sanitary sewer in a larger steel pipe storm drain as a means of separating domestic wastes from storm water.

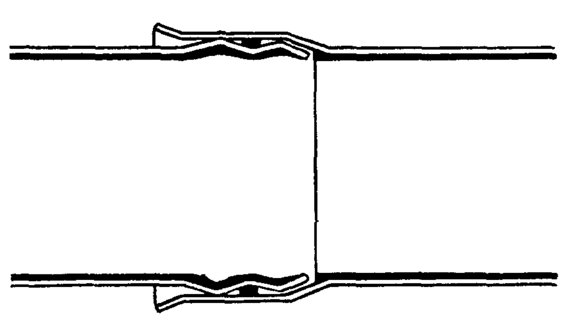


Fig. 20. Stab-type joint for steel pressure-sewer pipe.

Steel pipeline (96-in.) carries effluent from Baltimore activated sludge plant 4-1/2 in. to steel plant for use as cooling water.

DESIGN

When steel pipe is corrugated, its strength and ability to resist bending under superimposed loads is increased. Whether corrugated pipe is welded or riveted, the design begins with selection of the thickness or gage of the sheet metal.

There are two ways of determining the gage of metal to be used for a particular installation. The first makes use of published tables that have been developed from standards set by the American Association of State Highway Officials (AASHO). These tables are based on gross loadings of 20, 15, or 10 tons with and without live loads. Tables of this type are available from manufacturers of corrugated steel pipe. The second procedure is known as the ring compression method of design.[33]

Ring compression analysis. By mathematically analyzing corrugated steel pipe behavior in a backfilled trench, it is possible to calculate the required gage of the metal without relying on tables.

The method is based on the principle that corrugated steel pipe installed in a well-compacted backfill acts as a thin ring in compression, with uniformly distributed forces acting along the periphery of the structure. The calculation is expressed mathematically as

$$C = PR \qquad \text{Eq. 16}$$

where:

C = compression in the ring (lb per lin ft)
P = external radial pressure (lb per sq ft)
R = radius at point of measure (ft)

Compression is assumed to be constant throughout the ring (neglecting friction and bending).

Computation steps. There are six steps involved in designing a pipe structure by this method, as follows:

Dead load. Using a value of 100 lb per cu ft as the weight of the backfill, P from Eq. 16 becomes 100 lb per sq ft. Dead load therefore is

$$DL = HC \times P \qquad \text{Eq. 17}$$

where:

DL = dead load (lb per sq ft)
HC = depth of cover (ft)

Live load. Handbooks and published tables provide data on live loads from trucks of different weight. The method for calculating live loads can be the same as that used in the design of cast iron pipe, as described in Manual of Practice No. 2 (page M15).[24] Diagrams and tables for truck loads are given in AWWA Handbook H-1.[35]

Compression ring. The dead load is added to the live load, and the sum is multiplied by one half the span (ft) or by the pipe radius (ft).

Gage determination. The compression value is multiplied by a safety factor of three for corrugated pipe or by a factor of four for multiplate structures. Then the proper gage is selected from a manufacturer's table of seam strengths.

Flexibility. The flexibility is checked to ensure that the pipe structure will have adequate moment strength for handling and for resisting the shock of backfilling and the ultimate backfill load. The following formula has been recommended for calculating the maximum flexibility factor:[36]

$$FF = \frac{D^2}{EI} \qquad \text{Eq. 18}$$

where:

FF = flexibility factor
D = pipe diameter (in.)
I = moment of inertia of wall (in.)
E = modulus of elasticity (psi)

Minimum cover. In calculating minimum cover, the assumption is made that a round pipe becomes a compression ring with top dead load balanced at a cover of approximately one-fourth the diameter. During backfilling, the pipe must have a great enough bending resistance to withstand compaction pressures. Because of this bending strength, the minimum cover required may be reduced to one-eighth instead of one-fourth the diameter, but the minimum cover should never be less than 1 ft.

CHARACTERISTICS

Corrugated steel pipe has both strength and flexibility, and, because of its configuration (corrugations), it distributes the load upon it more or less uniformly around its entire periphery. Unit pressure at top and bottom is as little as one-third that on a rigid pipe structure; this fact has a direct bearing on the life of the pipe. Under normal conditions, coated corrugated pipe will have an acceptable durability.

Unless coated, this type of pipe is subject to attack by wastes of low pH, hydrogen sulfide, and other corrosive materials. Coatings and linings will be discussed later.

The hydraulic flow characteristics of corrugated pipe depend on whether or not the interior of the pipe is coated and lined. For example, in sewer design computations using Manning's formula, the following n-values are recommended:

Uncoated, 1/2-in. corrugations	0.024 to 0.026
Asphalt coated and 25 percent paved	0.021 to 0.023
Smooth asphaltic lining	0.012 to 0.015

MANUFACTURE

The gage of metal used is no. 16 for pipe up to 21 in. in diameter. Lower gage numbers (heavier plate) are used for pipes 84-in. in diameter or larger. Copper-steel alloy is used in some types of pipe.

In forming corrugated pipe, sheets of steel of proper size for the required diameter are rolled and formed into corrugated sections, then riveted along the longitudinal and circumferential seams in the valleys of the corrugations. Multiplate pipe sheets are formed to the proper radius.

Helical pipe is lock seamed into an integral unit of the desired length. In this type of pipe, the corrugations are formed diagonally around the pipe instead of at right angles

TABLE 23—RANGE OF WEIGHTS OF CORRUGATED STEEL PIPE

Pipe type	Weight (lb/ft) 6-in., 16 gage	36-in., 12 gage	96-in., 8 gage
Standard (galvanized)	5.8	51.0	212
Fully asphalt coated	7.0	59.5	231
Half coated, invert paved	8.0	63.2	241.5
Fully coated, invert paved	9.0	70.7	251

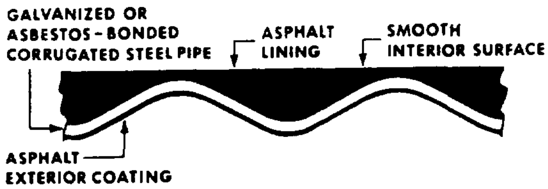


Fig. 21. Procedure for providing smooth interior surface in corrugated steel pipe.

to the length of the pipe. The continuous helical seam is tightly locked and folded automatically.

Corrugated pipe is fabricated in sizes from 6- to 96-in. in diameter in the regular corrugated or helical-type corrugated product. Pipe lengths run from 20 to 30 ft. The weight per foot of pipe depends on the pipe diameter and gage of metal used, and whether or not the pipe is coated, partially coated and paved, or fully coated. The examples in Table 23 indicate approximate weights.

Lining and coating. Corrugated pipe may be obtained with different types of coatings and linings. All standard corrugated pipe is galvanized with zinc coating (2 oz per sq ft). Bituminous coatings may be applied over the galvanized surface to provide additional protection. Pipe may be partially coated, with the invert paved. Some pipe is lined with asphalt to produce a smooth interior surface throughout the pipe (see Fig. 21). The asphalt is applied centrifugally.

Another type of coating is used to produce asbestos-bonded pipe, which provides resistance to severe corrosion conditions. This material is produced by pressing asbestos felt into the surface of the molten zinc coating as the flat sheets come from the galvanizing rolls. The sheets are then passed through equipment that saturates the exposed fibers. After the excess saturant is squeezed out, the sheets are cooled, corrugated, and formed into pipe, then coated with hot-dip bituminous coating.

Joints are made in the field by riveting or spot welding, then coated for protection. Shipping is by truck or flatcar.

Manufacturers

The following companies manufacture steel pipe, but not all those listed produce pipe of all the types that have been covered in this section.

American Cast Iron Pipe Co., Birmingham, Ala.
American Pipe & Construction Co., Monterey Park, Calif.
Armco Steel Corp., Metal Products Div., Middletown, Ohio
Bethlehem Steel Corp., Bethlehem, Pa.
Lone Star Steel Co., Dallas, Tex.
Republic Steel Corp., Cleveland, Ohio
Southern Pipe & Casing Co., Azusa, Calif.
Thompson Pipe & Steel Co., Denver, Colo.
Traverse City Iron Works, Traverse City, Mich.
Trinity Valley Iron & Steel Co., Fort Worth, Tex.
U. S. Steel Corp., Pittsburgh, Pa.

Section 12—Wrought Iron Pipe

In the field of wastewater disposal, wrought iron pipe is used in pumping stations, for force mains, stream crossings (both underwater and aerial), outfall lines, sewer system downshafts, and in treatment plant piping systems. Inplant piping systems that may consist of wrought iron pipe include influent and effluent lines to various processes, lines for handling all types of sludge, for transporting chemical solutions, gas, air, oil, water, sewage, and chlorine, for sludge digester heating systems, and for plant heating systems. For some applications, galvanized wrought iron pipe may be used.

Wrought iron pipe is also used for guard railings. Other applications of wrought iron in wastewater disposal systems include manhole steps, weir plates, bar screens, tide gates, etc.

Design and manufacture

Wrought iron pipes and fittings used in wastewater disposal systems are the same as those manufactured for use in water supply systems.

The composition of wrought iron pipe, its physical, chemical, and mechanical properties, methods of manufacture, coating and lining, handling, and shipping, as well as the available sizes, are covered in some detail in Manual of Practice No. 2 (pp. M33 to M35).[24]

Characteristics

There are several characteristics that make wrought iron pipe useful in wastewater disposal and inplant piping systems. For example, it is resistant to internal and external corrosion, has mechanical strength to resist shock and fatigue, has a smooth internal surface to provide good hydraulic flow characteristics, has abrasion resistant properties, is weldable, and can be coated and lined to meet conditions encountered in operation.

Manufacturers

The following companies produce wrought iron pipe for use in wastewater disposal systems.

A. M. Byers Co., Ambridge, Pa.
Grinnell Co. Inc., Providence, R.I.

Section 13—Pipe Lining in the Field

The lining and coating of various kinds of pipe during manufacture has been discussed in the previous sections of Part 2. This section is devoted to the lining of new pipe in the field, either before or after placement. Lining-in-place of existing sewers is a maintenance matter and is discussed in Part 4.

Cement-mortar

Cement-mortar lining may be applied to pipe sections before installation or to new lines after installation. The equipment and method of application used are the same as those for water main lining-in-place (see Manual of Practice No. 2, p. M 48).[24] This method of lining is applicable to any type of pipe where lining appears to be warranted to meet conditions in the sewer.

In 4- to 144-in. diam. pipe, the lining may be done by special machines that utilize centrifugal application of the cement mortar. The mandrel process for applying cement-mortar linings may be used for pipes from 4 to 16 in. in diameter.

Epoxy linings

Acid-resistant epoxy mortar lining may be applied at the manufacturer's yard to new concrete pipe or in the field to pipe from 24 to 144 in. in diameter.

The lining material is composed of liquid epoxy resin, amine hardener, and inert material. The epoxy resin is a condensation product of biphenol and epichlorhydrin (in various ratios). When epoxy resins are reacted with amines, amides, and similar chemicals, cold-cure epoxy compounds are produced.

A number of formulations for sewer lining are available to resist various types of wastes, including oils, greases, acids, alkalies, etc. The formulations consist of a liquid epoxy resin modified with an amine hardener to provide flexibility, high impact strength, fast curing, and good chemical resistance. The liquid resin-hardener is combined with clean silica sand, coke, or other inert materials to provide hardness and abrasion resistance and to improve the thermal expansion characteristics of the lining.

The method of applying acid-resistant epoxy mortar linings in the field consists of lining each section of the pipe before installation, although the whole sewer line may be lined in place after installation. The epoxy mortar lining is applied centrifugally by a special machine (see Fig. 22). This type of lining may also be applied to pipe by the manufacturer.

Before linings are applied in place, joint areas in concrete pipe are filled with cement mortar and troweled smooth. When the pipe is lined at the factory or on site before installation, the bell and spigot areas are painted with a roller or brush, using a coating of 100 percent solids epoxy. Additional protection may be provided by pointing up the joints after placement.

Other lining materials

A number of commercial lining materials may be brushed or sprayed on in the field. Included in these materials are asphaltic and coat tar substances, chlorinated rubber paints, vinyl plastic formulations, and epoxy resins. The selection and application of such materials should be made only after consultation with the manufacturers of such products.

Fig. 22. Epoxy-mortar lining of concrete pipe in the field before installation.

Manufacturers

Many companies provide sewer lining services or manufacture materials for lining new sewer pipe before or immediately after installation. The following list is not necessarily all-inclusive. Furthermore, none of the companies listed here provides all the types of linings and lining materials discussed in this section. Some of these companies provide only one or two types of linings, others provide application service, still others supply only the coating material.

Ace Pipe Cleaning Co., Inc., Kansas City, Mo.
Amercoat, Inc., Brea, Calif.
American Pipe and Construction Co., Monterey Park, Calif.
Centriline Div., Raymond International, Inc., New York, N. Y.
Halliburton Co., Duncan, Okla.
Inertol, Inc., Newark, N. J.
Koppers Co. Inc., Tar and Chem. Div., Pittsburgh, Pa.
Mainlining Service, Inc., North Tonawanda, N. Y.
National Power Rodding Corp., Chicago, Ill.
National Water Main Cleaning Co., Newark, N. J.
Pipe Linings, Inc., Wilmington, Calif.
Protectowrap Co., Denver, Colo.
Reilly Tar and Chem. Co., Indianapolis, Ind.
Robinson Pipe Cleaning Co., Canonsburg, Pa.

Section 14—Inplant Piping Systems

In the selection of pipe materials for inplant piping systems, the design engineer must consider the particular use of a pipeline and the conditions to be encountered. For example, consideration must be given to the material's ability to withstand attack by the fluid carried and to withstand the expected operating pressures and temperatures. Obviously, a pipeline that will carry an acid solution must be acid-resistant; lines intended to carry a liquid having a high grit content should be abrasion-resistant; heating system lines should be unaffected by temperature; lines for carrying digestion tank gas should be resistant to low pH, hydrogen sulfide, etc.

Pipelines that carry raw sludge may become coated internally with grease layers, which must be removed at intervals. Such grease accumulations may be removed by pumping hot water through the lines or by using mechanical cleaning equipment. If hot water cleaning is used, the pipe and its joints must be capable of withstanding the expansion caused by the temperature increase. If mechanical cleaning is used, the lines must be able to withstand the scraping action of the equipment.

Lines that become clogged by the deposition of calcium carbonate, as in the vacuum filter discharge from lime-condition sludge dewatering operations, may have to be cleaned by acid.

Within such restrictions as may be imposed by the conditions mentioned or other operating conditions, the design engineer has a wide range of materials available for use in inplant piping systems, including asbestos-cement, cast iron, concrete, reinforced resins, plastics, steel and wrought iron. Clay pipe may be used for inplant sewer systems; rubber (both hard and flexible) or glass may be used for chemical feed lines, copper or brass may be used for lines serving hydraulic or pneumatic valve or instrument systems, etc. This manual will not attempt to cover brass, copper, glass, or rubber piping materials.

PART 3 / INSTALLATION PRACTICES

Section 1—Trenching Practices

The practices involved in excavating trenches for sewer pipe are generally applicable to all types of pipe materials. For information on tunneling, see WPCF Manual of Practice No. 9.[26]

Excavation

Trenching for sewer lines, like that for water lines,[24] may be done by hand or by trenching machine, backhoe, clamshell, dragline, or front-end loader. The choice of machine may depend on the location of the sewer; that is, in open country, one type of equipment might be used, but in built-up or paved areas, another type of equipment might be more practical.

Trench depth. In general, the trench should be dug no deeper than necessary for meeting the elevation of the gradeline as established by hydraulic design. Generally, too, it is not necessary to lay a sewer below the frostline unless there is a possibility of frost heave, but, as pointed out previously, the trench-bottom grade should avoid "bucking" the surface grade, wherever possible, to avoid excess excavation. Except in rock ledge or water bearing soil, mechanical excavation is usually stopped about 4 in. above the invert elevation, and the remaining excavation is done by hand. (See discussion under bedding, below.)

Trench width. For a discussion of trench width, see Part 2, Section 2, and also Manual of Practice No. 2.[24] The minimum width of trench used must allow room for the pipe installers to work. Widths given in Manual of Practice No. 2 (p. M38)[24] for asbestos-cement, cast iron, and concrete pipe are applicable to sewer pipelines. When sewers are laid on a curve, wider trenches are required for most types of pipe (except for those that are flexible).

For clay pipe sewers, the maximum permissible trench width is usually set forth in the project specifications, but it is generally equal to the outside diameter of the pipe socket (or bell) plus 12 in. Recommended trench widths are shown in Table 24.

Excavated material. The soil excavated from the trench should be piled on one side of the trench in such a way as to prevent it from rolling back into the open trench. The pile should be placed far enough from the side of trench to allow walking room between the pile and trench. Pipe should be strung on the side of the trench opposite the pile.

Under most conditions, a trench should be opened for no more than two pipe lengths ahead of the installation.

The procedure to be followed if rock or bad soil is encountered is generally the same for sewer pipe as for water lines.[24] Where ledge rock is encountered, excavation is usually to a depth of 12 in. below grade. For other rock formation excavation procedures, see Manual of Practice No. 2.[24] In bad soil, excavation below grade and placement of selected bedding may be done for two reasons: To protect pipe that is not acid-resistant, and to compensate for soil (particularly fill) that will not provide good support.

TABLE 24—RECOMMENDED TRENCH WIDTHS FOR CLAY PIPE[27]
(Measured at top of pipe)

Pipe size (in.)	Trench width (ft)
6	1-3/4
8	2
10	2-1/4
12	2-1/2
15	2-3/4
18	3
21	3-1/2
24	3-3/4
27	4
30	4-1/2
33	4-3/4
36	5

Sheeting and bracing

The need to use sheeting and bracing in sewer construction projects depends on the depth of trench, condition of the soil, requirements of state accident commissions, and local ordinances, where they exist. Safety of both workmen and the public is essential, and trench sidewalls should be protected against cave-in whenever the possibility exists.

Simple or skeleton bracing may be obtained with 12-in. planks (2 or 3 in. thick) braced by pipe trench jacks. For wider trenches or for poor soil, a system of wales and timber cross struts, or a movable shield, may be required (see Fig. 17 in Manual of Practice No. 2[24] or see WPCF Manual of Practice No. 9.)[26]

Dewatering

Sewer pipe should be laid in dry trenches, not only to ensure good bedding, but also to allow jointing procedures to be done properly. There are two basic methods for dewatering trenches: simple pumping from the trench and well point pumping.

In the simple method, the suction line of a contractor's pump is dropped into the trench, and the pump is operated as necessary to remove accumulated water. One variation of this method involves placing a 4- to 6-in. bed of suitable drainage material below grade in the trench bottom to facilitate flow of water to the pump suction line. Another variation is the placement of a perforated drain tile or pipe in the bed of drainage material, gravel, or rock used as selected bedding for the sewer pipe.

The other basic method of dewatering employs wellpoints driven on either side of the trench to a depth below the level of the trench bottom. The system is operated continuously to keep the ground water level below the trench bottom.

Section 2—Pipe Installation

Many practices involved in installation of sewer piping are the same as those for water mains; some are applicable to different types of pipe material. The following discussion will cover both general practices and practices applicable to particular pipe materials.

Pipe handling

In the unloading of sewer pipe from trucks or railroad cars and the subsequent handling and stringing along the right of way of the sewer, care and attention should be exercised, as in handling water supply pipe. This subject is discussed in Manual of Practice No. 2 (p. M37).[24]

The admonitions given there are also applicable to types of pipe not discussed in that manual, e.g., bituminized-fiber, clay, reinforced resin pipe, etc.

Bedding

Part 2, Section 2 of this manual contains a discussion of the relation of bedding conditions to supporting strength of the pipe, and the relation of supporting strength to the selection of pipe material and pipe class. Besides supporting strength, three factors must be considered in selecting the type of bedding to be specified on a sewer construction project. These factors are: cost of construction, stabilization necessary to overcome poor soil conditions, and possible soil subsidence during the life of the sewer.

Good soil. In good clay soil that is free of excessive water, sewer pipe can be laid simply; the only requirement is that the trench width and bottom shape conform to the pipe dimensions. Overexcavation and backfilling may be less costly than trimming of trench bottoms to fit the pipe shape. Such backfilling is done with pea or roofer's gravel to provide a bedding that shapes iteslf to the pipe and provides the necessary supporting strength.

Poor soil. Soft or poor soils may require overexcavation to some appreciable depth with backfill of coarse gravel or rock covered by pea gravel. The need for such stabilization usually can be determined only as excavation proceeds.

Bad soil. Where soil is very poor or is subject to future subsidence, it may be necessary to install timber platforms, reinforced concrete cradles, or piling driven to grade before excavation.

Joint holes. As in the laying of water pipe, the trench bottom must provide for the particular type of joint used. Joint-hole preparation for asbestos-cement, cast iron, concrete, plastic, steel and wrought-iron pipe is covered in Manual of Practice No. 2 (p. M39).[24]

Pipe placement

There are a number of general directions that apply to the laying of all types of sewer pipe:

Individual lengths of pipe should be inspected for damage before being lowered into the trench, and dirt or foreign matter should be removed, particularly at the ends.

Pipe lengths should be handled with care in being lowered into the trench, whether the lowering is done by hand, by snub ropes, or by machine. Pipe should never be pushed off the side of the trench, no matter how shallow.

Bell and spigot type pipe should always be laid upgrade, with the bell facing upgrade. Pipe that uses other types of joints may be laid in either direction, but it is preferable to lay it upgrade because the trench will act as a drain, reducing the soil moisture content.

When pipelaying is not in progress, the open pipe end should be closed with a tight fitting stopper to keep out foreign matter.

Where the sewer direction changes on a predetermined curve, the pipe lengths should be deflected no more than the maximum recommended by the manufacturer. For deflection data on asbestos-cement, cast iron, mechanical joint, and concrete pipe see Tables 35, 36, 37 in Manual of Practice No. 2.[24] Allowable deflections in clay pipe sewer lines are as follows:

Pipe size (in.)	Deflection (in./lin ft)
4–12	1/2
15–24	3/8
27–36	1/4

Pipe grade and line

The grade of the trench bedding, that is, the sewer invert grade, as well as the line, should conform to the design and specifications; it is the inspector's responsibility to check this conformance. Probably the most common method of ensuring that the desired grade is obtained is the use of grade bars (batter boards) and taut strings, checked by standard surveying instruments.

Another method for ensuring that the desired pipe grade is obtained employs a laser beam produced by an automatic grade light.[38] Utilizing a single batter board and pole arrangement at one point (e.g., a manhole) and a mirror (pipe target) at the next joint to be made, it is possible to maintain both correct grade and a straight line as the pipe lengths are laid.

The method has several advantages: pipelaying may proceed directly behind a digging machine; the setting of batter boards is eliminated; excavation to grade is more accurate because of constant reference; less manpower is required; and pipelaying time may be cut as much as 20 percent.

Jointing procedures

According to WPCF Manual of Practice No. 9,[26] "the characteristics of a good joint in sewer pipe include watertightness, resistance to root penetration, resistance to corrosion, a reasonable degree of flexibility, and durability." The desirability of these characteristics is evident in light of previous discussion of infiltration, root penetration, etc.

The characteristics desired may be obtained with any type of currently available joint if care is used in making the joint. Joint flexibility is not possible with flange joints, screwed couplings, and welded joints. Flanged joints are used only for inplant piping, where flexibility is unnecessary. Screwed couplings and welded joints (either electric or solvent-weld) usually are made on pipe that is made of materials with some degree of inherent flexibility. The joints available for each pipe material are discussed in Part 2.

The jointing procedure used in sewer construction depends on pipe material, type of joint, and the type of equipment used for mating the joint. The following discussion is organized on the basis of pipe material. Several of the various pipe materials utilize a rubber-gasket joint and different methods of securing the joint.

One method applicable to rubber gasket joints for all types of pipe employs a unique device known as a "pipe popper" (Fig. 23). The steel and aluminum device, for use on sewer pipe 18 to 42 in., consists of two main sections, a spring-loaded anchoring assembly, and a removable jacking unit. The sketch in Fig. 23 indicates the construction arrangement and the operation of the device. Joint mating is performed quickly by one man.

Methods of cutting pipe in the field to make joints or to insert fittings will be covered in Manual of Practice No. 4.

ASBESTOS-CEMENT PIPE

The same general type of coupling and rubber-ring gasket joint is used for both pressure and nonpressure asbestos-cement pipe. Jointing is essentially the same as for water mains (see Manual of Practice No. 2, p. M40.)[24]

The pipe is delivered with a rubber ring and the coupling in place on one end of the pipe, generally termed the "belled end." As in the laying of all bell and spigot pipe, the bell end is laid in the direction of construction.

The joint is made in the following manner: the inside of the coupling is cleaned, and the rubber gasket is inserted in the depression inside the open end of the coupling; the "unbelled" end of the pipe is properly lubricated and inserted

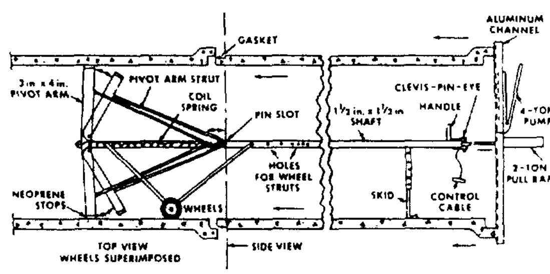


Fig. 23. Device for mating gasketed pipe joints.

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into the coupling; and the pipe is "pushed home" until the joint is seated properly.

"Pushing the pipe home" may be done by using a crowbar to exert pressure against a block of wood across the free end of the pipe.[24] A mechanical puller device may be used to seat large sizes of pipe, but the use of such equipment should be in accordance with manufacturer's directions.

BITUMINIZED-FIBER PIPE

In sizes up to 8-in. diam., bituminized-fiber pipe is furnished with 2-degree tapered ends and couplings to match; sizes from 8 to 18 in. are furnished with push-fit collars. Pipe ends may be cut or tapered in the field. Large size pipe may be joined by butyl-rubber collars tightened by steel bands.

For the tapered-end or push-fit collars, jointing is accomplished by placing the 12-in. coupling on the forward end of the pipe, then placing a wooden block over the coupling and tapping the block with a hammer or light sledge to drive the coupling tight. The next length is then inserted into the cleaned, free end of the coupling and driven home by pressure exerted against a block at the next coupling. More secure joints and tighter seals may be obtained, if required, by brushing a solvent-adhesive compound into the free end of the pipe before it is inserted into the coupling.

CAST IRON PIPE

Joints on cast iron pipe sewers are made in the same way as those on water supply lines, whether the type of joint is bell and spigot, mechanical, push-on, or flexible ball and socket. Details of jointing procedures for cast iron pipe joints are given in Manual of Practice No. 2 (pp. M40).[24]

CLAY PIPE

Clay pipe joints are of the bell and spigot type, therefore, jointing procedures are determined by the materials used to make the joint tight. Several kinds of material, in different forms, have been or are used in making up clay pipe joints.

Mortar-jute. Joints made with this material are no longer recommended because they are rigid, are not resistant to acid, and are hard to make up properly, particularly beneath the pipe. This type of material was the first used in making "tight" joints. The procedure consisted of calking oakum or jute into the rear of the annular space between the bell and spigot, then packing with cement mortar.

Pressure mortar. This type of jointing material is applied by packing mortar against a removable flange form. Although joints made with this material were an improvement over mortar jute joints, the disadvantages of cement-mortar were not eliminated.

Hot-poured bitumen. A joint made with this material is known generally as a hot-poured joint. The jointing procedure is very much like that used for lead joints on bell and spigot cast iron pipe.[24] The spigot end of the clay pipe is centered in the bell by a ring of calked jute, then melted bituminous material is poured into the joint. The joint is provided with an asbestos-rope snake and gate to permit pouring and to hold the melted material until it cools and sets. The cooled material is then calked into the bell to produce a tight seal.

Disadvantages of bitumen joints include the tendency to become brittle when cold and to flow in warm weather; the difficulty of pouring in cold weather; and the tendency to form steam with extraneous moisture on the pipe surface, causing impairment of surface adhesion or appearance of fissures in the sealing block.

Cold bitumens. There are three methods of making joints with cold bituminous materials. These procedures do not have the disadvantages of hot-pouring procedures, but the weakness of the material—the tendency to crack in cold weather and flow in warm weather—is the same.

Buttered-bitumen. Another material used for making clay pipe joints is a plasticized bitumen, in which a softening agent has produced a "butter" that can be troweled into the annular space around the spigot end in the bell. This material will air-set as the "solvent" evaporates.

Ribbon-gasket. An extruded ribbon gasket, which may be fortified with fibers or dust, may be used for making joints. The ribbon is wound around the pipe and calked into the bell, without using heat.

Slip-seal. In making slip-seal joints, which are also called die cast or premolded joints, complementary precast rings are placed around the spigot and inside the bell. Both rings have a tapered design. When pushed together, they become wedged, causing the joint to become sealed. These rings are generally cast on the pipe at the factory.

Sulfur-silica. This type of material is a mixture of sulfur and sand; it is poured hot and sets as it cools. It tends to be brittle and may be attacked by sulfur-eating bacteria.

Compression joint. Materials that may be used in making this type of joint are natural or synthetic rubber, e.g., neoprene, or plastics and resins, such as polyvinyl chloride, polyesters, polyurethanes, epoxies, etc.

These materials all have the same advantages: they form flexible joints that allow for maximum deflection; they are resistant to the acids, alkalies, and gases generally found in a sewer; they do not require the use of a spacing material such as jute; they are not subject to shape changes during storage, regardless of weather or temperature; they are resistant to shear loading; when designed for the proper residual compression, they resist leakage, root penetration, deflection and shear; and they do not require the use of heat in the jointing process. Only one disadvantage is noted; some wastes may attack or tend to dissolve these jointing materials. These effects can usually be avoided by proper selection of materials.

These jointing materials are manufactured in accordance with ASTM Des. C425-60T, which also specifies laboratory test requirements and field performance and acceptance tests. There are three types of joints covered by this ASTM specification.

Type I. The same resilient joint material is used in the bell and on the spigot. Either one of the rings may differ in hardness from the other, but controlled complementary design ensures a positive mating pattern of closure.

Type II. Jointing material on the spigot end may differ in composition from that in the bell, and the hardness and resiliency of one may differ from that of the other, but the controlled complementary design will ensure proper mating and closure.

Type III. The jointing material is a single, true-round, resilient gasket or compression ring. It has a controlled and calculated final shape within the annular space after the joint is made. The gasket or ring may or may not be attached to the spigot or inserted in the bell at the time the pipe is manufactured.

Make-up procedure. The procedures for making up these compression ring joints are practically the same for all types. Lubricating materials are applied to the pipe end or gasket to offset frictional resistance during the insertion of the spigot into the bell. Pressure is applied to the end of each pipe to force it home and provide the desired joint.

CONCRETE PIPE

The jointing procedure for concrete pressure pipe in a force main or pressurized sewer is the same as that for concrete water mains, as described in Manual of Practice No. 2 (p. M41).[24] For gravity sewer lines, the choice of the jointing procedure will depend on the type of joint and jointing material used. Regardless of joint type or material, "construction" should be done in a manner that will ensure watertightness and resistance to root penetration.

In preparing project specifications, the design engineer will call for one of four types of joints (bell and spigot, tongue and groove, modified tongue and groove, or a collar of concrete or other material) and for one of three types of jointing procedures (using cement mortar, commercial jointing compound, or single rubber ring gasket).

Jointing compounds. A number of commercial products are available for use with bell and spigot, tongue and groove, or modified tongue and groove joints. The compounds include combinations of coal tar and mineral fibers, bitumastic, creosote, sulfur-silica, asphalt, resins and gums, and various other patented materials. The jointing compound should be selected on the basis of experience.

Cement-mortar bell and spigot joint. In making up this type of joint, the interiors of both the bell and the spigot are cleaned and wetted and a stiff cement-mortar (one part portland cement and two parts clean fine sand) is applied. The steps involved in making the joint include placing the mortar, fitting the spigot into the bell, forming a mortar bead around the joint inside the pipe, and smoothing the mortar bead.[29]

Cement-mortar tongue and groove. The first step in making this type of joint is the cleaning and wetting of both the tongue and the groove. Then cement mortar is carefully placed under the pipe and in the bottom of the joint. The free pipe is inserted into the previously laid section, and the annular space is filled with mortar. During the fitting operation, mortar is squeezed out onto the inner and outer surfaces of the pipe. The inner joint surface is smoothed by a long-handled brush; the outer bead pointed by trowel.

Diaper joint on bell and spigot. The procedure for making this type of joint begins with calking jute into the bell. Next the joint is wrapped with a diaper cloth of heavy canvas, the edges of which contain flexible wire, and the wires are tightened. A wet sand-cement grout is then poured into the joint or pumped in through a funnel, using a plunger pump. The diaper is left in place after filling. A tight joint is obtained, even if the joint is made in a wet trench.[29]

Diaper joint on tongue and groove. In making this type of joint, a cheese cloth dipped in portland cement-mortar is wrapped around a conventional tongue and groove joint. An 8-in. wide diaper is used to hold a 1/2-in. layer of cement-mortar in place during curing. The band is cured with a covering of moist earth, sand, canvas, or burlap. If backfilling is not done immediately, curing with water for 48 hr is required.[29]

Cement-mortar oakum joint for bell and spigot. The procedure for making this type of joint is essentially the same as those described for bell and spigot water pipe[24] and for cement-mortar joints on clay pipes. There is one difference: the oakum is dipped in cement-mortar (one part cement to two parts sand), and the calking is done about four or five lengths behind the placement operation.[29]

Cement-mortar oakum joint for large diameter tongue and groove. In this jointing procedure, the tongue and groove pipe is laid as previously described except that oakum is used in addition to the cement-mortar. In pipes larger than 36-in. diam., the calking is done from inside the pipe. The oakum is dipped in cement-mortar before being placed. For smaller pipe sizes, calking is done from the outside.[29]

Concrete collar. A prefabricated reinforced concrete collar is attached to one end of each pipe length at the manufacturing plant. The collar is calked in layers onto the pipe end with neat cement (two parts cement to one part sand) until the collar is full. Approximately half the collar length extends beyond the end of the pipe. Reinforcing in the collar should correspond to reinforcing in the pipe, and the collars should be made by the process used for the pipe.

Collars are at least 7 in. long and range in thickness from 1-3/8 in., for 8 in pipe diam., to 5-in. (minimum) for 72-in. pipe.

When the pipe joint is made up, the uncollared end of a pipe section is inserted into the collar of a previously laid pipe section, and the joint is sealed by calking cement-mortar (two parts cement to one part sand). After the joint is made up, it is covered with a moist cloth and cured for three days.[29]

Cement-mortar, tongue and groove, with external bands. In some installations, external bands of concrete mortar are used on tongue and groove joints. The jointing procedure consists of hand placing a stiff mortar around the joint to form an encircling band. The operation is usually carried out four or five lengths behind the laying operation. Backfilling of the trench to the springline of the pipe is done immediately to prevent the band from falling off. The mortar used in making the band is stiffer than that used between the joint surfaces. Protection and curing are essential to the strength of the final joint. Such external bands are usually not required on heavy-wall pipe with tongue and groove joints but may be used on lines less than 24 in. in diameter. The details of making this type of joint appear in the Concrete Pipe Handbook.[29]

Single-rubber-ring gasket. Because of its economy, ease of construction, and satisfactory performance record, the single-rubber-ring gasket joint has largely superseded all other types of joints for use on concrete sewer lines.[29]

In the manufacture of the pipe, the ends are produced with attention to close tolerances, and a space is left for the rubber ring. The procedure for making up the joint is generally the same as that described previously for asbestos-cement, cast iron, and clay pipe joints utilizing flexible ring gaskets.

Jointing compounds. The procedure for making up bell and spigot joints with commercial compounds such as bitumastic, asphalt, resins, etc., is practically the same as that described previously for clay pipe.

Fiberglass reinforced collar. This type of joint closure is used on concrete pipe with recessed spigots on both ends, each spigot having a recessed space to hold a rubber ring gasket. The band or collar is made of epoxy resin impregnated with fiberglass rovings and fiberglass fabric in various combinations. The glass strands are wound circumferentially on a form to obtain the desired tensile strength and elasticity. This band is generally used in pressure pipe systems and is corrosion-resistant, resilient, and flexible; it permits up to 1-in. angular deflection on curves, and is made in sizes from 12 to 72 in. inside diameter. The jointing procedure consists of placing the rubber ring gaskets on the ends of the pipe and seating the band.

Noncircular pipe jointing. When elliptical or other noncircular pipe is installed, it should be placed in accordance with the manufacturer's labels of "bottom" or "top," and should not be more than 5 degrees from the vertical or horizontal axis. Care must be exercised in placing the pipe joint to ensure that each section is in the same vertical or horizontal axis as the previous length. Tongue and groove joints are used, and the procedure for making up the joint is the same as described previously.

PLASTIC PIPE

The procedure used for jointing plastic pipe depends on the type of pipe, pipe size, and type of joint. Generally, the joints are made outside the trench, particularly for small sizes, and the pipe is then lowered into the trench.

ABS pipe. In small sizes, this type of pipe may be joined by victaulic or Dresser-type joints or by solvent welding. In the solvent-weld procedure, the tapered pipe ends (male and female) are brushed by a solvent that softens the plastic, then pushed together and the two pipe sections turned slightly against each other to form a tight grip. Chemical interaction between the two ends takes place as the solvent evaporates, and the pipe is permanently joined.

PE pipe. The jointing procedures for PE pipe were given in Manual of Practice No. 2 (p. M26).[24]

PVC pipe. The solvent-weld method of jointing is applicable to PVC pipe joints employing couplings and to bell and spigot PVC pipe.

Some PVC pipe produced has a bell end in which a rubber O-ring gasket is fitted. Jointing is accomplished by pushing the spigot end into the bell, thereby compressing the O-ring and forming a watertight seal.

Styrene-rubber plastic pipe. This type of pipe is joined using a coupling and the solvent-weld procedure. The inside of the coupling and the outside of the pipe end are brushed with a "cement" solvent; the pipe end is inserted into the coupling and given a quarter turn to distribute the cement. Within 20 to 30 min, the joint is dry. Joints may be made either inside or outside the trench.

Truss-type plastic pipe. This type of pipe is composed of an ABS plastic and utilizes a coupling and chemical welding process for making the joint. The pipe end and inside of the coupling are first brushed with a primer, then with a "cement." The pipe end is then "shoved home" into the coupling and given a quarter turn. Sufficient cement should be used to produce a continuous bead between the end of the coupling and the pipe surface. When making the joint, the pipe installer must make certain that the pipe is "all the way home" upon insertion. If it is not, he must remove the pipe immediately, clean the ends and the coupling, and repeat the cementing operation.

Plastic lined pipe. This type of pipe is generally joined by flanged fitting or couplings screwed to threaded pipe ends.

Plastic liners. Plastic liners for concrete sewers are described in Part 2, Section 8. This lining material is joined by heat-welding the liner in one section of pipe to that in the next, forming a continuous lining.

REINFORCED RESIN PIPE

Glass-reinforced resin pipe is joined by a solvent-weld procedure using couplings. Joints may also be made by wrapping the butted or jointed pipe ends with fiberglass cloth impregnated with a resin and softened by a solvent. As the cloth is wrapped around the pipe, liquefied resin is brushed on. Any joint thickness may be obtained.

Reinforced plastic-mortar pipe has a bell and spigot type joint that utilizes a rubber ring gasket. The jointing procedure is similar to that used for any other bell and spigot O-ring gasket joint.

STEEL

Procedures used for jointing steel pressure sewers depend on the type of coating and lining. Generally, the procedures used are the same as those for water supply piping.[24]

WROUGHT IRON PIPE

Welding procedures for jointing wrought iron pipe sewers are the same as those for water supply lines.[24]

Inspection and Testing

Specifications for inspecting and testing sewer lines after installation are not generally as detailed or complete as those for water supply lines. There are, however, some ASTM specifications for field performance and acceptance testing of sewers. Also, some organizations, governmental bureaus, and consulting engineers have developed their own specifications for inspection and testing of newly installed sewer lines. The following discussion presents several specifications that may be considered typical.

INSPECTION

Three areas require inspection during or after construction. Any deficiencies found must be corrected so that the sewer construction meets specifications.

Grade and line. During the course of construction of a sewer line, both the grade and the line of direction should be checked at regular intervals—certainly from manhole to manhole, and sometimes from pipe length to pipe length

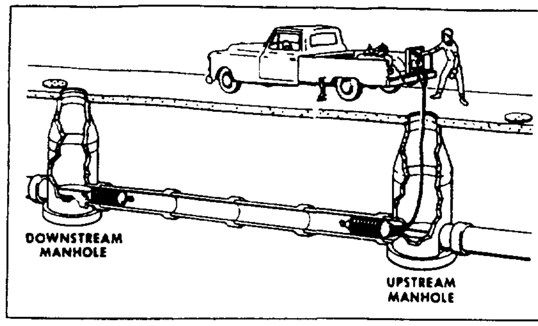

Fig. 24. Method for making air test of sewers.

—depending on soil conditions, bedding, type of pipe, and type of joint. Methods for checking grade and line have been discussed previously.

Bedding. Where particular types of bedding or selected fill are specified, or where areas of bad soil or rock excavations may be encountered, the bedding or fill should be checked regularly to make certain that it meets the specifications.

Sewer interiors. Sewers larger than 30 in. in diameter can be entered and examined carefully for uneven grades, cracked or broken pipe, excessive water leakage at joints, debris, or irregular surfaces at joints. Small sewers may be inspected between manholes by strong light directed down the sewer barrel or by TV. Manhole interiors should be inspected at the same time time as the sewers. Unacceptable conditions in sewer interiors should be remedied. All sewers should be flushed after construction and before testing.

TESTING

Testing of sewers consists of determination of infiltration and exfiltration, or of leakage from force mains.

Force mains. Before backfilling, pressure sewers should be tested at a hydrostatic pressure of 60 psi for at least 30 min, and all fittings, valves, and joints should be inspected for leaks. Repairs should be made where necessary. After backfilling, hydrostatic tests should be made for at least 24 hr at 40 psi. Leakage should be less than 50 gpd per in. diam. per mile.

Infiltration. Infiltration tests are usually made by sealing off a length of sewer, then actually measuring the infiltration for a period of several hours. Measurements may be made by a weir, or by pumping the discharge through a meter, or by measuring it in some other manner.[4] Acceptable limits for infiltration were stated in Part 1.

Exfiltration. Exfiltration or head tests are used to measure the tightness of the sewer. Generally, exfiltration tests are made in a dry trench. These tests are usually made by closing off a section of the sewer and the manhole at the upper end of the section. The line is then filled with water under a head of from 1 to 4 ft above the upper manhole invert. Measurement of exfiltration (leakage) is made by recording the drop in water level in the manhole over a period of time. If the leakage rate is great, it may be measured by metering water into the manhole at a rate just sufficient to maintain a constant water level.

In the exfiltration test, it is necessary to consider possible absorption of water by the pipe and manholes and leakage from the manholes themselves. The test is valid only if all fittings, tees, and wyes are stoppered tightly and if all entrapped air was bled off as the line was being filled.

Specifications for acceptable exfiltration rates should be based on engineering judgment, with due consideration of all factors involved. A typical acceptable limit is 100 gpd per in. diam. per mile of pipe.

Air testing. Another way of determining the tightness of a sewer line is by the low pressure air test.[39] In this test, all

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stubs, wyes, tees, and pipe ends are tightly capped; the line is cleaned, plugged, and placed under air pressure. Figure 24 shows one system for making such a test.

At the start of the test, the air pressure is raised to 4 psig greater than the average backpressure of any ground water. After 2 min or more, during which the air temperature is stabilized, testing is started at a pressure of 3.5 psig. The time required for the pressure to drop from 3.5 to 2.5 psig is determined as the basic measurement of the test.

Various engineers and organizations have set minimum time limits as acceptable for this drop of 1 psig. Some time limit ranges for different sizes of pipe are as follows:

Pipe size (in.)	Time allowed for 1 psig drop (min)
4	2
6	3
8	4
10	5
12	5.5
15	7.5
18	8.5
21	10.0
24	11.5

Other engineers and organizations have different ways of expressing the acceptable leakage rates. Some early methods specified the time allowed for 1 psig drop in seconds per linear foot, but this method is now considered as the less satisfactory approach. Other engineers specify that a sewer line will be acceptable when, at a test pressure of 3 psig (above ground water pressure), the total rate of air loss from the section under test is no greater than 2.0 cfm, or 0.0030 cfm per sq ft of internal pipe surface.

This type of test has also been used in sewer maintenance surveys to determine sewer repair needs.

Backfilling

The backfilling operation is just as important in sewer construction as it is in the laying of water mains. The method of backfilling will depend on trench width, character of excavated soil, excavation method used, degree of compaction required, and type of pipe material.

BACKFILL MATERIAL

Regardless of type of pipe material or method used for backfilling, the backfill material should be good soil; it should contain no large rocks, no bad soil, and no large clay lumps. The material placed at the sides of and immediately above the pipe should be of the best possible quality; it should be readily compactable soil or granular fill. Selected granular fill material may be crushed stone or pea gravel.

COMPACTION

The degree of compaction required depends on the location of the sewer. In open country, compaction is usually unnecessary; under city streets, a high degree of compaction may be necessary, particularly if the street surface is to be restored immediately; and under flexible macadam paving, compaction required is more than in open country, but less than in the city.

The method of compaction depends on the type of soil used for backfill. Cohesive clays, except in small particle sizes, cannot be compacted by flooding or jetting. Mechanical tamping may be possible if the particle size is not too large. In wide trenches, clays are usually removed as large lumps, and these do not compact well unless placed in thin layers and compacted by power equipment. Blending of clay lumps with sand makes compaction possible by dozers or rollers.

Granular, cohesionless material may be consolidated by flooding and poling, a procedure that is described in some detail in WPCF Manual of Practice No. 9.[26] Granular materials may be readily compacted by using immersion-type vibrators as water is added to the trench. Water jetting may be used with or without vibrators.

Project specifications should cover the type of material to be placed around the pipe, the depth of such material, and the method by which it is to be compacted.

BACKFILLING OPERATIONS

Backfilling of a trench should be done in three separate steps.

Initial lift. Fine granular soil or selected fill should be placed with care by hand or machine to a depth of 1 ft above the top of the pipe. The pipe should not be disturbed during placement operations. After the soil is placed, it should be compacted by flooding, jetting, or mechanical equipment, as described previously. If compaction by water jetting is not feasible, the backfill should be added in 4- to 6-in. layers and compacted by machine. Layering and compaction may also be more feasible on large diameter pipe. Jetting operations should be performed with care to avoid floating the pipe.

Intermediate lift. This second "layer" of backfill should extend from 1 ft above the pipe to 1 ft or less below the ground surface. This "lift" may be added all at one time if the backfill material is not cohesive. Compaction by flooding and poling or jetting should follow, to produce the desired degree of compaction. Cohesive soils (clay, etc.) should be placed in 4- to 6-in. layers and compacted by machines. If the excavated soil can not be compacted by these methods, selected fill must be used.

Final lift. The final layer should consist of relatively dry material mounded slightly above the ground level.

Surface restoration. Some time after backfill operations are completed, paved surfaces should be restored,[26] using acceptable street paving methods.

Special problems

In some locations, sewers may have to be constructed under railroads, under principal traffic arteries, across ravines, and under or over streams. Such installations require special construction methods,[26] which will not be covered in this manual. The construction of outfall structures also requires special techniques[26] that are not covered here.

Section 3—House Sewers and Inplant Systems

House sewers

House sewers, preferably larger than 4-in. in diameter, should be laid with a minimum slope of 1/4 in. per ft, in a straight line and grade.[26] Provision should be made for rodding and flushing in the event of stoppages. Joints should be tight, and general workmanship should be equal to that of street sewer installation, so as to minimize infiltration and root penetration.

The house sewer should enter the street sewer at an angle of about 45 degrees from the horizontal. Such a connection will help to prevent backflooding of the house sewer when the street sewer is flowing full. Connections of house sewers to large street sewers should be made above the springline of the street sewer. Connections to deep street sewers may be made through concrete-encased, vertical risers. Additional details on house sewer installation, including diagrams, may be found in WPCF Manual No. 8.[26]

Inplant systems

The installation of pipe in pumping stations and wastewater treatment plants is usually done during construction of the facility. The type of joint used (bell and spigot, flange, coupling, etc.) will depend on the type of pipe, the possible need for dismantling the line for maintenance, the location, and the type of fittings or joints available for a particular type of pipe. Pipe runs of more than two or three lengths usually must be supported by hangers, piers, or other means.

Nonrigid pipe will usually require support (e.g., a channel) for the entire run. Plumbing and sewer lines may be buried inside or outside building structures. Yard sprinkling systems are always buried, and provisions should be made for draining them before cold weather. Potable water lines may be exposed within structures or buried outside, as layout dictates.

The design of inplant piping systems should be accompanied by specifications for the method of installation, joints, and supports. The specifications should also include a color-code designation for each system.

PART 4 / MAINTENANCE

Maintenance of wastewater disposal systems is confined mostly to cleaning and repair of collection systems, although some cleaning operations may be required in inplant piping and house sewers.

Section 1—Collection Systems

Many operating difficulties in wastewater treatment plants and problems in sewers are caused by such conditions in the collection system as excessive infiltration, root penetration, deposits of grit, grease, and solids, septic conditions, hydrogen sulfide formation, and sewer deterioration.

Extent of problems

A survey of 225 cities, made by the author, indicated that infiltration existed in 70 percent of the systems, that it was general in about half of the systems, and that it had been on the increase in about 30 percent of the communities with old systems. The amount of infiltration ranged from 0 to 800 percent of the dry weather flow. In cities under 200,000 population, it ranged from 38 to 75 percent of dry weather flow.

Sewer problems existed in 97.5 percent of the 225 communities replying. These problems were: tree roots (in 97.5 percent of the communities), hydrogen sulfide (in 32 percent), and acid conditions (in 31 percent).

Based on the survey replies, it is estimated that 45 percent of the existing sewer systems show some deterioration, and 36 percent of the communities have had an average of 7 to 8 sewer failures a year.

More than 90 percent of the cities replying, practice sewer cleaning and root removal; about one third use copper sulfate for root control.

Inspection policy

Every municipal or industrial organization responsible for supervision of a collection system should have a maintenance department and a regular sewer inspection program. The frequency of inspection and the size of the maintenance department will depend on the size of the community and the size and complexity of the sewer system. The subjects of policy codes, departmental organization, personnel requirements, staff responsibilities, interdepartmental relationships, types of crews, records, permits, and other related general information are covered in detail in WPCF Manual of Practice No. 7 [40]

Whatever the system size, maintenance inspection should be made on a routine basis and repair work performed as necessary. It is not satisfactory to clean and repair sewers only when serious conditions develop. Such a policy is more costly than routine inspection and maintenance.

GENERAL INSPECTION

Sanitary sewers should be inspected at least once a year. For large systems, a regular inspection schedule should be followed so that the entire system may be covered during the year. In areas where explosive hazards, stoppages, or traffic damage are likely to occur, two or three inspections should be made each year. All inspections should follow a basic plan and procedure with respect to the conditions that should be observed.

Usually, an inspection crew of three workman and a foreman is sufficient; larger repair crews may be required.

Procedures. The inspection crew should work from one manhole to the next, preferably up the sewer line. Observations should be made for the following undesirable conditions: excessive extraneous water (infiltration, manhole cover leakage, roof drainage); gasoline or oil; gases and vapors; root penetrations; deposits or stoppages; manhole deterioration; and changes in or unevenness of sewer grade.

Visual observation procedures based on experience and reference to records of previous inspections will generally serve to locate difficulties. Where excessive extraneous water is caused by leaky manhole covers or illegal roof drainage, inspections may be necessary during periods of rainfall. Infiltration from ground water, however, can be observed at any time when the ground water table is high.

TV and photographic inspection is an excellent technique for locating undesirable conditions between manholes, particularly infiltration, poor joints, root penetration, deposits, and sewer barrel deterioration.

The advent of small industrial television cameras made it possible to inspect the entire length of a sewer. Photographing the TV screen whenever an undesirable condition appears makes it possible to have a record of the condition and a notation of the exact location. Large communities may purchase TV camera equipment, others may employ a service organization for this type of inspection. Some companies have equipment for inspecting and grouting leaking sewers in tandem operations.

Cleaning sewers

There are four methods that may be used in cleaning sanitary sewers; flushing, cleaning with mechanical equipment, cleaning with hydraulically-propelled devices, and addition of chemicals to the sewer. The choice of method depends on the cause of the sewer problem, location, size, and type of sewer, and individual supervisor's experience.

For sanitary sewers, the interval between cleaning operations should be adjusted to the rate at which undesirable conditions, deposits, or stoppages develop. Large and long sewers may be cleaned once every three to five years, with one-third, one-fourth, or one-fifth of the sewer cleaned each year in sectional rotation. The cleaning operations may be required every year or every other year in smaller and shorter sewers, and in some cases, as in dead-end or flat sewers, cleaning may be necessary several times during hot weather.

FLUSHING

Many communities do not permit automatic flushing devices at any point on a sewer because of the possibility of contaminating the potable water supply through cross-connections. Other communities use flushing systems that utilize the sewage flow itself and have an arrangement to automatically discharge a stored volume. Where the normal flow of sewage is at a scouring velocity, there is a natural continuous flushing action, and deposits do not accumulate. Root penetration, however, may still be a problem.

Flushing by fire hose is generally not effective because high velocities cannot be maintained for any considerable distance down the sewer. The best alternative is the use of hydraulically propelled devices (see below).

MECHANICAL CLEANING

Mechanical devices for sewer cleaning include sectional wooden rods with various tool attachments; steel buckets or cutters on cables to remove obstructions; light flexible steel rods (segmented or continuous) with end tools such as screws, augers, and sandcups; and a turbine-type cleaner with cutting knives and wire brush attachments.

The procedure used in cleaning sewers that are plugged or almost plugged generally involves making one pass with sewer rods before inserting a bucket or cutter on a cable. Irregular sewers, which might be damaged by heavy equipment, should be cleaned by light flexible steel rods coupled into a continuous line (or a continuous steel rod) to which the cleaning attachments are fastened.

In using a steel rod system, the tool and rod are fed into the sewer until the obstruction is reached, then the rod is twisted by a hand ratchet or portable gasoline powered unit. Grease and heavy obstructions in sewers larger than 15 in. in diameter are generally removed with a powered turbine-type cleaner. Sand may be removed by sandcups on steel rods or by steel scoops on cables. Figure 25 shows a machine for feeding flexible steel cable into a sewer; also shown are a number of tool attachments and the pipe for conducting the cable into the bottom of a manhole. There are various other types of tools pulled through a sewer by winch drawn cable. These tools include root saws, collapsible scrapers, flexible buckets, blade cutters, cork screws, sand beaders, spearheads, porcupines, etc. Instructions for proper use are issued by the equipment manufacturers.

HYDRAULICALLY-PROPELLED TOOLS

There are several types of self-propelled hydraulic flushing devices. Three of them are the sewer scooter, sewer hoe, and sewer (beach) ball. The design and operating principles of the latter two are shown in Fig. 26, adopted from Navdocks MO-212.[41] The use of these devices depends on a partial closure of the sewer, with a resulting buildup of head behind the device. This hydraulic head pushes the device forward and allows a high velocity of liquid to escape beneath it, thus jetting away deposits.[40]

Another type of hydraulically self-propelled device is the turbine nozzle, which is attached to the end of a fire hose, and then introduced into the sewer. The action of the backward-pointing jets moves the nozzle forward and pulls the hose behind it; the forward jet cuts the debris, which is flushed ahead of the nozzle. Only old fire hose should be used for this purpose, and it should be painted an identifying color.

CHEMICAL TREATMENT

Copper sulfate introduced into sewers will successfully control and remove tree roots. Periodic dosage is most effective, and the chemical may be added at manholes or through residential water closets. If addition is through manholes, the amount of chemical to be used should be determined by trial and error and experience. If addition is through household water closets, it is generally sufficient to add 2 lb annually, preferably in the spring. The chemical should be placed in the toilet bowl and flushed with enough water to remove all crystals from the bowl.

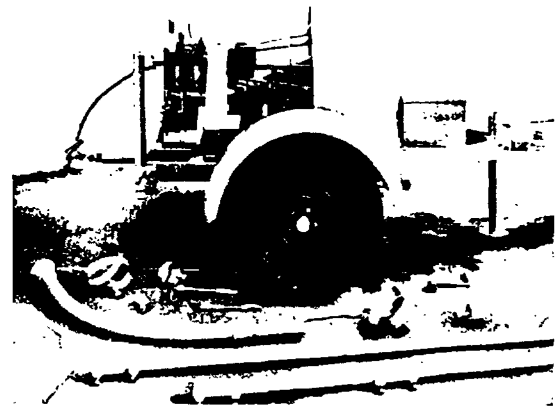

Fig. 25. Powered flexible steel cable sewer cleaning equipment, with various tool attachments.

Storm sewer systems

Storm sewer systems should be inspected annually, generally on the same schedule as sanitary sewers serving the area. Storm sewers should also be inspected after each severe storm and should be cleaned as necessary. Cleaning should be done with mechanical tools and methods, not by hydraulically propelled tools.

Force mains

Where force mains are used to transport wastewater or sludge, clogging or reduction of carrying capacity may result from deposition of grease on the interior surface of the pipe. The need for cleaning will be indicated by a gradual increase in pumping pressures. Cleaning may be done by hydraulically-propelled go-devils. Main cleaning services are available for force main cleaning.

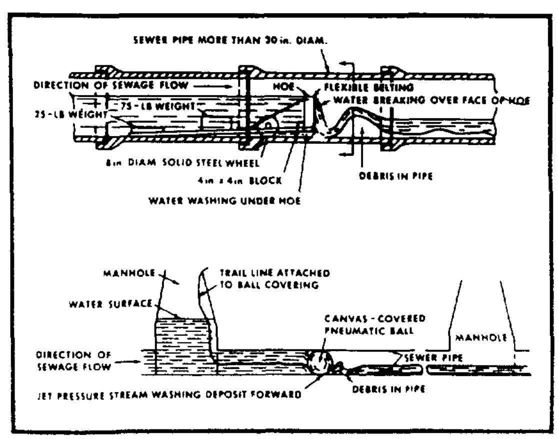

Fig. 26. Hydraulic-self-propelled sewer cleaning tools (Above) sewer hoe; (below) beach ball.

Appurtenances

Part 1, Section 6 discusses appurtenances, many of which require cleaning.

Inlets and catch basins should be inspected during or after each severe storm, or at least annually. Equipment, such as buckets, orange peels, etc., is manufactured especially for cleaning inlets and catch basins, and cleaning should be done when inspection indicates its necessity.

House sewer cleaning is seldom a responsibility of the municipal sewer department. The property owner usually contracts with a sewer cleaning company for that service.

Traps (oil, grease, sand, etc.) should be inspected and checked at regular intervals. Experience will dictate the interval between inspections; cleaning should be scheduled as inspections indicate the need.

Junction chambers, overflows, and similar appurtenances should be inspected after each severe storm and cleaned and repaired as necessary. *Manholes* should be inspected at the same time as the sewer itself. *Lift stations* should be inspected, cleaned, and maintained as set forth in Manual of Practice No. 1.[42]

Outfall sewers

Outfall sewers may be part of the collection system or part of the treatment plant system. If they have been properly designed and constructed, they will require a minimum of maintenance, but they should be checked or inspected at regular, though perhaps extended, intervals.

Inspection procedures should include checks to make certain that the effluent has a free outlet, that there has been no settlement of the line or the outfall structure itself, that no drifting sand (in ocean outfalls) has restricted the opening, and that floating ice or a violent storm has not damaged the outfall anchorages and foundations.

Section 2—Sewer Repair

Part 3 of this manual pointed out the need for proper design, proper selection of pipe, and careful installation procedures to ensure long life and resistance to infiltration, root penetration, deterioration, and pipe failure for any cause. With modern pipe and pipe joint design, and proper installation, the likelihood of pipe failure, leakage, etc., in new systems is considerably smaller than in old systems.

A review of Part 3 on installation procedures will indicate possible causes of failure in old sewers (e.g., soil movement, poor bedding, traffic loads, root growth, faulty tapping for house sewers, etc.)

Collapsed sewers and sewers that are badly cracked must be dug up and replaced, but leaking sewers, deterioriated interior sewer surfaces, and poor joints can be repaired by inplace lining procedures.

Lining in place

According to the results of the survey of 225 cities mentioned previously, in-place lining of sewers has been practiced in more than 20 percent of the communities surveyed, but less than half these cities indicate that lining of sewers was a part of regular maintenance practices. Apparently, in many cities, in-place lining is resorted to when sewer conditions become intolerable. Types of sewer linings used by surveyed cities include cement-mortar (30 percent of communities where linings are used), bitumastic (27 percent), special paints (19 percent), and plastics (12 percent). At the time of the survey, in-place lining with epoxy-mortar had just been introduced.

CEMENT-MORTAR LINING

After a sewer has been cleaned and removed from service, it can be lined with cement mortar by the same method used for lining water mains.[24] Sewers so lined have an increased flow capacity because of the smooth, jointless bore and the lower roughness coefficient. Infiltration and root penetration are eliminated and the deteriorated surface restored. One of the difficulties of lining sewers in place is the problem of providing continuous sewer service to an area during the lining operation. This difficulty can, however, be overcome.

Another method of in-place cement-mortar lining involves the use of a TV camera and grouting machine in tandem. This arrangement is used to determine points of leakage and to seal the sewer at those points rather than complete in-place lining. In large sewers, pressure grouting or pointing may be used.

EPOXY-MORTAR LINING

The in-place application of an epoxy-mortar lining has been successful in both municipal and industrial sewers. As in in-place cement-mortar lining, the sewer must be removed from service. The method of application is the same as that described in Part 2, Section 8.

PLASTIC LINERS AND ASPHALTIC PAINT

The application of plastic liners or asphaltic paints in concrete sewers (as described in Part 2, Section 8) is possible if the sewer can be taken out of service. Whatever the method used, lining of pipe in place is quite desirable if infiltration is a sewer problem.

Manufacturers

Some companies manufacture equipment for the cleaning and/or inspection of sewer systems; other companies sell sewer cleaning and inspecting equipment and also provide cleaning and/or inspection services; still other companies only provide sewer cleaning and/or inspection services. In the following listing, no effort has been made to indicate whether a company produces equipment, provides services, or does both.

AAA Pipe Cleaning Co., Cleveland, Ohio
Ace Pipe Cleaning, Inc., Kansas City, Mo.
American Pipe Services, Minneapolis, Minn.
Centriline Div., Raymond International, Inc., New York, N. Y.
Certified Laboratories, Ft. Worth, Tex.
Champion Corp., Hammond, Ind.
Community Utility Equipment & Supplies, Inc., Winter Park, Fla.
Flexible, Inc., Culver City, Calif.
Flexible Pipe Cleaning Co., South Houston, Texas
Halliburton Co., Duncan, Okla.
Inspectoline, Inc., College Point, N. Y.
Logan Clay Products Co., Logan, Ohio
Mainlining Service Co., North Tonawanda, N. Y.
Mobile Dredging & Pumping Co., Mobile, Ala.
National Chemsearch Corp., Irving, Tex.
National Power Rodding Co., Chicago, Ill.
National Water Main Cleaning Co., Newark, N. J.
O'Brien Manufacturing Co., Chicago, Ill.
Ohio Tool and Engineering Co., Springfield, Ohio
Penetryn System, Inc., Latham, N. Y.
Pilot Manufacturing Co., Torrance, Calif.
Robinson Pipe Cleaning Co., Canonsburg, Pa.
Sanfax Corp., Atlanta, Ga.
Sanitary Hydraulics, Inc., Cleveland, Ohio
Solvay Process Div., Allied Chem. Co., New York, N. Y.
W. H. Stewart, Inc., Syracuse, N. Y.
Turbine Sewer Machine Co., Milwaukee, Wis.
Video Pipe Grouting Inc., Chicago, Ill.
Wayne Manufacturing Co., Pomona, Calif. □□

water and wastes engineering / MANUAL OF PRACTICE NUMBER THREE

AUTHOR'S NOTE

As in the case of Manual of Practice No. 2,[24] this manual has referred to future manuals for the presentation of information and discussion of certain matters and items related to the subjects covered here.

Because of space limitations in a manual of this kind, it is necessary to present the material in more than one issue. Therefore, when Manual No. 4 is published, it, together with Manuals No. 2 and 3, will make one unit on the subject of pipes, valves, hydrants, and appurtenances in both water supply and wastewater systems.

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