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SEWER BEDDING AND INFILTRATION

GULF COAST AREA

U.S. ENVIRONMENTAL PROTECTION AGENCY

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SEWER BEDDING AND INFILTRATION

GULF COAST AREA

by

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for

OFFICE OF RESEARCH AND MONITORING
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ABSTRACT

Problems of excessive infiltration are found in the Gulf Coast area, particularly those localities associated with high water table and deltaic or alluvial soils. Infiltration and leaking sewers can cause problems of water pollution and economics. Costs of sewerage systems can be significantly increased from both a capital and an operating point of view.

Ground water infiltration studies were performed on several sewer systems in 1962-63 and again in 1970 with the results being compared. Infiltration measurements in the systems ranged from zero to 111,560 gallons per inch of diameter per mile per day. The infiltration was slightly increased in some lines and was greatly decreased in others. The decrease is attributed to soil and grease clogging the breaks, as was observed in subsequent television inspection. Infiltration has been found to vary with time. The high infiltration rates were attributed to poor construction methods used by contractors on the main sewer system and by plumbers on house connections. A survey of 1600 manholes showed 3.5 percent to have infiltration at the time of the inspection and others likely to develop infiltration during periods of heavy rainfalls. Most of these could be easily repaired to prevent infiltration. Poor construction procedures are considered to be the most significant contributor to infiltration and sewer failure. This situation can be remedied through adequate inspection and testing.

Bedding and select cover (fill) should provide even distribution of load and support for the pipe. A second function of this material should be to impede the flow of water surrounding the sewer when the pipe is laid below the water table. The material should completely surround the pipe. A coarse granular material such as clam or oyster shells, gravel, crushed stone, etc., provides excellent support and load spreading but does not impede flow. Mixtures of these with sand and other materials can provide flow impedance.

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CONCLUSIONS

1. Sewer settlement alone is not a significant cause of infiltration in clay sewers with factory moulded compression joints. The main cause of infiltration rates in modern vitrified clay sewers is poor construction procedures. Careless joining of factory moulded compression joints is conducive to excessive infiltration. Dropping fill material directly onto the pipes causes breaks and cracks, expecially in the pipe bells.

2. Observations made with a testing frame in the laboratory on vitrified clay sewers showed little settlement with a range of from zero to 3.5 centimeters (1.38 inches). Sewer settlements observed in the field were considerably larger ranging from zero to 1.50 feet. Although similar beddings were used, no correlation could be observed between the laboratory and field studies.

3. Sewer settlement appears to be caused by the drawdown of the water table either during or after construction. In the drawdown phenomena, the pressure on compressible strata beneath the sewer is increased.

4. In areas of high ground water table, extremely permeable materials such as shells or gravel are undesirable for sewer foundations. These materials serve as conduits along and surrounding the sewers, and readily permit the flow of water along the bedding to leaking joints, cracks or breaks, in the sewer.

5. Where high water tables exist, sewer beddings may be greatly improved by the addition of expanding materials such as bentonite. Sand and Portland cement mixed with coarse granular material such as shells and gravel also provide excellent beddings for sewers. Mixtures of this type also tend to reduce the flow of water along the trench bottom and to reduce the effect of undermining of the sewer should a leak develop.

6. The moulded joint sewer pipe used in this research showed excellent load bearing, deflection and infiltration resistance characteristics. In joint deflection tests on this pipe, deflection angles as high as 10.9 degrees were observed with a head of 30 feet of water imposed on the joint before leakage occurred.

7. The properties of pipe joints for brittle pipe are of considerable import relative to infiltration.

8. Garbage disposal units used in homes appear to have introduced a detrimental factor in the hydraulics of sewers. Cold water introduced by

infiltration causes the grease to coagulate and form masses at joints and broken sections of sewers.

9. The manhole survey showed 3.5 percent of those inspected to have infiltration. A higher percentage no doubt would be subject to infiltration during periods of rainfalls. Manholes are easily repaired. Periodic manhole inspection and maintenance would be advantageous in reducing infiltration on sewer systems.

10. The establishment of infiltration specifications through the New Orleans area was greatly influenced by this project.

RECOMMENDATIONS

1. Standards for sewer construction and limits of infiltration should be adopted for all new sewer systems. These should include all factors to insure the proper laying of the pipe and filling the trench in a manner to protect the sewer. Close supervision should be provided during the construction of sewers to assure that the specifications are adhered to.

2. Infiltration tests for sewer acceptance should not be relied on as the only means of sewer construction control, but should be utilized along with effective inspection during construction.

3. When running infiltration tests on a sewer system, the practice of testing the entire system at one time should be discontinued in favor of testing the component parts. The length of line to be tested at one time should be small enough so that areas of leakage will be isolated.

4. A good base has been established with the test sewers used in this project. These sewers should be examined and studied periodically in the future to determine the amounts of settlement and infiltration.

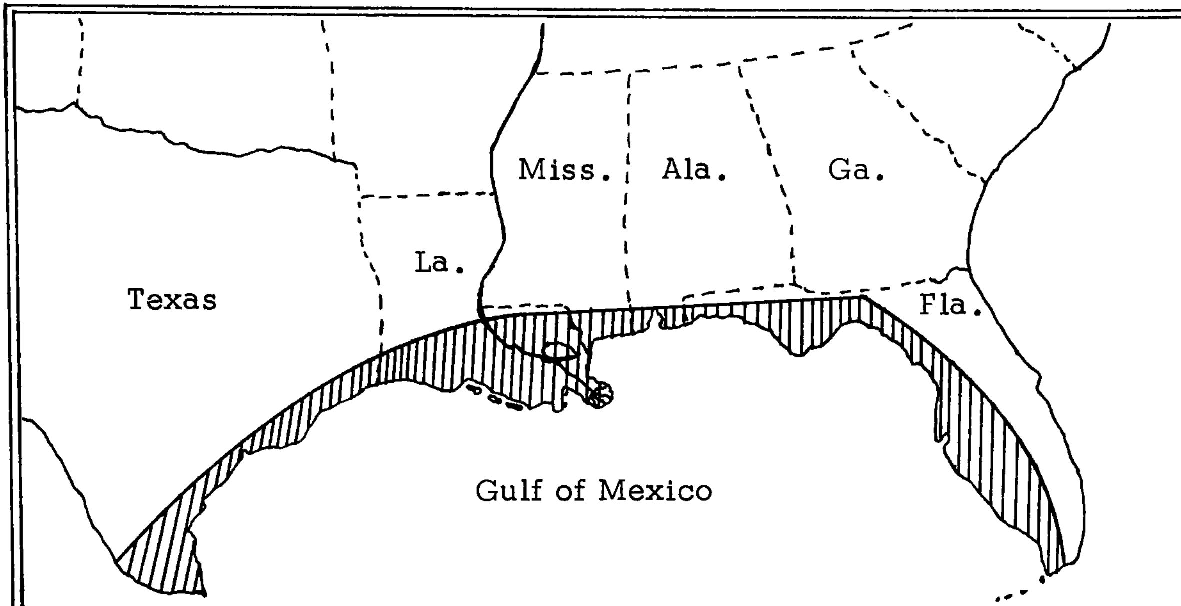
5. Where high water tables exist and soil conditions are unfavorable, Portland cement or an expanding clay mineral like Bentonite should be used with coarse granular materials for sewer beddings.

6. Manholes on sewer systems should be inspected periodically,and the necessary repairs provided where infiltration is observed.

7. Adequate plumbing codes should be adopted for the construction of house sewers with inspection required before connections are permitted to sewer systems. Particular attention should be devoted to the connection of the house sewer to the main system. Breaking into the main sewer system to make the connection should be prohibited.

SECTION I

INTRODUCTION



THE GULF COAST AREA
UNITED STATES

Many locations in the southern coast of the United States along the Gulf of Mexico, shown above, experience higher infiltration rates and greater maintenance difficulties with sanitary sewers than other sections of the nation. Infiltration related water pollution causes health hazards and other intangible expense in the form of lost low cost recreation and the degradation of our natural patrimony. In addition to pollution costs, excessive infiltration places additional financial burdens on sewerage authorities through capital outlay in the construction of transport and treatment facilities, as well as additional operation expenses for sewer maintenance. It is with the presentation, delineation, and possible solutions of these problems that this manual deals.

OBJECTIVES

The objective of this manual is three-fold.

1. An attempt to obtain and delineate information that will be

helpful to those persons engaged in the design, construction, maintenance, and regulation of sewer systems.

2. To present in a concise manner the results and findings of research conducted during the past eight years.

3. To provide recommendations as to additions, deletions, and changes in the planning, construction and acceptance of sanitary sewers in the area of study.

SCOPE

The purpose of this manual is the presentation of information concerning sanitary sewers. In so doing the following discussion topics are presented:

1. The nature, status and cost of infiltration.

2. Methods of measuring infiltration.

3. The causes, measurement and various aspects of sewer settlement.

4. Sewer bedding materials.

5. Sewer construction in general and with respect to infiltration control.

THE GULF COAST AREA

The Gulf Coast area includes the shore line of four states as well as the delta of the Mississippi, largest river in the nation. It is comprised of the southeastern part of Texas, the southern parts of Louisiana, Mississippi and Alabama as well as the western half of the Florida peninsula. The parts of the Gulf Coast area that are of primary concern in this manual are those in which the in situ soils behave poorly as foundations and in trenches accompanied by water tables located close to the ground surface. These conditions predominate in the swamps and marshes of the deltaic and alluvial plains as well as the coastal salt marshes. The largest of these areas is the conjunction of the Mississippi River alluvium and deltaic plain joined with the Louisiana-Texas coastal marsh.

The topography is flat and near sea level with much of the area being covered with tropical and semitropical vegetation. Only two rivers, the Mississippi and the Apalachicola, form deltas into the Gulf of Mexico, but many other streams are concentrated along the coast providing the area with a maze of surface waterways.

The climate is mild and subtropical with an average temperature of 67° F. Rainfall is abundant throughout the area with as much as 66 inches per year recorded in some localities. Prevailing winds are generally from the south.

The low lying areas with their exceedingly fertile alluvial and deltaic soils have attracted settlers since the first European colonization almost three hundred years ago. Continued growth of the region; the development of petroleum resources; and the influx of many varied and expanding industries have over the years been conducive to metropolitan development in large population centers such as New Orleans, Mobile, Houston, Beaumont, Lake Charles and Lafayette.

SECTION II

INFILTRATION

Infiltration is the entrance of water other than sewage into sanitary sewers. It may be comprised of either one or both of the following:

1. Storm runoff entering through manhole covers or illicit connections.

2. Ground water seepage influent through joints, cracks, breaks and defective fittings or other appurtenances.

Infiltration adversely affects receiving water quality as well as the cost of sewage transport and treatment.

STORM WATER INFILTRATION

The flow through openings in manhole covers that are inundated can account for large amounts of water infiltrating a sanitary sewer system. In studies by A. M. Rawn, the leakage through manhole covers with one inch of submergence varied from 20 gallons per minute (gpm) to 70 gpm and went as high as 127 gpm with a submergence of six inches.

In the coastal marsh and deltaic regions of the Gulf Coast area, street flooding occurs frequently during heavy rains making this problem of leakage into manholes a major one.[1]

An illicit connection is any direct installed inlet into a sanitary sewer which allows ingress of storm waters. The most common of these connections involves roof gutter downspouts as well as yard, driveway, and foundation drains.

Large quantities of water can usually be expected from downspouts resulting in a runoff from roofs of 100 percent of the precipitation. Excessive infiltration of this type may cause serious problems of overloading in sanitary sewers during and following heavy precipitation.

Illicit connections are usually prohibited by law, but they remain a problem in areas not covered by or developed prior to adequate plumbing inspection. Smoke tests run by sewer authorities in southern Louisiana indicate that this mode of infiltration can be quite extensive in older urban areas. Municipal sewer authorities are frequently reluctant to release such findings because of the political implications of having to condemn large numbers of illicit house connections.

Interflow between the sanitary and storm sewers can occur when the pipes are contiguous with adjacent leaks and when the intervening material is amenable to flow. In a study conducted by the New Orleans Sewerage and Water Board, this type of infiltration was found to be widespread.[2] It was determined in this study that this interflow occurred at locations where the sanitary house connections crossed beneath and close to the storm sewers as shown in Figure 1. It is believed that the breaking of the house connections was caused by the settlement of the storm sewers. The flow was permitted through the intervening clam shell bedding of the storm sewers. It was also found in this study that the same interflow occurred at intersections where the storm sewer crossed the sanitary main and the two pipes were in close proximity.

GROUND WATER INFILTRATION

Of all the influencing factors relative to ground water infiltration, workmanship is the most critical. It is also the parameter most subject to variation. It is self-evident that a poorly constructed sewer system will be one that will perform badly.

There are many variables which can affect the presence and extent of ground water seepage into sanitary sewer systems. The following factors may also influence infiltration either individually or in combination with one another.

Sewer Foundations

Through their failure to provide proper support and their ability to transmit large quantities of water, inadequate sewer foundations can adversely affect the infiltration characteristics of sewers.

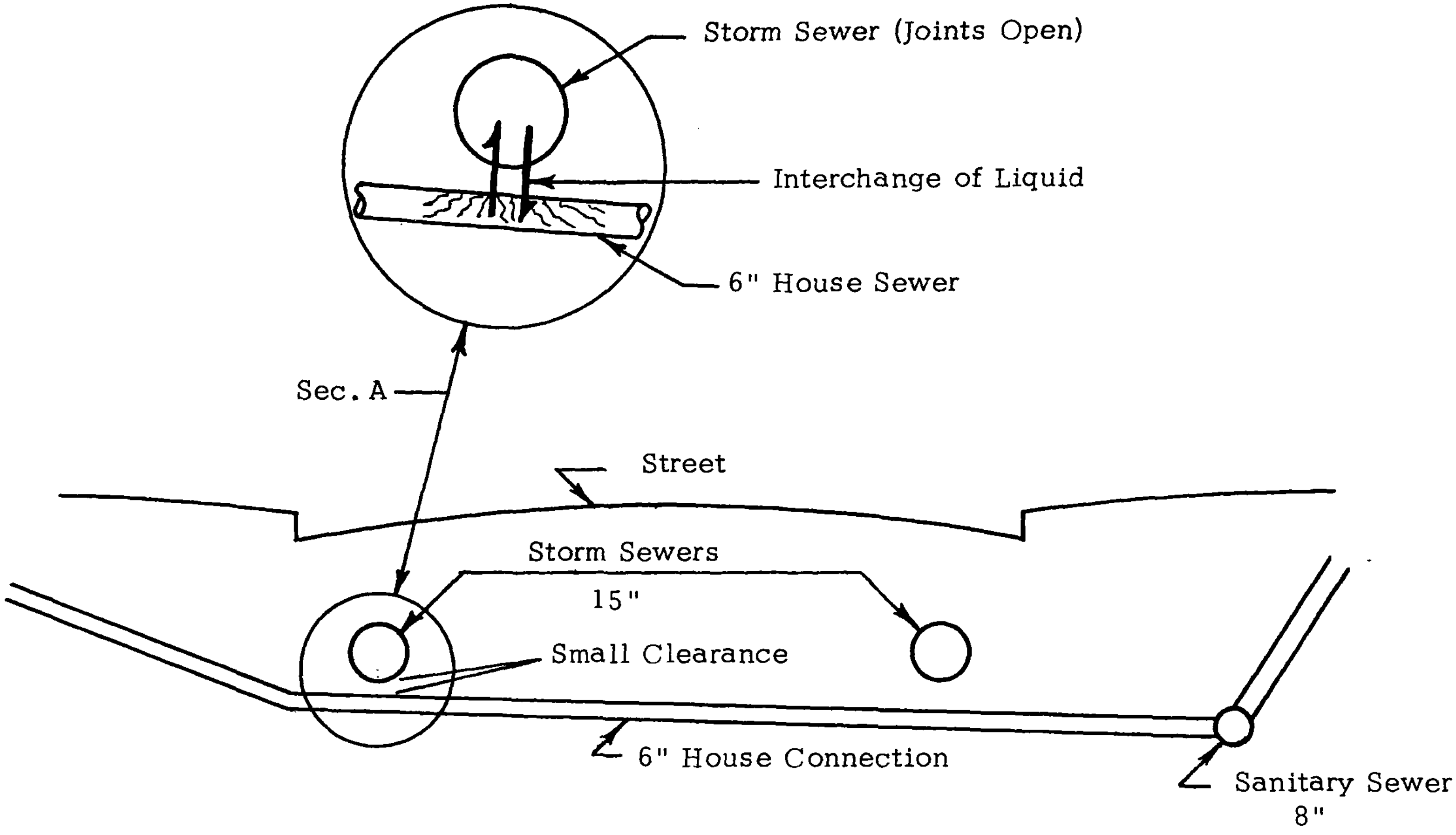
Pipe Joints

The properties of the pipe joint are of considerable influence on infiltration. All other measures for the control of infiltration are of secondary importance unless the pipe joints are tight.

An ideal joint possesses the following properties:

1. It is water tight and will remain so with time.

2. It resists corrosion from both sewage and substances in the soil.



TYPICAL INTERCONNECTION OF SANITARY AND STORM SEWERS
FIGURE 1

3. It is flexible.

4. Its material is resilient.

5. It is durable.

6. It is easily assembled in the field.

7. It must be economical.

The relationship of infiltration to joint flexibility and resilience may not be easily seen. In poor soils, particularly soft clays and peats, there may be movement of the pipe due to settlement of the soil and backfill long after the sewer has been installed. Joints should be flexible enough to sustain a reasonable amount of this movement. The joint material must be resilient in order to allow this flexibility.

Ease of installation is important in so far as it is reasonable to assume that the number of improperly installed joints will increase with the complexity of the joint used.

Appendix A is the report of a detailed study of joint deflection and leakage for a particular joint (8 inch polyurethane factory moulded joint as manufactured by the W. S. Dickey Clay Manufacturing Company).

House Connections

A house connection is any branch from the main sewer that provides service to a user. These are of major concern in infiltration control as they may account for large portions of sewer systems. House sewers should be installed with the same quality of workmanship and materials as the main (municipal) sewer. This is often quite difficult to accomplish since the greatest length of house sewers is usually installed by plumbers whose work is often improperly inspected.

Wyes, tees, and stacks can be extremely troublesome if considerable care is not exercised in their installation. If these connections are not properly closed or if they are broken during backfilling, a great deal of ground water may gain entrance to the system. It has long been recognized that wyes and tees are weak points in sewer systems, but with the advent of monolithic fittings, part of this problem seems to have been solved. House connections have been observed as accounting for 90% of the infiltration in a system. [3]

Manholes

Although extensive infiltration can take place in or near manholes, they do not present as great a problem as other components of a sewer system. This is mainly due to the ease with which they are inspected and repaired.

In a survey of 1600 manholes in the Greater New Orleans area a total of 402 or 25.1% were found to have interior cracks in the walls, around the steps, around the inlet and outlet pipes, inverts, or bottoms, and 56 or 3.5% were actually leaking at the time of inspection. Observations show that these leaks can be easily repaired. Appendix B summarizes this study.

Infiltration problems have also been encountered due to differential settlement between the sewer pipes and the manholes in a system.

Pipe Material

The material of which the pipe is made has no appreciable effect on infiltration in modern sewers so long as this material possesses sufficient strength to withstand the forces to which it is subjected and is not susceptible to corrosive attack by the sewage or the soil.

Water Table

In order for significant ground water infiltration to take place the sewer must be laid below the water table. In addition to the obvious proximity of water, sewers laid below the water table are usually constructed with greater difficulty than those in drier soil. The seepage of water into sewer trenches upon pumping may cause lateral and/or vertical instability of the walls and bottom, thus adversely influencing workmanship during construction.

When the water table is lowered after construction, subsidence can cause sewer settlements which may result in cracking of the pipes.

Soils

There are two general characteristics of the soil which greatly influence sewer infiltration. These are its water bearing capability and its properties as a foundation material.

The water bearing capability depends to some extent upon the volume of water which may be held in the soil, but primarily upon the ease with which the water may flow through the interconnected voids in the soil mass. Void ratio and permeability are both dependent upon grain size, distribution, grain shape, and the structural arrangement of the soil grains. Clays have the ability to retain much water, but as a rule they have low permeabilities and consequently small delivery capability. The reverse is true of sands. Certain combinations and stratifications of sands, clays, and intermediate materials can hold as well as provide large amounts of water. Many organic soils, such as peats, have both water holding and water delivery potential.

The amount and variety of movement that a sewer experiences is closely related to the types, conditions, and stratifications of the surrounding soil. In theory these factors, in conjunction with the seepage propensity, water regimen, and shear strength of the soil, should form the basis for the selection of a sewer bedding.

Ground Surface Characteristics

The disposition of the ground surface can exert some effect on the infiltration properties of a sewer. The availability of precipitation to the mass of ground water is a function of the runoff coefficient which in turn depends on the topography as well as the local vegetation. The type of vegetation will also influence the tendency toward root penetration into joints and cracks in sewers.

Climate

Rainfall and temperature are the two climatic variables which enter directly into the infiltration problem. It is evident that rainfall is an influential parameter in the replenishment of ground water. In warmer climates, water percolates through the soil more readily because viscosity varies inversely with temperature.

EFFECTS OF INFILTRATION

Extent of the Problem

Infiltration creates problems of health, aesthetic, sociological and economic impact. The overflowing of sewers and the pollution of receiving waters are health problems of significant importance when the public bathing areas of our natural water courses are polluted. Children from low income families are often deprived of the only swimming facilities economically available to them. Infiltration increases the capital and operating cost of sewage transport and treatment.

Ground water infiltration is widespread, but only in localities where the water table is high is the ground water seepage a significant problem. Many sewer systems throughout the nation possess significant storm water infiltration. In a national inventory of sanitary sewers and combined sewer flows, it was found that 14% of the respondents indicated a problem with excessive dry-weather flows and 53% indicated problems with increased wet-weather flows.[4] It was also found that 36% reported the flows did not exceed design or code limitations, 25% stated that they did, and 35% were unaware whether or not their flows were excessive. It may be concluded from this survey that one-third of the nation's sewer authorities are not fully aware of the extent of their infiltration problems.

In a survey of 39 sewer authorities in the Gulf Coast area, replies indicated that dry-weather flow accounted for an average of 14% of the total flow. Thirteen, or 53%, of those answering reported that they had no information on dry-weather flow.[4]

Water Pollution

Receiving waters are degraded through infiltration with regard to pollution control, plant bypassing, combined sewers, and interflow between sanitary and storm sewers. From a survey in 1967, it was found that the average annual time in which water pollution control plants were bypassed was 350 hours.[4] In combined sewers, infiltrated water makes hydraulic demands on much needed sewer and sewage treatment capacity, thus increasing the total time of bypass. It has been shown that the interflow of sewage between sanitary and storm sewers is responsible for a significant part of the pollution of the southern shore of Lake Pontchartrain at New Orleans.[2]

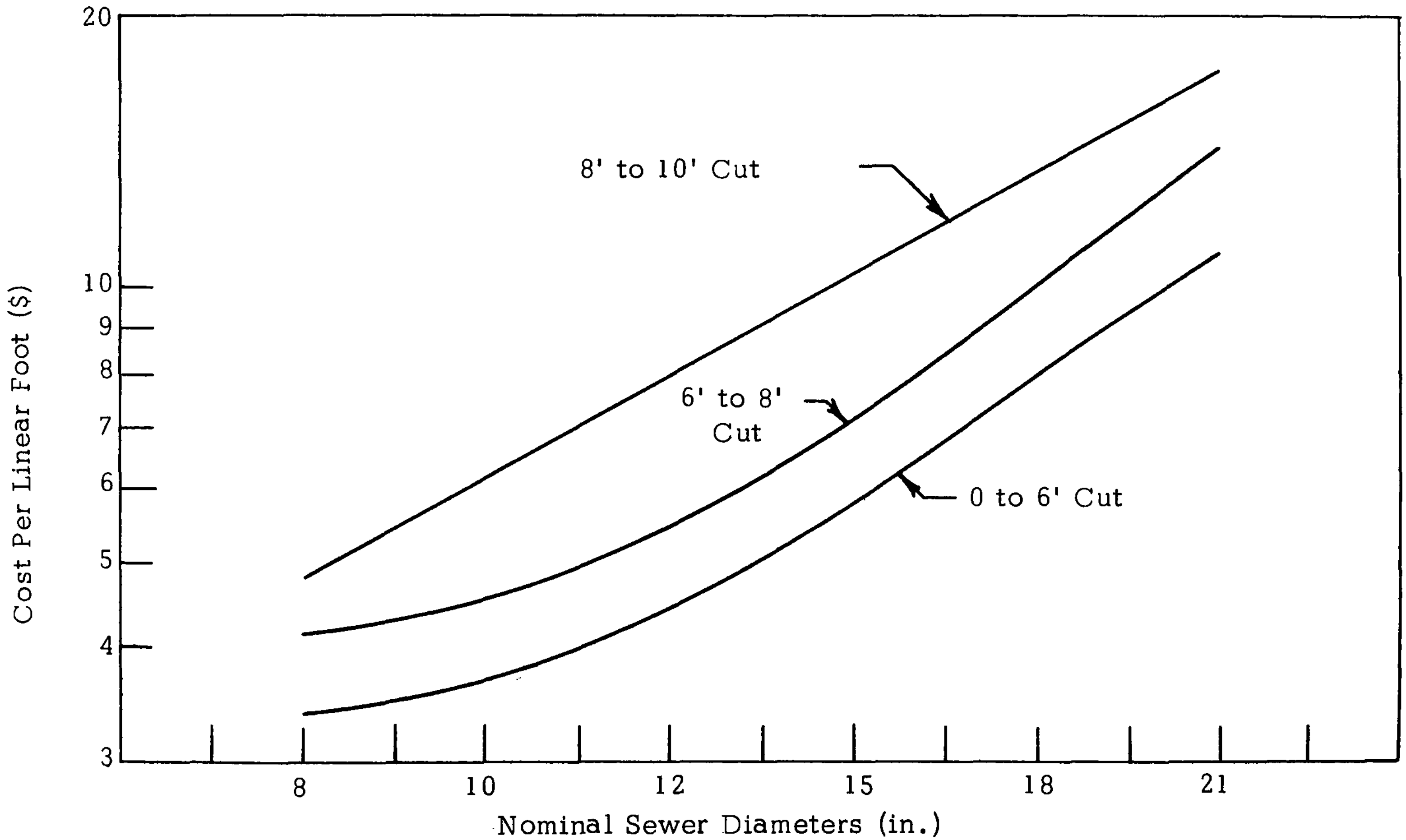
COST OF INFILTRATION

The tangible cost of infiltration is reflected in the construction and operation of sewage collection systems and pollution abatement facilities as well as the enormous expense of pollution.

Collection Systems

Infiltration causes a need for larger sewers as well as greater pumping capacity. An indication of the cost of sewers with respect to increased capacity is shown in Figure 2.[5]

Infiltration can cause the collapse of streets and other structures in the

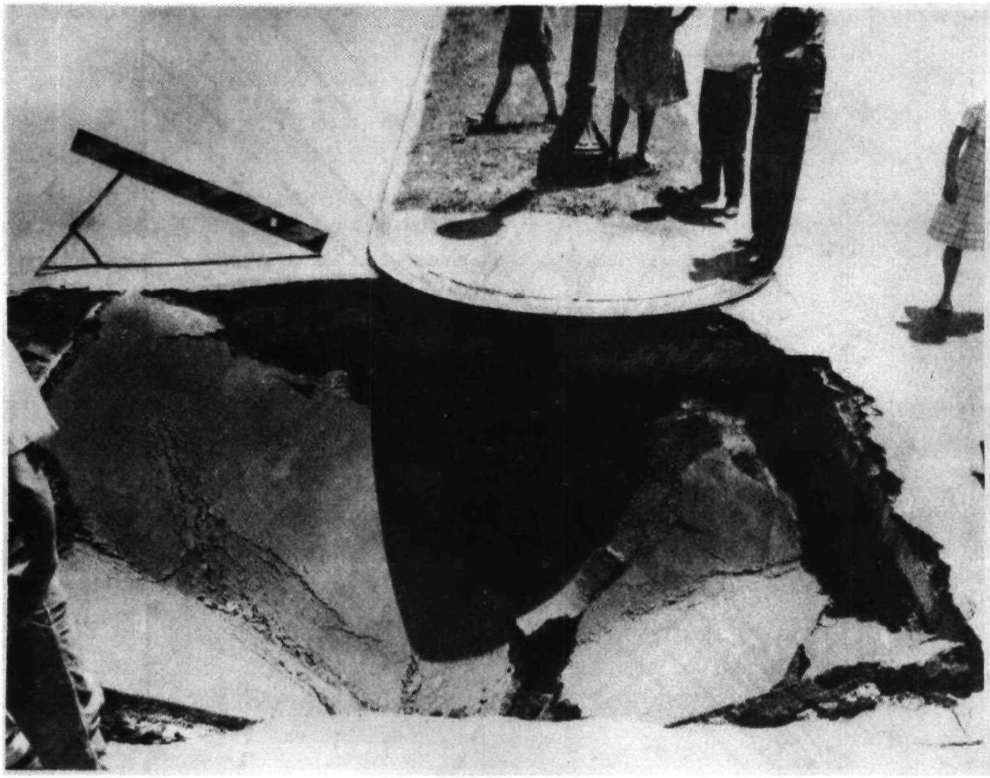


Note: Curves For National Averages.
1967 Values

Note: Diameters Shown are those Available.

CLAY SEWER COST (INSTALLED)
FIGURE 2

vicinity of the sewer. When the surrounding soil and/or the backfill is a fine non-cohesive material in a loose state, it can be washed into the sewer and carried through the system, thus undermining surface structures and even the sewer itself. Figure 3 shows a street collapse due to infiltration undermining.

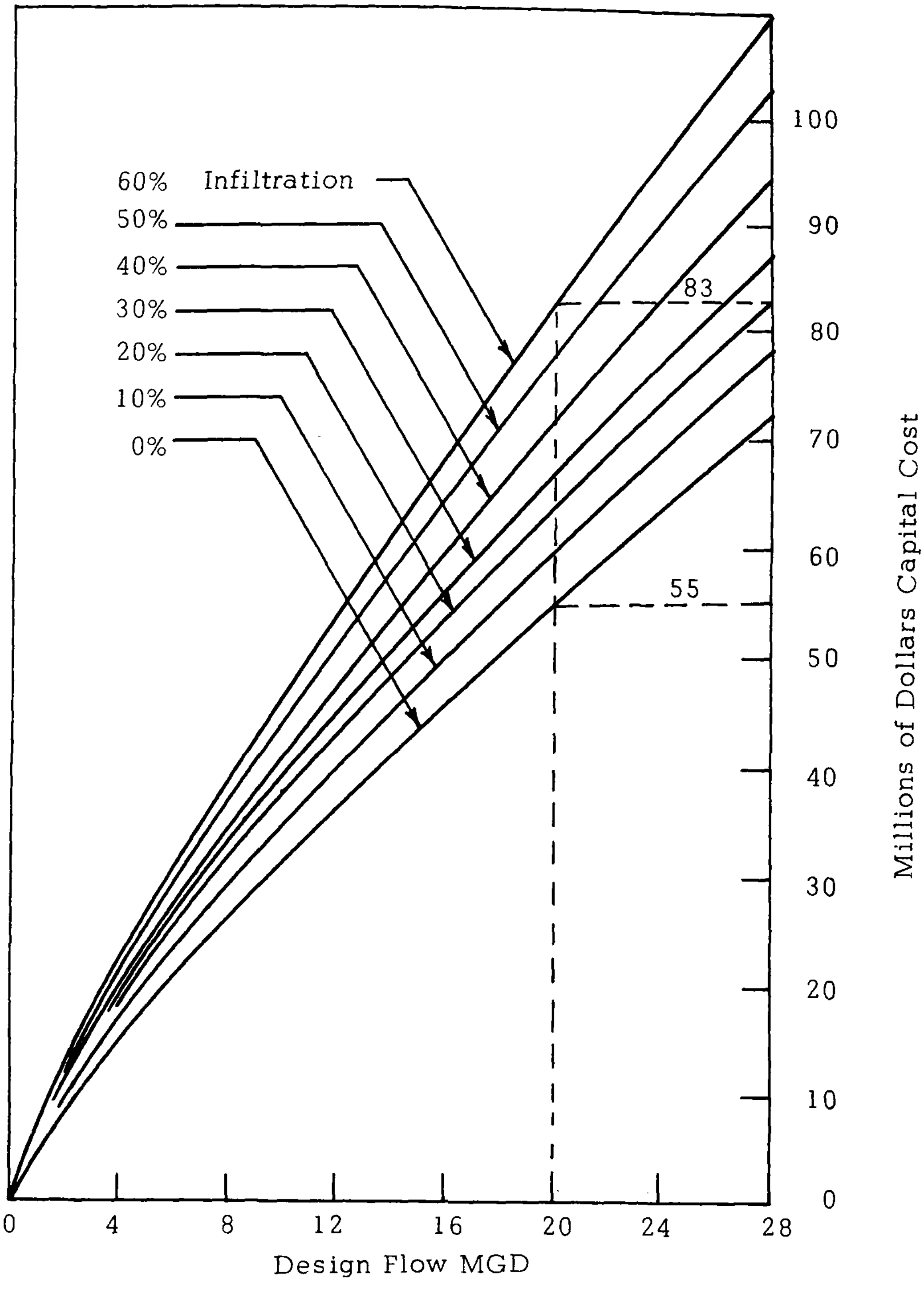


STREET COLLAPSE DUE TO INFILTRATION
FIGURE 3

Sewage Treatment

The greatest tangible cost of infiltration is incurred in the added cost of construction and operation of water pollution control plants.

Figure 4 is a family of curves showing the capital cost of activated sludge treatment at various percentages of infiltration allowance. For example, at a design flow of 20 M.G.D. (million gallons per day) with no infiltration, the capital cost of treatment would be 55 million dollars; however, with an added infiltration flow of 12 MGD (60% increase) the cost would be 83 million dollars. [5]



CAPITAL COST-ACTIVATED SLUDGE TREATMENT
FIGURE 4

Information for all sewage treatment cost curves was obtained from one data source, and was given in June 1967 dollars. [6]

Figure 5 shows the added capital cost incurred as a result of infiltration for activated sludge treatment. Figures 6 and 7 are families of curves showing the total and added total cost, respectively, due to infiltration, and thus reflecting operational expenditures as well as capital debt service.

Figures 8, 9, 10 and 11 provide infiltration costs for trickling filter treatment, and Figures 12, 13, 14 and 15, for primary treatment.

It can be seen from these curves that the cost of treating infiltrated water is only slightly less than that for sewage.

INFILTRATION MEASUREMENT

Infiltration measurement can be either qualitative or quantitative. The qualitative measurements are made to determine the presence and source of infiltrated water, whether of storm or ground water origin. The quantitative tests are made to ascertain the amount of non-sewage water flowing in a sewer at a given time.

Qualitative Observations

The following methods can be used for detecting and locating infiltration.

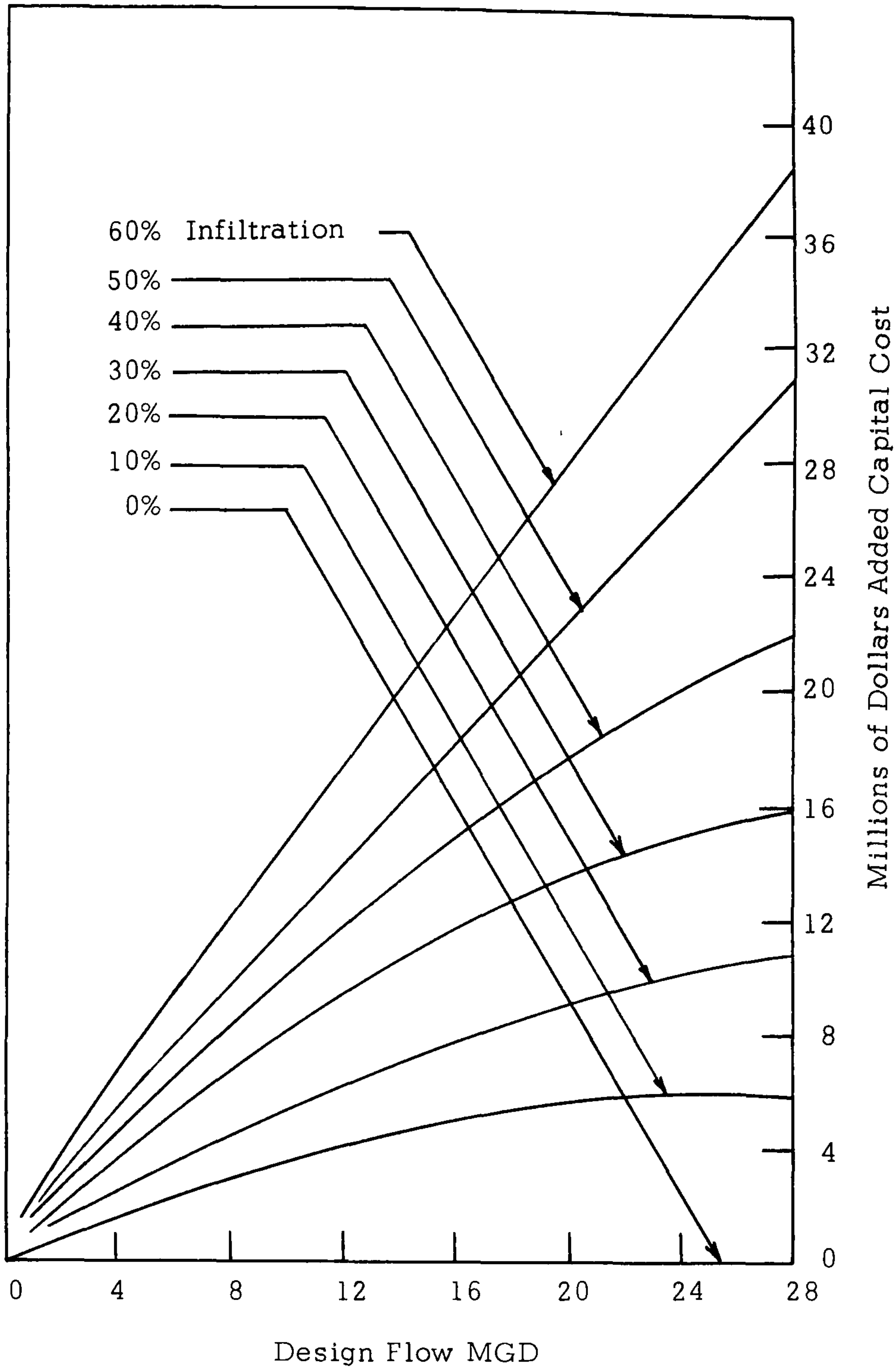
Smoke Testing

This method is used for the detection of illicit connections. It consists of isolating a section of sewer and either placing a smoke bomb in a manhole or pumping in smoke produced with a generating machine. The neighborhood served by the isolated section is then visually inspected for smoke escaping from roof downspouts, yard drains, driveway drains, etc. The escaping of smoke from any of these fixtures is considered proof of an illicit connection.

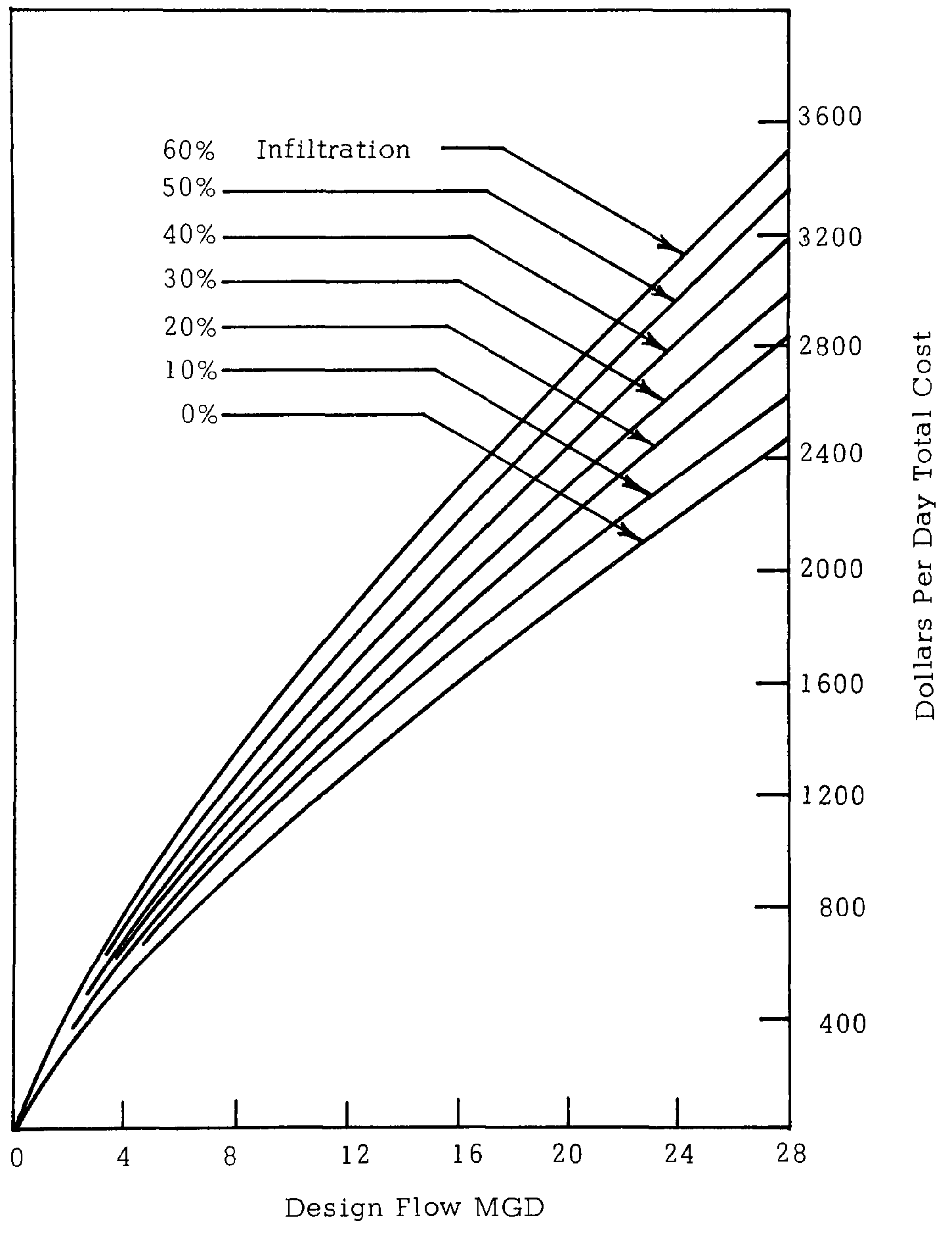
Dye

Dye, of a fluorescent variety, can be poured into appurtenances suspected of being illicitly connected. The dye will be observed at the closest downstream manhole if there is an illicit connection.

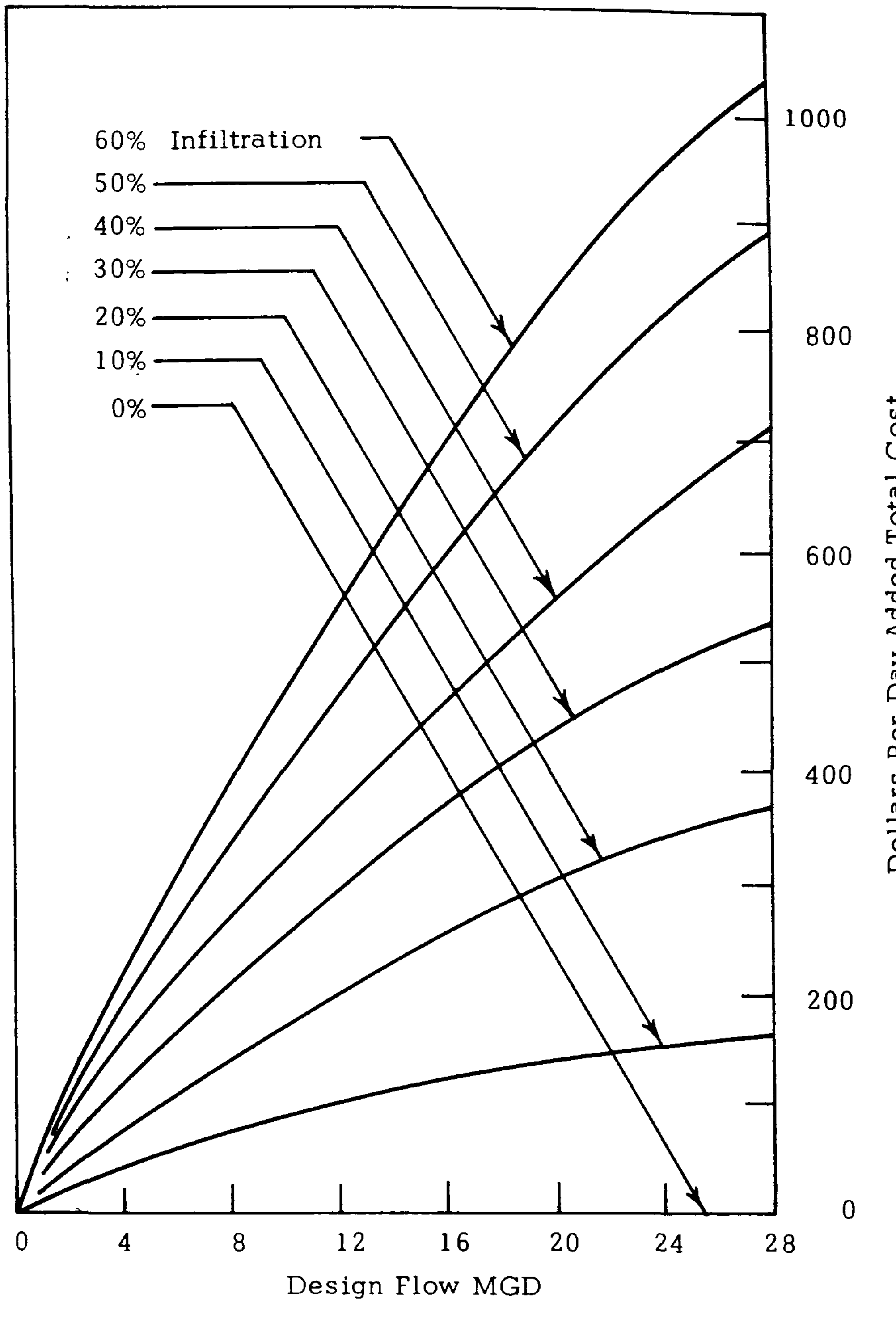
Dye may also be used to detect infiltration in foundation drains and house connections. The dye is poured on the ground near the foundation



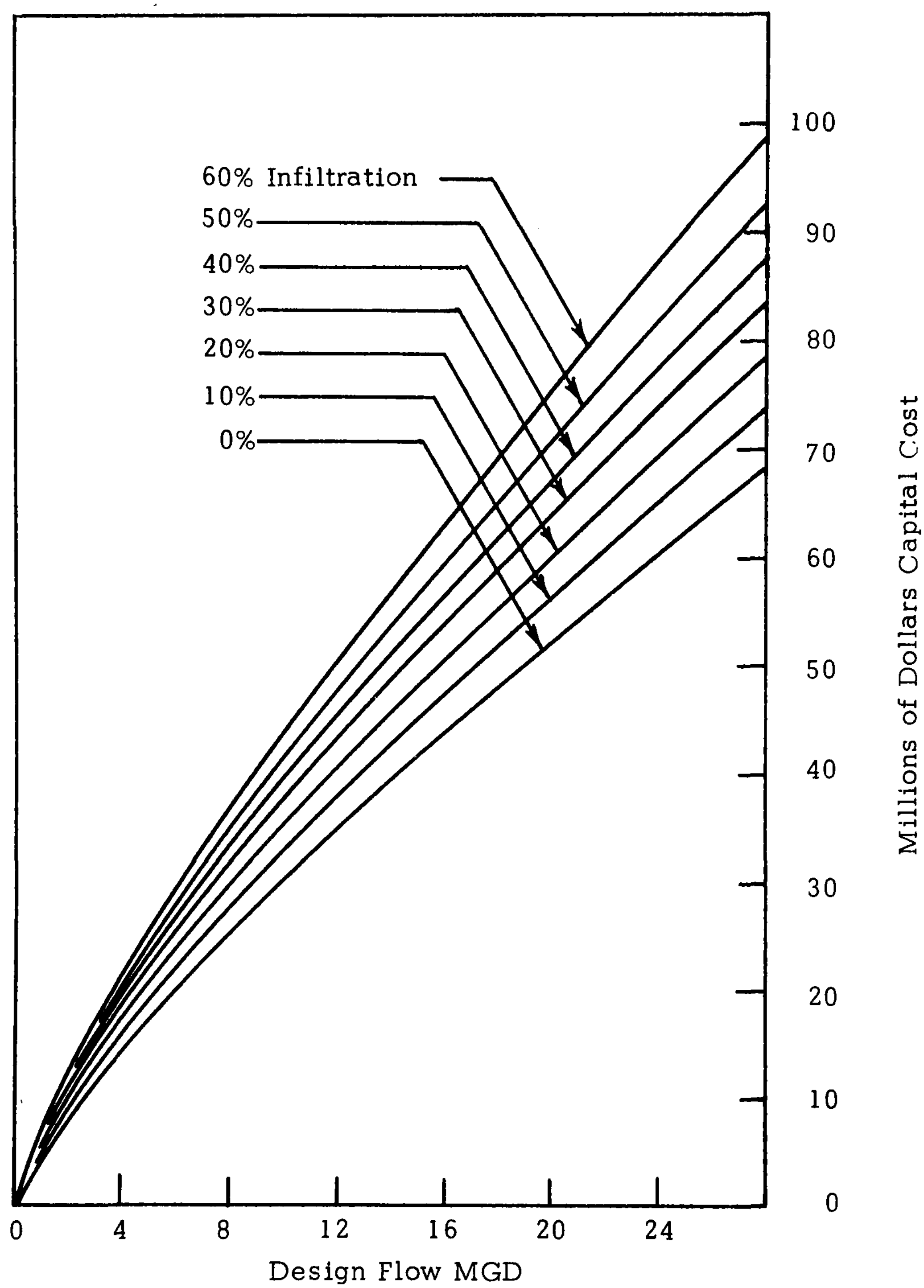
ADDED CAPITAL COST DUE TO INFILTRATION
ACTIVATED SLUDGE TREATMENT
FIGURE 5



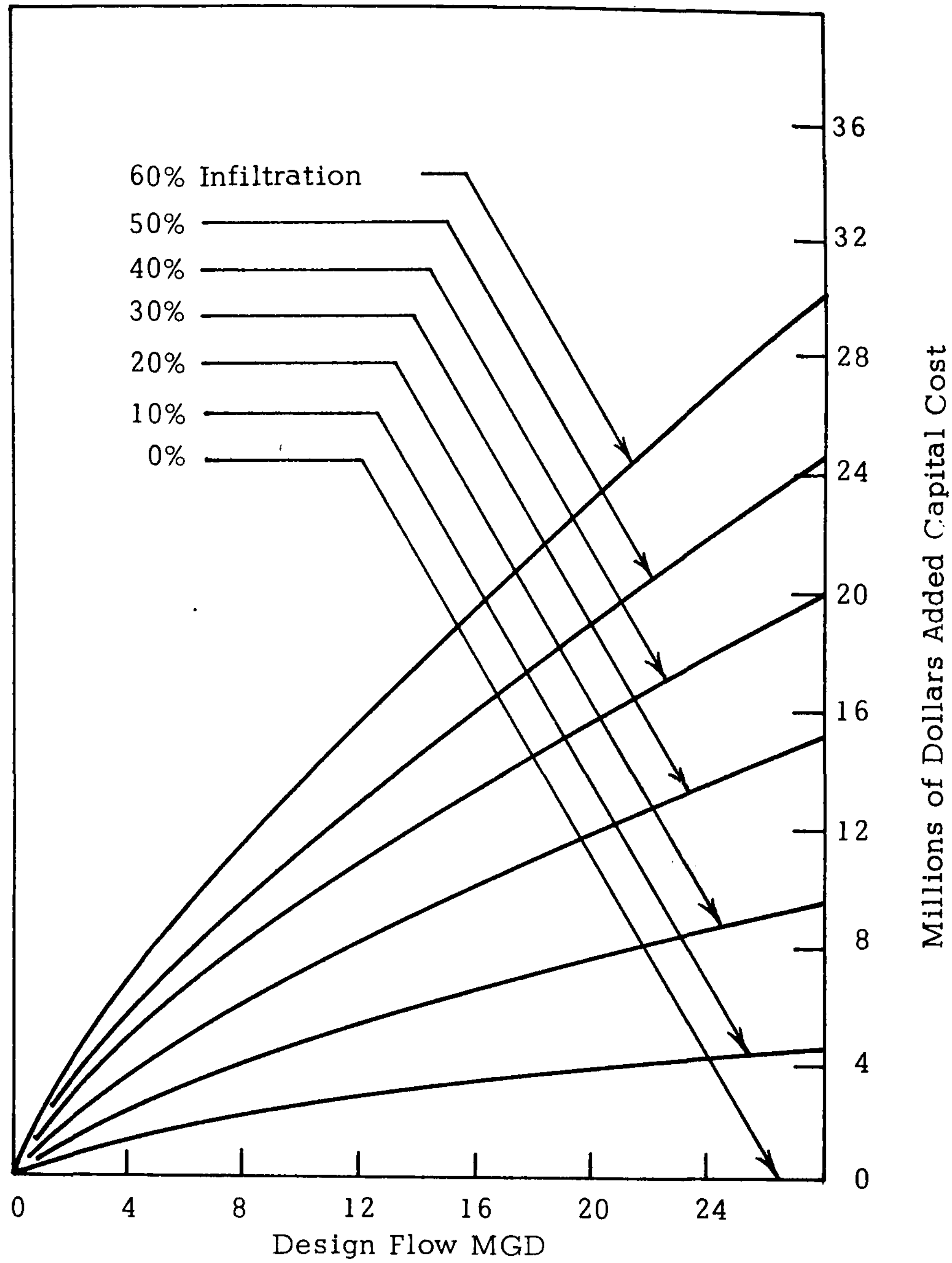
TOTAL COST-ACTIVATED SLUDGE TREATMENT
FIGURE 6



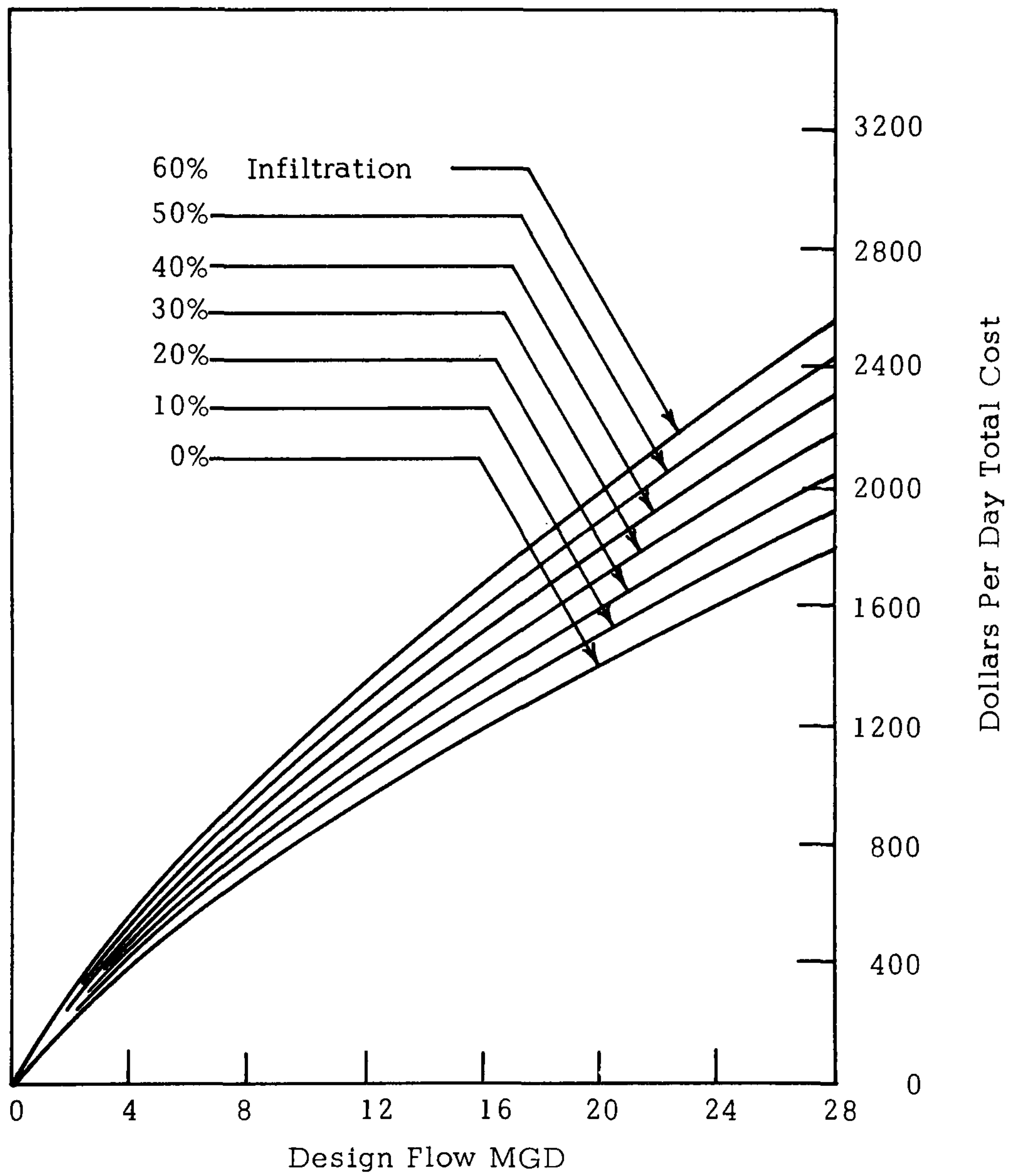
ADDED TOTAL COST DUE TO INFILTRATION-ACTIVATED SLUDGE
FIGURE 7



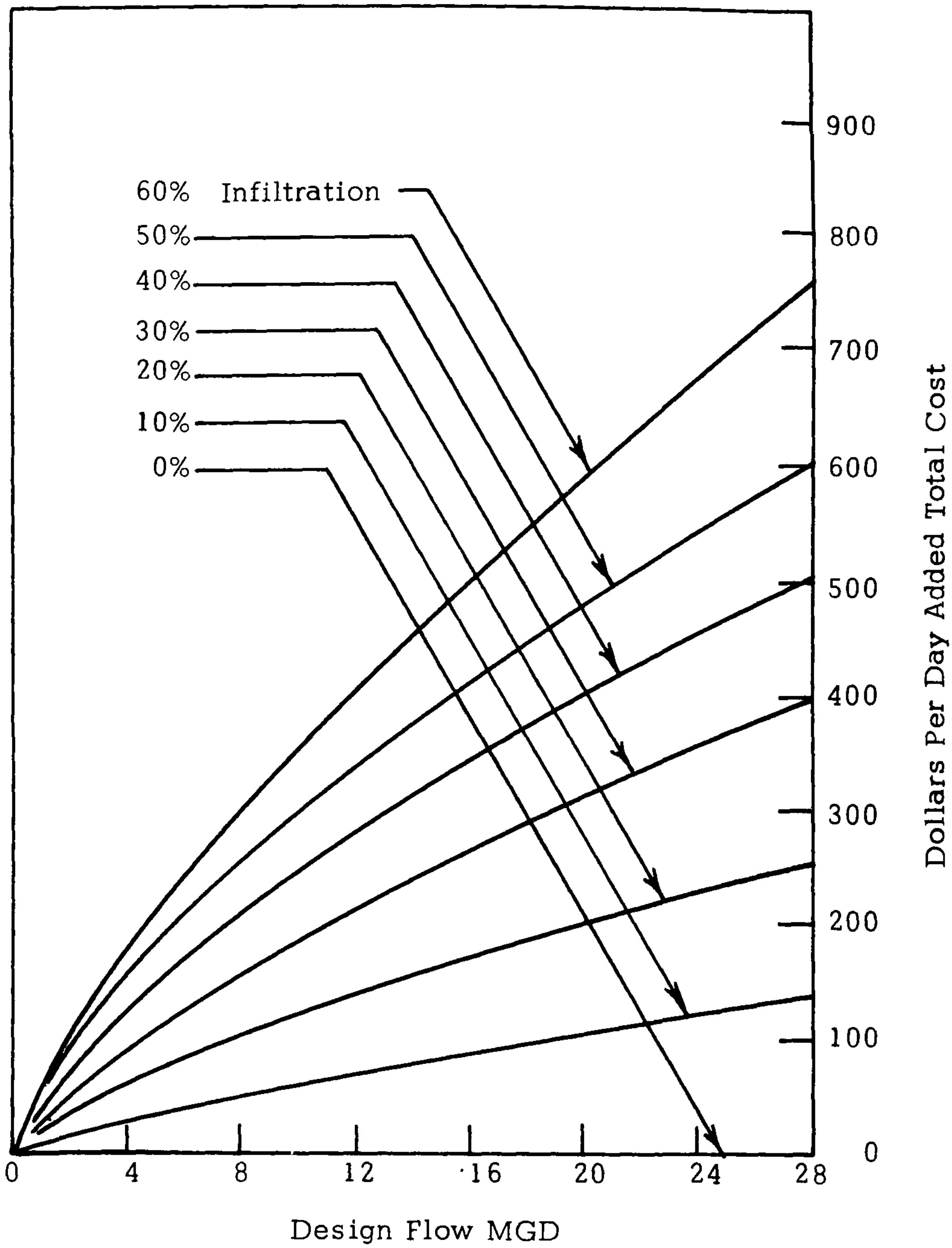
CAPITAL COST-TRICKLING FILTER TREATMENT
FIGURE 8



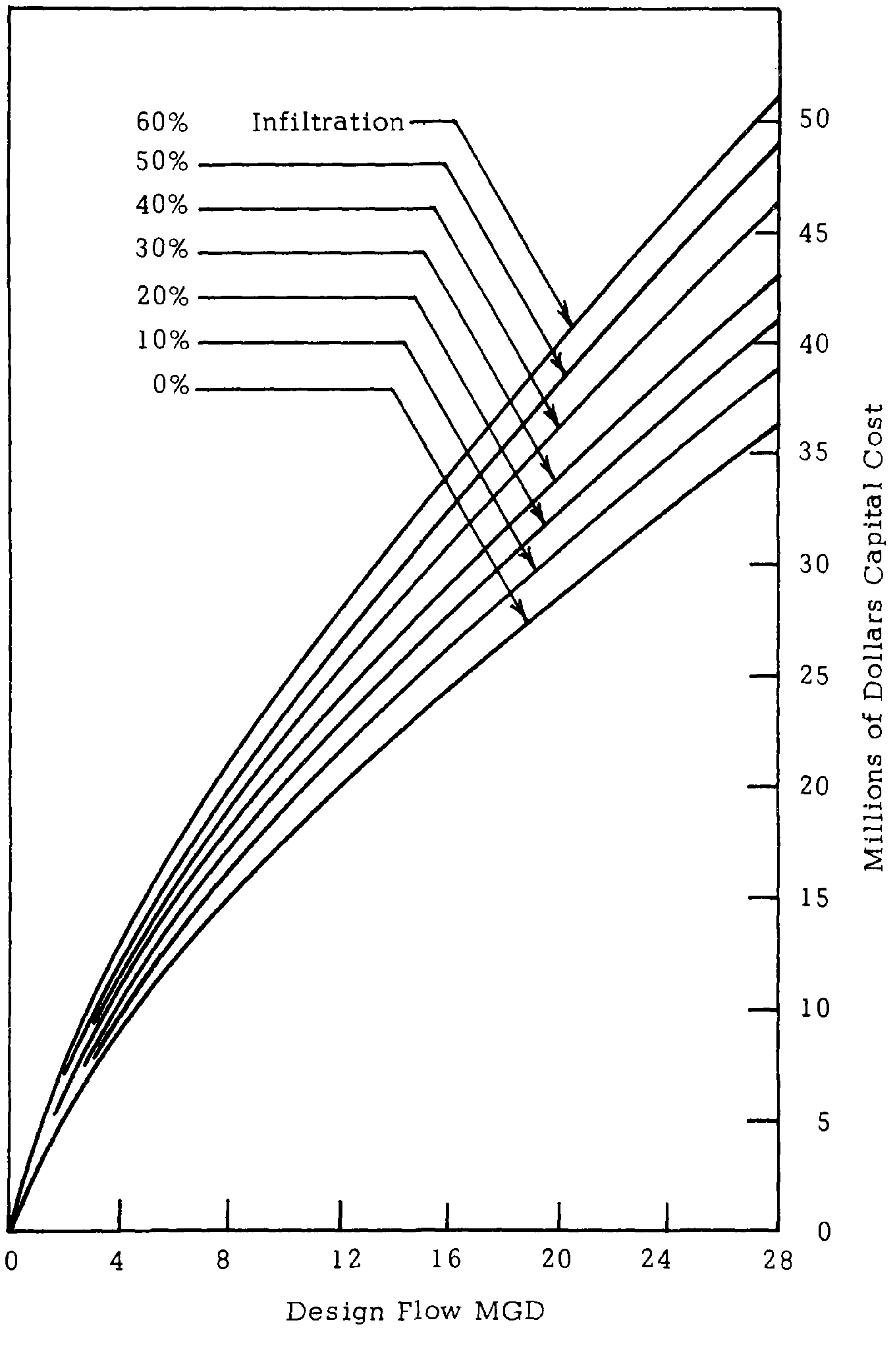
ADDED CAPITAL COST - TRICKLING FILTER TREATMENT
FIGURE 9



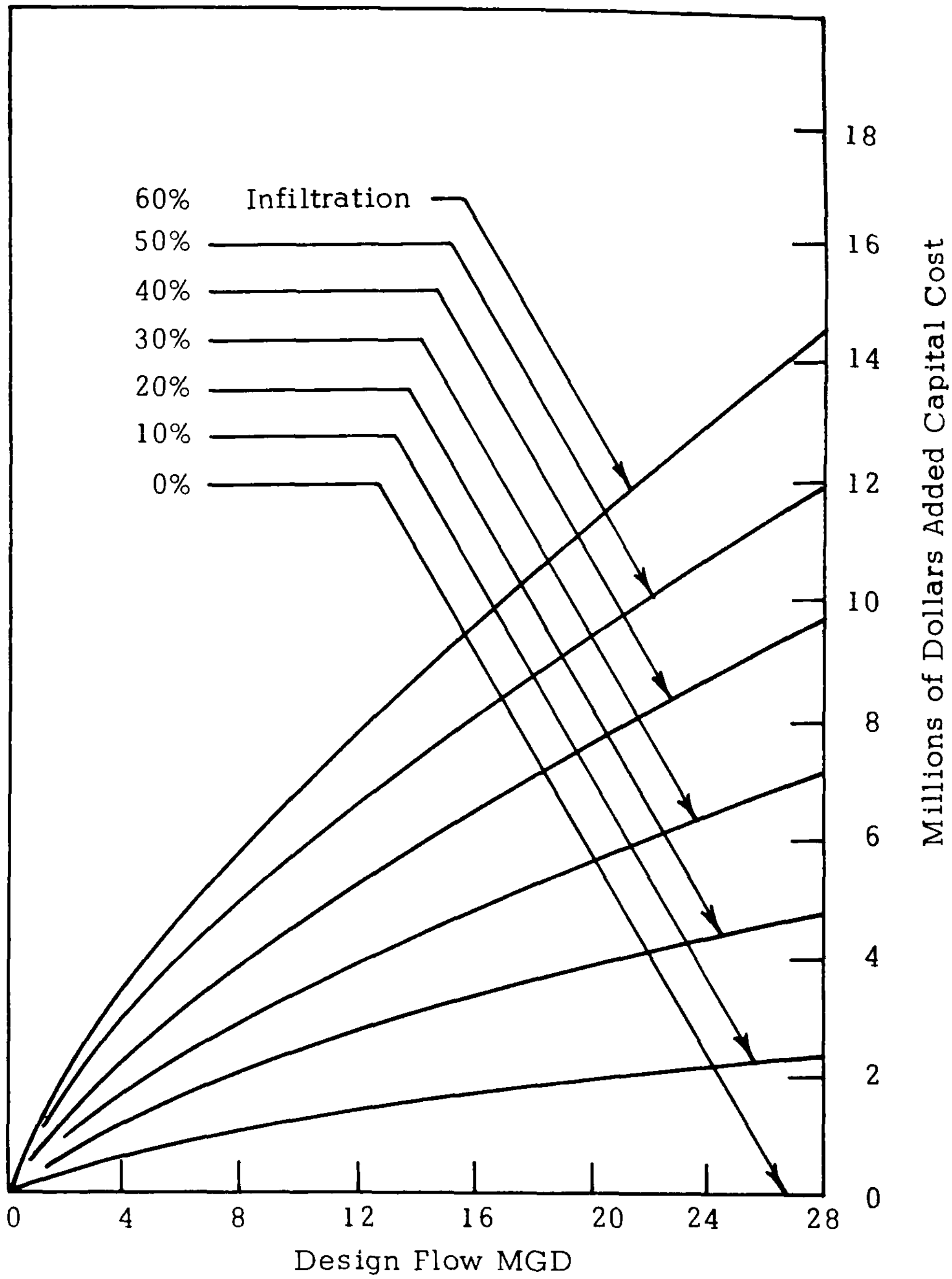
TOTAL COST-TRICKLING FILTER TREATMENT
FIGURE 10



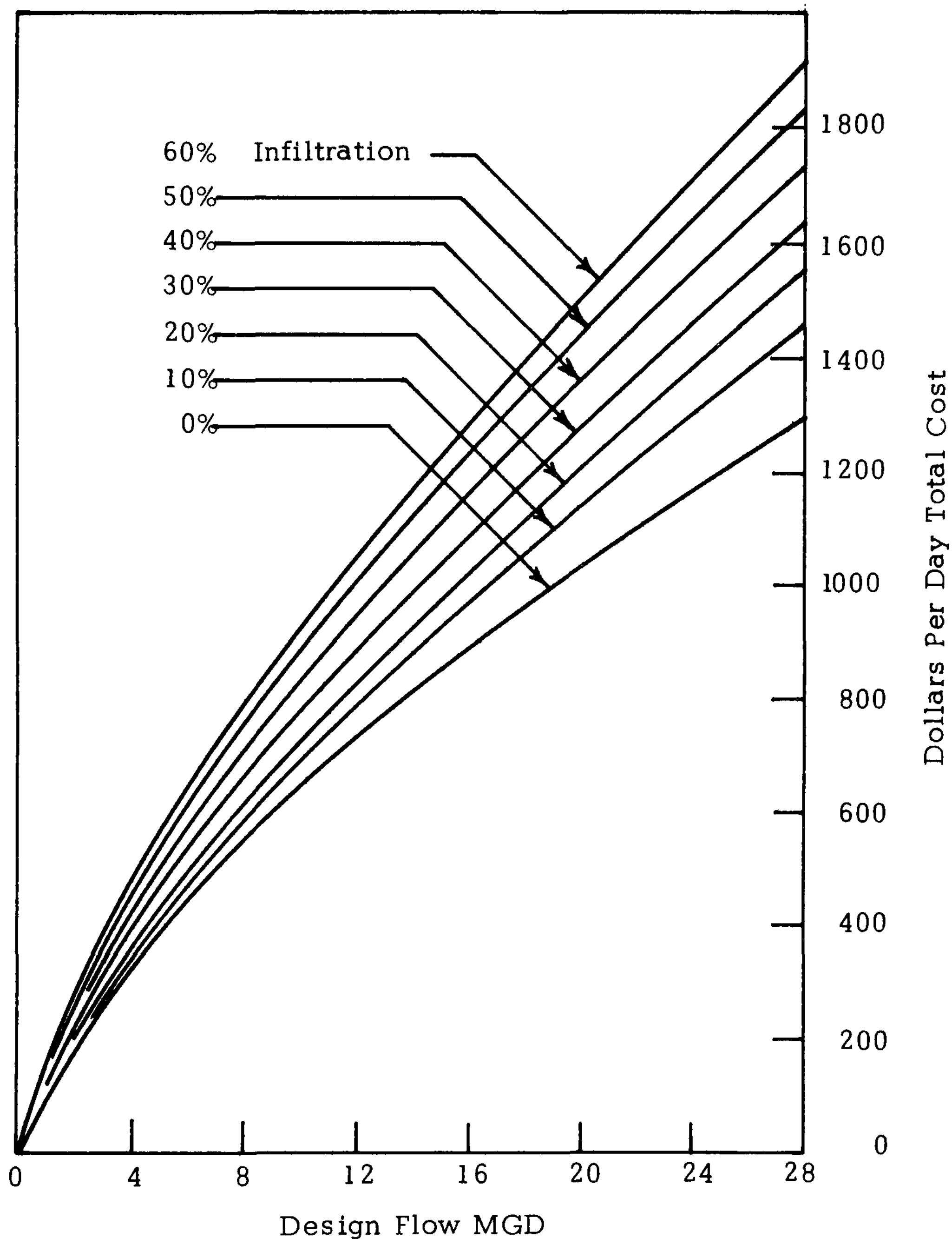
ADDED TOTAL COST-TRICKLING FILTER PLANTS
FIGURE 11



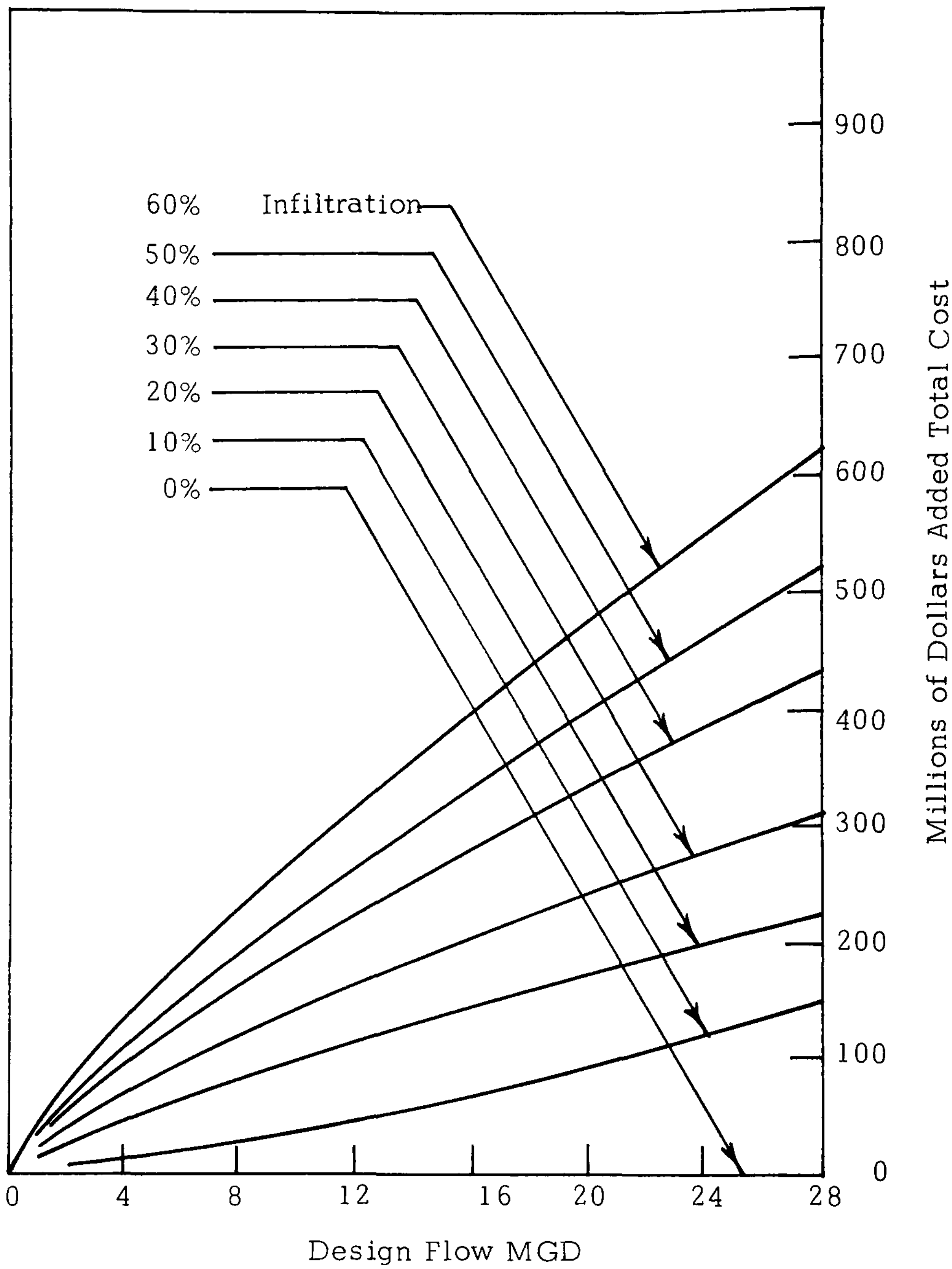
CAPITAL COST-PRIMARY TREATMENT
FIGURE 12



ADDED CAPITAL COST DUE TO INFILTRATION
PRIMARY TREATMENT
FIGURE 13



TOTAL COST-PRIMARY TREATMENT
FIGURE 14



ADDED TOTAL COST-PRIMARY TREATMENT
FIGURE 15

or above the house sewer. The ground is then wet with a lawn sprinkler. The presence of this dye at the nearest downstream manhole is proof of infiltration. There are dyes available for this purpose that are detectable at very low concentrations. Other tracers such as radioactive material and soluble chemicals that are readily detected can also be used.

Mirror Inspection

The simplest method for the detection of ground water infiltration is visual inspection with the use of a mirror. This is done by reflecting light into the sewer line. This method is best suited for detecting large leaks that are near manholes.

Photography

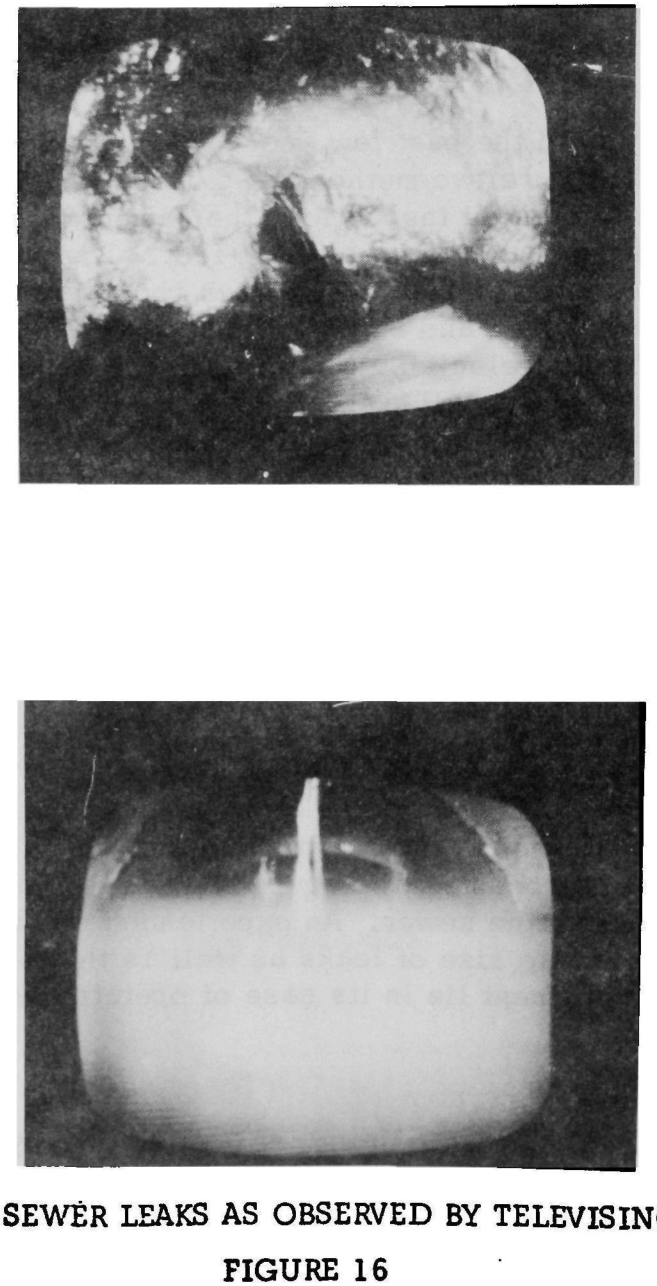
Photography has, in the past few years, come into wide use for sewer inspection. There are two methods employed, television and still photography. With television inspection, the camera is pulled through the sewer with a rope or a cable marked in feet. The observations are made on a television screen. Figure 16 shows photographs taken from a television monitor of leaks and breaks in a sewer line. The photographs were taken from the television monitor. Using the same methods, a special camera may be pulled through the sewer to take still pictures. Still shots have a disadvantage in that time is required for developing, but their cost is considerably lower than that of television. Both of these methods are excellent for locating small and large leaks. Also, with these methods, the size of the leaks can be more accurately determined.

Sounding

Sounding is a relatively new innovation in infiltration detection. The New Orleans Sewerage and Water Board has recently used an instrument called a "Dripaphone" for the detection of leaks in sewers. This instrument consists of a sound detection device inside of a bottle. The operator listens on earphones for the sound of water dripping on the bottle as it is pulled through the sewer. An experienced operator is able to determine the approximate size of leaks as well as the location. The advantages of this equipment lie in its ease of operation and low cost.

Air Pressure

Two other methods for determining infiltration employ air pressure. In the first, a sewer is plugged and a pressure is maintained with the use



SEWER LEAKS AS OBSERVED BY TELEVISING

FIGURE 16

of a blower. A correlation is then made between the air needed to maintain the pressure and the possibility of leakage. This method is not very exact since the correlation is difficult to make. A more exact method, using air, consists of maintaining a pressure in a sewer before the trench is backfilled. The leaks are then observed from the outside of the pipe. This second procedure can also be carried out using water instead of air.

Quantitative Measurement

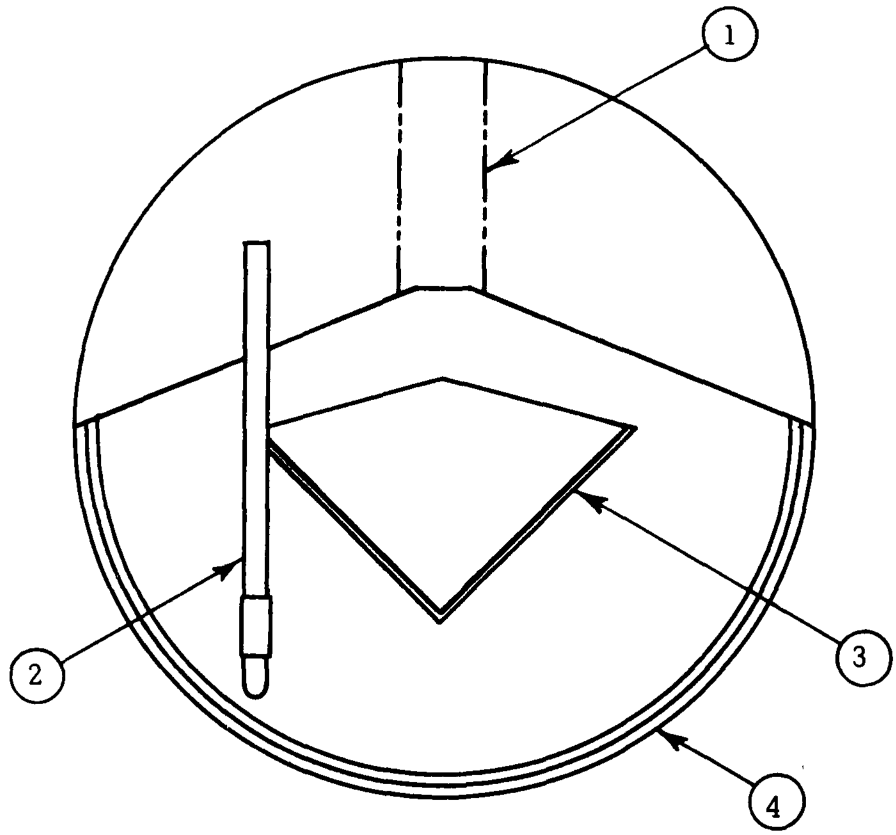
In quantifying the infiltration flow into a sanitary sewer there are several procedures that can be used. Each can be utilized during two general periods in the life of a sewer. Infiltration can be easily determined prior to the connection of house or building sewers as the entire flow at this time is attributable to ground water infiltration. After the sewer is put into service, some means of segregation of sewage and infiltration must be employed. This can be accomplished by plugging the house sewers and measuring flow or measuring the flow during a period of natural or requested non-use. At best, it is difficult to measure infiltration after a sewer is put into service.

It is important in measuring infiltration that the lines be unobstructed and that the flow be allowed to stabilize prior to measurement in order to obtain accurate readings. In making flow measurements, several readings should be taken at sufficient time intervals to insure that a reasonably constant discharge has been achieved.

Weirs

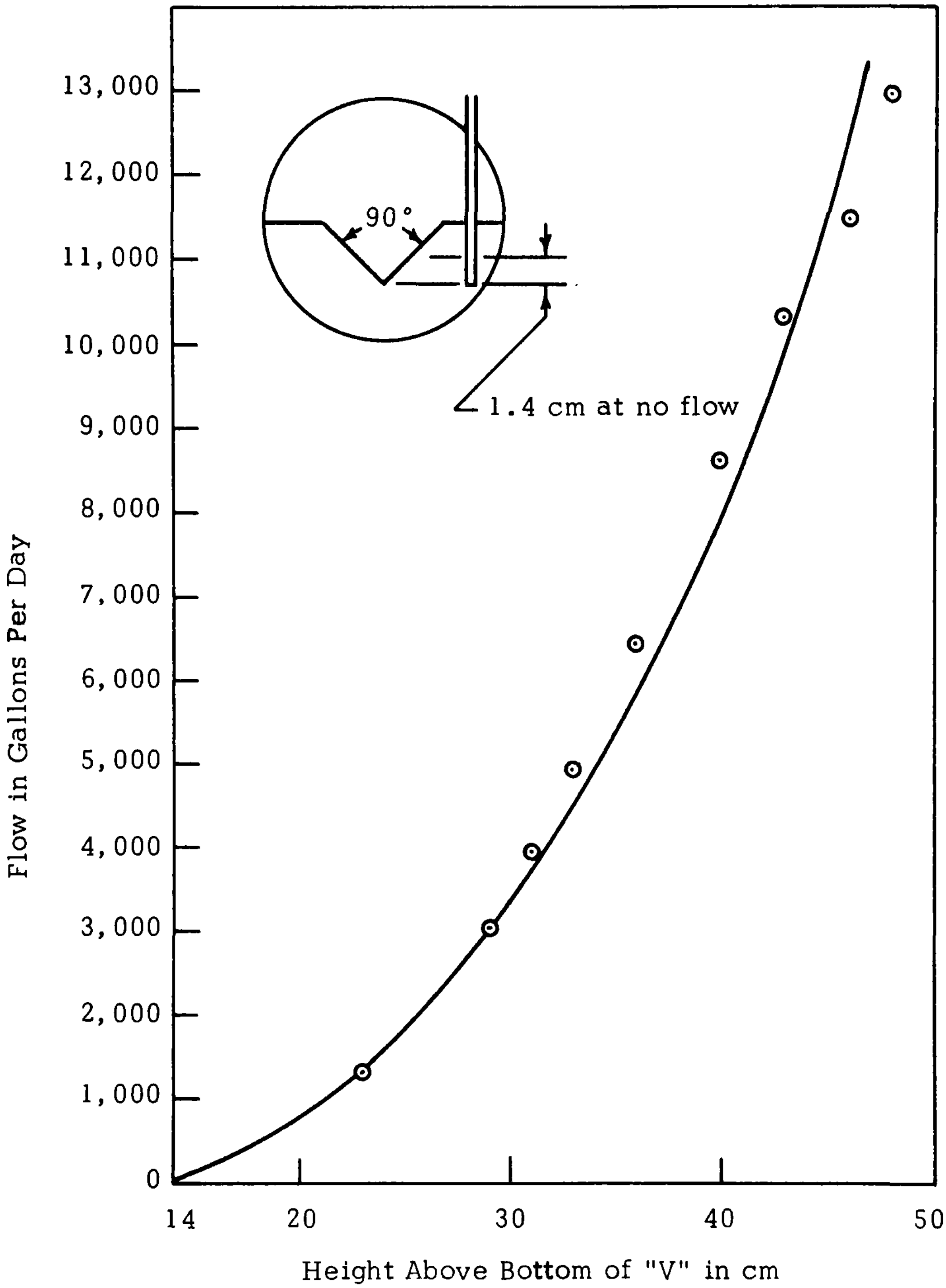
Weirs have long been used for the measurement of various kinds of flow. The same principle and methods are involved in their use for infiltration measurements. The section of sewer is plugged on the upstream end, and the weir is placed at the lower end. By knowing the characteristics of the weir and the head of the water, the flow may be calculated.

A typical 90° "V" notch weir is shown in Figure 17. The hydrostatic head at the notch is observed in the piezometer glass. Figure 18 is a calibration curve for such a weir. Plastic or metal weirs of this type are commercially available and are calibrated to read flow directly. It is not advisable to use weirs for small discharges because the continuity of flow is not uniform at low flows due to the surface tension effects. This method finds its greatest application in the range of moderate discharges. If the discharge is too high, the water rises above the top of the weir. If too low, the weir cannot be read.



1. Clamping Device
2. Observation Glass
3. Weir Notch
4. Rubber Seal

WEIR FOR MEASURING SEWER FLOW
FIGURE 17



CALIBRATION CURVE FOR A TRIANGULAR 90° WEIR
FIGURE 18

Catchment

This method involves the volume or weight measurement of all flow in a given time. The procedure consists of damning the downstream end of the sewer section that has been isolated for study. A small pipe must protrude through the dam. A device with the pipe protruding can be sho fabricated from metal with the appropriate seals or it can be made in the field with clay and a short length of thin wall tubing. Figure 14 shows several arrangements of clay dams in manholes.

Two factors relative to the dam and pipe must be considered. No leakag must be allowed around the edges of the dam and the tubing must be of sufficient size to allow the maintenance of non-pressure flow. The measurements are made by catching the water in a container and measur: the time with a stop watch. The water can then be weighed or its volum can be determined with a graduated cylinder. It is quite common to use a calibrated container of a convenient size. This method is quite accurate over a wide range of discharge, but is particularly useful for low flows where weirs are inaccurate.

Area Velocity Method

This prodedure consists of measuring the velocity and the area of flow and then calculating the discharge from the continuity equation, $Q = AV$, with Q being discharge, A equalling the cross-sectional area of flow, and V being the velocity of flow.

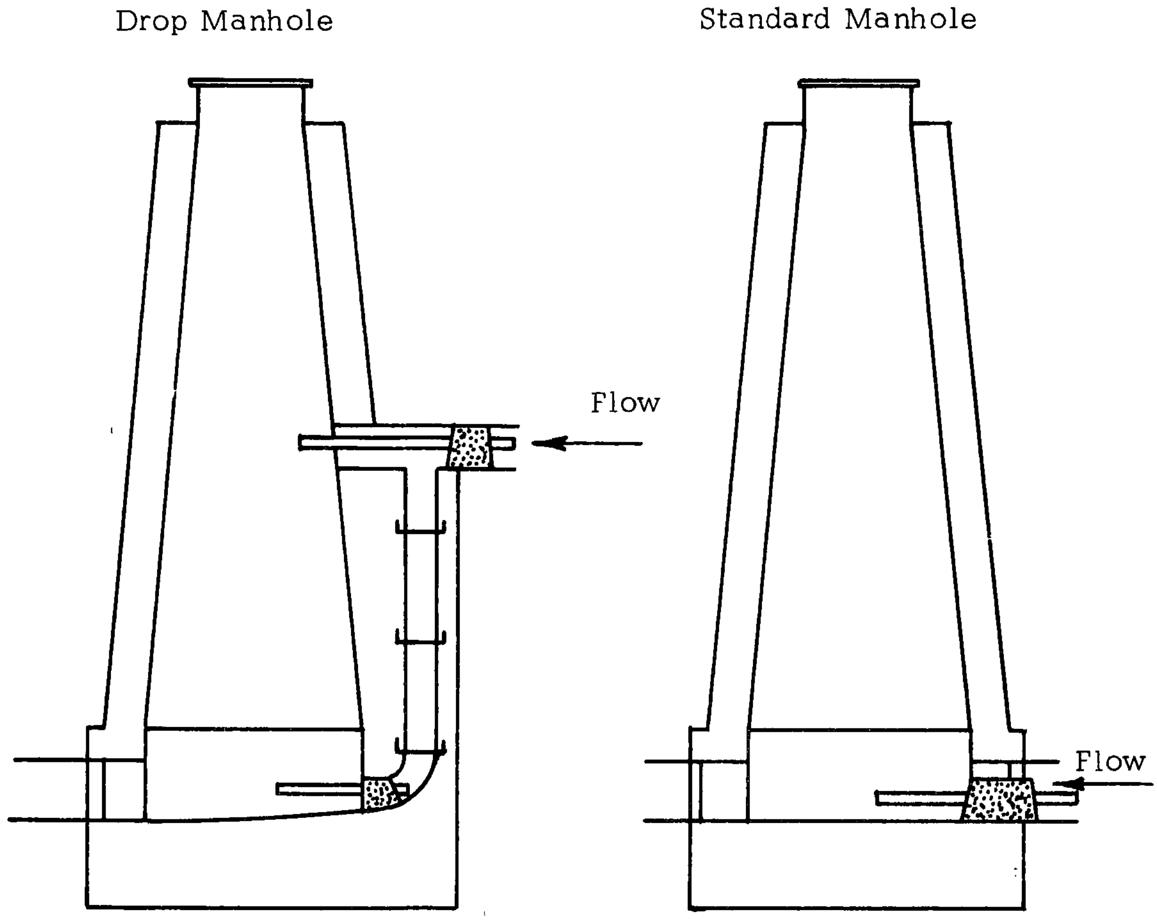
An estimate of the velocity can be made by timing the traverse of a float or a dye between two manholes. The area of flow can be determined from one or more depth measurements. Figure 20 gives the relationship of depth to area of flow for circular pipes up to 18 inches in diameter.

FIELD STUDIES

Two infiltration studies were performed in the Greater New Orleans Area between 1962 and 1970. In one study, performed on sewers laid in 1962 and 1962, infiltration was measured shortly after construction and monitored again in 1970. In the second study infiltration was measured on two test sewers which were laid in 1967-68.

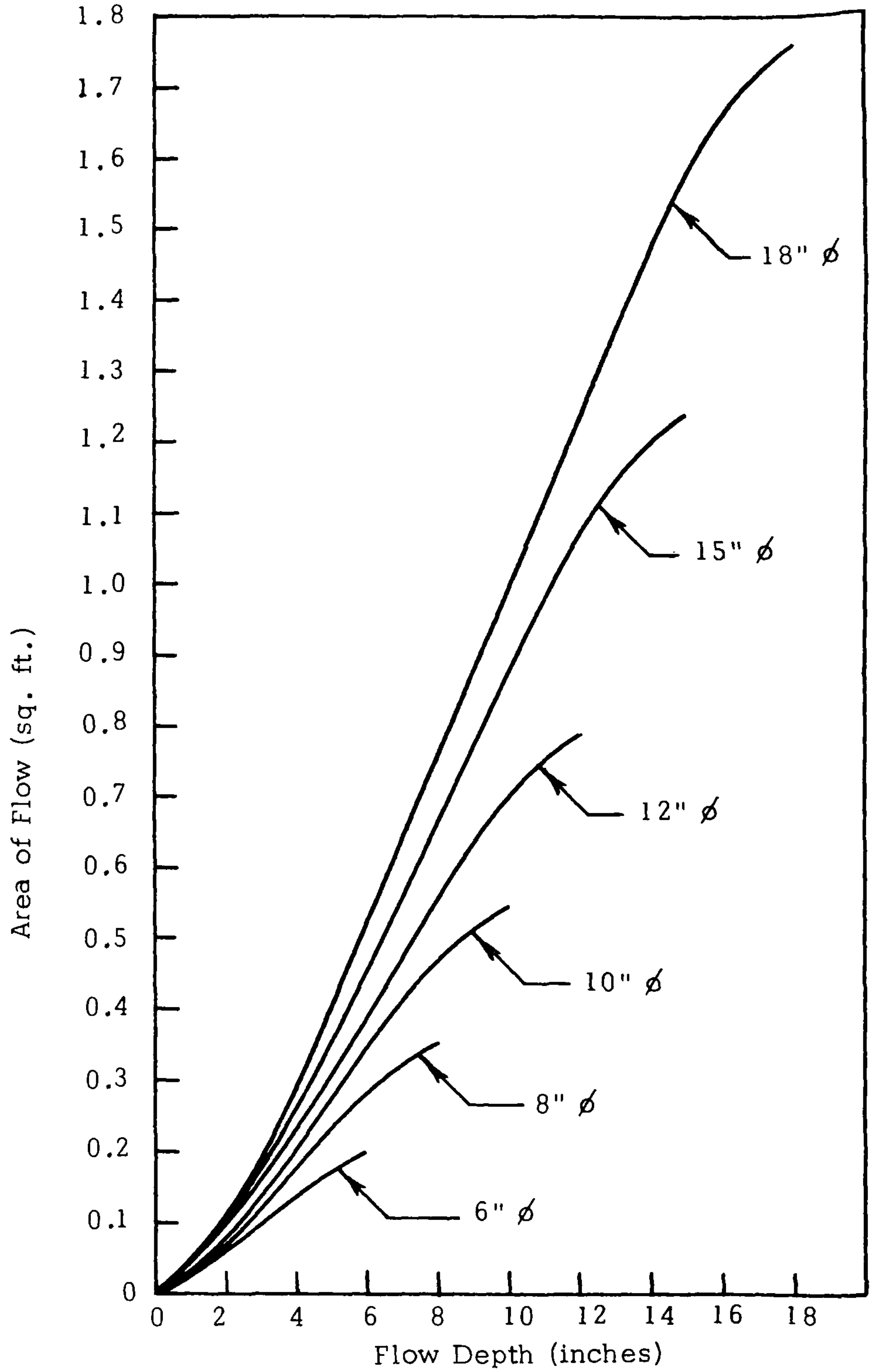
Long Term Infiltration Measurements

The project was initiated in 1962 through infiltration studies that were made on five separate systems in the City of New Orleans, accounting



Note: Dams in Drop Manholes Can Be Built Either in the Line or in the Bottom of the Drop.

CLAY DAMS IN MANHOLES
FIGURE 19



AREA OF FLOW IN PARTIALLY FILLED
CLAY SEWER OF VARIOUS DIAMETERS
FIGURE 20

for 69,020 linear feet of sewer. The sewers had just been installed in sections of the City being developed for subdivisions and house connections had not yet been made to the system. At that time the City of New Orleans did not require infiltration test procedures on new sewer installations. The objectives of these initial studies were to develop infiltration tests procedures and infiltration limits to be included in the New Orleans specifications for sewer construction. This initial study served as the basis for the continuation of the work through the financial support received by Federal Demonstration Grants and the Dickey Clay Products Co., Inc. [6]

These first infiltration measurements were made in 1962 and 1963 with four to five readings generally being taken on each system. In the current project, sections of the five separate sewer systems were selected for re-study with measurements being made during the summer of 1970. These latest measurements provide a long term - eight year period comparison, for infiltration with sewers laid with the conventional beddings used in the Gulf Coast Area. All lines used in this study were vitrified clay. Records of the City of New Orleans are no longer available on the specific type of joint used on each sewer line tested. All were either "O" ring or moulded bead compression joints.

Materials and Methods

When construction was completed on new sewers the lines were usually filled with water. The procedure used in performing the infiltration test under these conditions is as follows:

a) The sewer was pumped dry.

b) The sewer was cleaned by flushing.

c) The clay dam arrangement was constructed.

d) When the water built up behind the dam and the flow became stable through the pipe, a flow measurement was made utilizing the catchment method.

Readings were taken in five minute intervals until the flow became stabilized. When several constant readings were obtained the test was considered complete.

On sewers that have been in use, the testing procedures were somewhat similar but arrangements were made to eliminate sewage flow. This was accomplished in the study by informing the residents along the test section of the nature of the study and requesting that no water be used for the test period. Experience showed that the residents were very cooperative in this respect and many were quite interested in the project.

After the residents along the sewer were requested to discontinue using water, the test procedures described above were used. In older lines the experience usually was that the flow took longer to stabilize. Initial readings were high with the flow gradually diminishing to a constant low level. The lowest series of constant readings were taken as the amount of infiltration in the line.

In computing the infiltration into the sewers in gallons per inch mile of line, the average outside diameter was used. As extra strength clay pipe was used in all installations tested, the average of the minimum and maximum values indicated for barrels in the dimension tables of the ASTM specifications was taken. Table 1 is a tabulation of the values used in computing the infiltration.

TABLE 1

INCH MILES PER 100 FEET OF PIPE FOR VARIOUS DIAMETERS

Diameter-Inches	Inch Miles per 100 Ft. of Pipe
6	0.137
8	0.18
10	0.223
12	0.265
15	0.331
18	0.395

When the infiltration was measured in gallons and a period of time in seconds, the infiltration was computed as indicated in the following example.

Given:
- Diameter = 10 inches
- Length of Line = 380 feet
- Flow = 2.8 gallons
- Time = 102 seconds

Solution: From Table 1

Inch Miles = .223 x 3.80 = 0.847

$$\text{Time} = \frac{102}{60} = 1.7 \text{ minutes}$$

$$\text{Flow} = \frac{2.8}{1.7} = 1.65 \text{ gpm}$$

Solution (cont):

$$\text{Flow} = 1.65 \times 60 \times 24 = 2380 \text{ GPD}$$

$$\text{Infiltration} = \frac{2380}{0.847} = 2810 \text{ gallons/inch mile/day}$$

All sewers studied in 1962 and 1963 were made of vitrified clay. Records are not available on the specific type of bedding or joints on each of the lines tested. It was reported that some were "O" ring and other consisted of moulded bead compression joints. Some of those used were polyvinyl-chloride joints and others were polyurethane joints. The first joint immediately adjacent to each manhole on the systems studied was a hot poured joint. Infiltration measurements included the flow contributed by the 6 inch house connections and manholes as well as the sewer being tested.

Five separate systems were tested in this part of the project. All were located in the City of New Orleans. These are shown as Systems 1 to 5 on Figure 21. Table 2 shows the length of sewers in each system, the type of joint and describes the beddings used.

It may be noted from Figure 21 that the systems were in different parts of the City of New Orleans. Four extended along a four mile section known as New Orleans East which is adjacent to Lake Pontchartrain and the other is in the western side of the city. Apendices C,D,E,F and G show the sewers in each system. The following observations are made concerning the systems:

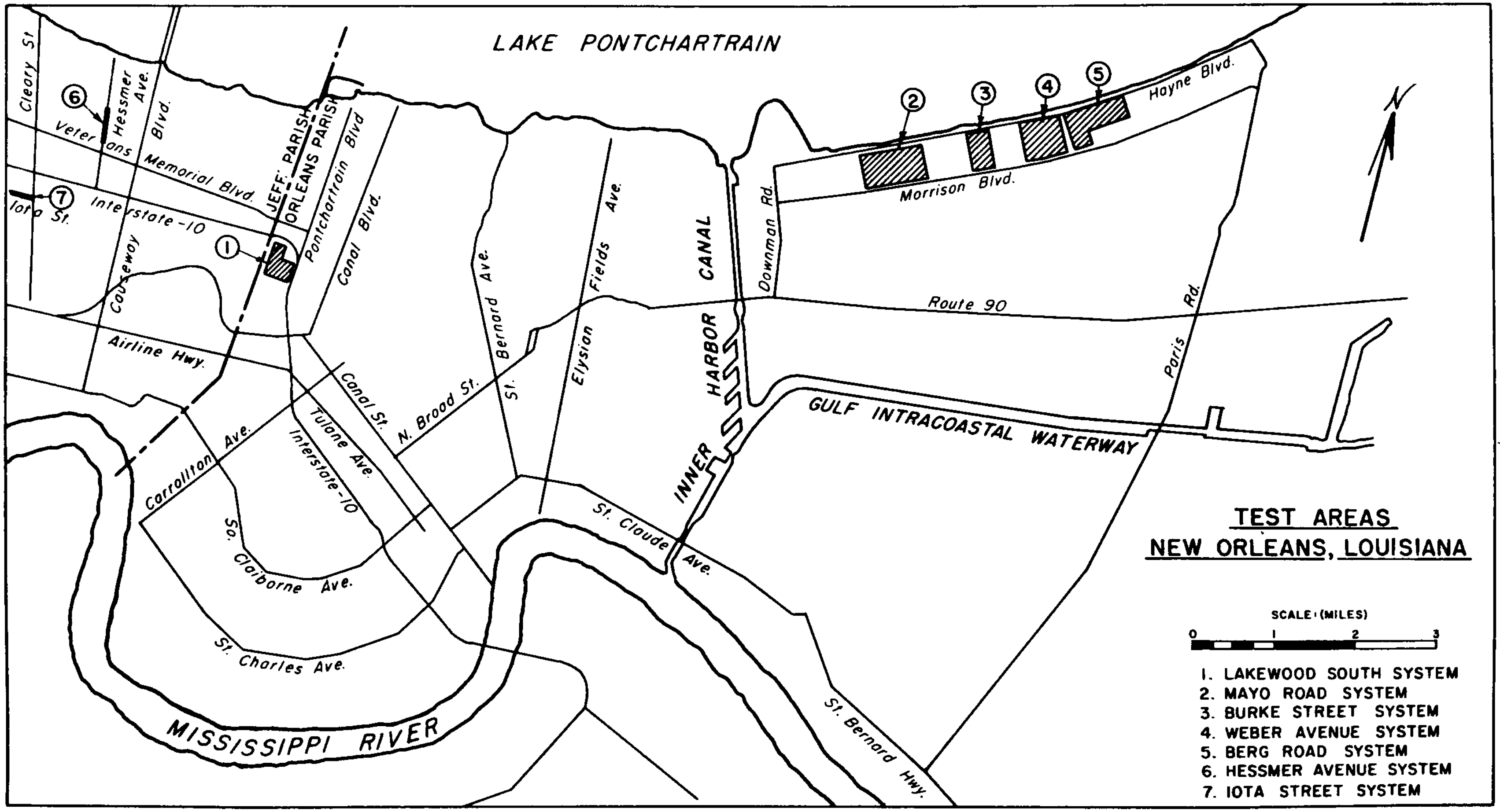
a) There were different contractors on the jobs and because of this there were various methods of construction used.

b) Each system had different types of joints.

c) The depths of the lines varied.

d) The soil conditions in the systems ranged from coarse sand to soft clay.

e) The systems tested were in two different areas of the city. This made a difference in the amount of rainfall on each system. In turn the variation in rainfall may have caused a possible difference in the heights of the water tables and in the hydrostatic heads on the pipes.



TEST AREAS
NEW ORLEANS, LOUISIANA
MAP OF SEWER SYSTEM
FIGURE 21

TABLE 2

LENGTH, JOINTS AND BEDDINGS OF SEWER SYSTEMS

System	Length of Lines Feet	Type of Joint	Description of Bedding
Mayo Road	13,390	P.V.C Beaded	Clam shell 8" below pipe and to top of pipe
Lakewood South	6,290	P.V.C Beaded	Clam shell 6" below pipe and to spring line
Weber Avenue	15,840	"O" Ring	Clam shell 6" below pipe and to top of pipe
Burke Street	17,400	"O" Ring	Clam shell 6" below pipe and to top of pipe
Berg Road	16,100	"O" Ring	Clam shell 6" below pipe and to spring line

Results - 1962-1963 Tests

Ninety-six flow readings were taken on sewer lines in the five separate systems. As these systems had just been installed there was no sewage flow in the systems. As house connections were made to the system, the tests were discontinued. This is the reason why only one set of readings was taken on the Weber Avenue, Berg Road and Mayo Road systems. Tables 3 , 4 , 5 , 6 and 7 show the physical characteristics of the systems studied and Tables 8 , 9 , 10, 11 and 12 show the infiltration in gallons per inch mile per day that was recorded on the lines.

The amount of rainfall in the vicinity of the systems was recorded during the test period. The rainfall observations are shown in Table 13. The Metairie Gauge is located in the vicinity of the Lakewood South System and the Citrus Gauge is located near the Mayo Road, Burke Street, Weber Avenue and Berg Road Systems.

A review of the infiltration records of the system shows considerable variations with single line readings and wide range between individual lines. Of the 48 lines tested eight were found to have no infiltration and one of the lines of the Weber System (Line 2-12) recorded the maximum infiltration of 111,560 gallons per inch mile per day.

Significant variations occurred within the same lines where several observations were made. Line 7-8 of the Lakewood South System, for example, where seven observations were made showed a 400 percent difference with a minimum of 909 and a maximum of 3610 gallons per inch mile per day. No correlation appears to exist between rainfall and infiltration. Similarly the depth of the sewer appears to have no effect on infiltration. This is probably due to the fact that in the areas studied, the ground surface was at or near Mean Gulf Level and the ground water table is within a few feet of the ground surface. As a consequence, sewers are consistently under a hydraulic head of considerable magnitude.

The following observations were made concerning the systems tested:

Mayo Road System

In the Mayo Road System, the infiltration in Line 7-8 was found to be 16,050 gallons per inch mile per day. The line was shined with mirrors from both ends and no leaks could be seen. A closed circuit television camera was run through the line and a leak was found in one joint The line was dug up and it was discovered that the bell was cracked. After the pipe was repaired the line was televised again and found to be almost dry.

TABLE 3

PHYSICAL CHARACTERISTICS OF THE MAYO ROAD SYSTEM

Number	Length of Line	Inch Miles	Average Depth
2-3	8"- 720.0' 6"- 48.0'	1.361	8.1'
1-3	8"- 660.5' 6"- 132.0'	1.370	7.1'
3-4	8"-1675.0' 6"- 372.0'	3.519	10.1'
4-5	12"- 608.2' 10"- 318.3'	2.320	10.4'
5-6	15"-1770.3'	5.866	11.4'
4-10	15"-2139.3' 12"- 608.2' 10"- 318.3	9.410	11.6'
7-8	15"- 381.6'	1.265	10.3'
8-9	18"- 1589.5'	6.284	11.5'
8-10	18"-2051.5'	8.112	11.7'

TABLE 4

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE MAYO ROAD SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
2-3	8/17/62	0	250	-*
1-3	8/17/62	1,313	250	+
3-4	8/17/62	539	250	+
4-5	8/17/62	541	250	+
5-6	8/17/62	248	250	-
4-10	5/ 8/63	10,712	250	+
7-8	7/21/62	16,050	250	+
8-9	7/21/62	0	250	-
8-10	5/ 8/63	828	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 5

PHYSICAL CHARACTERISTICS OF THE LAKEWOOD SOUTH SYSTEM

Number	Length of Line	Inch Miles	Average Depth
10-12	8"-744.0' 6"-424.0'	1.918	8.0'
11-12	8"-375.4' 6"-224.0'	0.961	8.5'
7-9	8"-681.4' 6"-500.0'	1.916	8.5'
5-6	8"-418.8' 6"-271.0'	1.126	8.0'
3-4	8"-741.8' 6"-524.5'	2.135	8.5'
1-2	8"-417.9' 6"-268.5'	1.119	8.1'
12-13	18"-145.7' 6"- 60.0'	0.661	12.5'
7-8	8"-269.5' 6"-225.0'	0.794	8.9'

TABLE 6

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE LAKEWOOD SOUTH SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
10-12	8/10/62	3870	250	+*
	9/ 7/62	3840	250	+
	10/ 9/62	4230	250	+
11-12	11/ 6/62	1875	250	+
	12/ 4/62	1715	250	+
	1/ 8/63	1873	250	+
	4/23/63	1713	250	+
7-9	8/10/62	3320	250	+
5-6	8/10/62	0	250	-
	9/ 7/62	0	250	-
3-4	8/10/62	0	250	-
	9/ 7/62	0	250	-
1-2	8/10/62	1970	250	+
12-13	8/10/62	2780	250	+
	9/ 7/62	2472	250	+
	10/ 9/62	2540	250	+
	10/23/62	4650	250	+
	11/ 6/62	2370	250	+
	12/ 4/62	1530	250	+
	1/ 8/63	2511	250	+
	4/23/63	2440	250	+
7-8	8/10/62	925	250	+
	9/ 7/62	1508	250	+
	10/ 9/62	3610	250	+
	10/23/62	1220	250	+
	11/ 6/62	2850	250	+
	12/ 4/62	925	250	+
	1/ 8/63	909	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 7

PHYSICAL CHARACTERISTICS OF THE WEBER AVENUE SYSTEM

Number	Length of Line	Inch Miles	Average Depth
1-2	8"-1298.1' 6"- 425.0'	2.919	9.1'
3-4	8"-1566.3' 6"- 623.0'	3.773	7.5'
5-6	8"-1286.4' 6"- 406.0'	2.871	8.1'
7-9	8"-1494.6' 6"- 551.0'	3.446	7.6'
8-9	8"-1509.2' 6"- 429.8'	3.305	7.6'
2-12	12"-1216.8'	3.227	12.0'
2-10	12"- 410.2'	1.088	11.3'
10-11	12"- 408.1'	1.082	12.1'
11-12	12"- 398.5'	1.056	12.7'
13-14	8"-1128.8' 6"- 150.0'	2.237	9.5'
15-16	8"-1124.1' 6"- 100.0'	2.159	9.5'
17-18	8"-1143.8' 6"- 175.0'	2.298	9.5'

TABLE 8

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE WEBER AVENUE SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
1-2	3/20/63	3,364	250	+*
3-4	3/20/63	2,673	250	+
5-6	3/20/63	1,508	250	+
7-9	3/20/63	1,256	250	+
8-9	3/20/63	2,178	250	+
2-12	3/28/63	111,560	250	+
2-10	4/ 4/63	42,613	250	+
10-11	4/ 4/63	0	250	-
11-12	4/ 4/63	0	250	-
13-14	3/28/63	2,413	250	+
15-16	3/28/63	3,580	250	+
17-18	3/28/63	2,136	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 9

PHYSICAL CHARACTERISTICS OF THE BURKE STREET SYSTEM

Number	Length of Line	Inch Miles	Average Depth
1-3-4	12"- 620.1' 8"-3227.1' 6"- 516.5'	8.184	8.6'
1-2	8"-2124.6' 6"- 298.5'	4.234	9.9'
5-6	8"-1212.9' 6"- 104.0'	2.325	7.7'
7-8	8"-1199.8' 6"- 68.0'	2.250	7.7'
9-10	8"-1197.8' 6"- 105.0'	2.299	7.7'
11-14	8"-1578.5' 6"- 122.0'	2.937	6.7'
12-13-14	8"-2265.5' 6"- 314.0'	4.502	7.2'
15-4	10"- 351.9' 8"- 623.3' 6"- 81.0'	2.016	8.1'
16-17	18"-1156.6' 6"- 235.0'	4.898	11.5'

TABLE 10

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE BURKE STREET SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
1-3-4	8/24/62	1319	250	+*
	10/ 1/62	4505	250	+
	10/30/62	3700	250	+
	11/20/62	3360	250	+
	12/11/62	2950	250	+
1-2	8/24/62	1821	250	+
5-6	8/24/62	316	250	+
	10/ 1/62	426	250	+
	10/30/62	328	250	+
	11/20/62	0	250	-
	12/11/62	0	250	-
7-8	8/24/62	552	250	+
	10/ 1/62	1044	250	+
	10/30/62	385	250	+
	11/20/62	568	250	+
	12/11/62	592	250	+
9-10	8/24/62	587	250	+
	10/ 1/62	957	250	+
	10/30/62	448	250	+
	11/20/62	442	250	+
	12/11/62	564	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 10 (continued)

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE BURKE STREET SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
11-14	8/24/62	197	250	-*
	10/ 1/62	732	250	+
	10/30/62	335	250	+
	11/20/62	768	250	+
	12/11/62	800	250	+
12-13-14	8/24/62	2525	250	+
	10/ 1/62	2664	250	+
	10/30/62	1867	250	+
	11/20/62	1370	250	+
	12/11/62	1145	250	+
15-4	8/24/62	1165	250	+
	10/ 1/62	1448	250	+
	10/30/62	2190	250	+
	11/20/62	1070	250	+
	12/11/62	2240	250	+
16-17	8/24/62	4500	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 11

PHYSICAL CHARACTERISTICS OF THE BERG ROAD SYSTEM

Number	Length of Line	Inch Miles	Average Depth
1-2-3	8"-1691.4' 6"- 556.1'	3.805	5.8'
4-5	8"-1200.2' 6"- 350.0'	2.640	5.3'
6-7-8	8"-1747.5' 6"- 462.4'	3.779	5.8'
9-10	8"-2013.1' 6"- 674.5'	4.547	7.6'
11-14	8"- 953.0' 6"- 26.0'	1.749	5.4'
12-13-14	8"-1409.8' 6"- 271.5'	2.908	4.9'
15-16	8"-1132.8' 6"- 125.0'	2.210	6.9'
17-18	8"- 691.2' 6"- 69.0'	1.338	7.5'
19-20	8"-1125.4' 6"- 225.0'	2.333	6.9'
21-22	8"-1126.2' 6"- 250.0	2.368	6.9'

TABLE 12

INFILTRATION EXPRESSED IN GALLONS PER INCH MILE PER DAY RECORDED IN THE BERG ROAD SYSTEM

Number	Date	Infiltration gal/in/mile/day	Current Allowable Infiltration Specification gal/in/mile/day	
1-2-3	2/7/63	4055	250	+*
4-5	2/7/63	2045	250	+
6-7-8	2/7/63	2508	250	+
9-10	2/7/63	2639	250	+
11-14	2/7/63	0	250	-
12-13-14	2/7/63	1062	250	+
15-16	2/7/63	4889	250	+
17-18	2/7/63	1494	250	+
19-20	2/7/63	5143	250	+
21-22	2/7/63	9199	250	+

*Minus sign indicates value measured is within the current infiltration specification and a positive sign indicates that the measured value is not within the current infiltration specification.

TABLE 13

MONTHLY RAINFALL RECORD
CITY OF NEW ORLEANS

	Month	Rainfall-Inches per Month Metairie Gauge	Citrus Gauge
1962	July	2.36	3.03
	August	3.30	3.95
	September	4.25	5.78
	October	2.44	1.71
	November	2.45	3.53
	December	3.10	3.90
1963	January	3.65	5.71
	February	5.90	6.45
	March	1.76	1.17
	April	2.11	3.72
	May	1.46	4.34

Lakewood South System

In the Lakewood South System several sources of infiltration were found in line 10-12. One major leak was adjacent to a manhole where there was a poor seal between the pipe and the manhole. This leak was measured and approximated at 500 gallons per day. In another joint on an 18" line adjacent to a manhole, a leakage amounting to one thousand gallons per day was found. This was a hot poured bituminous joint used for the last pipe section adjacent to the manhole.

Weber Avenue System

In line 2-12 of the Weber Avenue System it may be noted from Table that the infiltration was 111,560 gallons per inch mile per day. The major portion of this was found to be coming from a hot poured joint adjacent to a manhole. The joint was open at the top and the hot poured material used to make the joint had been squeezed out of the bottom.

Burke Street System

In the Burke Street System, line 1-2 had the greatest infiltration with a value of 2664 gallons per inch mile per day. A television inspection of this line showed several cracked bells that were causing the infiltration.

Results of 1970 Tests

As a part of the current project some of the lines used in the 1962-1963 tests were selected for infiltration measurements. These tests were made during the summer of 1970. The purpose of this portion of the study was to determine the changes that may have occurred in the five systems during the period between the measurements. In selecting the lines to be tested, consideration was given to the magnitude of infiltration in the initial study, type of beddings and number of house connections. It was recognized that the fewer houses along the lines selected, the easier it would be to eliminate residential flow. A cross section of lines was selected where both maximum and minimum infiltration flows were recorded on the initial survey. Materials and methods used in the 1970 study were identical to those used in the 1962-1963 tests.

A comparison of the results of the two infiltration tests are shown in Table 14. A tabulation of repairs performed on the system during the interval between the two tests and the number of house connections in 1970 is presented in Appendix H.

At the time that the infiltration studies were made on the sewers in the

TABLE 14

COMPARISON OF INFILTRATION TESTS OF 1962-1963 to 1970

System & Line Numbers	Infiltration Tests Run 1962-1963: Date of Infilt. Test	Infiltration Tests Run 1962-1963: Infiltration*	Infiltration Tests Run 1970: Date of Infilt. Test	Infiltration Tests Run 1970: Infiltration*	Interval Between Tests Yrs.	Interval Between Tests Mo.	Infiltration* + Increase - Decrease *
Weber							
2-12	4-63	111,560	6-70	6,660	7	2	-104,900
11-12	4-63	0	6-70	1,535	7	2	+ 1,535
2-10	4-63	42,613	6-70	8,110	7	2	- 34,503
Lakewood South							
7-9	8-62	3,320	5-70	2,100	7	9	- 1,220
5-6	8&9-62	0	5-70	1,710	7	9	+ 1,710
1-2	8-62	1,970	5-70	1,630	7	9	- 340
Burke							
15-4	8 to 12-62	1,622	6-70	2,480	8	0	+ 858
Mayo							
4-5	8-62	541	8-70	12,600	8	10	+ 12,069
4-10	5-63	10,712	6-70	3,350	7	1	- 7,362
7-8	7-62	16,050	7-70	1,170	8	0	- 14,880
Berg							
17-18	2-63	1,494	6-70	1,830	8	4	+ 336
19-20	2-63	5,143	6-70	1,545	8	4	- 3,598

*Gallons per inch of diameter per mile per day.

City of New Orleans in 1962-1963, there were not requirements included in the city's specifications on infiltration. As a result of the 1962-1963 infiltration studies the City of New Orleans adopted specifications for sewer construction limiting the infiltration to 1000 gallons per inch mile per day. In March of 1966 the infiltration limitation in the specifications for new sanitary sewer construction was reduced to 250 gallons per inch mile per day. These are the standards currently used by the City of New Orleans.

A review of Table 14 indicates that substantial reductions have occurred in the infiltration of some of the lines. For example, this is particularly true in line 2-12 of the Weber Avenue System where the infiltration dropped from 111,560 to 6,660 gallons per inch mile per day. No doubt some of the decrease in this line and others was due to repairs provided during the interim. In the case of line 2-12, after the major leak in the joint adjacent to a manhole was repaired, a substantial decrease in the infiltration followed. Other repairs made to the lines studied are shown in Appendix H.

In each of the lines measured in the 1970 study the infiltration exceeded the present allowable limit set in the New Orleans specifications of 250 gallons per inch mile per day. The highest recorded was line 4-5 of the Mayo Road System of 12,600 gallons per inch mile per day. It is interesting to note also that lines 11-12 of Weber and 5-6 of Lakewood where no infiltration was recorded in 1962-1963, now show infiltration rates exceeding 1500 gallons per inch mile per day.

<u>1970 Television Inspection</u>

To determine the cause of the infiltration in the system the following lines were selected for televising.

System	Line	Diam. Inches	Length Feet	Amount of Infiltration Gal/Inch Mile/Day
Weber Ave	2-12	8	1216	6600
Mayo Road	7-8	15	381	1170

Considerable difficulty was experienced in televising these sections because of blockages in the lines. The blockages experienced included breaks in sewers, roots of trees and large accumulations of grease. The sections of sewers studied were all serving new subdivisions. It is the common practice in residential construction in this area to equip the new homes with garbage disposals on the kitchen sinks. It is believed that the cold water entering the sewers through infiltration was causing the grease to coagulate and in some cases mix or adhere to mud entering the sewers through cracks or other openings. Large quantities of grease were observed on the television camera when it was removed from the sewer. In some cases a mixture of grease and clay at joints was observed with no infiltration. Apparently the mixture had succeeded in sealing off joint leakages.

The following comments are submitted concerning some of the conditions found in the lines:

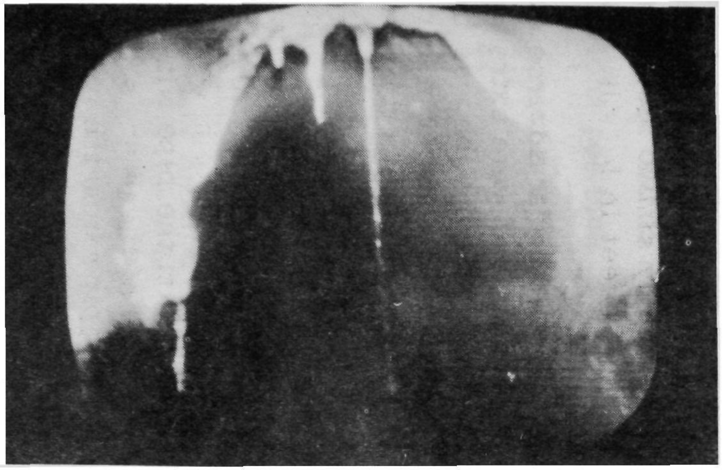
Weber Avenue

Between manholes 2 and 10 a break was found through which soil and roots had entered. Large quantities of grease were observed in the mass of roots and mud. The sewer appeared to have partially collapsed and the camera could not pass the blockage. In another section of this line a leaking joint was found near a house connection. The house connection appeared to have been made by breaking through the sewer and inserting a smaller (probably 6" diameter) pipe into the main conduit. A considerable accumulation of grease was noticed in the area of the leaking joint. In the 1216 feet of this line that were televised approximately twelve leaks appeared to be present that were caused by breaks, improper house connections or open joints. Figure 22 shows television photographs of some of the conditions found.

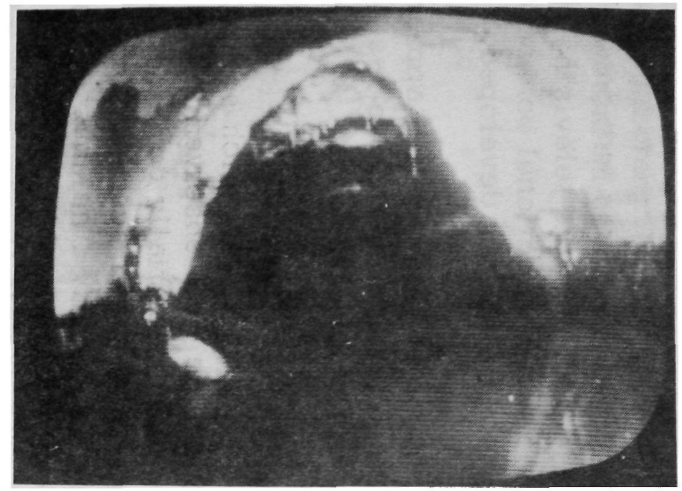
Mayo Road

Conditions observed along this line were generally similar to those found in the Weber Avenue System. This line was 381 feet in length. Three house connections made by breaking the sewer were observed and in each case infiltration appeared to be occurring. Considerable accumulation of grease was noticed around each connection. Photographs of the conditions found in this line are shown in Figure 22.

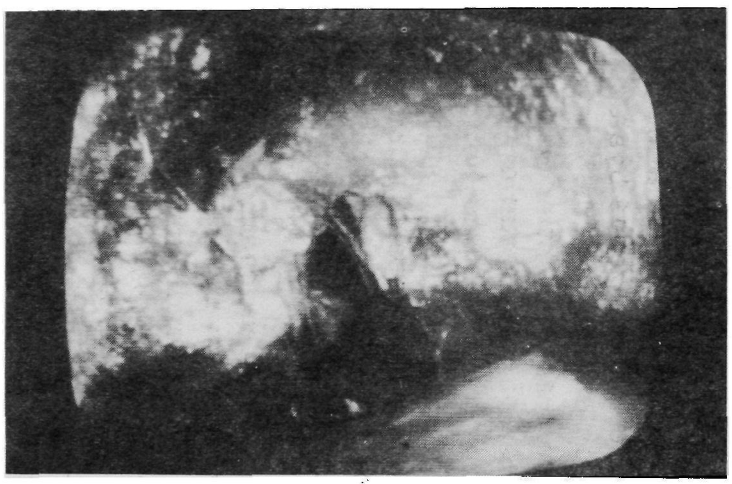
The results of the studies made in 1962-1963 and 1970 clearly indicate that large quantities of infiltration are entering the system. The amounts found in every line studied in 1970 are far in excess of the City of New Orleans' limit of 250 gallons per inch mile per day. Observations made during the laying of these systems in 1962 and 1963 indicated that poor construction methods were used. A new factor appears to have been introduced in the hydraulics of sewage flow with the inception of the garbage disposal units used in homes. The use of these units is estimated to increase the organic content of domestic sewage by 50 per cent. This material with the grease that is included, will undoubtedly add to sewer maintenance problems. This condition was strikingly



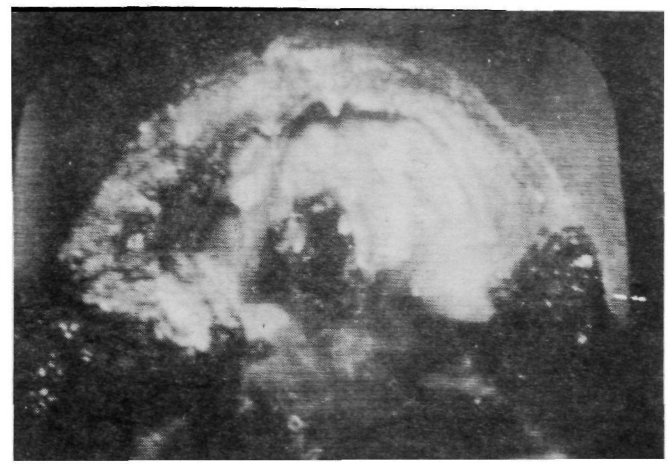
Leaking Joint - Weber Ave.



House Connection Broken into Top of Sewer
Mayo Road



Tree Root - Weber Ave.



Grease Accumulations at House Connection
Weber Ave.

FIGURE 22 - PHOTOGRAPHS FROM TELEVISION MONITOR

emphasized through conditions observed in the lines that were televised.

Closer supervision over plumbers making connections to main sewer lines appears to be warranted. It was very apparent from the televising of the lines that in almost every case where the non-conventional connection was made by breaking into the main sewer line, a leak developed.

Where leaks occur in breaks or defective joints some sealing appears to occur through backfill soil entering the opening. Grease also has a tendency to adhere or mix with soil entering these openings.

Test Sewer Studies 1968-1970

During the period from 1967 to 1970, the two test sewers located in Jefferson Parish, Louisiana, were observed during and after construction. One was located on Iota Street (constructed in November and December 1967) and the other, on Hessmer Avenue (constructed in May and June 1968). Section V provides a description of these studies. Each consisted of three sections between manholes. Table 15 shows the infiltration records of each section of each test sewer. On 9-14-70 Sections I and II were not measured because the bottom of the manholes were constantly flooded with infiltrated water.

The construction practices used on the Iota Street sewer were generally good with the single exception that backfill was dropped onto the pipe. Although continuous pumping was required in order to maintain a dry trench, the conditions of soil and water could be considered good and no sheeting was required. An average trench width of two feet was maintained throughout the construction.

In contrast,the sewer on Hessmer Avenue was laid under adverse conditions of soil and water and the construction practices were extremely bad. The soil at the bottom of the trench throughout the job was in a constant semi-liquid state, and the slight upward movement of particles indicated an impending quick condition. The side flow of particles and water through the sheeting existed throughout the work. Poor construction practices were common and are listed as follows:

1. The trench was maintained with a bottom width of from 4 1/2 to 5 feet.
2. Bedding material was dropped directly on the pipe with a front end loader.
3. Backfill was pushed onto the bedded pipe from the upper edge of the trench. At times the impact from this procedure could be strongly felt by observers alongside of the trench.

4. The method of adjusting the grade downward was for two or three laborers to jump on the pipe in unison. This practice was so common that any other would be considered an oddity.

TABLE 15

INFILTRATION TEST SEWERS
JEFFERSON PARISH, LOUISIANA

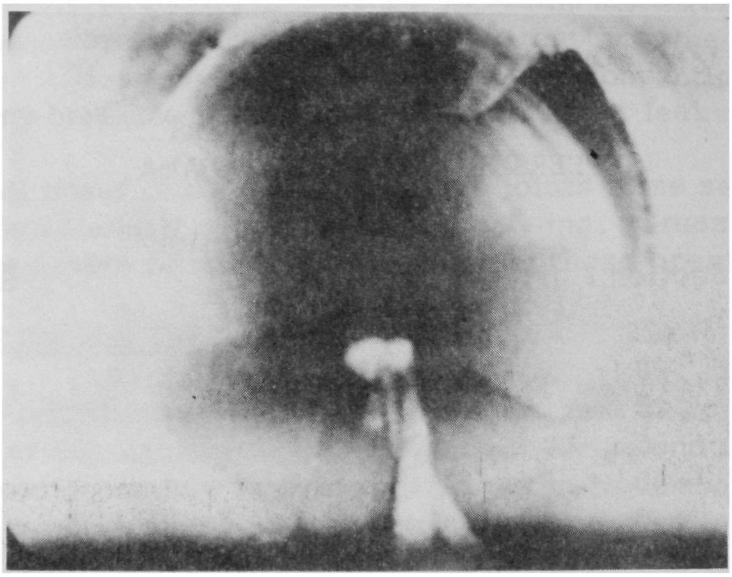
	Iota Street Infiltration*		
Date	Section I	Section II	Section III
1-19-69	425	752	1090
2-23-68	0	0	473
3-2-68	0	0	0
6-1-68	0	0	0
8-27-68	0	0	0
1-2-69	0	0	0
8-9-69	0	0	0
1-17-70	0	0	0
4-30-70	0	0	0
8-12-70	0	0	0

	Hessmer Avenue Infiltration*		
Date	Section I	Section II	Section III
7-19-68	662	1140	584
8-7-68	31	236	650
8-27-68	0	595	177
9-14-70	-	-	31000

*Gallons per inch of diameter per mile per day.

In April of 1968 both test sewers were televised. No leaks, breaks or cracks were found in the Iota Street installation. One leak caused by a cracked bell was found in Section III on Hessmer Avenue, and is shown in Figure 23.

During April of 1970 the Hessmer Avenue test sewer was televised again to determine the cause of the high infiltration. The line was found to be so badly damaged and had so many obstructions caused by breaks that it was impossible to run the camera through the entire system. Only portions of Section II and III could be televised. Numerous small leaks were observed along Section III until a collapsed section was reached. In Section II several small leaks were observed, and an obstruction consisting of bedding material (clam shell) and pieces of broken pipe prevented the passage of the camera. Figure 24 shows pictures taken in this line.

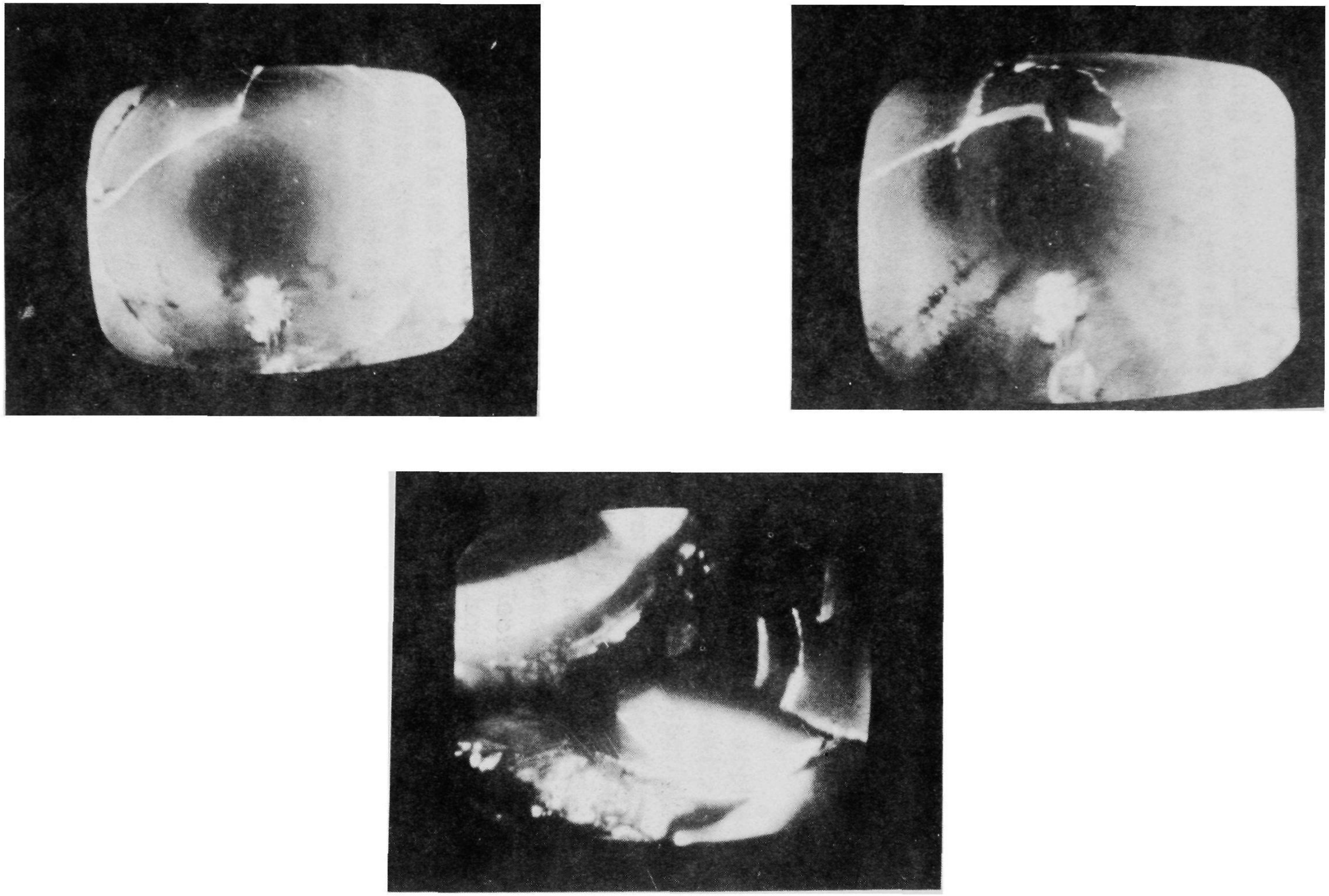


LEAK FOUND IN HESSMER AVENUE 1968
FIGURE 23

CONCLUSIONS

It appears from these studies that the predominant factors influencing infiltration are construction procedures. It is thought that soil conditions effect their greatest influence in the degree to which they influence construction. The practice of breaking the trunk sewer to form a house connection should be prevented by closer supervision of plumbers making these connections.

As a result of the 1962-63 infiltration studies,the City of New Orleans established its first infiltration specification for new sewer construction.



PHOTOGRAPHS IN HESSMER AVENUE TEST SEWER 1970

FIGURE 24

SECTION III

SEWER SETTLEMENT

COMPRESSION THEORY

According to the Terzaghi theory of consolidation, the compression settlement of a structure is composed of the sum of the compressions of the underlying clay strata within the zone of influence of the applied load.[7]

The settlement is dependent upon:

1. The vertical permeability of the compressible underlying strata.
2. The drainage of the compressible underlying strata.
3. The thickness of the underlying strata.
4. The applied load (pressure to each stratum).
5. The pre-loading history of each stratum.

In order for settlement to take place a load must be applied to compressible strata beneath the structure. This load is usually generated by the net weight of the structure. Table 16 shows a comparison between the weight of soil displaced by clay sewer pipe and the pipe itself. For example, with 8 inch sewer pipe laid in a soil with a unit weight of 80 pounds per cubic foot, the weight of the soil, previously occupying the location of the pipe, is 37 pounds per linear foot and the weight of the sewer is 26 pounds per linear foot. This leaves a net difference of 11 pounds per linear foot after construction, and with the sewage at design flow, there is no net positive load. It can be seen that for the range of unit weights given, all the weights after construction are lighter than those before, and at design flow the only positive pressures are seen in the lightest soil and are very small. This table excludes any net change in load due to the bedding or the disturbed or replaced backfill. Most granular bedding causes very little net change in weight, and this change is a reduction where clam or oyster shells are used. If select backfill is used, it may be heavier than the material which occupied that space before construction. More commonly the original soil is used as backfill, and in this disturbed state is less dense than prior to excavation, causing a decrease in the net load if there is any. It can be seen, therefore, that the net load produced by a sewer on an underlying compressible strata is usually negative or zero, and some means of load imposition other than net weight must exist for sewers to settle.

TABLE 16

COMPARISON OF WEIGHT OF PIPE WITH
WEIGHT OF SOIL REMOVED

Nominal Pipe Size, Inches	Weights in Pounds per Linear Foot of Soil Replaced by Pipe Exclusive of Bedding				Approximate Weight Clay Pipe, Pounds per Linear Foot	
	Soil Unit Weights (pcf)*					Flowing
	62	80	100	125	Dry	1/2 Full
6	17	22	27	34	17	23
8	29	37	46	58	26	37
10	45	58	72	90	35	52
12	64	83	104	130	49	74
15	99	128	160	200	78	116
18	144	186	232	290	115	170
21	193	248	311	389	150	225
24	255	329	412	515	200	298

*Pounds per Cubic Foot

MECHANISMS OF DOWNWARD MOVEMENT

There are three mechanisms that enable sewers to settle: undermining, soil remoulding, and drawdown, of which there are several types. These phenomena can be classified as general subsidence, localized subsidence, construction settlement, and undermining.

General Subsidence

In localities where water tables are high and soils are compressible, general subsidence is a function of urbanization as it produces drainage of an area. The cause of this generalized settlement is the lowering of the water table. For every foot the water table is lowered, a load of 62.4 psf is added to underlying strata because of the corresponding loss of buoyant pressure. It follows, therefore, that a significant increase in load and subsequent settlement of structures can be caused by lowering the water table only a few feet if the underlying soils are highly compressible. This generalized settlement over a large area usually causes no serious problems with sewers unless the downstream end of the system is not within the area of subsidence, in which case sewage will be backed up in the system. This may then result in the sewage arriving at the point of disposal in a septic condition.

Localized Subsidence

The subsidence mechanism discussed above can affect sewers and other structures under extremely localized conditions. In this case the water table is drawn down by one of the following:

1. A canal or stream in the vicinity.
2. A leaking storm or sanitary sewer.
3. A shallow well or dewatered excavation.

This type of subsidence can cause local sewer settlement sufficient to result in flattening and even reversal of the sewer grade. It is highly unlikely that this differential settlement can produce structural damage or joint opening in clay sewers. In a study of clay sewers (8 inch beaded polyurethane joint) a deflection in excess of 10 degrees (1.65 inches per foot) was observed while the joint maintained its integrity. The deflections produced in a length of clay pipe as a result of all subsidence will, in all probability, not exceed the ASTM specification for deflection.[8]

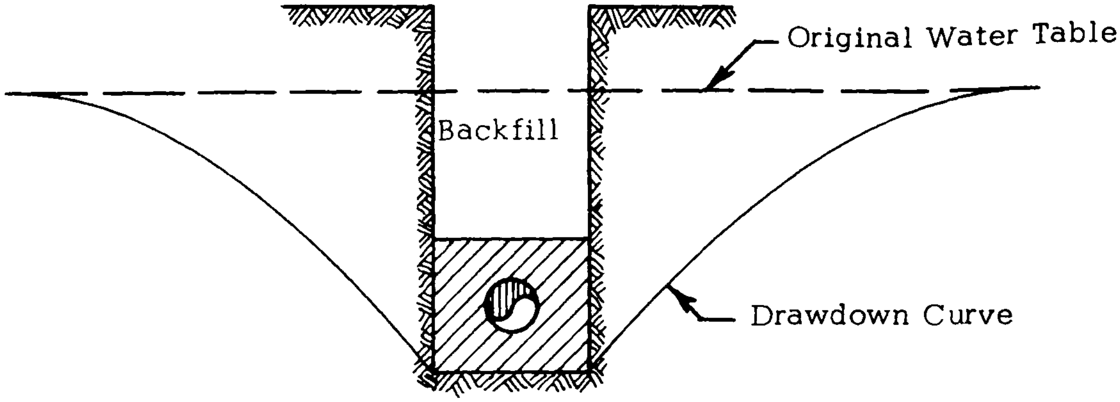
Construction Settlement

This condition is probably responsible for a great portion of sewer settlement. It is the special case of localized subsidence in which the sewer construction itself lowers the water table causing subsequent settlement. In areas of high water table, dewatering by well points or trench pumping is usually required in sewer construction.

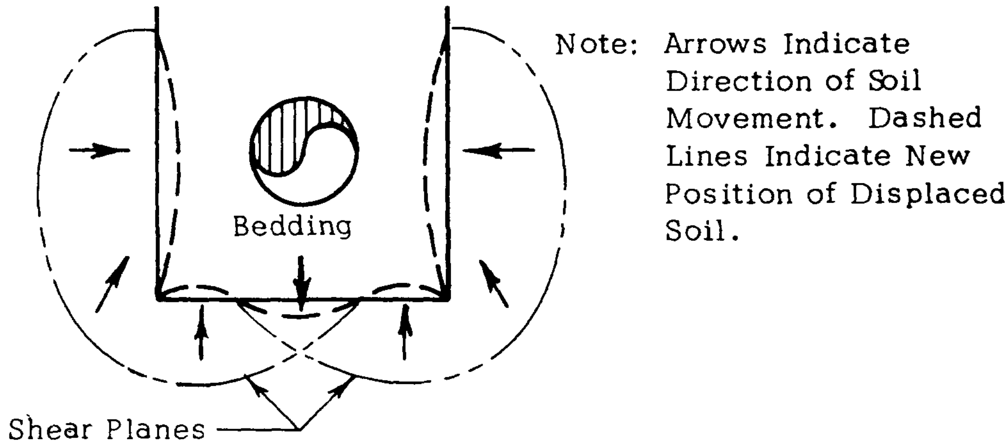
In order for appreciable settlement to occur, the water table drawdown must be maintained for a sufficient time to effect consolidation of underlying compressible strata. Two factors aid in the maintenance of the drawdown even though only a small section of trench may be open at one time. The use of extremely permeable granular bedding material will cause the transmission of water for great distances along the trench. The backfill, because of its disturbed condition, will usually transmit large amounts of water, except when backfill is composed predominantly of soft clay. Figure 25 shows the drawdown condition for a sewer trench. The movement produced by this mechanism occurs during or immediately after construction since a shearing and not a compression phenomenon is taking place.

Undermining

The undermining of sewers can cause not only settlement but complete failure of a sewer and surrounding structures. In order for this to exist,



Drawdown of Water Table Due to
Sewer Construction



Downward Movement of Pipe Due to Failure
of Remoulded Adjacent Underlying Strata

CONSTRUCTION CONDITIONS CAUSING SEWER SETTLEMENT
FIGURE 25

the following four conditions must be simultaneously present:

1. A sand or silt must underlie and/or surround the sewer structure.

2. The sewer must be located below the water table.

3. There must be a sewer leak of sufficient magnitude to cause the transport of the sand or silt.

4. The bedding material interposed between the leak and the soil must be permeable enough to allow the passage of soil.

Undermining should be avoided at all cost since it can cause a great deal of damage and even loss of life in the case of sudden failure of overlying structures.

SETTLEMENT MEASUREMENT

Two methods of measurement have been used for measuring sewer elevations. One was fixed to the sewer, and it was intended as a permanent gage. The other was a jetting device used to locate the sewer and serve as a temporary form of level rod to the pipe.

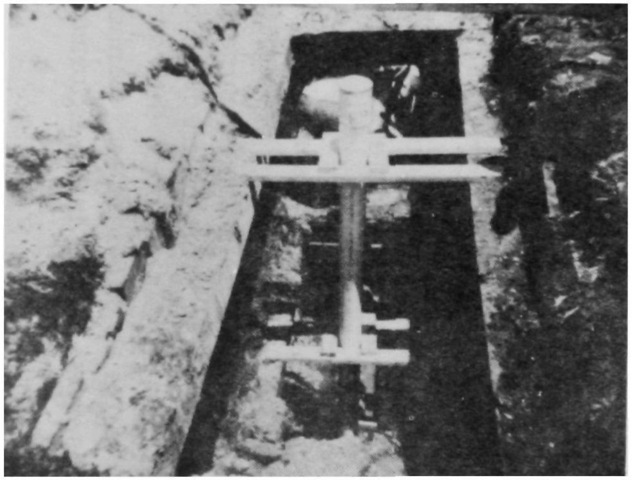
Fixed Settlement Gages

These gages consisted of a casing made of P.V.C. pipe going from the surface down to the sewer. All gages were provided with two slip joints to avoid damage to the sewer. A level rod could be placed on the sewer through the casing and the elevation determined with an engineer's level. Figure 26 contains two photographs of one of these gages.

Several problems arise with the use of this gage. It is difficult to install and the materials are relatively expensive. It is susceptible to destruction by construction equipment working in the area. It has also been found that people occasionally fill the casing with soil.

Jetting Device

This device consisted mainly of a small diameter pipe connected to a garden hose to supply water from a fire hydrant. Figure 26 contains a photograph of this jet in use. Level readings were taken on the top of the jet. Very accurate results can be obtained by this method. It is also inexpensive to fabricate and operate and it requires no protection since it is not left in the ground. This method was found to be superior to the use of casings for settlement determinations. The destruction of many of the permanent gages necessitated the development of this device. In these studies sewer settlements as large as 1.5 feet and manhole settlements in excess of 0.7 feet were observed. This is an extremely large



Sanitary Settlement Devices

Jetting Device for Measuring Settlement

SEWER SETTLEMENT MEASURING DEVICES

FIGURE 26

settlement in light of the three-tenths of one percent grade to which these sewers were laid. Complete settlement records are presented in Section V.

SECTION IV

SEWER BEDDINGS

Sewer beddings are generally composed of either coarse granular materials, concrete, lumber or combinations of the three. Their primary purpose is to provide even support and load distribution to the pipe. Figure 27 illustrates desirable and undesirable conditions of loading and support. The part of the bedding that underlies the pipe should provide evenly distributed support thus preventing stress concentrations. The overlying bedding material will perform the same function of distribution with respect to the backfill load.

It has been found that the coarsest possible angular shaped material that will not produce point load problems is the most desirable from the point of view of pipe support.[9] This is due to the fact that the column of support beneath the pipe covers a much wider area when coarse material is used as shown in Figure 28. It is for this reason that sand alone is less desirable as a bedding material.

The bedding (following the joint and the pipe) should provide a second line of defense against infiltration. In this respect, the extensive use of coarse granular materials presents an outstanding drawback since these beddings serve as "French Drains" permitting water to travel long distances along the sewer to pipe openings. They also allow the transport of soil fines into the pipe which can cause shoaling in the lines, grit problems in sewage treatment facilities, and undermining of the sewer and/or surrounding structures.

LABORATORY TESTING OF BEDDING MATERIALS

Permeability

The permeability of a bedding material is a measure of its water carrying capacity. It is defined in Darcy's Law for laminar flow through a permeable media:

$$Q = K \frac{H}{L} A$$

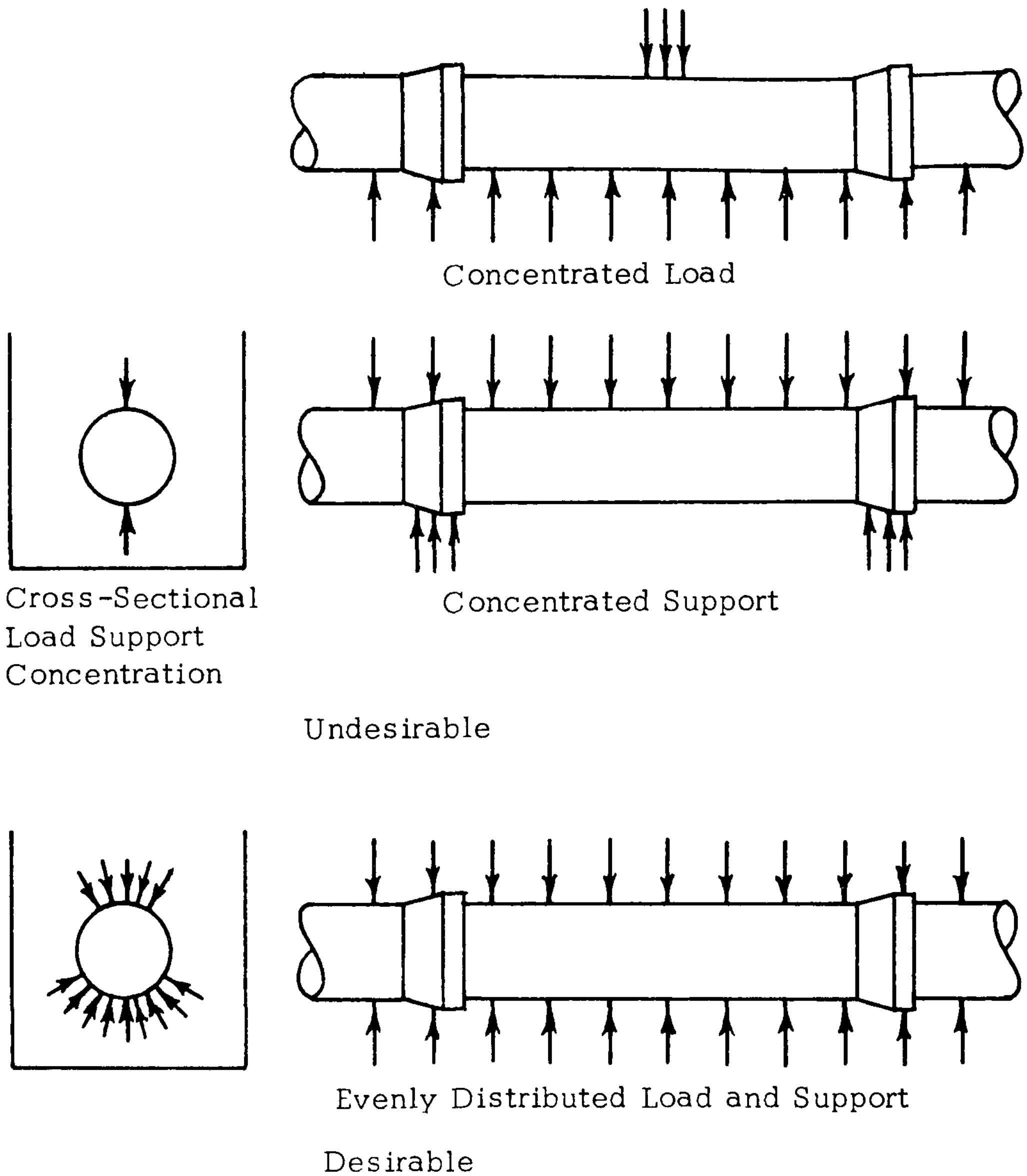
Q = Flow Rate, volume/time

H = Head Loss for the Length in Question

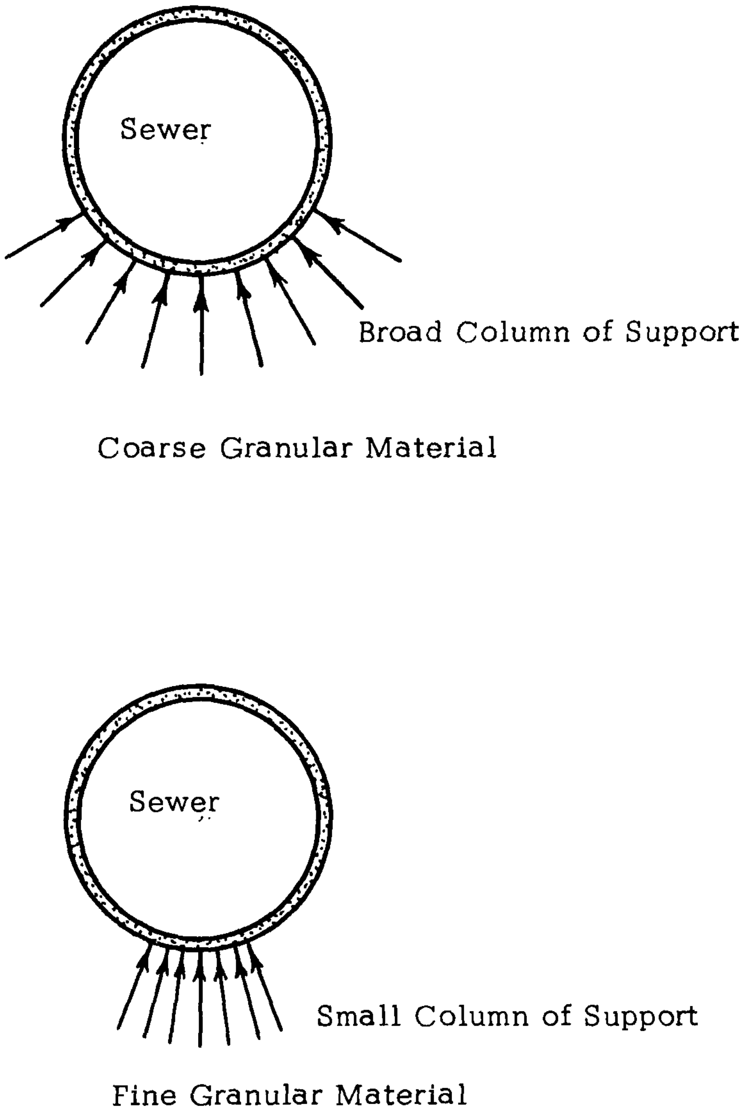
L = Length of Travel

A = Cross-sectional Area of Soil Mass

K = Permeability, length/time



PIPE LOADING AND SUPPORT CONDITIONS
FIGURE 27



PIPE SUPPORT BY COARSE AND FINE
GRANULAR MATERIALS
FIGURE 28

A study was performed in order to compare the permeability of several bedding mixtures made from common materials. The mixtures and their indices of permeability are given in Table 17 . The term Index of Permeability is used instead of Permeability because it could not be determined if flow was truly laminar throughout the sample during testing. For practical purposes the index and the true permeability can be used interchangeably. These permeability tests were run on eight inch diameter samples using a constant head permeameter constructed during the project.

Samples "T" and "U" as shown in Table 17 were selected for long term permeability testing. Sample "T" was soaked in water and tested for 479 hours and sample "U" was soaked and tested for 1381 hours. Figures 29 and 30 illustrate the results of these tests and show that the index of permeability decreased approximately 45 percent for both samples.

Shear Tests

Table 17 also shows the results of shear tests run on the same materials for which permeability was studied. It can be seen that the shear (reported as angle of internal friction) varied approximately between 42^{o} and 50^{o} which is not considered to be a great fluctuation.

FIELD STUDIES

Field studies were initiated in 1968 on two test sewers located in Jefferson Parish, Louisiana. In these studies, bedding performance was completely overshadowed by construction procedures as the prime influences in sewer behavior relative to infiltration, and efficacy of one bedding relative to another could not be ascertained. The beddings used are described in Section V. These materials were readily prepared and placed during construction with those containing Portland cement, demonstrating an ability to stabilize the trench bottom where impending quick conditions were encountered.

MATERIALS RECOMMENDATIONS

Many different materials and combinations of materials are used with varying success throughout the Gulf Coast Area. Table 18 shows the frequency of use of various materials as bedding by 40 sewer authorities in the area. Some authorities indicated that more than one of these materials was used or that combinations of two or more were utilized for a standard bedding.

TABLE 17

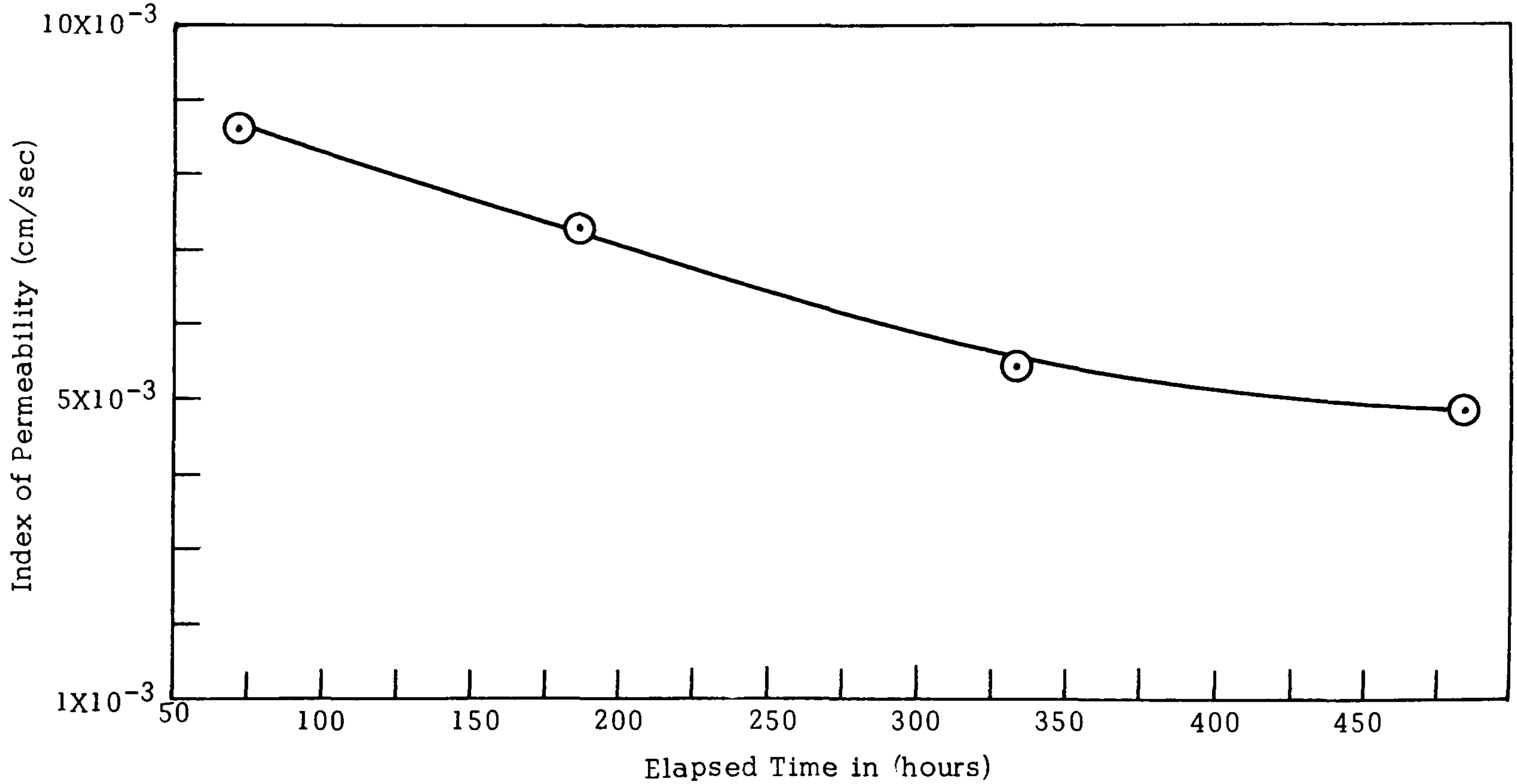
INDICES OF PERMEABILITY AND
ANGLES OF INTERNAL FRICTION
MIXED MATERIALS

Sample	Sand %	Coarse Shell %	Fine Shell %	Portland Cement %	Bentonite %	Other %	Index of Permeability** (cm/sec)	Angle of Internal Friction From Shear Test
A	59.1	40.9					*	
B	58.6	41.4					*	
C	57.7	42.3					$0.6x10^{-2}$	
D	59.0	41.0					$0.54x10^{-2}$	
E	49.6	50.4					$1.12x10^{-2}$	
F	38.5	61.5					$2.37x10^{-2}$	48°30'
G	29.1	70.9					$3.73x10^{-2}$	45°40'
H	19.2		80.8				*	45°25'
I	38.8	61.2					$3.35x10^{-2}$	46°25'
J	40.2		59.8				$2.91x10^{-2}$	42°40'
K	29.5		70.5				*	50°10'
L	50.0		50.0				$1.1x10^{-2}$	45°00'
M	37.4	54.4		5.2			$1.07x10^{-2}$	45°00'
N	36.8	57.7		5.5			$3.8x10^{-2}$	42°50'
O	39.2	54.5		5.3	1.0		$3.5x10^{-2}$	45°20'
P	43.5	57.1		6.0	1.2	Lime 1.2	$2.99x10^{-2}$	48°00'
Q	38.5	55.1			3.2	Lime 3.2		44°30'
R	39.8	45.0		8.7	6.5		$6.68x10^{-2}$	46°10'
S	43.2	46.1		6.4	4.3			44°50'
T+	45.0	48.4		6.6			$0.9x10^{-2}$	48°00'
U+	42.7	46.5		6.4	4.4		$0.4x10^{-2}$	44°50'

*Too permeable to measure.

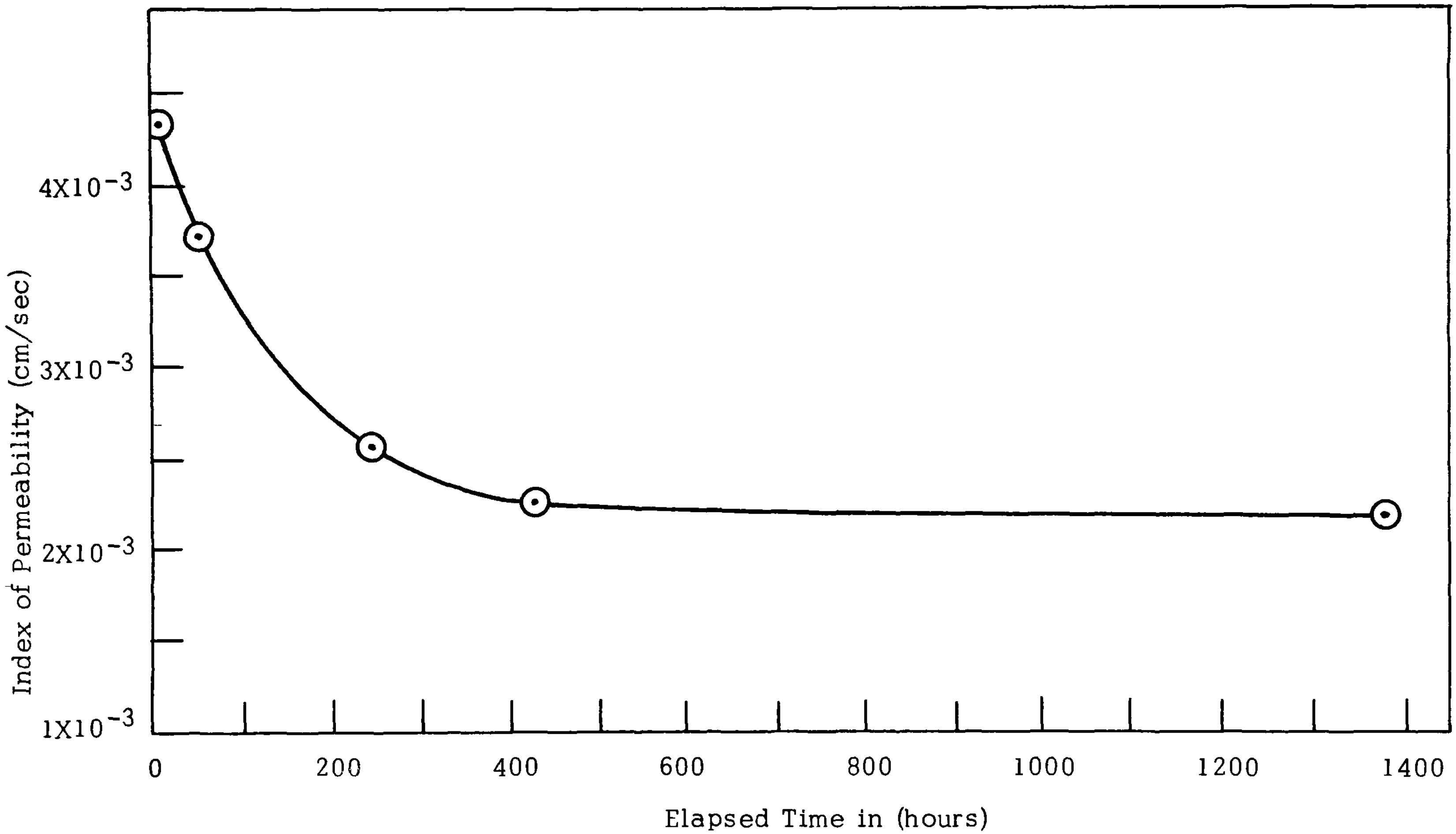
+Representative of the two mixtures used in the field.

**Permeability adjusted to 20°C.



Note: Sample Mixture "T" - Sand - Shell - Portland Cement
Curve - Average from Eight Samples

AVERAGE LONG TERM PERMEABILITY SAMPLE "T"
FIGURE 29



Note: Sample Mixture "U" - Sand - Shell - Portland Cement - Bentonite
Curve - Average from Eight Samples

AVERAGE LONG TERM PERMEABILITY SAMPLE "U"
FIGURE 30

TABLE 18

FREQUENCY OF BEDDING MATERIAL USE*

Clam and/or Oyster Shell	16
Gravel	8
Crushed Stone	7
Sand	4
Cement Stabilized Sand	3
Board Bottom	5
Piles	5
Concrete Encasement	3
Slag	1
Sand and Shell Mixed	1
No Bedding Used	7

*From survey

Coarse Aggregates

As can be seen from Table 18 clam or oyster shells find wide usage as a bedding material. An analysis of clam shell is shown in Appendix I. Both of these materials provide good pipe support; however, oyster shells are more difficult to shape, so that care should be taken to insure uniform contact between the pipe and the bed. Masses of these shells possess angles of internal friction in excess of 45^{o} and with available moisture and time a cementing phenomenon takes place. Oyster (reef) and clam shells are available throughout the Gulf Coast area. Coarse gravel is also readily available in most localities and also provides excellent support. On the other hand crushed stone is almost unknown in many areas along the Gulf Coast.

The materials, as previously mentioned, provide extensive channels for water transmission when they are used alone. Even though coarse aggregates provide good support, they should be used only in conjunction with some system for retarding flow where the sewer is located below the water table. Where the subsoil is very soft, graded materials should be used to prevent the soil from penetrating the bedding or the bedding from penetrating the soil.

Sand

Sand is the only fine aggregate that is used alone as a bedding material to any great extent. This is undesirable in light of the small column of support provided (with its associated cross-sectional point load) beneath the pipe. Sand is, however, an excellent constituent of bedding mixtures.

Mixtures

Combinations of materials in mixtures provide an excellent means of retarding the flow of water in the bedding. Sand and shell serve as excellent base constituents for such mixtures, and they are both available through most of the Gulf Coast area.

Whenever a mixture of fine and coarse aggregates is used in constructing a bedding, an ideal combination would contain enough fines sufficient to fill the voids between the coarse material. This yields a bedding that has the support properties of the coarse aggregate and the water transmission characteristics of the fines. In practice it is more efficacious to provide less fine material than the optimum and rely on migration in place to provide the optimum in the field (provided that no binding or cohesive effects have occurred at the time of placement). Slight vibration by hand compaction will usually cause this migration.

Sand and Shell Mixtures

If leakage occurs with a bedding of this type, the sand may be transported into the pipe. This can be prevented by using sand of a larger effective size, but this makes the bedding more permeable. A better solution is to provide a binder that will prevent the transport of sand.

Another problem associated with unbound sand is the possibility of floatation under quick trench conditions.

Portland Cement

In the field study, it was found that with an impending quick condition in a 5 foot width trench of shell bedding, stabilization was accomplished by spreading from one half to one sack of Portland Cement on the shell surface. Concrete beddings should be avoided where soils are soft and appreciable settlement is likely to occur. The additional weight of concrete will aggravate the settlement, and because of its rigidity, cracking of bedding and pipe is probable.

Bentonite

Bentonite is a clay mineral with an expanding lattice structure that enables it to swell with the addition of water. An analysis of a particular type of bentonite is shown in Appendix J. The idea of its use is to provide a barrier to water flow by expanding into and filling the voids in a sand-coarse aggregate mixture. Undoubtedly there are other materials that would have the same effect and could be tried or developed for this purpose.

In using material such as this it is important that the amount used is less than that which would cause a serious reduction in strength due to separation of the granular component. The bedding combinations used in the field studies indicated that four percent or less bentonite will not cause separation in a sand and clam shell mixture.

Lumber

Planking in the trench bottom can be beneficial by providing uniform longitudinal support. The following factors should be considered in the use of planking:

1. Cross-Sectional Support - Where lumber is used below the bedding in alignment with the pipe, it should be several inches wider than the horizontal projection of the pipe. Without this there will be

a difference of supporting ability across the pipe due to the changing of the column of support.

2. Point and Line Loadings - It is sometimes the practice to place the pipe barrels on short spans with no planking beneath the bells. This should of course be avoided since it provides only line support for the pipe (column of support as narrow as possible).

Piling

Pilings are used successfully throughout the Gulf Coast Area and usually consist of 2x timbers that also serve as sheeting or 2x timber bents. When using piles to support sanitary sewers the following factors should be considered:

1. Sufficient trench flooring and bedding should be used to insure the even distribution of support.

2. If the soil possesses a sensitive structure, pile driving may decrease soil shear strength by liquifaction or seriously increase settlements due to loss of preconsolidation. This phenomenon will only occur near the pile; however, the extent of its effect should be considered.

COST OF BEDDING MATERIALS

The cost of bedding materials is shown in Table 19. These data are for purchase in New Orleans in December of 1970 on a delivered basis.

The information for Portland Cement and bentonite in various percentages is given as their fractions of cost as portions of mixtures. Bentonite could probably be purchased in bulk at some saving especially if its demand was raised above the current level.

For the purpose of estimation the weights of materials are given as follows:

Clam Shell	1750 #/cy
Reef Shell	1400 #/cy
River Sand	2400 #/cy
65% Reef Shell & 35% Sand	3200 #/cy
65% Clam Shell & 35% Sand	3000 #/cy

TABLE 19

COST OF BEDDING MATERIALS

Material	Cost per Cubic Yard	Cost per foot of Trench, 8" pipe*
Clam Shell	$ 3.25	$ 0.48
Reef Shell	3.45	0.51
River Sand	1.85	0.27
Clam & Sand (65%-35%)	4.05	0.60
Reef & Sand (65%-35%)	4.25	0.63
Portland Cement ($1.50/94# Sack)		
4 1/2%	1.69	0.25
5%	1.86	0.28
6%	2.25	0.33
Bentonite ($2.71/100# Sack)		
4 1/2%	3.06	0.45
5%	3.36	0.50
6%	4.07	0.60
Clam & Sand (65%-35%)+Portland Cement		
4 1/2% Cement	5.74	0.85
5% Cement	5.91	0.88
6% Cement	6.30	0.93
Reef & Sand (65%-35%)+ Portland Cement		
4 1/2% Cement	5.94	0.88
5% Cement	6.11	0.91
6% Cement	6.50	0.96
Clam & Sand (65%-35%) + Bentonite		
4 1/2% Bentonite	7.11	1.05
5% Bentonite	7.41	1.10
6% Bentonite	8.12	1.20
Clam & Sand (65%-35%) + Bentonite		
4 1/2% Bentonite	7.31	1.08
5% Bentonite	7.61	1.13
6% Bentonite	8.32	1.23

*Average Trench Width of 36"

SECTION V

SEWER TESTING

LABORATORY SIMULATION STUDIES

These studies were conducted in the laboratory with a testing frame designed to simulate loadings and beddings that may be used on sewers installed in the field. It was anticipated that this testing frame would provide a means of observing the tightness of joints, compaction of soils, settlement and movements of sewer pipes with various soils and bedding combinations.

The testing frame was equipped with an overhead loading system that permitted the development of a backfill equivalent of a trench of 17 feet depth. Three types of soils commonly found in the Gulf Coast area were used in the study. Figure 31 is a cross-section of the 23 foot long testing frame, and Figure 32 is a picture of the apparatus in operation. Three different types of soil (sand, clay and organic soil) were used with 8 inch clay sewer laid with several beddings.

In using the loading frame it was very difficult to simulate the true condition of laying sewers with beddings used under field conditions. The results of the loading frame tests were therefore at best of marginal value. For this reason similar testing for sewer and bedding behavior is not recommended.

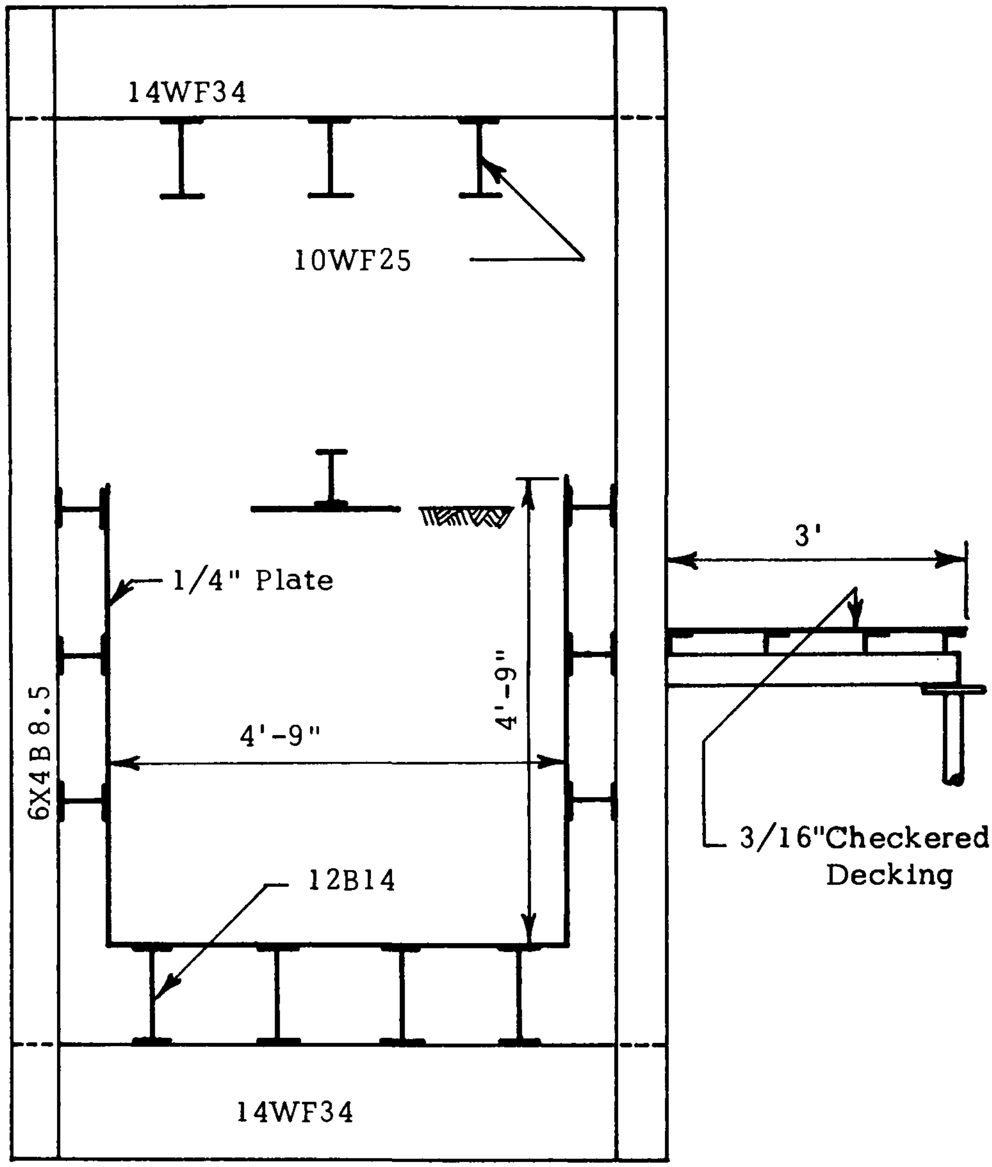
TEST SEWERS

This portion of the project dealt with a study of sewers in the field that were laid under controlled conditions. Two separate systems were used, both located in Jefferson Parish which is adjacent to the City of New Orleans.

Each installation consisted of three sections of sewers located between four manholes. Combinations of different materials were used for each bedding. Measurements were made on infiltration and settlement of these lines over a two year period. The two systems used in this portion of the study were located on Iota Street and Hessmer Avenue. These are shown as Systems 6 and 7 on Figure 21.

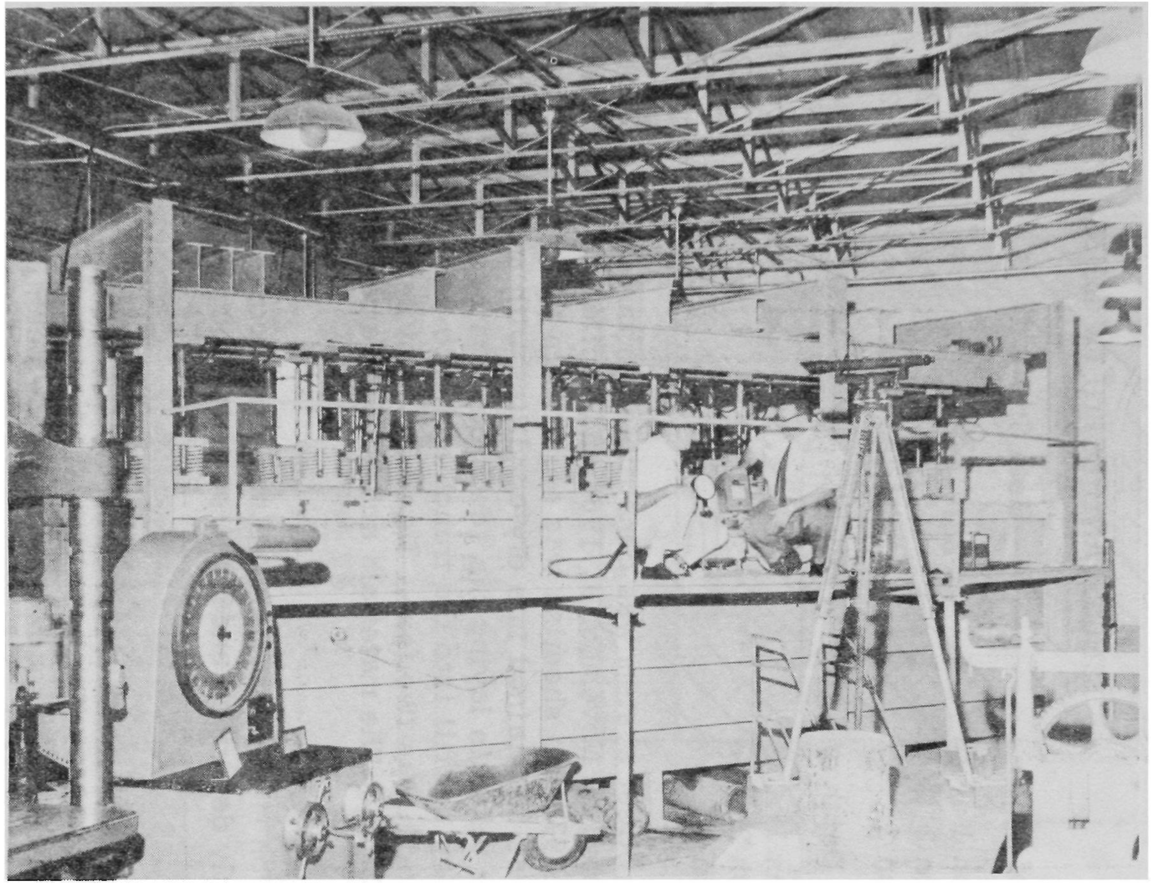
Materials and Methods

Both sewers were constructed by the same firm under contract with the Parish of Jefferson and with a subsidy from this research project. Eight



Notes: Tank 23' Long
Observation Deck on Each Side. One Shown.

TESTING FRAME CROSS SECTION
FIGURE 31



TESTING FRAME IN OPERATION

FIGURE 32

inch extra strength vitrified sewers with polyurethane factory moulded joints manufactured by W. S. Dickey Clay Mfg. Co. were used in the systems. Each system was laid in three sections with different beddings used in each section. Table 20 shows the length of the lines and the average depth in each section.

TABLE 20

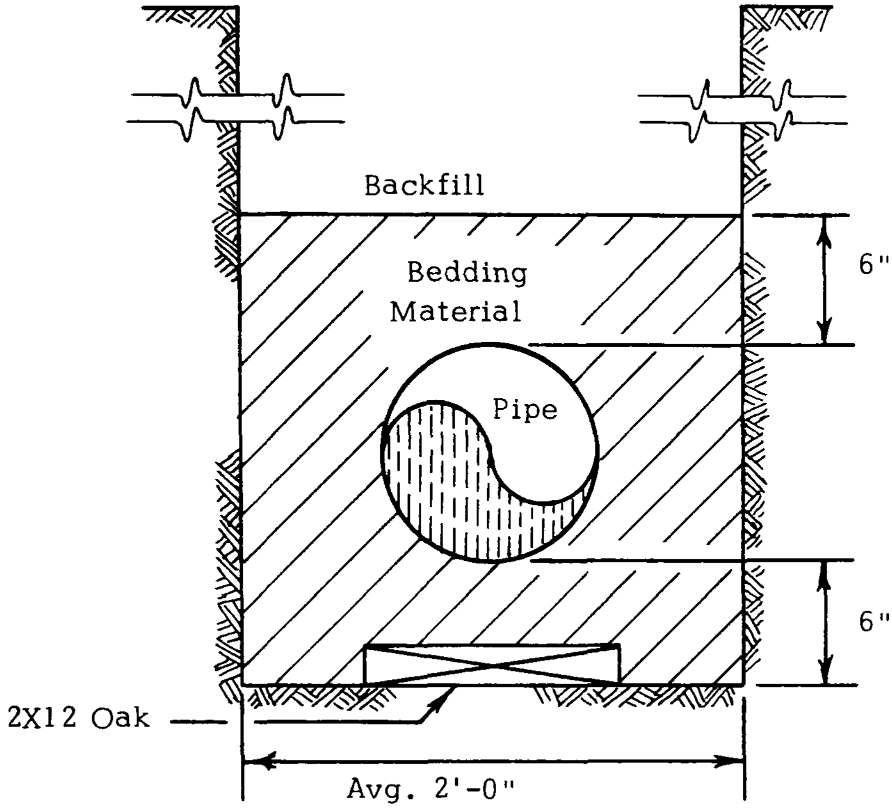
LENGTH AND DEPTH OF LINES

	Iota Street	Hessmer Avenue
Length of Line		
Section 1	229'	195'
Section 2	240'	225'
Section 3	245'	263'
Average Depth of Line		
Section 1	7.8	10.0
Section 2	6.9	9.2
Section 3	6.2	7.9

The Iota Street system was constructed in three days. Section I was constructed on November 3, 1967 and Sections II and III on December 5 and 6, 1967. No sheeting was required in the construction and the trench was maintained in a dry condition with moderate pumping. Good care was taken in laying the sewer but this backfilling was accomplished by pushing the fill into the trench and onto the bedded pipe. The average trench width was two feet. Three different beddings were used, one in each section. The materials and bedding arrangements are shown in Figure 33.

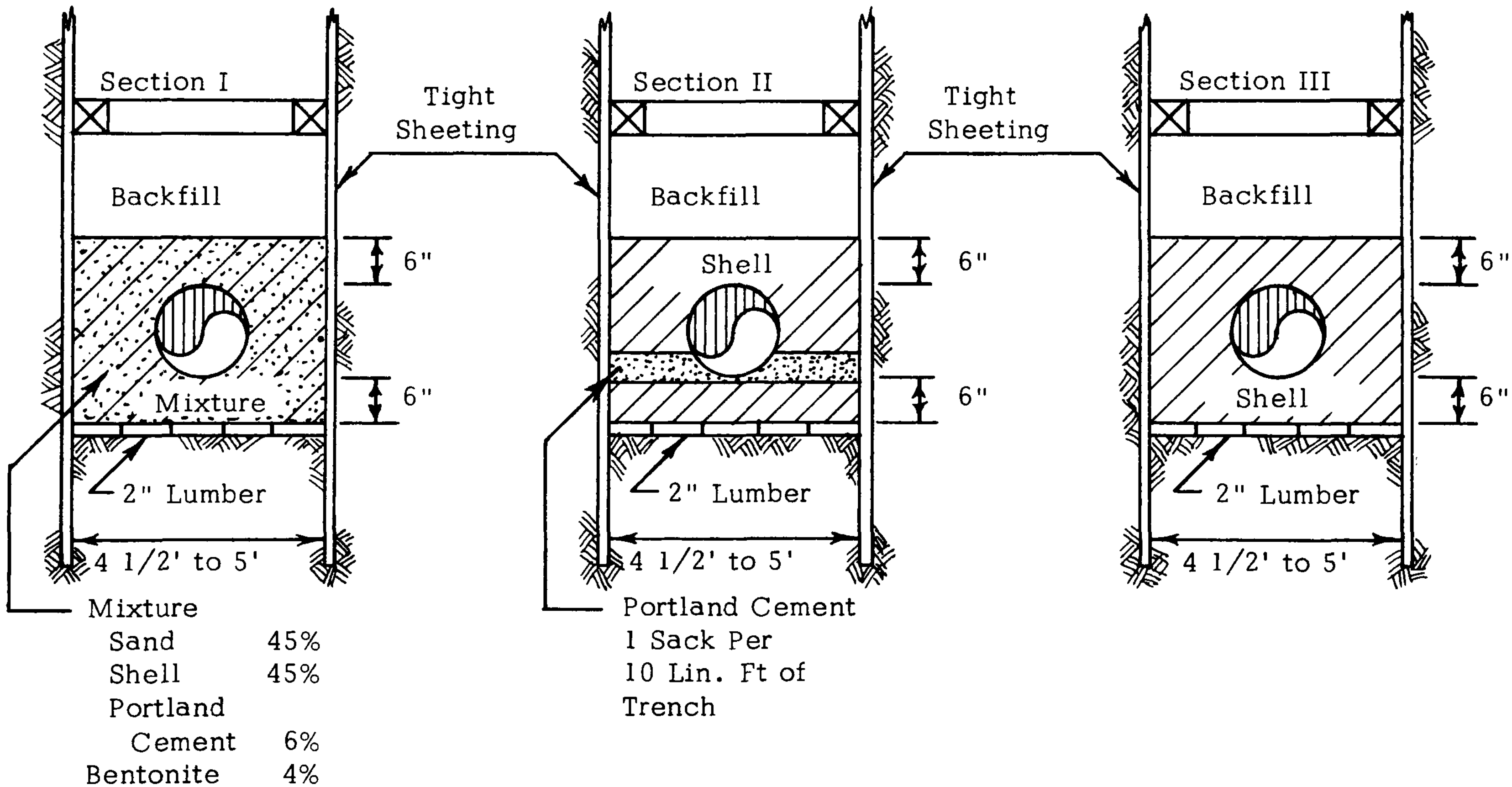
Infiltration measurements were made in accordance with the procedures previously described under the section, Long Term Infiltration Measurements.

The Hessmer Avenue system was under construction from May 16, 1968, to June 11, 1968. Its location was about 2 miles from the Iota Street sewer. A concrete roadway had already been provided on Hessmer Ave. and about 25% of the lots were fully developed with apartment buildings and residences. Septic tanks and package treatment units were used in the area. Sheeting with wale and strut supports at the third points were used for the entire sewer trench. Constant dewatering with several pumps was required during the entire construction period. On many occasions the pumps could not completely dewater the trench and the water elevation was above the sewer invert. The beddings used in the three sections of this installation are shown in Figure 34.



Section I.	Coarse Clam Shells Only
Section II.	Sand 47%
	Portland Cement 6%
	Coarse Shells 47%
Section III.	Sand 45%
	Coarse Shells 45%
	Portland Cement 6%
	Bentonite 4%

SEWER FOUNDATIONS IOTA STREET
FIGURE 33



SEWER FOUNDATIONS HESSMER AVENUE
FIGURE 34

Construction Procedures

The method of construction was typical of that used in the coastal marsh areas of the Gulf Coast. A back-hoe was used for excavation and de-watering was accomplished from within the trench by continuous pumping with diaphragm and/or centrifugal pumps. Where sheeting was required, it was driven prior to excavation with bracing being placed as the trench was deepened. The sheeting was not pulled after construction, but was cut off two feet below the ground surface.

Construction steps following excavation were as follows:

a) The trench bottom was finished by laborers with shovels.

b) Two inch timber was laid in the trench bottom.

c) The bedding material was deposited and spread to grade on the timber.

d) The pipe was laid to grade.

e) Additional bedding material was deposited on top of the pipe.

f) The trench was backfilled.

The sewer laying was advanced using this procedure while maintaining only as much open trench as necessary.

Settlement Gages

Gages were designed to be used in determining the settlement of the test sewers. Two types were used. One was fixed to the pipe intended to provide a permanent type of gage. The other was a jetting device used to locate the sewer and serve as a temporary form of level rod to the line. Both are described in Section III.

Results

The two test sewers were studied for settlement and infiltration over a period extending from 1967 to 1970. The results of the two systems located on Iota Street and Hessmer Avenue are summarized as follows.

Iota Street

This system was part of a new subdivision and street construction had not yet been completed. A sand fill of from two to three feet had been provided at the street location. Where the sewer trench was dug the ground surface was at the original elevation. Figure 35 shows the cross-sectional relationship between the test sewer and the street fill. The sewer was located outside of the street area about 9 feet from the curbing.

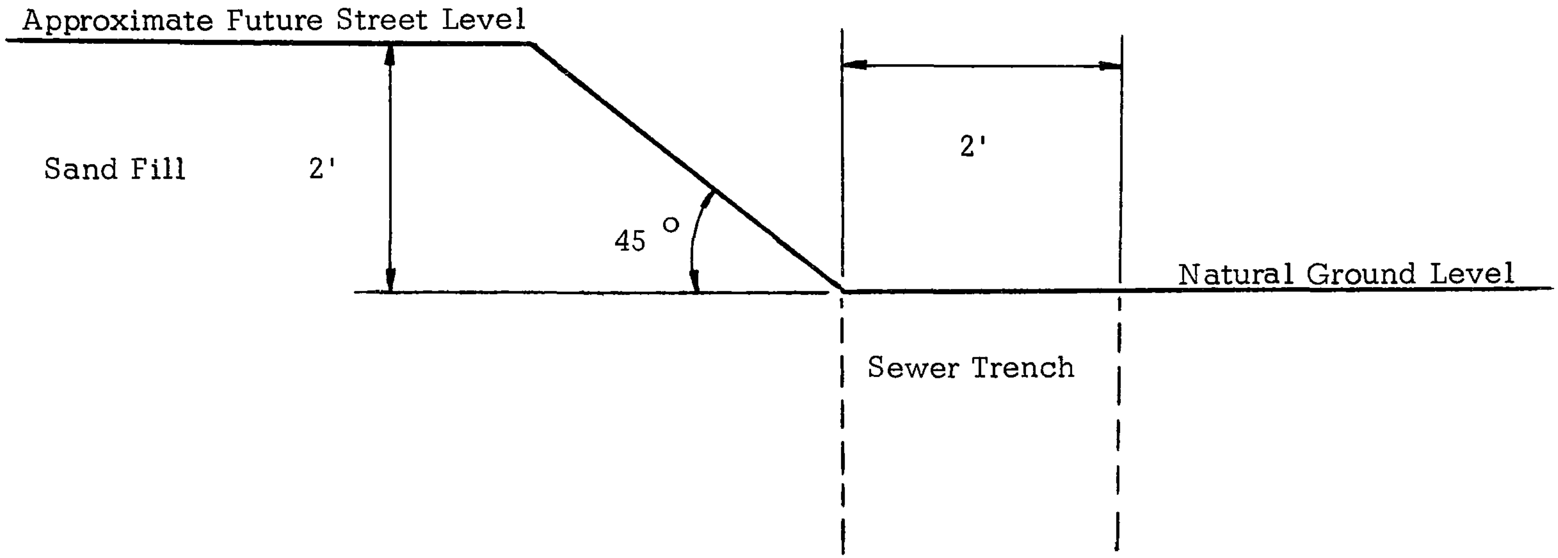
As mentioned above, 26 gages were located along the Iota Street line. The location of these gages was established by stations beginning at the downstream end of the line. Two soil borings were taken, one at each end of the line. The analyses and the soil samples are shown as Appendix K and L. The soil at this site consisted of an organic material from the ground surface to a depth of 2 to 3 feet. Beneath this to the depth of the boring was a finely layered system of clay silt and sand. The soil surrounding the pipe consisted of a very soft silty clay of the "CL" (Lean Clay; Sandy Clay; Silty Clay of low to medium plasticity) and "MH" (silt, fine sandy or silty soil with high plasticity) varieties with alternating layers of sand and silt.

When the Iota Street line was constructed no apartment buildings or residences had been constructed along the line. Over the period of study of the line extending from 1967 to 1970, no construction has been made along this location and there are still no connections to the line. The sewer has been measured or checked ten times for infiltration. The infiltration tabulated in gallons/inch of diameter/mile/day is shown as follows:

Date	Section I	Section II	Section III
1-19-69	425	752	1090
2-23-68	0	0	473
3-2-68	0	0	0
6-1-68	0	0	0
8-27-68	0	0	0
1-2-69	0	0	0
8-9-69	0	0	0
1-17-70	0	0	0
4-30-70	0	0	0
8-12-70	0	0	0

It may be noted from the above tabulation that readings taken on January 19 and February 23, 1968 showed evidence of infiltration. An observation made on March 2, 1968 showed no infiltration. The line was televised on April 2, 1968 and no leaks, cracks or breaks were observed in the sewer. No repairs were made on the line after the completion of the construction. Apparently heavy soils such as clays, had sealed the opening initially causing the infiltration to the line.

Table 21 shows the settlement observations taken on the Iota Street sewer.



CROSS-SECTION OF IOTA STREET SITE

FIGURE 35

Station 0+00 is at the downstream end of the system at Section I. All elevations were read with an engineer's level from a bench mark in the area. Readings from November 3, 1967, to April 22, 1968, were taken by means of the permanent gages installed on the sewers. Shortly after April 22, 1968, Iota Street was paved and the property adjacent to the street filled and graded. This construction work destroyed most of the gages along the line. Accordingly, the readings shown for December 20, 1969, were obtained by means of the jet device already described.

It may be noted from Table 21 that most of the settlement took place immediately after the construction. It is believed that a significant part of the settlements was caused by the drawing down of the water table in the location of the sewer during and shortly after construction thereby increasing the effective load on the compressible clay strata below the pipe. This drawdown is thought to be caused by construction pumping and water transmission through the permeable beddings or disturbed backfill.

The speed at which settlement takes place is proportional to the number of drainage faces. The type of soil at both study sites is subject to relatively fast settlements under applied load due to the very large number of drainage faces presented to the clay by the intermingling sand and silt layers. In order for settlement to take place, a long time is not required; however, the period of settlement can not be precisely determined because the number and relationship of drainage faces are unknown.

On the Iota Street sewer, the drawdown was probably a result of the construction, and this drawdown could have been responsible for the greatest portion of the settlement. The remainder of this sewer's downward motion can be attributed to the dropping of backfill on the sewer. Most of the settlement in this sewer occurred between the construction and the first reading date. The minimum settlement recorded is 0.22 feet and the maximum is 0.52 feet. No correlation exists between settlement and types of beddings used on this test sewer. As no severe settlement occurred on this line and no damage was observed during construction or the televising, the sewer appears to be in good condition. This condition is confirmed through numerous recent observations of the line when no infiltration was reported.

Table 22 shows the elevation of the manholes over the period of the study. It is interesting to note that two of the manholes were also subjected to damage through the construction of the streets following the elevation taken on April 22, 1968. The settlement of the manholes was very slight ranging from 0.02 feet for MH 913 to 0.14 for MH 898.

TABLE 21

SETTLEMENTS
IOTA STREET TEST SEWER

Station	Settlements (Feet) Date 11-3-67	12-14-67	12-21-67	1-6-68	4-22-68	12-20-69
0+00	MH879 Section I (Constructed 11-3-67)					
0+13	0.03	0.14	0.12	0.12	0.20	0.22
0+26						0.27
0+33	0.12	0.17	0.14	0.16	0.23	
0+41						0.21
0+53	0.14	0.17	0.15	0.17	0.24	0.16
0+76						0.23
0+78	0.14	0.17	0.15	0.17	0.24	
1+01						0.26
0+98	0.00	0.01	0.01	0.03	+0.02	
1+18	0.17	0.17	0.16	0.21	0.21	0.32
1+43						0.38
1+45	0.15	0.19	0.18	0.20	0.27	
1+72	0.13	0.17	0.17	0.21	0.26	
1+90						0.29
1+94	0.04	0.10	0.11	0.13	0.20	
2+16	----	0.14	0.15	0.16	---	
2+19						0.39
2+29	MH898 Section II (Constructed 12-5-67)					
2+40	----	0.29	0.29	0.32	----	0.39
2+51						0.52
2+72	----	0.31	0.32	0.36	0.39	
2+80						0.35
2+99	----	0.29	0.31	0.32	0.39	0.42
3+20						0.35
3+21	----	0.22	0.26	0.25	0.32	
3+45						0.26
3+51	----	0.27	0.31	0.30	0.37	
3+65						0.45
3+80	----	0.22	0.24	0.23	0.36	
3+93						0.42
4+07	----	0.32	0.35	0.35	0.40	
4+13						0.50
4+27	----	0.39	0.42	0.40	0.47	
4+32						0.43
4+54	----	0.25	0.25	0.26	----	0.49

TABLE 21 (continued)

SETTLEMENTS
IOTA STREET TEST SEWER

Station	Settlements (Feet) Date 11-3-67	12-14-67	12-21-67	1-6-68	4-22-68	12-20-69
4+69	MH913 Section III (Constructed 12-6-67)					
4+80						0.44
4+89	----	0.32	0.32	0.32	0.33	
5+00						0.49
5+16	----	0.53	0.51	0.53	0.55	
5+20						0.41
5+46	----	0.32	0.31	0.33	0.32	
5+60						0.40
5+73	----	0.29	0.28	0.30	0.31	
5+80						0.40
6+12	----	0.28	0.26	0.30	0.31	
6+19						0.37
6+37	----	0.24	0.21	0.25	0.25	
6+39						0.38
6+61	----	0.24	0.21	0.24	0.24	
6+80						0.41
7+14	MH914					

Hessmer Avenue

The conditions experienced during the construction of this system were exceptionally bad. The soil at the bottom of the trench was constantly in a semi-liquid state and the upward movements of particles in several locations indicated a quick condition. Side flow of water and particles occurred during the entire construction. The sewer was constructed adjacent to a paved street at a distance of 9 feet from the curbing. Although the line was only 8 inches in diameter a trench width of 4 1/2 to 5 feet was maintained during the construction. Three soil borings were taken along this installation. The results of the soil analyses are shown in Appendices M, N and O. The organic top soil layer extended to a distance of about 4 feet from the ground surface. All the soil below this level consisted of a very soft silty clay of the "MH"[19] type, in a fine layered system, with sands and silts.

Because of the poor soil conditions experienced at this location, construction practices were below standard. Shells and combinations of

TABLE 22

MANHOLE ELEVATIONS AND SETTLEMENTS
IOTA STREET TEST SEWER

Datum: As Established in Study

Station	Elevations (feet) Date Read						Total Settlement
	11-3-67	12-14-67	12-21-67	1-16-68	4-22-68	12-27-69	
MH879	98.11	98.11	98.12	98.12	98.05	*	0.06
MH898	--	98.22	98.21	98.18	98.16	98.08	0.14
MH913	--	98.46	98.45	98.45	98.45	98.44	0.02
MH914	--	97.73	97.73	97.73	97.71	*	0.02

mixed materials prepared for the beddings were dropped into the trench and on top of the pipe after it was placed in position. During the laying of the pipe it was the common practice to have several laborers jump on the pipe to adjust the grade downward. Backfill was pushed onto the bedded pipe from the ground surface creating a severe impact on the pipe.

Table 23 shows the settlement observation on Hessmer Avenue. Station 0+00 is the beginning of the system at the downstream end of the line at Section I. These elevations were also read with an engineer's level from a benchmark in the area. The readings from July 9, 1968, to November 16, 1968, were taken on the 23 permanent gages installed on the sewers. As the construction of residences and apartments developed following this period, many of the gages were destroyed or covered with automobile driveways and parking areas. The readings shown in Table 23 for January 10, 1970, were all taken with the jet. It may be noted that only ten observations could be obtained along the line because of the large paved areas that had been provided.

TABLE 23

SETTLEMENTS
HESSMER AVENUE TEST SEWER

	Settlements (Feet)				
	Date				
Station	7-9-68	8-1-68	8-22-68	11-16-68	1-10-70
0+00	MH362 Section I (Construction 5-16 to 5-22-68)				
0+07					0.8
0+09	0.19	0.38	0.34	0.51	
0+29	0.26	0.44	0.41	0.58	0.9
0+49					0.9
0+51	0.23	0.44	0.38	0.62	
0+76	0.38	0.56	0.47	----	
0+83					0.9
1+00	0.18	0.52	0.45	----	
1+06					0.8
1+27	0.18	0.40	0.35	----	
1+62	0.01	0.20	----	----	
1+95	MH363 Section II (Construction 5-23 to 6-3-68)				
1+98					1.0
2+20	0.56	0.48	0.52	----	
2+60	0.33	0.53	0.55	----	
2+82	0.43	0.59	0.64	----	

TABLE 23 (continued)

SETTLEMENTS
HESSMER AVENUE TEST SEWER

Station	Settlements (Feet) Date 7-9-68	8-1-68	8-22-68	11-16-68	1-10-70
3+17		Destroyed			
3+34		Destroyed			
3+54		Destroyed			
3+89	0.42	0.57	0.67	----	
4+20	MH364	Section III (Construction 6-4 to 6-11-68)			
4+40	0.42	0.59	0.71	----	
4+72	0.56	0.74	0.80	1.08	
4+92	----	----	----	----	
5+24	0.50	0.65	0.81	----	
5+44	0.50	0.66	0.89	1.14	
5+64	0.49	0.64	0.84	1.09	
5+89					1.45
5+91	0.51	0.67	0.98	----	
5+93					1.5
6+16	0.39	0.57	0.76	----	
6+36					1.45
6+60	0.32	0.46	0.72	----	
6+53					1.2
6+83	MH365				

A significant amount of settlement occurred within the first few months following construction. As in the case of Iota Street, this is believed to be due to drawing down the water table and also dropping backfill on the top of the pipe. This latter condition may also account for some of the damage to the pipe. The last settlement readings on the sewer showed values as high as 1.5 feet. No correlation exists between settlement and types of beddings used on this test sewer.

Table 24 shows the five manhole elevation readings from July 9, 1968, to September 26, 1970. A maximum of 0.74 feet was recorded on one of the manholes. These high values also reflect settlements due to the bad soil conditions in the area and difficult construction conditions experienced.

Infiltration measurements were made on the Hessmer Avenue line on four occasions. The infiltration measured in gallons/inch of diameter/mile/

day was as follows:

Date	Section I	Section II	Section III
7-19-68	662	1140	584
8-7-68	31	236	650
8-27-68	0	595	177
9-14-70	-	-	31,000

In the tabulation shown above it should be noted that the upper end of the line begins at Section III with flow towards Section II and I. Sections I and II could not be measured for infiltration because the bottoms of the manholes were flooded with water from infiltration. A review of the infiltration observation indicates excessively high rates. The amounts are far in excess of the 250 gallons per inch of diameter per mile per day that are now required in the construction specifications of Jefferson Parish. These specifications were adopted after the line was constructed in 1968.

In order to determine the cause of the high infiltration in this line, it was televised on April 16 and 17, 1970. The line was found to be so badly damaged and had so many obstructions that it was impossible to run the camera through the entire system. Only a portion of Sections II and III could be televised. Numerous small leaks were observed along Section III. At station 4+77 the sewer was crushed and the shells and other debris at the location prevented the passage of the camera. In Section II several small leakages were observed and at Station 1+47 an obstruction consisting of shell and broken pipe prevented the passage of the camera.

The high infiltration rates and damage to the Hessmer Avenue line were probably due to the poor soil conditions experienced and the difficulties encountered with the construction. This is evidenced by the large settlement values experienced with this sewer, some as great as 1.5 feet. The laying of the sewer was followed by construction of apartment buildings, concrete parking areas and automobile driveways. As noted above, a trench width of 5 feet was used with the center line of lthe trench 9 feet from the street curbing. During the construction of the sewer, structural cracks developed which are now present in the street are illustrated in Figure 36. The weight of the over burden and vehicular traffic may have contributed to the settlement and failure of this sewer.

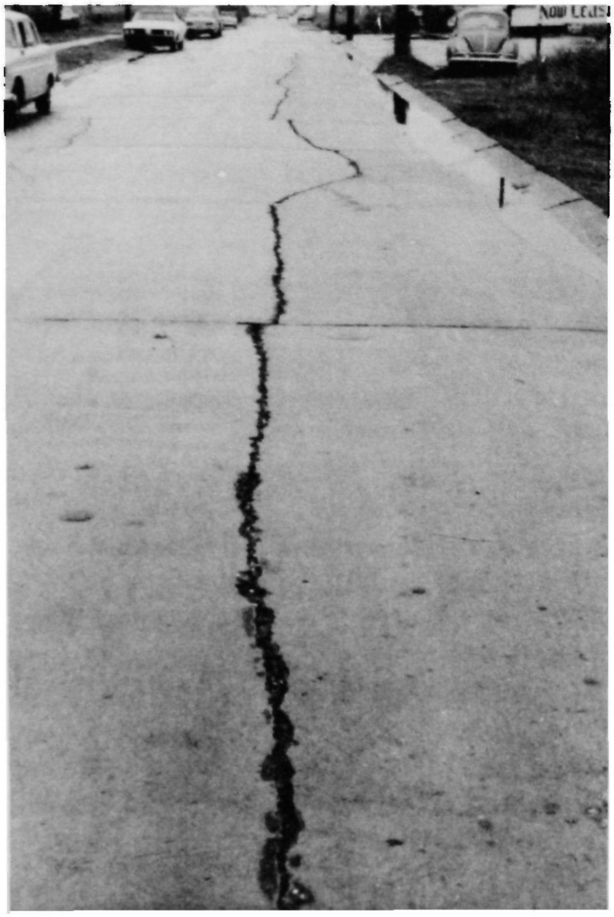
The studies on the two test sewers indicate that settlement within the beddings is small in comparison to the soil below. The soil settlement is believed to be caused by the water table being lowered at the location during and shortly after construction. The water table drawdown is

TABLE 24

MANHOLE ELEVATIONS AND SETTLEMENTS
HESSMER AVENUE TEST SEWER

Datum: Utility Survey -- M S L

Station	Elevations (feet) Date Read					Settlement From First To Last Reading Date
	7-9-68	8-1-68	8-22-68	11-16-68	9-26-70	
MH362	16.86	16.67	16.70	16.48	16.17	0.69
MH363	16.59	16.40	16.41	16.58	16.48	0.11
MH364	16.38	16.19	16.08	15.77	15.56	0.72
MH365	16.76	16.58	16.33	16.15	16.02	0.74



STRUCTURAL DAMAGE TO STREET PAVEMENT - HESSMER AVE

FIGURE 36

believed to be due to trench dewatering construction and water transmission through the permeable beddings or disturbed backfill.

No correlations existed between the settlements observed in the field tests and the laboratory studies. This was due to the difficulties experienced in simulating, in the testing frame, the true conditions experienced with the field studies. An example of this is the settlement that occurs in the soil below the field test sewers, believed to be due to the lowering of the water table.

SECTION VI

GULF COAST AREA SANITARY SEWER SURVEY

This study was performed in the latter part of 1967 and the beginning of 1968. The survey was designed to obtain background information on sewers in the Gulf Coast area. The survey was sent to the responsible officials of 71 cities and sewer districts located in the Gulf Coast area. The survey form is shown in Appendix P. Thirty-nine replies were received for an effective return of 55%. The estimated population of the area considered was 7,250,000. The sample reporting represented a population of 4,582,000 for a return of 63%. The study showed that 13,568 miles of sanitary sewers were in use in the reporting areas. Approximately 6 miles of combined sewers were reported to be in use. Table 25 gives the results of the types and lengths of sewers in use:

TABLE 25

TYPE AND LENGTHS OF SEWERS

Type of Sewer	Length (miles)	Percent of Total
Clay - Factory Joint	2754	20.3
Clay - Other Joints	5989	44.1
Concrete	4479	33.0
Cement Asbestos	216	1.6
Plastic	14	0.1
Other	116	0.9

It may be noted that clay pipe is more commonly used in the area. The factory joint has generally replaced the cement-mortar and bituminous joints used in the older sewers.

Several communities reported that more than one type of bedding material was used. Table 26 shows the materials used for sewer beddings and the frequency of use.

The table indicates a preference for clam and oyster shell for sewer beddings. These shells are readily available in coastal waters and in many sections have an economic advantage over other materials. Seven communities reported that no special beddings were used.

Information was requested on specification requirements for infiltration. Of those reporting, 74% provided information on infiltration and 26% did

TABLE 26

BEDDING MATERIALS AND FREQUENCY OF USE

Material	Frequency of Use
Clam and Oyster Shell	16
Gravel	8
Crushed Stone	7
Sand	4
Cement Stabilized Sand	3
Board Bottom	5
Piles	5
Concrete Encasement	3
Slag	1
Sand and Shell Mixed	1
None Used or Only Seldom	7

not. Table 27 gives the results on infiltration requirements. The weighted average according to the length of sewer was 571 gal/inch of diam/mile/day. The weighted average according to sewage flow was 486 gal/inch of diam/mile/day.

TABLE 27

INFILTRATION SPECIFICATIONS

	No. of Political Divisions	Population	Length of Sewer (miles)	Length of Sewer (Percent)	Infiltration Specifications g/in/mi/dy
	1	15,000	44	0.3	1500
	3	1,464,000	4,433	32.7	1000
	14	516,000	2,017	14.8	500
	2	61,000	82	0.6	400
	3	787,000	2,166	16.0	300
	4	1,153,000	2,547	18.8	250
	1	71,000	250	1.8	200
	1	42,000	160	1.2	100
	10	473,000	1,869	13.8	None
Total	39	4,582,000	13,568	100.0	

SECTION VII

SEWER CONSTRUCTION

The manner in which a sewer is constructed is the most important factor governing its behavior throughout the duration of its use. Only with good construction practices can an adequate design be transformed into a serviceable sewer requiring a minimum of maintenance. This can only be accomplished by the enforcement of good performance and procedural specifications.

INSPECTION

In recent years there had been a tendency to supplant on site inspection with post construction observation and testing of sewers. The argument for this type of control is that "performance specifications are always superior to procedural specifications." Unfortunately this type of measure is not presently available since infiltration, settlement, and sewer failure may manifest themselves at various time intervals after construction. IN LIGHT OF THE ABOVE IT CAN BE SEEN THAT COMPETENT AND THOROUGH INSPECTION SHOULD FORM THE BASIS FOR ANY PROGRAM OF CONSTRUCTION CONTROL AND SHOULD BE CONSIDERED THE FIRST LINE OF DEFENSE IN THE EFFORT TO OBTAIN QUALITY SEWERS.

Inspectors should be skilled in the methods of construction and knowledgeable of the specifications to which sewers are built. They should also be well trained in the procedures of measurement and observation that will enable them to apply sound judgment in questions of construction procedures and quality. Salaries should be adequate to attract competent personnel and training provided to enable them to execute their jobs properly.

It is common practice to assign the responsibility for multiple sewer jobs in different areas to one inspector. This makes adequate inspection difficult. Where only a small section of trench is kept open at a time, the inspector may see only a small fraction of the sewer prior to backfilling. This practice should be discontinued in favor of continuous inspection throughout construction.

As a part of an inspector's duties, he should keep a detailed set of construction notes in a field book. In addition normal reports should be kept as a permanent record by the sewer authority.

By maintaining adequate inspection the cost of proper construction practices will be included in the bid price. It is much cheaper to pay for proper construction practices and good inspection than to assume the burden of improper sewer performance and additional maintenance. Too often a low bid price may be predicated on short cuts and the practice of poor workmanship on the job.

It should be carefully noted that good inspection coupled with adequate and accurate post construction testing provides the surest means of obtaining quality sewer construction in the Gulf Coast area.

TRENCH WIDTH

The design trench width should be determined by consideration of the load on the pipe and the supporting strength of the pipe.

Load on Pipe

The load on a sewer pipe is a function of trench width and the weight of the material. The wider the trench the greater is the load. The accepted method for determining loads on sewer pipe is with the Marston Formula. [11]

$$W_c = C_d \, w \, B_d^2$$

where:

W_c = Load on the pipe in pounds per linear foot

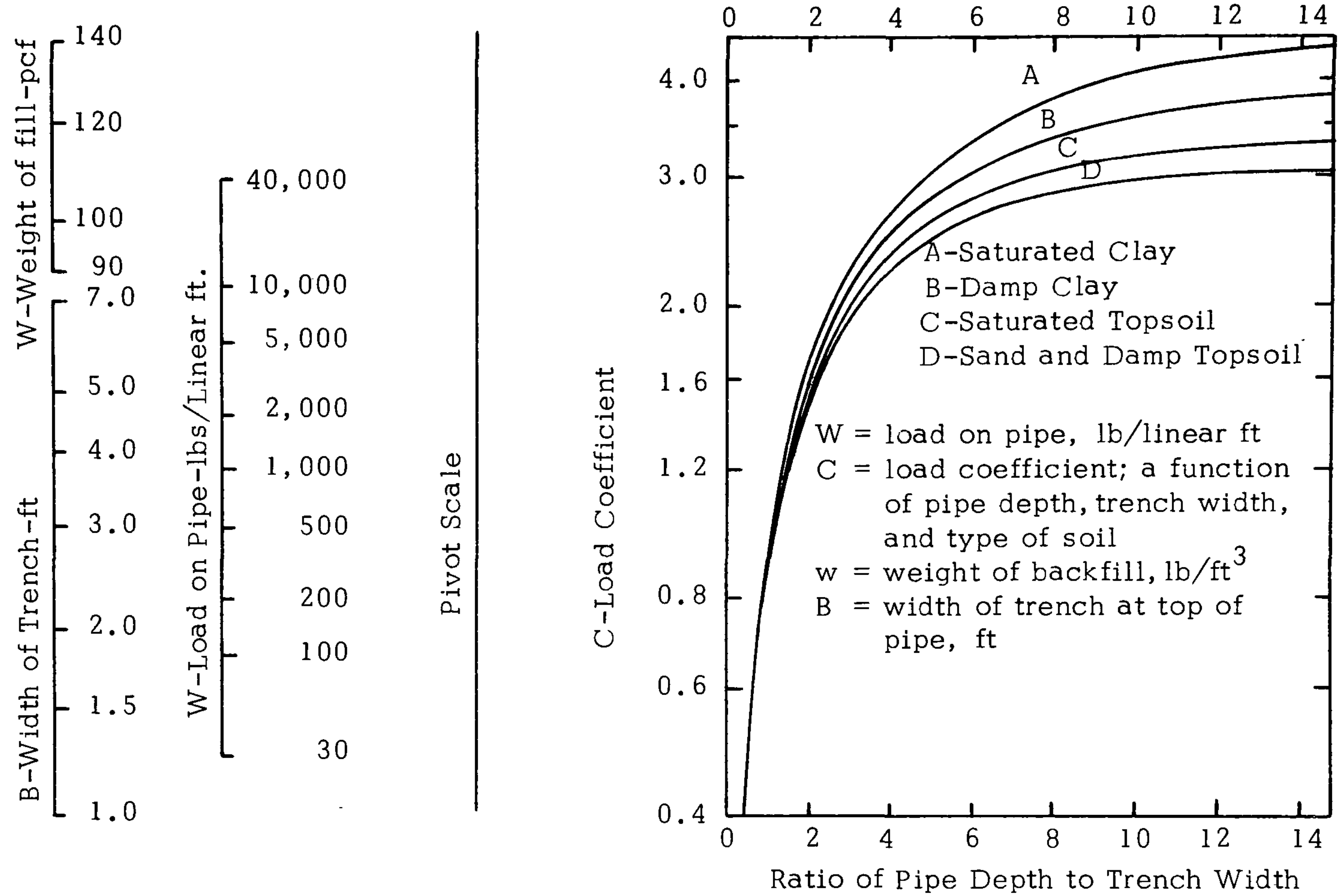
C_d = A dimensionless coefficient which is a function of the ratio of height of fill to width of trench, internal soil friction, and friction between the trench walls and the fill

w = The unit weight of the backfill in pounds per cubic foot

B_d = The width of the trench at the top of the pipe in feet

It can be seen that the load on the pipe is a function of the square of the trench width, and a small increase in trench width results in a large increase in load. Accordingly, trench widths should be kept as narrow as possible while still allowing working room.

There have been a number of tables, nomographs and curves for the solution of the Marston Formula, the complexity of which hinges about the determination of the coefficient. One such nomograph which was recently developed by Mouser and Clark is presented in Figure 37. [12]



LOADS ON BURIED PIPES
FIGURE 37

The following example illustrates the use of this nomograph:

8 inch clay sewer

Depth to top of pipe = 10 feet width of trench at top of pipes 2.5 feet

Saturated topsoil fill, 115 pounds per cubic foot

Pipe depth to trench width ratio $= \frac{10}{2.5} = 4.0$

Solution: Load = 1700 Pounds per Linear Foot

Another method which is commonly used is found in the tables located in the Clay Pipe Engineering Manual. [13]

Supporting Strength of Pipe

The laboratory supporting strength of pipe is normally determined by the three-edge test. [2] The field supporting strength is related to the laboratory supporting strength by the load factor which is a function of the bedding according to,

Field Supporting Strength = Load Factor x Laboratory Supporting Strength.

The beddings discussed in this manual should be assigned a load factor of at least 2, provided that they are compacted in lifts.

TRENCH PREPARATION

The preparation of the trench is an extremely important part of construction as it greatly affects the conditions under which the pipe is laid and therefore the subsequent behavior of the sewer.

Dewatering

Under normal conditions a sewer should not be laid in a flooded trench because of the inability to insure good joining and the proper formation of the pipe bedding. The methods used for dewatering are interior trench pumping and well pointing. Where quick or impending quick conditions are anticipated, well pointing can be used as a method of stabilization in addition to dewatering if the soil conditions permit this type of operation. Where quick conditions develop in conjunction with interior trench pumping, additional pumping capacity will not alleviate but only aggravate the problem.

Sheeting and Bracing

Sheeting and bracing should, where necessary, provide sufficient lateral support to prevent the collapse of the trench walls. This is its primary purpose. It can also be used as friction piling for support of the pipe. This requires the attachment of a trench flooring system by nailing it to the sheeting.

Trench Flooring

When flooring is used it should be relatively even, with reasonably straight lumber and no overlapping of planks. Uneven flooring can cause conditions of point support.

Stumps

In many localities of the Gulf Coast area large cypress and other stumps are encountered in sewer construction. When these are found it is occasionally the procedure to cut (with axes and chainsaws) a portion of the stump to permit passage of the sewer. An illustration of this is shown in Figure 38. If possible this procedure should be avoided since stumps beneath the pipe can cause conditions of uneven support.

BEDDING MATERIALS

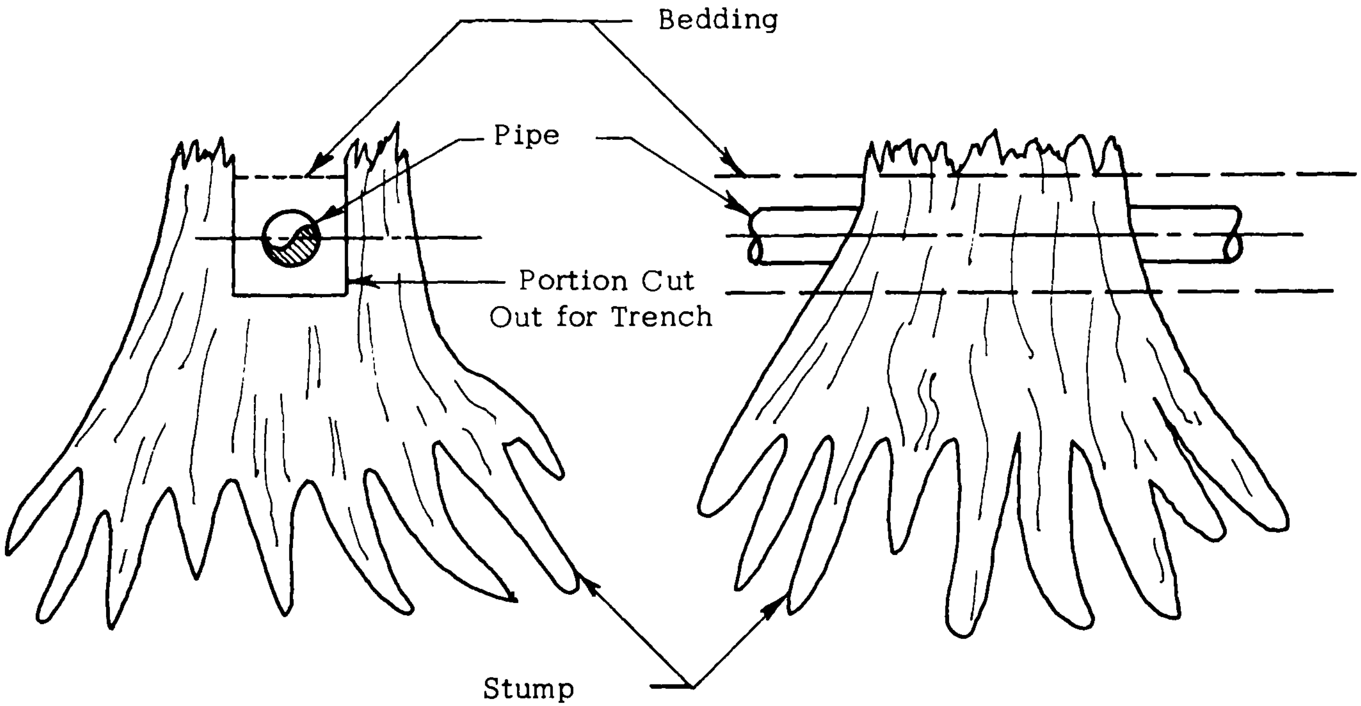
As has been previously mentioned, the bedding material should have the ability to provide support and load spreading as well as retard the transmission of water. Materials or combinations of materials with these properties should be specified.

Care should be taken to insure that the specified thicknesses of bedding material both above and below the pipe are adhered to. In addition to the thicknesses shown on the design drawings, a provision should be added to the specifications stating that the bedding material below the pipe should be sufficiently thick to stabilize the trench bottom.

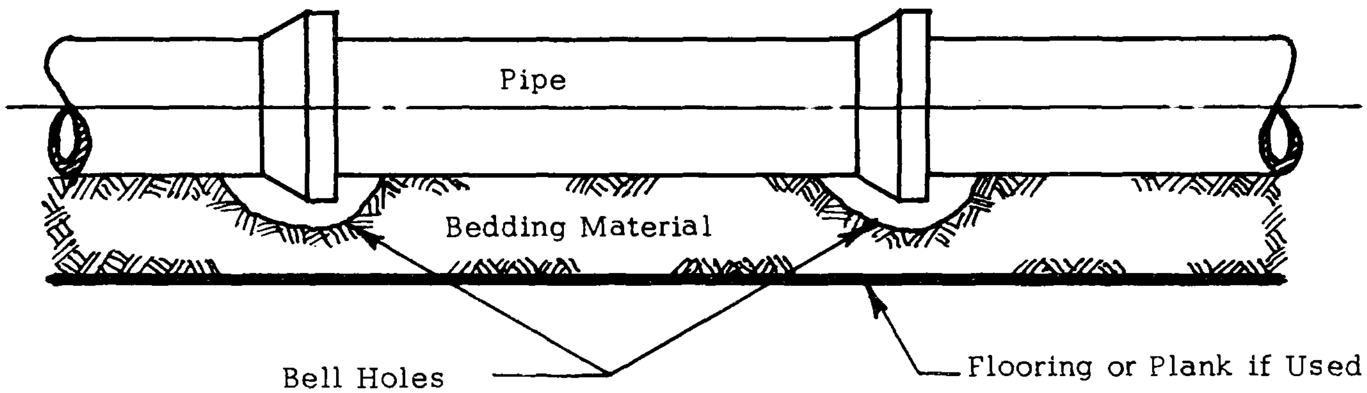
Where timber is used below the bedding material the pipe bells should not rest on the timber and should be unsupported as shown in Figure 39. Bell holes should be provided whether timber is used or not used.

LAYING OF PIPE

The laying of the pipe should be done with great care and under the close supervision of the inspector. Cracked or broken pipe should not be used.



SEWER LAID THROUGH STUMP
FIGURE 38



UNSUPPORTED PIPE BELLS
FIGURE 39

Line and Grade

The alignment or horizontal location of a new sewer usually presents very little problem as compared to the difficulties associated with setting grade (slope). It is advisable to bring the underlying bedding to approximate grade prior to laying each length of pipe. All adjustments in grade should be made prior to laying each length of pipe, and should be accomplished by working the underlying bedding material. There should be no blocking of the pipe with bricks, tiles, etc. to obtain grade. The practice of adjusting the grade by having laborers jump on the pipe should be strictly prohibited.

In light of the range of settlements that can occur, careful consideration should be given to specifying steeper grades on sanitary sewers to prevent septic conditions from developing in the sewage. In the flat terrain of the Gulf Coast area such a specification would necessitate a greater amount of pumping and therefore greater expenditure in sewer construction.

Joining

The pipe manufacturer's construction instructions should be followed in connecting lengths of pipe together. Care must be taken to see that the joint is clear when the coupling is effected and that no foreign materials such as shells or gravel get wedged in the joint. Soil and foreign materials in the joints can cause cracked or broken pipe with resulting large leaks. In the case of compression joint bell and spigot pipe, joining pressure should not be applied with a pry bar in a manner that would damage the bell.

Sealants

It has become common practice in some localities to use sealing materials on the outside of "O" ring and compression bead joints as a means of meeting the infiltration specifications. This practice should be forbidden since it provides only a procedure by which cracked or broken joints can be made temporarily water tight.

BACKFILLING

Backfilling includes the use of select material placed alongside (sidefill) and directly above the pipe as well as the general material with which the remainder of the trench above the pipe is filled.

Select Fill

It is recommended that the pipe always be covered and side filled with select and compacted material. This will insure even distribution of the backfill load to the pipe. The select material should preferably be the same as the bedding material. This material should be compacted in at least three lifts as shown in Figure 40. The select backfill should never be dropped onto the pipe but should be carefully poured along the trench wall.

General Fill

This material should have any large stumps, logs and other debris removed before it is used as backfill. It should never be dropped into the trench but should be carefully placed as shown in Figure 41.

HOUSE SEWERS

House sewers can be considered in two separate parts, municipal and private.

Municipal Connections

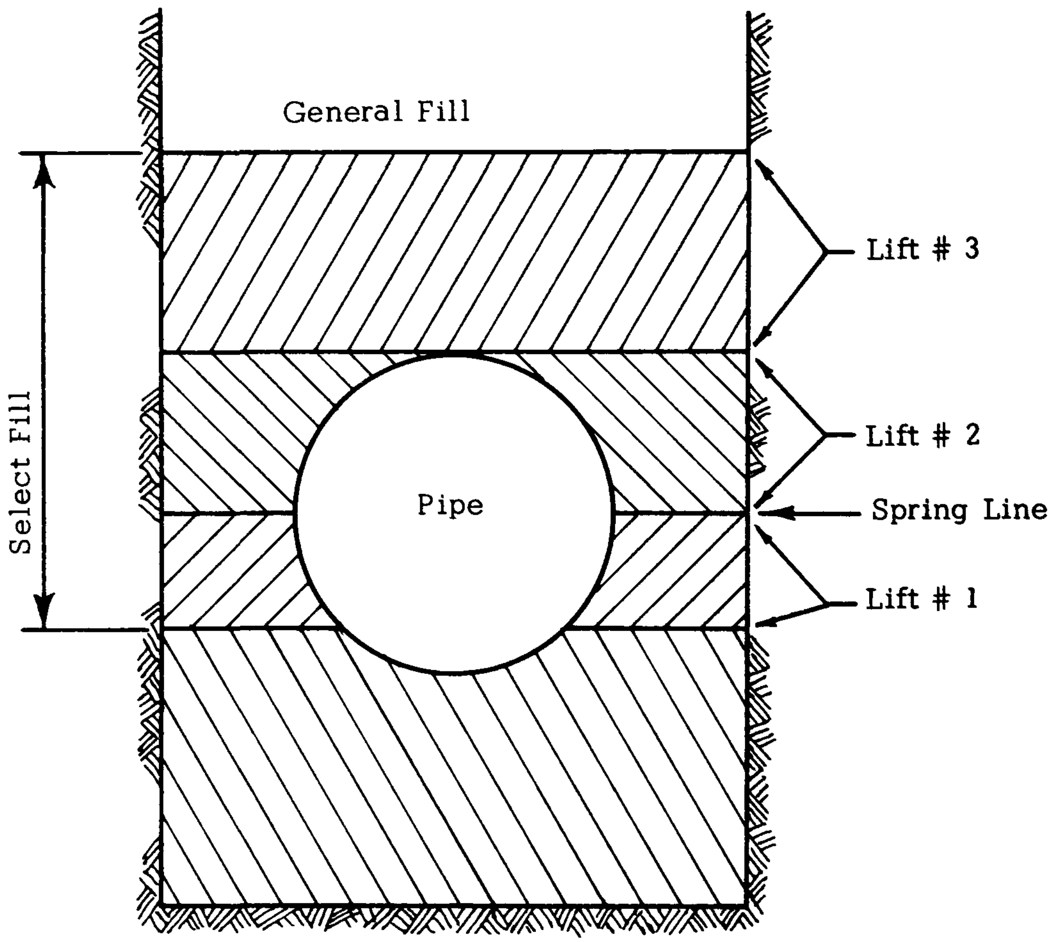
A municipal connection is that part of the house connection that is made at the time that the municipal sewer is constructed. These connections should be made with care, and the use of monolithic fittings (Tees and Wyes) is strongly recommended.

In light of recent findings in New Orleans concerning the interflow between storm and sanitary sewers involving house connections, the following recommendations are made.[2]

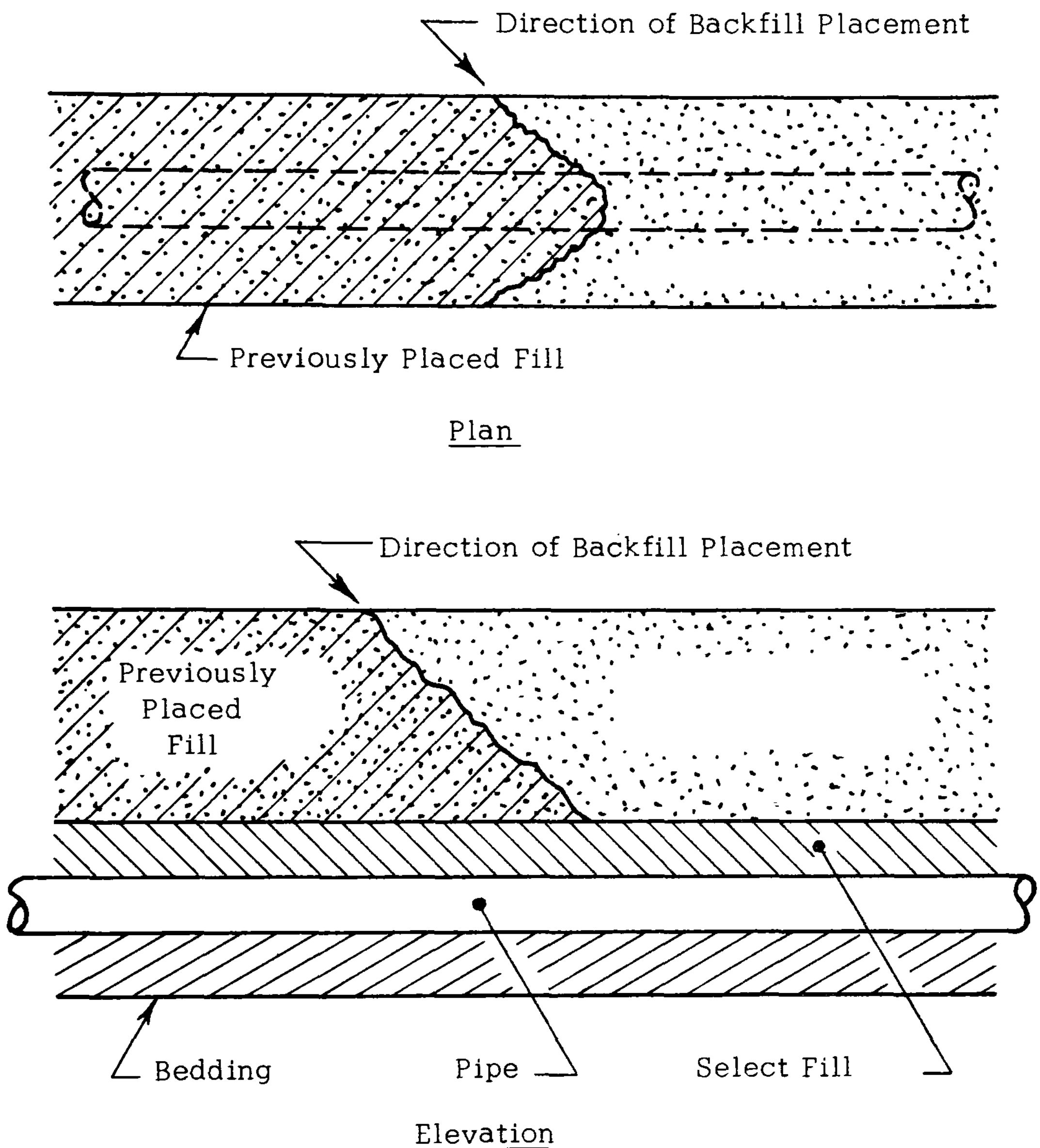
1. Sanitary and storm sewers should be planned at the same time so that grades and locations can be worked out to the benefit of both systems.

2. Wherever storm and sanitary sewers (especially house sewers) cross one another, sufficient cushion should be provided to insure the integrity of both pipes. This cushion material should be of a flow retardant nature.

3. Wherever house sewers cross one another the house sewer should pass over the storm sewer if possible.



COMPACTION OF SELECT BACKFILL
FIGURE 40



PLACING OF GENERAL BACKFILL
FIGURE 41

4. Siphons in house sewers should be avoided.

5. Where a large number of house sewers will be in spatial conflict with the storm drains, it may be desirable to provide one sanitary sewer on each side of the street.

Private Connections

A private connection is that portion of a house connection that is made by the plumber. The most important factor concerning the private portion of a house sewer is inspection. The work of plumbers in laying these pipes should be properly inspected. If no municipal connection is available, the connection should not be made by merely breaking the municipal sewer and inserting a pipe. Any connections of this type should be made by the sewer authority using proper fittings.

MANHOLES

Based on construction observations and a survey of 1600 manholes in the Greater New Orleans area, the following recommendations are made.

1. The practice of raising the manhole frame by wedging several bricks between it and the wall should be discontinued. This practice affords ready entry of water from the surrounding soil during rainy weather especially if the water table is near the ground surface. In raising a frame the wall should be brought to the proper level and a mortar seal should be placed between it and the frame.

2. Great care should be taken to insure that the point of connection between the sewer and the manhole is water tight. The practice of building a manhole over the top of a pipe and then breaking the pipe should be avoided. Breaking the pipe inside a manhole will cause breaks extending outward into the sewer. This breaking of the sewer can also disturb the seal between the pipe and the manhole wall.

3. A joint should be provided in the sewer just outside of the manhole to allow for any differential in settlement.

4. Where the sewer is supported on piles the manholes should also be pile supported.

5. Heavy loads should be kept off of manholes until the mortar has reached its design strength.

6. The use of manhole covers with ventilation holes should be avoided in areas where street flooding is common.

INFILTRATION SPECIFICATION

Specifications for infiltration have in the past twenty years found wide use. In a survey study in the Gulf Coast area 74% of the sewer authorities answering indicated that they had an infiltration specification. Table 28 is a comparison of the infiltration specification together with other data collected during the survey. There seems to be no relationship between the various parameters and the value of the infiltration specification reported. The weighted average of these infiltration specifications according to length of sewer sampled was 571 gallons per inch of diameter per mile per day, and weighted according to sewage flow was 486 gallons per inch of diameter per mile per day.

It is recommended that a specification of not more than 200 gallons per inch of diameter per mile per day be adopted in areas with high water tables. This value can be accomplished in conjunction with a good system of "on the job" inspection. It is believed that much less than 200 gallons per inch of diameter per mile per day can be achieved with good inspection and factory made joints.

SEWER ACCEPTANCE

Ideally the measure used for sewer acceptance would be one or a group that would delineate the behavior of a sewer over its entire lifetime. Unfortunately, no such measure exists. Instead, tests and observations are made which are hoped will be indicative of lifetime sewer behavior. If good inspection is available then the following inspection procedure will provide a good review for acceptance following sewer construction.

1. Infiltration tests should be run on the entire system and selected small segments. If a test is run only on the entire system, bad conditions in any one component will not be detected because of the compensating effect of the non-leaking parts of the system. The size and number of segments should be based on the engineer's knowledge of the system and the inspector's construction log.

2. All manholes should be inspected.

3. All lines should be lamped for straightness. Lines can be checked for straightness by jetting as previously discussed.

TABLE 28

INFILTRATION SPECIFICATIONS
IN COMPARISON WITH OTHER DATA

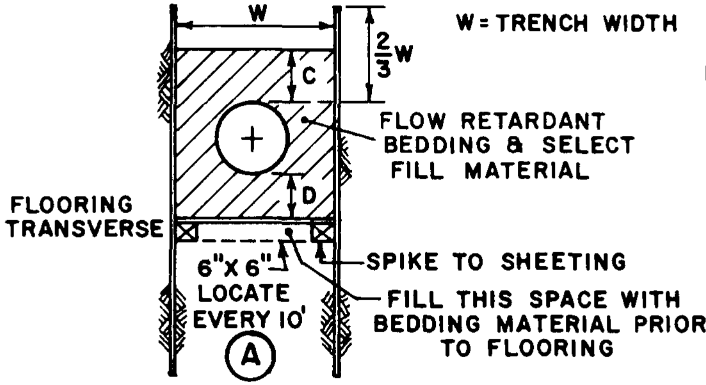
Inf. Spec. g/in/mi/dy	Sampled Length of Sewer Miles	Sampled Population	No. of Political Divisions	% Length of Sewer	% Population
1500	44	15,000	1	0.3	0.3
1000	4,433	1,464,000	3	32.7	31.9
500	2,017	516,000	14	14.8	11.3
400	82	61,000	2	0.6	1.3
300	2,166	787,000	3	16.0	17.2
250	2,547	1,153,000	4	18.8	25.2
200	250	71,000	1	1.8	1.6
100	160	42,000	1	1.2	0.9
None	1,869	473,000	10	13.8	10.3
	13,568	4,582,000	39	100.0	100.0

4. Any lines not meeting the infiltration specification can be televised and repaired based on these findings. The televising of entire systems on a routine basis would probably be justified, in known problem areas.

The practice of accepting sewers only on the basis of one infiltration test at the terminus of the system should be discontinued.

SEWER CONSTRUCTION DETAILS

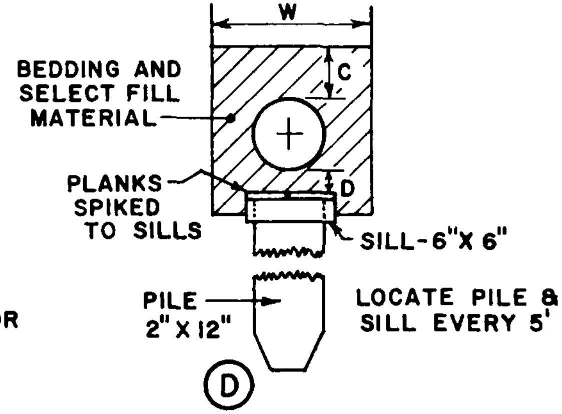
Figure 42 presents a typical sewer construction detail for the Gulf Coast area.



NOTE: IF PILE SUPPORT IS NOT DESIRED, DO NOT SPIKE FLOOR SYSTEM.

SHEETED TRENCH W/ FLOORING BELOW WATER TABLE

SCALE: NONE

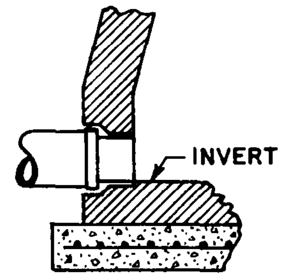


ALTERNATE PILE DETAIL

SCALE: NONE

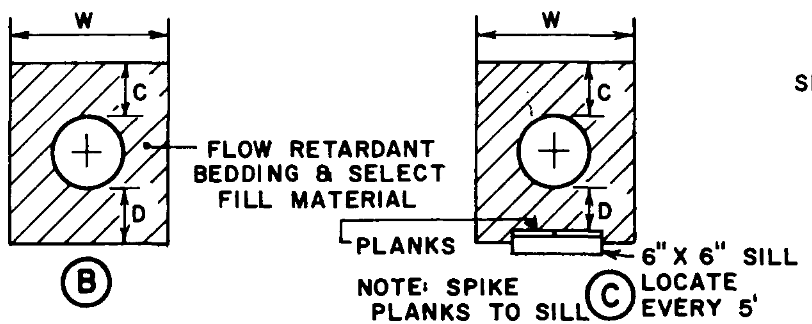
BEDDING & COVER MINIMUM THICKNESSES

NOMINAL PIPE SIZE	D	C
6"	4"	6"
8"	6"	8"
10"	8"	10"
12"	10"	12"
15"	13"	15"
18"	16"	18"



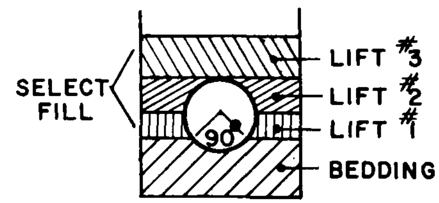
MANHOLE CONNECTION DETAIL

SCALE: NONE



NON-SHEETED TRENCH BELOW WATER TABLE

SCALE: NONE



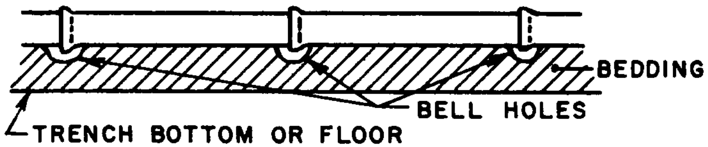
NOTE: HAND TAMP

PLACEMENT & COMPACTION OF BEDDING & SELECT FILL MATERIAL

SCALE: NONE

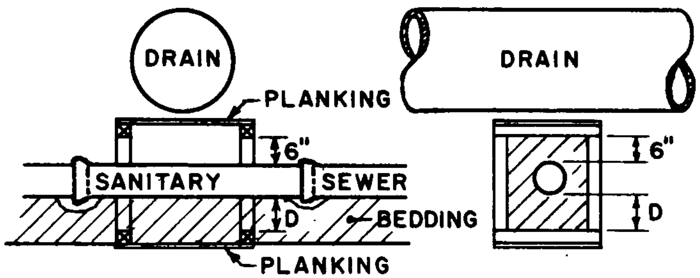
SEWER DETAILS
CLAY PIPE
GULF COAST AREA
FIGURE 42
Sheet 1 of 2

NOTE: NO PIPE BELL SHALL REST ON BEDDING MATERIAL OR SUB-PIPE LUMBER.



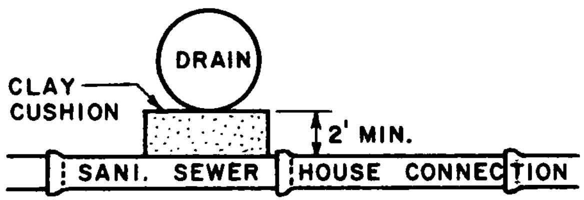
BELL HOLE DETAIL

NO SCALE



SEWER-DRAIN CROSSING

NO SCALE



HOUSE CONNECTION-DRAIN CROSSING

NO SCALE

GENERAL NOTES

1. ALL DETAILS ABOVE WATER TABLE SAME AS THOSE BELOW EXCEPT FOR BEDDING AND SELECT FILL MATERIAL.
2. BEDDING AND SELECT FILL ARE SAME MATERIAL.
3. BEDDING AND SELECT FILL MATERIAL ABOVE WATER TABLE NEED NOT BE FLOW RETARDANT.
4. BEDDING AND SELECT FILL MATERIAL BELOW WATER TABLE MUST BE FLOW RETARDANT MATERIAL.
5. TRENCH WIDTH SHOULD BE AS NARROW AS POSSIBLE AND NOT TO EXCEED THAT WHICH WOULD PRODUCE A PIPE SAFETY FACTOR OF LESS THAN 1.5.
6. CUT ALL SHEETING OFF AT LEAST 2½" BELOW GROUND SURFACE.
7. DO NOT PULL SHEETING.
8. SHEETING MAY BE USED IF NECESSARY FOR ANY TRENCH.
9. IF TRENCH IS OVERDUG, FILL TO GRADE WITH SELECT FILL MATERIAL.
10. ALL PLANKING BELOW PIPE SHOULD BE AT LEAST 2" LUMBER.

SEWER DETAILS
CLAY PIPE
GULF COAST AREA
FIGURE 42
Sheet 2 of 2

GLOSSARY

1. BACKFILL: That material that is used to cover a sewer in a trench extending from the sewer or select fill to the ground surface.

2. BENTONITE: A clay with a high content of montmorillonite. It has an expanding lattice structure which enables it to absorb large amounts of water. Bentonite deposits are normally formed by chemical alteration of volcanic ash.

3. COHESION: The capacity of a soil to resist shearing stress, exclusive of functional resistance.

4. DRAWDOWN: The change in elevation of water table due to pumping or other drainage.

5. FRICTION ANGLE: The angle of internal friction in a granular material. The angle increases with density, and for loose materials is approximately equal to the angle of repose.

6. GROUND WATER INFILTRATIONS: The seepage of ground water into an opening in a sewer.

7. HOUSE CONNECTION: That portion of a sewer extending from the trunk sewer to the plumbing in a residence or apartment.

8. ILLICIT CONNECTION: A connection from a residence, apartment, etc. which introduces liquid other than sewage (usually stormwater) into the sanitary sewer.

9. INFILTRATION: Any water other than sewage entering a sanitary sewer.

10. INFILTRATION SPECIFICATION: A condition for acceptance of a sanitary sewer from a contractor by a sewer authority. This specification limits the amount of infiltration acceptable in a sewer system.

11. INFILTRATION UNITS: Those units used in reporting infiltration. They are as follows:

    a) Gallons per inch of diameter of pipe per mile of line per day.

b) Gallons per day - The system characteristics and size must also be given if the reporting is to be effective.

c) Gallons per mile of pipe per day - The pipe sizes and their respective lengths must also be given for the reporting to be effective.

d) Gallons per acre per day - The system characteristics and size as well as scale maps must also be provided for this reporting to be effective.

12. JOINTS (PIPE):

a) COMPRESSION: A joint made utilizing a compression bead in the bell end and a bearing pad on the spigot. This joint is made of resilient material.

b) FACTORY MOULDED: A joint that is manufactured and not constructed in the field.

c) HOT POURED: A joint constructed in the field by the application in a hot liquid state of bituminous material.

d) MORTAR: A joint constructed in the field of portland cement mortar.

e) "O" RING: A manufactured joint that consists of one or more rubber compression rings confined in seatings on both the bell and spigot ends of the pipe.

13. LIQUID LIMIT: The water content in percent of dry weight at the point where the consistency of a cohesive soil changes from the plastic to liquid state. This parameter is based on an operationally defined test.

14. MONOLITHIC FITTINGS: Clay pipe fittings (wyes and tees) that are formed in one operation.

15. PERFORMANCE SPECIFICATION: A specification that is gauged based on the behavior of the finished product or some behavioral characteristic. A performance specification does not provide directions as to how to obtain a satisfactory end product.

16. PERMEABILITY: The characteristic of a soil or granular material

to transmit water through its interstitial spaces.

17. PLASTIC LIMIT: The water content in percent of dry weight at the point where the consistency of a cohesive soil changes from the solid to the plastic state. This parameter is based on an operationally defined test.

18. PRIVATE CONNECTION: That portion of a house connection that is constructed by a private plumber working for the sewer user.

19. PROCEDURAL SPECIFICATION: A specification based on providing detailed instructions for the construction of a product.

20. SELECT FILL: A high quality material used for the backfilling directly above and in contact with a sewer pipe.

21. SEPTIC SEWAGE: Wastewater which is in the process of anaerobic decomposition.

22. SEWAGE - SANITARY: The wastewater from homes, apartments, etc. which enters a sewer system through plumbing fixtures.

23. SEWAGE - STORM: Precipitation runoff which is normally carried in drainage systems.

24. SEWER BEDDING: That material placed beneath a sewer pipe that forms the foundation for the pipe.

25. SOIL REMOULDING: The process whereby a cohesive soil is kneaded or worked. This process normally creates a softening in a virgin soil which is considered as being caused by destruction of the orderly arrangement of the molecules and the destruction of the structure produced during original deposition.

26. STORM WATER INFILTRATION: The entrance of stormwater into a sanitary sewer.

27. SUBSIDENCE: The decrease in elevation of the ground surface or a particular stratum of soil due to the lowering of the water table.

28. UNDERMINING - SEWER: The process whereby the material supporting and surrounding a sewer is removed by hydraulic forces, thus denying support to the sewer.

29. VOID RATIO: The ratio of the volume of the voids to the volume of the solid material in a soil mass.

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APPENDIX A

DEFLECTION AND JOINT RESISTANCE TESTS

The purpose of this study was the acquisition of information concerning the behavior of the joint of the pipe to be used throughout this project. Two types of tests were conducted. The first consisted of deflection tests designed to determine the interrelationships at impending leakage, of deflection angle, hydrostatic head and external load. The second consisted of loading tests in which the moment resistance and flexibility of the joint were determined.

All pipe tested was 8 inch diameter vitrified clay extra strength with a polyurethane factory moulded joint, as manufactured by the W. S. Dickey Clay Manufacturing Company. Each section of the pipe was 5 feet in length. Prior to performing all the tests described in this section, the pipes and joints were carefully inspected for defects. Only good specimens conforming to applicable specifications were used.

DEFLECTION TESTS - NO LOAD

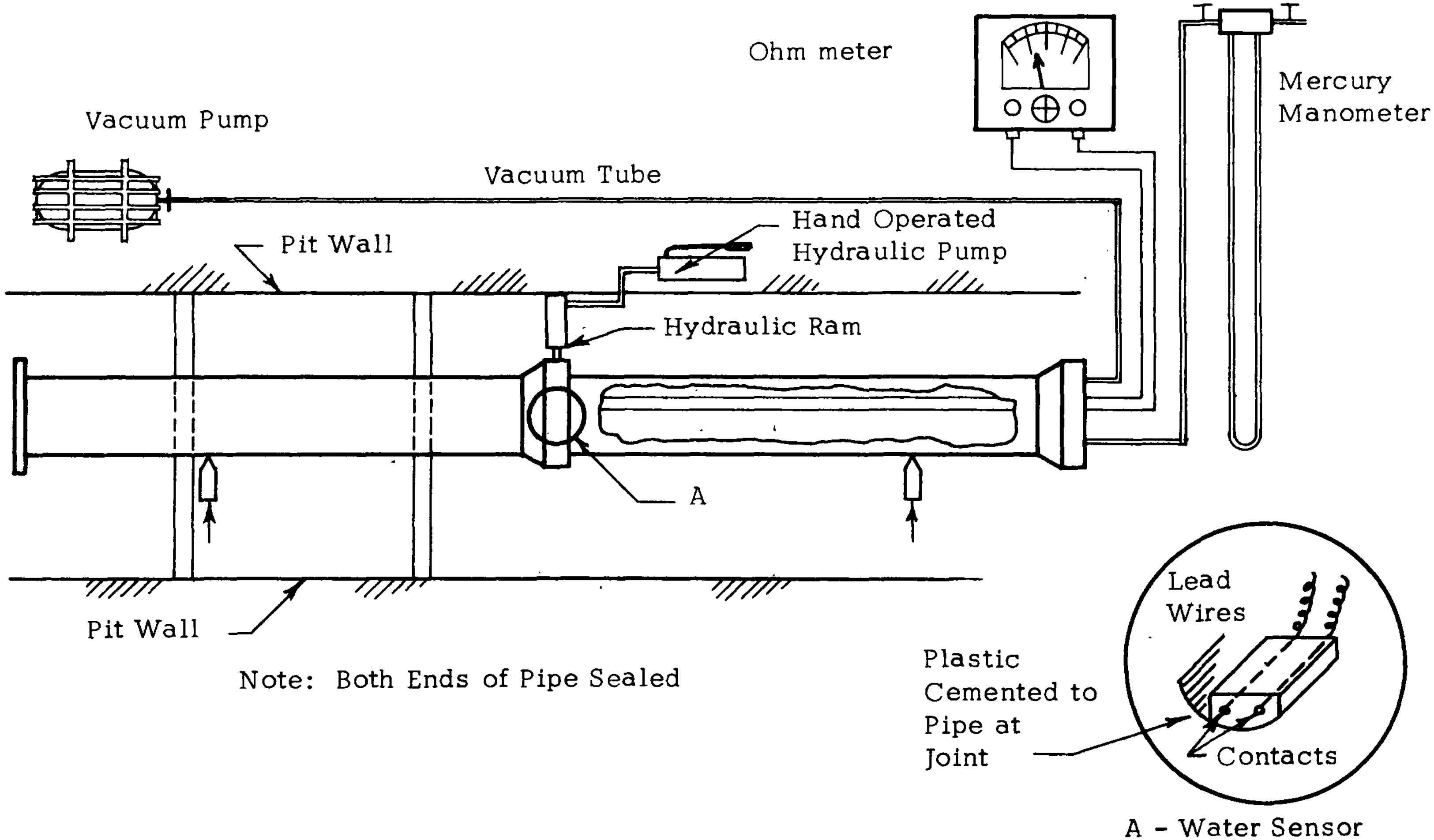
This study was made with two sealed sections of pipe submerged in water. The pipe was subjected to a vacuum and deflected until leakage occurred in the joint.

Materials and Methods

The test was performed in a flume in a hydraulic laboratory. Two sections of pipe were placed in a wooden cradle which confined the pipe allowing movement only in the horizontal plane. Figure A 1 is a diagram of the testing equipment. The cradle, along with the pipe, was lowered into the pit prior to starting each test. After positioning this assembly in the bottom of the pit, it was secured horizontally by means of wedges bearing on the pit walls and vertically with sufficient lead weights to overcome floatation.

The unjointed ends of the pipes used were sealed so that they were air and water tight. The spigot ends were covered with plywood caps, and the seal was made using liquid rubber cement. The belled ends were capped with 8 inch clay stoppers, and the seal was reinforced with liquid rubber. Liquid rubber was also used at openings for wires and vacuum tubes. This was done prior to the beginning of each series of tests.

The deflection was set in the joint using a small hydraulic ram, and was measured by determining the distance traversed by moving a plumb line



PIPE JOINT TESTS ASSEMBLY FOR TESTS PERFORMED
AT TULANE UNIVERSITY
FIGURE A 1

from the initial position of the joint to the final position at which leakage occurred.

The pipe joint, in the testing position, was covered by two inches of water. The desired differential head between the outside of the joint and the inside of the pipe was obtained by creating a vacuum in the pipe. This vacuum was read with a mercury manometer.

Leakage of the joint was determined by the presence of water in the pipe as detected by a simple water sensor. When the sensor became immersed, the reading on the ohm meter changed from that of the resistance between the contacts in air to that of the resistance in the water which acted as an electrolyte. The observance of this change signaled the leaking of the joint. Pipe sections were changed after each series of variation of hydraulic head.

The sequence of testing was as follows:

a) Polish sensor contacts.
b) Assemble pipe section in cradle.
c) Lower cradle and pipe into pit.
d) Secure cradle.
e) Set desired differential head by evacuating the pipe.
f) Deflect joint until leakage occurs.
g) Measure deflection.

Results

The results of the deflection tests under no loading are shown in Table A1. It may be noted that the hydrostatic head which varied between 6 and 30 feet of water, had little effect on joint leakage under pipe deflection. The range of deflection where leakage occurred was from 6.95 to 10.92 degrees. The median of the test was 9.75 degrees and the average of 9.72 indicates a good sewer joint which should allow normal pipe movements experienced in construction without failure occurring.

The ASTM standard specifications for permissible joint deflection of vitrified clay pipe using materials having resilient properties are shown in Table A2.

The deflections in terms of inch per linear foot of pipe were computed for the minimum, median and maximum values shown in Table A3. These values for the 8 inch diameter and five foot linear sections used in the test are tabulated in Table A4.

TABLE A 1

PIPE JOINT DEFLECTION TESTS-NO LOAD

Head Ft. of Water	Deflection Angle Degrees	Head Ft. of Water	Deflection Angle Degrees
10	6.95	6	9.87
10	7.68	10	9.87
10	8.68	14	9.87
10	8.98	18	9.87
10	8.98	24	9.87
10	8.98	30	9.87
10	8.98	14	10.81
10	9.12	14	10.85
6	9.75	4	10.92
8	9.75	8	10.92
12	9.75	18	10.92
14	9.75	24	10.92
16	9.75	30	10.92
18	9.75		
22	9.75		
30	9.75		

TABLE A 2

DEFLECTION PER FOOT OF PIPE LENGTH*

Nominal Diameter (inch)	Deflection per Foot of Pipe Length (inch)
4 to 12 inclusive	1/2
15 to 24 inclusive	3/8
27 to 36 inclusive	1/4

*Standard Specifications for Vitrified Clay Pipe Joints Using Materials Having Resilient Properties - ASTM Designation: C 425-64

TABLE A 3

DEFLECTION ANGLE SUMMARY

Angle (degrees)	Deflection per Foot of Pipe Length (inch)
6.95 (minimum)	1.46
9.75 (median)	2.07
10.92 (maximum)	2.32

It may be noted that the deflections obtained in the test compare very favorably with the limits provided by the ASTM specifications. The joint of the 8 inch pipe used in the test deflected nearly three times the ASTM limiting amount of 1/2 inches per foot before leakage occurred. This comparison further indicates the good resilient qualities of the joint of the sewer used in the project.

DEFLECTION TESTS-UNDER LOADING

These tests were performed by project personnel at the research laboratory of the W. S. Dickey Clay Products Co. at Pittsburg, Kansas. The test consisted of applying a predetermined load to the joint and deflecting the pipe until leakage occurs.

Materials and Methods

Figure A2 shows the method used in the test. The shear load was applied across the joint by means of a lever system and was measured with a dynamometer. The deflection was obtained by means of a screw jack. Hydrostatic heads of 10 and 20 feet were used in the test. Pipe sections were changed after each series of variation of loadings.

Results

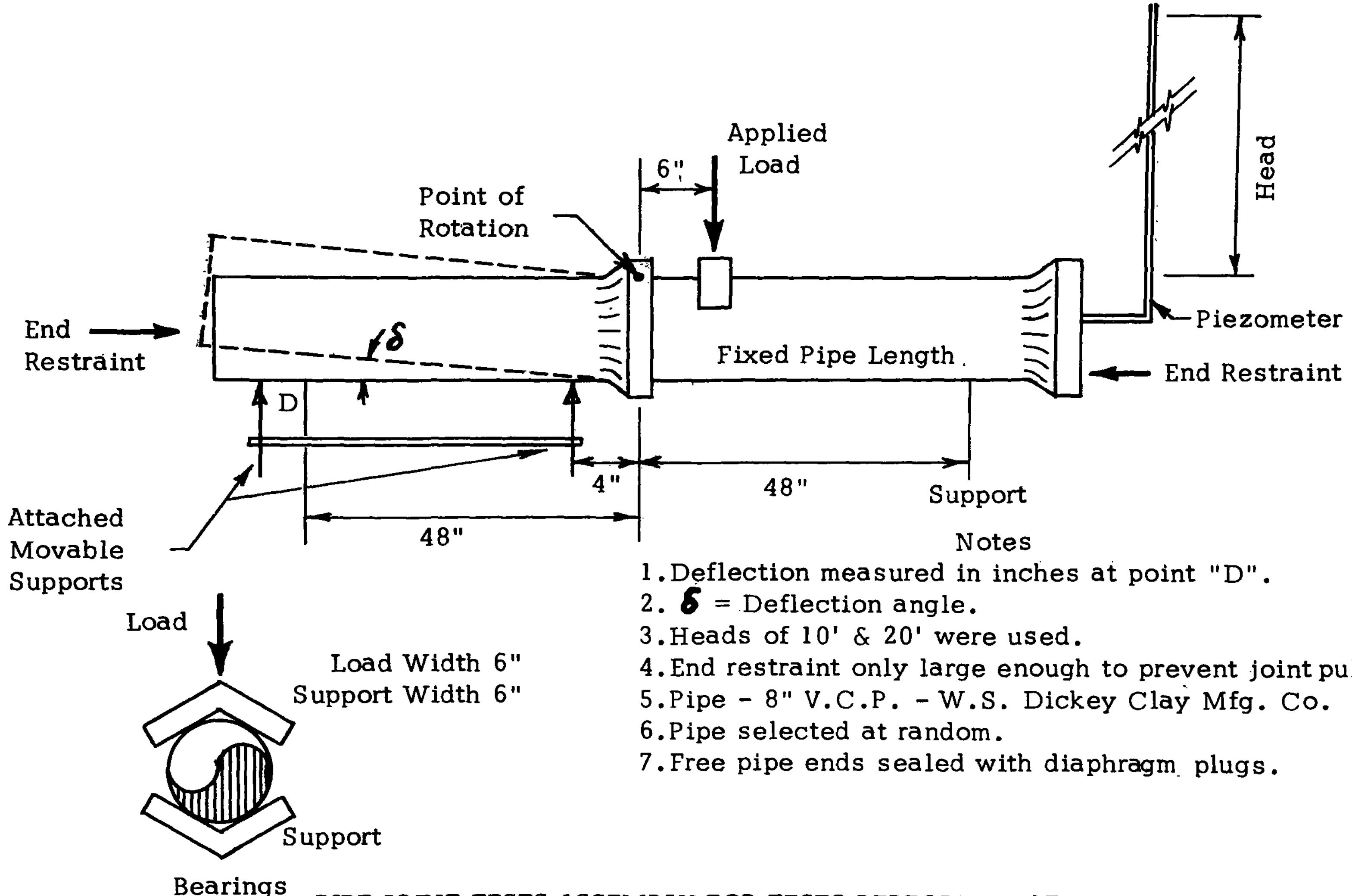
The results of the joint deflection tests under the loadings used are shown in Table A4. No significant differences were noted in the joint leakage in the 10 and 20 foot heads used in the test.

Figure A3 is a plot of the deflection angle where leakage occurred with respect to the load applied on the joint. This curve provides a means of determining the limiting deflection angle at the joint for applied loads. As the depth of a sewer trench increases and the load of the backfill material on the sewer increases, the limit of the deflection angle of the joint decreases.

TABLE A 4

PIPE JOINT DEFLECTION TESTS - UNDER LOADING

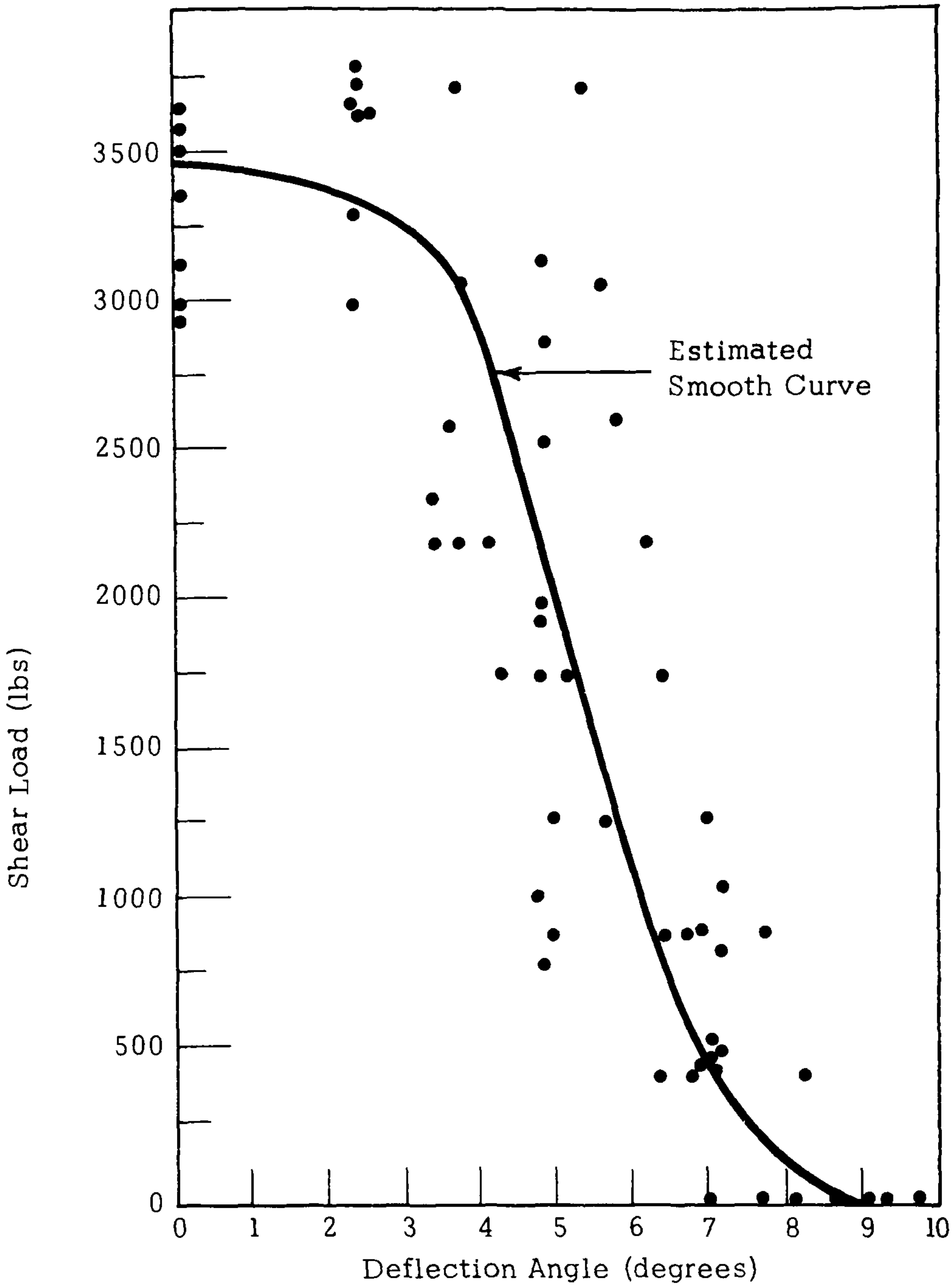
Head Ft. of Water	Load Lbs.	Def. Angle Degrees	Head Ft. of Water	Load Lbs.	Def. Angle Degrees
10	895	4.98	10	3386	0
10	1289	5.65	10	3780	2.38
10	1748	5.13	10	3714	3.58
10	436	6.13	10	3124	4.78
10	895	6.35	10	1050	7.13
10	1289	6.75	10	3518	0
10	1748	5.96	10	3714	2.38
10	2208	5.13	10	3058	3.58
10	2670	4.03	10	2533	4.78
10	436	7.35	10	827	7.13
10	895	6.83	10	3386	0
10	1289	4.91	10	3649	2.38
10	1748	4.76	10	3518	3.58
10	2208	3.71	10	2861	4.78
10	3126	0	10	761	7.13
10	3386	2.38	10	3649	0
10	2336	3.58	10	3518	2.38
10	1024	4.78	10	2993	3.58
10	563	7.13	10	2273	4.78
10	3386	0	10	761	7.13
10	3649	2.38	20	436	6.75
10	2993	3.58	20	895	6.38
10	2008	4.78	20	1289	5.79
10	433	7.13	20	1748	4.25
10	2993	0	20	2208	3.35
10	3321	2.38	20	436	8.22
10	2599	3.58	20	1895	7.71
10	1925	4.78	20	1289	6.98
10	499	7.13	20	1748	6.38
10	2927	0	20	2208	6.25
10	2993	2.38	20	2667	5.79
10	2468	3.58	20	3061	5.50
10	761	4.78	20	3520	5.28



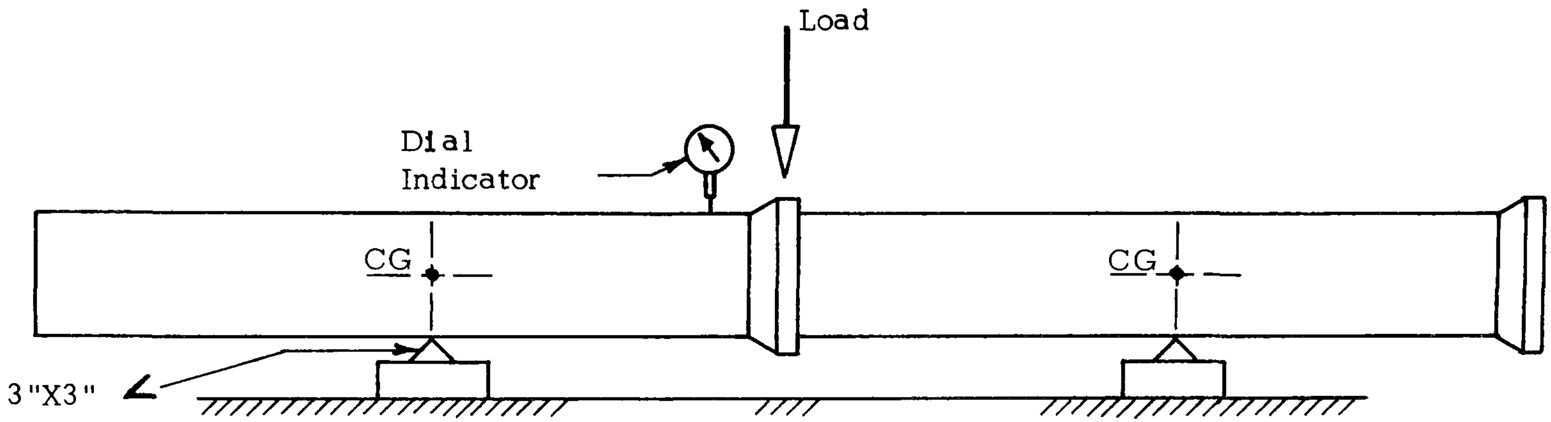
Notes

1. Deflection measured in inches at point "D".
2. δ = Deflection angle.
3. Heads of 10' & 20' were used.
4. End restraint only large enough to prevent joint pullout.
5. Pipe - 8" V.C.P. - W.S. Dickey Clay Mfg. Co.
6. Pipe selected at random.
7. Free pipe ends sealed with diaphragm plugs.

PIPE JOINT TESTS ASSEMBLY FOR TESTS PERFORMED AT
PITTSBURG, KANSAS
FIGURE A 2



DEFLECTION ANGLE AT IMPENDING LEAKAGE VS. SHEAR LOAD
FIGURE A 3



Note: The load was applied in increments and the dial indicator was read at each increment.

CG = Center of gravity of a particular length of pipe.

Load was applied by placing lead weights in a 30 gallon drum and filling the drum with water.

PIPE JOINT BENDING RESISTANCE
FIGURE A 4

JOINT RESISTANCE TEST

The purpose of this study was to determine through deflection tests the resistance moment of joints.

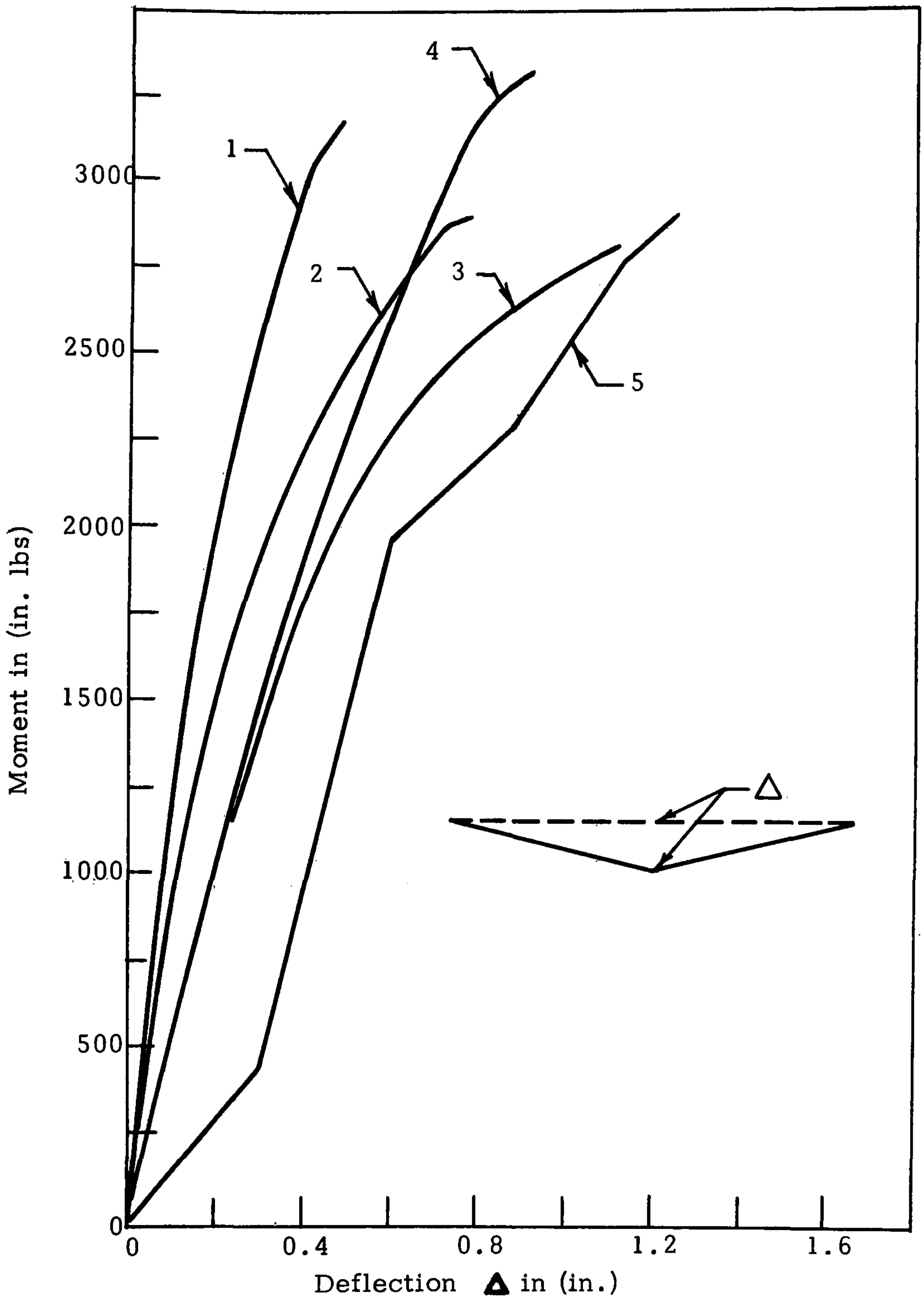
Materials and Methods

Two four foot lengths of pipe were assembled in this study. Figure A 4 shows the arrangement that was used. Prior to testing all lengths of pipe were balanced to determine their centers of gravity. Before each test, the two lengths of pipe to be used were joined and placed across the two fulcrums located beneath their centers of gravity. By supporting the pipes in this manner, no moment was imparted to the joint due to the weight or location of the pipe lengths. The joined pipes were allowed to remain undisturbed for 24 hours before the test was run. The load was applied directly to the pipe joints. The deflection was measured by means of a dial indicator gage which was read for each increment of load applied. Five series of tests were performed with the pipe sections being changed for each run.

Results

The moment in terms of inch-pounds was determined for each load applied in this study. Figure A5 shows the moment deflection curves that were developed from the five tests. The results showed that the joint used did not offer much resistance to moment. The variations in the curves were due to the difficulty experienced in applying loads of the desired amounts to the joints, and also to differences in joining stress relaxation. Disturbances occurred even though loads were applied as softly as possible.

The results of this test indicated that the joint used in this study was flexible and when deflected does not transfer excessive loads to the bell or spigot of vitrified clay sewers.



MOMENT RESISTING CAPACITY OF THE PIPE JOINTS
FIGURE A 5

APPENDIX B

MANHOLE SURVEY

Observations of sewer construction methods and inspection of manholes during infiltration studies indicated that manholes contribute greatly to infiltration in sewer systems. In order to evaluate the significance of this source of infiltration further, a manhole survey was conducted during the summer of 1970. A total of 1600 manholes was surveyed in the metropolitan area of the City of New Orleans. This survey included 32 different sewer systems that were selected on the basis of age, location, depth and type of construction. The age of the manholes varied from one year to 67 years with 21 years as the average.

The land area in the systems surveyed represented approximately 22 square miles. Manholes in the Lakewood South System which had been studied for infiltration were included in the survey. The manholes ranged in depth from 3 to 24 feet with 10 feet being the average depth of the 1600 inspected.

Materials and Methods

Sections included in the survey ranged from those of the original sewer systems constructed in New Orleans in 1903 to some constructed within the last year. As the individuals collecting the information worked alone, the survey for safety reasons was limited to collecting data that could be observed from the street level.

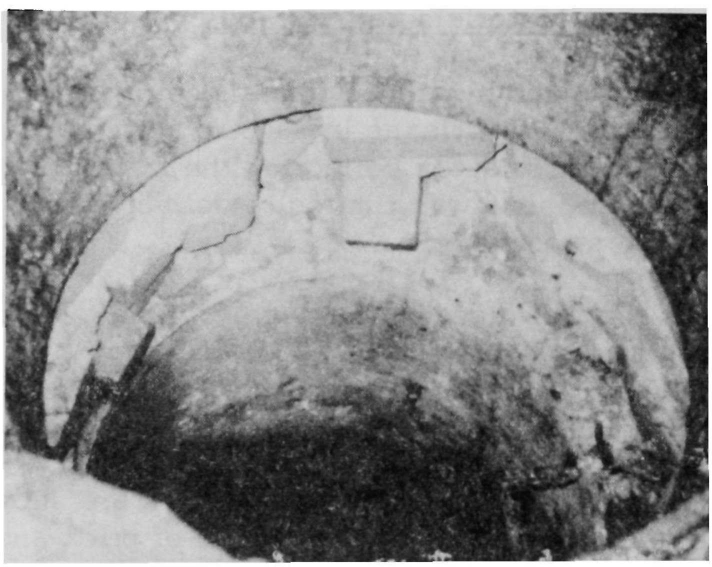
Appendix N shows the form used in the survey. One of these forms was filled out for each manhole inspected.

Results

The results of the inspection of the 1600 manholes are shown in Table B 1. All of the manholes inspected were constructed of brick and 48 were found to have no cement mortar inner lining or the lining had deteriorated. A total of 402 manholes were found to have interior cracks in the walls, around the steps, around the inlets and outlets sewer pipes, inverts or bottom. Castings on the top of the manholes were found to be cracked in 15 installations.

Of the 1600 manholes inspected 56 or 3.5 percent were observed to have infiltration at the time of the inspection. A greater number would no doubt be subject to infiltration if inspections were made during periods of rainfalls. Figure B 1 shows photographs of typical conditions found in the survey.

Displaced Manhole Collar



Poor Manhole Construction of Collar and Interior Wall

PHOTOGRAPHS OF MANHOLES

FIGURE B 1

TABLE B 1

MANHOLE SURVEY

Item	Number	Percent of Total Manholes Inspected
Total Inspected	1600	100.0
Brick - Cement Linings	1552	97.0
Brick - No Linings	48	3.0
Cracks		
Walls	387	24.2
Around Steps	3	0.2
Inlets and Outlets	5	0.3
Invert	1	0.1
Bottom	6	0.4
Castings	15	0.9
Infiltration Observed	56	3.5
Steps		
Iron	1540	96.3
Aluminum	42	2.6
None	18	1.1

This survey indicated that manholes do contribute greatly to infiltration in sewers. The condition is the result mainly of poor manhole design, construction practices and maintenance. The following is a listing of some of the major causes of the infiltration that were observed during the inspection:

a) Settlement of manhole because of poor foundations causing breaks in the sewer pipe.

b) Settlement of sewer adjacent to manholes.

c) Improper construction of cement mortar linings inside and outside the manhole.

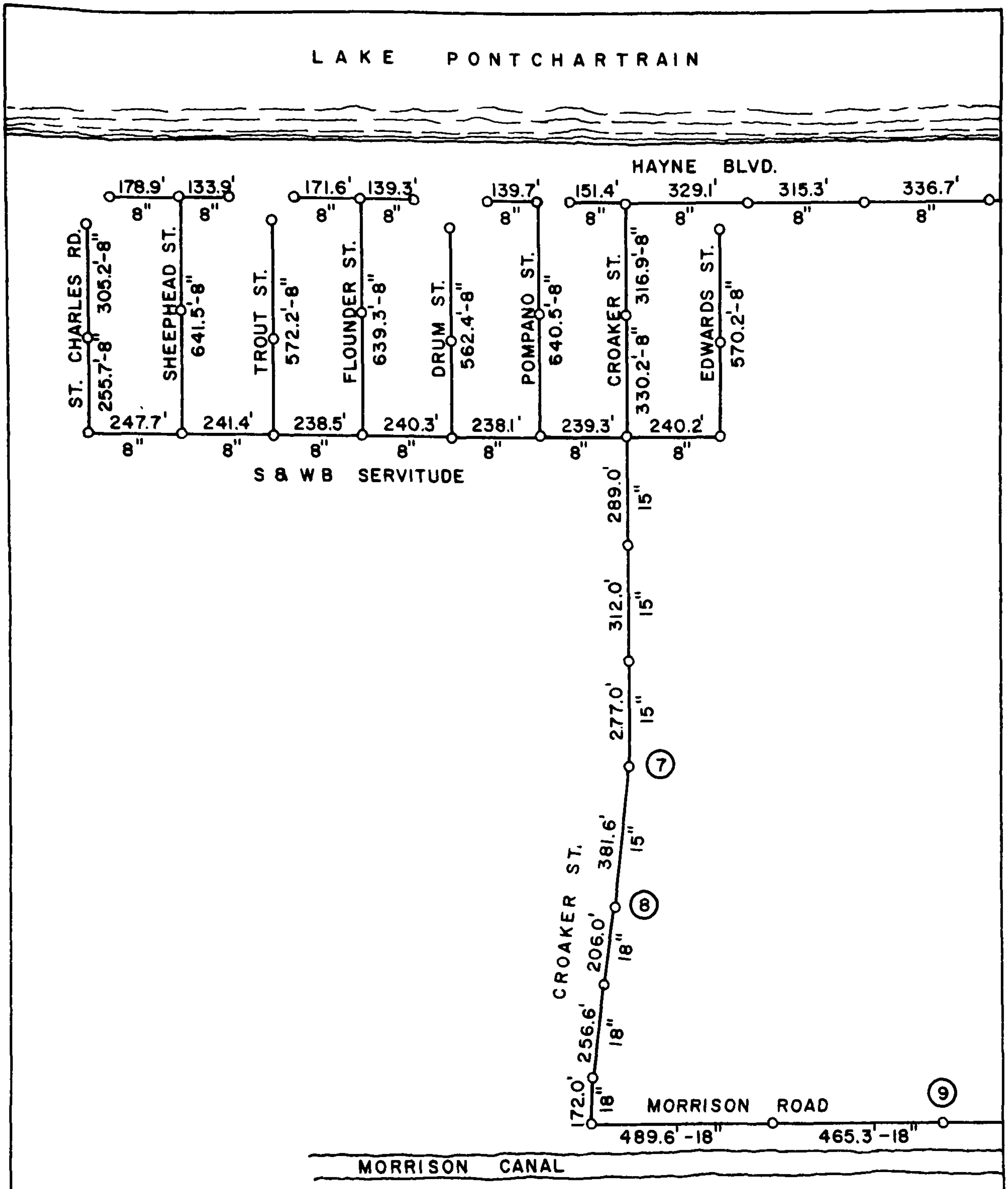
d) Deterioration of the cement mortar linings inside and outside the manhole.

e) Cracks developing in the foundation, side walls and castings.

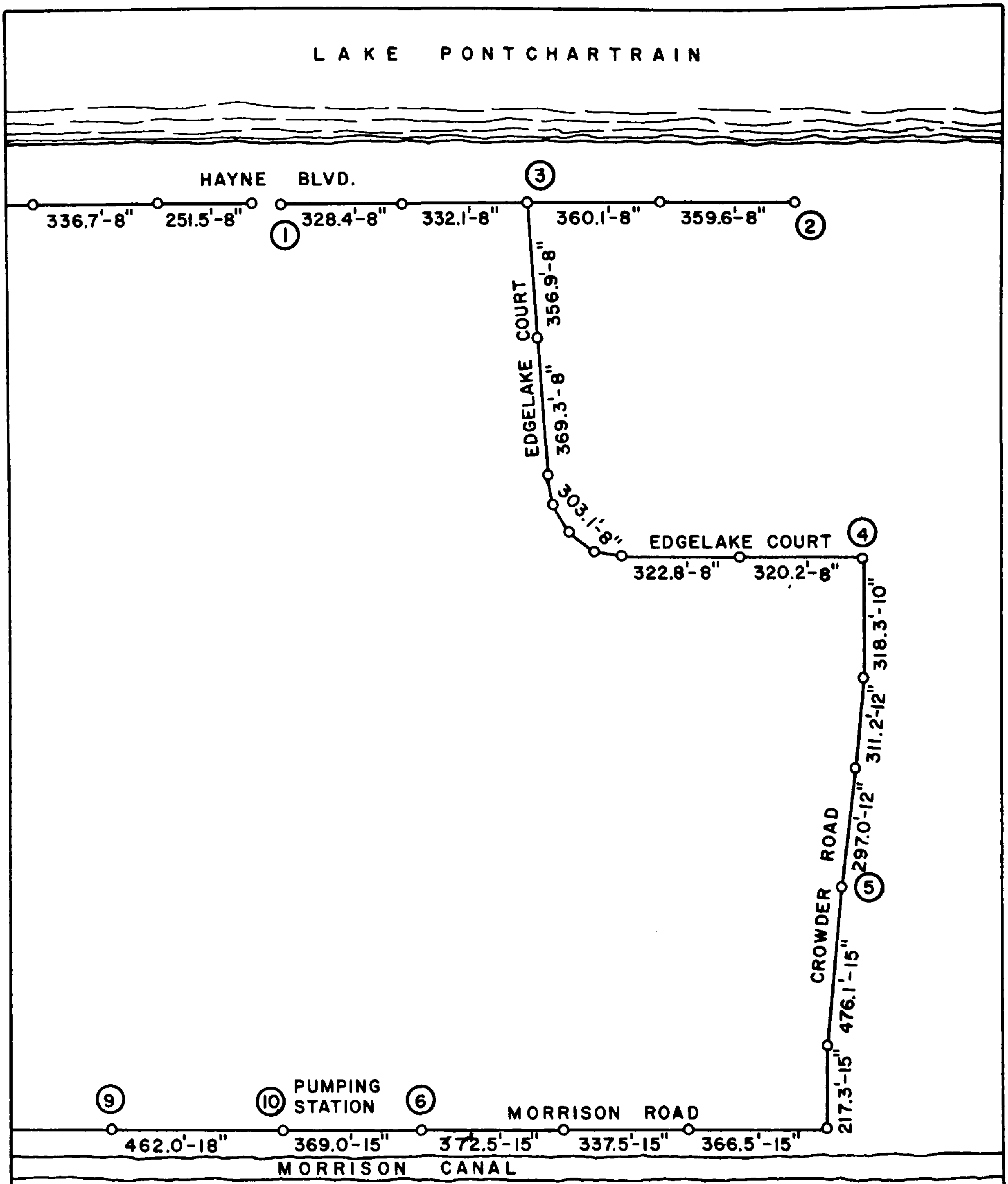
f) Improper seals for the inlets and outlets of sewers at the manholes.

g) Improper construction methods when manholes are raised or lowered.

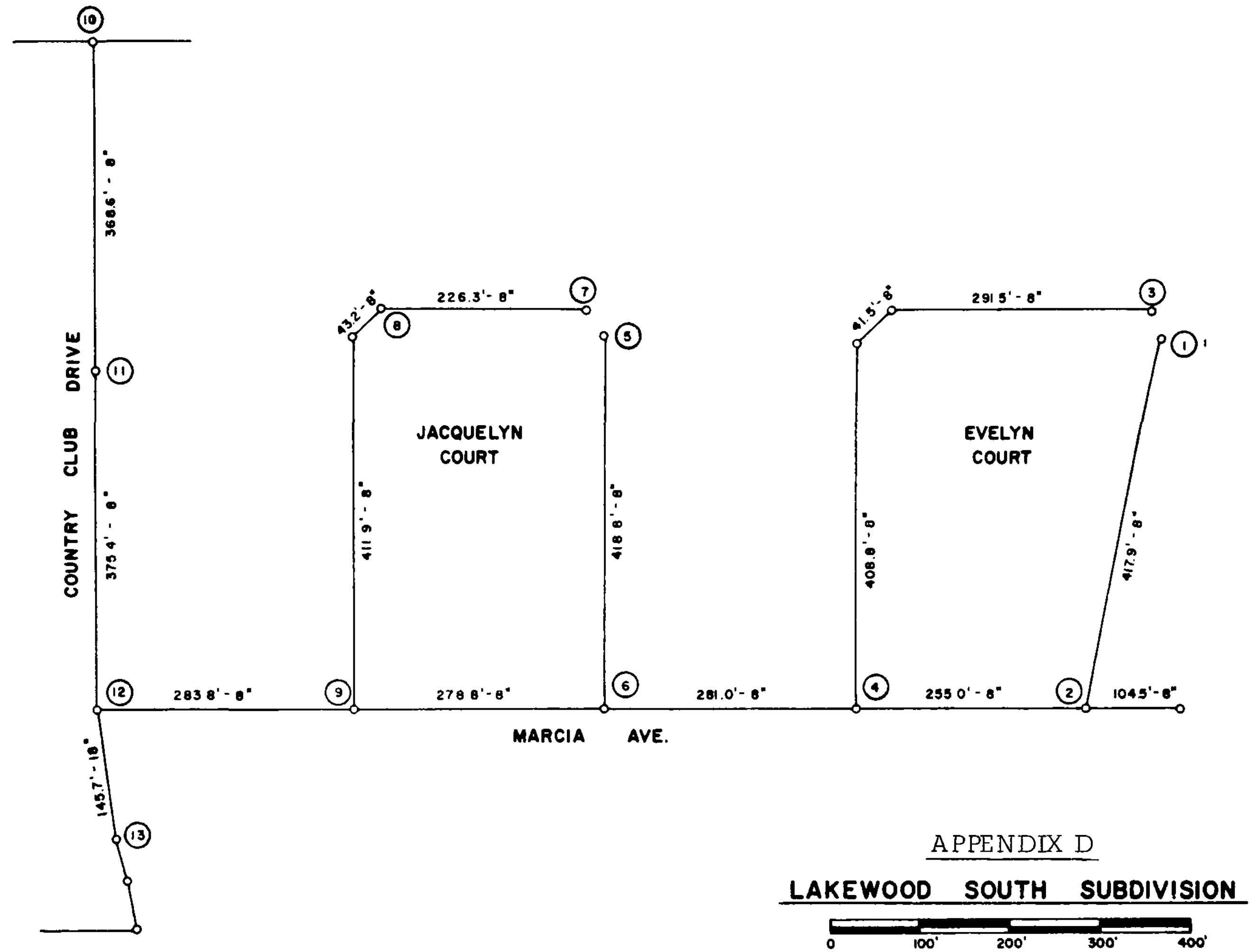
h) Dislodging of castings from top of manhole by heavy equipment used for land clearing, filling or leveling the ground.



APPENDIX C
MAYO ROAD SYSTEM
Sheet 1 of 2

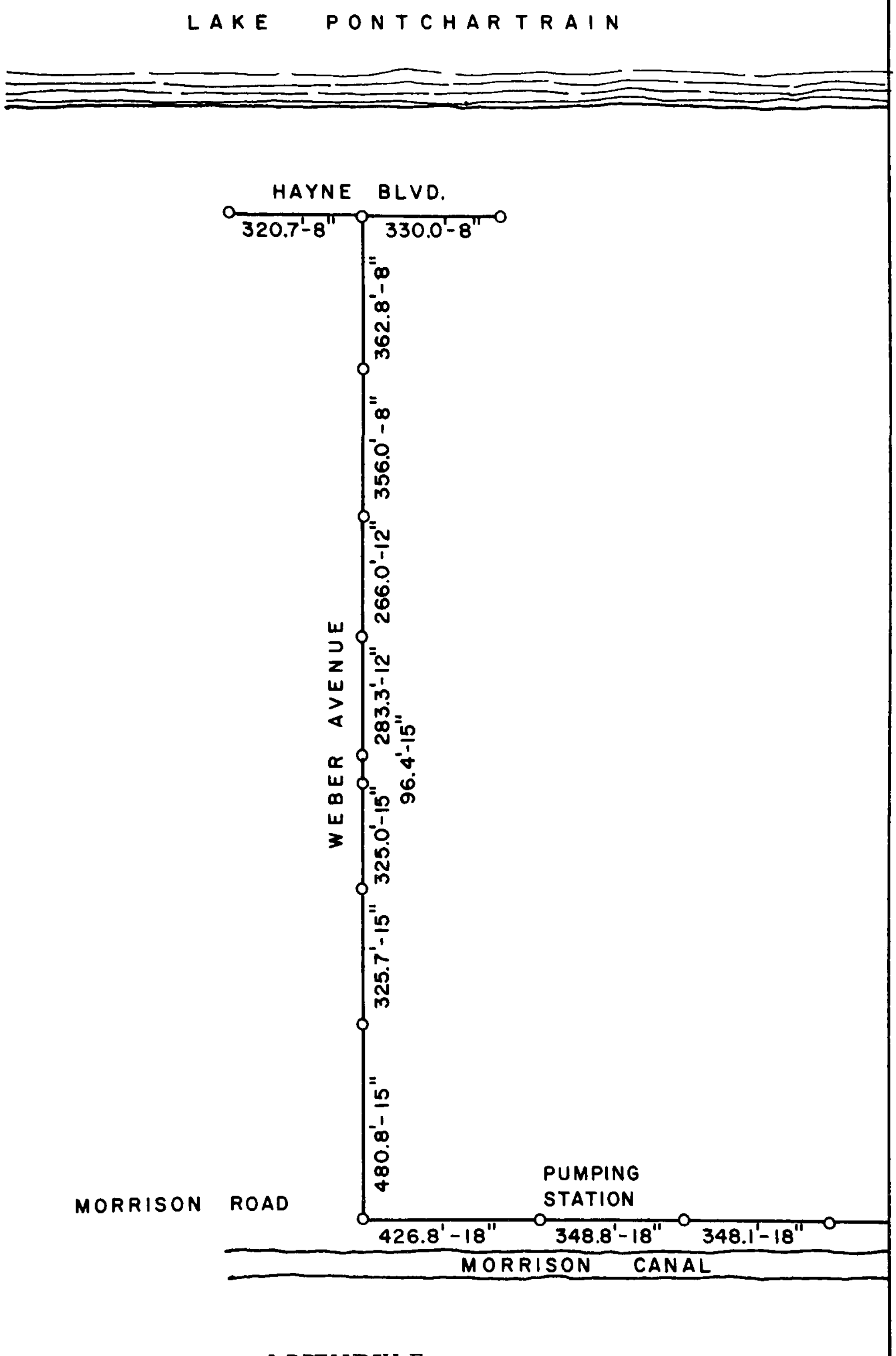


APPENDIX C (CONTD.)
MAYO ROAD SYSTEM
Sheet 2 of 2

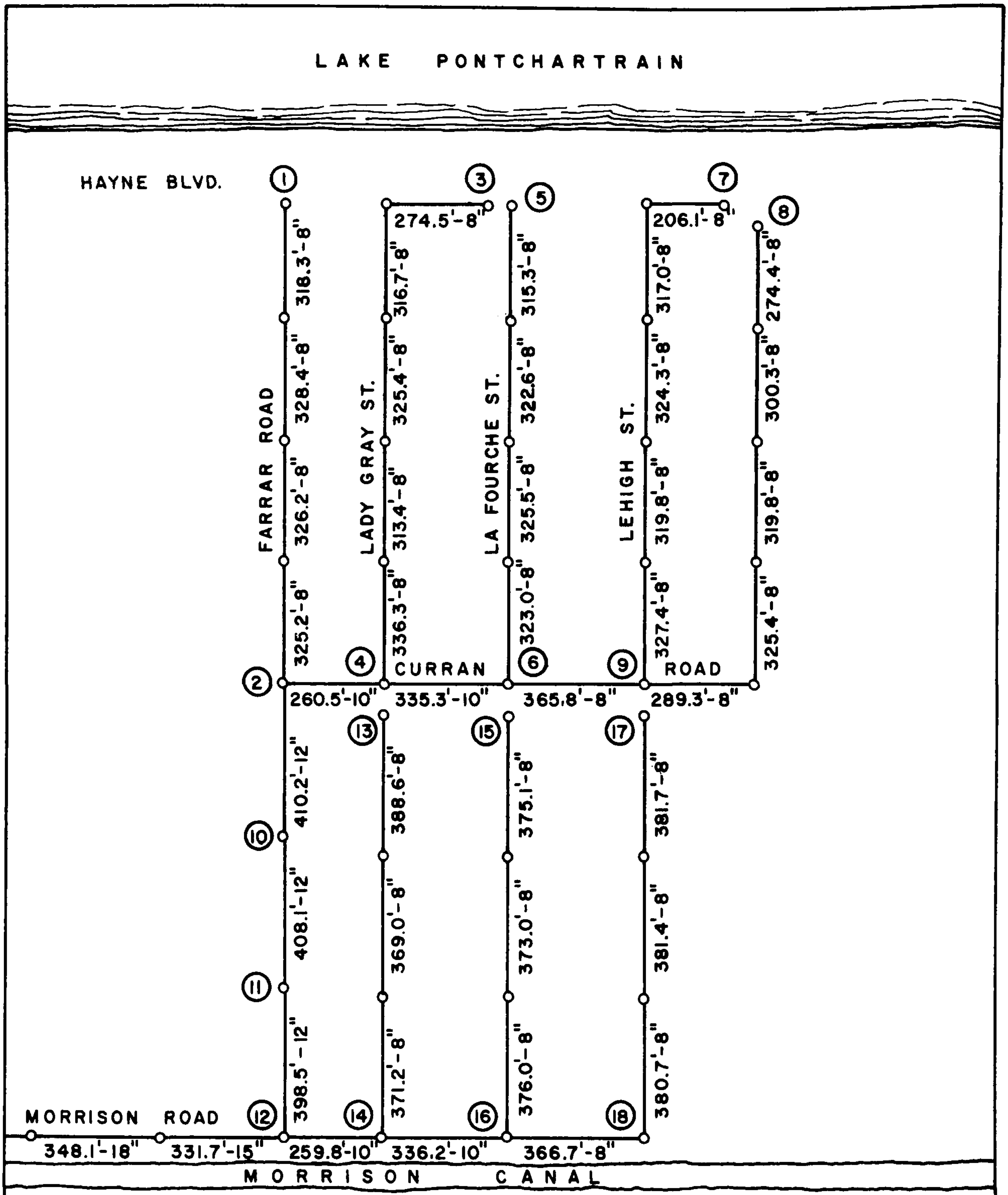


APPENDIX D

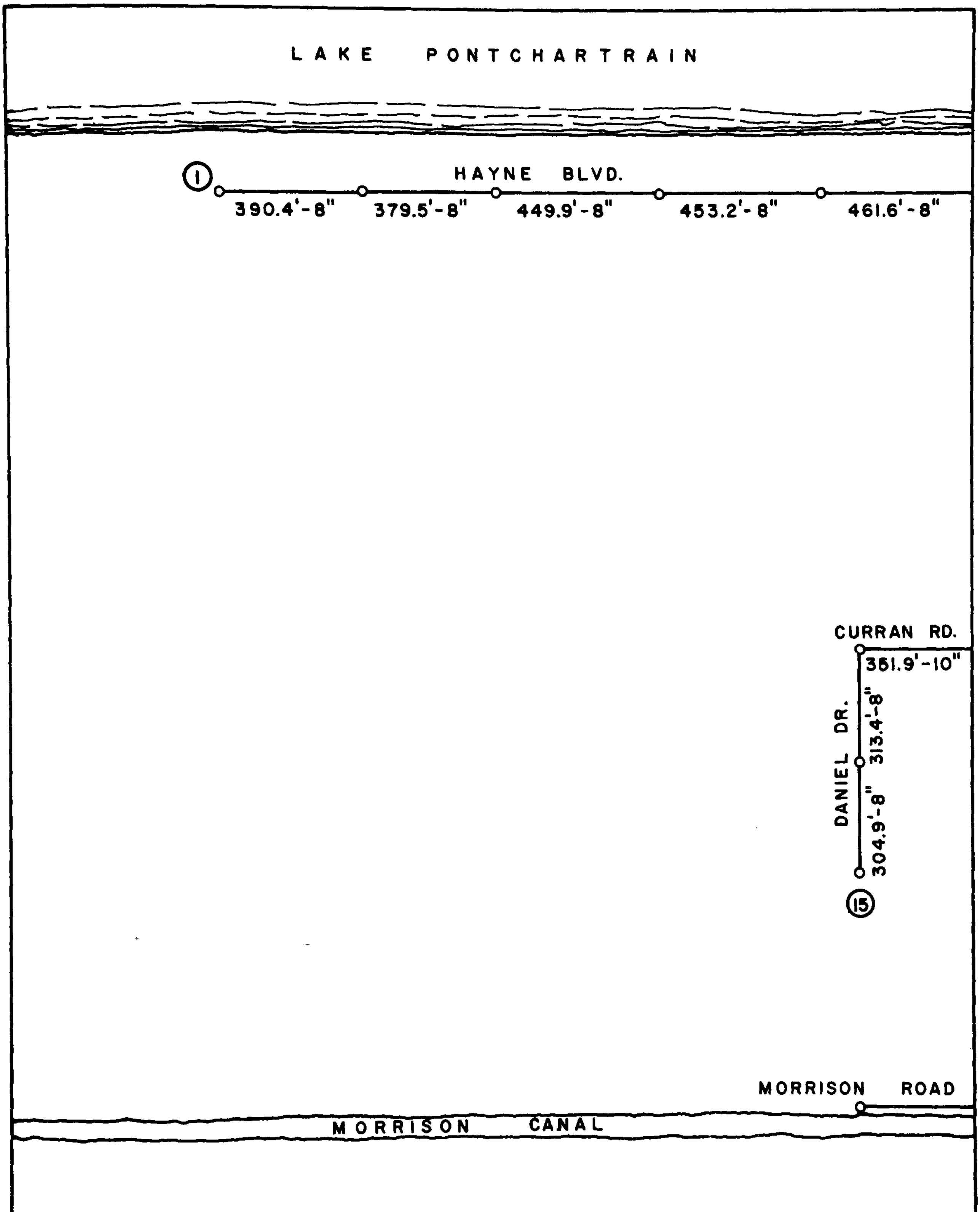
LAKEWOOD SOUTH SUBDIVISION



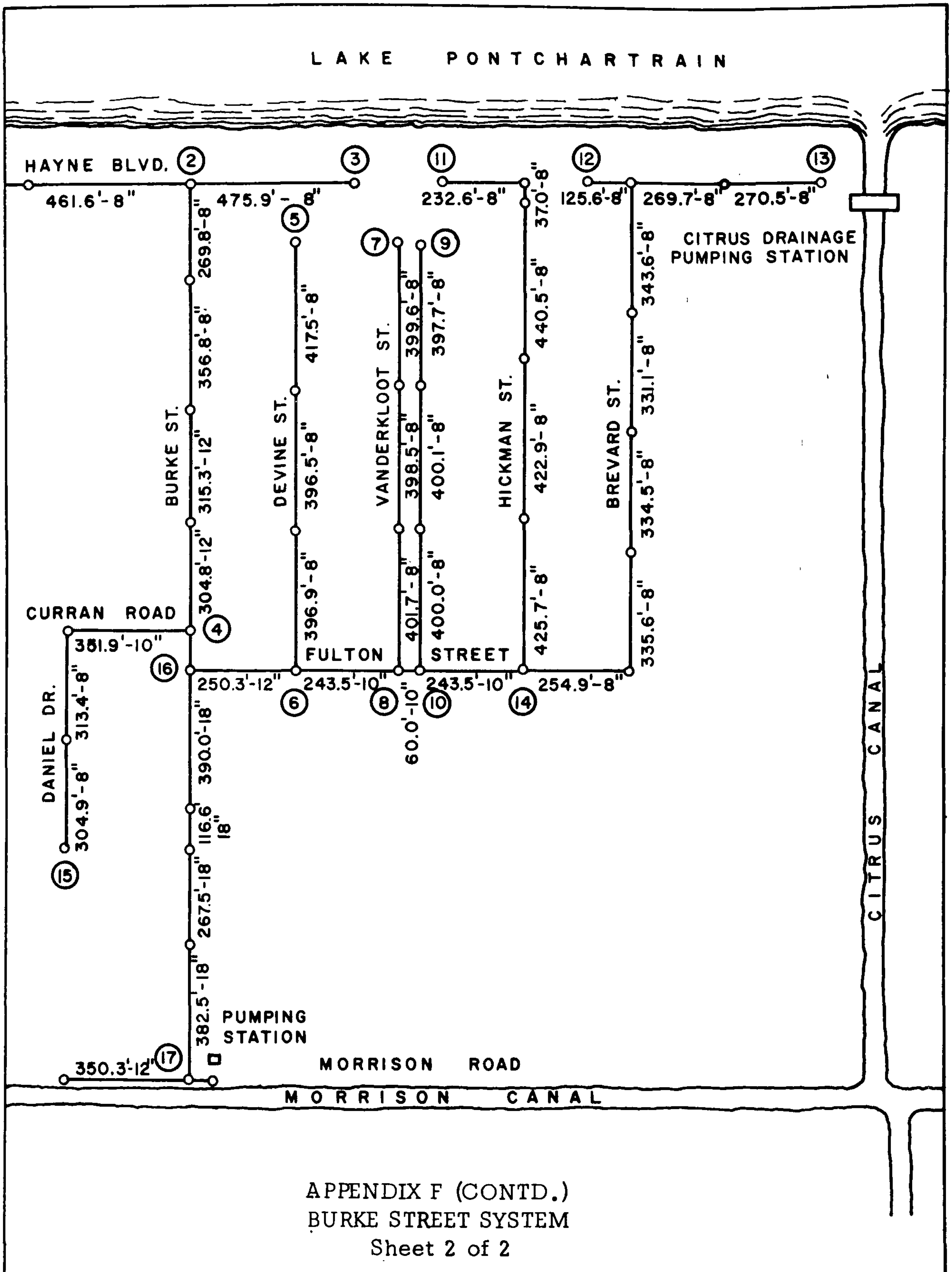
APPENDIX E
WEBER AVENUE SYSTEM
Sheet 1 of 2



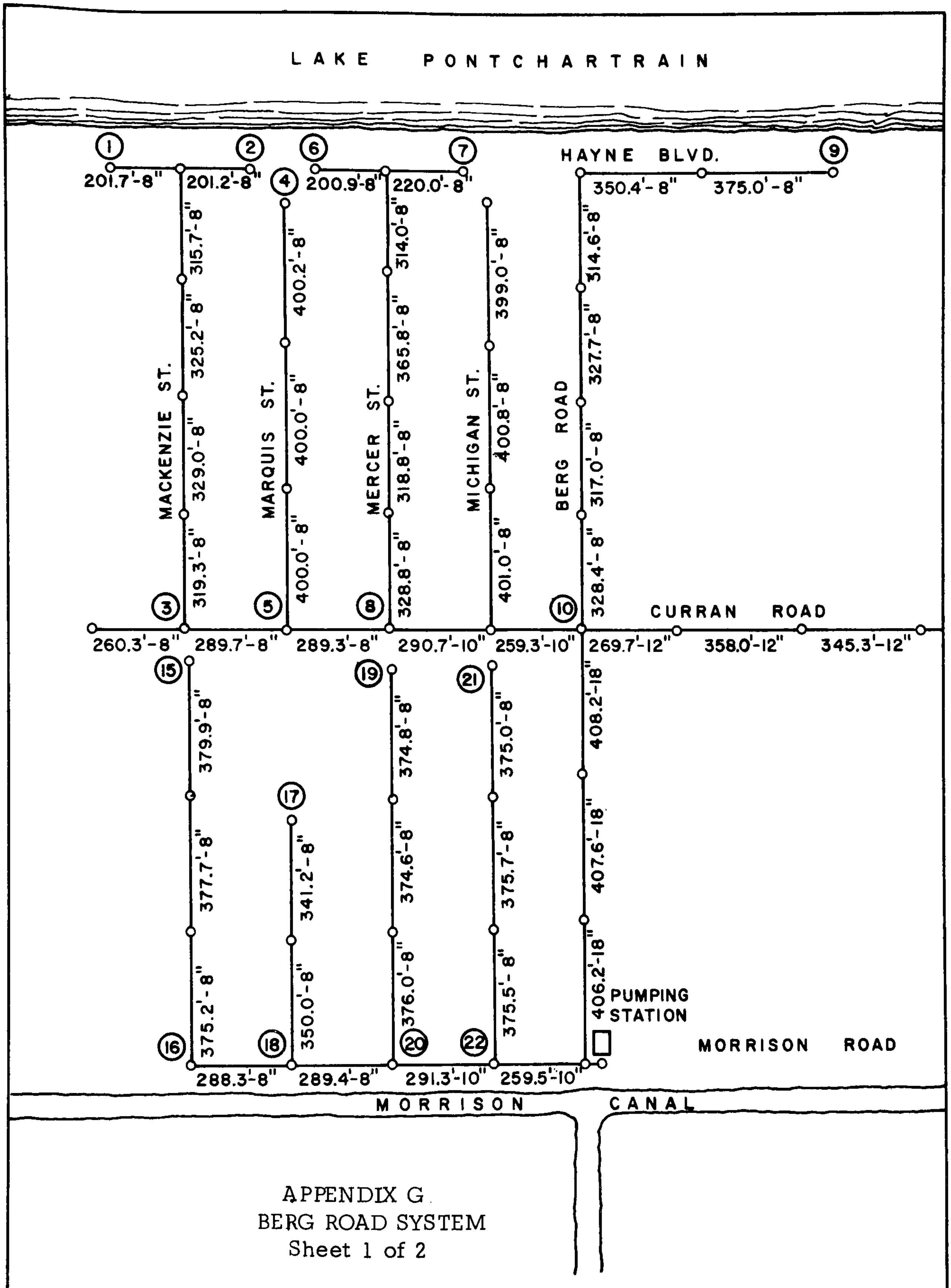
APPENDIX E (CONTD.)
WEBER AVENUE SYSTEM
Sheet 2 of 2



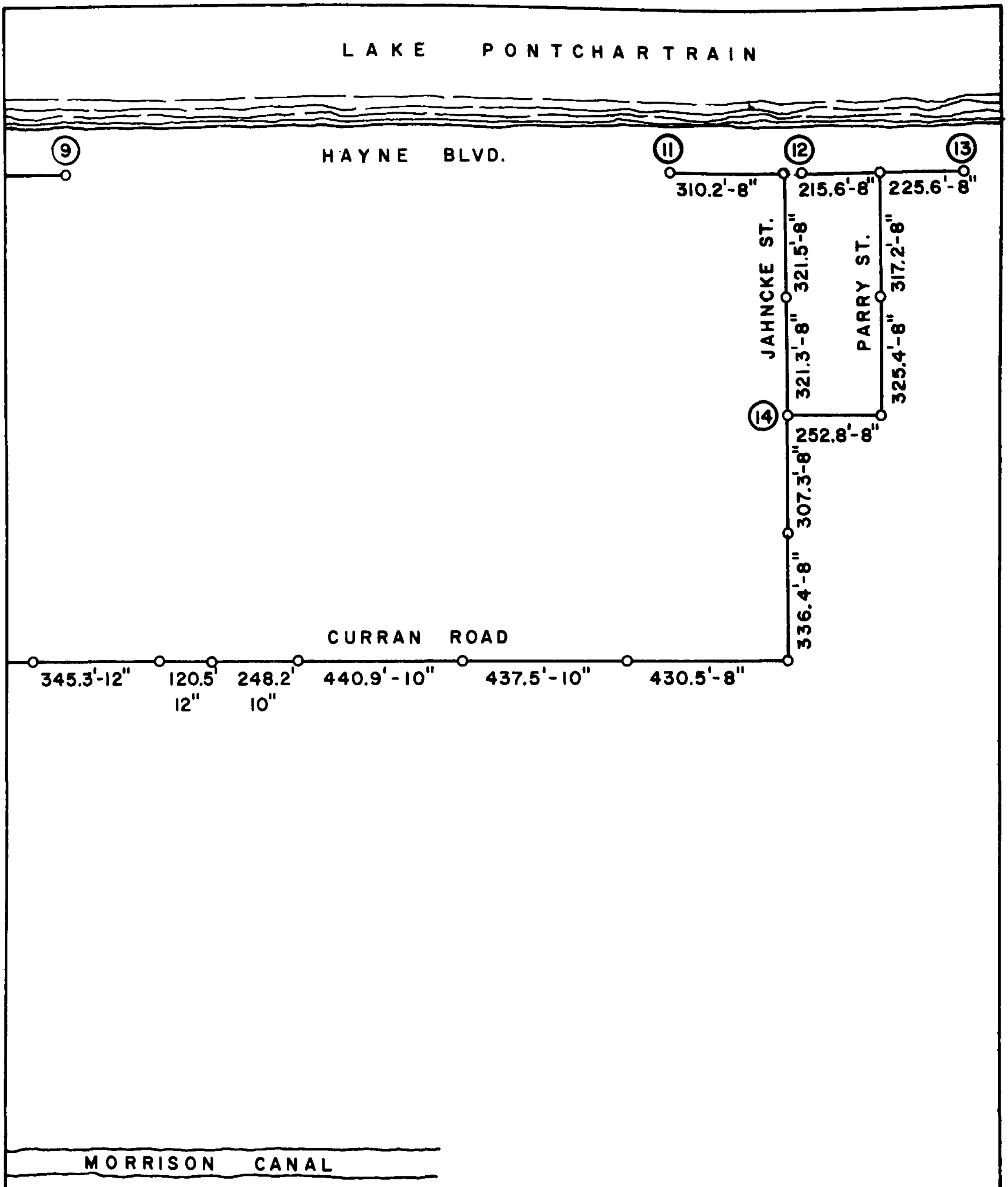
APPENDIX F
BURKE STREET SYSTEM
Sheet 1 of 2



APPENDIX F (CONTD.)
BURKE STREET SYSTEM
Sheet 2 of 2



APPENDIX G
BERG ROAD SYSTEM
Sheet 1 of 2



APPENDIX G (CONTD.)
BERG ROAD SYSTEM
Sheet 2 of 2

APPENDIX H

MAINTENANCE RECORD AND HOUSE CONNECTIONS

System & Line Numbers		Number of House Connections in 1970
Weber		
2-12	5-22-70 Raise manhole covers	5
11-12	Stub in manhole Left open - repaired	0
2-10		2
Lakewood South		
7-9	Tie - ins recorded	13
5-6	8-27-65 5666 Evelyn Ct. Choke freed	7
1-2	Tie-ins recorded	11
Burke		
15-4	12-31-64 10714 Curran Rd. House connection repaired	17
	5-70 Manhole covers raised	
Mayo		
4-5	5-26-70 Raise manhole covers	0
4-10	10-9-67 Mayo Rd. Repair casting	0
	10-9-62 15" Pipe replaced	
7-8	9-19-62 Line flushed	4
	7-21-70 "Y" replaced at 7320 Mayo Rd.	
Berg		
17-18	5-27-70 Mercer St. Raise House connection repaired	7
19-20	12-11-62 Repaired water seeping from line in manhole to pump station conn.	20
	7-19-65 Marquis St. rodded	

APPENDIX I

CLAM SHELL

ANALYSIS

Material	Percent Dry Basis
Aluminum Oxide as Al_2O_3 ($R_2O_3 = Fe_2O_3$)	12.99
Silica, as SiO_2	50.01
Iron Oxide, as Fe_2O_3	5.13
Calcium, as $CaCO_3$	21.17
Calcium, as CaO	0.53
Magnesium Oxide as MgO	1.79
Sulfate as SO_4	2.31
Chlorides, as Cl	0.44
Carbon Dioxide as CO_2	9.91
Loss on Ignition 600°C as organic	6.58
Loss on Ignition 1000°C	14.47

APPENDIX J

WYOMING BENTONITE
TYPICAL PHYSICAL AND CHEMICAL PROPERTIES

X-RAY ANALYSIS

85% Montmorillonite
5% Quartz
5% Feldspars
2% Cristobalite
2% Illite
1% Calcite and Gypsum

SCREEN ANALYSIS - (Ground Material)

99.6% thru 100 mesh
91.4% thru 200 mesh
76.2% thru 325 mesh

CHEMICAL ANALYSIS

SiO_2	55.44%
Al_2O_3	20.14%
Fe_2O_3	3.67%
CaO	.49%
MgO	2.49%
Na_2O	2.76%
K_2O	.60%
Bound Water	5.50%
Moisture at 220°F	8.00%
Total	99.09%

MISCELLANEOUS PROPERTIES

Specific gravity of dried material	2.79
Specific gravity of natural material	2.00
Fusion temperature	2444°F
Weight of dried bulk unpulverized	71 lb per cu ft
Weight of pulverized material	61 lb per cu ft
Weight of crude, crushed, undried material	80 lb per cu ft
Refractive index	1.557
pH of 6% water suspension	8.8
Liquid Limit	500 - 700%

APPENDIX K

BORING NC-1 IOTA STREET

Sample	Depth (ft) From	Depth (ft) To	Specific Gravity	Average Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Friction Angle	Cohesion (psf)	BORING RECORD
	0	7.5							Drilled Through
1	7.5	10		54					Soft Gray Clay with Peat and Layers and Lenses of Coarse Sand.
2	10	12.5							No Sample Obtained.
3	12.5	15		54	35	28			Soft Gray Silty Clay - Sample Kept in Plastic Bag.
4	15	17.5							No Sample Obtained.
5	17.5	20	2.72	38	34	25			Soft Gray Silty Clay - Sample Kept in Plastic Bag.
6	20	22.5		36	33	26			Soft Gray Silty Clay.
7	22.5	25		44					Soft Gray Silty Clay.

APPENDIX L

BORING NC-2 IOTA STREET

Sample	Depth (ft) From	Depth (ft) To	Specific Gravity	Average Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Friction Angle	Cohesion (psf)	BORING RECORD
	0	7.5							Drilled Through.
1	7.5	10							Soft Gray Clay with Silt Layers - Sample Kept in Plastic Bag.
2	10	12.5							No Sample Obtained.
3	12.5	15	2.60	55	46	23			Very Soft Gray Silty Clay with Layers of Fine Sand-Sample Kept in Plastic Bag.
4	15	17.5	2.47	28					Soft Gray Silty Clay - Sample Kept in Plastic Bag.
5	17.5	20		36	36	22	$0^{\circ}46'$	100	Gray Clayey Silt with Traces of Sand.
6	20	22.5		41	38	20	$0^{\circ}59'$	123	Gray Clayey Silt with Traces of Coarse Sand.
7	27.5	25							No Sample

APPENDIX M

BORING ND-1 HESSMER AVENUE

Sample	Depth (ft) From	To	Specific Gravity	Average Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Friction Angle	Cohesion (psf)	BORING RECORD
	0	7.5							Drilled Through
1	7.5	10		90	88	32	$0^{\circ}32'$	36	Soft Gray Clay with Silt Layers.
2	10	12.5							No Sample Obtained.
3	12.5	15		60					Soft Gray Clay with Silt Lenses.
4	15	17.5		80	71	31	$0^{\circ}0'$	145	Soft Gray Clay with Silt Lenses.
5	17.5	20		85	70	34	$0^{\circ}24'$	85	Soft Gray Clay with Silt Lenses.
6	20	22.5							No Sample Obtained.
7	22.5	25	2.60	87	51	25			Very Soft Gray Silty Clay - Sample Kept in Plastic Bag.

APPENDIX N

BORING ND-2 HESSMER AVENUE

Sample	Depth (ft) From	Depth (ft) To	Specific Gravity	Average Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Friction Angle	Cohesion (psf)	BORING RECORD
	0	7.5							Drilled Through
1	7.5	10		85	83	35	$0^{\circ}24'$	40	Soft Gray Clay with Humus and Rootlets.
2	10	12.5	2.53	50					Gray Clayey Silt - Sample Kept in Plastic Bag.
3	12.5	15		39	54	25			Soft Gray Clayey Silt.
4	15	17.5	2.60	61	47	20	$4^{\circ}24'$	61	Soft Gray Clayey Silt.
5	17.5	20							No Sample Obtained.
6	20	22.5							No Sample Obtained.
7	22.5	25		64	56	23			Soft Gray Clay - Sample Kept in Plastic Bag.

APPENDIX O

BORING ND-3 HESSMER AVENUE

Sample	Depth (ft) From	Depth (ft) To	Specific Gravity	Average Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Friction Angle	Cohesion (psf)	BORING RECORD
	0	7.5							Drilled Through
1	7.5	10		211			0°15'	75	Soft Gray Clay with Traces of Humus.
2	10	12.5							Gray Clayey Silt.
3	12.5	15		46	55	25			Gray Clayey Silt.
4	15	17.5		78					Gray Clay with Silt Lenses.
5	17.5	20	2.73	75	77	24			Soft Gray Clay with Silt Lenses - Sample Kept in Plastic Bag.
6	20	22.5							No Sample Obtained.
7	22.5	25		68	64	27	1°43'	46	Gray Clay with Silt Lenses.

APPENDIX P

MANHOLE SURVEY FORM

I. Identification
- A. Location
  1. System Area ____________________
  2. Street and number ____________________

II. Characteristics and Condition

_______ A. Depth

B. Material
- _____1. Brick with interior finish

C. Water
- _____2. No flow
- _____3. Depth

D. Casting
- _____1. Off center
- _____2. Cracked or broken

E. Walls
- _____1. Major cracks
- _____2. Cracks around casting
- _____3. Cracks around steps
- _____4. Cracks around entrances
- _____5. Signs of infiltration

F. Invert
- _____1. Cracked or leakage
- _____2. Needs flushing

G. Bottom (exclusive of invert)
- _____1. Cracked or leakage
- _____2. Excessive debris

_______ H. Entrances and Outlets (number)
- _____1. Line manhole
- _____2. Junction manhole
- _____3. Drop manhole
- _____4. Terminal manhole

I. Steps
- _____1. Iron
- _____2. Aluminum
- _____3. Bad condition

J. Remarks

____

____

____

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1 Accession Number	2 Subject Field & Group	
W		**SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM

5 *Organization*

Tulane University, New Orleans, Louisiana

6 *Title*

Sewer Bedding and Infiltration Gulf Coast Area

10 Author(s)	16 Project Designation
Mayer, John K. Macdonald, Frank W. Steimle, Stephen E.	EPA Contract 80-04-68, Project 11022 DEI 21 Note

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Infiltration, Sewers, Manholes

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Sewer Bedding

27 *Abstract*

Problems of excessive infiltration are found in the Gulf Coast Area. Infiltration can cause problems of water pollution and economic expenditures. Cost of sewage treatment and sewerage systems can be adversely effected in both capital and operating costs by infiltration. The primary cause of infiltration found in this study was poor construction methods used by contractors and by the "tapin" practices of plumbers in making service connections.

Abstractor	Institution