TABLE OF CONTENTS
F 900 REHABILITATION DESIGN

LIST OF FIGURES

LIST OF FIGURES

F 900 INTRODUCTION AND PURPOSE OF REHABILITATION

F 901 INTRODUCTION

A significant part of the Clean Water Program funding is for construction projects that improve the hydraulic capacity and the structural integrity of the existing sewer system. This includes the evaluation and reduction of extraneous flows into the sewer system.

This section provides guidelines and procedures that will assist in the investigation and design of sewer system rehabilitation. Strategies are also developed to optimize project funding. The methods of investigation for planning and design emphasize control of current and future rehabilitation costs.

F 902 PURPOSE

This section provides technical guidance for the planning and design of a rehabilitation program. It includes a description of materials and techniques used, and describes the applicability and advantages of each. Also, it outlines factors in selecting appropriate materials and techniques to solve specific problems.

This section does not attempt to cover all possible design conditions. Such a scope is not possible due to the inherent nature of pipeline rehabilitation. Designing a rehabilitation project can seldom be done "by the book" because unusual conditions are the rule and not the exception.

The City has a sewer system, constructed from a wide variety of materials. This variability in age and type of materials rules out a formula approach to design of rehabilitation projects. Each project should be planned and designed considering the characteristics of the existing materials and the overall system it serves. When conditions do not clearly indicate which materials or techniques to use on a particular project, consult an expert in rehabilitation to evaluate the best options.

F 903 GLOSSARY OF TERMS

Bypass: A temporary arrangement of pipes and valves to route flow around a hydraulic structure or appurtenance.

Bypass Pumping: The conveyance of sewage flows by pumping around a hydraulic structure or appurtenance.

Cracks: Crack lines visible along the pipe barrel length and/or circumference.

Debris: Soil, rock, sand, grease, roots, etc. in a sewer line excluding items mechanically attached to the line, such as protruding service connections, protruding pipe, joint materials, etc.

Exfiltration: Leakage of flow from a sewer into surrounding ground.

Flow Control: A method whereby normal sewer flows or a portion thereof are blocked, retarded, or diverted (bypassed) within certain areas of the sewer collection system.

Flow Reduction: The process of decreasing flows into a sewer system or of removing a portion of the flow already in a sewer system.

Greenbook: This is in reference to the Standard Specification for Public Works Construction - APWA/AGC

Infiltration: The water entering a sewer system through defective pipes, pipe joints, connections, or maintenance hole walls.

Inflow: The water discharged into a sewer system, including service connections, from such sources as roof drains, cellar, yard, and area drains, foundation drains, cooling water discharges, drains from springs and swamp areas, maintenance hole covers, cross connections from storm sewers, combined sewers, catch basins, surface run-off, street washwaters, or drainage.

MSDS: The Manufacturers Safety Data Sheet (MSDS) provides information for safe and proper use of their materials.

Point (Spot) Repair: Repairing damaged pipe at specific or isolated locations.

Primary Sewers: Sewers with the most significant consequences in the event of failure (see F 922.4).

Rehabilitation: All aspects of upgrading the performance of existing sewer systems. Structural rehabilitation includes point (spot) repair and renewal. Hydraulic rehabilitation covers replacement, reinforcement, and flow reduction.

Renewal: Construction of a new sewer, on or off the line of an existing sewer. The basic function and capacity of the new sewer being similar to those of the old.

Replacement: Construction of a new sewer, on or off the line of an existing sewer. The function of the new sewer will incorporate that of the old, but may also include increased capacity.

F 904 REHABILITATION POLICY

Rehabilitation of sewers is to be encouraged rather than replacement whenever possible. However, the following policies shall be adhered to at all times.

a. Rehabilitation shall always consider and allow replacement as an alternative except for those instances where reconstruction is impossible due to existing physical conditions or other constraint.

b. Except where precluded as stated above, all plans for rehabilitation of sewers shall allow both a construction and bid option for replacement with VCP, PVC lined RCP and where appropriate, other approved plastic pipes.

c. When included on the plans or in the specifications, at least two different rehabilitation processes, not including replacement, shall be listed.

d. Pipelines to be rehabilitated shall be structurally sound. Pipes with minor longitudinal cracks and/or voids shall not be considered for rehabilitation. Circumferential cracks, leaking joints and abraded and/or corroded pipe can be rehabilitated. RCP that has been abraded or corroded to the extent that reinforcing steel is exposed can be rehabilitated, provided the steel is still present and can be treated, and concrete, mortar or slurry can be used to replace the missing concrete. Pipes having steel that is extensively corroded or absent are not to be rehabilitated, but localized point repairs may be considered. In all cases the Structural Engineering Division and the Bureau of Sanitation Wastewater Collection Division shall be consulted in arriving at any decisions.

F 905 PROPRIETARY REHABILITATION METHODS

Many of the rehabilitation methods described in this chapter are proprietary. These methods are often patented and are sometimes available from a single franchise contractor or vendor only. In most cases, this precludes the existence of any competition, creating sole source products or technologies. If there is no alternate for a "sole source" item, or even if two or three alternatives are specified, bids are invariably increased by the sole source bidder.

While it is preferable to specify methods that are not sole source in order to allow for competition, allowing sole source methods will be necessary. Therefore, sole source methods may be specified when the particular method is suitable, but only if sufficient alternates are also specified.

F 910 SEWER SYSTEM INVESTIGATION

F 911 INTRODUCTION

This section outlines the methodology for sewer system investigation. The specific methods employed for evaluation are discussed in Section F 920. Key steps in the investigation are outlined on the flow charts shown in Figures F911A and F911B. The cursory and detailed investigation procedures are described for each activity.

F 912 IDENTIFYING AND INVESTIGATING PRIMARY SEWERS

A detailed investigation shall be made on each system identified as a qualifying primary sewer. A primary sewer is one where failure would have impact on performance elsewhere in the system or where failure would have serious economic impact on the City. Primary sewers are prioritized for a detailed investigation because these failures are difficult to deal with and tend to result in significant disruption and inconvenience to the City.

If the primary sewer is not hydraulically overloaded the structural condition of the sewer shall then be investigated. If the structural condition of the sewer requires rehabilitation then hydraulic modeling and a detailed investigation shall be performed. Then a wide range of rehabilitation alternates should be considered.

There are some instances where a detailed investigation is not feasible. In those instances a cursory investigation shall be made. In a cursory investigation, information is obtained from review of available data and whatever is easily accessible, without expending time or resources to develop additional data. Cursory investigations are appropriate for low priority elements of the system. However, this approach is also taken to obtain essential information as a temporary measure until the time and resources are available to do a thorough investigation. A cursory investigation shall not be substituted for a detailed investigation on a qualifying primary sewer.

A cursory investigation shall be performed when any of the following criteria are met:

a. The sewers have adequate capacity meeting performance standards,

b. There is no history of capacity deficiencies in the primary sewers now or with further area development,

c. It is expected that any needed rehabilitation method will not reduce needed capacity in the primary sewers,

d. The sewers are not categorized as primary sewers.

F 913 IDENTIFYING SYSTEMS

Identification of primary sewers shall be done at the start of the planning investigation. They shall be identified on maps of suitable size for investigation. Systems not containing a primary sewer shall be identified as minor and shall be categorized for cursory investigation having a lower priority. Large systems, containing more than one primary sewer, may have to be subdivided to better manage the investigation and model the system. In many instances, it will be obvious how to subdivide the system at the outset. Where the presence of suitable features is less clear, the subdivision must be left until later, when the limits of the hydraulic investigation are determined.

F 914 OUTLINE OF DETAILED INVESTIGATION

The detailed investigation involves four distinct phases. These are shown in Figure F 911A and are described in the subsequent subsections.

F 914.1 PLANNING INVESTIGATIONS (PHASE I)

Phase I is work which shall be accomplished before the detailed investigation of the sewer system commences.

a. Review System Records: Identify the primary sewers from existing system maps and records.

b. Categorize Sewers: Categorize sewers relative to their importance to the system operation. This rating system shall consider what impact on the system or potential liability to the City would result if failure occurred. Detailed criteria for categorizing is given in this section.

c. Identify Primary Sewers: Primary sewers are those where failure, emergency repairs, crisis response or spillage will be most expensive or disruptive, and where hydraulic failure will have serious consequence to the public or existing structures.

d. Document Performance: All records of stoppages, collapses, spills, crisis responses, and damages shall be collected and studied in detail. These are available from the Bureau of Sanitation. The extent and frequency of these problems should be noted. The spills and collapses shall be checked in detail to establish if there is evidence of potentially more problems. This will provide in-formation for initiating an immediate rehabilitation and/or replacement program.

e. Detailed Investigation : A Detailed Investigation is justified whenever the primary sewers are, or are suspected to be, hydraulically overloaded or where corrosion or structural problems are possible, and where rehabilitation is constrained by insufficient capacity. Where these conditions are known not to exist, the Cursory Investigation may be selected.

f. Prioritize Detailed Investigations: The Detailed Investigation requires resources which are normally limited. To best utilize available resources prioritize the system placing the most critical problems first.

g. Update System Records: Existing system maps and records shall be updated where necessary to provide sufficient information for the hydraulic, corrosion and structural investigations. The computerized maintenance management system shall be utilized to access information on the sewer system.

F 914.2 ASSESS SYSTEM CONDITION (PHASE II)

The Sewer System condition requires an assessment of I/I, structural condition and system hydraulics. The initial activity for assessing the system condition is closed circuit television (CCTV) viewing and/or persons inspection and survey work as discussed under hydraulics.

F 914.2.1 ASSESS INFILTRATION/INFLOW CONDITIONS (PHASE II-A)

Phase II-A assessment involves evaluating extraneous flows other than normal flow into the sewer system. These extraneous flows are classified as infiltration from groundwater levels and/or rainfall, and inflow from storm drainage sources, which enter the system through cracks, joints, porous walls, breaks, and voids.

a. Infiltration/Inflow Condition: The CCTV video and/or person inspection will provide information that is beneficial for determining points of extraneous flow (e.g. displaced joints, cracks, voids, and leaking, broken or illegal service connections, etc) and identify mainline and service connection problems.

b. Flow Monitoring: Records of existing measuring devices in the system shall be reviewed and correlated to determine dry and wet weather flows. A flow monitoring program shall be initiated. This will entail locating measuring devices at selected locations.

c. Quantifying Extraneous Flows: An analysis shall be performed to determine normal system flow. The total flows after a rainfall event include groundwater infiltration (GWI), storm water inflow (SWI) and rainfall dependent infiltration (RDI). These sources shall be quantified and subtracted from the measured flow to determine the base sanitary sewage system flow.

F 914.2.2 ASSESS STRUCTURAL CONDITION (PHASE II-B)

Phase II-B assessment involves inspection of the primary sewers and identification of needs for rehabilitation, replacement and/or future condition monitoring requirements.

a. Structural Condition: The CCTV video and/or person inspection will provide information for locating structural problems, e.g. cracks, breaks, displaced joints, missing pipe pieces, clay liners, roots, sags, corrosion, etc.

b. Evaluate Corrosion Condition: The corrosion or deterioration of a cementatious or corrodable material will continue until there is a failure. Thus, corrosion shall be identified and an assessment made of its progression, so remedial action can be taken before failure occurs.

c. Quantify Problem Areas: A rating system shall be established for identifying the structural or corrosion failure state, magnitude, condition and progress. (See Section F 920.)

F 914.2.3 ASSESS HYDRAULICS (PHASE II-C)

Phase II-C assessment involves the investigation of the hydraulic performance of the sewer system in general and the primary sewers in detail, to establish their actual performance and any needs for improvement.

a. Hydraulics: The actual flow rates the system is experiencing shall be determined.

b. Develop a Hydraulic Model: A hydraulic model of the system should be developed upon which the system performance and needed improvements can be based. (Detailed information on selecting and verifying a hydraulic model is readily available (EPA Models, etc.) and is not covered in this Section. Selection, calibration, and verification of an appropriate model should be done by an engineer experienced in this specialty.)

c. Confirm Field Conditions: The mapping and "as-built" construction drawings are necessary input, however, invert elevations and pipe diameters shall generally be verified in the field.

d. Assess Hydraulic Performance: The model is run with a range of flow conditions to access its hydraulic capacity.

e. Locate Areas of Performance Deficiencies: Sewer reaches which fail to meet the minimum required hydraulic performance criteria shall be identified, and the deficiencies noted.

f. Assemble Data: Information obtained in the Infiltration/Inflow, Structural and Hydraulics assessments shall be assembled and evaluated.

g. Identify Systems Needing Rehabilitation/Replacement: This work may entail point repair, rehabilitation, relief or parallel sewers and/or replacement.

F 914.3 DEVELOP THE SYSTEM USAGE PLAN (PHASE III)

Phase III involves producing a plan to accomplish over-all system improvements in the most cost effective way. (See F 970)

a. Set Priorities for each Problem: This plan allows projects to be completed in successive stages to facilitate planning within funding constraints. Priorities shall be established for each specific problem based on available funding.

b. Consider Rehabilitation Options and/or Replacement: Consideration of all possible solutions to the problems shall be identified, taking into account scheduling and coordinating the work.

c. Develop Consistent Solutions to Problems: To expedite the design and construction work, a format for developing consistent solutions to the problems shall be utilized.

d. Identify Cost Effective Solutions: The objective is to identify the most cost effective combination of solutions on which the system usage plan can be based.

e. Establish System Usage Plan: When proposed projects are identified, an implementation schedule shall then be prepared. The plan shall include project activities, such as relief lines, interties and bypassing that affect the primary sewer components.

F 914.4 IMPLEMENT THE SYSTEM USAGE PLAN (PHASE IV)

Phase IV consists of implementing the system usage plan and monitoring the system to ensure the plan is appropriate or is modified as necessary.

a. Design and Construct Rehabilitation/Replacement Projects: This involves taking the individual prioritized projects in the system usage plan, together with the established design criteria, and developing these through detailed design and construction. The timing of this shall be coordinated with other project work in the system, updated as necessary by subsequent findings and scheduled to be accomplished within available funds.

b. Monitor Conditions of Primary Sewers: The Infiltration/Inflow reduction and the structural condition of the primary sewers shall be monitored regularly to determine that the assessed needs and priorities are being attained and continue to be adequate.

c. Adjust Hydraulic Model as Needed: The hydraulic model shall be kept updated so it continues to represent the ongoing improvements in the system. This is necessary so that the model can be used reliably in design work and to assess unforeseen changes.

d. Review Usage Plan as Needed: Updating the sewer mapping and records is an ongoing requirement. Events or circumstances may change which will impact the planned future projects. Such changes shall be noted on maps and records, and appropriate modifications made to the usage plan.

F 915 OUTLINE OF CURSORY INVESTIGATION

The Cursory Investigation involves the same four phases and has similar steps as the Detailed Investigation, however, at a reduced level. These steps, shown in Figure F 911B, have generally been described in the detailed investigation.

F 920 EVALUATION METHODS AND PROCEDURES

F 921 INTRODUCTION

A complete evaluation is required to assess the system condition to develop correct conclusions and recommendations for sewer system rehabilitation. The framework for carrying out the system investigation has been discussed in Section 910. The specific items and their methods will be discussed in this Section as outlined below.

EVALUATION METHODS

A. Preliminary Analysis:
   1. Analysis approach
   2. Location maps and plans
   3. Establish networks
   4. Categorize sewers
   5. Review and Evaluate Records
   6. Evaluate monitoring or gaging stations.

B. Inspection Program:
   1. Closed circuit television (CCTV)
   2. Manholes and lamping
   3. Ground surface condition
   4. Pumping stations and other structures
   5. Smoke testing
   6. Dye-water testing
   7. Infrared thermography
   8. Radar and sonics
   9. Groundwater monitoring

C. Flow monitoring:
   1. Introduction
   2. Measuring methods
   3. Types of flow

D. Data Evaluation Summary:
   1. Conclusions
   2. Recommendations.

F 922 PRELIMINARY ANALYSIS

The steps of evaluating the sewer system for determining its condition are discussed in this Section. Concurrent with evaluating the system, known system problems are evaluated for prioritization.

F 922.1 ANALYSIS APPROACH

The analysis approach is to review all available data on the sewer system such as: previous reports and studies, plant and collection system records, sewer system history, sewer system maps, records on areas prone to surcharging, plant and station flow metering, soils, groundwater, and climatological information.

The evaluation of sewer conditions identifies structural problems, assesses their severity and the consequences of structural failure. It also identifies opportunities for rehabilitation or replacement based on structural conditions, consequence of failure, and opportunities for capacity improvement.

F 922.2 LOCATION MAPS AND PLANS

To analyze the sewer system, it is necessary to obtain the locations, sizes, age and identification of the pipelines and appurtenances. The mapping system requires ongoing updating with as-built information. The maps shall show interties and relief pipelines along with pumping stations and treatment plants with overflows and outfall pipelines. The system maps will be utilized for conducting virtually all of the desk top preliminary analysis.

F 922.3 ESTABLISH NETWORKS

The pipeline system shall be divided into networks, based upon the hydrographic or grade basin for identification and categorizing purposes. The grade basin shall be further divided into areas and subareas. The various boundary divisions and subdivisions are developed in order to more easily evaluate each piping system.

F 922.4 CATEGORIZE SEWERS

After the sewer system networks have been established, each sewer pipeline is categorized. The sewer categories are primary and minor as discussed in Section 910.

The primary sewers are:

a. Trunks
b. Interceptors
c. Reliefs
d. Outfalls
e. Force mains (18 inches and larger).

All other sewers are important, but shall be identified as minor. Sewers at the upper reaches of the grade basin may be ignored unless there are known problems that exist.

F 922.5 REVIEW AND EVALUATE RECORDS

Typical records required for this work are maintenance and operation files (e.g., data on repair, stoppages, collapse, diaries, service connections, street flooding, flood damages, law suit records and other related data). This information, available from the Bureau of Sanitation, is useful in the field investigation prioritization work.

F 922.6 MONITORING AND GAGING STATIONS

Flow monitoring and gaging stations shall be selected at strategic locations within the established networks. These temporary flow measurement locations will supplement the existing permanent gaging stations. This flow information shall be used for identifying sewer system component data and in confirming any hydraulic modeling work.

F 923 INSPECTION PROGRAM

Sites of in-pipe inspection for locating points of inflow, infiltration, corrosion and structural problems are normally indicated by the findings during the preliminary analysis and subsequent investigation. Many of the field investigation methods do not provide complete information for making a decision on sewer system rehabilitation/replacement. There are many methods and procedures, and it is necessary to consider their limitations in selecting among them. The combination of two or more methods usually provides sufficient information for making a cost effective evaluation.

F 923.1 CLOSED CIRCUIT TELEVISION (CCTV)

Some CCTV or person inspection is normally required for thorough internal pipe and appurtenant inspection. The pipe size or internal dimensions that permit in-pipe observation are as follows:

a. For 39 inch and larger--person inspection and CCTV

b. For 24 inch to 39 inch--person inspection (crawler) CCTV

c. For 24 inch and smaller--CCTV and lamping.

Preparatory to person inspection, cleaning and proper ventilation is necessary as well as the consent and presence of Bureau of Sanitation personnel following normal safety procedures. The degree of cleaning needed depends on the extent of physical movement required. Proper ventilation, including gas monitoring, is a safety precaution. Three people minimum are required for person inspection information gathering method.

It is usually more cost effective to clean and pull a CCTV camera through the pipeline. There are times, however, when person inspection supplements CCTV for identifying suspected problems in more detail. Bureau of Sanitation Personnel experienced in internal pipe inspection provide direct, on the spot, interpretation of the problems. Logging and photo work can be accomplished with much more reliability by experienced personnel.

CCTV used with continuous recording video monitoring is an excellent tool for detailed study. When the video is in high resolution color, another dimension is made available for study purposes. It is much easier to judge magnitude and degree of corrosion and location of voids behind the pipe wall with colored film. However, black and white does provide better clarity, but requires greater expertise for accurate problem interpretation.

F 923.2 MAINTENANCE HOLES AND LAMPING

Observations with lamping at maintenance holes and structures provide information beneficial for making decisions on inflow, infiltration, corrosion and structural problems in the pipeline and the structures. Normally corrosion starts at the concrete structures due to the turbulence of flow which can cause erosion and/or sulfide break out, the initiator of the cycle for corrosion. Also, infiltration/inflow, cross connections, and illegal connections can be observed at the maintenance holes.

F 923.3 GROUND SURFACE CONDITION

Driving and/or walking the pipeline route provides the above ground information for determining certain geological or surface conditions. Features above ground which may affect the sewer system include swales, surface drainage, types and volume of traffic, industries contributing flow, etc.

F 923.4 PUMPING STATIONS AND OTHER STRUCTURES

It is necessary to check all reinforced concrete structures, such as pumping and lift stations, large junctions, major drops, pressure force main outlets and/or receiving maintenance holes.

F 923.5 SMOKE TESTING

The purpose of smoke testing is to locate RDI/I sources. Sources readily detected include roof, yard and area drain connections, catch basins and broken service lines. A non-toxic, non-staining "smoke" (usually a zinc chloride mist) is forced through a maintenance hole reach of sewer pipe using an air blower up to distances of 600 foot intervals. The smoke surfaces through open pipe connections and defects.

Smoke testing is ineffective when the pipeline is flowing full, groundwater is over the top of pipe, or when the pipeline has sags or water traps. Also, windy days may disperse the smoke and make detection difficult. (Note: The fire department should always be advised in advance of scheduled smoke testing.)

F 923.6 DYE-WATER TESTING

Dye-water testing or flooding is done alone or in conjunction with CCTV. This testing can determine possible sources of SWI, such as area drains or catch basins suspected of being connected to the sewer pipelines, or sources of RDI indirectly contributing through the soil and pipe cracks. The nearest downstream maintenance hole is observed for dye appearance which confirm the suspected SWI or RDI connection.

The dye (Rhodamine B) is used in tablet form to minimize exposure to field personnel. Dye testing is normally used to complement smoke testing of suspect areas. Normally CCTV is used, after the dye penetrates the pipeline, to precisely locate the problem area.

F 923.7 INFRARED THERMOGRAPHY

Infrared thermography is a technique for locating voids around sewer pipelines. An infrared scanner can be mounted on a building, on overhead equipment and in aircraft and focused on a pipeline alinement measuring temperature differences in the pavement above the sewer. The use of thermography permits surveying large areas in a short time and locating problems in a non-destructive manner. It does however require verifying suspect problem areas by "truth" borings. This is obviously accomplished at a lower cost than random borings to find void areas. Infrared thermography can provide information for estimating the size and severity of the void, but not the depth below the ground. It also is more effective on shallow than deep sewers.

F 923.8 RADAR AND SONICS

Ground penetrating radar has similar advantages (e.g., speed, non-disruptive, and non-destructive), as infrared thermography. Large areas can be surveyed in a relative short time to locate general problems. Other underground utilities and certain dense thick soils can provide some measurement interference. This does provide the depth of the void; however, it does not provide its size or severity.

Ground penetrating radar is often used in combination with infrared thermography to provide complete information regarding the subsurface conditions.

The concept of sonic caliper measurements is a relatively new technology developed in 1983. The sonar device is passed through a pipeline, measuring the degree of corrosion at the crown and the amount of debris in the bottom.

Depending upon the flow in the pipeline, it is possible to obtain desired data in one or two hours for a two mile long pipeline. The sonic-caliper inspection can supplement the normal CCTV inspection. The CCTV will permit locating cracks, leaking joints, seepage and roots, but not the desired depth of corrosion or bottom silt and sludge buildups.

F 923.9 GROUNDWATER MONITORING

Groundwater depths and normal fluctuations shall be identified along pipeline alignments. This information is necessary for determining groundwater infiltration and its impact on field investigations and any subsequent rehabilitation/replacement project activity. When it is known that groundwater exists or can exist in a pipeline area, it is suggested that observation wells be constructed and monitored.

F 930 FLOW MONITORING

F 930.1 INTRODUCTION

The objective of a flow monitoring program is to quantify the magnitudes of flow occurring in the pipeline. It is also desirable to obtain flow measurements during and after a rainfall event. By determining and interpreting these flows correctly, dry weather and wet weather flow can be quantified. Also, with representative locations of monitoring points, problem piping systems can be identified for I/I purposes.

Proper locations for flow monitoring stations are normally upstream of major junction chambers. Locating monitoring equipment in areas that are known to surcharge would be ineffective. Other means are utilized to determine the reason for the surcharging condition (i.e., computer modeling). When pipeline problem locations are identified, the smoke and dye testing and CCTV inspections can be reduced.

F 930.2 FLOW MEASURING DEVICES

The following are devices used to measure flow and an assessment of their suitability:

a. Weirs have proven to be unacceptable because of clogging behind the weirs and obstructions of the weir crest.

b. Flumes normally provide accurate information. However, an expensive upstream stilling well is usually necessary. Under some conditions this can be justified.

c. Micro-processor based systems automatically record flow level and/or velocity and store data in solid state memory. This data is retrievable by use of a portable computer during the data collection period. The equipment is calibrated to provide a print out of flow measurement.

d. Electronic depth measuring equipment is normally better than mechanical equipment. The point of measurement should be upstream of the maintenance hole turbulent flow.

Formulae to calculate flow:

$$Q = VA$$

$$V = \frac{1.486\ S^{1/2}\ R^{2/3}}{n}$$

Q = flow (cfs)
A = Area (sq. ft.)
V = Velocity (fps)
S = slope of pipeline (usually in feet per foot
R = hydraulic radius (ft) i.e. Area/Wetted Perimeter
n = friction factor, usually 0.013

F 930.3 DETERMINING I/I FLOWS

It is necessary to determine the pipeline's base flow. Depths shall be determined during the low flow level time of the day, usually at night. The low-flow times, less the known service flows, (i.e., industry or 24 hour operations) provides the infiltration discharges. This flow can be considered groundwater and/or water supply pipeline leakage infiltration. If it is determined that groundwater does not exist in the contributing area, then the source shall be located. If it is considered to be groundwater, then observation wells at or near the pipeline shall be monitored in order to determine seasonal fluctuations.

It is possible to correlate groundwater levels with normal base flow infiltration. During rainfall events the inflow effects are normally the cause for rapidly rising sewer levels that are initially observed. Inflow can also be excessive from low lying ground surface areas subjected to surface runoff that find their way into the pipeline system or cross connections from the drain piping network.

F 931 DATA EVALUATION SUMMARY

The data evaluation leads to conclusions that enable development of a systematized summary of the pipeline survey. It is necessary to identify major problems with their respective solutions and to prioritize reaches critical to these solutions in order to develop an effective plan for rehabilitation.

F 931.1 CONCLUSIONS

Elimination of the majority of extraneous flows or leaks may be attainable, however the following factors should be considered before adoption of such a plan:

a. Determine what a clean or unpolluted flow leak really is, e.g., subsurface drainage may be a contaminated leachate or contain toxic material washed from basement floors, or wash outs from internal leaks.

b. Determine whether more corrosive sewage and odor conditions may develop because of lowered flow when major clean extraneous sources are eliminated.

c. Determine affects of lowered or more concentrated flow on the existing bare concrete piping system.

d. Assess affect on the public of any sudden decision to eliminate extraneous sources and the associated problems of enforcement

e. Evaluate affects of the flow sources into the drainage collection system and the ultimate disposal thereof.

Cost estimates for the individual phases of the evaluation survey depend upon the actual conditions in the pipeline system. The evaluation cost items are:

a. Physical survey
b. Rainfall simulation
c. Preparatory cleaning
d. Internal inspection
e. Survey report.

The primary goal is the development of a cost-effective solution (Section F 970), but the most important factor of consideration remains the overall impact on water quality.

The elimination of an extraneous flow source appears to be the obvious engineering choice, but its removal may degrade the overall water quality in the sewer. Other means of handling the extraneous flows may have subsequent impact on the environment and public, and this should not be overlooked.

F 931.2 RECOMMENDATIONS

Any rehabilitation program should include guidelines for evaluating repair methods, such as:

a. The necessary pipe sizes to maintain needed capacity.

b. Acceptable rehabilitation methods to solve the structural problems encountered in each reach or service area.

c. Identification of sewer reaches which cannot be rehabilitated and should be replaced.

d. Estimated costs for rehabilitation as well as replacement.

e. An outline of technical specifications for each of the rehabilitation techniques.

f. A schedule for rehabilitation or replacement that ensures taking care of the most serious problems first.

F 940 REHABILITATION METHODS AND MATERIALS

F 941 INTRODUCTION

The selection of rehabilitation methods and materials depends on an understanding of the specific problems to be corrected. It is also important to evaluate external as well as internal factors before a decision can be made on the methods and materials that will most effectively solve the problem.

The effects of the pipe zone soil structure and groundwater conditions are essential considerations in the analysis of pipeline rehabilitation. Groundwater can rise and fall, creating a soil pumping action adjacent to the leaking or failing pipe. The movement of groundwater can affect the soil around the pipeline. The soil type and grain size can impact the rate of this soil pumping action and its effects on the pipeline. Soil structure and groundwater conditions also greatly influence the feasibility of certain methods or materials.

Other factors which significantly influence the choice of methods and materials are:

a. Accessibility
b. Magnitude of flows
c. Available bypassing or rerouting flows
d. Mechanism of failure or problem
e. Type and magnitude of problem
f. Rights-of-way
g. Lateral connections
h. Length and size of pipe(line)
i. Need for up-sizing

The best rehabilitation procedure chosen for a pipeline repair is the one that takes into account all of these conditions, and meets the parameters for solving the entire problem.

F 942 METHODS AND MATERIALS

The various internal and external rehabilitation methods and materials are outlined as follows:

REHABILITATION METHODS

A. Pipeline Preparation

1. Cleaning
2. Closed Circuit Television (CCTV)
3. Root Control
4. Groundwater Monitoring

B. External

1. Chemical Grouting

    a. Acrylamide Base Gel

2. Cement Grouting

    a. Cement
    b. Micro-fine Cement
    c. Compaction

C. Internal

1. Chemical Grouting

    a. Acrylamide Base Gel
    b. Acrylic Base Gel
    c. Acrylate Base Gel
    d. Urethane Base Gel
    e. Urethane Base Foam

2. Reinforced Shotcrete Placement

3. Concrete Placement

4. Segmented Liners

    a. Fiberglass Reinforced Cement
    b. Fiberglass Reinforced Plastic
    c. Reinforced Plastic Mortar
    d. Polyethylene (PE)
    e. Polyvinyl Chloride (PVC)

f. Steel

5. Continuous Pipe

   a. Polyethylene (extruded)
   b. Polybutylene (extruded)
   c. Polypropylene (extruded)

6. Short Pipe

   a. Polyethylene (external profile)
   b. Polyethylene (internal profile)
   c. Polyvinyl Chloride
   d. Reinforced Plastic Mortar
   e. Fiberglass Reinforced Plastic
   f. Ductile Iron (cement lined)
   g. Ductile Iron (polylined)
   h. Steel

7. Cured-in-Place-Pipe (CIPP)

8. Deformed Pipe
   a. Deformed HDPE
   b. Folded PVC
   c. Thermal Reduction Process

9. Spiral Wound Pipe

   a. PVC Lining System

10. Coatings and Linings

11. Mechanical Sealing Devices

12. Spot (point) Repair

13. Trenchless Replacement

   a. Pipe Bursting
   b. Micro Tunnelling

c. Directional Drilling
d. Pipe Jacking; and
e. Fluid Jet Cutting

14. Replacement (Conventional)

Note: "Wastewater System Engineering Division" is currently evaluating various rehabilitation methods and materials for their viability. Some have been evaluated and accepted.

Specifications for those appear in Appendix B.

The following table lists rehabilitation options, advantages, disadvantages and diameter ranges.

TABLE F 942A
PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Pipeline Preparation			
Cleaning	Increases effective capacity May resolve localized problems	May be costly and cause damage May become a routine requirement	All
Root Removal	May increase effective capacity May resolve localized problems	May be costly Problem likely to recur	All
Internal Grouting	Seals leaking joints and minor cracks Prevents soil loss Low cost and causes minimal disruption Can reduce infiltration Can include root inhibitor	Infiltration may find other routes of entry Existing sewer must be structurally sound	All
External Grouting	Improves soil conditions surrounding	Difficult to assess effectiveness Can be costly	All

TABLE OF 942A (cont'd)

PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Pipeline Preparation (cont’d)			
Short Pipe (PE, PB, PVC, RPM, FRP, DI, Steel)	High strength-to-weight ratio Variety of cross section can be manufactured Minimal disruption	Some materials easily damaged during installation Larger pipes may require stage grouting External lateral connection	4” to 144”
Cured-in-place pipe	Rapid installation No excavation Accommodates bends and minor deformation Maximizes capacity Grouting not required Internal lateral connection	Full bypass pumping necessary High set-up costs on small projects	4” to 108”
Deformed Pipe			
U-Liner/Nu-Pipe	Rapid installation Continuous pipes Maximizes capacity No excavation Grouting not required Internal lateral connection	Relies on existing pipe for installation support	2.5” to 24”

TABLE OF 942A (cont'd)

PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Swage Lining /Roll Down	Rapid installation Maximizes capacity Minimal excavation Grouting not required Internal lateral connection	Relies on existing pipe for installation support	3” to 24”
Spiral Wound Pipe			
Danby	Tailor-made inside the conduit No excavation required External lateral connection Maximizes capacity Non-circular available	Joints rely on sealants Relies on existing pipe for support Required careful grouting of annulus Large diameter requires person entry	3” to 120”
Coatings	Connections easily accommodate Zero / minimal excavation Variety of cross sections possible	Difficult to supervise May be labor intensive Control of infiltration required	4” and larger
Mechanical Sealing	Seals leaking joints and minor cracks Prevents soil loss Low cost and causes minimal disruption Can reduce infiltration	Infiltration may find other routes of entry Existing sewer must be structurally sound Suitable for person entry sewers only	Person-entry only

TABLE OF 942A (cont'd)

PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Spot (Point) Repairs	Deals with isolated problems	Requires excavation for small conduits May require extensive work on brick sewers	All
Pipe Linings			
Reinforced Shotcrete placement	Variety of cross sections possible	Requires person entry – may be labor intensive Lacks corrosion resistance	36” and larger
Concrete Placement	Same as above	Same as above	36” and larger
Segmented Linings	High strength-to- weight ratio Variety of cross section can be manufactured Minimal disruption	Some materials easily damaged during installation May require temporary support during grouting Labor intensive Requires person entry	36” and larger
Continuous Pipe (Fusion-welded Polyethylene / Polybutyline / Polypropylene)	Quick insertion Large-radius bends accommodated	Circular cross section only Insertion trench disruptive High loss of area in smaller sizes Less cost effective where deep External lateral connection	4” to 63”

TABLE F 942A (cont'd)

PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Trenchless Replacement			
Pipe Bursting	Can replace a variety of materials Not dependent on condition of existing conduit Size for size or size increase	Potential damage to adjacent laterals Lateral connections require disconnection Full bypass pumping required Only suitable for brittle pipes	4" to 20" existing pipe
Microtunnelling (Includes pipe jacking)	High groundwater heads Slurry can be water Can deal with cobbles Small diameter Shafts Can excavate plain, weak concrete	Service connections Bentonite slurry requires treatment Off-line only	6" to 36"
Directional Drilling	Rapid installation Long distances Can be used in tidal / surf zone and under water Variety of pipe materials	Surface disruption Generally not suitable for gravity lines Difficult to use in sandy / granular material Off-line only	4" to 36"

TABLE F 942A (cont'd)

PIPELINE REHABILITATION OPTIONS

Rehabilitation Option	**Principal Advantages**	**Principal Disadvantages**	**Diameter Range**
Fluid Jet Cutting	Range of up to 400 feet Accurate steering Capable of steering around obstructions Minimal surface disruption Small self-contained equipment	Possibly of service damage operation difficult in sandy or granular soils Not suitable for gravity lines Off-line only	2” to 14”
Conventional Replacement			
Open Cut	Removes all problems in length Traditional design	Expensive, particularly if deep Disruptive	All
Tunneling	Removes all problems on length Traditional design Minimizes disruption Flexibility on line / elevation	Usually more expensive than open cut May need expensive ancillary works	Greater than 36”

Table 942 B defines size designation for circular and irregularly shaped pipelines.

TABLE F 942 B

PIPELINE SHAPE AND SIZE DESIGNATIONS

Circular shape	**Existing Pipe**
Small diameter	15-inch and smaller
Intermediate diameter	16-inch to 33-inch
Large diameter	34-inch and larger
Irregular shape	
Small size circumference	60-inch and less
Intermediate size circumference	61-inch to 100-inch
Large size circumference	101-inch and larger

943 PIPELINE PREPARATION

Prior to initiating any rehabilitation work, it is necessary to prepare the pipeline.

F 943.1 CLEANING

The purpose of cleaning is to remove foreign materials from the sewer in advance of CCTV monitoring work. The degree of cleaning depends on the type(s) of rehabilitation work planned. However, there are times when CCTV work may be done in advance of cleaning.

When pipe joint grouting is intended, the pipe joints shall be cleaned for satisfactory seating of the packer equipment. The success of the other phases of work depends a great deal on the cleanliness of the pipelines. Some conditions which may prevent cleaning from being accomplished include broken pipe, major blockages and serious corrosion and structural problems.

Cleaning equipment used may include a hydraulically propelled, high-velocity jet (hydrocleaner) or mechanically powered equipment. The proper equipment is usually determined in advance and normally depends on pipe type and condition.

F 943.2 CLOSED CIRCUIT TELEVISION (CCTV)

After cleaning is completed, the pipeline sections are visually inspected by CCTV. The television camera shall be one specifically designed for pipeline work. The lighting for the camera must be suitable to allow a clear picture of the entire periphery of the pipe. See F 920.

F 943.3 ROOT CONTROL

Roots removal from the pipeline is necessary for maintaining proper flow conditions and for reducing infiltration and/or structural damage to the pipeline. Special attention should be given during the cleaning operation to ensure complete removal. Removal procedures usually require the use of mechanical equipment, such as rodding machines, bucket machines, winches using root cutters, porcupines and high velocity jet cleaners.

Chemical root treatment may be used for a more complete removal.
Pipeline cleaning and/or root removal should not be done prior to chemical root treatment. The chemicals attack the root tips, therefore, they must be intact for proper kill of the root system. When extensive grease, root masses or debris preclude application of the chemical, some prior cleaning will be necessary. Proper chemical root treatment requires several months of exposure prior to chemical grouting of pipeline joints.

Chemical root treatment (Foaming Method) is intended to kill roots and to inhibit regrowth without damaging the trees or plants, the environment, or the wastewater treatment plant process. The chemical root treatment must be EPA registered and labeled for use in sewer pipelines. The Manufacturers Safety Data Sheet (MSDS) shall be obtained and reviewed prior to any use. The active ingredient for killing roots is usually a nonsystemic herbicide which will kill roots at low concentrations. The active ingredient must be detoxified by natural processes following its use. The common composition of such a chemical is:

Active Ingredients	**Percentage (%)**
Sodium Methyldithiocarbomate (anhydrous)	24.25
Dichlobenil (2, 6 - dichlorobenzonitrile)	1.77
Inert Ingredients:	73.98

One such chemical is a water soluble, foaming, surface-active formulation of VAPAM plus Dichlobenil, placed in the sewer in the following concentration:

To Water	Add Chemical	Amt. Foam Produced
5 Gal.	1 Qt.	100 Gal.

Sewer pipe capacity;

Pipe Dia. (inches)	Foam per L.F. (Gals)
4	0.7
6	1.5
8	2.5
10	4.0
12	6.0

F 944 EXTERNAL REHABILITATION

External rehabilitation is performed by excavating outside the pipe or from inside the pipe depending upon the pipe diameter. The common methods are variations of chemical and/or cement grouting. These methods are appropriate for solving problems of significant groundwater movement, washouts, soil settlement and soil voids.

F 944.1 CHEMICAL GROUTING

Chemical grouts consist of a mixture of three or more water soluble chemicals which produce stiff gels from properly catalyzed solutions. The grouts produce a solid precipitate as opposed to cement or cement/clay grouts that consist of suspensions of solid particles in a fluid. The reaction in the solution may be either chemical or physiochemical and may involve only the constituents of the solution or these constituents reacting with other substances encountered. In the latter type, the reaction causes a decrease in fluidity and a tendency to solidify and form occlusions in channels or fill voids in the material into which the grout has been injected.

F 944.1.1 ACRYLAMIDE BASE GEL

The most widely used chemical grout for curtain walls, especially in the fine soils is acrylamide base gel. Acrylamide grout is mixed in proportions that produce stiff gels from dilute water solutions when properly reacted.

Before a successful application can be made with acrylamide grout, the following criteria shall be evaluated:

a. The desired result
b. The nature of the grout zone
c. The application equipment
d. Alternative procedures
e. The plan of injection

The grout injection plan shall include gel times to be used, quantities of acrylamide and the probable layout for grout injection points. After work starts, the work plan shall be modified based on additional information that is developed during the job.

No natural soil or rock formations has yet been found in which a gel will not form. However, the injected solution must remain in the grout zone until gelation occurs. In dry soils and in flowing groundwater, there often is a tendency for the grout to disperse. Gravity and capillary forces in dry soils disperse the grout solution and may cause the gel to be ineffective. As in pipe joint grouting, dispersion can be avoided by saturating the soil prior to grouting and by the use of very short gel times. In soil void work, however, a dry soil mass cannot be as efficiently stabilized as a soil mass below the water table.

Dilution around the outer edges of the grout bulb may occur in wet soils when long gel times are used. The flowing groundwater distorts the normal shape of the stabilized mass and can displace it in the direction of flow.

In turbulent flow conditions, dilution can be minimized by short gel times. In open formations or in fissures, solids such as bentonite or cement may be added to the grout solution to help produce a more complete block to flowing water. Acrylamide application is most successful in saturated or partially saturated soils.

Acrylamid is used primarily to reduce leakage rather than increase strength. It does, however, improve the structural integrity indirectly by stabilizing the surrounding soil mass. Acrylamide is a toxic chemical that can be absorbed into the body through broken skin, inhalation, and swallowing. Because of this toxicity, potential hazards in handling and usage can occur if not supervised by technically qualified personnel. Acrylamide materials will be discussed in Sub-section F 945.1.1.1.

F 944.2 CEMENT GROUTING

Cement grout consists of a slurry (particulate suspension) of cement and water. Materials such as sand, bentonite, or accelerators may be added. Because of its particulate nature the use of cement grout is normally restricted to fractured rock and large-grained soils, where the voids are large enough to facilitate penetration and permeation.

F 944.2.1 CEMENT

Portland cement grout can be used to form impermeable subsurface barriers but is restricted in application to medium sands or coarser materials because of the larger size of cement particles (See micro-fine cement). For purposes of filling voids and washouts adjacent to sewer pipelines, various Portland cements have been used successfully. Type III cement is often selected because of its small particle size.

A range of water cement ratios can be used depending on subsurface conditions. Strength characteristics are generally not important where grouting is primarily intended to fill voids surrounding a buried sewer pipeline. Proper design of the water to cement ratio results in grout mixtures which are easy to mix and inject, and have strengths of 500 to 1,000 psi. Clays can be added to cement for grouting, to form gels, and to prevent settlement of the cement from suspension. They do, however, have the problem of no well-defined setting time and they have a slow strength development. Because of this, they are normally not utilized in sewer rehabilitation void grouting when groundwater is present.

Portland cement grouts may also be used as a filler and accelerator in silicate grouts and may be compatibly mixed with acrylamide to improve water shutoff capabilities and injection characteristics. For extremely large void filling applications, other cements such as pozzolan and fly ash mixes can be used and are more economical than straight Portland cement and soil-cement mixtures.

F 944.2.2 MICRO-FINE CEMENT

Micro-fine cement consists of finely ground cement that allows it to penetrate fine sands that ordinary Portland cement cannot penetrate. Beside excellent permeability, it provides needed strength and durability with a set time of 4 to 5 hours. When combined with sodium silicate, with no organics, a 1 to 3 minute gel time can be attained for underground water control.

F 944.2.3 COMPACTION GROUTING

Compaction grouting is the injection of very stiff, low-slump, mortar-type grout under relatively high pressure to displace and compact soils in place. Compaction grouting acts as a radial hydraulic jack, physically displacing the soil particles and moving them closer together. The technique is used to strengthen loose, disturbed or soft soils or for control of settlement. Compaction grouting is used primarily on large pipelines applied through the pipe wall into the surrounding soil.

F 945 INTERNAL REHABILITATION

Internal rehabilitation methods are performed from within the pipeline, either remotely or through point entry or person entry, in order to complete the work. The various installation methods are discussed in this section.

F 945.1 CHEMICAL GROUTING

Chemical grouting is most commonly used to reduce infiltration. It can be used to seal deteriorated and leaking pipe joints, service connections, open joints, maintenance holes and structures. Grouting will not provide structural repair, and is inappropriate for longitudinal or circumferential cracks, broken or crushed pipes. Although chemical grouting is normally used in small diameter pipes, intermediate and large diameter pipes can also be successfully grouted at the joints with special equipment.

Grouting of pipelines is generally accomplished using a sealing packer and CCTV camera. The packer is usually made of a hollow metal cylinder having an inflatable rubber sleeve on each end of a center band. The grout is pumped into the space created between the two inflated sleeves straddling the pipe joint. Depending upon the type of packer, the grout and the initiator solutions are mixed together, applied into this space and forced through the joint leak into the surrounding soil. The grout displaces the groundwater and fills the voids between the soil particles (Figure 945-1).

A remote CCTV is used to position the packer on the pipe joint and to inspect the joints before and after the sealing operation (See Figure F945.1). The sealing packer and CCTV are pulled by cables through a sewer section from maintenance hole to maintenance hole. In addition, air or water testing equipment is used to determine the effectiveness of the sealing.

On person entry sewers, maintenance holes and structures, leaking joints and/or walls can be injected with chemical grouts using a nozzle-type applicator (Figure 945-2).

There are several different types of chemical grouts which are categorized as either gel or foam. With each of the grouts there are a multitude of different types of additives, e.g. initiators, activators, inhibitors and various fillers. The general grout formulations are chemicals and water. When there is groundwater present, normal practice dictates that a higher concentration of chemicals are utilized due to the dilution potential. Because of soil and moisture variability, formulating the correct mixture is largely dependent on trial and error, rather than scientific principles.

The various parameters that affect the performance are:

a. viscosity control;
b. gel time variables
c. influence of temperature
d. influence of pH

e. presence of entrained oxygen in the solution
f. contact with particular metals
g. influence of ultraviolet rays
h. presence of mineral salts
i. velocity of groundwater flows
j. capabilities of placement equipment
k. other soils and water conditions

The properties of the grout also vary in:

a. appearance
b. solubility
c. swelling and shrinkage
d. corrosiveness
e. stability
f. strength

The various additives for grouts also affect:

a. viscosity
b. density
c. color
d. strength
e. shrinkage

Therefore, the environmental conditions shall be taken into consideration for proper formulation and this shall be done on a case-by-case basis.

Another critical aspect of effective grouting is the proper operation of the equipment, i.e. the grout packer, pumps, tanks, formulation, mixing and application. The pre-mixing of the final grout mixture is conducted in two separate tanks. One is the grout tank and the other is the catalyst tank. The grout tank contains water, grout and buffer, while the catalyst tank contains water, oxidizer catalyst and at times fillers.

F 945.1.1 CHEMICAL GEL GROUTS

The most commonly used gel grouts are of the acrylamide, acrylic, acrylate and urethane base types. All the gels are resistant to most chemicals found in sewer pipelines. All produce a gel-soil mixture that is susceptible to shrinkage cracking. All except the urethane base gels are susceptible to dehydration. These deficiencies can be reduced by using chemical additives. In addition to the chemical differences in composition, discussed under materials, there are the following important differences:

> Acrylamide base gel is significantly more toxic than the others. (Grout toxicities are of concern only during handling and placement or installation). The non-toxic urethane base gels are EPA approved for potable water pipelines. Urethane gels use water as the catalyst, where as the other gels use other chemicals. Therefore, the urethane gels require avoiding additional water contamination for proper curing.

F 945.1.1.1 ACRYLAMIDE BASE GEL

Acrylamide grout is a mixture of three or more water soluble chemicals. The acrylamide itself is the base chemical in the mixture. The concentration of acrylamide is normally at a minimum of 10% of the total mixture weight.

Catalysts such as triethanolamine (TEA) or T+ and ammonium persulfate (AP) are part of the mixture. The T+ is normally 1%, where the AP is 0.5% of the total mixture. The catalyst percentages are increased for shortening the gel times. Also, gel times will be slower if the temperature of the grout mixture decreases, etc. A rule of thumb is that gel time is reduced by half for each 10^{o}F increase in temperature. The controlled reaction time can be varied from about ten seconds to one hour. The desired reaction gel time is normally set faster where high or flowing groundwater is encountered to prevent dilution of the grout mix.

The catalyst T+ acts as a buffer, where the AP is a granular strong oxidizing initiator chemical. A shrinkage control agent is sometimes added to the mixture for protection against freezing temperatures or dehydrating conditions required for the gel. One or more catalyst aids are also added in order to reduce the amount of other catalysts required to achieve a specific gel time. There are chemicals available to achieve increases in compressive and tensile strengths as well as elongation properties. Potassium Ferricyanide behaves as an inhibitor and can be used to extend the gel time.

A filler such as diatomaceous earth (Celite) can be added to improve shrinkage characteristics which also shortens the gel time. Additives for external grouting are: Celite, silica flour, sawdust or bentonite for also reducing shrinkage in large void filling. The use of Portland cement for external grouting reduces the gel time, however, it forms a more rigid mass. The additives increase the viscosity, thereby reducing the penetrability of the mixture, and prevent it from being filtered out from the chemical sealant. Certain chemical additives will maintain a true single phase chemical grout whereas particulate additives transform the grout into a two phase system. Depending upon the soil grain sizes and other conditions, the additive is normally at a proportion of 5% to 30% by weight of the mixture. Where fine soils are present, the use of fillers should be less than 5%.

The amount of water can vary for the mixture but is normally in the range of 75% to 90%. The grout mixture, without fillers, has flowability similar to water.

F 945.1.1.2 ACRYLIC BASE GEL

The acrylic grouts are water solutions of acrylic resins with several types for different applications. After being mixed with catalysts a cohesive gel is formed. The set time can be closely controlled from a few seconds for flowing water condition to several hours for normal conditions.

These grouts are good for use in sewer pipe joints, maintenance holes and structures. The acrylic grouts have a viscosity similar to water prior to gelation. These grouts have a tendency to swell in water allowing a water tight sealing effect.

The standard formulation for the acrylic gel is:

a. Water (44 gal.)
b. Acrylic grout (14 gal.)
c. TEA (0.5 gal. or 1%)
d. Sodium persulfate (5 lbs.)

F 945.1.1.3 ACRYLATE BASE GEL

The acrylate grouts are very similar to the aforementioned grouts and need not be discussed in detail.

The standard formulation, by weight, for the acrylate gel is:

a. Water (61%)
b. Acrylate grout (35%)
c. TEA (2%) and AP (2%) and
d. AP (2%)

In those situations where shrinkage control is paramount the suggested formulation, by weight, would be:

a. Water (56%)
b. Acrylate grout (35%)
c. TEA (2%)
d. Ethylene glycol (2%)

It should be noted that the acrylate grout is in a water solution at 40% concentration.

F 945.1.1.4 URETHANE BASE GEL

Urethane grout is a solution of a prepolymer which cures upon reaction with water. During the reaction the gel remains hydrophilic, i.e., it absorbs water plus holds it within a cured gel mass. Upon being cured, the resultant gel is resistant to the passage of water. Since the prepolymer is cured by water, premature contamination by other water must be avoided during application.

The formulation obviously is water sensitive and various water to grout ratios provide various strengths. The ratio needed to provide a strong gel ranges from 5:1 to 15:1, by volume. Ratio less than this will produce a foam reaction, where ratios greater will produce a weak gel.

An example formulation would involve an 8:1 ratio of compounded material for pipe joint grouting, e.g.:

Water Side Tank:
Water - 40 gals. (333 lbs.)
Shrink Control - 10 gals. (80 lbs).
Celite - 50 lbs.

The normal procedure is that the water is added to a 50 gallon tank. Then the shrink control is added and thoroughly mixed. This is followed by the addition of an optional filler, e.g. Celite, with volumetric adjustments made due to tank capacity. The mixture containing filler is continuously agitated. Under application conditions 8 to 10 gallons of the mixture is combined with each gallon of urethane chemical for grouting.

F 945.1.1.5 URETHANE BASE FOAM

Urethane foam is used primarily to stop infiltration into maintenance holes. These leaks occur through cracks in the foundation or base (or wall), through joints formed by the base, corbel or upper frame interfaces or through pipe penetrations into the maintenance hole wall. Grout injections are placed into predrilled holes and the grout is injected under pressure.

When cured it forms a flexible gasket or plug in the leakage path. When mixed with an equal amount of water, the grout expands and quickly cures to a tough, flexible closed-cell rubber. In some applications the material is used without premixing with water, however, it will eventually require an equal amount of water for total cure.

F 945.2 REINFORCED SHOTCRETE PLACEMENT

Shotcrete is the application of concrete or mortar conveyed through a hose and pneumatically projected at high velocity onto a surface. Shotcrete includes both the wet and dry mix processes, but the term "Shotcrete" usually refers to the wet process, whereas the dry mix process has come to be commonly referred to as "Gunite". Shotcrete and Gunite linings can provide structural strength and improved hydraulic performance, with some improvement in corrosion resistance. See Figures F 945.2 and F 945.3.

Shotcrete and Gunite linings are used in large diameter (42 inch and larger) sewers. These linings can also be used in maintenance holes and other structures. Various segmented liners can be incorporated onto the finished cement for total corrosion protection.

The shotcrete processes, are similar in materials use and generally utilize steel or mesh for reinforcing purposes. Also, various latex polymers can be added for improved bond strength, reduced absorption and permeability and increased chemical resistance.

Table F 945.2A

Typical Shotcrete and Gunite Mixes
Wet Mix (Shotcrete) Design

Material	Quantity per cubic yard
Cement (Type I, II, or V)	750 lbs.
3/8" Pea Gravel	800 lbs.
Concrete Sand	2,040 lbs.
Super plasticizer (Optional)	Standard dosage
A. E. A.	As required for 4-7% air
Liquid Accelerator (Optional)	3-5% by weight of cement
Water	286 lbs

Table F 945.2B

Dry Mix (Gunite) Design

1 part Cement (Type I, II, or V)
3 to 4 1/2 parts Concrete Sand
Accelerator/Admixture (Optional)
Maximum 4 gallons of water

A comparison of wet and dry mix shotcrete:

Table F 945.2C

**Comparison of Shotcrete (Wet Mix)
and Gunite (Dry Mix)**

	Shotcrete	**Gunite**
Rebound	Low	High
Dust	Low	High
Compound Air Required	Lower	Higher
W/C Ratio Control	Support Crew	Nozzleman
Volume Rate	High	Low
Nozzleman Skill Required	Low	High
Compressive Strength	Lower	Higher
Mix Design	Flexible	Less Flexible
Small Volume Work	Poor	Good

Shotcrete that can be placed with not more than 3 to 3 1/2 gallons of water per sack of cement will possess high density and have less shrinkage. Shotcrete can have twice the in-place density or strength as poured or hand-placed structural concrete.

Due to the extremely high density and low permeability of well-placed shotcrete, the penetration of water is held to a minimum. Shotcrete is usually more chemically resistant to acids than ordinary concrete. The percentage of voids can be less than one-half that of poured concrete, and water absorption is somewhat less than five percent. Shotcrete walls are normally three or four inches in thickness (Figure 945-3).

F 945.3 CONCRETE PLACEMENT

Lining with reinforced or nonreinforced concrete is an effective rehabilitation method for a variety of conduit shapes. The slip form or fixed form construction practices are utilized for concrete placement. This method is used in large diameter (42 inch and larger) sewers with adequate access where materials can be handled effectively. The sewer must be thoroughly cleaned and dewatered prior to rehabilitation.

When used, the designed steel reinforcement is affixed to the existing pipe. The forms are positioned providing the desired finished wall section prior to the concrete being poured. The structurally reinforced or nonreinforced concrete can be designed for rehabilitation of an existing pipeline. The structural condition of the existing conduit determines whether or not steel reinforcing is required. Reinforcing steel can be single or multiple layers of welded wire mesh or hand-placed cages attached to the existing pipe wall by threaded inserts. The new concrete wall can be varied in thickness, depending upon the design. The concrete mix can also be varied and various corrosion resistant additives and cements can be utilized. Various segmented liners can be incorporated into the forming for total corrosion protection.

F 945.4 SEGMENTED LINERS

Segmented liners can be manufactured in virtually any shape and length from a number of different types of materials, discussed below. These liners can be installed in one or several segments, or in one sheet circumferentially and joined together longitudinally. This work is generally accomplished in a dry sewer there- fore bypassing of sewage is required. See Figure F 945.4

Segmented liners manufactured from a wide assortment of materials have varying resistance to corrosion. These liners can be incorporated with concrete placement or pressure grout can be applied after their erection.

945.4.1 FIBERGLASS REINFORCED CEMENT

Fiberglass reinforced cement (FRC) liners are prefabricated thin panels designed for large diameter (42 inch and larger) sewers. After the existing pipeline is thoroughly cleaned and dewatered the segments are provided in 4 to 8 foot lengths which overlap at the circumferential joints. The segment ends may be predrilled for pipeline fixety by screw, or impact nail gun. The segmented rings are anchored on spacers and, upon final assembly, the section(s) are cement pressure grouted in the annulus provided. Service laterals are cut in and grouted.

This method provides flexibility to accommodate variations in grade, slopes, cross-sections and deterioration. The linings are not designed to support earth loads, however, they are effective in maintaining the existing pipe's remaining structural integrity.

The interior smooth surface can improve hydraulic capacity, however, long term affect is currently unknown. Although the segmented sections are lightweight and easy to handle, the installation is labor-intensive and slow.

The FRC liners are normally three-eighth inches in thickness, but can vary. These liners are composed of Portland cement, fine sand and chopped, fiberglass rovings. The fiberglass must have a surface finish that is compatible with the high alkaline cement environment. These linings have high mechanical and impact strengths. They are also highly resistant to abrasion with negligible absorption and permeability. Additives can be included into the cement matrix along with "E" type glass for acid resistance.

945.4.2 FIBERGLASS REINFORCED PLASTIC

Fiberglass reinforced plastic (FRP) liners are similar in most respects to the aforementioned cement liners, however, they are more corrosion resistant and less permeable to the sewage fluid and gases. The segments are also lighter weight and easier to install.
The FRP liners are normally one-half inch in thickness, but can vary. These liners are composed of thermosetting plastic resin and chopped, fiberglass rovings. The fiberglass must have a surface finish that is compatible with the type of resin employed. The fiberglass reinforcement is of the acid corrosion resistant variety. The resins employed are normally, Bisphenol A, vinylester or isophthalic, acid resistant types. These liners are highly resistant to abrasion with negligible absorption and permeability features.

945.4.3 REINFORCED PLASTIC MORTAR

Reinforced plastic mortar (RPM) liners are similar to cement segments, however, they are more corrosion resistant having about the same weight and installation features.

The primary difference between FRP and RPM liners is the addition of a fine sand/resin mortar in the matrix, for RPM. The same resin/fiberglass designs are used, however, a sand free inner surface must be provided due to its inherent corrosion resistance short comings.

F 945.4.4 POLYETHYLENE (PE)

Polyethylene (PE) sheets can be placed in the pipeline covering the upper 270 or 300 degree inner circumference. The sheets are normally 20 feet in length and are placed in one or two segments circumferentially. The sheets are affixed to the pipe that has been thoroughly cleaned utilizing "molly" bolts or pins connected to the remaining wall section. The joining together of the sheets circumferentially and longitudinally is achieved by use of a special fusion welding system. The extrusion or butt welding method is used for sealing the ends. This can also be used for protecting maintenance holes and other structures.

Polyethylene sheet liners can be manufactured in thickness of 40 to 240 mil. The sheet thickness is designed with consideration for anticipated temperature range, diameter of the pipe and the degree of circumference to be covered. The high density polyethylene (HDPE) sheets must be free of extractable plasticizers or copolymers, maintaining physical properties having low level shrinkage or swelling from normal sewage conditions. In general, PE has good corrosion resistance properties, especially High Density PE (HDPE). Low Density PE (LDPE) and Medium Density PE (MDPE) usually have lower corrosion resistance properties than HDPE. PE may be considered for use in rehabilitation, provided the installation is satisfactory. To date the use of "Molly Bolts" or pins for attaching the PE has not proved satisfactory and shall not be permitted.

The various HDPE properties are listed in Table F 945.4.4 below:

Table F 945.4.4
HDPE Properties

Property	**ASTM Test Method**		**Thickness**	
		60mil	80mil	100mil
Density (g/cc)	D792/1505	0.94	0.94	0.94
Melt Index (gm/10 min)	D1238	0.45	0.45	0.45
Tensile Strength @ Break (psi)	D638	4500	4500	4500

Table F 945.4.4
HDPE Properties

Property	**ASTM Test Method**	**Thickness**		
		60mil	80mil	100mil
Tensile Strength @ Yield (psi)	D638	2500	2500	2500
Elongation @ Break (%)	D638	800	800	800
Elongation @ Yield (%)	D638	15	15	15
Modulus of Elasticity (psi)		80,000	80,000	80,000
Environmental Stress Cracking Resistance (Max. hrs.)	D1149 Cond. C (100^{o}C)	5,000	5,000	5,000

F 945.4.5 POLYVINYL CHLORIDE (PVC)

PVC sheets are placed in the pipeline by methods similar to those described above for PE. The PVC liners are composed of high molecular weight PVC resin combined with chemical resistant pigments and plasticizers. The PVC liner is extruded of plastic materials having a cell classification of 12454-B, 13364-A or 13364-B as defined in ASTM D1784. These cell classes are the only ones that shall be permitted.

The liners are normally 65 mils (0.065 inches) in thickness. The liners have a minimum elongation of approximately 200% (ASTM D412) and a tensile strength of 2200 psi (ASTM D638). The Shore Durometer D hardness is approximately 50 at ambient temperature (ASTM D2240). The standard sheets are 4 feet by 8 feet, having a 3/8 inch high tee section, spaced 2 1/2 inches apart circumfer-entially and placed longitudinally.

F 945.4.6 STEEL

An access pit location is chosen and excavated, straddling the existing pipeline. The exposed pipe section is removed providing access inside the pipeline. A twenty foot length of welded steel pipe having plain ends and cut longitudinally is lowered into the access pit. The steel wall is folded over itself reducing the overall diameter permitting easier entry.

A mobile carrier mounted on wheels transports the liner sections in either direction down the existing pipeline. The liner is expanded in place at the select location, in the existing pipeline. For concentric positioning it is necessary to have bars welded to the liner outside. For eccentric positioning the liner is set on the bottom of the existing pipeline. The longitudinal seam is closed by butt welding. The ends of the adjacently placed segments are either lap or butt welded in place. After placement of the liners, the space between the old and the new pipes is pressure grouted, normally through grout holes in the liner. The inside of the steel liner is normally cement mortar lined.

Welded steel pipe liners are made by butt or offset butt electrically welded straight or spiral seam cylinders, fabricated from plates or sheets. The plates or sheets comply with the physical and chemical requirements of ASTM A-570, or to ASTM A-283. The wall thickness will be determined by the design but will usually be 3/8 to 1/2 inch depending upon the corrosion potential. The finished in-place liners will be pressure grouted and lined with 1/2 to 3/4 inch cement mortar having corrosion resistant additives. The longevity of this method can be somewhat limited and is discussed in F 950. It should be noted that at a significantly higher first cost, stainless steel 300 series would be preferred.

945.5 CONTINUOUS PIPE

The continuous pipe method (sliplining) is the insertion of a smaller diameter pipe inside of an existing pipe utilizing the hole in the ground as access for trenchless construction.

Sliplining of existing deteriorated pipelines can be accomplished by use of a continuous slipliner of different types of olefin plastics. The sliplining methods will be discussed in this subsection for the various material types. The use of slipliners requires the construction of an insertion pit which is used as access for the pipe. Upon completion of the work, the access pit is backfilled and compacted. Sliplining pipes are manufactured from a wide assortment of different types of materials having various resistance to corrosion (Figures 945-4 & 945-5). Typical detailed design examples are provided at the end of this Section. (See Figure F 945.5)

F 945.5.1 POLYETHYLENE PIPE (EXTRUDED)

PE is normally manufactured in 39 foot lengths (12 meters). These lengths are fused together at the job site. After the insertion pit(s) are located and excavated, the top part of the existing pipe is removed for access into the line. The PE pipe is then pulled into the pit and into the existing pipeline. Pipe pulls have been done up to 1,000 feet or more dependent upon the slipliner diameter. Pulls of 800 feet are normal and depend upon the existing pipe diameter and alignment. The butt-fusion process is very sensitive because the proper fusion temperature must be reached to attain proper strength. The larger the diameter, the thicker the wall, and the longer it takes for a proper fusion. Also, after the fusion is made a certain time period is required for proper curing prior to the pull. Inside bead formed at butt fusion joint, especially for diameters up to 12 inch, should be trimmed to avoid constriction. This is important if line is mandrelled-bead reads as "deflection" and may exceed specifications - especially in small diameters.

The pipe is attached to an acceptable pulling head and connected to a winch, usually electrical, and cabled to the pulling end of the operation. Rollers are used above ground to facilitate the movement of the pipe, avoiding sharp objects that may damage the pipe during the pull. The slipliner is pulled through the entire section, without stopping, during the insertion. The pipe liner is usually cable pulled into the terminal maintenance hole at least two extra feet. The pipe is stretched during the pull operation and requires approximately 24 hours to contract to its normal length. Service connections are usually exposed and then connected to the liner after the twenty four hour waiting period using a heat fusion saddle or tapping saddle. The entire connection shall be sealed and anchored by encasement in concrete, cement-stabilized sand or other approved material. The surrounding soil shall be compacted to a high density prior to backfilling, to minimize settlement.

When 1 inch or more of annular space exists between the liner outside and old pipe inside diameters, grouting is usually recommended for the entire length to achieve stability and strength. Access for the grouting operation is normally at maintenance holes, insertion pits and service connections. The pipe must be designed to withstand these grouting pressures.

When less than 1 inch of annular space is available, grouting is infeasible, and other measures must be taken to prevent damage from instability. The entry points at maintenance holes must be sealed, and the service connections should be concrete encased in order to minimize liner pipe movement that may shear the saddles. For PE installation under certain flow conditions, bypassing the sewage may be necessary.

PE pipe is manufactured in three types of resin: low, medium and high density. The one used for sewer sliplining is of the high density (HDPE) variety. High density compounds are rigid, hard, strong, tough and corrosion resistant. Structural characteristics are a function of wall thickness design as in most plastic and homogeneous materials. Due to the low modulus of elasticity, careful design considerations must be given to buckling. PE pipe is characterized by the Standard Dimensional Ratio (SDR), and pipe grades are classified by environmental stress-cracking resistance. ASTM Standards are available for reference, testing and design. The PE material standards are: ASTM D1248 and D3350. The ASTM D-3350 Standard is normally referenced for pipe cell classification for material properties. The primary properties of concern for HDPE sliplining pipe are as follows:

Table F 945.5.1
HDPE Properties

PROPERTY	**ASTM TEST METHOD**	**VALUE**
Density, g/cm^3	D1505	0.941-0.955
Melt Index-condition E	D1238	< 0.15
Flexural Modulus, psi	D790	110,000-160,000
Tensile Strength @ yield, psi	D1693	3000 - < 3500

Table F 945.5.1 (cont'd.)
HDPE Properties

PROPERTY	ASTM TEST METHOD	VALUE
Environmental Stress Cracking	D1693	
Resistance:		
a. Test Condition		A
b. Test Duration, h		192
c. Failure, max %		0
Hydrostatic Design Basis (psi)	D2837	1600
Color and UV Stabilizer		C 2% carbon black min.

The long term tensile and flexural modulus values are extremely important for determining buckling resistance. This shall be discussed in Appendix A, where design examples are provided.

945.5.2 POLYBUTYLENE (EXTRUDED)

The Polybutylene (Pb) sliplining method is virtually the same as PE extruded pipe.

Pb pipe is extruded and resembles medium density PE pipe in stiffness and chemical resistance, but has higher strength under sustained stress. It also retains this strength at higher temperatures. Its upper temperature limit is about 180 degrees F for gravity sewer applications. The Pb pipe is manufactured in accordance to ASTM F-809.

The long term tensile and flexural modulus values are extremely important for determining buckling resistance.

945.5.3 POLYPROPYLENE (EXTRUDED)

The Polypropylene (PP) sliplining method is virtually the same as PE and Pb extruded pipe.

PP pipe is extruded and has similar stiffness but better chemical, temperature and strength characteristics than PE and Pb. The PP pipe is manufactured in accordance to ASTM D-4101.

945.6 SHORT PIPE

The short pipe method is the insertion of a smaller diameter pipe inside of an existing pipe, by pushing and/or pulling, utilizing the hole in the ground as access for trenchless construction. (See Figure F 945.6)

Rehabilitating the existing deteriorated pipeline can be accomplished by use of gasketed or welded pipe lengths depending upon the type of material used. These methods will be discussed in this Subsection for the various material types. These methods require the construction of an insertion pit which is used as access for the pipe. Upon completion of the work, the access pit is backfilled and compacted. These materials, in the form of manufactured pipe, have varying resistance to corrosion (Figure 945.6).

945.6.1 POLYETHYLENE (EXTERNAL PROFILE)

This PE pipe product is manufactured in 20 foot lengths. These lengths are generally connected together using a bell and spigot joint configuration utilizing an elastomeric sealing gasket. The spiral rib design permits a constant inside diameter with a varying outside profile rib dependent upon design conditions.

A jacking pit is excavated approximately 5 feet longer than the pipe segment length and 2 feet wider than the existing sewer pipe outside diameter. However, the insertion pit dimensions are normally dictated by the dimensions of the liner jacking equipment. The top half of the old pipe, in the pit, is removed for liner pipe access. The pipe is placed and is pushed, or pushed and pulled through the existing pipe.

Upon completion of the insertion procedure the annular space between the pipes is pressure grouted. The entire jacking operation can be accomplished under a sewer flowing condition. The liner can be inserted upstream or downstream, even when the existing pipe is flowing at half capacity, alignment permitting. The jacking pit and other procedures are virtually identical to the aforementioned PE (external profile) pipe.

Spiral rib is manufactured from HDPE resin. This PE pipe should be manufactured in accordance to ASTM F-894. This pipe must also meet the aforementioned physical and chemical parameters.

F 945.6.2 POLYETHYLENE (INTERNAL PROFILE)

This PE pipe product is manufactured in twenty foot lengths. These lengths are generally connected together using a bell and spigot joint configuration, utilizing an elastomeric sealing gasket. The internal profile design permits constant inside and outside diameters. Service connections or laterals are made similar to the procedures used for PE extruded pipe.

PE (Internal Profile) pipe is manufactured from HDPE resin. The physical and chemical parameters listed for PE extruded pipe must be attained.

F 945.6.3 POLYVINYL CHLORIDE

Polyvinyl Chloride (PVC) is manufactured in 10 or 20 foot lengths. It has been utilized in 3 foot joints when inserted from within a maintenance hole. The lengths are generally connected together using a bell and spigot configuration utilizing an elastomeric sealing gasket. However, a solvent cement has been used under a sewer bypass condition (check MSDS sheets). The jacking pit and other procedures are virtually identical to the aforementioned PE Corewall pipe.

PVC pipe is extruded of plastic materials having a cell classification of 12454-B, 13364-A or 13364-B as defined in ASTM D1784. These cell classes are the only ones that shall be permitted

The pipe must also meet ASTM D-3034, for small diameters or ASTM F-679 for large diameters. Additives and fillers, including but not limited to stabilizers, antioxidants, lubricants, colorants, etc., are to be 10 parts or less by weight per 100 parts of PVC resin in the compound.

945.6.4 REINFORCED PLASTIC MORTAR

The Reinforced Plastic Mortar (RPM) pipe is manufactured in 20 foot lengths. These lengths are generally connected together using a bell and spigot joint configuration utilizing an elastomeric sealing gasket. The centrifugal manufacturing process provides a constant outside diameter having a slightly larger dimension at the joint. Various thicknesses are available. When thicker walled pipe is used, the joints can be recessed so that the outside diameter is constant. The jacking pit and other procedures are virtually identical to the aforementioned PE (external profile) pipe.

RPM pipe is centrifugally cast using a polyester resin, chopped fiberglass roving and sand. This composite wall can be varied in composition and thickness for adjusting wall stiffness and strengths. The pipe has a resin rich lining and coating that provides excellent corrosion resistant features. The pipe is manufactured to meet ASTM D-3262 for stiffness and structural requirements and ASTM D-3681 for acid resistance.

945.6.5 FIBERGLASS REINFORCED PLASTIC

Fiberglass Reinforced Plastic (FRP) pipe is normally manufactured in 40 foot lengths, however, 20 and 60 foot lengths are also available. These lengths are generally connected together using a bell and spigot configuration utilizing a fiberglass overwrap sealing closure; however, gasketed and cement joints are also available. The filament winding manufacturing process provides a constant inside diameter. The outside diameter is normally controlled by the bell size which is larger than the barrel size. The jacking pit and other procedures are virtually identical to the aforementioned PE (external profile) pipe.

FRP pipe is similar in many respects to the RPM pipe, however, it is normally made by filament winding without sand in the composite wall in conformance to the same ASTM Standards.

F 945.6.6 DUCTILE IRON (CEMENT LINED OR POLYLINED)

Ductile Iron pipe is normally manufactured in 20 foot lengths. These lengths are generally connected together using a bell and spigot joint configuration utilizing an elastomeric sealing gasket. The centrifugal manufacturing process provides a constant outside diameter, however, the bell is several inches larger and controls the size for insertion. The jacking pit and other procedures are virtually identical to the aforementioned PE Corewall pipe.

Ductile Iron pipe shall be manufactured according to the AWWA C-151 Standard. The sizes, classes, grades or thicknesses shall be determined by the designer. Due to the high flexural modulus the concern for the buckling resistance is at a minimum, but shall be calculated. The cement mortar lining should be double the normal amount as follows: 1/8 inch for 3 inch to 12 inch; 3/16 inch for 14 inch to 24 inch; and 1/4 inch for 30 inch and larger.

When internal corrosion is of concern and sulfide control is not incorporated into the design sewer flows, it is recommended to use the 40 mil minimum polylining. This polylining shall be placed throughout the inner surface of the pipe length, from spigot end face to beyond the sealing elastomeric gasket.

F 945.6.7 STEEL

Steel pipe is normally manufactured in 40 foot lengths, however, 20 foot lengths are also available. These lengths are generally connected together by welding the plain ends. The welded joint closures necessitate bypassing the sewage flows during construction. The joint welding can be completed within the insertion pit area. The jacking pit and most of the other procedures are virtually identical to the aforementioned PE Corewall pipe. The steel pipe material was discussed in Subsection F 945.4.6

F 945.7 CURED-IN-PLACE-PIPE (CIPP)

The CIPP is a resin saturated material that is inverted into the existing pipeline, either hydrostatically or with air pressure. (See Figure F 945.7) The sewage flow must be bypassed around the area of work prior to inversion. After the pipeline has been cleaned and televised the saturated fabric is inserted through a maintenance hole or convenient entry point. After the application of the inversion process, the temperature of the water or air is increased by use of a heat exchanger or the application of steam. This cures the resin saturated material, forming a hard impermeable pipe within the old pipe. The inversion forces and heat press the fabric material tightly against the existing pipe, creating dimples at the service connections or laterals. After the resin sets, the downstream closed end is carefully cut and removed in order to avoid creating a vacuum which may collapse the newly formed pipeline (Figure 945-7).

The final activity is pulling a CCTV through the line for final inspection. In tandem, and connected to the CCTV, is a cutting device used to restore the service connections, locating the dimples visually with the camera.

The components of the cured-in-place-pipe are:

a. flexible needled felt
b. thermosetting resin
c. catalyst

The flexible needled felt can be made of a woven or a non woven, or a combination woven and non woven material.

The primary function of the felt is to carry and place the thermosetting resin which cures into the shape of the conduit. Thermosetting polyester resins utilize cobalt, perkodox and/or trigonox for catalyzing and accelerating the polymerization. The catalyst quantities vary from one-half to five percent of the total resin mix. Thermosetting vinylester resins utilize the same type catalysts in like concentrations. Thermosetting epoxy resins are significantly more complex on placement and curing. The epoxy resin manufacturer normally provides a proprietary curing agent, for a given type resin, in quantities varying from 2 to 33%.

The CIPP physical properties are shown on Table 945.7:

Table 945.7

PHYSICAL PROPERTIES - CIPP
TYPICAL VALUES FOR COMPOSITE

PROPERTY	ASTM TEST METHOD	POLYESTER	EPOXY	UNIT
Tensile Strength	D638	3,000	4,000	psi
Flexural Strength	D790	4,500	5,000	psi
Tensile Strength	D638	200,000	250,000	psi
Flexural Modulus	D790	250,000	300,000	psi

Note 1 Values listed are considered pipe initial minimums as defined in ASTM D638 and D790. Long Term pipe values are defined as 50 year and are determined by ASTM D2990 Test Method.

Note 2 Enhanced resins are available, however, long term characteristics must be identified.

945.8 DEFORMED PIPE

This method utilizes extruded polyethylene or polyvinyl chloride materials that are either deformed during the manufacturing process or during installation. These methods are similar in many respects, however, differences are apparent and these are discussed in this Subsection.

It is normal to monitor the existing pipeline by use of a CCTV camera. A proofing pig should be pulled through the line to verify dimensions and remove protruding laterals, etc, prior to liner insertion.

945.8.1 DEFORMED HDPE

The extruded HDPE pipe is deformed 25% to 30% and wound on a large containment spool. This spool is transported to the job location. A cable is strung through the deteriorated pipe and attached to the deformed pipe. The HDPE pipe is then pulled through an existing maintenance hole or access point (Figure 945-8).

Appropriate sleeves and rollers are used to protect the deformed pipe during installation. When the deformed pipe is in place it is cut and the processing manifolds (pipe end closing assembly used for heat and pressure control within liner) is inserted and secured at both pipe ends. The temperature and pressure measuring instruments are attached to the deformed pipe at both ends.

Through the use of steam and air pressure, the deformed pipe is progressively reformed to conform to the existing pipe wall. After the pressure and temperature are held at set levels for a set time, a cool down period is started. When this process returns to ambient condition, the equipment is detached and service laterals are normally reinstated through an internal remotely controlled tapping apparatus.

945.8.2 FOLDED PVC

The extruded PVC pipe is deformed/folded 20% to 25% and wound on a large containment spool. This spool is transported to the job location. A heat containment tube is normally placed inside the deteriorated pipe in order to assist in the retention of heat necessary to soften the folded pipe. A cable is strung through the containment tube and attached to the folded pipe. The heated PVC pipe is then pulled through an existing maintenance hole at the access point. Care is taken not to damage the folded pipe during installation. After the PVC pipe is fully extended within the existing pipe, the folded pipe is cut off at the starting point. Through the use of steam and air pressure, a mandrel is pushed through the folded pipe, progressively rerounding the pipe. The PVC pipe conforms to the existing pipe wall providing a tight-fitting pipe within a pipe. After the pressure and temperature is held at set levels for a set time, a cool down period is started. When this process returns to ambient condition, the equipment is detached and service laterals are normally reinstated through an internal remotely controlled tapping apparatus (Figure 945-8).

945.9 SPIRAL WOUND PIPE

The spiral wound rehabilitation method normally uses strips of extruded PVC material. The strips are transported to the job location in rolled bundles. The various spiral wound methods are either rubber gasket or activated polyurethane adhesive, sealed or unsealed.

945.9.1 PVC LINING SYSTEM

The PVC strips are machine formed using clips at the strip interface and pushed through the deteriorated pipe from a maintenance hole on small diameter pipes. On large diameter pipes the machine can be utilized with person-entry assistance or panels can be affixed to the pipes inner wall. The strips and panels are manufactured with a profile backing that provides space for injecting grout. The PVC and grout composite provides long term buckling resistance, however, design relationships must be calculated.

Service laterals are normally reinstated through external excavation and reconnection on the non-person-entry diameters. Person-entry diameters permit internal service lateral reinstatement.

F 945.10 COATINGS AND LININGS

The application of any coating or lining requires correct surface preparation. It is necessary to clean any concrete surface in advance of applying any protective material. Also, most protective materials require a dry surface for developing a long term adhesive bond.

There are hundreds of coatings and linings systems available that are marketed for protecting concrete systems that are subjected to sewage environment. Certain detailed research and testing has been conducted by Los Angeles County and the list of viable systems are as follows:

a. Epoxy
b. Polyester
c. Mastic/polyvinyl chloride (PVC).

Note: The cured material shall meet the Chemical Resistance criteria, Greenbook Section 210-2.3.3.

The list is identified under generic headings, however, each will be discussed below utilizing certain proprietary identifying components.

The epoxy resin coating material must consist of a primer and a moisture insensitive solventless, amine cured, two-component, 100% solids system for application on either dry or damp concrete surfaces.

The polyester resin coating material must consist of a primer, a sand-extended overlay, and a top coat, all derived from an unsaturated, styrenated polyester resin. The coating must be dimensionally stable, have a low styrene yield, and a low heat generation on curing. The coating must be fast curing, resistant to moisture, dilute acids, etc. (as above for epoxy). The resin must provide the same expansion and contraction rates as the concrete after curing.

The PVC sheeting (50 mil minimum) material must have a fast cure, epoxy polyurethane concrete primer, high solids, polyurethane mastic/joint sealant and a surface activator for bonding to the concrete. The primer shall be a two component mix that has high tolerance for moisture and strongly bonds to the concrete substrate.

The polyurethane mastic shall be permanently flexible, non-flow type; and resistant to weathering, aging, dilute acids, etc. (as above for epoxy). The activator is applied to the PVC/PU surface to provide cross-linkage with the polyurethane mastic.

F 945.11 MECHANICAL SEALING DEVICES

Mechanical sealing devices require surface preparation for proper seating and sealing. These devices are used for sealing leaking and or corroded joints (See Figure F 945.11). These can be used in pipelines and/or maintenance holes.

F 945.12 SPOT (POINT) REPAIR

Point repairs may be used to correct isolated or severe problems in a pipeline segment, and can be an initial step in the use of other rehabilitation methods. Point repairs, are usually limited to the replacement of only a short portion of a pipeline or lateral connection.

The technical considerations and the factors influencing the cost of a point repair are the same as those described in a following section for excavation and replacement. When making point repairs, special consideration shall be given to the materials and methods to be used to connect the replacement pipe to the existing pipeline. Flexible couplings are often used to join pipes together. Concrete collars and encasement also are used occasionally. The repair of pipe connections to maintenance holes is another type of point repair. This is covered in the following section.

F 945.13 REPLACEMENT

It is not always possible or desirable to rehabilitate an existing pipeline. Hydraulic capacity is frequently a problem and, while renovated systems can exhibit lower friction coefficients and give small increases in capacity, larger pipes are frequently required. Similarly, the existing pipe network may not be located in the most appropriate locations to serve both existing and proposed infrastructure. In such cases it will be necessary to replace or supplement the existing pipes.

Traditionally, open cut and tunnelling methods have been employed in such situations. These techniques have many limitations. Trenching techniques are severely disruptive, particularly in heavily urbanized areas, while tunnelling has only become economic at greater depths and in larger sizes.

In recent years trenchless replacement and construction techniques have been gaining ground on the more traditional methods. These include pipe bursting, microtunnelling, directional drilling, pipe jacking, and fluid jet cutting. In addition, minimum excavation techniques are also becoming more popular in less congested environments.

None of these systems can be considered appropriate in all circumstances. Particular limitations include the close proximity of other buried utilities, the presence of large boulders in the soil, and solid rock.

F 945.13.1 PIPE BURSTING

Pipe bursting is the method of inserting a new pipe of equal or larger diameter into an existing pipeline by fragmenting the existing pipe and forcing the material into the surrounding soil. The enlarged hole is then available for inserting the new pipe. (See Figure F 945.13.1).

The bursting of the pipe material is accomplished by the use of pneumatic or hydraulic bursters. Depending on the specific system, the mole is either directionally guided or towed by a winch, the new pipe being either towed or jacked in immediately behind the mole.

Several designs of bursting heads have been developed, consisting in their simplest form of a series of tubes increasing in size from the front of the machine. Each size increase is accomplished by a conical shaped transition piece. Special expanding knuckles are fitted to the mole to crack the joints. Hydraulic expanding bursting machines have also been developed.

A sleeve pipe is towed directly behind the mole to protect the final pipe from scoring damage by the broken pipe fragments. After the moling operation is completed, the sleeve is lined with HDPE which forms the final pipeline.

Various other final pipe materials have also been used with varying success, including vitrified clay, fiberglass reinforced plastic, and concrete pipes.

The method is suitable for the replacement of pipes manufactured from brittle material such as vitrified clay, unreinforced concrete, asbestos cement, PVC and cast iron. It is not suitable for the replacement of steel, ductile iron, reinforced concrete pipes, polyethylene pipes, or ABS composite.

The size suitability of the system is shown in Table F 945.13.1.

Table F 945.13.1

Size Suitability for Pipe Bursting

Existing Internal Diameter (inches)	8	12	15	18
Size for size internal diameter (inches)	8	12		17.7
Oversize internal diameter (inches)	11	12.4	15.7	__
	12.4	13.8	17.7	__
	13.8	15.7	__	__

The maximum length between insertion pits will depend on many factors including the existing pipe material, joint design, pipe surrounding material and ground conditions. Typically, the length of insertion should be limited to 200 to 300 feet.

Joints can cause considerable delay to the progress of the insertion. It is preferable to approach the bell from the rear, and moles now incorporate stress raising fins to break out joints.
Pipe surrounding material has a particularly noticeable effect. The effect of concrete surround is dependent on the extent of the concrete, its strength, and the bursting capability of the moling equipment. The material surrounding the pipe must be able to accommodate the necessary enlargement of the pipe and not induce frictional affects that cannot be overcome. Trees in the vicinity of a sewer can reduce the rate of progress due to large roots. The ease of replacement increases as the soil type changes from sands and gravels to clays. Moling in sands or cohesionless materials, and particularly wet sands, tends to result in shorter drive lengths than for clays due to the high friction effects caused by almost immediate soil relaxation into the replacement pipe.

The principal advantages of the system are:

a. Speed of installation - with rates of up to 120 feet of installed pipe per hour, a considerable saving over trenching in an urban environment. The insertion rates are often quoted at feet per minute, which does not take account of set-up time, including pipe welding (if continuously welded pipe is used), excavation of the insertion pit and laterals, reconnection and ancillary works. Rates of between 0.5 and 4 feet per minute have been achieved, although hard ground conditions can reduce the rate considerably.

b. Reduced reinstatement costs - particularly in dense urban areas.

c. Improved environmental and traffic management - experience has shown that this may be overstated. Consideration should be given to the location of lead-in trenches, the number of open holes necessary for the reconnection of laterals, and the space required for laying out the pipe.

d. Cost saving with respect to diversion of the utility plant - this is somewhat offset by concern about the effects of the vibrations caused by the system.

e. Lower unit replacement costs - typically 20 to 40 percent lower than conventional open cut methods.

The equipment has a limited size capability, although as the system develops and becomes more widely available, the size range may increase.

The principal disadvantages of the system are:

a. Surrounding materials - the system is only suitable for brittle materials, and cannot always cope with concrete surround. This can be a particular problem if the pipeline construction is not known or only isolated sections are surrounded in concrete. In sewers constructed near bedrock, or on piles, the forces exerted by the bursting machine will be uneven, resulting in a tendency for the equipment to rise. Similar problems may exist where large boulders are located close to the existing pipeline.

b. Rates of progress - particularly dependent on the pipe material and ground conditions, making it difficult to precisely predict construction times.

c. Laterals - it is necessary to excavate all lateral connections and disconnect them before bursting to limit damage, and reconnect them only after the new pipe is fully installed. This may be a problem where large numbers of laterals are involved, and services to the consumers may be cut for an extended period, if construction problems occur.

d. Expansive action - one of the greatest perceived disadvantages is the risk of damage to adjacent services, structures, and the ground surface, particularly where surfaces are paved. The expansive action of the mole results in movements in the material surrounding the pipeline. The amount of movement depends on the soil material, the degree of expansion, and the type of pipe surround, etc. Movement is transmitted through the surrounding material, including strains and bending forces in adjacent pipelines, particularly transverse crossings. These forces can cause movement of the pipeline and, depending on the magnitude of the force and the condition of the pipe, could cause structural damage or leakage at a joint. A significant amount of research has been completed in this area, leading ultimately to pipe proximity charts. Shallow operations will be significantly influenced by the close proximity of the ground surface, leading to a generally upward movement during expansion, with disturbance localized and intensified above the moling process. In deeper expansions, such as those typically experienced for sewers, the zone of disturbance is more likely to be contained by compression in the surrounding soil. In homogeneous soils the expansions will be radial, while the presence of a hard layer below the expansion, i.e. bedrock, piles, trench bottom with weaker backfill, the ground movement will be directed upwards. The degree to which movement is localized and contained by volume change will depend on the strength and compressibility of the backfill.

e. Surface disturbance - will vary from slight heave associated with little visible damage to pronounced heave with severe surface cracking and opening of existing joints and defects. Much of the disturbance will be transient, produced during moling, with some subsequent convergence.

F 945.13.2 MICROTUNNELLING

Microtunnelling has a high unit construction cost when compared to traditional open trench systems. Unless the disruption costs are high and are included in the total construction cost, microtunnelling will not be competitive.

In relation to extraneous flows, microtunnelling may be considered as an option in urban areas where an existing pipeline is to be abandoned, or requires upsizing, but is still below the size for conventional tunnelling.

Microtunnelling is a method of excavation to permit the installation of a pipe by pipe jacking. This requires the use of a remote controlled, steerable tunnel boring machine in the size range of 6 to 36 inch diameter. The machines fall into two categories, auger systems and slurry systems. See Figures F 945.13.2A and F 945.13.2B.

F 945.13.2.1 AUGER SYSTEMS

Auger systems incorporate a series of helical augers within the tunnel boring to transport soil from the cutting head to the jacking pit or starting shaft, where it is removed. The cutting head is connected directly to the auger flight and is driven from an electric motor located in the jacking shaft. A choice of cutting heads is available for differing soil conditions. Crushing heads are also available to deal with cobbles, and recent developments include equipment that can remove existing sewers.

Steering is accomplished by activating several small hydraulic steering jacks near the front of the machine. Directional control is achieved using a laser beam emitter located in the jacking pit, and a target located on the rear of the tunnelling machine. Groundwater at the level of the tunnelling machine can result in over-excavation. This can be limited by the injection of slurry, water, or compressed air at the cutting head.

F 945.13.2.2 SLURRY SYSTEMS

A small diameter discharge pipe installed within the lining of the tunnel carries the soil removed by the slurry shield machine directly to a treatment tank at ground level. The slurry liquid normally consists of a bentonite/water mixture, although water alone may be suitable in some soils or machines. In soils containing cobbles or stones, a crushing head is needed to grind the material down to a consistency suitable for passing through the small diameter discharge pipe. The drive to the cutting head is applied directly from a motor and gearbox located at the front of the tunnelling shield. Steering and control takes place in a manner similar to that used in the auger system (Figure 945-13.2B).

F 945.13.2.3 PIPE INSTALLATION

The pipeline is jacked behind the microtunnelling machine, thereby providing the forward motion of the machine. Additional lengths of pipe are added at the insertion pit, the cycle continuing until the complete pipe string is pushed or jacked forward. Pipes are manufactured from a variety of materials including concrete, vitrified clay, fiber reinforced plastic, fiber reinforced cement, asbestos cement, ductile iron, and steel. Special joints have been developed to provide a smooth internal and external profile, the joints being contained within the pipe wall. The joint should also be designed to cope with the jacking forces, and be capable of small deflections without leakage. Other specific requirements of a jacking pipe are that it should be able to withstand direct and eccentric jacking forces, soil and traffic loads should be supported safely, and the pipe material should have sufficient durability for the sewer environment.

The advantages of microtunnelling are the close control of line and grade, and capability of installing a permanent lining in standard lengths between access points. The ability to work in difficult ground conditions and in congested areas with minimal surface disruption. Also, it is competitive at depths greater than 15 to 20 feet.

Disadvantages include high initial capital cost, requiring extensive support services. Larger obstacles such as boulders can cause considerable difficulty. The system is only suitable for applications where deep pipes require replacement with larger pipes, or where there is insufficient scope for reducing extraneous flows in upstream sewers, creating a need for additional interceptor sewers in the downstream reaches.

F 945.13.3 OTHER TRENCHLESS SYSTEMS

The other trenchless type systems available, while significant in their development, are not directly applicable for use in dealing with problems of extraneous flows. Such techniques include steerable systems such as directional drilling and fluid jet cutting, and non-steerable systems such as impact moling, impact ramming, and auger boring.

F 945.13.3.1 DIRECTIONAL DRILLING

Directional drilling is used predominantly for the installation of long, vertically curved pipelines, usually under bodies of water such as rivers, estuaries, and canals (See Figure F 945.13.3.1). Using substantial surface equipment, and being capable of drives well in excess of 3,300 feet, the technique is best suited to major installations which warrant the use of the expensive and heavy equipment.

The technique involves the drilling of a small diameter pilot hole in a shallow arc. A washover pipe slightly larger than the pilot tube follows the drill string, acting both as temporary support and a method of reducing friction on the drill string prior to enlargement. The completed pilot bore is enlarged using back reaming techniques until large enough to receive the final pipe, which is normally steel, although PE and bundles of pipes have also been used.

F 945.13.3.2 FLUID JET CUTTING

Fluid jet cutting uses a remote controlled and guided tool which incorporates high pressure (1,000 to 4,000 psi) slurry jet nozzles for cutting soil to provide a pilot bore. (See Figure F945.13.3.2) The final "tunnel," available in sizes between 2 and 14 inches in diameter, can be up to 400 feet long and 34 feet deep. The process is monitored from the surface, and adjustments to the direction of drilling made in both the vertical and horizontal planes. Accuracy is within $\pm$ 6 inches, making the system suitable for pressure lines and gravity lines where the tolerance to line and level is not critical.

F 945.13.3.3 IMPACT MOLING

Also known as soil displacement hammers and piercing tools, use compressed air to drive a cylindrical percussive hammer through the soil to form a hole. The soil is simply consolidated, and not removed from the pipeline. The system is non-steerable, and is not appropriate for gravity lines.

F 945.13.3.4 IMPACT RAMMING

Impact ramming is a development of impact moling where a large impact mole, located in a drive pit, is used to hammer a steel casing into the ground. Soil enters the open ended sleeve, and is removed by jetting, mechanical cutting, or simply pushing out the soil plug. The system is limited in drive length to about 100 feet, and is only applicable to medium and larger crossing type work over modest lengths.

F 945.13.3.5 AUGER BORING

Auger boring consists of a rotary cutting head followed by an auger flight that is used for soil removal. The equipment has a wide use in crossing type work, but is not appropriate for dealing with extraneous flow problems.

F 945.13.4 CONVENTIONAL REPLACEMENT

The ultimate, and perhaps most complete solution to extraneous flow problems is complete replacement of the pipeline. This is also achieved, to some degree, with some of the lining and trenchless replacement options, in that a new pipe is provided. The inflow part of extraneous flows is not solved.

Traditional open cut techniques are often economical in relatively open suburban and rural environments, where the disruption can easily be accommodated. In heavily congested urban areas, or where the sewers are deep, lining and trenchless systems become more cost competitive.

Tunnelling only becomes an option when large sewers with severe extraneous flow problems are to be rehabilitated.

F 945.14 SEWER BYPASSING

When a sewer pipeline requires replacement or rehabilitation it usually requires bypassing of flows. A bypassing method shall be implemented to minimize spillage. Temporary, bypass pipes and pumps are usually installed so that the sewerage flows out of the upstream maintenance hole past the rehabilitated or replaced pipeline and into the downstream maintenance hole.

F 945.15 MAINTENANCE HOLE REHABILITATION

Maintenance holes are rehabilitated to correct structural deficiencies, to address maintenance concerns, and to eliminate extraneous flows. Maintenance hole rehabilitation may also minimize or prevent corrosion of the internal surface caused by sulfuric acid formed when hydrogen sulfide gas is released from the sewerage into the sewer environment (Figure 945.15).

Many methods to rehabilitate maintenance holes are currently available. New products and application technologies are continually being developed. The evaluation of each method should consider:

a. The type or types of problem

b. The physical characteristics of the structure such as the construction material

c. The condition and age

d. The location of the maintenance hole with respect to traffic and accessibility

e. The risk of damage or injury associated with the current condition of the structure

f. The cost/value in terms of rehabilitation performance.

F 945.15.1 MAINTENANCE HOLE CONDITIONS

The following subsections discuss maintenance hole conditions which could result in maintenance hole rehabilitation work.

F 945.15.1.1 STRUCTURAL DEGRADATION

The definition of structural degradation varies with maintenance hole material composition, shape, and size. Structural degradation does not necessarily mean structural failure. For purposes of maintenance hole inspections, structural degradation may be defined as damage to any of the structural components of a maintenance hole. Structural degradation can occur due to the following:

a. Movement and Displacement: Structural degradation of maintenance holes will occur with three dimensional displacement and movement. In areas where temperature variations are common, degradation of the frame seal, chimney and top portion of the cone can occur. Vertical separation can be dramatic, particularly where maintenance hole frame castings are monolithically encased with rigid and flexible pavement. Horizontal movement of the frame occurs as the encased frame reacts to the thermal expansion and contraction of the surrounding pavement caused by temperature variations. Three dimensional movement can also occur to the entire maintenance hole structure due to settlement and movement of the ground around the maintenance hole. This differential movement can be pronounced in certain clay or unstable soils. Such loading can impose unbalanced point loadings and increase tensile stress failures. Maintenance holes made of brick and block are particularly susceptible to displacement and joint separation where unstable soils exist. Traffic induced loads can result in three dimensional movement of the maintenance hole cover, frame and chimney section causing cracks and fractures.

b. Corrosion Environments: When sulfides are present in the wastewater stream due to the natural biodegradation of the sewage, structural deterioration is likely to occur to all concrete surfaces. The factors that control sulfide generation are:

1. Wastewater velocity

2. Ambient water pH, and air temperature within the sewer system

3. Oxygen availability

Under extreme conditions, total structural degradation of unprotected concrete maintenance holes can occur in less than five years. Hydrogen sulfide structural degradation of a maintenance hole can be controlled through effective maintenance hole rehabilitation, although wider measures may also be appropriate to control the generation of the sulfides.

F 945.15.1.2 EXCESSIVE EXTRANEOUS FLOW

Recent studies have indicated that a significant percentage of identified extraneous flow is from defective maintenance holes. Factors which need to be considered when evaluating and quantifying potential extraneous flow from maintenance holes include:

a. Ground saturation
b. Water table fluctuations
c. Inspection data on type and condition of maintenance hole

A relative ranking of several common maintenance hole extraneous flow sources that contribute to the problem of excessive wet weather flows are listed in Table F 945.15.1.2.

Table F 945.15.1.2
Ranking of Maintenance Hole Infiltration

Source Defect	Extraneous Flow Type	GPM Range
Vented Cover(1)	Inflow	1.0 - 3.0
Poor cover/rim fit	Inflow	0.1 - 5.0
Frame seal	Inflow	0.5 - 5.0
Cone(2)	Infiltration(3)	0.1 - 5.0
Wall(2)	Infiltration	0.1 - 2.0
Bench/trough	Infiltration	0.1 - 2.0

(1) Includes pickhole vent chips that are subject to ponding
(2) Priority brick, block, precast, cast-in-place
(3) Rainfall induced

F 945.15.1.3 MAINTENANCE

Conditions that hinder normal maintenance and operations of a collection system should be considered in maintenance hole rehabilitation. These conditions include:

a. Deteriorated maintenance hole steps
b. Offset frames
c. Buried maintenance holes
d. Maintenance holes that are inaccessible due to location
e. Other utilities passing through maintenance holes
f. Non-structural problems that affect operations and maintenance access to the collection system

F 945.15.2 REHABILITATION METHODS

The rehabilitation of maintenance holes can be divided into the following methods:

a. Chemical grouting
b. Coating systems
c. Structural linings
d. Corrosion protection
e. Maintenance hole components

F 945.15.2.1 CHEMICAL GROUTING

Chemical grouting systems have achieved success in reducing extraneous flows into maintenance hole structures. When applied properly, the process is a cost-effective option. Grouts do not add to the structural integrity of the maintenance hole. The success of grouts in reducing maintenance hole extraneous flows is largely dependent on:

a. Soil conditions
b. Groundwater conditions
c. Injection patterns
d. Gel time/grout mixture
e. Containment of excessive grout migration
f. Selection of the proper type of grout

There is a wide range of grouts on the market for pressure application. These include acrylamide, acrylate, acrylic, urethane gel, and urethane foam. (See F 945.1)

The common applications for pressure grouts are for:

a. Brick maintenance holes
b. Active extraneous flows
c. Structurally sound maintenance holes
d. Cohesive soils with optimal moisture content
e. To improve and fill voids or stabilize the surrounding soil

Careful inspection of the contractor's work during the actual grouting operation is essential to insure adequate grouting of the structure. A test program should be performed after grouting to verify proper maintenance hole sealing. Some considerations for high-pressure grouting applications are as follows:

a. Ambient air temperature above 40 degrees F
b. Chemically stable and resistant to acids, alkalis, and organics
c. Controllable reaction times
d. 15 percent shrinkage control
e. Viscosity of approximately 2 centipoise
f. Constant viscosity during injection period

Differing gel types should be considered for use on different areas and depths of the maintenance hole structure. This approach has been successfully applied in some projects, although other projects have been successful utilizing only one type of gel for all depths. For projects with varying gel types, urethane foams have been used in the upper 5 feet of the maintenance hole with urethane or acrylamide gels in the lower sections.

F 945.15.2.2 COATING SYSTEMS

Coating systems have been used to restore maintenance hole structures for several years. Coating systems range widely in their applications. In each application, a cementitious material containing Portland cement, finely graded mineral fillers, and chemical additives is applied in one or more layers to the interior of a maintenance hole that has been adequately cleaned and prepared. Most coating systems provide for both mechanical and chemical bonding. The system can be used to coat the entire maintenance hole, including reconstruction of the bench and invert. Coatings are ideally suited for brick structures that show little or no evidence of movement or subsidence, since the coatings have little intrinsic structural qualities in shear and tension.

The most common and successful application is where the following conditions are prevalent:

a. Brick structure

b. Observed extraneous flows
c. Missing of deteriorated mortar joints
d. Site conditions that prevent excavation or reconstruction

Coating systems can be machine or hand applied. Surfaces should be prepared by high-pressure water blasting, using a minimum pressure of 5,000 psi to etch the structure and remove defective material. All active extraneous flows should be eliminated before coating the maintenance hole. Where necessary, voids should be hand packed with an appropriate patching compound. If the potential for H_2S generation exists, the finish coat should be protected with an inorganic liquid polymer product to impregnate and protect the final surface. As an alternative, corrosion-resistant additives can be incorporated into the mix design. The entire process (cleaning, prep, coating, and clean-up) should be carefully monitored if an independent contractor is performing the work. Post-rehabilitation dyed-water testing should be performed on a random sample of completed maintenance holes to insure a successful project.

There are several coating systems available under various trade names. In general, they are variations of the same basic components and mix designs. The basic coating "system" and characteristics of each component of the system that produce an effective application for maintenance hole renewal are as follows:

a. Patching Compounds - Rapid set (20 min.), self-bonding, high strength concrete patching mortar, must be resistant to temperature fluctuation environments, minimum compressive strength of 4,000 psi (30 days), maximum volume change of 0.02 percent, and contain no calcium chloride, gypsum, lime or high alumina cements.

b. Plugging Compounds - Used for locations of "active" infiltration, set time of 30-60 seconds, mix design conforming to ASTM C150 and ASTM C144, mechanical and active chemical bonding to saturated surfaces.

c. Coating Compounds - Mix design includes cementitious pozzolonic mix of portland cement, chemically-active aggregates, and proprietary additives to enhance system performance, minimum 30-day compressive strength of 3,000 psi and a tensile strength of no less than 10 percent of compressive strength, chemical bond must meet or exceed 150 psi, coating system must meet or exceed specification based on ASTM C495, C496, C293, C596, C666 (Method A), C267, and C321.

If properly applied, and under low corrosion-potential conditions, mechanical and chemical bonding will meet or exceed the 10-year longevity criteria established for most coating systems. For aggressive environments, it is not recommended to provide sacrificial thickness to the coating system. A specification should require the contractor to add sulfide-resistant additives to the mix design. In very aggressive corrosive atmospheres, plastic, polymer or epoxy coatings/linings should be used. The remaining factor that can significantly impact the longevity of the coated structure is creep or long term differential movement of the maintenance hole structure. Since most coating systems have very little shear or tensile strength, cracks may develop.

F 945.15.2.3 STRUCTURAL LININGS

Structural rehabilitation of a maintenance hole is any method that totally restores the structural integrity of a maintenance hole through in-place, non-destructive methods. In-situ rehabilitation methods, such as poured-in-place concrete, have been used in a variety of applications. The application of reconstruction methods has been limited to the following conditions:

a. Standard maintenance hole dimensions, i.e. 48 to 72 inch inside diameter
b. Substantial structural degradation
c. Accessible location
d. Project size
e. Life-cycle cost justification

The condition of most maintenance hole structures does not justify structural reconstruction on the sole basis of reducing and controlling extraneous flows. Reconstruction methods are not cost competitive with coating and pressure grouting systems based on initial construction cost. Consideration should be given to a life-cycle cost analysis of reconstruction. Structural reconstruction methods that are currently available are:

a. Poured-in-place concrete
b. Placed PVC rib-lock liner
c. Prefabricated reinforced plastic mortar
d. Prefabricated fiberglass reinforced plastic
e. Prefabricated high density polyethylene
f. Spiral-wound liner
g. Cured-in-place structural liners

A typical section through a rehabilitated maintenance hole is shown in Figure F 945.15.2.3.

General recommendations for structural lining methods that need to be used are:

a. Minimum finished inside wall diameter of 36 inches
b. Six-bag (Type I or II) portland cement mix design
c. Minimum 30-day compressive strength of 3,500 psi
d. Minimum wall thickness of 3 inches for maintenance hole depths up to 10 feet, special analysis beyond 10 feet
e. Special cement mixes for corrosion resistance

Any linings should be designed to withstand the external pressures imposed by the groundwater. Vertical traffic/ground loadings will be carried by the existing maintenance hole structure, as it would be difficult to stand the lining on suitable foundations or provide sufficient thickness to carry the loads without restricting the access size.

If vertical structural deterioration is the problem, total replacement may be the most economic solution. The economies of such rehabilitation depend on such factors as severity of chemical attack or corrosion, location, depth of maintenance hole and water table, number of maintenance holes requiring rehabilitation or replacement, and wastewater flow control measures needed.

In some situations, structural rehabilitation is not practical, and replacement is necessary. The details of maintenance hole construction are widely known, and replacement should always include safety and operational considerations. Additionally, replacement often is preferable to other rehabilitation measures where temperature fluctuations create special problems.

Rehabilitation should also include measures to ensure maintenance hole safety and efficient channel hydraulics. Access ladder rungs and step irons are important for safety and, if the maintenance hole is seriously deteriorated, are frequently also suspect. Many communities and wastewater agencies do not install steps in new maintenance holes. Weak rungs should either be replaced with a new corrosion-resistant rung or removed completely.

The efficiency of the present channel should also be evaluated. If the flow is restricted or if disturbances are causing extraordinary head losses, repair work should improve the hydraulic characteristics. The existing base may have to be partly removed and reconstructed to provide better geometry and/or surface finish. Flows must be plugged temporarily and quick-setting products used, or flows temporarily rerouted while the structure is being repaired. Flexible sleeves can also be used to contain flows during repair.

Another important consideration is the entry requirement of maintenance equipment. Cleaning tools, TV cameras, and in-line rehabilitation tools, such as grouting packers all require about 24 inches of straight pipe access. The channel should be built accordingly and self-cleaning benching provided.

F 945.15.2.4 CORROSION PROTECTION

Maintenance holes subjected to corrosive atmospheres must be protected with a non-cement type coating. The marketplace offers a variety of plastic, polymer, and epoxy coatings that are effective in protecting the maintenance hole walls from the corrosion of sulfuric acid. Bituminous coatings have not proven to be effective in corrosion control of maintenance holes. The effectiveness of corrosion protection is dependent on the
preparation and cleaning of the substrate wall of the maintenance hole.

F 945.15.2.5 MAINTENANCE HOLE LEAKAGE

Leakage problems common with maintenance hole frames and covers include surface water entering through the holes in the cover, through the space between the cover and the frame, and subsurface water entering under the maintenance hole frame. Tests have consistently shown that these sources account for a significant portion of maintenance hole leakage.

Ground movement, thermal expansion and contraction of the surrounding pavement and traffic loadings cause the seal between the frame and cover to break and deteriorate, allowing subsurface water to enter the maintenance hole. This water, entering the maintenance hole after running along pavement subgrades, washes subgrade material in with it, resulting in the settlement of the pavement around the maintenance hole.

Maintenance hole covers can be sealed by either replacing them with new watertight covers; by sealing existing covers through the use of rubber cover gaskets and rubber vent and pick hole plugs; or by installing watertight inserts under the existing maintenance hole covers.

The maintenance hole frame-chimney joint area can be sealed internally without excavation when frame alignment and chimney condition permit or either internally or externally when realignment or replacement of the frame or reconstruction of the chimney and/or cone requires excavation. This sealing can be achieved by either installing a flexible manufactured seal, designed for this purpose, or by applying a flexible material to either the surface of the chimney and frame or between the adjusting rings and under the frame.

The method used must not only be watertight but must also have the flexibility to allow for the repeated movement of the frame through out the project's design life.

Table F 945.15.2.5 lists rehabilitation options, advantages and disadvantages.

Table F 945.15.2.5

MAINTENANCE HOLE REHABILITATION OPTIONS

Rehabilitation Options	**Principal Advantages**	**Principal Disadvantages**
Rehabilitation of maintenance hole structure by plugging, patching , and coating and sealants. (Both non-cementitious& cementitous , with or without plastic lining)	Improve structral conditon, eliminate leakage and provide corrosion protection. Little distruption	Will not rehabilitate badly deteriorated or structurally unsound maintenance holes
Repair or rebuilding of maintenance hole chimney and cone section when excavation is required	Rehabilitate badly deteriorated or structurally unsound chimney and cone section	Excavation required
Step removal and / or replacement	Improve access and safety and eliminate leakage	Installation difficulty, cost
Replacement of maintenance hole frame and cover	Improve service life and alignment, adjust grade, and eliminate leakage	Excavation required, cost
Structural relining	Renew structural integrity	Reduction of diameter, cost
Sealing of frame-chimney joint and chimney above cone	Eliminates inflow while allowing movement of the frame	Minor reduces access in chimney, cost
Seal or replace cover, or install insert	Eliminates inflow and stop rattle	Raises cover slightly

Table F 945.15.2.5 (cont'd.)

MAINTENANCE HOLE REHABILITATION OPTIONS

Rehabilitation Options	Principal Advantages	Principal Disadvantages
Chemical grouting of maintenance hole structure	Eliminates infiltration and fills voids in surrounding soil	Does not improve or rehabilitate interior of maintenance hole
Total replacement	New maintenance hole	Cost

F 945.16 SEWER LATERAL REHABILITATION

Service lateral sewers are pipelines that branch off the sewer main and connect building sewers to the public sewer main. Lateral sewers may be as small as 4 inches in diameter, normally ranging from 15 to 100 feet in length.

Lateral sewers are built with any one of several products and are usually laid at a minimum self-cleansing grade from the building to the immediate vicinity of the main sewer. At the main sewer, the grade may change abruptly in order for the line to descend to the main sewer. Lateral sewers normally enter sewer mains at angles ranging from 30 to 90 degrees from the axial flow direction and at vertical angles ranging from 0 to 90 degrees. In some developments, the same trench is used to route potable water service connections and the lateral sewer. Any leaks in the potable water line can enter the lateral sewer line if it is not watertight.

The construction and maintenance of lateral sewers is complicated because separate agencies have jurisdiction over different portions of the sewers. The connection between the building's plumbing and drain system and the property line is often considered an extension of the in-structure facilities; therefore, it is ordinarily installed under plumbing or building codes and tested and approved by plumbing officials or building inspectors. The section of the lateral sewer between the property line and the street sewer, including the sewer main connection, usually is installed under sewer use rules. Inspection and approval are the responsibility of the Department of Building and Safety and the Public Works - Engineering Division.

For many years the effect of leaking lateral sewers on the collection system and treatment facilities was considered insignificant. Research studies sponsored by EPA indicate that in many cases a significant percentage of the extraneous flows is the result of defects in lateral sewers. These defects include cracked, broken, or open-jointed pipes. Lateral sewers may also transport water from inflow sources such as roof drains, cellar and foundation drains, basement or sub-cellar sump pumps, and "clean water" from commercial and industrial effluent lines.

F 945.16.1 REHABILITATION METHODS

Some of the rehabilitation methods used for larger main sewers are also applicable for service laterals. These include chemical grouting, cured-in-place pipe lining, deformed pipe lining, pipe bursting, and spray-on lining. The reduction in capacity imposed by conventional sliplining methods in smaller pipelines makes such rehabilitation an unlikely option.

Unlike rehabilitation of main sewers, access to lateral sewers can often be limited, making rehabilitation more difficult. This is often combined with the additional problems of tree roots, structures and landscaping over the sewers. However, these problems also have a greater impact on the conventional replacement systems.

F 945.16.1.1 CHEMICAL GROUTING

Three chemical grouting methods are currently available for sealing lateral sewers: pump full method, sewer sausage method (patented process), and camera-packer method (patented process).

a. Pump Full Method: This method involves injecting a chemical grout through a conventional sealing packer from the sewer main up the lateral sewer to an installed plug. As the grout is pumped under pressure, it is forced through the pipe faults into the surrounding soil where a seal is formed after the gel has set. After the sealing has been accomplished, excess grout is augured from the lateral sewer and it is returned to service.

b. Sewer Sausage Method: This method uses a camera-packer unit in the sewer main with the injection of grout from the sewer main up the lateral sewer to seal the pipeline. A tube is inserted into the lateral sewer before sealing to reduce the quantity of grout used and to minimize the amount of cleaning required after the sealing has been completed. The grout is pumped under pressure around the tube, up the lateral sewer, and through any pipe faults into the surrounding soil where the seals are formed after the gel sets.

c. Camera-Packer Method: Unlike the other methods described, this method only repairs faults seen through a television camera. First, a miniature television camera and a specialized sealing packer are inserted into the lateral sewer. Using a tow line previously floated from the lateral sewer access to the downstream maintenance hole of the sewer main, the camera-packer unit is pulled into the lateral sewer. The camera-packer is then slowly pulled back out, repairing faults that are seen through the television camera. The deepest leaking joints are sealed first. Joints and cracks are sealed in a manner similar to the conventional methods used for sealing joints in sewer mains. Once the repairs have been completed, the equipment is removed and the lateral sewer returned to service. The costs for this method vary, depending on the difficulties encountered when repairing lateral sewers. When estimating costs, allowances should be made for such things as difficult site access and excavation dewatering.

F 945.16.1.2 CURED-IN-PLACE PIPE LINING

The technology for sealing lines as small as 4 inches by Cured-in-Place (CIPP) lining is in common use. As with sewer mains, CIPP lining will reduce extraneous flows and improve the structural integrity of the existing pipeline.

The steps for lining a lateral sewer using the CIPP process are similar to those for lining a sewer main. An access point requiring excavation, is usually needed on the upstream side of the lateral sewer. Another variation from sewer main installations is the use of a special pressure chamber to provide the needed pressure to invert the fabric material through the lateral pipeline. The fabric is terminated at the entrance of the lateral sewer to the sewer main.

After the curing process is completed, the downstream end of the liner is opened by excavation or via a remotely controlled cutting device placed in the sewer main. The upstream end is trimmed and the newly lined pipe is connected to the rest of the existing lateral sewer, restoring it to service. The excavated soil is then replaced and all equipment is removed, completing the process.

F 945.16.1.3 SPRAY-ON LININGS

Recent developments in spray-on lining technology shows significant promise for relining small diameter sewers. The basic technology is the same as for larger sewers, although with miniaturized equipment. Difficulty may be experienced with bond in areas of high infiltration.

For a discussion of the other lining systems (Deformed U-liner pipe and folded Nu-Pipe, Rolldown and Swagelining, and Pipe Bursting) see the relevant subsections under F 945 or F 946.

F 945.16.1.4 OTHER REHABILITATION MEASURES

The methods discussed above to rehabilitate service laterals will reduce extraneous flows resulting both from high groundwater levels and from rainstorms. In addition to these repairs, efforts need to be made to remove sources of inflow that may be connected to the lateral sewer. Inflow sources connected are usually located on private property. A public awareness/public relations program often is needed. Such programs are intended to persuade property owners (without threat of legal consequences) to make the needed repairs to help correct a community problem.

The following table lists typical types of inflow sources found on private property and possible rehabilitation measures.

Table F 945.16.1.4A
Typical Inflow Sources on Private Property & Rehabilitation Measures

Inflow Source	Possible Rehabilitation Measures
Connected downspout	Plug service connection opening and redirect downspout
Connected storm sump	Repipe to grade
Connected storm sump with diverter valve	Remove diverter valve
Defective or broken cleanout	Repair or replace as necessary
Connected area drain	Disconnect drain and install new sump pump
Connected crawlspace drain	Seal drain and install new sump pump
Connected foundation drain	Disconnect drain and install new sump pump

The following table lists rehabilitation options, advantages and disadvantages.

Table F 945.16.1.4B

LATERAL CONNECTION REHABILITATION OPTIONS

Rehabilitation Option	Principal Advantages	Principal Disadvantages	Diameter Range
Internal Grouting	Seals leaking joints and minor cracks Prevents soil loss Low cost and minimal disruption Can reduce infiltration Can include root inhibitor		4” and larger
	Rapid installation No excavation Accommodates deformation Maximizes capacity Grouting not normally necessary	Full bypass pumping necessary Sole source often necessary High set-up costs on small projects	4” to 108”
Other Rehabilitation Measures (U-Liner, Nu-pipe, Pipe Bursting, Coatings & Directional Drilling)	See Other tables	See other tables	See other tables

F 946 MISCELLANEOUS METHODS AND MATERIALS

There are several relatively new rehabilitation methods and materials that are being introduced into the United States. Most of this technology has been developed internationally, is proprietary and is gradually being promoted into this country. It is difficult to discuss this generically, therefore the specific trade names will be provided and described briefly in this subsection. The order of this presentation has no bearing on their relative viability. Those methods and materials discussed in detail in Section F 940 shall not be addressed here. These methods and materials are currently being evaluated by the "Wastewater System Engineering Division"

F 946.1 PIPELINING

The rehabilitation methods of pipelining technologies shall be discussed and includes:

a. Cured-in-Place Pipe
b. Deformed Pipe
c. Spiral Wound Pipe
d. Segmented Slipline Pipe
e. Pipe Bursting and Sliplining

F 946.1.1 CURED-IN-PLACE PIPE

The cured-in-place pipe technologies shall be discussed and include:

F 946.1.1.1 INLINER

A polyester felt tube impregnated with a thermosetting plastic resin is placed by pulling the liner into the original pipeline. The curing is completed by circulating hot water followed by cool-down under pressure.

F 946.1.1.2 PALTEM

A woven seamless polyester fabric tube impregnated with an epoxy resin. The liner with resin is inverted into the original pipeline by air pressure and is steam cured.

F 946.1.1.3 PHOENIX

Similar to Paltem.

F 946.1.2 DEFORMED PIPE

The deformed pipe technologies are shown in Figure F 946.1.2 and include:

F 946.1.2.1 ROLLDOWN

An extruded polyethylene pipe with outside diameter approximately 2.5 percent larger than the original pipe's inside diameter. The rolldown process reduces the diameter by approximately 10 percent for pull through insertion and then stabilizes, conforming to original pipe's diameter (Figure 946.1.2.1).

F 946.1.2.2 SWAGE LINING

Extruded medium or high density polyethylene is fused at the job site and pulled through a heating element. The pulling process reduces the diameter approximately 12 percent thence it is pulled and pushed through the original pipeline. The PE is sized for a tight fit into the original pipeline after it stabilizes. (See Figure 946.1.2.2).

F 946.1.3 SPIRAL WOUND PIPE

F 946.1.3.1 ETERLINE

Similar to Danby except that the continuous spiral joint utilizes two rubber gaskets for sealing.

F 946.1.3.2 RIB LOC

Similar to Danby except that the continuous spiral joint utilizes a water activated polyurethane adhesive for sealing.

F 946.1.4 SEGMENTED SLIPLINER PIPE

The segmented slipliner pipe technologies will be discussed and includes:

F 946.1.4.1 DEMCO TERRALINE

Short lengths of threaded polyolefin pipe are joined in a maintenance hole and are pulled into the original pipeline. The threaded flush joints are sealed with a mastic compound or O-ring.

F 946.1.4.2 INTERLINE

A polyethylene membrane is pulled through the original pipeline. Short lengths of PVC liner are then inserted through the membrane.
A third temporary sleeve is then inserted prior to grouting the annulus.

F 946.1.4.3 RINTUBE

Short lengths of injection molded polypropylene are inserted into the original pipe. The segments are positioned between service laterals and the annulus is remotely grouted.

F 946.1.4.4 VIP-LINER

HDPE pipe having short lengths is inserted into the original pipeline at the maintenance hole. Service laterals are precut and the annulus is grouted.

F 946.1.5 PIPE BURSTING AND SLIPLINING

The pipe bursting and sliplining technologies will be discussed and includes:

F 946.1.5.1 EXPRESS

The existing pipe is burst by mechanically expanding equipment which is then contracted for ease of movement. This process is normally utilized for increasing the pipe diameters insitu. The various plastic liner pipe, e.g. GRP, PVC, HDPE are pulled through the newly broken pipeline.

F 946.1.5.2 PIPE INSERTION MACHINE (PIM)

Similar to Express except HDPE is normally pulled through the original pipeline.

F 946.1.5.3 XPANDIT

The system equipment is placed in the pipeline through a maintenance hole access. The pipe bursting head is pulled through the existing pipeline and hydraulically expanded, breaking the brittle pipe. Three foot long HDPE pipe segments are pushed through the pipeline directly behind the head. The HDPE pipe is of equal size or larger than the existing pipeline.

F 946.2 MECHANICAL REFORMING

Mechanical reforming provides a structural repair by utilizing an insitu no-dig rehabilitation method.

F 946.2.1 LINK PIPE

PVC multi-hinged segments which are collapsed for positioning in the damaged pipeline. A remote or direct controlled jacking device then expands the collapsed segments in the pipeline.

F 946.2.2 SNAP-LOCK

Similar to Link Pipe except the materials are made from Stainless Steel Sheet.

F 946.2.3 MAGNALINE

Cylindrical electomeric burster is hydraulically operated placing

PVC pipe with clips in the original rerounded pipe.

F 946.3 LOCATING SERVICE CONNECTIONS

Various types of equipment has been developed for locating service connections after a pipeline has been sliplined. These technologies permit insitu reconnection without street surface disruption.

F 946.3.1 INSIGHT

Thermal imaging camera permits locating the service connection through the liner.

F 946.3.2 GULECTRON

After sliplining is completed, a locator/cutter/TV assembly can locate service connections using a built-in "radar system".

F 946.3.3 HYDRO-JETCUT SYSTEM

The system uses a scissor-jack device for remotely placing transponders in service connections, one at a time, prior to sliplining. After lining, the locator/cutter can accurately center the cutter at the service connection.

F 946.4 CUTTING IN SERVICE CONNECTIONS

The reinstatement of service laterals without disturbing the above ground streets is normally preferred. Various mechanical and/or hydraulic cutters have been researched for accomplishing this task.

F 946.4.1 GULECTRON

This mechanical lateral cutter can drill, cut and mill plastic, steel, clay and concrete materials. Water is used to cool the milling head and also to clean the lens of the integral TV camera.

F 946.4.2 HYDRO-JETCUT SYSTEM

The cutter has two water nozzles which are rotated on an arm to cut a circular hole. The cutter can also operate at an angle for cutting an elliptical hole. The cutting is normally achieved at a pressure of 4500 psi but can operate up to 10,000 psi.

F 946.5 CUTTING-OFF SERVICE CONNECTIONS AND ROOTS

In advance of sliplining and/or inversion it is necessary to remove protruding service connections and heavy root systems.

F 946.5.1 AMKRETE PROCESS

This skid mounted, air powered, diametrically expanding, steel saw type rotary cutter can be used for cutting sewer intruding objects.

F 946.5.2 AQUACUT SANDJET SYSTEM

This system uses water at about 2,000 psi combined with dry sand to cut intruding objects made of iron, steel, concrete, plastic, clay, scale and also roots.

F 946.5.3 DRILLING EQUIPMENT

Similar to the Amcrete Process

F 946.5.4 HYDRO-JETCUT SYSTEM

This system uses water at pressures up to 10,000 psi and 14 GPM to cut intruding objects made of concrete, plastic, clay, scale, rubber gaskets and also roots.

F 946.6 AMER-PLATE PVC T-LOCK

Extruded sheets of PVC T-Lock placed over the exterior of corroded concrete pipe. These sheets are attached to the existing pipe with adhesive. The seams between adjacent sheets of the liner are sealed by heat-fusing a PVC weld strip over the interface. Then a reinforced concrete cap is placed over the PVC sheets.

F 950 REHABILITATION LIFE PROJECTIONS

F 951 INTRODUCTION

Materials for pipeline rehabilitation projects are often selected based on the lowest initial cost of the alternatives. When the alternative materials have different life spans, the material with the lowest initial cost may not be the most economical choice if its expected service life is shorter than that of the other materials.

Alternative materials should be evaluated by using the least-cost analysis. This method equates the cost of materials that have different service lives. Least-cost and life-cycle analysis will be discussed in detail in Section F 970.

In order to accomplish a correct least-cost or life-cycle analysis, it is first necessary to develop the expected longevity of each replacement pipe and/or rehabilitation alternative. Tables found in the following sections provide projected service life values.

F 952 REPLACEMENT PIPE LIFE

Replacement pipe life projections are listed below for various pipe materials:

Table F 952
Replacement Pipe Projected Life

MATERIAL	DIAMETER (inches)	PROJECTED LIFE (years)
Vitrified Clay Pipe	4-42	75
Reinforced Concrete Pipe(with PVC liner)	42-264	75
Plastic Pipe	4-15	50

Note: The projected life values are based on proper design, construction, inspection, and maintenance of the facility.

See Section 400 for a discussion of these pipe materials.

F 953 REHABILITATION MATERIALS

Rehabilitation pipe material life projections are listed below for each alternative.

Table F 953A
Rehabilitation Materials Projected Life

Materials	Wall Design	Diameters (inches)	Projected Life (years)
Polyethylene	Solid	4-63*	50
Polyethylene	Corewall	18-72	50
Polybutylene	Solid	3-42*	50
Polyvinyl Chloride	Solid	4-36	50
Ductile Iron	Solid	4-60	75
Steel (Stainless)	Solid	4-120	25 (75)
Cured-in-place pipe	Composite	4-108	50

* Nominal outside diameters. All others are based on nominal inside diameters.

Note: The projected life values are based on proper design, construction, inspection, maintenance and operation.

When the slipliner outside diameter is greater than 90 percent of the existing pipe inside diameter, grouting is not necessary and/or is impractical. Special design, construction, inspection, and maintenance provisions must be made in order to minimize the problems occurring when not grouting.

Ductile iron pipe has excellent long term longevity. The selection of cement or polylining should be determined by the sewer corrosivity.

Steel pipe has excellent structural characteristics and can be varied in thickness. Steel does have low corrosion resistance, therefore it has been given a projected twenty five year life.

Certain grades of stainless steel (Series 300) have excellent corrosion resistance features and should be evaluated under some conditions. Rehabilitation material life projections are listed below for each alternative.

Table F 953B

Rehabilitation Materials Projected Life

Material	Projected Life (years)
Chemical Grouting:	
Acrylamide	20
Acrylic	20
Acrylate	20
Urethane	20
Urethane Foam	20
Reinforced Shotcrete:	20
Concrete	20
Segmented Liners:	
Polyethylene	50
Polyvinyl Chloride	50
Steel (Stainless)	25 (75)
Coatings and Linings	*
Mechanical Sealing Devices	*

Case-by-case basis

Note: The projected life values are based on proper design, construction, inspection, maintenance and operation.

F 960 EVALUATION ASSESSMENTS

F 961 INTRODUCTION

The goal of rehabilitation work on sewers is to arrest future deterioration. There is also an option of deferring rehabilitation until the risk of collapse is unacceptable. Acceptable risk depends on many factors, external and internal to the sewer. This assumes sewers do not normally fail suddenly, without first showing signs of distress. In this case, scheduled monitoring of the system and documenting the progress of the deterioration is necessary. The expenditure of construction funds is delayed until there is a risk of losing rehabilitation options as a result of increasing pipeline degradation.

The decision on which approach to take is directly dependent on the level of information available on the sewer system, and on the level of financing that can be provided for sewer rehabilitation. Based on the information initially developed, the following alternative approaches are proposed for evaluation:

Level 1 - Monitor and gather more information
Level 2 - Stabilize existing sewer
Level 3 - Rehabilitate existing sewer
Level 4 - Replace existing sewer

F 962 MONITOR

This alternative is to gather additional information to justify and support a decision to either rehabilitate or stabilize the existing sewer. By verifying the quality of the piping and the competence of the soil around the sewer, a proper program can be formulated that provides, as a minimum, the stabilization of the sewer. Conversely, if problems are discovered through additional data collection, a higher level of rehabilitation may be indicated.

The program to "gather more information" should be formulated to establish a routine inspection program and monitor performance to develop needed information for design. The additional information usually results in a cost savings in a selected rehabilitation method.

Follow-up inspections should be made at 6 months and at 1 year after the initial inspection, unless the decision is made to initiate a Level 3 or Level 4 program. A lined or replaced sewer will also require inspection to verify the construction integrity and is usually included in the project activity. Intervals between inspections can increase as confidence increases. Subsequent inspections can be made every 2 to 3 years, depending on initial and subsequent findings. The purpose of the frequent inspections initially is to provide early indication of change and provide for opportunities to adjust the monitoring program and/or the decision making process.

This approach recognizes that the pipe will reveal conditions that may indicate further degradation and/or excessive distress in the sewer. Although regular inspection of sewers should be done, regardless of the material of construction, systems known to have problems or those of unlined concrete pipe and cracked clay pipe are more critical.

The monitoring program and research will provide pipeline information as follows:

a. FAILURE MODE
   1. Corrosion
   2. Structural
   3. Pipe Deficiency
   4. Joint Leaks

b. FAILURE STATE
   1. Magnitude
   2. Condition
   3. Progress

c. SOIL CONDITION
   1. Soil Type (Pipe Zone)
   2. Soil Type (Backfill)
   3. Groundwater

This information will be collected and compiled for use in determining the level of activity needed.

F 963 STABILIZE

The alternatives of point (spot) repair of failed or failing pipe, and/or stabilization of pipe soil environment, can extend the useful life of the existing sewer pipeline. Point repair is the replacing of a collapsed or seriously fractured pipe length in one or more areas between maintenance holes, in lieu of total pipeline rehabilitation or replacement. This alternative stabilizes the pipeline at those particular areas of distress. Once an initial point repair program is accomplished, subsequent repair would be done in response to new or deteriorating defects discovered during subsequent inspections. It is normally more cost effective to proceed to Level 3 (Rehabilitation), coincidental with the initial point repair, for the entire pipeline, if it is warranted.

The general stabilization alternative is the modification and stabilization of soil around the pipeline. This work is intended to restore soil competence around the sewer and produce the uniform circumferential loading that favors the strengths of a pipe. The need for this work will be determined from the findings of the information gathering effort. Since the results of this work influence the load carrying capacity of the pipe, cement or chemical grout stabilization could be appropriate with either the normal Level 2 (stabilization), or Level 3 (rehabilitation) alternatives (See F 942).

F 964 REHABILITATE

When the pipelines are found to have corrosion, breaks or fractures, or unsound materials and other signs of excessive loading or deterioration, an effort greater than stabilization is required to provide confidence in their future serviceability. Rehabilitation is the next level of effort and involves various lining systems constructed within the existing sewer (See F 942). The rehabilitation system can be designed to provide corrosion protection and certain levels of tolerance under structural duress (See tables this Subsection). Some rehabilitation methods can be designed to structurally support the soil loading conditions with or without the remaining strength of the existing pipe. Other re-habilitation methods require the composite support of the existing pipe. The pipeline size and environmental factors, such as accessibility, impact on current service requirements, etc. all influence the choice of a rehabilitation method or system. The selection criteria and screening will be discussed in Section F 970.

The following tables list the criteria to select acceptable rehabilitation methods for condition of existing pipe and pipeline. Condition I applies to unprotected concrete surfaces that have experienced surface corrosion with aggregate exposed, and minor cracks or fractures having no pipe wall displacement. In the event joints are leaking, or open, with minor displacement, chemical grouting or mechanical sealing devices may be used. It should be noted that point (spot) repair is normally used at needed locations. Also, total replacement may be considered desirable, but is usually unnecessary at this point.

Under Condition I, the following rehabilitation methods/materials may be appropriate:

INTERNAL REHABILITATION
CONDITION I

a. Reinforced Shotcrete

b. Concrete Placement

c. Segmented Liners

1. Fiberglass Reinforced Cement
2. Fiberglass Reinforced Plastic
3. Reinforced Plastic Mortar
4. Polyethylene (sheets)
5. PVC (sheets)

d. Continuous Pipe

1. PE Pipe (extruded)
2. Pb Pipe (extruded)
3. PP Pipe (extruded)

e. Short Pipe:

1. PE Pipe (external profile)
2. PE Pipe (internal profile)
3. PVC Pipe
4. RPM Pipe
5. FRP
6. DIP (cl)
7. DIP (pl)
8. Steel Pipe

f. Inversion Lining (CIPP)

g. Deformed Pipe:

1. Deformed HDPE
2. Folded PVC
3. Thermal Reduction Process

h. Spiral Wound Pipe

1. PVC Lining System

i. Coatings and Linings

j. Spot (point) Repair

k. Trenchless Replacement

l. Replacement

Condition II applies to unprotected concrete surfaces that have experienced corrosion where steel reinforcement is exposed. Also, cracks or fractures having minor displacement may be rehabilitated. It should be noted that point (spot) repair is normally used at needed locations. Also, total replacement may be considered desirable.

Under Condition II, the following rehabilitation methods/materials may be appropriate:

INTERNAL REHABILITATION
CONDITION II

a. Reinforced Shotcrete
b. Concrete Placement
c. Continuous Pipe
   1. PE Pipe (extruded)
   2. Pb Pipe (extruded)
   3. PP Pipe (extruded)

d. Short Pipe
   1. PE Pipe (external profile)
   2. PE Pipe (internal profile)
   3. PVC Pipe
   4. RPM Pipe
   5. FRP Pipe
   6. DIP Pipe (pl)

e. Spiral Wound Pipe
   1. PVC Lining System

f. Inversion Lining (CIPP)

g. Point (spot) Repair

h. Trenchless Replacement

i. Replacement

Condition III applies to unprotected concrete surfaces that have experienced corrosion where in some locations steel reinforcement is missing or holes through the wall exist. Also, cracks or fractures having serious displacement, and holes or slab-outs occurring in the wall can normally be rehabilitated. The existing pipeline will require pulling a TV Camera or slipliner proofing section through the line, verifying available cross section to rehabilitate. It should be noted that point (spot) repair is normally required in addition to total rehabilitation. Also, total replacement may be considered more desirable. The life cycle and cost effectiveness comparison shall be discussed in detail in Section F 970.

Under Condition III, the following rehabilitation methods/materials may be appropriate:

INTERNAL REHABILITATION
CONDITION III

a. Continuous Pipe
   1. PE Pipe (extruded)
   2. Pb Pipe (extruded)
   3. PP Pipe (extruded)

b. Short Pipe
   1. PE Pipe (internal profile)
   2. RPM Pipe
   3. DIP (pl)

c. Spiral Wound Pipe
   1. PVC Lining System *

d. Inversion Lining (CIPP)

e. Point (spot) Repair

f. Trenchless Replacement

g. Replacement

* Person-Entry pipe only - Structural preparation may be required depending on magnitude of holes.

** Depends on magnitude of holes.

F 965 REPLACEMENT

When the pipelines are found to be beyond repair and/or rehabilitation, utilizing any of the methods, then total replacement is recommended. Normally this condition exists at specific locations and point repair or rehabilitation may be the most cost effective measure in the remaining system. Where pipelines that are determined to be hydraulically overloaded, and upgrade rehabilitation will not improve the flow condition, pipeline replacement or relief line construction is recommended.

F 970 METHOD SELECTION PROCEDURES

F 971 SPECIFIC APPLICATIONS

The methods employed for repairing or rehabilitating a leaking or failing pipe or pipeline system are contingent upon various parameters of the existing system. For example, pressure and non-pressure pipelines will require different methods, procedures and timing in accomplishing the remedial work.

Type and location of service will also have heavy impact on procedures and/or methodology employed in doing the repair. A large diameter pipeline, (e.g. sewer force main or gravity sewer), could have major environmental impact and any threat of failure usually requires immediate resolution. A small diameter pipeline at an extremity of the system is important, but the urgency of repair is not as significant. Pipeline operation and maintenance must be understood and properly managed to carry out repairs or rehabilitation. The major collection, transfer, and/or receiving points must be operated and controlled in a satisfactory manner during construction. Emergency and contingency plans must be worked out in advance and able to be put in operation at a moment's notice. The need for providing ongoing service cannot be overemphasized.

F 972 SELECTION CRITERIA

When it is determined that a sewer pipeline requires some work in order to keep it functioning satisfactorily for its intended purpose, it is necessary to evaluate all possible construction methods to accomplish the needed repair.

The selection criteria used for proper evaluation of the various methods shall include any viable rehabilitation and replacement alternative.

The selection process is accomplished through evaluation procedures as follows:

a. Screening

b. Life-cycle considerations
c. Least-cost analysis

These procedures will be discussed in detail in the following Subsections.

F 973 SCREENING

The initial screening of rehabilitation methods is discussed in Subsection F 964. After the pipeline condition is determined and the problem(s) identified, various methods can be considered viable if they are compatible with the developed degradation criteria.

The next series of screening criteria is listed below:

a. Hydraulics:
   1. Size reduction
   2. Pipe Shape or geometry
   3. Initial impact
   4. Long Term impact

Note: The Manning "n" value for sewers flowing d/D = 0.50 has been set at 0.014 for VCP, RCP, PVC lined RCP and all plastics (new or rehabilitated).

b. Structural
   1. External loadings
   2. Internal loadings
   3. Grouting annulus

c. Corrosion:
   1. H_2S0_4 resistance requirement
   2. Other.

Note: See Greenbook Section 2.10 - 2.3.3.

d. Constructability:
   1. Work activity on pipe/pipeline
   2. Bypass-Internal/External/None
   3. Access

4. Groundwater impact
5. Preparation of existing pipeline
6. Right-of-Way needs
7. Safety
8. Other utility considerations
9. Traffic impact
10. Time required
11. Irregularities of existing pipe/pipeline
12. Ease of service connections
13. Inspection

e. Material Considerations:
1. Proven technology
2. Competitive alternatives
3. Availability
4. Quality control
5. Longevity considerations
6. Repairability
7. Abrasion resistance
8. Safety
9. Cleaning needs
10. Mobilization
11. Inspection.

f. Benefit/Impact:

1. Delay relief pipeline need
2. Affect on future rehabilitation

g. Installation Rate

h. First Cost:
1. Material
2. Installation.

i. Design Life

j. Life-Cycle Evaluation:
1. Cost effectiveness
2. Life-cycle considerations
3. Least-cost analysis

A rating system must be developed to compare the viability of various rehabilitation methods. The various screening categories will normally be very similar when comparing projects, however, with experience and location knowledge, the rating system on priorities may change. The viability of some alternatives will be obvious when compared to others for a given situation on a project. The rating system should be developed for the first seven items. The cost, design life and life-cycle evaluation items should be analyzed after the rehabilitation list has been reduced to those that are viable. Normal practice is also to analyze replacement on all projects for comparison, unless it is obviously impractical for use, normally due to environmental constraints.

F 974 LIFE-CYCLE CONSIDERATIONS

Life-cycle costing is a method of calculating the total project cost over the life of the project, including the initial cost, operation and maintenance costs, and replacement costs. It is an especially good method for comparing costs of projects that have high operation and maintenance costs, or high replacement costs. Life-cycle costing compares total cost by converting all costs over the planning period to present worth in a common base year or to annual costs.

This method can be effectively used for comparing costs of pipeline repair, replacement, and rehabilitation over the planning period (project life). The repair alternative usually involves high annual costs. Rehabilitation and replacement involve higher initial cost, but lower operation and maintenance costs, and are generally more cost effective.

Experience with pipeline rehabilitation has generally been limited to the past 25 years, with increasing intensity during the past 10 years. The confidence in projecting longevities with plastics is lower than with the more conventional, historically used materials. (This was addressed in Section F 950, in detail.) Estimates accepted for longevities of the various materials will be critical to the results of life-cycle costing. Equally critical is the proper evaluation and use of tangible and intangible project cost items. These various factors are listed below.

Table F 974A

FACTORS TO EVALUATE - TANGIBLE ITEMS

Inspection	Construction Time	As-Built Drawings
Engineering	Construction Cost	Mapping
Rights-of-Way	Business Disruption	Rehabilitation Options
Easements	Mobilization	Service Laterals
Other Utilities	O & M Savings	Materials
Cost to Business	Detour Costs	Material Storage
Cost to Government	Flow Bypassing Cost	Dewatering Cost

Table F 974B

FACTORS TO EVALUATE - INTANGIBLE ITEMS

Noise	Pedestrian Inconvenience
Safety (pedestrians & vehicular)	Traffic Inconvenience
Dust/Dirt	Settling of Curbs
Road Surface	Bidding Environment
Road Settlement	Telephone Complaints
Chuck Holes	Liability Exposure
Parking	Emergency Vehicles
City Reputation	Bus Rerouting

The direct and indirect cost to a pipe project of each of the tangible items are normally incorporated in a comparison of the various rehabilitation methods vis à vis that of replacement. The general relative first cost comparison is made between pipeline rehabilitation and replacement, as shown below. These comparisons are made for a pipeline experiencing a Condition II status. (See Subsection F 964)

Table F 974C

COST COMPARISON*

Tangible Item	**Rehabilitation**	**Replacement**
Inspection	x	
Engineering	x	
Rights-of-Way	x	
Easement	x	
Other Utilities	x	
Cost to Business	x	
Cost to Government	x	
Construction Time	x	
Construction Cost	*	*
Business Disruption	x	
Mobilization	*	*
O & M Savings		x
Detour Costs	x	
Flow Bypassing Costs	*	*
As Built Drawings	x	
Mapping	x	
Rehabilitation Options	**	
Service Laterals		x
Materials	*	*
Material Storage	x	
Dewatering Cost	x	

x Normally least cost

* The various rehabilitation alternatives vs replacement (Rehab cost can vary between 50% & 150%)

** More viable rehabilitation alternatives reduce cost and induce competition.

Table F 974D

COMPARISON EDGE

Intangible Item	**Rehabilitation**	**Replacement**
Noise	z	
Safety	z	
Dust - Dirt	z	
Road Surface	z	
Bus Rerouting	z	
Emergency Vehicles	z	
Parking	z	
City Reputation	z	
Pedestrian Inconvenience	z	
Traffic Inconvenience	z	
Road Settlement	***	
Settling Curbs	***	
Bidding Environment	z	
Telephone Complaints	z	
Chuck Holes	z	
Liability Exposure	z	

z Normally has edge

*** Some authorities indicate a trench in a paved area reduces pavement life by one half to two-thirds. Also, curbs have a tendency to displace during and after trenching, causing cracks, etc.

F 975 LEAST-COST ANALYSIS

The well established principle of present value has been used for several decades by engineers to perform economic comparison analysis. The method, however, has certain vulnerabilities because of the assumptions that must be made about future interest and inflation rates.

Historical relationships between interest rates and inflation provide meaningful information. In the short run the volatility of interest and inflation differences can be significant. The two rates interact and influence each other so that in the long run they tend to move together, resulting in a relatively constant differential between the two. The planning period, i.e., 50 to 75 years, tends to balance these differences and in municipal work the inflation/interest ratio has been 0.9953 (See Formula) over the past 35 years.

The inclusion of indicators of inflation and interest rates over the life of the project allow for the adjustments described above.
The following formula is used for calculating the effective current cost (or present value cost) of a material.

$$ECC = P_o + P_r \{[(1+I)/1+i)]^n + [(1+I)/(1+i)]^{2n} + \ldots\ldots + [(1+I)/(1+i)]^{mn}\} \ldots + M_j[(1+I)/(1+i)]^j + \ldots\ldots + M_{j+1}[(1+I)/(1+i)]^{j+1} + \ldots + M_{j=n}[(1+I)/1+i)]^{j=n}$$

where: ECC = Effective current cost, \$ (i.e., present value)

P_o = Original material and installation cost, \$
P_r = Future replacement cost (current \$), \$
I = Inflation rate, % (average rate over the life)
i = Interest rate, % (average rate over the life)
n = Usable material service life, year (See F 950)
m = Number of times material would require replacement over the design life.
M_j = Estimate maintenance cost (current) in the year j, \$
$(1+I)/(1+i) = 0.9953$

Note: The need for maintenance (M_j) generally starts 5 to 10 years after new construction.

This equation, when applied to each material (i.e., replacement and rehabilitation) under consideration, provides a ready means of equitable comparison between the alternatives (See F 940 and F 950). The following table provides an example of the various items for comparing replacement and rehabilitation alternatives.

Table F 975

Least Cost Analysis of
Pipeline Rehabilitation Alternatives

	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Inflation/Interest Ratio	0.9953	0.9953	0.9953	0.9953
Project design life, yr.	75	75	75	75
Est. service life, yr.	20	50	50	75
No. replacements required	3.75	1.5	1.5	1
Original cost	?	?	?	?
Replacement Cost (curr. $)	?	?	?	?
Effective Current Cost	?	?	?	?
Rank (1 is lowest ECC)	1	3	4	2

F 976 INSPECTION

The purpose of inspection is to insure that the work is performed as specified in the contract and that results are achieved as expected by the City. The expected success of any pipeline rehabilitation/replacement project normally requires coordination between the Inspector and the Design Engineer. The intent of the Engineer's work shall not be circumvented in the field by the contractor and/or the inspector. When field conditions vary somewhat from those characterized in the plans and specifications, certain field modification may be required. These field changes shall be coordinated with the Design Engineer.