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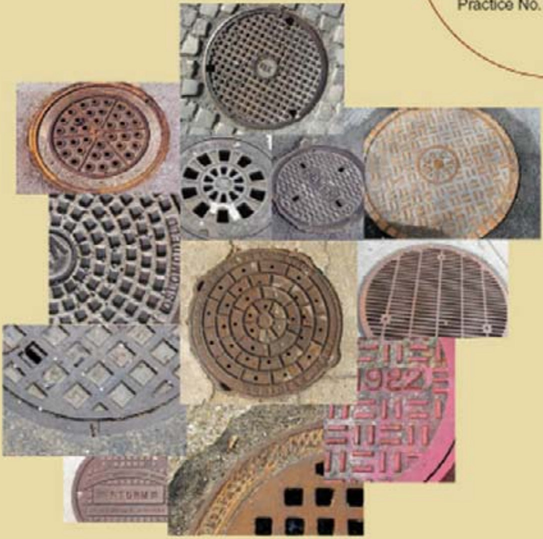

Manhole Inspection and Rehabilitation

Second Edition

ASCE

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Manhole Inspection and Rehabilitation

Second Edition

Prepared by
the Committee on Manhole Rehabilitation of
the Pipeline Division of
the American Society of Civil Engineers

Edited by
Joanne B. Hughes

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INTRODUCTION

The phrase "manhole" was first used to describe the access holes between the decks of old sailing ships. The word "manhole" (initially) had nothing to do with sewers. It wasn't until later that the term was used to describe the structure through which access to sewers for maintenance could be achieved. Perhaps the name was adopted because it was, in essence, a hole into which a person would go to do maintenance, or possibly it was adopted because a man would make his way from one level (street level) to another level (the sewer beneath the street). The word "sewer" is derived from the term "seaward" in Old English. Early sewers in the London area were open ditches that led to the Thames River, and from there on down to the sea ("seaward").

Manhole structures are a significant asset to communities and the principal means of access for collection system maintenance. As of 2007, there were an estimated 20 million manholes in the United States alone. Evaluating and estimating the life of these structures is of considerable importance in the financial planning of agencies, particularly in respect to depreciation allowances and rates of return on investment. However, the actual estimate of economic life (the age when a manhole becomes more cost effective to replace than to rehabilitate) is a function that must be recognized on a local basis. One of the goals of this book is to provide an inspection and condition grading protocol that provides logical follow-up steps that can be taken to maintain and improve on the health of these structures.

The construction industry has witnessed evolutionary improvements in materials and standards. The evolution in manhole materials is occurring from brick to concrete to plastic materials. These changes have occurred because of manpower requirements and the ease of construction and environmental laws. Brick, commonly used through the 1930s, was labor intensive to install, considering the number of bricks needing placement as a structure was built. Concrete materials were seen as a significant development, and because the manhole could be built in lifts (or segments), using precast materials, the construction culture evolved. Today, another factor driving change results from attacks of nature in the forms of water infiltration and hydrogen sulfide (H_2S). H_2S issues have driven the industry to look for new construction materials that would resist infiltration and corrosion, as well as allowing for structures to be built in lifts. Manholes are now being created from inert materials, for example, fiberglass and polyethylene.

Corrosion severely compromises the structural integrity of both brick and concrete components, costing millions of dollars yearly for repairs. A naturally occurring compound, H_2S exists in a dissolved state within wastewater. When released into a gaseous state, it comes in contact with the moist surfaces of manhole walls, and as concentration levels rise, bacteria colonies proliferate, forming an extremely corrosive slime layer that can rapidly cause weakening and decomposition of even the most massive concrete and steel structures. Plastic materials have proven themselves to be resistant to this attack while maintaining their integrity.

In managing manhole assets, there are two key objectives, first to minimize the overall cost to the community of creating, maintaining, and replacing the structure, and second to achieve intergeneration equity through a planned approach to maintain and increase the longevity until eventual replacement of the manhole is required.

Through an effective manhole inspection program, agencies can accurately identify, inventory, and evaluate the condition of these structures. An archival history of trends also aids in determining the most cost-efficient times for rehabilitation. Methods to remove excessive manhole infiltration and inflow (I/I), reduce corrosion, improve manhole structural integrity, address public safety related issues, and to implement general system maintenance needs can be identified through consistent data gathering techniques. Furthermore, infiltration generally enters through structural deficiencies. Once the structural condition is compromised, future problems will likely occur.

Excessive infiltration and inflow (I/I) are serious problems for wastewater collection and treatment systems. The hydraulic effects of these extraneous flows are particularly important because they use valuable collection and treatment system capacity that is needed for urban growth. Public health and economic issues, as well as the environmental impacts of bypassed, spilled, and untreated wastewater flows caused by I/I, are deterrents to the overall objective of protecting our water resources. Furthermore, they can be a public health hazard. Prolonged leakage can create voids outside a manhole structure with the potential of removing soil fines, resulting in the loss of lateral soil support and creating structural issues. This book provides technical guidance for implementing a successful manhole inspection and rehabilitation program. The following aspects of manhole inspection and rehabilitation are addressed:

- safety;
- manhole inspection, including
  - condition assessment and
  - data recording;
- quantification of I/I and structural conditions;
- manhole rehabilitation methods;
- cost-effectiveness analysis and rehabilitation method selection;
- construction inspection and quality control; and
- terminology.

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SAFETY

Asset management, including the inspection, repair, replacement, and installation of underground systems without digging, necessitates a higher worker awareness and preparedness than ever before. Manhole access and entry to these potentially dangerous environments requires strict compliance to all applicable local, state, and federal standards. Successfully performing inspection and work without injury or death should be a primary concern of everyone providing services in this hazardous environment.

Evaluation of the manholes requiring access and accurate identification of a safety plan is necessary on every project. Workers must be aware of the hazards that are present within manholes, as well as the methods and equipment necessary to perform safely within such environments.

The next section illustrates and discusses the hazards associated with manholes, especially those related to sewer manholes, and the procedures before entry, on entry, and for rescue operations that should be incorporated into any existing safety program.

POTENTIAL HAZARDS

The many hazards to which personnel can be exposed while performing operations in manholes include the following:

- traffic,
- material use,
- atmospheric conditions,
- entrapment or engulfment,

- falling objects,
- mechanical and electrical hazards,
- ladders and scaffolding,
- lighting and noise,
- animals and pests,
- blood-borne pathogens,
- trenching and excavation, and
- restricted communication.

PROJECT SAFETY ASSESSMENT

Each of the hazards that may be encountered by personnel must be identified and evaluated to prepare and implement control measures and monitoring procedures:

Traffic—Traffic can present the most immediate and frequent danger to workers, whether you are opening one manhole lid for a quick inspection or performing major rehabilitation work. Work sites shall be evaluated and secured with necessary signage, safety cones, barricades, or other traffic control mechanisms, including visible protective clothing to ensure worker protection from traffic hazards.

Equipment and materials—Workers must be educated and trained to properly use and handle all equipment and materials to be used during inspection or on the project. In addition to general safety hazards of manhole cover opening, workers shall understand all equipment, material handling and safety communication, and any hazards associated with the use of these tools within the manholes. Materials and equipment shall be evaluated for flammability, oxygen displacement, potential spills, contamination, and other hazards. Safety equipment must be inspected for wear and calibrated for use on a regular basis and as regulated by law. An appropriate plan identifies restrictions for safe use within the manholes.

Personal protection—Protective clothing, gloves, boots, and eye protection required to protect workers from injury shall be provided and used. Personal hygiene practices shall be followed. Prohibition of smoking, drinking, and other potentially hazardous practices shall be instituted as necessary.

Physical hazards—Workers must be educated and trained in the identification of potential hazards and equipped with procedures and control measures to reduce or eliminate the potential for injury.

Confined space entry—A plan must be designed to protect employees who enter manholes (confined spaces) and may be exposed to hazardous atmospheres, engulfment in materials, conditions that may trap or asphyxiate because of converging or sloping walls, or other safety or health hazards. Manhole entry necessitates an individualized plan because of the various hazards present, many exposing workers without warning.

> Sewer entry differs in three vital respects from other permit entries; first, there rarely exists any way to completely isolate the space (a section of a continuous system) to be entered; second, because isolation is not complete, the atmosphere may suddenly and unpredictably become lethally hazardous (toxic, flammable, or explosive) from causes beyond the control of the entrant or employer; and third, experienced sewer workers are especially knowledgeable in entry and work in their permit spaces because of their frequent entries. Unlike other employments where permit space entry is a rare and exceptional event, sewer workers' usual work environment is a permit space.[1]

PROCEDURE BEFORE ENTRY

Before entry, a written plan must be established for workers to follow every time a manhole is opened. The plan should include the following:

- Site- and traffic-related hazards and potential hazards resulting from equipment or vehicles necessary to perform the inspection or work shall be evaluated with necessary procedures identified to maintain safe working conditions.
- Connecting system layout, earlier hazards or incidents at the work site, environmental changes that could affect the manhole, surrounding facilities producing effluent discharged into the system, and other likely hazards that may be encountered shall identified. Proper procedures for managing these potential hazards safely shall be included in the written plan.
- Complete identification of materials, equipment, and procedures to be used during the project shall be evaluated to ensure that all potential hazards are mitigated within the written plan. Personal protective equipment shall be identified for worker protection from sewage, materials, and other contaminants to which they may be exposed. Exhaust fumes from generators, ventilation or other equipment, sparks or open flames generated from equipment or procedures, flow bypass or diversion, and electrical and mechanical lock-out requirements shall be included in the evaluation of potential hazards.

[1]Occupational Safety and Health Standards, 29 CFR 1910.146, App. E.

- Communication devices and methods shall be identified and tested for reliability, including rescue communication.
- Because of the potential danger wet weather events create on sewage flow in most systems, the weather service shall be contacted for the possibility of rain or flash flood conditions.

PROCEDURE ON ENTRY

- Ensure that the site is secure.
- Ensure that all equipment necessary to enter safely is at the site and available for use.
- Post the confined space entry permit required space signage and complete the entry permit, including the following:
    - Identify rescue procedures, trained and capable rescue personnel, and appropriate rescue equipment; provide workers with the rescue plan; and ensure that they understand rescue procedures.
    - Identify and control atmospheric hazards:
        - Test the atmosphere to identify (1) toxic gases, such as hydrogen sulfide and carbon monoxide; (2) oxygen levels, including deficiencies and oxygen-rich atmospheres; and (3) flammable atmospheres caused by methane or other flammable dusts, gases, or vapors.
        - Initiate ventilation to remove atmospheric hazards and provide a controlled atmosphere safe for entry.
        - Continue atmospheric testing to ensure that hazards are identified quickly on recurrence.
        - Prepare workers for safe entry based on atmospheric conditions and hazards identified.
- Identify respiratory protection requirements and ensure that workers are protected from atmospheric hazards. Air purifying respirators (APRs) do not protect workers from many toxic gases, including hydrogen sulfide. Workers entering a confined space where respirator use is required must be evaluated by a health professional, properly fitted with the respirator, and trained for its use as regulated by law.
    - Ensure that trained workers are available to perform supervisor, attendant, and entry functions.
    - Identify procedures to ensure that workers are protected from harmful substances or circumstances occurring within the system. Whenever possible, isolate the manhole(s) where the work is to be carried out.

  - Identify structural or physical hazards in the manhole that may cause injury during entry or the work process and provide safety procedures to entry personnel.
- Enter and perform work based on the written safety plan.

PROCEDURE FOR RESCUE

Ensure rescue procedures, trained personnel, and all required equipment are in place and available before manhole entry. In the event that rescue becomes necessary, the following procedures should be included:

- emergency communication, including notifying appropriate medical response authorities (ambulance and rescue services);
- worker rescue assignments;
- respiratory protection requirements;
- first aid requirements;
- rescue equipment and procedures; and
- site directions for medical response and access to perform rescue.

Rescue is truly a matter of life or death, so it may come as a surprise that being prepared to react properly and promptly in rescue situations is one of the most common components of a safety plan that is not practiced, enacted, or enforced.

Be prepared. A comprehensive and proactive safety program that management develops, implements, and enforces reduces the likelihood of accidental injury or death.

Key components of such a safety plan should include project assessment, maintenance of programs and training, complacency reduction, evaluation, and disciplinary programs.

As the regularity of performing inspection and work within manholes continues to rise, it is up to owners, contractors, other employers, and employees to work together proactively to ensure the safety and health of those exposed to the many hazards of such places as manholes, connecting systems, and other confined spaces.

Box 2-1. Permit Required Confined Space Entry Checklist

Secure the area; implement measures to prevent unauthorized entry:

- Identify and mark permit required confined spaces.
- Secure the area and erect barriers to protect personnel and prevent unauthorized entry.

Identify and evaluate hazards:

- atmospheric—e.g., oxygen content, flammable gases, combustible dust, and toxic gases (H_2S or CO);
- mechanical—e.g., electrical and mechanical equipment, piping, valves, and pressurized vessels and lines;
- external—e.g., traffic, pedestrians, construction equipment, external operations, and weather;
- communications—e.g., restrictions to visual, verbal, radio, or signals or requirements for explosion-proof equipment;
- illumination—e.g, lighting deficiency or requirements for explosion-proof equipment;
- entry and exit restrictions—e.g., entrance access, size, shape, locations, internal barriers, occupancy loads, and means of entry and egress;
- slip and fall—e.g., ladders, rungs, scaffolds, and slippery or irregular surfaces;
- falling objects—e.g., falling tools, equipment, or debris;
- thermal effects—e.g., temperature extremes, heat stress, hypothermia, or frostbite;
- noise and vibration—e.g., mechanical operations producing harmful levels of noise or vibration, or restriction of communications;
- chemicals—e.g., chemical hazards presented by the environment, processes, or accidental exposure; and
- biological—e.g., exposure to biological agents, blood-borne pathogens, waste, or decomposing matter.

Specify acceptable entry conditions, ensuring that the following requirements are met:

- Provide all parties access to testing results, entry permits, the written entry program, and emergency and rescue procedures.

- Isolate the space to the extent possible.
- Purge, inert, flush, or ventilate the space to eliminate or control atmospheric hazards.
- Provide barriers to protect entrants from external hazards.
- Provide testing equipment to monitor atmospheric conditions accurately.
- Provide ventilation equipment required to obtain and maintain acceptable atmospheric conditions.
- Provide personal protective equipment to further protect from hazards not eliminated by engineering controls.
- Provide lighting equipment for safe work practice and to properly illuminate exits.
- Provide ladders, tripods, winches, or other means of safe ingress and egress.
- Provide rescue and emergency equipment required by the rescue plan.

Atmospheric Testing

- Testing equipment shall be of proper sensitivity and specificity to identify and evaluate any hazardous atmosphere that may exist or arise.
- Testing shall be performed by qualified individuals trained in the operation of the specific instruments.
- Evaluation of test results shall be performed by qualified individuals.
- Test duration shall be in accordance with the minimum response time of the test instrument.
- Testing of possible stratified atmospheres shall be made in increments of 4 ft in the direction of travel and to each side.
- Tests shall be performed in the following order: oxygen content (lack thereof may affect further testing), combustible gases, and then toxic gases.
- Document the test instruments, testing personnel, and test results on the entry permit.
- Provide all parties an opportunity to observe testing and to review test results.

Assignment of Roles and Responsibilities

- Designate and document the persons having active roles in the entry (e.g., entrants, attendants, entry supervisor, and testing and monitoring personnel).

- Identify the duties of such designated persons and ensure that each has the training and equipment to fulfill his or her respective responsibilities.
- Provide at least one safety attendant outside the permit space for the duration of entry operations.
- Include in the permit the means and procedures necessary if the attendant is to monitor multiple spaces.

Emergency Response and Coordination of Activities

- Designate the procedure for summoning and providing for rescue and emergency services and preventing unauthorized rescue attempts.
- Designate procedures for the coordination of entry operations when multiple employers or entities are operating in the same area.

Entry Supervisor Authorization

- Ensure that all criteria set forth by the permit are met and can be maintained.
- Verify that all personnel are aware of hazards and responsibilities.
- Review compliance of the permit with the written program.
- Notify all parties of the commencement of entry.
- Sign the permit authorizing entry.

For informational purposes only. Refer to local, state, and federal regulations for compliance requirements and recommendations.

Box 2-2. Confined Space Entry in Sanitary Sewers

Sanitary sewers provide a lethal combination of hazards that kill many workers every year. Because of their construction, it may not be possible to completely isolate the work area from sources of hazards. Additionally, because many areas cannot be fully isolated, atmospheres can rapidly change, creating a lethal environment. Although working in confined spaces may be a rare occurrence for most workers, the frequency with which sewer workers enter and operate in confined spaces can result in deadly complacency. The following fact sheet illustrates some of the unique hazards involved in sewer operations and may clarify some of the misconceptions regarding safe entry operations.

- Atmospheric testing equipment should monitor and provide a visual display of the following conditions and sound an alarm at the prescribed limits (testing for other potential hazards may also be advisable depending on conditions):
  - oxygen content equal to or less than 19.5%,
  - flammable gas or vapor equal to or greater than 10% lower flammable limit (LFL),
  - hydrogen sulfide gas equal to or greater than 10 parts per million (ppm), or
  - carbon monoxide equal to or greater than 35 ppm.
- Perform atmospheric testing of structures that could have stratified atmospheres at 4-ft increments in the direction of travel.
- All sewer spaces should be considered permit required until pre-entry procedures demonstrate otherwise.
- Unless completely and positively isolated from all sources of potential hazards, all sewer manholes are considered permit required confined spaces, regardless of depth.
- All vertical entries of depths greater than 5 ft require a mechanical device for personnel retrieval.
- Negative pressure ventilation, such as sucker-type fans placed on adjacent manholes, do not meet the requirements to allow entry under the alternate procedures per section 1910.146(c)(5) and do not meet the intent of forced, clean air ventilation.
- Respiratory protection standards require that persons capable of immediate rescue be provided for in instances when personnel wearing respiratory protection are working in Immediately Dangerous to Life or Health (IDLH) atmospheres.

- Air-purifying type respirators do not provide protection from toxic gases or oxygen-deficient atmospheres.
- Cancelled permits are required to be retained for at least one year to facilitate the required annual review of an employer's permit required confined space program.
- A written copy of the operating and rescue procedures should be present at the work site and should be accessible by all employees.
- Weather conditions and events, even well removed from the work site, can affect flow and atmospheric conditions in a sewer system and should be monitored before and during confined space entry operations.
- Most deaths in sewer-related confined spaces result from atmospheric hazards. Redundancy and emergency planning for atmospheric controls should be addressed in the entry procedures and permit.
- The prevention of entry into confined spaces during an emergency by would-be rescuers is a difficult, but life-saving duty of the attendant that should not be understated. More than 60% of confined-space deaths are would-be rescuers. Only properly equipped and trained rescuers should perform entry rescues.
- Performing specialty operations in sewers may compound the number and degree of hazards. Careful job safety analysis should be performed to adequately evaluate the hazards of an already complex and dangerous situation.

For informational purposes only. Refer to local, state, and federal regulations for compliance requirements and recommendations.

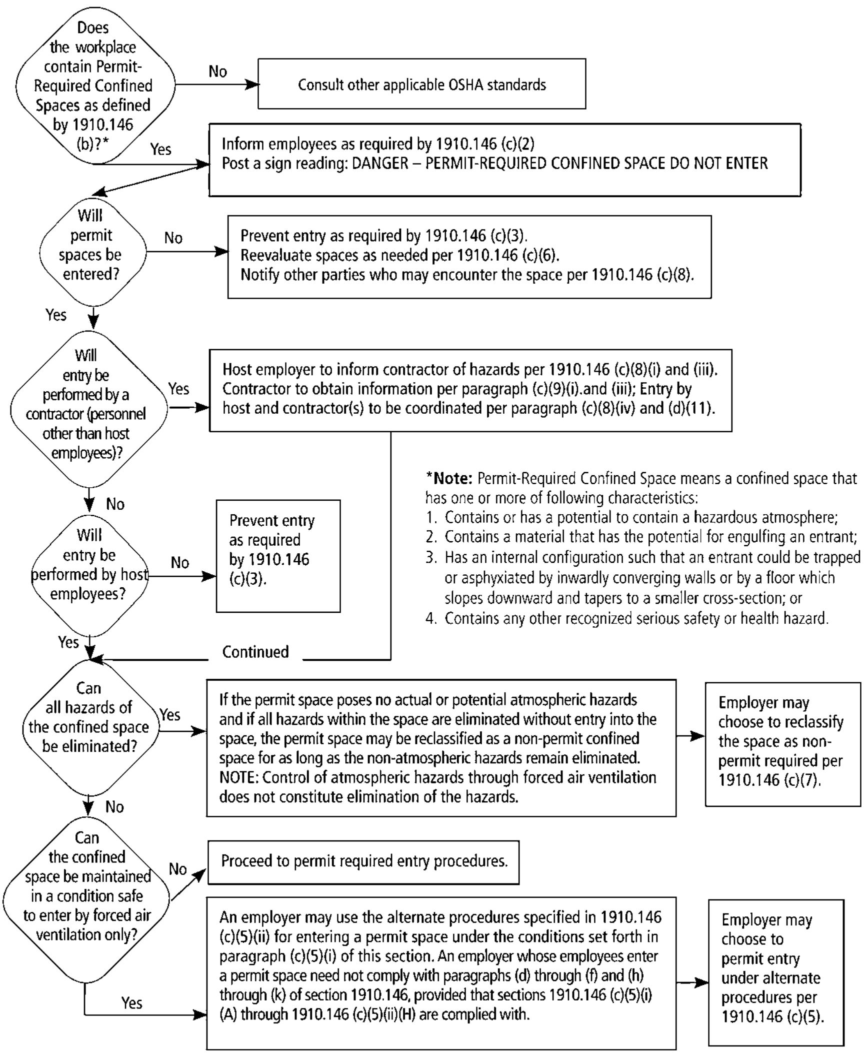


FIGURE 2-1. Permit Required Confined Space Decision Flow Chart. For informational purposes only. Refer to local, state and federal regulations for compliance requirements and recommendations.

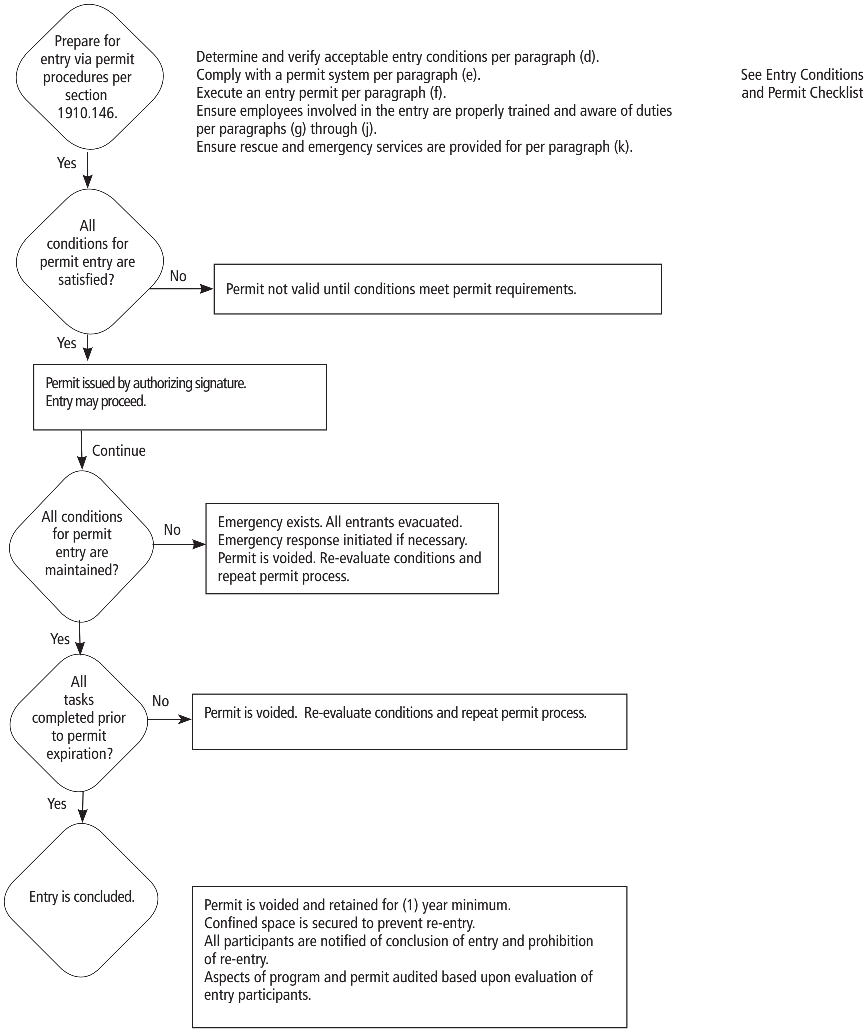


FIGURE 2-2. Permit Required Entry Procedures Flow Chart. For informational purposes only. Refer to local, state and federal regulations for compliance requirements and recommendations.

3

MANHOLE INSPECTION

BACKGROUND

Manhole inspections are performed for a variety of reasons, including the following:

- to inventory system assets;
- to evaluate the condition of the structure, flow conditions, and debris;
- to determine rehabilitation effectiveness over time;
- to inspect construction or establish warranty repair;
- to update maps;
- to identify structural and infiltration/inflow (I/I) defects; and
- to prioritize maintenance and rehabilitation.

TERMINOLOGY

Various inspection techniques and procedures may be used in performing manhole inspections and, to a large degree, are project specific. Nevertheless, common terminology is important to communicate information properly for analysis, design, and construction. Manhole components are defined in Table 3-1 and shown in Fig. 3-1.

TABLE 3-1. Manhole Components

Component	Definition
Cover	The lid that provides access to the interior of the manhole
Frame	The cast or ductile ring that supports the cover
Frame seal	Material or device to prevent intrusion of water at the joint between the frame and the chimney, a frame and cone, or frame and flat-top slab
Clear opening	The smallest entryway into the manhole
Chimney	The narrow vertical section built from brick or from concrete adjusting rings that extends from the top of the cone to the frame and cover
Joint seal	Material or device to prevent intrusion of water at the joint between precast wall sections or cone and wall section
Cone	The reducing section that tapers concentrically or eccentrically from the top wall joint to the chimney or the frame and cover (sometimes referred to as corbel, when made of brick)
Wall	The vertical barrel portion extending just above the bench joint to the cone
Pipe seal	The material or device at the pipe and wall or cone interface for preventing entry of water
Drop inlet	An inlet connection entering at both the invert and at some higher elevation through the manhole wall. The higher inlet is on grade with the incoming gravity line to facilitate cleaning and inspection. The invert inlet is connected to direct the flows through the channel. Drop inlets can be outside or inside the manhole structure
Bench	The concrete or brick floor of a manhole generally shaped as a fillet to direct incoming flows to the outlet piping and to minimize solids buildup. Includes wall to bench joint
Channel	The shaped flow way within the bench. Includes bench to channel joint
Invert	The line of lowest elevation along the bottom of the channel
Base	The supporting slab structure of the manhole

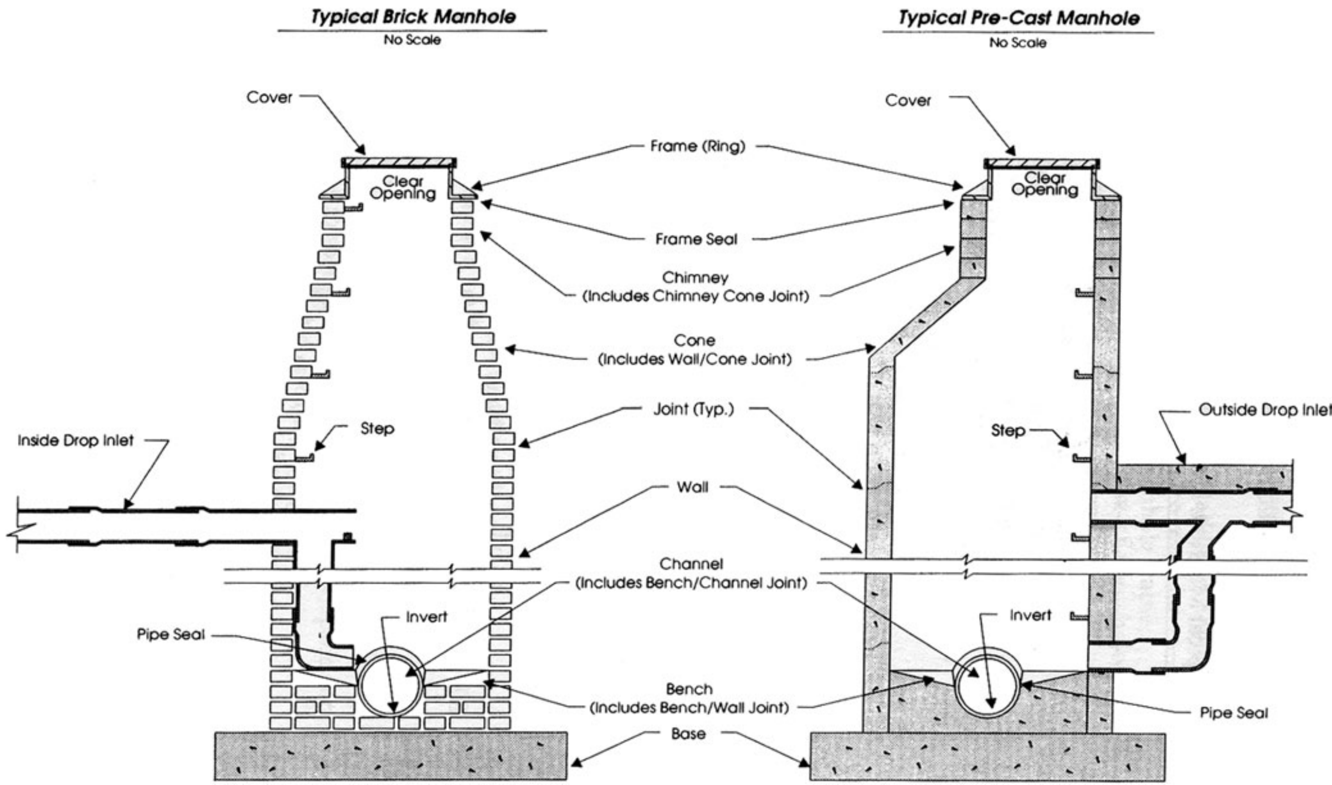


FIGURE 3-1. Manhole Components.

MAPPING

Before any inspections, the best available system maps should be obtained and prepared for inspection activities by establishing structure identification numbers if these do not exist. Each manhole, mainline cleanout (if present), and line segment should have a unique number to identify it from all others. One method for numbering line segments uses a combination of the upstream and downstream manhole numbers. Keep in mind that the use of dashes, commas, or combinations of alphanumeric numbers may limit the usefulness when working with databases or mapping software. For example, a manhole numbered A20-4 could be written as A20-004, A204, or A20-04. In this example, none of the numbers exactly matches A20-4, and most databases interpret these numbers as representing individual manholes.

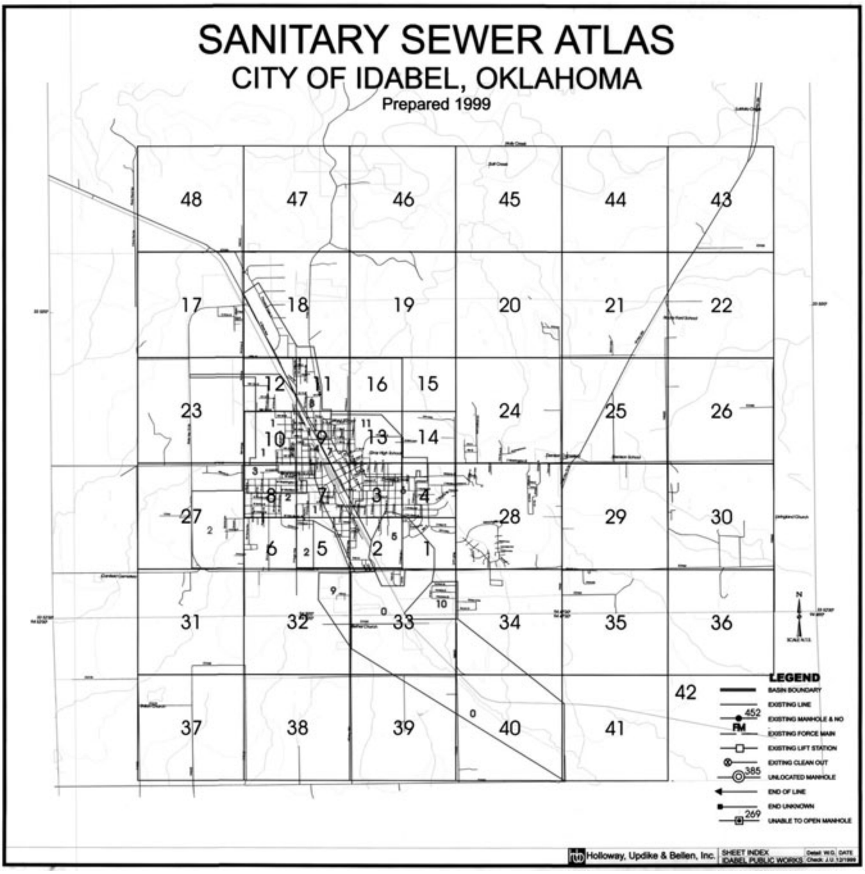


FIGURE 3-2. Example Grid Map.

Another method of numbering uses a grid system. Figure 3-2 presents an example of a grid system for numbering assets. The manholes in each defined area can be numbered using the grid identification. For example, a manhole numbered C40100 would identify manhole 0100 in section C4. With the grid system, manholes can be numbered consecutively or each grid area can restart numbering from the beginning (example: B20010 and C50010 each represent manhole number 0010, yet each is a unique identifier).

Yet another numbering system uses drainage basin boundaries. Abbreviations of the drainage area with a manhole number or numbered drainage areas can be used. For example, it Basin 3 is the Little Walnut Creek drainage basin, the manhole numbering system could include the following nomenclature:

LWC0100 = Little Walnut Creek, manhole 0100
or
30100 = Basin 3, manhole 0100

Other numbering and grid systems can be developed that use, e.g., survey section numbers or pump station service areas. The factors that should be considered when preparing an asset numbering system include using unique numbers for each asset, a map scale that can easily be used by field crews (consider an 11 × 17-in. map book) and an identification system that easily depicts where in the system the asset is located.

Where possible, establish a system that allows new manholes to be added between existing structures. One way to accomplish this result is to determine the total number of manholes in the system, for example 680, and to add a zero to it, or 6800. Start by numbering the first manhole 10, the second 20, etc. This system allows future manholes to be added between existing manholes. In this example, a new connecting manhole between manholes 10 and 20 could be numbered 21. Start numbering from downstream and work upstream following the branches of the sewer system. Keep in mind that field crews rely on the developed system to locate individual manholes. Having a logical system reduces the time in searching maps to locate manholes.

The inspection techniques used vary depending on the type of information desired. For instance, if the primary emphasis for the inspection is mapping, a surface inspection may be all that is required to meet project objectives. A visually correct map can be relatively inexpensive to develop and does not require costly base maps. A visually correct map may not have the mapping accuracy of a surveyed manhole location; however, a visually correct map can be effective when there are limited other structures in the vicinity. The use of survey-grade global positioning system (GPS) receivers or traditional surveying is required to obtain the neces-

FIGURE 3-3. Using a Survey Rod to Obtain Rim-to-Invert Distances.

sary accuracy for elevation data (0.10–0.01 ft) that may be used in developing more accurate manhole coordinates. Field crews can estimate the rim-to-invert distance for each pipe in the manhole by using a survey rod (Fig. 3-3). However, significant pipe invert elevation error can occur if the pipe invert elevation varies from the center of manhole invert elevation or if the rod is not perfectly vertical during measurement. The most accurate rim-to-invert measurements are obtained using internal inspections and appropriate measuring tapes, rulers, and levels to obtain an accurate pipe invert elevation. Using this information and a detailed elevation survey (GPS or conventional level survey to 0.10–0.01 ft) of the rims provides good rim and pipe invert elevations.

GPS receivers can provide data for use in many geographic information system (GIS) mapping applications. Accuracy of GPS receivers varies greatly, and it is important that the equipment and accuracy be selected to meet the project objectives. It is common to use both conventional surveying methods and GPS where tree canopy or buildings interfere with GPS signals, thus degrading accuracy.

CONDITION EVALUATION

If the objective is to evaluate the manhole condition to determine necessary rehabilitation, to establish a maintenance program, or to conduct a visual pipe inspection of connecting pipes, internal inspections are required. Defects typically found in manholes are listed in Table B-1 in Appendix B.

The following sections discuss manhole conditions that could indicate the need for rehabilitation work. These conditions include structural degradation, excessive infiltration/inflow (I/I), and maintenance concerns.

Structural Degradation

The definition of structural degradation varies with manhole materials, shape, and size. Structural degradation does not necessarily mean structural failure. For purposes of manhole inspections, structural degradation is defined as damage to any of the structural components of a manhole. Structural degradation can occur because of the following:

Movement and Displacement. Structural degradation of manholes (Figs. B-1 and B-2 in Appendix B) and degradation of the frame seal occur with three-dimensional displacement and movement. In areas where freeze-thaw cycles are common, degradation of the frame seal, chimney, and top portion of the cone are generally more pronounced. Vertical separation can be dramatic, particularly where manhole frame castings are monolithically encased within rigid or flexible pavement. Horizontal movement of the frame occurs as the encased frame reacts to the thermal expansion and contraction of the surrounding pavement, traffic loadings, snowplows, and other physical impacts. Three-dimensional movement can also occur to the entire manhole structure because of settlement and movement of the ground around the manhole. This differential movement can be pronounced in certain clay or unstable soils. Such conditions can impose unbalanced point loadings and induce tensile stress failures. Manholes made of brick and block are particularly susceptible to displacement and joint separation where unstable soils exist. Traffic-induced loads may also result in three-dimensional movement of the manhole cover, frame, and chimney section, causing cracks and fractures.

Corrosive Environments. When corrosive chemicals are present in the sewer stream or when environmental conditions within a sewer system are conducive to production of sulfides in the wastewater stream, structural degradation is likely to occur to concrete surfaces, cast and ductile iron surfaces throughout the interior of the structure, and connecting pipes. Corrosion commonly occurs in manholes at the discharge end of force mains. The factors that affect sulfide generation are the following:

- low wastewater velocity or extended retention times,
- temperature of wastewater generally greater than 15°C (60°F),
- release of dissolved oxygen, and

- dissolved hydrogen sulfides greater than 0.3 mg/L and high biological or biochemical oxygen demand (BOD).

Under certain conditions, total structural degradation of unprotected precast manholes can occur in less than five years. Tests have been conducted with a concrete corrosion test chamber to determine the rate of corrosion at differing hydrogen sulfide concentrations. Reinforced concrete sewer pipe is considered structurally unsound once reinforcing steel is exposed. This same criterion can be applied to manholes.

Structural degradation of manholes induced by hydrogen sulfide can be controlled through effective manhole rehabilitation, although corrective measures within the sewer system may also be appropriate to inhibit the generation of sulfides. Current studies indicate that the rate of corrosion is not uniform but accelerates over time. Figure B-3 in Appendix B presents a concrete access structure that is severely corroded because of hydrogen sulfide. Note that the concrete has corroded to the point that individual aggregate is exposed. Although severely corroded, this structure can be effectively rehabilitated to extend the life of this asset.

Excessive Infiltration/Inflow (I/I)

Studies have indicated that a significant percentage of I/I is a result of defective manholes. For example, vented manhole covers (Fig. B-4 in Appendix B) that are located in low ponding areas can contribute significantly to wet-weather inflow. Identifying those vented manhole covers that are subject to inundation can lead to a replacement program to reduce wet weather inflow. Figure B-5 in Appendix B shows an example of active groundwater infiltration passing through the brick manhole walls. Factors that need to be considered when evaluating and quantifying potential I/I from manholes include the following:

- location with respect to side easements, rights-of-way, curbs, and so on;
- surrounding surface type (i.e., grass, pavement) and condition;
- surrounding soil and backfill types;
- water table fluctuations and soil saturation;
- inspection data on type and condition of manhole;
- inspection data on manhole I/I and flow rating schedule; and
- size and age of leak.

Maintenance

Field conditions that hinder normal maintenance and operations of a collection system should be considered in manhole rehabilitation. These conditions include the following:

- deteriorated manhole steps;
- offset frames;
- buried manholes;
- manholes that are inaccessible or difficult to work on because of location;
- excessive chimney height;
- lack of bench or channel; or
- other utilities passing through manholes (Fig. B-6 in Appendix B).

DATA RECORDING

Recording of data during the inspection phase of a project is one of the most critical phases of any rehabilitation effort. The data gathered in the field are used to analyze the problems observed within the structures, to determine necessary rehabilitation requirements, to prepare plans and specifications, to prepare cost estimates, and to assist contractors in preparation and submittal of bids. Because all of the subsequent rehabilitation efforts are based on the accuracy and quality of the inspection data, the data must be gathered in a well-thought-out and organized manner. Any errors recorded during the inspection phase may carry over into design and construction. Experienced inspection crews in association with a quality control plan allow for a more thorough inspection and minimize errors.

Data can be recorded in any number of ways, which to a large part will be dictated by the number of inspections to be performed and the abilities of the staff. Following is a summary of common methods of recording data:

1. Paper forms: Printing and recording data on paper forms is one method of collecting data. One advantage of paper forms is that the hard copy form can be completed in the field without the need for field computers. For the data to be useful, periodic input of the data into a database for analysis, quality assurance and quality control (QA/QC), and possible linking to GIS maps are required. Using optical character recognition (OCR) software can speed the input of data into an electronic database but does not guarantee that data entry errors will be captured or corrected without a comprehensive data review. Field forms should be stored in binders and in a secure location until all data have been electronically input and backup copies have been secured.
2. Personal digital assistants (PDAs) and handheld computers: PDAs and handheld computers provide a rapid method of recording the field data in an electronic format. Some hardware allows capture of

GPS coordinates and digital photographs. In addition, software can be developed that provides some level of error checking during data entry. For example, when a technician enters a pipe size that is outside the programmed nominal diameter, the software may generate a message asking the field technician to confirm that the pipe size is correct. Limitations of the software should be considered, such as the ability to correct entries without scrolling through the entire database. Screen size is usually small, and maps may be difficult to see in direct sunlight.

3. Laptop and pen-based computers: Although laptop computers have been widely used in the field and have the same capabilities as workstations, the cost is much higher. Advantages include error checking (QA/QC) software routines during data entry, interactive mapping capability, GPS coordinate capture, digital photograph capture, and all the various peripheral hardware available for laptop computers. Laptops can be purchased specifically with outdoor displays that can easily be viewed in direct sunlight and can be constructed to operate better in outdoor environments. Pen-based computers that use a touch screen stylus for data entry are another method of data recording that eliminates the need for keyboard entry.

With all electronic methods of data recording, the need to back up data at least daily during field inspection is critical. In addition, extra batteries or battery chargers are necessary, depending on the hardware selected and the battery life.

Many formats for gathering data are available and are project dependent and system dependent. For example, a system composed of combined sewers has terminology and data requirements that may vary widely from a separate sewer system. In addition, data requirements for a municipality where residents have basements varies from those communities without basements. For these reasons, the field form may require custom data fields to address particular concerns or physical conditions specific to the community. Example manhole and pipe inspection (sometimes referred to as "lamping the lines") forms are presented in Figs. 3-4 and 3-5. The manhole form addresses the manhole structure, and the pipe form documents conditions in each incoming and outgoing pipe at the manhole.

Data from the field forms can be input into an electronic database in the office or directly in the field. Figure 3-6 shows a typical data entry screen for manhole and pipeline data entry.

SANITARY SEWER - MANHOLE VISUAL INSPECTION

Project Name: ____________
Project Number: ____________
Date: ____________
Crew Leader: ____________

Basin: ____________ **Sub-Basin/Area:** ____________
Map No: ____________ **Manhole No:** ____________
Downstream Length (ft): ____________

Area Photo: ____________
Internal Photo: ____________

Asset Type: ____________ (M=Manhole, C=Cleanout, P=Pumpstation, E=EOLS, T=Tee Connection)
Inspection Status: ____________ (Y=Yes, B=Buried, L=CNL, O=CNO, S=Surcharged, N=No Access, D=Dog, LG=Locked Gate, H=homeowner)

General Street Location

Address Num ____________ **Street Name:** ____________

GPS DATA **Accuracy:** ____________

	Degree	Min	Sec
GPS N:			
GPS WO:			

Asset and Area Information

Surface Cover: ____________
(ST=Street, GU=Gutter, AL=Alley, DW=Driveway, SW=Sidewalk, FD=Field, TW=Trees/Woods, PL=Parking Lot, SH=Road Shoulder, DD=Drainage Ditch, CR=Creek, WB=Within Building, YD=Yard, OT=Other)

Surface Material: ____________
(P=Paved, U=Unpaved)

Asset Grade: ____________
(X=At Grade, A=Above Grade, B=Below Grade)

Grade Inch: ____________
(Indicate inches above or below grade)

Lid Type: ____________
(V=Vented, S=Solid, B=Bolted, O=Other, N=None)

Number of Vent Holes: ____________

Inflow Dish: Y / N

Inflow Potential: ____________
(N=None, L=Light, M=Moderate, S=Severe)

Asset Diameter: ____________
(48 = Standard 48" Round, 60 = Std 60" Round, VLT=Vault (Give vault Dimensions), CO=Cleanout)

Vault Dimensions: ______ in. x ______ in

Asset Material: ____________
(B=Brick, SB=Seal Brick, C=Concrete, F=Fiberglass, SC=Sealed Concrete, OT=Other (add comment)

Material if Other: ____________

N
Manhole Sketch

Rim to Outgoing Pipe Depth (ft): ____________
Outgoing Pipe Diameter (in): ____________
Debris Depth (in): ____________

Manhole Defects Found

	Location*	Defect**	Rating	Roots	I/I	PhotoID
1						
2						
3						
4						
5						
6						

*Location: LD=Lid, FR=Frame, FS=Frame Seal, CH=Chimney, CO=Cone, WA=Wall, ST=Steps, BN=Bench, PS=PipeSeal, IN=Invert

**Defect: BPS=Bad Pipe Seal, BRK=Broken, CRK=Crack, CCL=Collapse, DET=Deterioration, HOL=Hole, JNT=Joint Defective, LOO=Loose, MBR=Missing Bricks/Morter, MIS=Missisg,

Rating: L = Light, M = Moderate, S = Severe
Roots: N = None, L = Light, M = Moderate, S = Severe
I/I: N = None, E = Evidence, A = Active

Comments: ____________

FIGURE 3-4. Typical Manhole Inspection Form.

Pipe Visual Inspection Form

Project: ________ Basin: ________ Sub-Basin: ________ Manhole No: ________

Pipe Photo 1: ________

Pipe Photo 2 (Drop): ________

Line Type: ________
(M=Mainline, L=Service, A=Abandoned, B=Bypass, I=Interconnect, X=StormSewer Connect, S=Stubout, F=Force Main)

Pipe No: ________

Inspected: ________
(Y=Yes, S=Surcharged, F=High Flow, O=Obstruction/Debris, N=Not Inspected)

Pipe End: ________
(O = Outgoing, I = Incoming)

Clock Position: ________

Pipe Length (Ft.) ________
(Required if "O")

Pipe Depth (Ft.): ________

Pipe Size (In): ________

Pipe Material: ________
(VC=Clay, CO=Concrete, IR=Iron/Steel, PV=PVC, LI=Liner, OT=Other)

Surface Cover: ________
(ST=Street, GU=Gutter, AL=Alley, DW=Driveway, SW=Sidewalk, FD=Field, TW=Trees-Woods, PL=Parking Lot, SH= Road Shoulder, DD=Drainage Ditch, CR=Creek, WB=Within Building, YD=Yard)

Debris Depth (Inches): ________

Drop Type: ________
(N=None, ID=Inside Drop, OD=Outside Drop)

Surface Material: ________
((P = Paved, U = Unpaved)

Pipe Defects

	Defect	Rating	Roots	I / I
1	____	____	____	____
2	____	____	____	____
3	____	____	____	____
4	____	____	____	____

Pipe Defects: BKP = Broken Pipe, CCL = Collapse, CRK = Crack, DET = Deterioration, DFP = Deformed Pipe, DIP = Defective Inside Drop, DOP = Defective Outside Drop, HOL = Hole, JNT = Defective Joint, OBS = Obstruction, PSG = Pipe Sag

Rating: L=Light, M=Moderate, S=Severe

Roots: N=None, L=light, M=Moderate, S=Severe

I / I: N=None, E=Evidence, A=Active

Comments: ________

FIGURE 3-5. Typical Pipe Inspection Form.

At a minimum, necessary data includes the basic physical description of the structure being investigated and the following:

1. Location in relation to permanent physical features, such as street addresses, GPS coordinates, and the like, to ensure that the manhole can be found quickly during subsequent phases of the project and to provide a permanent location reference.
2. Manhole construction, as well as the geometry, should be sketched with key physical dimensions, such as overall depth, wall diameter, and frame opening. A sketch should be prepared showing each incoming and outgoing pipe. The sketch can be compared to the map for updating and establishing the continuity between manholes and pipelines.
3. Structural and leakage observations should be recorded to assist in prioritizing repair recommendations.
4. Evidence of cracking, differential settlement, progressive deterioration, and corrosion should be recorded and photographed. Testing the pH of the wall or crown of the pipe provides qualitative information on corrosion potential. A pH of 2 or less is a strong indication of active corrosion. Air monitoring of hydrogen sulfide in parts per million at the bottom of the manhole immediately on opening the

FIGURE 3-6. Data Entry Screen.

cover can provide additional qualitative information on corrosion potential and potential odors.

The level of detail to be obtained during the inspection depends on the project goals and objectives. Recording the date of the inspection provides a historical record of the last inspection, and the name of the inspector can be used for quality control should the data be incomplete or questionable. Keep in mind that some data (depth of flow and velocity, for example) require confined space entry, which requires additional time to obtain and thereby reduces daily production. Comprehensive manhole and pipeline inspections should address the following:

1. date and time of inspection and name or initials of the crew leader;
2. location of the manhole (GPS coordinates), including address, asset identification number, and traffic conditions;
3. surface material;
4. easement type and condition;
5. diameter of the clear opening of the manhole frame;

6. condition and number of vent holes;
7. potential for ponding;
8. the structural condition and leak potential (evidence of active leaks) of the following:
   a. frame seal,
   b. chimney,
   c. cone,
   d. wall,
   e. joint seals,
   f. bench,
   g. channel,
   h. pipe seals, and
   i. steps;
9. construction material of the following:
   a. chimney,
   b. cone,
   c. wall,
   d. channel, and
   e. bench;
10. manhole rim-to-invert measurement for each pipe (depth);
11. shape of manhole, including height and diameter measurements of frame, chimney, cone, and wall; safety and access impediments due to construction geometry;
12. evidence of surcharge or overflow;
13. amount of deposition in the channel; and
14. configuration and data for incoming and outgoing pipe, including the following:
    a. size;
    b. shape, if other than round;
    c. material;
    d. condition, including cracks, breaks, and collapsed pipe;
    e. presence of roots;
    f. presence of deposition;
    g. depth of flow;
    h. measured or estimated velocity of flow; and
    i. corrosion condition.

Photographs should be taken during the inspection to record field conditions and observed defects. The use of digital cameras can provide the documentation of current conditions and allow the photographs to be attached to databases and mapping documents. In addition, the photographs provide historical information that can be referred to in evaluating the rate of deterioration since the previous inspections. For most applications, the use of low-resolution (640×480 pixels) photographs reduces the digital file size and storage requirements. Four basic types of digital photographs may be obtained during the investigation. Table 3-2 describes each photograph type.

Maintenance management software has unique coding systems to identify defects in the pipe and manhole. These coding systems allow rapid sorting and querying of databases. When used consistently, these programs standardize defect coding, making possible the detection of manhole condition change over time. By using a common vocabulary, benchmark conditions can be established, allowing for better monitoring of the health of manholes. The National Association of Sewer Service Companies (NASSCO) is a non-profit trade association with a mission to become the standard bearer for rehabilitation technologies. A comprehensive standardized coding system for manhole defects is evolving through the collaboration of ASCE, NASSCO, and other industry participants.

Manhole inspection programs can be phased or, if needed, performed in an overall program during a relatively short time span. Advantages of a phased approach are the following:

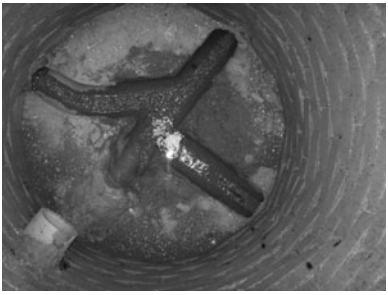
1. It allows for orderly inspection by a few key people with specialized training and experience working with gravity sewer systems. This situation allows greater data consistency and more opportunity to adjust to new information and recording requirements.
2. It allows for easier assimilation of data without overwhelming the municipality or sewer agency with data.
3. It allows the municipality or agency to maintain inspection crews from year to year.
4. Rehabilitation can also be phased.
5. It allows easier funding of annual costs.

Advantages of a comprehensive inspection program performed over a short time are the following:

1. It allows faster response to system needs.
2. It allows ranking of system deficiencies, considering all data, to ensure that repairs and resources are concentrated on the highest priority items.
3. It allows quantity discounts of rehabilitation materials.
4. It minimizes mobilization costs and management costs.
5. It establishes uniform baseline condition information for comparison with future studies or maintenance activities.

The frequency of inspections depends on the service area, but it should not be longer than 10–15 years. Shorter manhole inspection frequencies

TABLE 3-2. Photographs Obtained during Investigation

Area photo—A view of the manhole taken in the direction of the outgoing pipe provides both visual location and surface cover. Also, the condition of easements can be evaluated.	
Internal photo—This photograph is taken to show the internal view of the manhole. Orientation is that north is the top of the photo, which allows verification of maps.	
Pipe photo—Each incoming and outgoing pipe is photographed to record defects near the manhole. It is common for the manhole or pipe to settle, creating problems near the manhole.	
Defect photo—Structural and I/I defects should be documented and photographed.	

are recommended for areas with known corrosion, excessive I/I, or other maintenance problems. In addition, designated critical collector and interceptor sewer line manholes should be inspected more often than every 10 years, even yearly for especially critical areas. A suggested inspection frequency is shown in Table 3-3.

TABLE 3-3. Suggested Manhole Inspection Frequency

Manhole Condition	Inspection Frequency (yrs)
General	5–10, 15 maximum
Corrosion or other maintenance problems	1–2
Designated critical sewers	1–3
Creek and stream locations	1–2
New or rehabilitated manholes[a]	1–2

[a]One year, then adjust appropriately:
for a 10–25-year repair life, inspect every 2–5 years;
for a >50-year repair life, inspect every 10–15 years.

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4

QUANTIFICATION OF INFILTRATION/ INFLOW (I/I) AND STRUCTURAL CONDITIONS

INFILTRATION/INFLOW

Quantification of I/I is necessary for cost-effective manhole evaluation and to estimate the amount of extraneous flow that may be removed through rehabilitation. The evaluation of the structural condition is important for maintenance planning and for assisting with selection of the most appropriate rehabilitation method. The evaluation of manholes is as much an art as it is a science and relies greatly on the informed judgment of experienced inspectors. Quantification of I/I is usually based on a brief visual inspection and not actual measurement of I/I. Likewise, the structural condition evaluation must also be based on visual evidence. It is recommended that the inspection activities include observations of both I/I flow rate estimation and manhole structural conditions. This method provides greater precision when determining which components are cost-effective to repair and which methods of rehabilitation are applicable.

Of particular importance is a careful check for voids outside of the manhole structure created by I/I defects that remove external support and that affect the remaining strength of the manhole wall. The presence of voids outside of a manhole may be determined by looking for depressions or sags in the surface soil surrounding the manhole in nonpaved areas. Signs of voids in paved areas may include alligator cracking in asphaltic concrete and spalling, cracking, or tipping in pavements. Interior indicators may include significant staining at joints, cracks, and seals.

A rating system should be established before any manhole inspection activities. It is suggested that a five-point rating system be considered for both I/I flow and structural evaluation for all items except manhole cover inflow. Cover inflow should be estimated based on drainage area, depth of ponding, number of holes in the cover, and the condition of the cover and frame-bearing surface.

The description of each observation, corresponding to each rating, can be project-specific but should provide for reproducible and meaningful results. An example rating schedule with corresponding I/I flow is given in Table 4-1. These rates have been successfully applied to projects by several of the authors and are based on field management and project experience. Nevertheless, the assigned rates should be reviewed and adjusted, if necessary, for each project.

An alternative method of calculating inflow rates and total flows can be managed by use of the rational formula, $Q = kiA\tau$, where Q is the defect flow rate in gallons per minute, k is a modified unitless surface runoff coefficient generally developed or estimated for use over a basin, sub-basin, or catchment area, i is the rainfall intensity for the design storm event in inches per hour, A is the tributary area contributing flow to the manhole in square feet, and τ is an adjustment factor to account for actual or anticipated I/I flow through component defects. The modified runoff coefficient k is typically one quarter of the value of the rational formula runoff coefficient because a reduced portion of the overland flow can actually get to the manhole defects. Because the original rational formula calculates flow in cubic feet per second and inputs the catchment area in acres, the units must be corrected for this modified formula. The rational formula is used to compute overland flow and is useful for manhole defect flow analysis when coupled with manhole component defect adjustment factors. Table 4-2 provides unitless adjustment or reduction factors (τ) for rainfall-induced flows from defects commonly found in manholes and uses a five-point value system for the adjustment factors. For example, flow rate calculations for a defective frame seal with a 3 rating (moderate I/I, dripper) from Table 4-1 have a default flow rate of 0.4 gpm, with a tributary area of 5,000 sq.ft., in a single-family residential neighborhood with a runoff coefficient C value of 0.35 (k value of 0.09), during a storm with an intensity of 1.5 in./h, and from Table 4-2, a τ value of 0.4. Correction for units to get to gallons per minute would be 7.48 gal/cu.ft. × 1 h/60 min × 1 ft/12 in. = 0.01 gpm.

The inflow from this defect would be calculated by $Q = CiA\tau$, or

$$Q = 0.09 \times 1.5 \text{ in./h} \times 5{,}000 \text{ sq.ft.} \times 0.4 \times 0.01$$
$$Q = 2.7\,\text{gpm}$$

Note that the rational formula provides reasonable results on manhole components except for cover pick or vent holes. Inflow through holes in the cover should be calculated using an orifice equation that accounts for tributary area, depth of ponding, and diameter and number of holes. As ponding depth increases, the rate of flow through each hole increases geometrically. Table 4-3 provides an explanation of condition ratings. The values in Table 4-2 were developed over time based on numerous field evaluations, testing and observation; however, values to be used must be reviewed for varying conditions and locations.

Infiltration flows may be calculated in the same manner. However, as is observed when sewer flows are monitored to evaluate the effects of storms, infiltration sources respond slower and the effects are more long term than inflow sources. Infiltration sources tend to respond to rainfall events with a higher volume but lower flow rate, whereas inflow sources tend to have high flow rates but lower total volumes because of the shorter duration.

STRUCTURAL CONDITIONS

For structural conditions, a series of descriptions that correspond to each rating can also be developed to provide the necessary information for the structural evaluation of manholes. Serious structural degradation may exist from load-bearing soil washout even though major identifiable defects may not be evident on the interior surfaces of the manhole. An approach for a structural rating schedule for manholes is given in Table 4-3.

The I/I flow rating and manhole structural rating systems can be used in developing composite manhole rating numbers to prioritize manholes needing repairs.

TABLE 4-1. Manhole I/I Flow Rating Schedule

Component	Rating/Description/Default Defect Flow (gpm.) No I/I 1	Minor I/I (Weeper) 2	Moderate I/I (Dripper) 3	Heavy I/I (Runner) 4	Severe I/I (Gusher) 5
Cover[a]	No evidence	Pick holes or other unsealed cover No ponding	Corroded bearing surface No ponding	Ponding <1 in. with pick holes or other unsealed cover	Ponding >2 in. pick holes or other unsealed cover
Frame seal	0.0 No evidence	0.2 Water marks	0.4 Some soil present at cracks	0.8 Heavy soil or roots 1/8-in. gap in drainage area	≥1.6 ≥1/8-in. gap in drainage area
Chimney	0.0 No evidence	0.2 Water marks at 1 location	0.4 Water marks at 2–3 locations or mineral deposits Joint leak (<10%)	0.8 Multiple water marks Mineral deposits Joint leak (<25%)	≥1.6 Multiple water marks Mineral deposits Drainage area Joint leak (>25%)
Corbel or cone	0.0 No evidence	0.2 Water marks at 1–2 locations	0.4 Water marks at 3–4 locations or mineral deposits Joint leak (10%)	0.8 Multiple water marks or mineral deposits Joint leak (25%)	≥1.6 Multiple water marks Mineral deposits or soil present Joint leak (>25%)

Wall	0.0 No evidence	0.1 Water marks at 1–2 locations	0.2 Water marks at 3–4 locations or mineral deposits Joint leak (10%)	0.4 Multiple water marks or mineral deposits Joint leak (25%)	≥0.8 Multiple water marks Mineral deposit or soil present Joint leak (>25%)
Pipe seal	0.0 No evidence	0.1 Water marks at 1–2 locations	0.2 Water marks at 3–4 locations or mineral deposits Seal leak (10%)	0.4 Multiple water marks or mineral deposits Seal leak (25%)	≥0.8 Multiple water marks Mineral deposit or soil present Seal leak (>25%)
Bench	0.0 No evidence	0.1 Water marks at 1–2 locations	0.2 Water marks at 3–4 locations or mineral deposits Joint leak (10%)	0.4 Multiple water marks or mineral deposits Joint leak (25%)	≥0.8 Multiple water marks Mineral deposit or soil present Joint leak (>25%)
Invert or channel	0.0 No evidence	0.1 Water marks Hairline crack beneath flow	0.2 Water marks Mineral deposits or 1/16-in. crack beneath flow	0.4 Water marks and mineral deposits 1/8-in. crack beneath flow	≥0.8 Mineral deposits Soil 1/4-in. crack beneath flow

Note: % refers to the percentage of circumference that contains the indicated observation.

[a] No default cover inflow provided because inflow depends on type of cover, condition of cover, and ponding depth. Calculate leakage using manufacturer's data or appropriate orifice equations for pick holes or vent holes.

TABLE 4-2. Manhole Defect Flow Adjustment Factors

		Construction Type								
Manhole Component	Condition Rating[a]	Brick	Precast	Block	VC Pipe	RC Pipe	Cast-in-Place	Mortar	PVC Coated	Other
Vented cover (1/0)[b]		—	—	—	—	—	—	—	—	1.00
Cover-to-rim fit	Good	—	—	—	—	—	—	—	—	0.00
	Fair+	—	—	—	—	—	—	—	—	0.05
	Fair	—	—	—	—	—	—	—	—	0.10
	Fair–	—	—	—	—	—	—	—	—	0.20
	Poor	—	—	—	—	—	—	—	—	0.30
Frame seal	Good	—	—	—	—	—	—	—	—	0.20
	Fair+	—	—	—	—	—	—	—	—	0.30
	Fair	—	—	—	—	—	—	—	—	0.40
	Fair–	—	—	—	—	—	—	—	—	1.20
	Poor	—	—	—	—	—	—	—	—	2.00
Chimney	Good	0.00	0.00	0.00	—	—	0.00	0.00	0.00	0.00
	Fair+	0.10	0.06	0.06	—	—	0.05	0.06	0.06	0.06
	Fair	0.20	0.12	0.12	—	—	0.10	0.12	0.12	0.12
	Fair–	0.39	0.31	0.31	—	—	0.30	0.31	0.31	0.31
	Poor	0.57	0.49	0.49	—	—	0.49	0.49	0.49	0.49

Corbel or cone	Good	0.00	0.00	0.00	—	—	0.00	0.00	0.00	0.00
	Fair+	0.10	0.05	0.06	—	—	0.06	0.06	0.06	0.06
	Fair	0.20	0.10	0.12	—	—	0.11	0.12	0.12	0.12
	Fair–	0.35	0.25	0.24	—	—	0.23	0.24	0.24	0.24
	Poor	0.50	0.40	0.35	—	—	0.35	0.35	0.35	0.35
Wall	Good	0.00	0.00	0.00	—	—	0.00	0.00	0.00	0.00
	Fair+	0.05	0.04	0.04	—	—	0.04	0.04	0.04	0.04
	Fair	0.10	0.07	0.07	—	—	0.07	0.07	0.07	0.07
	Fair–	0.28	0.18	0.18	—	—	0.18	0.18	0.18	0.18
	Poor	0.46	0.29	0.29	—	—	0.29	0.29	0.29	0.29
Bench	Good	0.00	0.00	0.00	—	—	0.00	0.00	0.00	0.00
	Fair+	0.06	0.02	0.06	—	—	0.02	0.02	0.05	0.05
	Fair	0.11	0.03	0.11	—	—	0.03	0.03	0.10	0.10
	Fair–	0.19	0.07	0.17	—	—	0.06	0.06	0.15	0.15
	Poor	0.26	0.11	0.22	—	—	0.09	0.09	0.20	0.20
Invert or channel	Good	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fair+	0.05	0.03	0.05	0.05	0.05	0.03	0.01	0.03	0.03
	Fair	0.10	0.06	0.09	0.09	0.09	0.05	0.02	0.05	0.05
	Fair–	0.25	0.09	0.17	0.23	0.23	0.09	0.04	0.06	0.13
	Poor	0.40	0.12	0.24	0.37	0.37	0.12	0.06	0.06	0.20

TABLE 4-2. *Continued*

		Construction Type								
Manhole Component	Condition Rating[a]	Brick	Precast	Block	VC Pipe	RC Pipe	Cast-in-Place	Mortar	PVC Coated	Other
Pipe seal	Good	—	—	—	—	—	—	—	—	0.00
	Fair+	—	—	—	—	—	—	—	—	0.10
	Fair	—	—	—	—	—	—	—	—	0.20
	Fair–	—	—	—	—	—	—	—	—	0.35
	Poor	—	—	—	—	—	—	—	—	0.50

[a] Condition Rating	I/I Observed	Structural Conditions Observed
Good	No I/I	No structural defects
Fair+	Minor I/I (weeper)	Minor defect identified
Fair	Moderate I/I (dripper)	Multiple minor defects or moderate defect identified
Fair–	Heavy I/I (runner)	Multiple moderate defects or major defect identified
Poor	Severe I/I (gusher)	Major defects identified

[b] If the cover has vent or pick holes, an orifice equation is used to calculate inflow rates. 1 = vented, 0 = not vented.

TABLE 4-3. Manhole Structural Rating Schedule

Component	Component Material	Rating and Description				
		1	2	3	4	5
Cover fit		Good	Tight	Loose	Rocking	None
Cover condition		Good	No gaskets	No bolts	Corroded or pitted	Cracked or deteriorated
Frame		Good	Chipped, corroded, or pitted	Cracked	Broken (missing pieces)	Deteriorated (combination of 2, 3, and 4)
Frame seal		Good	Cracked (1/16 in.)	Cracked (1/8 in.) or misaligned (>3 in.)	Cracked (1/4 in.) with open joint	Deteriorated or missing
Chimney	Brick	Sound	Cracked mortar	Missing mortar	Missing bricks	Deteriorated or voids
	Precast rings or poured	Good	Hairline crack(s)	Cracks (1/16 in.), chipped (any), or missing grout or sealant	Cracks (1/4 in.), chipped (10%), or 10% of wall profile missing and missing grout or sealant	Cracks, pieces missing, exposed reinforcing (1 ft × 1 ft) or 20% or more of wall thickness lost
Wall	Brick	Good	Cracked mortar	Missing mortar	Missing bricks	Deteriorated
	Precast or poured	Good	Hairline crack(s)	Cracks (1/16 in.) or chipped (any)	Cracks (1/4 in.), chipped (10%), or 10% of wall profile missing	Cracks, pieces missing, exposed reinforcing (1 ft × 1 ft) or 20% or more of wall thickness lost

TABLE 4-3. *Continued*

Component	Component Material	Rating and Description 1	2	3	4	5
Pipe seal	Brick	Good	Cracked mortar	Missing mortar	Missing bricks or grout	Exposed soil or missing bricks
	Precast or poured	Good	Hairline crack(s)	Cracks (1/16 in.) or chipped (any)	Cracks (1/4 in.) or chipped (10%)	Cracks, pieces missing, or exposed soil
Bench	Brick	Good	Cracked mortar	Missing mortar	Missing bricks or grout	Exposed soil or missing bricks
	Precast or poured	Good	Hairline crack(s)	Cracks (1/16 in.) or chipped (only)	Cracks (1/4 in.) or chipped (10%)	Cracks, pieces missing, or exposed soil
Invert or channel	Brick	Good	Cracked mortar	Missing mortar	Missing bricks or grout	Exposed soil or missing bricks
	Precast or poured	Good	Hairline crack(s)	Cracks (1/16 in.) or chipped (only)	Cracks (1/4 in.) or chipped (10%)	Cracks, pieces missing, or exposed soil
Steps		Good (new)	Slight corrosion or chipped, but serviceable	Corrosion (26%) or unserviceable	Broken or missing step, corrosion (50%), or unserviceable	Deteriorated, hazardous, or unserviceable

Note: % refers to the percentage of circumference that contains the indicated observation.

5

MANHOLE REHABILITATION METHODS

Once information is gathered through the inspection process, data are reviewed and necessary manhole repairs are classified according to priority and methodology. The implementation of manhole maintenance or a rehabilitation project is generally intended to correct structural deficiencies, satisfy maintenance requirements, eliminate I/I, and prevent future corrosion. Material and technology choices for rehabilitation depend on the specific reasons for the implementation of the project (Table 5-1).

Many products available may fulfill the maintenance requirements and control I/I within manholes. Some of these technologies require minimal training and little or no specialized equipment. This type of work includes specialty products such as:

- lid replacement or hole plugs to remove inflow,
- lid seals and dishes to stop and collect inflow coming from the manhole lid, and
- chimney seals and flexible sealants intended to repair chimney joints and rings and remove inflow.

CHIMNEY SEALS

Manhole frames, covers, and chimneys present multiple opportunities for inflow and infiltration. Surface water can enter through holes in the cover and through the space between the cover and the frame. Infiltration results from subsurface water entering from under the manhole frame and through the chimney. These sources of I/I may account for a significant amount of leakage.

TABLE 5-1. Manhole Rehabilitation Options

Option	Satisfy Maintenance Requirements	Correct Structural Deficiencies	Eliminate I/I	Prevent Future Corrosion	Comments and Limitations
Lid seals and dishes	X		X		
Chimney and joint seals	X	X	X		
Chemical grouts	X		X		
Portland-based cementitious coatings	X	X	X		pH > 3
Calcium aluminate (cementitious) coatings		X	X	X	pH > 2
Polymer or additive modified cementitious coatings		X	X	X	Protection dependent on corrosion inhibitor or polymer additive
Rigid polymer coatings		X	X	X	May be installed as composite system with cementitious base repair for cost savings
Flexible polymer coatings			X	X	May be installed as composite system with cementitious or rigid polymer base repair to effect structural repair
Cured-in-place composite liners		X	X	X	
Thermoplastic liners				X	Uses cementitious or polymer base to install and effect structural repair

Manhole covers can be sealed, generally through replacement with new watertight covers or by installing asphaltic mastic sealant and plugging vent or pick holes. The use of manhole dishes or inserts under the manhole covers is also common to capture residual water, especially in flood-prone areas. Rubber gaskets can be used, with best results achieved if the frame and cover are grooved specifically for a gasket.

Ground movement, thermal expansion and contraction of the surrounding pavement, frost heave, and traffic loadings cause the seal between the frame and chimney to break and deteriorate, allowing subsurface water to enter the manhole. This water, entering the manhole after running along pavement subgrades, washes subgrade material in with it, resulting in settlement of the pavement around the manhole. Concentric surface cracks are evidence of subgrade washout.

The frame–chimney joint area can be sealed internally without excavation when frame alignment and chimney conditions permit. When excavation is required to replace the frame or to reconstruct the chimney and/or cone, the frame–chimney joint can be sealed internally, externally, or both. Several methods for sealing this joint include mechanical seals (Fig. B-7 in Appendix B), flexible urethane and epoxy applied sealants (Fig. B-8), mastic and rubber adhesive laminate, and cured-in-place reinforced liners (Fig. B-9).

The following methods can be used to repair manholes requiring more comprehensive rehabilitation: chemical grouting, miscellaneous spot repairs, coatings providing corrosion protection, and structural liners.

CHEMICAL GROUTING

Chemical grouting is typically used in manholes for I/I control and void stabilization. It is also commonly used in conjunction with coating and lining technologies to stop infiltration before their installation. Manhole grouting requires training and equipment for proper installation and effectiveness. The success of grouts in reducing manhole I/I depends largely on all of the following factors:

- soil conditions,
- moisture conditions and groundwater table elevation,
- injection patterns,
- gel time and grout mixture,
- containment of excessive grout migration,
- selection of the proper type of grout,
- experience of the grouting crew, and
- the project quality control program.

The wide range of grouts on the market for pressure injection falls into these categories: acrylamide, acrylic resins, acrylate, urethane gels, and urethane foam, as further described here:

Acrylamide: Grout mixture of three or more water-soluble chemicals. The acrylamide itself is the base chemical in the mixture. The concentration of acrylamide is normally in the range of 10% to 11.5% of the total weight mixture. Catalysts such as triethanolamine (TEA) and ammonium persulfate (AP) are part of the mixture.

Acrylic resins: Water solutions of acrylic resins with several types for different applications. These grouts have a tendency to swell in water, allowing a watertight seal. The catalyst TEA and sodium persulfate are commonly used.

Acrylate: Similar to the acrylamide and acrylic grouts, the catalysts TEA and AP are used in the mixture.

Urethane gels: Solution of a prepolymer that cures on reaction with water. Hydrophilic grouts absorb water and hold it within a cured gel mass. Ratios range from 5 parts of water for 1 part urethane to 15 parts of water for 1 part urethane. Too much water creates a weak gel, and too little water produces a foam reaction.

Urethane foam: Primarily used to stop infiltration in maintenance holes and not used with remote-controlled equipment (packer method). When mixed with an equal amount of water, the grout cures into a tough, flexible, closed-cell, rubberlike foam.

Where the following conditions are observed, pressure grouting within manholes can be used:

- brick manholes with somewhat tight joints,
- active I/I,
- structurally sound manholes,
- cohesive soils with optimal moisture content, and
- manholes with voids or unstable surrounding soil.

The most common grouting techniques used within manholes include curtain grouting, expanded gasket placement, and horizontal crack injection.

Curtain grouting (Fig. B-10 in Appendix B) is a technique used to encapsulate a structure. Curtain grouting is performed on manholes by drilling through the manhole walls in a pattern starting from the bottom of the structure and rotating (in a serpentine or coil shape) toward the top of the structure. Specially designed packers are then inserted into the drilled holes, and the grout is pumped through these mechanical packers. The drilled holes within the structure allow for the placement of the grout on the outside of the structure to encapsulate the structure from any groundwater infiltration.

The primary uses for curtain grouting are to control infiltration and stabilize the structure. The equipment necessary to perform this task is drill bits and a drill, a dual- or single-component pump, an injection gun and packers, chemical grout, and safety equipment.

The expanded gasket placement technique (Fig. B-11 in Appendix B) consists of physically inserting a resin-soaked foam rod or dry oakum into a joint. This resin-soaked rod with the polyurethane grout reacts with the incoming groundwater to expand and isolate the joint or pipe connections to the manhole, re-forming a watertight gasket. This technique is also used around pipes where they enter the manhole structure.

Horizontal crack injection targets the seams between the precast concrete sections. Many times the original seals were improperly installed or have eroded, allowing groundwater to leak into the manhole. The leaks are generally sealed using hydrophobic or hydrophilic urethane grouts. Holes are drilled into the seam where the sections are joined. A grout injection packer is inserted into the hole, and grout is pumped into the crack and outside the wall of the manhole to create an impermeable barrier to the infiltration.

COATINGS AND LINERS

Correcting structural deficiencies, elimination of infiltration, and prevention of corrosion may require the use of a monolithic coating or liner within the manhole. Knowledge of the following project and structure criteria is essential to making optimal selection of material and application technology:

- accessibility,
- downtime available for the rehabilitation process,
- existing and future conditions related to corrosion,
- existing structural deterioration, and
- existing infiltration.

In addition to understanding current conditions of the structure in need of repair, understanding relevant characteristics of available products is also essential. The question of which product or system to use is complicated by the myriad of solutions available. The answer is revealed by product type, its installation capabilities, and service performance matched successfully with the condition for which it is being used: structural rebuild, corrosion protection, or infiltration elimination.

Preparation for installation of these coating systems is essentially the same for all product types. Following good coating practices as standardized through NACE, SSPC, and ASTM, the basic steps include the following:

1. cleaning, decontaminating, and creating an adequate profile of the host substrate;
2. eliminating infiltration and diverting and bypassing flows;
3. repairing and/or resurfacing concrete and masonry surfaces;
4. application of the coating system(s); and
5. inspection and testing.

Cleaning and profiling of concrete and masonry substrates includes the removal of oils, grease, incompatible existing coatings, waxes, form release, curing compounds, efflorescence, sealers, salts, or other contaminants that may affect the performance and adhesion of the coating to the substrate. Concrete and/or mortar damaged by corrosion, chemical attack, or other means of degradation are also removed so that sound substrate remains. The preparation process chosen should also remove all laitance and weak concrete to expose subsurface voids and to open honeycombs, bug holes, and air pockets. Several methods are available to accomplish proper preparation; the most common methods are high-pressure water cleaning (5,000–10,000lb/in.^{2}), water jetting (>10,000lb/in.^{2}), and dry and wet abrasive blast. A knowledgeable and properly equipped contractor chooses the right methods to prepare a uniform, sound, clean, neutralized surface suitable for the specified coating products.

Although many of the coating systems used in manhole rehabilitation boast moisture and surface tolerance, active infiltration should be stopped before application of the coating to achieve optimal adhesion and long-term performance. The use of hydraulic cements and chemical grouts has proven successful in preparing manholes to receive a coating or lining system while permanently or temporarily stopping infiltration.

Repair or patching products are used to fill voids, honeycombs, bug holes, spalls, cracks, and other surface anomalies that may affect the performance or adhesion of the coating system. This process is less intensive when using cementitious coating systems because the same materials are generally used for the repair as the coating itself. However, it is also common to use cementitious coatings to resurface severely corroded concrete and masonry manholes to repair, smooth, or rebuild surfaces with rough profiles, making them suitable to receive polymer coatings or thermoplastic liners. These resurfacing and repair products should be installed to minimum thickness as recommended in manufacturers' published guidelines. Should rebuild be necessary, thickness should be determined based on structural deficiencies and product strength.

There are basically four types of coatings and liners: cementitious, thermoplastic liners in conjunction with cementitious or polymer materials, polymers, and reinforced cured-in-place.

Cementitious

Cementitious coatings can provide an economical answer to infiltration problems. Structural restoration or renewal requires 1 to 4 in. of product, with nonstructural I/I elimination or resurfacing generally specified at a minimum of 1/2 in. Corrosion protection with cementitious products requires a more thorough understanding of this type of product and the ability of various formulations to defer the microbiologically induced corrosion process found in sanitary sewers. Cementitious products in sanitary sewer environments are corroded through the production of sulfuric acid by *Thiobacillus* bacterium. *Thiobacillus* produces dilute sulfuric acid, which attacks and deteriorates the cement paste hydrates, producing calcium salts on Portland cement and aluminum salts on calcium aluminate cement. These salts dissolve the calcium more quickly than the aluminum, exposing fresh surface area that is attacked again. Because of the calcium salts and the accompanying formation of ettringite, Portland cements are generally not recommended for environments where the pH is less than 3. However, these same products can be effective at controlling I/I and improving and rebuilding the structural integrity of a failing manhole. High alumina or calcium aluminate hybrid formulas are more effective at sulfide and microbiologically induced corrosion (MIC) protection because the alumina gel created during hydration is not attacked in wastewater until the pH falls below 3. Cement mix and aggregate choice can further extend the pH range (1–1.5) where corrosion can be avoided. Most cementitious materials are shotcrete (Fig. B-12 in Appendix B) or spincast (Fig. B-13) applied, although some are formed-in-place (Fig. B-14), all require specialized equipment and training for proper installation.

Thermoplastic Liners

Thermoplastic liners (Fig. B-15 in Appendix B) in rehabilitation are used in conjunction with cementitious or polymer basecoats to provide corrosion protection. Thermoplastic liners are also installed in the factory on manholes as a preventive maintenance measure in new construction. When used in rehabilitation, forms are usually set inside the manhole, and 2 to 4 in. of concrete is poured in the annular space, diminishing the manhole diameter by 4 to 8 in. After the cementitious base is set and forms are removed, all seams of the thermoplastic liner are fusion welded to protect against corrosion. As with all of these coating and lining products, proper installation is critical for success. Training and special equipment are necessary.

Polymers

Polymers can provide effective solutions to I/I, structural deficiencies, and corrosion. A wide variety of product types are being used in manhole rehabilitation, including epoxies, urethanes, and ureas. Epoxies (Fig. B-16 in Appendix B) can be formulated for moisture and surface tolerance, generally achieving the best bond to properly prepared underground substrates. Epoxies are also used as primers for ureas and urethanes. Urethanes (Fig. B-17) and ureas generally set up within seconds or minutes, whereas the set time for epoxies varies between 1 and 6 hours, depending on the formulation and temperature during installation. Recommended thickness ranges differ greatly among products and manufacturers. However, based on several independent studies and failure analyses of coatings in concrete and masonry wastewater structures, a minimum of 0.04 to 0.05 in. (40–50 mils) above the highest peak of the prepared profile has become an accepted industry standard. This minimum can relate to specifications averaging 0.125 in. (125 mils) but varying from 0.06 in. (60 mils) on relatively smooth surfaces up to more than 0.2 in. (200 mils) for rough surfaces and structural reinforcement. Because these coatings are generally applied relatively thin (1/8in. or less) and perform based on the composite system formed with the host structure, surface preparation is critical for adhesion and long-term service. Only 100% solid, solvent-free products should be considered because of safety and performance advantages. Spray and spincast (Fig. B-18) application requires specialized equipment and training.

Reinforced Cured-in-Place

Cured-in-place, generally felt- or glass-reinforced "bag" systems (Fig. B-19 in Appendix B), are only necessary for structural rehabilitation where the manhole will be subjected to future corrosion. The bag is custom made to premeasured size at the factory. Resin is impregnated into the bag at the job site. The bag is then lowered into the hole, steam-pressure-injected for 1–2h to cure, and holes are cut in the invert and pipe inlets, which are manually rehabilitated with troweled epoxy grouts before returning to service. This process is labor intensive and requires specialized equipment and applicator training. The system provides structural rehabilitation, eliminates I/I, and protects against corrosion. Surface preparation is critical and should include filling recessed voids to eliminate potential problems in annular space.

Testing and inspection of coatings and linings is another essential ingredient to ensure maximum performance of the installed system. See Chapter 7 for quality control and inspection processes.

Composite Systems

Several combinations of coating and liner materials result in a composite application serving multiple purposes necessary to achieve the solutions within a particular manhole structure. This combination is most commonly evidenced through the use of cementitious products for resurfacing or rebuilding deteriorated and structurally deficient manholes. The cementitious materials are then either coated with a polymer coating or a thermoplastic liner may be embedded into the cement base, both providing corrosion protection. Other systems include thick polyurethane foam or polymer mastics that may be coated with a thermoplastic liner or thin polymer topcoat.

SUMMARY

The decision making becomes easier once an understanding of the need is identified clearly. The advantages and limitations of the many rehabilitation options allow specifiers to custom design each project to meet both immediate and long-term needs. Table 5-2 provides an example decision matrix based on a predesigned condition rating for defects and available solutions for rehabilitating manholes.

TABLE 5-2. Manhole Rehabilitation Decision Matrix

Conditions Identified during Inspection		
Leaks and Spot Defects in Structurally Sound Manholes	Heavy Leaks in Structurally Impaired Manholes	Structurally Damaged Manholes
	Conditions of Ratings 1 and 2 Plus the Following:	Conditions of Ratings 1 Through 6 Plus the Following:
1. Isolated leaks	1. More than 15% of area leaking or leaks >5gpm during a rain event	1. Portions of wall missing
2. Inflow problems (a) around cover or (b) under frame	2. Some missing bricks	2. More than 1 in. or precast call corroded
3. Misaligned or broken casting	3. Repairable small void pockets	3. Exposed rebar
4. No evidence of corrosion present	4. More than 40 years old	4. Subjected to heavy traffic loading
5. Unsafe steps	5. Evidence of corrosion	5. Manhole located in a critical area within sewer system that requires a long-term cost-effective renewal solution with low risk
6. Minor damage to bench and/or leaking in channel	6. Unusable bench	
7. Area of low or no groundwater present	7. Leaking channel	
	8. High groundwater area	

Defect Rating		
1–2	*3–6*	*7–10*
Corrective Action		
1. Stop leaks with (a) hydraulic cement or (b) chemical grouting	1. Stop leaks with (a) hydraulic cement or (b) chemical grouting	1. Remove and replace
2. Install manhole dish or insert	2. Fill voids with high-strength cement and/or bricks to prepare for liner installation	2. Resurface with high-strength cement or rigit polymer to prepare for liner installation
3. Install frame and chimney seal	3. Reinforce and seal with structural liner (a) Cementitious–shotcrete, spincast, or formed-in-place, (b) polymer–rigid polyurethane or epoxy, or (3) cured-in-place manhole system	3. Reinforce and seal with structural liner (a) Cementitious - shotcrete, spincast, or formed-in-place, (b) Polymer - rigid polyurethane or epoxy, or (3) cured-in-place manhole system
4. Repair bench and/or channel	4. Install corrosion-resistant barrier. Use polymer or plastic liner in composite with non-resistant cementitious base liner	4. Install corrosion-resistant barrier. Use polymer or plastic linter in composite with non-resistant cementitious base liner

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6

COST-EFFECTIVENESS ANALYSIS AND REHABILITATION METHOD SELECTION

Standard cost-effectiveness analyses compare the cost of rehabilitation to the cost of transporting and treating excess flow resulting from I/I. This analysis is usually performed on each manhole component individually by listing the ratio of the repair dollars to the flow removed (in dollars per gallon per day) and comparing this ratio to a defined cost-effective ratio. The cost-effective ratio is peculiar to each system and requires a detailed analysis of cost components to determine accurately the optimum level of removal. If the ratio is less than or equal to the defined cost-effective ratio, then a defect is considered cost-effective to repair. If the ratio is greater than the defined cost-effective ratio, then a defect is not cost-effective to repair. Although this analysis procedure is an appropriate method, in practice, manhole repairs may include all manhole components for those manholes that have any cost-effective sources for repair. In other words, if a cost-effective defect repair is identified in a particular manhole, all other defects in the manhole should be considered for repair, whether they are individually cost-effective or not, because the single project mobilization may reduce the cost for the repair of all defects. For example, a manhole that requires the rebuilding of the cone and chimney may also require the replacement of the frame and the installation of a frame seal. The cost of these additional items is lower than if the repairs were each done individually because a construction crew is already mobilized. Because of this, a comprehensive analysis of total manhole rehabilitation methods and costs is usually more appropriate in certain situations. This idea is especially true for rehabilitation procedures that address multiple manhole components for the same bid unit cost.

In addition to I/I source removal, other cost and noncost factors should be considered during manhole rehabilitation. These factors include life-cycle costing of rehabilitation methods, risk of failure, damage to surface from unrepaired manholes (such as street settlement and maintenance and safety considerations), disruption, inconvenience, and life expectancy. For these items, it is necessary to adjust the dollars per gallons per day ratio to determine manholes that should be repaired.

The cost-effectiveness analyses should be performed considering rehabilitation, relief, and treatment costs at various levels of rehabilitation for a selected level of structure and storm protection. Once the cost-effective ratio is determined, a detailed evaluation of manhole repairs can be performed.

Evaluation of alternative manhole rehabilitation methods should use life-cycle costing, which considers the initial rehabilitation cost and the estimated life of the repair. Life-cycle costing can be performed with present worth analysis. This analysis shows how much money would be needed now to pay for all costs during the planning period. The present worth analysis requires an evaluation period, interest rate, and initial cost, as shown in Eq. 6-1, present worth analysis:

$$P = A\frac{(1+i)^n - 1}{i(1+i)^n} \tag{6-1}$$

where P = present worth dollars, A = estimated cost of performing the work, n = number of interest periods, and i = interest rate (use of current bond rates is appropriate and eliminates the need to factor inflation costs into the analysis).

Applying present worth analysis to typical manhole rehabilitation methods results in the present worth costs shown in Table 6-1. The initial costs and anticipated life are for planning purposes. Actual cost and life expectancy are a function of the materials specified, local conditions, and application. Local conditions that affect these items should be reviewed during project design. A rehabilitation matrix for manhole defects showing potential rehabilitation methods and various considerations for each manhole component is given in Table 5-2.

TABLE 6-1. Present Worth Cost of Typical Manhole Rehabilitation Method

Method	Description	Initial Cost Range	Anticipated Life (years)	Periods	Present Worth
Replace cover	Replace existing cover with a new cover	$120–240	50	1.0	$120–240
Install insert	Install an insert under cover to prevent inflow				
Plastic	Insert made of plastic	$50–75	5	10.0	$405–608
Stainless steel	Insert made of stainless steel	$100–130	15	3.3	$315–410
Replace frame	Replace existing frame with new one				
Sod	Replacement in the sod	$500–600	50	1.0	$500–600
Pavement	Replacement in the pavement	$1,000–1,200	50	1.0	$1,000–1,200
Adjust frame	Align vertically and horizontally				
Without excavation	Use of shim rings	$100–150	25	2.0	$195–293
With excavation	Assemble to new construction specs				
Sod	Adjustment in the sod	$250–650	50	1.0	$250–650
Pavement	Adjustment in the pavement	$1,000–1,200	50	1.0	$1,000–1,200
Seal frame and chimney rehabilitation	Rehabilitate frame seal joint or entire adjustment section of manhole				
Nonstructural repair	Eliminate I/I and to complement cement and epoxy rehabilitation				

TABLE 6-1. *Continued*

Method	Description	Initial Cost Range	Anticipated Life (years)	Periods	Present Worth
Applied	Material that is troweled, injected, or sprayed on	$250–400	7	7.1	$1,545–2,472
Mechanical	Premanufactured seal installed as a one-piece unit	$275–425	25	2.0	$537–830
Structural repair	Structural enhancement, eliminate I/I, and complement cement and epoxy rehabilitation	$400–800	40	1.3	$497–994
Chemical grout sealing	Eliminate I/I into the manhole in various locations	$500–1,000	15	3.3	$1,576–3,152
Full-depth-rehabilitation	Top to bottom rehabilitation				
Cementitious	Cement-based material sprayed, troweled, or spin applied at 1/2 in.				
Without corrosion protection	Portland-based coating for pH > 3	$585–1,125	10	5.0	$2,659–5,114
With corrosion protection	Calcium aluminate based coating for pH >2	$900–1,305	15	3.3	$2,837–4,113
Cementitious & polymer composite	Cementitious base at 1/2 in. with a polymer topcoat at 100 mils	$1,260–2,250	20	2.5	$3,038–5,426

Polymer	Polymer coatings sprayed, troweled, or spin applied for corrosion protection at pH <2				
Nonstructural repair	Polyurea, epoxies, polyurethanes, or other thinly applied (80–100 mils) material used only for corrosion protection	$1,125–1,350	20	2.5	$2,713–3,255
Structural repair	Epoxies and rigid polyurethanes with high-strength properties that enhance structural integrity (applied at 125–250 mils)	$1,260–2,700	25	2.0	$2,460–5,271
Cured-in-place liner	Fiberglass epoxy composite liner that enhances structural integrity and provides corrosion protection for pH <2	$3,375–6,300	40	1.3	$4,193–7,828
Poured in place with corrosion protection	Forms are used to pour cement and are then topcoated with a polymer coating or thermoplastic liner rebuilding structure with corrosion protection for pH <2	$6,300–9,000	50	1.0	$6,300–9,000
Steps replacement	Replacement of old steps with corrosion-resistant steps or ladder	$300–400	50	1.0	$300–400

TABLE 6-1. *Continued*

Method	Description	Initial Cost Range	Anticipated Life (years)	Periods	Present Worth
Seal precast joints (per joint)	Rehabilitate precast joints				
Cementitious	Seal with a cementitious coating	$125–200	7	7.1	$772–1,236
Chemical	Seal with chemical grout	$200–300	15	3.3	$630–946
Mechanical	Seal with a mechanical seal	$400–500	25	2.0	$781–976
Pipe connections (each)	Rehabilitate pipe connections				
Nonstructural repair	Eliminate I/I at the pipe connection using grout or nonstructural coating	$150–250	10	5.0	$682–1,136
Structural repair	Eliminate I/I and structurally enhance connection using cured-in-place liner	$250–350	40	1.3	$311–435
Invert rehabilitation	Rehabilitation of invert area				
Nonstructural repair	Eliminate infiltration in the invert area using chemical grout	$200–300	15	3.3	$630–946
Structural repair	Eliminate infiltration and rebuild invert with cementitious, polymer, or cured-in-place liner	$300–400	25	2.0	$586–781
Plastic insert	Installation of a premanufactured complete invert system	$700–1,000	40	1.3	$870–1,242
Replace manhole	Replacement of an old manhole with a new one				
Off road	Replacement in sod areas	$3,000–8,500	50	1.0	$3,000–8,500
On road	Replacement in pavement areas	$5,000–15,000	50	1.0	$5,000–15,000

7

CONSTRUCTION INSPECTION AND QUALITY CONTROL

DEFINITIONS

Quality control (QC) can be defined as a program of systematic checks in the manufacturing and construction environment that provides for a defect-free finished product. Quality assurance (QA) can be defined as a system of providing the highest possibility of success of a finished product through independent verification of all steps in the investigation, design, specification, manufacture, and installation of a product.

PURPOSE

Implementation of QC and QA during manhole rehabilitation provides for a high-quality rehabilitated manhole that meets project objectives and provides the anticipated structure life. This portion of the manual identifies key steps throughout the manhole rehabilitation process requiring QC and QA that can significantly influence project effectiveness. These steps include design functions, material selection, installation, and application methods.

DESIGN FACTORS

The project designer has the most significant overall influence on installed quality of a rehabilitation project. The designer must, at all times, be focused on the issues that affect the installed quality of the products being specified. This focus is important, beginning with the initial field investigation through design, specification preparation, installation, and inspection.

FIELD INVESTIGATIONS

The purpose of any rehabilitation project is to provide solutions that address specific needs and problems. For a manhole project, these problems include corrosion, hydraulic restrictions, structural deficiencies, leakage, and access problems. The purpose of the field investigation is to identify specific conditions for each manhole. In addition, the inspection should generate sufficient geometric information so that plans, specifications, and cost estimates may be accurately prepared. It is important that a thorough description of all conditions be made so that appropriate methods and materials can be specified. For example, the manholes that have deteriorated from infiltration and corrosion require the use of rehabilitation products that can effectively stop the infiltration and repair the damaged structure. Moreover, the installation of a corrosion barrier to prevent future degradation should be considered.

In addition to the manhole structure itself, erosion is the migration of surrounding support soils from immediately outside the manhole through seepage and leaks. When leaks are not stopped in a timely manner, large voids can occur that may lead to partial or total collapse of the roadway and the manhole. It is important, therefore, in the inspection and evaluation process to determine if such voids exist.

Field investigators should be trained to recognize and document defects and conditions common to manholes. They should also be familiar with common rehabilitation methods to associate rehabilitation alternatives and installation constraints. This knowledge better enables the investigator to obtain all pertinent information regarding rehabilitation at the manhole. The designer should perform comprehensive checks of field notes to ensure that information gathered is consistent among investigators, meaningful, and reliable. The number of manholes to be checked varies depending on the configuration of the system, the complexity of the problems encountered, and the experience of the investigator.

DESIGN

No one product or process solves all manhole problems in the most economic fashion. However, a variety of products are available in differing price ranges that will solve one or more problems. For the project to be a success, the rehabilitation methods selected should address all problems in a manhole. The selected methods must be able to be applied to the manhole in a high-quality, workmanlike manner. It is the responsibility of the designer to select the solutions that offer the best combination of technical problem solving and economy. For many manholes, a variety of alternatives may be applicable, and the economic selection must be made during the bidding process. In many instances, one proprietary solution may be available that solves a particular problem within a manhole. In these cases, the designer and the owner must agree on a mutually acceptable procurement method. The most important thing for the designer to keep in mind is that the project's success depends on the methods selected and their ability to address all of the problems in the manhole.

The designer should pay particular attention to the technical aspects of the processes selected. All claims made by vendors should be backed up by independent, third-party testing and opinions. Case studies of completed projects by bidding contractors should be checked to ensure that contracted field performance is acceptable. The expected service life of the process selected should be carefully analyzed and preferably substantiated with actual installed history. Only by selecting a technically appropriate, high-quality process, including contractor qualifications, can the designer assure the owner that the installed system will provide the expected service life.

SPECIFICATIONS

The process of preparing specifications is much more involved than copying standard specifications from previous projects. With the ongoing development of new and varied technologies, the importance of high-quality specifications is magnified. The specifications must clearly identify the expected results of rehabilitation for each manhole, including methods and materials believed to be capable of delivering such results. Clearly stating unacceptable options minimizes misunderstandings and legal actions during the bidding and construction process. Prequalification of contractors and subcontractors increases the chances of a high-quality finished product. The installing contractors must have appropriate training and successful experience with each method. This need is especially important with entire manhole rehabilitation or structural repair processes that require specialized equipment and proprietary processes to be successful. The specifications must indicate the acceptable technology, methods of testing, and the basis for acceptance or rejection of the work performed.

MATERIALS

One of the key areas of concern for the designer and the installer is the selection of appropriate materials for the project. The materials selected must offer the necessary levels of stress, load, and corrosion resistance. Extensive field application and testing data should be available before selection of a particular material for the project. Material that performs under laboratory conditions may not work in the field because of application limitations. It is imperative that the materials to be used be easily and reliably installed by those constructing the work. If the application process is overly complex or requires a high degree of field adjustments or equipment settings, it is less likely to achieve a high-quality installation. Materials or methods that require bone-dry surfaces for proper adhesion are unlikely to bond properly in the high humidity and leak-prone environment found in many manholes.

INSTALLATION

More than almost any other factor, the field installation controls the quality of the project and the expected service life of the rehabilitation being performed. Any method selected must provide for a simple and highly repetitive application process that may be learned by workers. Processes that require the use of extensive adjustments and judgment are less likely to succeed in achieving the desired results. Key factors to be considered during installation are repeatability, ability to inspect, and testing methods.

INSPECTION

The purpose of inspection during the construction phase of the project is to ensure that the specified products are used according to the specifications and accepted industry standards. Effective inspection requires the inspector's familiarity with materials and proper installation methods for each process to be used on the project, as well as the specified testing equipment and methods. Preconstruction meetings provide an ideal opportunity to discuss project execution, identify inspection checkpoints, and define responsibilities and authorities of all parties. The following sections provide some common inspection methods.

Chimney Seals

All surfaces should be prepared to be reasonably smooth and circular, clear of any loose materials or excessive voids to properly receive the seal or sealant materials. Inspectors should follow applicable recommendations shown below for coatings and liners when inspecting polymer applied sealants, adhesive laminates, and cured-in-place reinforced chimney seals. Manhole chimney seals should be visually inspected after installation for proper positioning and for tightness against and/or adhesion to the manhole and frame casting surfaces. No voids or visible leakage points should exist, and mechanical seal bands should be securely locked into place. External flooding and/or dye testing (Fig. 7-1) may also be performed to check for leakage before and after seal installation.

Coatings and Liners

Coating and lining systems are adhered to or anchored into the host structure; therefore, proper surface preparation is essential. Many methods are available and used to prepare manhole surfaces, including low- to high-pressure water cleaning, high-pressure water jetting, abrasive blasting, and degreasing. Surface preparation remains an important component of installation for mechanically anchored systems, such as sheet liners. These systems are installed in combination with either poured cement or polymer mastic materials. Inspectors should pay particular attention to the surface preparation. All infiltration must be stopped, flows diverted, and preparation performed in a manner that provides a uniform, sound clean neutralized surface suitable for the specified product. Inspectors may reference ASTM D4258 and D4259, NACE No. 6, SSPC SP-13, and ICRI 03732 standards as guidelines for the performance and inspection of concrete surface preparation.

FIGURE 7-1. Dye Test.

Testing and inspection of coatings and linings during and after installation is another essential ingredient to ensure maximum performance of the installed system. Steps for inspection and processes include:

- During application, including shotcrete, hand application, trowel, spray, or spincast techniques, the condition of equipment should be documented. Variables during application including weather, access, confined spaces, temperature, humidity, leakage, and flow, all potentially affecting the performance of coating systems. Inspectors should document ambient and application environment variables and verify that installation processes are being conducted in accordance with specifications and product manufacturer guidelines.
- Cementitious—Verify that proper water-to-cement ratio, finishing, and cure procedures are followed. Measure applied product thickness (Fig. 7-2) to verify coverage and obtain material use records for specification compliance. For products applied with formwork, the forms and cavity behind the forms should be inspected to ensure that they are clean and that the designed wall thickness is realized. Vacuum test fully rehabilitated manholes for a post-installation integrity check (ASTM C1244).
- Polymers—Verify proper component ratio, mix, and cure to a hardened state in accordance with manufacturer guidelines. Measure wet or dry film thickness of the applied coating and obtain material use records for specification compliance (ASTM D4414). Inspect

FIGURE 7-2. Cement Thickness Inspection.

FIGURE 7-3. Holiday Detection.

FIGURE 7-4. Adhesion Test.

coated surfaces for pinholes or breaches in the coating film using a properly calibrated high-voltage holiday detection instrument (Fig. 7-3) (ASTM D4787, NACE RPO-188). Adhesion testing (Fig. 7-4) may also be performed to evaluate the bond of the polymer to the manhole surface (ASTM D4541, D7234).

- Thermoplastic liners—Verify proper anchoring of panels and seam welding procedures. Welded joints shall have no visible cracks, separations, or unfused areas. Check for separation and unfused areas by probing with a putty knife or similar semisharp flat object. Test welds using a high-voltage holiday detection instrument set at 18,000–22,000 volts. Inspect adhesion of liner interface with existing materials.

- Cured-in-place liners—Verify that proper resin ratio, mix, and wet-out processes are met and that the installed system is cured to a hardened state in accordance with the specifications and manufacturer guidelines. Obtain material use records for specification compliance. Inspect liner termination points and adhesion of interface with other materials. Vacuum test for post installation integrity check (ASTM C1244).

The designer should communicate to the field inspectors the assumptions made during design of the project. This step ensures that the products are not applied in a manner that contradicts the basic design assumptions. Critical areas of concern exist regarding the structural integrity of the existing manhole, active water leakage, and the application thickness of rehabilitation products.

8

SUMMARY

The rehabilitation of manholes is important to overall sewer system operation and longevity. Application of appropriate materials in accordance with design assumptions must be achieved to ensure long, useful life of the repairs. The designer must take into account the condition of the manhole, the characteristics of the wastewater flowing through the manhole, and the ability of the methods being considered to solve the problems found during the field investigation.

The installation contractor must be capable of producing high-quality installations of the materials specified. Prior experience with each specified process is necessary and should be verified before the bidding during a prequalification process.

The field inspector must be familiar with the design assumptions and the correct installation methods for each process to be used. If each of these steps is followed carefully during the development of the rehabilitation project, then a successful project will result, yielding a high-quality end product that will significantly extend the useful life of the manholes.

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APPENDIX A

TERMINOLOGY

The American Public Health Association began compiling definitions of sewerage terms in 1915. Later, the American Society of Civil Engineers worked with APHA to finalize and publish these definitions. A sampling:

Sewer—A pipe or conduit, generally closed, but normally not flowing full, for carrying sewage and other wastes.

Flush tank—A chamber in which water or sewage is accumulated and discharged at intervals for flushing a sewer.

Lamp hole—A small vertical pipe or shaft leading from the surface of the ground to a sewer for admitting a light for purposes of inspection.

Manhole—A shaft, or chamber, from the surface of the ground to a sewer, large enough to enable a person to have access for the purpose of inspections or cleaning.

Manhole head—The cast iron fixture surmounting a manhole. It is made up of two parts: a frame, which rests on the masonry of the shaft and a removable cover. Frames are either "fixed" or "adjusted" in height. Covers are "tight," "ventilated," or "antirattling."

Sanitary sewer—A sewer that carries sewage and excludes storm, surface, and groundwater.[1]

[1] ASCE and APHA. (1928). *Definitions of Terms Used in Sewage and Sewage Disposal Practice*, ASCE, New York.

As in 1915, when a need for definitions of terms was established, the need still exists to further create verbiage to measure, record, create, and archive conditions of collection system components.

The most basic information we need in the wastewater collection industry is accurate information concerning the physical condition and maintenance needs of sewer pipes and manholes. Inspection techniques and documentation efforts have been for the most part utility specific, with more than 26,000 individual utilities in the United States. Many utilities have archived information that was generated in a subjective manner (based on individual interpretation). For example, it is not uncommon to see reports where a technician identifies a "level 3 crack" or a "major crack." Although they are understood by the person conducting the inspection, these terms make it difficult to detect change over time, and they make asset management extremely difficult. By removing subjective observations and using wording that denotes a specific condition, asset management functions are possible.

APPENDIX B

TABLE B-1. Typical Manhole Defects

Cover
Open vent or pick holes subject to ponding
Bearing surface worn or deteriorated
No gaskets or bolts for gasketed and bolted covers
Poor fitting—loose or tight
Cracked or broken
Missing

Frame
Bearing surface worn or deteriorated
No gasket for gasketed frames
Cracked or broken
Frame offset from chimney

Frame seal
No seal
Leaking frame or chimney joint
Cracked or missing seal
Frame offset from chimney

TABLE B-1. *Continued*

Chimney
Cracked or broken
Deteriorated

Cone
Cracked, loose, or missing mortar
Leaking cone or wall joint
Leaking lifting hole
Deteriorated

Wall
Cracked, loose, or missing mortar
Leaking wall joint
Leaking lifting hole
Deteriorated or corroded

Pipe seal
Cracked or loose mortar, or none
Leaking
Deteriorated

Bench
Cracked, loose, or missing pieces
Leaking channel to bench seal
Deteriorated
Debris or deposition

Channel
Cracked, loose, or missing pieces
Leaking channel to bench seal
Deteriorated
Poor hydraulics

Steps
Deteriorated, leaking at connection
Broken
Missing

FIGURE B-1. Displaced Ring.

FIGURE B-2. Cracked Chimney.

FIGURE B-3. Severe Hydrogen Sulfide Corrosion.

FIGURE B-4. Vented Manhole Subject to Ponding.

FIGURE B-5. Groundwater Infiltration through a Manhole Wall.

FIGURE B-6. Water Main Passing through a Manhole.

FIGURE B-7. Mechanical Seal.

FIGURE B-8. Applied Seal.

FIGURE B-9. Cured-in-Place Manhole Seal.

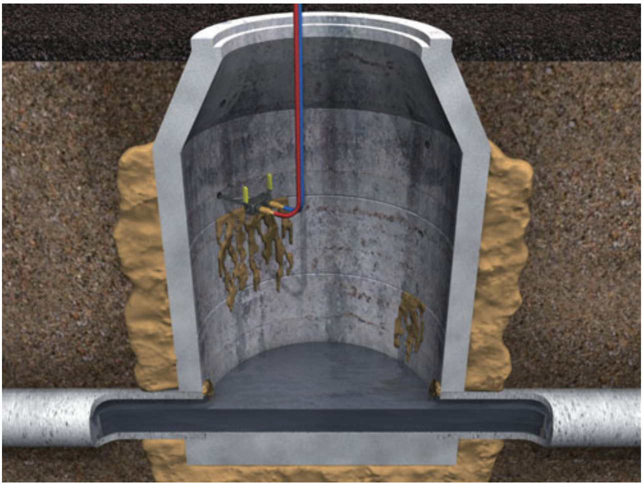

FIGURE B-10. Curtain Grouting Technique.

FIGURE B-11. Expanded Gasket Placement Technique.

FIGURE B-12. Shotcrete Application.

FIGURE B-13. Spincast Application.

FIGURE B-14. Formed-in-Place Installation.

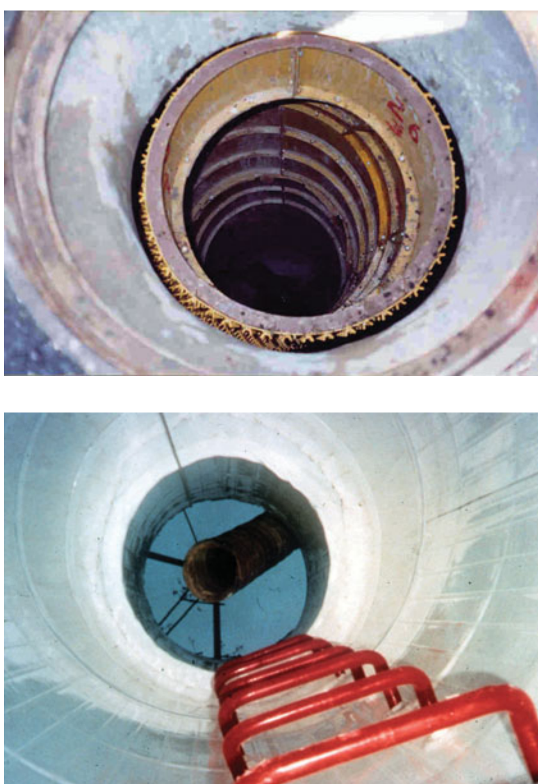

FIGURE B-15. Thermoplastic Liner Installed with Formed-in-Place Concrete.

FIGURE B-16. Epoxy.

FIGURE B-17. Polyurethane.

FIGURE B-18. Polymer Spincast.

FIGURE B-19. Cured-in-Place Manhole Liner.

FIGURE B-19. Continued

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