2021 Edition

DELAWARE DEPARTMENT OF TRANSPORTATION

Pipe Inspection and Remediation Guide

DelDOT

This guide is intended to compile industry best practices and does not have contract governance unless specifically cited.

Date	Update from Previous Version
3/3/2021	Updated Figure 5-1.

Table of Contents

Definitions and Abbreviations

Abrasion – Wearing or grinding away of material by water laden with suspended material.
Autogenous healing – A process where certain size cracks in concrete pipe can heal themselves as a result of a chemical reaction that takes place in the presence of moisture and air.
Backfill – The soil material used to refill the pipe trench after excavation and placement of pipe.
Buckling – Failure by an inelastic change in barrel cross-section shape.
Bulging – A condition where the pipe wall swells outward or protrudes from the nominal shape.
Circumferential cracking – A crack that occurs perpendicular to the pipe.
Coating – Any material used to protect the integrity of a structural element from the environment.
Contractor – The individual or legal entity contracting with the Department for performance of work.
Corrosion – Deterioration or dissolution of a material by chemical or electrochemical reaction with its environment.
Crack – A fissure in finished materials.
Crimping – Occurs when the metallic shell of a pipe begins buckling into many small waves along the perimeter of the pipe wall.
Crown – The top or highest point of a pipe's cross section.
Defect – A fault or imperfection in a finished element.
Deflection – Change in the original inside vertical or horizontal diameter of a pipe.
Delamination – Surface separation of concrete material.
Design crack – A crack in concrete which is between 0.01" and 0.10" in width.
Department – The Delaware Department of Transportation.
Efflorescence – A crystalline deposit that can form when water is present or moving across a pipe surface.
Engineer – The Chief Engineer of the Department, acting directly through an assistant or other authorized representative. The Engineer is responsible for engineering and administrative supervision of the contract.
Exfiltration – Occurs when contents inside of the pipe exits into the surrounding soil.
Faulting – A condition where pipe segments are offset either vertically or horizontally across a pipe joint.
Flexible pipe – A pipe with relatively little resistance to bending.
Flow control – Active management of pipe flow.
Galvanize – To coat with zinc.
GPS – Acronym for Global Positioning System. GPS describes a system of satellites orbiting earth used to determine terrestrial location.
Hairline crack – A crack in concrete which is smaller than 0.01" in width.
Hydro-jetting – A pipe cleaning method which utilizes high pressure water to remove debris and material from the storm drain system.
Infiltration – Occurs when contents outside of the pipe wall enter into the inside of the pipe.
Invert - The bottom or lowest point of a pipe's cross section.
Joint – A connection between two pipe sections or between a pipe and a buried structure.
Linear repair – Pipe remediations that occur linearly along a substantial length of a pipe.
Localized point repairs – Pipe remediations that occur at a spot location and not applied linearly along a pipe.
Longitudinal cracking – A crack that occurs parallel to the pipe.
Mandrel – A device that is pulled through a conduit to determine the deflection inside of the conduit.
Misalignment – A condition where pipe segments are incorrectly positioned in a way that creates a disruption in the pipe barrel.
NASSCO – Acronym for National Association of Sewer Service Companies.
Open cut remediation techniques – Pipe repairs that require open cut around a pipe to remediate a defect.

OSHA – Acronym for Occupational Safety and Health Administration.
PACP – Acronym for Pipeline Assessment Certification Program.
Percent deflection – A measure of a change in pipe's diameter relative to the nominal pipe diameter.
Pipe bedding – The material that is laid below a pipe that supports the pipe against the top and adjacent soil loads.
Pipe bursting – A pipe installation technique where new pipe is pulled through an old pipeline of equal or smaller size.
Pipe haunch – The horizontal cross section of the pipe that is located below the centerline of the pipe.
Pipe jacking – A tunneling technique for installing new pipe through use of hydraulic jacks.
Pipe lining – A trenchless pipe repair process where an existing pipe is lined with a foreign material to create a new flow surface inside of an existing pipe.
Pipe sliplining – A trenchless method of installing a new pipe inside of an existing pipe.
Post installation inspection – An internal inspection of a pipe that is performed after installation is complete.
Racking - Non-symmetrical vertical deformation with elliptical shape leaning one direction.
Remediation – The action of correcting a discovered defect.
Rigid pipe – A pipe with resistance to bending.
Slabbing – Tension failure of a concrete pipe characterized by the concrete wall peeling off the reinforcing steel.
Spalling – Separation of surface concrete due to fractures in the concrete parallel or slightly inclined to the surface of the concrete.
Stress crack – A crack in concrete which is greater than 0.10" in width.
Trenchless remediation techniques – Pipe repairs that do not require an open cut around the pipe to remediate the defect and instead remediates the damaged pipe segments from the inside.
Tunnel liner plate - A pipe installation technique where a new pipe is installed by creating a tunnel along the alignment of the proposed pipe.
Vacuum extraction – A storm drain cleaning method which utilizes suction to remove debris and materials from the storm drain system.

Chapter 1 Introduction

The Delaware Department of Transportation (DelDOT) has developed this guide to document Department policy and practice as well as to emphasize standards and practices that have been proven successful both in this state and on a national level. This guide serves the following purposes:

- Document DelDOT's policy for post installation pipe inspection,
- Document the current procedure for post installation pipe inspection,
- Provide guidance as well as document the requirements for anyone performing post installation pipe inspection on behalf of DelDOT, and
- Provide information and support for Storm Drain Report reviewers including recommended remediations and repairs for various defects discovered.

Several project types are defined for purposes of this guide to assist in establishing the roles and responsibilities for post installation pipe inspection:

- **DelDOT Administered** – This project type includes all improvements that are administered during the construction phase by the Delaware Department of Transportation. Table 1-1 of this guide describes the roles and responsibilities of the various entities involved in post installation pipe inspection for this project type.
- **Non-DelDOT Administered Improvements**– This project type includes all improvements that will become the maintenance responsibility of DelDOT, and which will not be administered by DelDOT during the construction phase. This project type primarily includes privately funded developer projects. Table 1-1 of this guide describes the roles and responsibilities of the various entities involved in post installation pipe inspection for this project type.
- **Maintenance Activities** – This project type includes all improvements that are constructed using DelDOT Maintenance forces or Maintenance contracts. Maintenance activities should adhere to the guidance provided by this guide.

Post Installation Inspection Activity	DelDOT Administered	Non-DelDOT Administered Improvements
Pipe Installation	DelDOT's Contractor	Developer
Pipe Cleaning	DelDOT's Contractor	Developer
Traffic Control for Pipe Cleaning	DelDOT's Contractor	Developer
Traffic Control for Pipe Inspection	DelDOT's Contractor	Developer
Post Installation Pipe Inspection	DelDOT's Representative	Developer
Storm Drain Report Generation	DelDOT's Representative	Developer
Pipe Defect Remediation Analysis	DelDOT's Contractor	Developer
Pipe Defect Remediation Analysis Approval	DelDOT	DelDOT
Pipe Defect Remediation	DelDOT's Contractor	Developer

Table 1-1: Post Installation Inspection Roles and Responsibilities

It should be noted that unless specifically cited in a contract, this guide does not have contract governance and as such, all appropriate information regarding deliverables and the equipment to be used to perform this work should be included in the appropriate contract documents or agreements.

1.1 Pipe Video Inspections During the Design Phase

Existing pipes that are to become part of the final drainage network can be investigated during the design phase to determine their condition and their suitability for use in the final drainage network. This guide should be utilized as a resource for these design phase investigations; however, these design phase investigations are not required to be measured to the same level of accuracy or precision as post installation inspections. The passage of time will have allowed more physical and qualitative evidence indicative of pipe defects to present themselves.

In all cases, proper communication and coordination is key to the performance of a successful design phase pipe video inspection. The information that is desired to be obtained as part of the design phase pipe video inspection should be clearly communicated to the pipe video inspection crew.

The results of this design phase inspection should be documented and compared to any construction phase inspections to evaluate any damage that may have occurred during the construction phase. Design phase investigation and documentation are valuable tools when disputes regarding contractor damage to the existing pipe network arise during construction. Design phase investigation should follow the recommendations and best practices provided in this guide.

1.2 Post Installation Inspection Requirements

All pipes that are to be utilized in the final drainage network of an improvement must be inspected for defects. Circular pipe openings that are 48” in diameter and pipe shapes of an equivalent size and larger will be inspected manually while all other pipe sizes will be video inspected in accordance with this guide.

Post installation pipe inspections are to be completed no sooner than 30 days after backfill placement or before the final layer of roadway material is placed. This 30-day period will not encompass the full timeframe required for complete consolidation of the soil surrounding the pipe; however, it is intended to give sufficient time to observe some of the effects that consolidation will have on the integrity of the installation. It is preferred to perform the post installation pipe inspection with the maximum amount of time for soil consolidation that the project or contract time will allow.

All defects that are discovered during post installation inspection shall be investigated for severity and when required, repaired in accordance with the guidance provided herein. A follow-up inspection will be performed after remediation to assure that repairs have been completed satisfactorily.

1.3 Manual Post Installation Inspections

Manual inspections are permitted for all pipe and pipe types with circular openings that are 48” in diameter and for shapes of an equivalent and larger size. The staff performing the manual inspection shall use a high-quality hand-held video camera or a digital camera capable of clearly documenting all observed defects. If the pipe is considered a confined space, provide entry for all project inspection personnel according to OSHA requirements.

Furnish pictures, still images, and/or video recordings of all areas of the pipe displaying the pipe material specific defects documented in the applicable material chapter of this guide. A light source must be provided so that all defects can be readily observed by the camera or video recording. A measuring tool should be placed next to the defect captured in a still image to assist in documenting the defect severity. All defect information must be documented in a Storm Drain Report as required by *Section 4.3 Storm Drain Deliverables* of this guide.

Deflection in flexible pipes shall be determined by measuring the diameter of the pipe at 10-foot intervals along the pipe using either a metal or a fabric tape. The measured diameter must be recorded to the nearest 0.25 inches. In addition to measuring the diameter at 10-ft intervals, the diameter should also be measured at any location exhibiting deflection, bulging, buckling, or racking. To determine the minimum deflected diameter, take 4 measurements spaced equally around the pipe as shown in Figure 1-1. Take all diameter measurements on corrugated pipe from the top of corrugation to the top of corrugation. Record all measurements and the percent deflection for each location. A minimum of 4 measurements per pipe segment are required to be recorded. Percent deflection is determined with Equation 1-1:

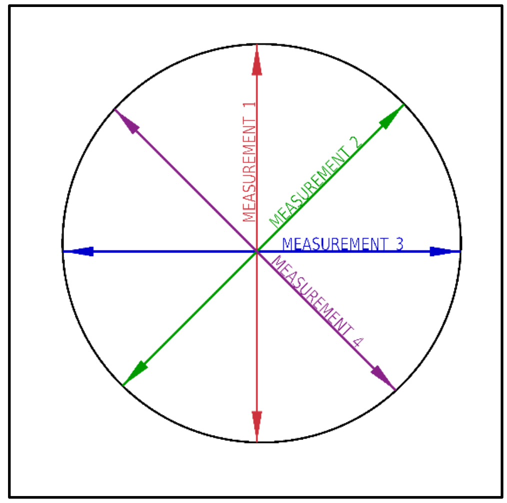


Figure 1-1: Deflection Measurement

Equation 1-1: $$\% \, Deflection = \frac{D_{Nominal} - D_{Measured}}{D_{Nominal}} * 100\%$$

where:

$D_{Nominal}$ = AASHTO Nominal Diameter

$D_{Measured}$ = The Minimum of the 4 Diameter Measurements of the Pipe

1.4 Maintenance Activity Considerations

It is not always practical for DelDOT maintenance work to follow the recommendations contained in this guide; however, the following situations present cases where post installation inspection in accordance with this guide should be considered following maintenance activities:

- **Longer Installations of Pipe** – Longer installations of pipe have an increased risk to the Department and justify the initial mobilization and setup costs. When several smaller segments of pipe are inspected, consideration should be given to inspecting the runs continuously.
- **High Traffic Volumes** – Pipes located under or in close proximity to high traffic volume roadways pose a higher inherent risk if failure or future maintenance activities are required.
- **Locations Where Other Available Post Installation Inspection Tools Are Not Effective** – For many installations, other post installation inspection tools cannot be used effectively. Some pipes are not readily accessible for extended camera viewers, which are capable of seeing into the pipe varying distances, and mandrels, which can be pulled through flexible pipe installations to determine if allowable deflection limits are exceeded.
- **Documented Installation Issues During Construction** – All pipes should have adequate construction inspection during the installation process. Quality of work issues noted during construction, such as poor bedding, difficulty with line and grade or pipe fit up, or improper

backfilling warrant additional consideration. Limited cover over pipe during construction could also affect the structural integrity of the material.

In all cases, the level of post installation inspection required should be considered on a case-by-case basis and the contract documents or pertinent professional services agreements should reflect the post installation inspection requirements.

Chapter 2 Inspection Preparation and Procedures

This chapter provides insight into the pre-inspection procedures and the coordination required prior to post installation pipe inspection and also documents the best practices that should be followed during the pipe inspection.

2.1 Pre-Inspection

Proper planning and coordination is a critical element in post installation pipe inspection. This section of the guide discusses several items which should be considered prior to inspection.

2.1.1 Traffic Control

All traffic control required to perform the post installation pipe inspection must adhere to the current edition of the Delaware Manual on Traffic Control Devices (DE MUTCD) in accordance with the contract documents or as directed by the Engineer.

2.1.2 Flow Control

All post installation pipe inspection will take place while the pipe is dry (no running water flow). If the Engineer agrees to the use of flow controls, then the flow controls must be in place and operational at time of inspection with sufficient precautions taken to ensure upstream damage or flooding does not occur at any time while in use. At the end of each day's operation, the flow controls shall be removed, and normal flow restored.

There are several alternatives that can be considered for flow control:

- **Pipe Plugging and Blocking** – The most common flow control technique is to block the line upstream of the section that is being inspected. The plug shall be designed so that all or any portion of the water can be released.
- **Pumping and Bypassing** – In certain cases, pumping and bypassing around a storm drain section may be required. The bypass system shall be of sufficient capacity to handle existing flow plus additional flow that may occur during a rain event. If pumping is required on a 24-hour basis, equipment should include back-up pumps, controls, and alarms attached to an automatic alert call out device, where possible. Noise created from a 24-hour pump operation must be analyzed in accordance with DelDOT Policy Implement Number D-03 entitled *Transportation Noise Policy*. Pumping operations must be analyzed prior to implementation to assess the need for acquiring permits.

2.1.3 Cleaning for Pipe Inspections

It is of extreme importance that all foreign materials in the pipe network be removed prior to inspection so that a clear, unobstructed view of the pipe can be obtained. All pipe blockages that prevent adequate cleaning must be removed prior to the cleaning. *Section 3.1 Pipe Cleaning* of this guide provides more information on the typical equipment that is used to perform pipe cleaning.

Cleaning should occur by setting up on the upstream access structure and cleaning toward the downstream end. If cleaning an entire section cannot be successfully performed from one structure, the equipment shall be set up on the opposite structure and cleaning again attempted.

The material removed from the pipe network shall be removed at the downstream structure of the section being cleaned. Allowing material to pass from one pipe run to the next shall not be permitted due to the risk of causing line stoppages. All material shall be disposed of in accordance with the contract documents as well as with all applicable laws and regulations.

Every precaution should be taken to avoid damage or injury during pipe cleaning operations. This includes the following:

- Precautions shall be taken to ensure that the water head pressure does not damage or cause flooding of public or private property being served by the storm sewer.
- Precautions shall be taken to prevent the jetting nozzle from exiting the pipe through open joints or damaged areas.
- No fire hydrant shall be used without permission from the utility owner. If permission is given, the hydrant shall not be obstructed in case of a fire in the area served by the hydrant.
- Gate valves, backflow preventors, or an air gap shall be incorporated in the direct connection to a potable water source as required by the utility owner.
- DelDOT employees will adhere to the Department’s Confined Space Entry Policy. All others will adhere to OSHA’s Confined Space Entry Regulations.

2.1.3.1 Pipe Cleaning Damage to Existing Pipe Runs

Contract documents or agreements should clearly assign liability for cases where the cleaning operation results in damage to either the newly installed drainage network or to any elements of the existing drainage network.

2.2 Post Installation Pipe Inspection Procedures

This section provides a description of several best practices that should be followed for post installation pipe inspections. Please note that equipment requirements for the inspection are contained in *Chapter 3 Equipment* and the required deliverables are discussed in *Chapter 4 Storm Drain Inspection Deliverables*.

The below items document the procedures that are to be followed during post installation pipe inspection:

- Post installation pipe inspection should be conducted no sooner than 30 days after backfill placement or before placement of the final lift of roadway cover in accordance with Section 601 of the Standard Specifications.
- Pipes must be clean at the time of inspection and all blockages which would prohibit a continuous operation removed. See Section *2.1.3 Cleaning for Pipe Inspections*.
- The pipe should be dry at the time of inspection. See Section *2.1.2 Flow Control* for more information.
- Identify and measure all defects and deficiencies described by the applicable chapter of this guide as well as all other potential points of interest.
- Inspection should begin at the inlet end and proceed downstream.
- The inspection will be performed one pipe run at a time.

The below items document the additional procedures and requirements that are to be followed when the inspection is being performed by video:

- All pipe inspections must be completed by a National Association of Sewer Service Companies (NASSCO) Pipeline Assessment Certification Program (PACP) certified professional.
- Each pipe run must be a separate reproduceable video file.

- The video should include oral identification before each run of pipe is filmed. This identification will include the project number or subdivision name, the structure number and the pipe run number corresponding to the schematic plans contained in the Storm Drain Report, the size of pipe, and the date and time.
- Provide a full unobstructed and centered view of the entire pipe. The view shall be centered both horizontally and vertically.
- The camera operator shall provide a continuous narrative during the videoing process. The operator shall stop and center the camera as needed to measure and discuss any defects or irregularities found during the videoing. All defects shall be described in accordance with this guide. Irregularities shall include any questionable item such as a stain, crack, paint mark, shadow, or character change in a pipe being inspected.
- The camera must move through the pipe at a speed not greater than 30 feet per minute or at a speed which allows for accurate measurements and reporting required by this guide, whichever is lower.
- The video shall indicate the distance traversed along the pipe. The distance shall have an accuracy of one foot per 100 feet.
- Film the entire circumference of each pipe joint. Film the joint in a complete counterclockwise direction followed by a complete clockwise direction.
- For flexible pipe, measure the deflection occurring at the point of the projected laser and at a minimum interval of 0.1 feet along the pipe.
- For flexible pipe, the laser projection head shall be positioned so that the laser ring fills a minimum 75% of the monitor screen height.
- Provide sufficient lighting to produce a clear image of the full circumference of the pipe.

Chapter 3 Equipment

This chapter provides a discussion of the equipment that should be utilized to perform post installation pipe inspection work. The equipment discussed in this chapter is considered the state of the practice equipment at the time of writing and may change in the future. It should be noted that unless specifically cited in a contract, this guide does not have contract governance and as such, all appropriate information regarding the equipment to be used to perform this work should be included in the appropriate contract document or professional services agreement.

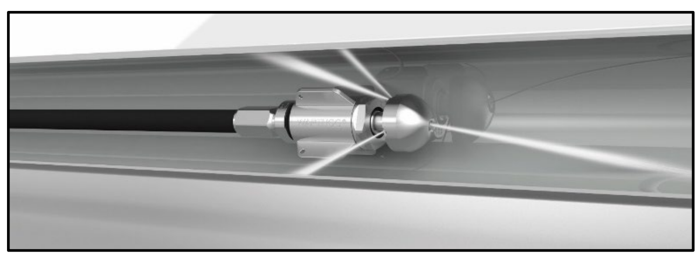
3.1 Pipe Cleaning

Pipe cleaning is essential to a proper video inspection and should be performed in consideration with the requirements discussed in *Section 2.1.3 Cleaning for Pipe Inspections*. Selection of the equipment used shall be based on the condition of the pipe at the time work commences. The equipment shall be capable of removing debris, materials and obstructions from the storm sewer lines and structures in accordance with the requirements of Section 601 of the Standard Specifications.

Pipe Cleaning Operation. Image Courtesy of Standard Pipe Services

There are generally two types of equipment that can be considered for use in pipe cleaning:

- **High-Velocity Hydro-Jetting** – this cleaning method, utilizes high pressure water to remove debris and material from the pipe. There are numerous proprietary high-velocity hydro-jetting equipment available for pipe cleaning as well as various nozzle types which have been designed for different cleaning applications. The hydro-jetting application can either be hydraulically propelled or can be mechanically propelled through the pipe. This cleaning method requires a water source that is safe to the downstream environment be on site during operation. The water source can either be a portable water tank or an available water source located on site. The equipment utilized should have its own auxiliary engine and pump.



Pipe Cleaning Nozzle. Image Courtesy of StoneAge Tools

- **Vacuum extraction** – vacuum extraction methods rely on suction to remove debris and materials from the storm drain system. Vacuum extraction is primarily utilized as a maintenance application and for structure cleaning, however, this method can be utilized for pipe cleaning in certain circumstances with the use of suitable equipment. The vacuum extraction trucks can either have a combination engine where the vacuum utilizes the same engine as the chassis or can be a dual engine where there is a separate engine for the chassis and the vacuum.

Combination Jetter and Vacuum Truck. Image Courtesy of Vacall Industries

All debris and materials collected during the pipe cleaning shall be removed and disposed of in accordance with Section 106.8 of the Standard Specifications using an extraction method approved by the Engineer. Precautions should be taken to ensure that no material is discharged downstream during the extraction procedure. Typically, this work is either performed by vacuum extraction or manual extraction. All material shall be disposed of in accordance with the contract documents as well as with all applicable laws and regulations.

3.2 Camera Requirements

When the pipes are to be inspected through use of a video camera, the video camera and all supporting video system hardware and equipment must be capable of producing a video that is clear, focused, and relatively free from roll, static, or other image distortion qualities that would prevent the reviewer from properly evaluating the condition of a pipe to the satisfaction of the Engineer. The color television camera used for the inspection shall be one specifically designed and constructed for such inspection work.

Pipe Video Rover. Image Courtesy of Envirosight

The camera inspection equipment must have the following features and capabilities for pipe video inspection:

- Produce a high-quality color image in a Motion Picture Experts Group (MPEG2 or MPEG4) format video with a minimum standard resolution of 720 x 480 pixels.
- Perform without obstructing the camera's view or otherwise interfere with proper documentation of the pipe's condition.
- Pan and tilt to a minimum 90-degree angle with the axis of the pipe and rotate 360 degrees.
- Capable of moving through the entire length of the pipe.
- Capable of providing sufficient lighting to produce a clear image of the full circumference of the pipe.
- Operative in 100% humidity conditions.
- Include a low barrel distortion camera lens.
- Capable of measuring cracks from 0.01" to 0.10" on an accurate and repeatable basis and joint separations greater than 0.5".

Laser Ring Profiler. Image Courtesy of Envirosight

- Capable of recording the station, milepost, distance along the invert of the pipe, or other indicators of location superimposed on the video.
- Provide a laser deflection measuring device, for use on flexible pipe, capable of measuring deflection to an accuracy of 0.5% or better and a repeatability of 0.12% or better. References of the equipment calibration are ASTM E 691 and ASTM E 177.
- Software capable of generating a report that includes the following:
    - Actual recorded length and width measurements of all cracks within the pipe.
    - Actual recorded separation measurements of all pipe joints.
    - Pipe ovality report.
    - Deflection measurements and graphical diameter analysis report in terms of x and y axis.
    - Flat analysis report.
    - Representative diameter of pipe.
    - Pipe deformation measurements, leaks, debris, or other damage or defects.
    - Deviation in pipe line and grade, joint gaps, and joint misalignment.
    - Displaying the pipe number as well as the “to” and “from” structure number corresponding to the schematic plans contained in the Storm Drain Report, the size of pipe, the date and time, the direction of travel, and the project number or subdivision name during the video.

3.2.1 Calibration Requirements

Laser profiling and measurement technology must be certified by the company performing the work to be in compliance with the manufacturer’s calibration procedures. This information shall be provided to the Engineer prior to beginning inspection.

3.3 Mandrels

The mandrel that is used for deflection tests shall be nine (or greater odd number) arm, non-adjustable, and fixed arm. The fixed arms shall be metal and fitted with pulling rings at each end, stamped or engraved on some segment other than a runner with the nominal pipe size and mandrel outside diameter. The diameter of the mandrels and matching proving rings shall be based upon the actual certified mean diameter as provided by the pipe manufacturer (0.95 x certified mean diameter for 5% deflection or 0.925 x certified mean diameter for 7.5% deflection). The Engineer shall inspect the mandrel and ensure its calibration prior to post installation pipe inspection to ensure the mandrel’s accuracy. The mandrel shall be pulled through the pipe by hand with a rope or cable. A pulley system which changes the direction of the pull may also be used so that no inspection staff be required to enter the pipe or manhole to pull the mandrel.

Deflection Mandrel. Image Courtesy of Cherne

Chapter 4 Storm Drain Inspection Deliverables

This chapter of the guide discusses the deliverables that are required to be provided to the Engineer when a post installation pipe inspection is performed. All appropriate information regarding submittal requirements should be included in the appropriate contract document or professional services agreement.

4.1 Video Requirements

When pipes are inspected through use of a camera, the resulting post installation pipe inspection video must be provided to the Engineer. The pipe video will be utilized by the Engineer as part of their review of the Storm Drain Report as well as to create a record of pipe condition at the time of the inspection. The captured video image shall be clear, focused, and relatively free from roll, static, or other image distortion qualities that would prevent the reviewer from evaluating the condition of the pipe.

The video produced shall follow the post installation pipe inspection procedures outlined in *Section 2.2 Post Installation Pipe Inspection Procedures* of this guide and be created by equipment that complies with the *Section 3.2 Camera Requirements*. The video provided shall be at the “Standard Play” speed and must be a high-quality color image in a Motion Picture Experts Group (MPEG2 or MPEG4) format video with a minimum standard resolution of 720 x 480 pixels.

4.2 GIS Information

As part of the post installation pipe inspection, all drainage system components must be located using Global Positioning System (GPS) techniques, within sub-meter accuracy. The results will be submitted to the Engineer in a format compatible with the Department’s existing ESRI GIS database format. Information to be included in this submission will include the following:

- Shapefile and/ or feature class of Structure locations (structure geometrics) and
- Shapefile and/ or feature class of Conveyance locations (pipe geometrics).

All GPS information shall be determined utilizing Delaware State Plane Coordinate System, U.S. Surveying Feet NAD 83 DATUM (NAD83 Delaware State Plane, US Foot).

4.3 Storm Drain Report Requirements

A Storm Drain Report which summarizes the results of the post installation pipe inspection is to be prepared for all post installation inspections. The report provided to the Engineer shall be reviewed and signed by a registered Delaware Professional Engineer verifying that the appropriate standard of care was provided during the inspection process.

All Storm Drain Reports shall include the following elements:

- Cover sheet contained in Figure 4-1,
- Table of contents,
- Schematic plans (see Section 4.3.1),
- Post Installation Pipe Inspection Defect Log contained in Figure 4-2,
- Discussion of results (see Section 4.3.2), and
- Inspection reports (see Section 4.3.3).

4.3.1 Schematic Plans

Schematic plans that show each structure and pipe run must be included in the Storm Drain Report. These plans must utilize a naming and numbering convention consistent with the construction plans whenever possible. The schematic plans must show the location of all points of interests and defects included in the "Discussion of Results" portion of the Storm Drain Report. All points of interests and defects must be dimensioned from a known location.

4.3.2 Discussion of Results

All installation defects described by the applicable chapter of this guide as well as all other potential points of interest must be described, measured, and photographed in this section of the Storm Drain Report. If a defect occurs continuously along the pipe wall, the Storm Drain Report should note the entire length in which the defect was found.

When a pipe segment or structure is inaccessible for video recording on DelDOT Administered projects, the Engineer shall be contacted. For non-DelDOT Administered projects, the appropriate project staff should be contacted to make the pipe segment accessible.

4.3.3 Inspection Reports

This section of the Storm Drain Report shall include all completed Post Installation Pipe Inspection Report Log sheets (Figure 4-3) and all other pertinent software reports and manual inspection logs including:

- Pipe ovality report,
- Deflection measurements and graphical diameter analysis report in terms of x and y axis,
- Flat analysis report, and
- The Manual Post Installation Pipe Inspection Deflection Log (Figure 4-4).

4.4 DelDOT Review

The Engineer must review the Storm Drain Report and accompanying Storm Drain Report deliverables to verify report completeness and all defect identifications. Once the Engineer is satisfied with the report and its contents, the report and all accompanying deliverables should be provided to the Contractor. The Contractor must assess each defect documented in the Storm Drain Report for severity and life cycle effect and submit remediation alternatives. The Contractor's submission to the Department must be signed by a registered Delaware Professional Engineer. The Engineer will provide concurrence or comments on the Contractor's submission.

In all cases, any remediation methods proposed by the Contractor must be approved by the Engineer before work commences. The Contractor is responsible for all supplemental work items that are affected by the remediation or replacement of pipe, as well as any additional pipe video inspections to ensure the quality of the work, at no additional expense to the Department.

Once repairs are complete, a follow-up inspection shall be performed to assure that all repairs have been completed satisfactorily.

DelDOT Storm Drain Inspection Report

Date Submitted:

Project Information:

Project/ Subdivision Name:

County:

District:

Project Number:

Contractor/ Developer:

Inspector Information:

Post Installation Inspection Contractor Company:

Construction Inspection Company:

I certify to the to the best of my knowledge and belief that the staff responsible for the creation of this report were qualified for the task and that the information contained in the report is accurate and follows the criteria and procedures outlined in the current DelDOT Pipe Inspection and Remediation Guide.

____

Staff Supervisor

____

Date

Apply Seal Above

Figure 4-1: Storm Drain Report Cover Sheet

Delaware Department of Transportation

DIVISION OF CONSTRUCTION
POST INSTALLATION PIPE INSPECTION DEFECT LOG

PROJECT INFORMATION

Project/ Subdivision Name: Project Number:
District County: Contractor/ Developer:
Notes and Comments:

INSPECTOR INFORMATION

Post Installation Inspection Contractor Company:
DelDOT Inspector: DelDOT Inspector:
Notes and Comments:

INSPECTION INFORMATION

Inspection Date	Pipe Run Number	Pipe Diameter	Pipe Material	Begin Structure (from Schematic Plans)	Distance from Begin Structure	Defect Type	Defect Description

Figure 4-2: Storm Drain Report Defect Log

Delaware Department of Transportation

DIVISION OF CONSTRUCTION

POST INSTALLATION PIPE INSPECTION LOG

PROJECT INFORMATION

Project/ Subdivision Name: | Project Number:

District | County: | Contractor/ Developer:

Notes and Comments:

INSPECTOR INFORMATION

Post Installation Inspection Contractor Company:

DelDOT Inspector: | DelDOT Inspector:

Notes and Comments:

INSPECTION INFORMATION

Inspection Date	Pipe Run Number (from Schematic Plans)	Pipe Diameter	Pipe Material	Pipe Length	Begin Structure (from Schematic Plans)	End Structure (from Schematic Plans)	Operator Name 1	Operator Name 2	Notes and Comments:

Figure 4-3: Post Installation Pipe Inspection Report Log Sheet

Delaware Department of Transportation

DIVISION OF CONSTRUCTION

MANUAL POST INSTALLATION PIPE INSPECTION DEFLECTION LOG

PROJECT INFORMATION

Project/ Subdivision Name:

Project Number:

District

County:

Contractor/ Developer:

Notes and Comments:

INSPECTOR INFORMATION

Post Installation Inspection Contractor Company:

Post Installation Inspector:

Post Installation Inspector:

DelDOT Inspector:

DelDOT Inspector:

Notes and Comments:

PIPE INFORMATION

Inspection Date:

Pipe Run Number:

Nominal Pipe Diameter

Pipe Material:

Begin Structure Number:

INSPECTION INFORMATION

Distance From Begin Structure	Diameter Measurement 1	Diameter Measurement 2	Diameter Measurement 3	Diameter Measurement 4	Minimum Diameter	% Deflection	Notes

Figure 4-4: Manual Post Installation Pipe Inspection Deflection Log

Chapter 5 Reinforced Concrete Pipe (RCP) Post Installation Inspection

This chapter discusses the common defects of RCP, the severity of the observed defects, the documentation required for the various defect types, as well as rehabilitation considerations. This chapter primarily pertains to post installation inspection; however, its contents and principles can be applied to existing drainage pipe installations as well.

RCPs must be inspected post installation to evaluate any issues which would affect their long-term in-place performance. All contract documents must specify the responsible party for repair of defects as well as the level of follow up inspection required to ensure the defects are repaired before they are accepted into DelDOT's maintenance inventory.

5.1 Defects

Unlike other pipe materials, rigid concrete pipe does not deflect appreciably before cracking or fracturing. As a result, shape inspections are of little value during RCP inspection. The most common defects in concrete pipes are joint defects and cracking.

The defect severity described in this section should be considered both individually and collectively with the other defects present. *Section 5.3 Remediation Flow Charts* provides a general guide for defect analysis and remediation.

5.1.1 Joint Defects

Joints in pipe segments are a critical evaluation area. Section 601 of DelDOT's Standard Specifications requires that joints be leak-resistant in accordance with ASTM C443. Accordingly, the installed joint separation must be less than either the manufacturer's recommendation or less than the distances specified in Table 5-1, whichever is less. The Storm Drain Report should clearly state the manufacturers allowable joint separation as well as the smaller value of the manufacturer's recommendation and the distances prescribed in Table 5-1.

RCP Shape	Maximum Joint Separation
12 to 36-inch diameter	0.75 inch
42 inch and larger diameter	1.25 inch
All elliptical pipe	1.50 inch

Table 5-1: Maximum Joint Separation

Pipe joints which show signs of exfiltration or infiltration are considered significant defects. Joint separations will accelerate damage caused by exfiltration and infiltration, resulting in the erosion of critical backfill material.

Concrete Joint Separation. Image Courtesy of Simpson, Gupertz and Hager

Large Concrete Joint Separation.

5.1.1.1 Joint Spalling

Spalling is defined as localized delamination of the concrete around the steel reinforcement and can be present at joint locations. Spalls at joint locations should be noted in the Storm Drain Report. Spalls that do not expose steel reinforcement or allow for the transport of fine soil through the spall are only considered minor in nature.

5.1.1.2 Joint Cracking

Joint cracking should be noted in the Storm Drain Report. Any related issues such as misalignment, signs of infiltration, or signs of exfiltration should also be noted in the report. If there are no signs of other related issues, this defect shall be treated in accordance with the requirements of *Section 5.1.2 Cracking* of this guide.

5.1.1.3 Faulting

Faulting occurs when the joints of the pipe become misaligned, leading to a non-uniform profile of the storm drain. This defect occurs more often in rigid alignments due to the characteristics of the pipe and can be a result of an allowable variance in the thickness of the spigot and end wall segments. This defect typically occurs when there is differential settlement and is an indicator of problems with the supporting soil or contractor grade control. Horizontal faulting, where pipe segments are offset horizontally, may also occur. Horizontal faulting can lead to loss of support from the embedment soil. This defect can be serious if faulting is allowing infiltration or exfiltration of the surrounding backfill.

5.1.2 Cracking

Cracking in RCP is a sign that the structural steel inside of the concrete pipe has accepted part of the loading. A properly designed RCP is expected to crack under service load conditions; however, excessively large cracks can jeopardize the service-life of the pipe. The orientation of the crack assists in determining the severity as well as the cause of the crack. The industry currently recognizes two types of concrete cracking:

- **Circumferential cracking** – This is cracking that occurs perpendicular to the pipe. This type of crack is generally considered less serious than longitudinal cracking as this cracking will not affect the structural load capacity of the RCP wall.
- **Longitudinal cracking** – This is cracking that occurs parallel to the pipe. This type of cracking is generally considered more serious in nature as this cracking can affect the loading capacity of the

RCP pipe wall. Cracks that are longitudinal may expose the circumferential steel which provides the structural component of the completed steel cage.

Cracking is evaluated based on the direction and width of the crack. In all cases, the crack width and length must be measured and documented in the Storm Drain Report. The crack width and length can provide clues as to the causes of the observed cracking. Crack widths are broken into three categories based upon the severity of the defect:

- **0.01” > Crack Width** – This crack type, also known as a hairline crack, is considered minor and only needs to be noted in the Storm Drain Report. The report should also note any other signs of distress such as differential movement, signs of loss of backfill, efflorescence, spalling, or rust stains as these could be signs of more significant issues.
- **0.01” ≤ Crack Width ≤ 0.10”** – This crack type, also known as a design crack, may be detrimental to the integrity of the pipe. This crack type as well as any other signs of distress present at the location including differential movement, efflorescence, spalling, or rust stains should be measured and noted in the Storm Drain Report. The contractor must perform an analysis of this crack type to assess the severity of the defect by analyzing the structural integrity of the installation, the existing environmental conditions, and the design service life of the installation. The contractor’s evaluation must result in a recommendation to the Engineer as to the need for remediation as well as the remediation alternative selected by the contractor, if required. In all cases, the Engineer must approve the recommendation provided.
- **0.10” < Crack Width** – This crack type, also known as a stress crack, is deemed significant and must be remediated. These cracks are typically a result of overloading or poor bedding.

Hairline Cracking.

Cracking in the pipe can lead to additional defects in the RCP section. *Sections 5.1.2.1*, *5.1.2.2* and *5.1.2.3* discuss additional defects that may be present with cracking.

5.1.2.1 Vertical Offset

Vertical offsets in pipes may develop at crack locations. This offset may lead to interruption of pipe flow. Any vertical offsets discovered should be documented in the Storm Drain Report.

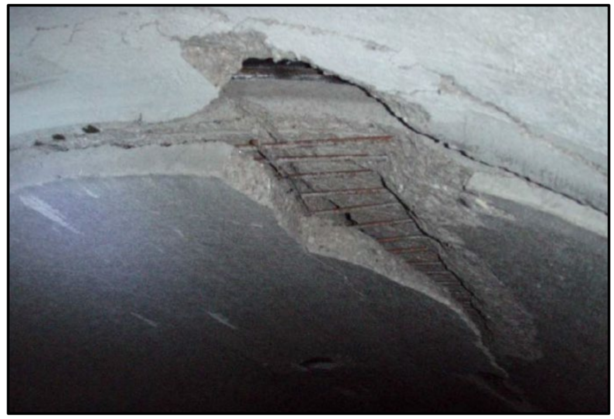
Crack with Vertical Offset. Image Courtesy of Kentucky Transportation Center

5.1.2.2 Crack Spalling

Spalling is defined as localized delamination of concrete and may develop along the edges of cracks in RCPs. Spalling along cracks is usually due to excessive shear forces and is typically the result of overloading or poor bedding support rather than simple tension cracking. Spalling can also be the result of corrosion of the reinforcing steel in areas where the steel does not have sufficient cover. Pipe experiencing this type of problem shall be repaired or replaced.

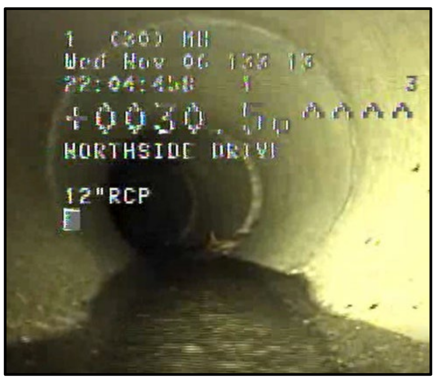
5.1.2.3 Slabbing

Slabbing is a radial failure of the concrete reinforcement cage due to excessive tension and usually occurs in pipes located in deep fills which creates a high shearing stress on the pipe. This defect results in excessive deflection which forces the concrete cover away from the reinforcement. Slabbing can be identified by offset across the face of the crack as well as large slabs of concrete "peeling" away from the sides of the pipe. Slabbing is a serious defect and pipes in this condition shall be repaired or replaced.



Slabbing. Image Courtesy of Kentucky Transportation Center

5.1.3 Misalignment

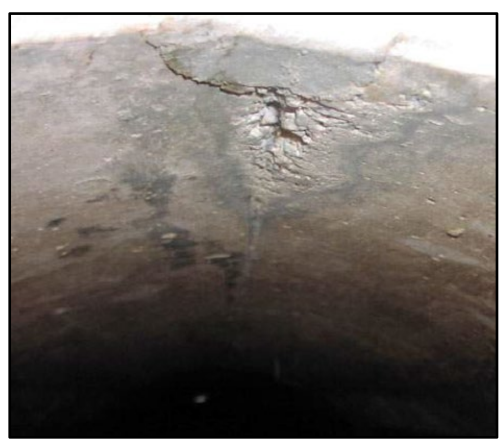


Misalignment

The barrel of the pipe shall be checked by sighting along the crown, invert, and sides of the culvert to assure it is aligned properly. Barrel misalignment can indicate barrel structural distress, joint distress, or loss of support through soil infiltration or exfiltration. Dips in the pipeline can promote sediment buildup in the pipe flowline, resulting in loss of hydraulic capacity. The vertical alignment shall be checked for sagging, faulting, and invert heaving. Misalignment may trap water and aggravate settlement by saturating soil through leaking joints. The horizontal alignment shall be checked for straightness or smooth curvature. When performing an inspection, the inspector must consider pipes laid with camber or a grade change in accordance with the contract plans or site requirements. Misalignment is typically an indicator of problems with the supporting soil or contractor grade control.

5.1.4 Spalling

Spalling is defined as localized delamination of concrete and can occur for numerous reasons. Spalling with no other defect present is considered minor in nature. Excessive spalling can be a symptom of a more serious defect and should be investigated to determine the cause and the associated severity. *Section 5.1.2.2 Crack Spalling* provides considerations for spalling occurring at crack locations and Section *5.1.1.2 Joint Spalling* provides consideration for spalling occurring at joint locations.



Spalling. Image Courtesy of Simpson, Gupertz & Hager

5.2 RCP General Considerations

This section provides a general discussion of several items which should be considered when analyzing an RCP defect.

5.2.1 Autogenous Healing

Autogenous healing is a process where certain size cracks can heal themselves as a result of a chemical reaction that takes place in the presence of moisture and air. In this process, calcium carbonate (a hard, white, crystalline substance) can form when unhydrated cement in the pipe wall reacts with moisture and oxygen. This process typically can occur in hairline and design cracks as defined in *Section 5.1.2 Cracking* of this guide.

Autogenous Healing. Image Courtesy of American Concrete Pipe Association

5.2.2 pH (Corrosive Environment)

The pH of the surrounding environment is an important consideration when analyzing defects and preparing remediation recommendations. Corrosive environments where the pH is less than 5.5, such as locations near vegetal or animal wastes, seawater, or other areas of high concentrations of chlorides may experience faster deteriorations. Accordingly, cracks should not exceed 0.01” in width in these strongly corrosive environments. Evaluation of the influent, ground water, and soil conditions should be made as outlined in ASTM G51, Standard Test Method for Measuring pH of *Soils for Use In Corrosion Testing* and ASTM D1293, *Standard Test Method for pH of Water*.

5.2.3 Installation Stabilization

An important consideration when analyzing severe RCP defects including cracks over 0.1” and for spalling and slabbing locations is the installation stabilization. Even though RCP installations are rigid and can withstand much higher loads than other pipe types, the installation still relies on passive lateral earth pressure for support. RCP will transfer load by exerting pressure onto the adjacent soil resulting in deformation and cracking of the pipe. This pipe deformation, as well as the continued backfill consolidation, builds the passive earth pressure surrounding the pipe. This process continues until stabilization is reached, at which point pipe deformation is prevented due to the counterbalance provided by the passive soil pressure. This process can take up to 7 weeks or more to complete. To determine when stabilization has occurred, a micrometer can be used to measure deflection at the 12, 3, 6 and 9 o’clock positions throughout the pipe run. These measurements should be taken weekly. Once deflection has ceased, the pipe can be considered to be in equilibrium and then cracks can be reamed out, damaged concrete can be removed, and the necessary areas can be repaired to protect the steel reinforcement from corrosion and to reestablish the invert flow line.

In cases where the pipe continues to deform and stabilization is not achieved, creating an equilibrium can be attempted by drilling holes through the pipe wall at the haunch area and injecting pressure grout between the pipe and the embedment soil. This procedure is intended to increase the lateral pressure along the pipe in order to reach stabilization. The deflection of the pipe should be monitored in order to determine when equilibrium is reached. Once equilibrium is reached, all damage should be repaired.

Should the pipe not reach equilibrium, some type of structural repair should be made so that the installation will not solely rely on the structural integrity of the installed pipe. Removal and replacement of the installed pipe or structural lining are potential final options.

5.2.4 Differential Settlement

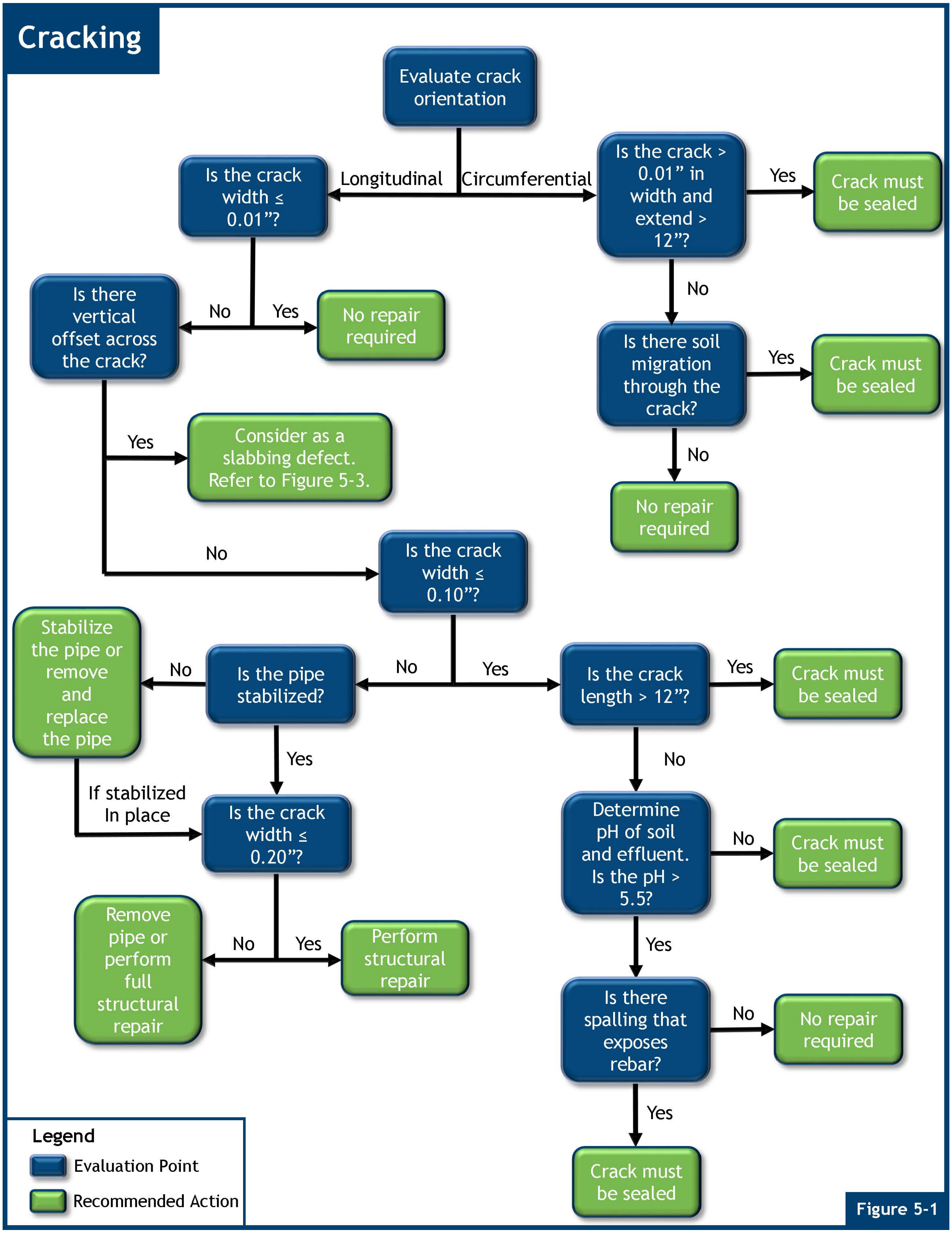
Differential settlement of the pipe can result in vertical offset or misalignment at the pipe joints. Separated joints are often found when severe misalignment is present. In fact, either problem may cause or aggravate the other. Joints should not be repaired until a solution to stabilize the surrounding soil has been made. If repairs must be made before the application has stabilized, then a flexible sealer should be used to seal cracks so they can adjust with future settlement.

5.3 Remediation Flow Charts

This section provides flow charts for the defect types established in *Section 5.1 Defects* of this guide. The flow charts provided in this section are considered a general guide for use. Judgement should be used with consideration to all signs of distress and gauged individually and collectively, to determine the required remediations. The various remediation methods available are discussed in detail in *Chapter 8 Remediation Treatments*. After remediation has been performed, the pipe shall be re-inspected to confirm that the defect has been adequately repaired.

5.3.1 Cracking

Cracks larger than 0.10" in width are rare and should be structurally evaluated to determine if the pipe is structurally capable of supporting loads. Pipes should be monitored to determine when they have reached equilibrium. Once equilibrium has been reached, all cracks should be structurally remediated.


Cracking
Evaluate crack orientation
Longitudinal
Circumferential
Is the crack width ≤ 0.01”?
Is the crack > 0.01” in width and extend > 12”?
Yes
Crack must be sealed
No
Yes
Is there vertical offset across the crack?
No repair required
No
Is there soil migration through the crack?
Yes
Crack must be sealed
Yes
Consider as a slabbing defect. Refer to Figure 5-3.
No
No repair required
No
Is the crack width ≤ 0.10”?
Stabilize the pipe or remove and replace the pipe
No
Is the pipe stabilized?
No
Yes
Is the crack length > 12”?
Yes
Crack must be sealed
Yes
No
If stabilized In place
Is the crack width ≤ 0.20”?
Determine pH of soil and effluent. Is the pH > 5.5?
No
Crack must be sealed
Remove pipe or perform full structural repair
No
Yes
Perform structural repair
Yes
Is there spalling that exposes rebar?
No
No repair required
Yes
Crack must be sealed
Legend
Evaluation Point
Recommended Action
Figure 5-1

5.3.2 Joint Defects

Joints must be leak-resistant in accordance with the contract documents to prevent infiltration or exfiltration which can lead to loss of backfill material.

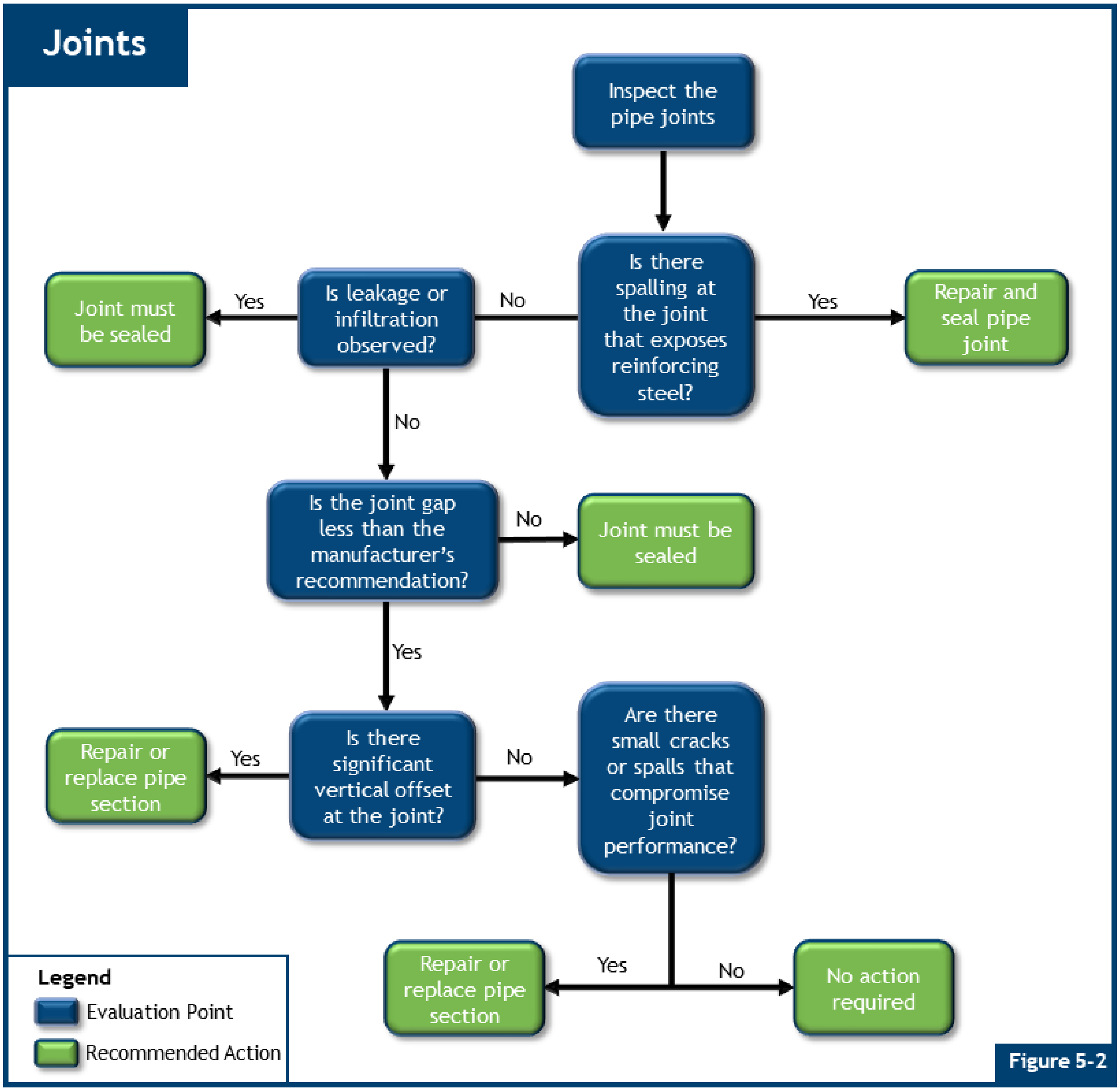


Figure 5-2

5.3.3 Spalling and Slabbing

If spalling occurs along crack planes, or if the pipe is exhibiting slabbing, it is important to remove all delaminated and/or loose concrete from above the reinforcing steel. If the pipe is stabilized and equilibrium has been achieved, then the exposed reinforcement can be cleaned and protected, and the pipe can maintain an appropriate service life.

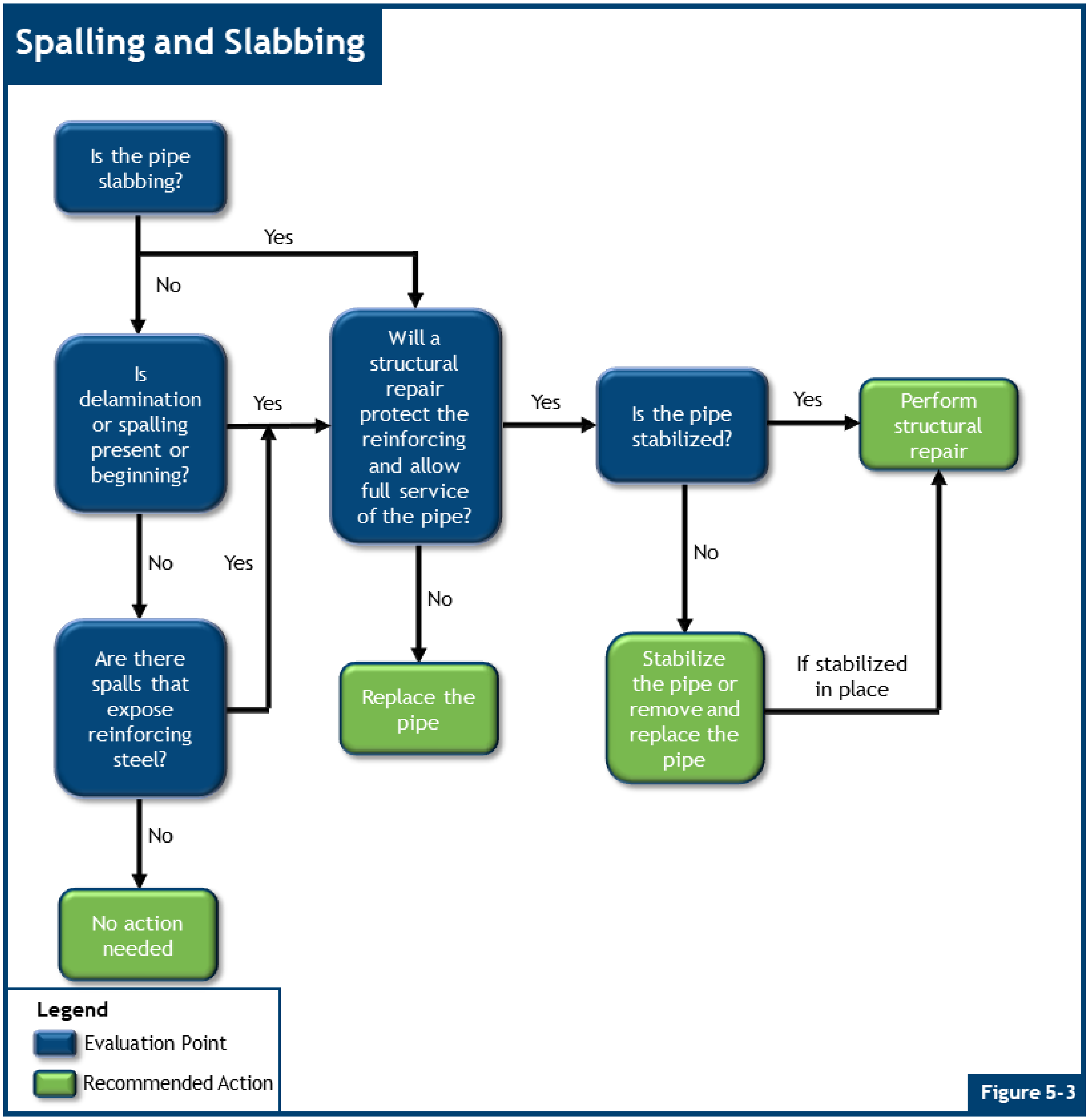


Figure 5-3

Chapter 6 Thermoplastic Pipe Post Installation Inspection

This chapter discusses the common defects of thermoplastic pipe, the severity of the observed defects, the documentation required for the various defect types, as well as rehabilitation considerations. This chapter primarily pertains to post installation inspection; however, its contents and principles can be applied to existing drainage pipe installations as well.

Thermoplastic pipes must be inspected upon completion to evaluate any issues which would affect their long-term in-place performance. All contract documents must specify the responsible party for repair of defects as well as the level of follow up inspection to ensure the defects are repaired before they are accepted into DelDOT's maintenance inventory.

6.1 Defects

As with all storm drain systems, pipe joints are a critical location which must be analyzed for defects. Because of the structural characteristics of thermoplastic materials, the most typical defect found in a thermoplastic pipe installations is deflection. Other liner defects including cracking, ripping, tearing, holes, buckling, bulging, and racking may also occur in thermoplastic pipe installations.

The defect severity described in this section should be considered both individually and collectively with the other defects present. Section *6.3 Remediation Flow Charts* provides a general guide for defect analysis and remediation.

6.1.1 Installation Deflections

As load on a flexible pipe increases, it distributes load to the surrounding backfill and becomes oval with the vertical diameter of the pipe decreasing and the horizontal diameter increasing. Deflection testing and measurement is necessary during inspection in order to properly evaluate the pipe's performance. There are many appropriate methods suitable for measuring deflection including pipe video inspection, mandrels, or direct measurement devices.

- **Pipe Video Inspection** – If a pipe video camera is to be used for deflection testing, it shall meet the requirements of *Section 3.2 Camera Requirements* of this guide and be able to produce all deliverables required by this guide.
- **Mandrels** – Mandrel inspections can be used to determine installation deflection in certain circumstances discussed in *Section 1.4 Maintenance Activity Considerations* of this guide. *Section 3.3 Mandrels* of this guide provides additional information on the use of mandrels.
- **Direct Measurement Devices** – Direct measurement of deflection is only allowed in pipes where the nominal diameter is greater than 48". See *Section 1.3 Manual Post Installation Inspections* of this guide for a discussion of additional requirements and practices required when direct measurements are taken to determine deflection.

Percent deflection is determined with Equation 6-1:

Equation 6-1: $$\%\,Deflection = \frac{D_{Nominal} - D_{Measured}}{D_{Nominal}} * 100\%$$

where:

$D_{Nominal}$ = AASHTO Nominal Diameter
$D_{Measured}$ = Smallest Interior Diameter of the Pipe

Recorded percent deflections that exceed 5% of the initial inside diameter are an indication of substandard installation and are required to be documented in the Storm Drain Report.

Where percent deflection exceeds 5% but is 7.5% or less, the contractor must perform an evaluation to determine the severity of the defect. The evaluation shall consider the severity of the defect, the structural integrity of the installation (using Section 12 "Buried Structures and Tunnel Liners" of the AASHTO LRFD Bridge Design Specifications), the existing environmental conditions, and the design service life of the installation. The contractor's evaluation must result in a recommendation to the Engineer as to the need for remediation as well as the remediation alternative selected by the contractor, if required. In all cases, the Engineer must approve the recommendation provided.

Pipe with Over 10% Deflection. Image Courtesy of Simpson, Gupertz & Hager

Where pipe diameter deflection exceeds 7.5%, remediation or removal is required.

6.1.2 Joint Defects

Joints in pipe segments are a critical evaluation area. Section 601 of DelDOT's Standard Specifications requires that joints be leak-resistant in accordance with ASTM D3212. Accordingly, the installed joint separation must be less than either the manufacturer's recommendation or 1", whichever is less.

Pipe joints which show signs of exfiltration or infiltration are considered significant defects. Excessive joint separations may lead to damage caused by exfiltration and infiltration resulting in the erosion of critical backfill material or oversaturation of the supporting subsoils.

6.1.3 Cracks, Tearing and Holes

Cracking, tearing, or holes can develop in thermoplastic pipe and can impair either the integrity of the barrel in ring compression or permit infiltration of groundwater or backfill. All instances of cracks, tears or holes discovered during post installation inspection must be either repaired or replaced.

Hole in Pipe. Image Courtesy of Kentucky Transportation Center

6.1.4 Misalignment

The barrel of the pipe shall be checked by sighting along the crown, invert, and sides of the culvert to assure it is aligned properly. Barrel alignment can indicate barrel structural distress, joint distress, or loss of support through soil infiltration or exfiltration. In some cases, misalignment can impact the design flow. The vertical alignment shall be checked for sagging, faulting, and invert heaving. The horizontal alignment shall be checked for straightness or smooth curvature. When performing an inspection, the inspector must take into account pipes laid with camber or a grade change in accordance with the contract plans or site requirements. Misalignment is typically an indicator of problems with the supporting soil or contractor grade control.

Misalignment. Image Courtesy of California Department of Transportation

Buckling. Image Courtesy of Simpson, Gupertz & Hager

6.1.5 Buckling, Bulging, or Racking

Buckling, bulging, and racking of the pipe are serious defects and must be documented in the Storm Drain Report. All instances of buckling, bulging or racking must be replaced.

6.2 Thermoplastic Pipe General Considerations

This section provides a general discussion of several items which should be considered when analyzing thermoplastic pipe defects.

Thermoplastic pipes typically have an elongated bell that allows for larger allowable joint gaps than the 1" required by the Standard Specifications. Should joint gaps exceed this 1" criteria, the manufacturer should be contacted to determine the actual allowable joint gap required to maintain a leak-resistant joint as there is variability in joint gap criteria amongst manufacturers and across different materials.

Another common defect in thermoplastic pipe is deflection. Deflection defects are typically caused by substandard pipe bedding.

6.3 Remediation Flow Charts

This section provides flow charts for the defect types established in *Section 6.1 Defects* of this guide. The flow charts provided in this section are considered a general guide for use. Judgement should be used with consideration to all signs of distress and gauged individually and collectively, to determine the required remediations. The various remediation methods available are discussed in detail in *Chapter 8 Remediation Treatments*. After remediation has been performed, the pipe shall be re-inspected to confirm that the defect has been adequately repaired.

6.3.1 Installation Deflection

Pipe installations may deflect post installation. It is critical to measure the percent deflection to determine if the defect requires remediation.

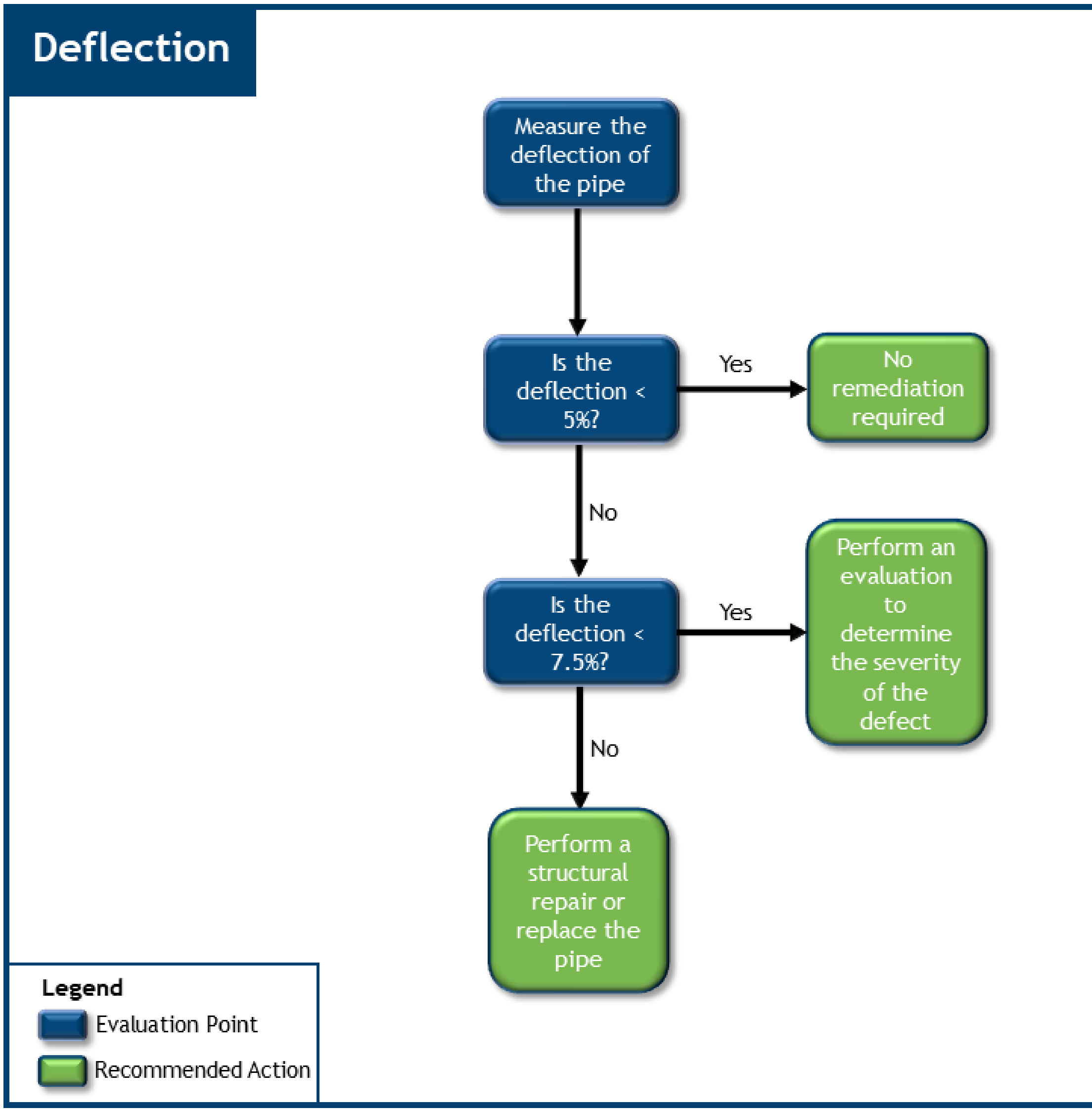


Figure 6-1

6.3.2 Joint Defects

Joints must be leak-resistant in accordance with the contract documents to prevent infiltration or exfiltration which can lead to loss of backfill material.

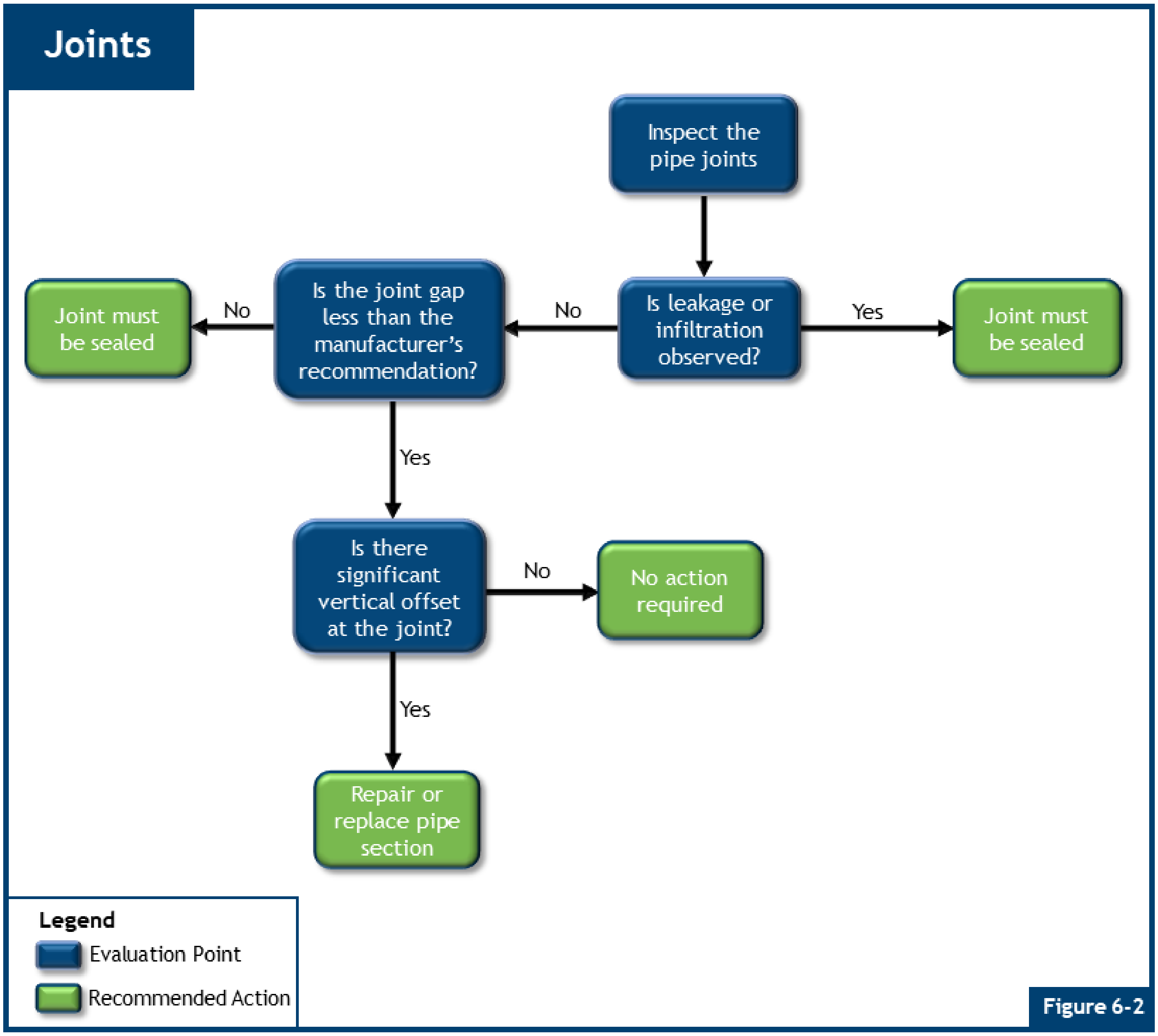


Figure 6-2

Chapter 7 Corrugated Metal Pipe (CMP) Post Installation Inspection

This chapter discusses the common defects of CMP, the severity of the observed defects, the documentation required for the various defect types, as well as rehabilitation considerations. This chapter primarily pertains to post installation inspection; however, its contents and principles can be applied to existing drainage pipe installations as well.

CMP must be inspected upon completion to evaluate any issues which would affect their long-term in-place performance. All contract documents must specify the responsible party for repair of defects as well as the level of follow up inspection to ensure the defects are repaired before they are accepted into DelDOT's maintenance inventory.

7.1 Defects

Defects that are typical with CMP include localized distortions like cracks, tears, holes, dents, misalignment, deflection, buckling, bulging, racking, coatings damage and joint separation. It is important to note that all defects may also have associated coatings damage that could affect the in-service performance of an installation.

The defect severity described in this section should be considered both individually and collectively with the other defects present. *Section 7.3 Remediation Flow Charts* provides a general guide for defect analysis and remediation.

7.1.1 Installation Deflection

As load on a CMP increases, it distributes load to the surrounding backfill and becomes oval with the vertical diameter of the pipe decreasing and the horizontal diameter increasing. Deflection testing and measurement is necessary during inspection in order to evaluate the pipe's performance. There are many appropriate methods suitable for measuring deflection including pipe video inspection, mandrels, or direct measurement devices. It should be noted that the deflection limits provided in this guide do not necessarily reflect the structural capability of the pipe but rather indicates poor installation practices that must be corrected to prevent future maintenance problems.

- **Pipe Video Inspection** – If a pipe video camera is to be used for deflection testing, it shall meet the requirements of *Section 3.2 Camera Requirements* of this guide and be able to produce all deliverables required by this guide.
- **Mandrels** – Mandrel inspections can be used to determine installation deflection in certain circumstances discussed in *Section 1.4 Maintenance Activity Considerations* of this guide. *Section 3.3 Mandrels* of this guide provides additional information on the use of mandrels.
- **Direct Measurement Devices** – Direct measurement of deflection is only allowed in pipes where the nominal diameter is greater than 48". See *Section 1.3 Manual Post Installation Inspections* of this guide for a discussion of additional requirements and practices required when direct measurements are taken to determine deflection.

Percent deflection is determined with Equation 7-1:

Equation 7-1: $$\%\,Deflection = \frac{D_{Nominal} - D_{Measured}}{D_{Nominal}} * 100\%$$

where:

$D_{Nominal}$ = AASHTO Nominal Diameter

$D_{Measured}$ = Smallest Interior Diameter of the Pipe

Recorded deflections that exceed 5% of the nominal inside diameter are an indication of substandard installation and are required to be documented in the Storm Drain Report.

Deflected Pipe. Image Courtesy of Simpson, Gupertz & Hager

Where percent deflection exceeds 5% but is less than 7.5% plus a manufacturing tolerance of either 1 percent of the nominal diameter or 0.5”, whichever is greater, the contractor must perform an evaluation to determine the severity of the defect. The evaluation shall consider the severity of the defect, the structural integrity of the installation (using Section 12 “Buried Structures and Tunnel Liners” of the AASHTO LRFD Bridge Design Specifications), the existing environmental conditions, and the design service life of the installation. The contractor’s evaluation must result in a recommendation to the Engineer as to the need for remediation as well as the remediation alternative selected by the contractor, if required. In all cases, the Engineer must approve the recommendation provided.

Where pipe diameter deflection exceeds 7.5% plus a manufacturing tolerance of either 1 percent of the nominal diameter or 0.5”, whichever is greater, remediation or removal is required.

7.1.2 Joint Defects

Joint Gap. Image Courtesy of Simpson, Gupertz & Hager

Joints in pipe segments are a critical evaluation area. CMPs commonly use a gasketed, banded and bolted restrained joint. This restrained joint requires a spacing in between the two ends of the pipes at a joint to allow the gasket and band to seat into and engage the annular CMP ends. The gap between the two pipe ends will vary due to the manufacturing process. Joint gaps that allow for infiltration or exfiltration are considered significant defects and must be documented in the Storm Drain Report. Table 7-1 shown below provides the maximum allowable gap for CMP with gasketed, banded and bolted restrained joints.

Pipe Diameter (in.)	Allowable Gap between Pipe Ends
15” to 24”	1 ½”
30” and larger	3”

Table 7-1: Maximum Joint Separation

7.1.3 Cracks, Tearing, Holes or Dents

Cracking, tearing, holes or dents can develop in CMPs and can impair either the integrity of the barrel in ring compression or permit infiltration of groundwater or backfill. All instances of cracks, tears, holes or dents discovered during post installation inspection must be either repaired or replaced.

Dent in Pipe. Image Courtesy of Simpson, Gupertz & Hager

7.1.4 Misalignment

The barrel of the pipe shall be checked by sighting along the crown, invert, and sides of the culvert to assure it is aligned properly. Barrel alignment can indicate barrel structural distress, joint distress, or loss of support through soil infiltration or exfiltration. In some cases, misalignment can impact the design flow. The vertical alignment shall be checked for sagging, faulting, and invert heaving. The horizontal alignment shall be checked for straightness or smooth curvature. When performing an inspection, the inspector must take into consideration pipes laid with camber or a grade change in accordance with the contract plans or site requirements. Misalignment is typically an indicator of problems with the supporting soil or contractor grade control.

7.1.5 Buckling, Bulging, or Racking

Buckling, bulging, and racking of the pipe are serious defects and must be documented in the Storm Drain Report. All instances of buckling, bulging or racking must be replaced.

7.1.6 Coatings Damage

CMP have coatings, both metallic and non-metallic, applied which protects the base metal from damage from their surrounding environment. Damaged coatings can lead to premature pipe failure. All coating damage including scratches, abrasions, tearing, scouring, peeling, or other damages must be documented in the Storm Drain Report.

7.2 CMP General Considerations

This section provides a general discussion of several items which should be considered when analyzing a CMP defect.

7.2.1 Environmental Assessment

When defects are detected, consideration must be given to the site conditions and their potential effect on the integrity of the pipe. The adverse effects that the surrounding environment can have on an installation can be accelerated in cases where the protective coating of a CMP is damaged. Of interest is the pH and resistivity of the effluent in the storm drain system as well as the surrounding soil. For metallic coatings typically, lower level pHs and resistivities will negatively affect the durability of a CMP. In addition, high moisture content soils and ground water tables that are above a pipe application produce greater exposure to water on the soil side of the pipe. For more information regarding appropriate locations for CMPs, please see Design Guidance Memorandum 1-20 entitled *Pipe Materials*.

7.2.2 Crimping of Pipe Wall

Crimping occurs when the metallic shell of a pipe begins buckling into many small waves along the perimeter of the pipe wall. Crimping is the result of large bending deformations and stresses and is more prevalent in smaller diameter pipes. Crimping could be an indication that the soil behind the pipe is not dense enough to prevent excessive bending deformations.

7.2.3 Allowable Joint Gaps

CMP typically uses a gasketed, banded and bolted restrained joint. This restrained joint requires a spacing in between the two ends of the pipes at a joint to allow the gasket and band to seat into and engage the annular corrugated pipe ends. If the band is tightened during installation before it is properly indexed with end corrugation, the band can jump to the next corrugation resulting in a gap of an additional 2-⅔”, which may exceed the maximum allowable joint gap as presented in *Section 7.1.2 Joint Defects*; however, as long as the pipe end is banded properly, this additional gap should not allow infiltration.

7.3 Remediation Flow Charts

This section provides flow charts for the defect types established in *Section 7.1 Defects* of this guide. The flow charts provided in this section are considered a general guide for use. Judgement should be used with consideration to all signs of distress and gauged individually and collectively, to determine the required remediations. The various remediation methods available are discussed in detail in *Chapter 8 Remediation Treatments*. After remediation has been performed, the pipe shall be re-inspected to confirm that the defect has been adequately repaired.

7.3.1 Installation Deflection

Pipe installations may deflect post installation. It is critical to measure the percent deflection to determine if the defect requires remediation.

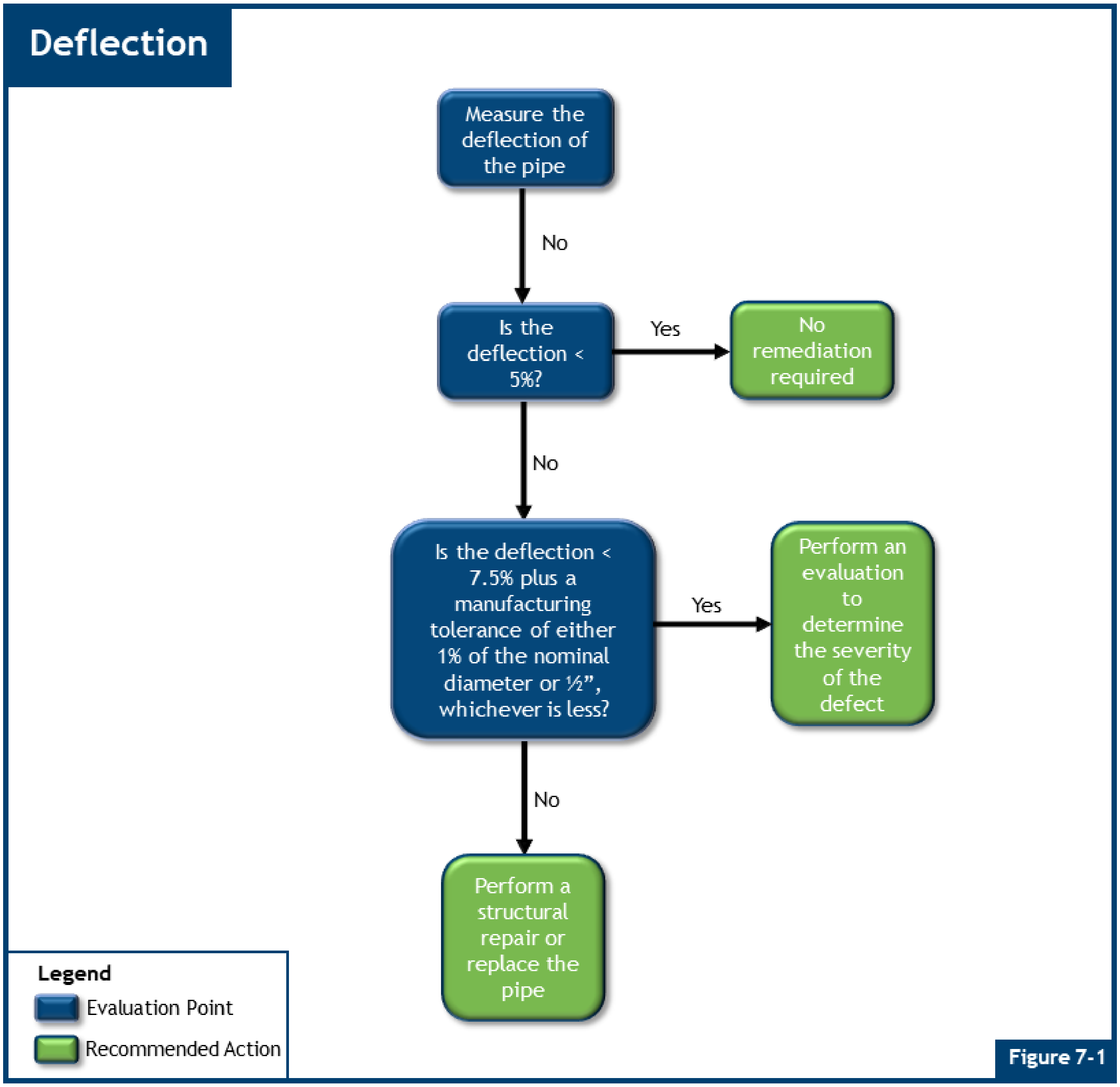
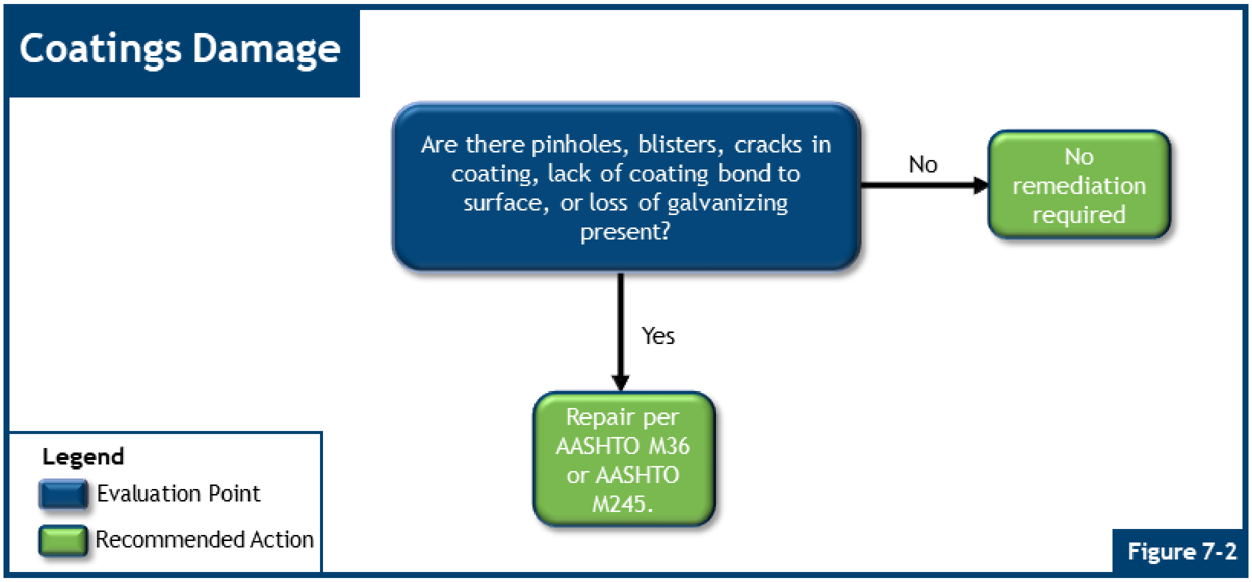


Figure 7-1

7.3.2 Coatings Damage

Metal pipes are coated to protect the metal pipe from their surrounding environment. Damages to the coating may affect the long-term performance of the installation.



7.3.3 Joint Defects

Joints should be provided in accordance with the contract documents to prevent infiltration or exfiltration which can lead to loss of backfill material.

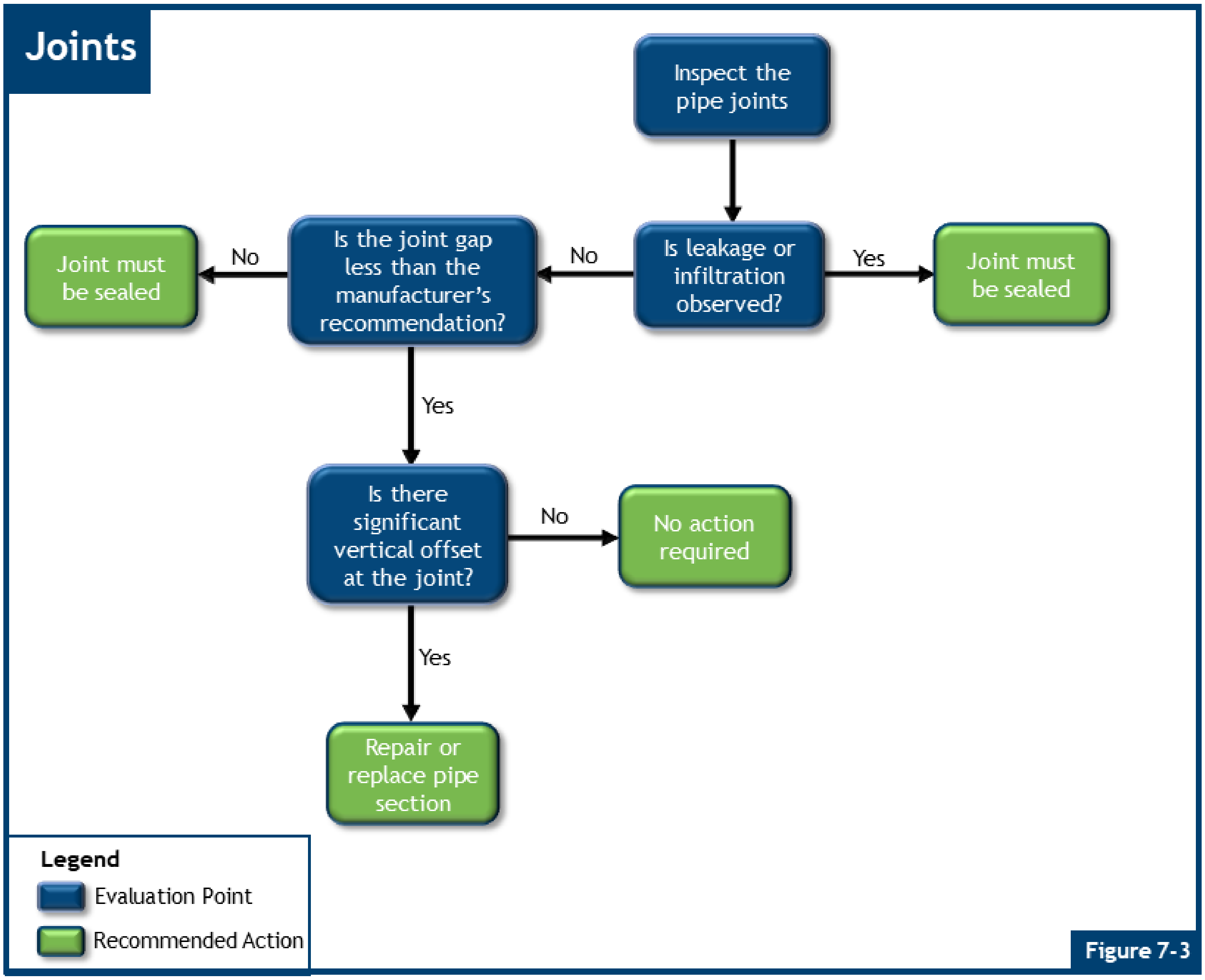


Figure 7-3

Chapter 8 Remediation Treatments

This chapter presents several remediation techniques for consideration; however, it is not intended to represent an all-inclusive list of remediation techniques. The remediation technique chosen for utilization must be selected based upon the defect observed as well as the site condition constraints present. Pipe remediations can either be applied as a localized point repair or can be applied as a linear repair along a length of the pipe. In general, remediation techniques can fall into two categories:

- **Trenchless techniques** – Trenchless remediation does not require an open cut around the pipe to remediate the defect and instead remediates the damaged pipe segments from the inside.
- **Open Techniques** – Open techniques require an open cut around the pipe to remediate the defect.

Whenever practical, trenchless techniques should be prioritized for defect remediation, especially once the final surface course has been placed. Repairs using open cut around the pipe are well documented and have been used often historically. As such, this chapter focuses on trenchless repair techniques. It should also be noted that some defects may require a combination of remediation techniques to properly repair an installation. Figure 8-1 provides a graphic representation of the pipe remediation techniques that are available for consideration.

In all cases, remediation should not take place until approved by the Engineer. After the remediation is performed, the remediation must be inspected to ensure that the attempt was successful.

8.1 General Considerations

The structural integrity of the existing installation must be considered when evaluating and recommending techniques for remediation. Installations that are in structural distress must either be removed and subsequently replaced or must be remediated with a method which restores the structural integrity of the installation. All remediations that are considered structural must be designed and sealed by a Professional Engineer. Trenchless structural repair techniques will inherently provide a smaller resulting diameter; however, the structural material is typically designed to be smoother than that of the host pipe to offset the resulting smaller pipe diameter's effect on flow capacity. A check to confirm adequate hydraulic capacity should be performed before decreasing the diameter of the existing pipe.

Consideration must be given to any and all potential downstream effects of the substances that are being proposed for use in pipe remediations. All potentially environmentally harmful substances shall not leave the project limits.

Access to the damaged pipe is a key consideration in the remediation evaluation process as the various remediation techniques presented in this chapter require different access levels. Priority should be given to selecting a remediation technique which will enable sufficient access to perform the repair and provide the least disruption to the traveling public and the construction schedule as possible.

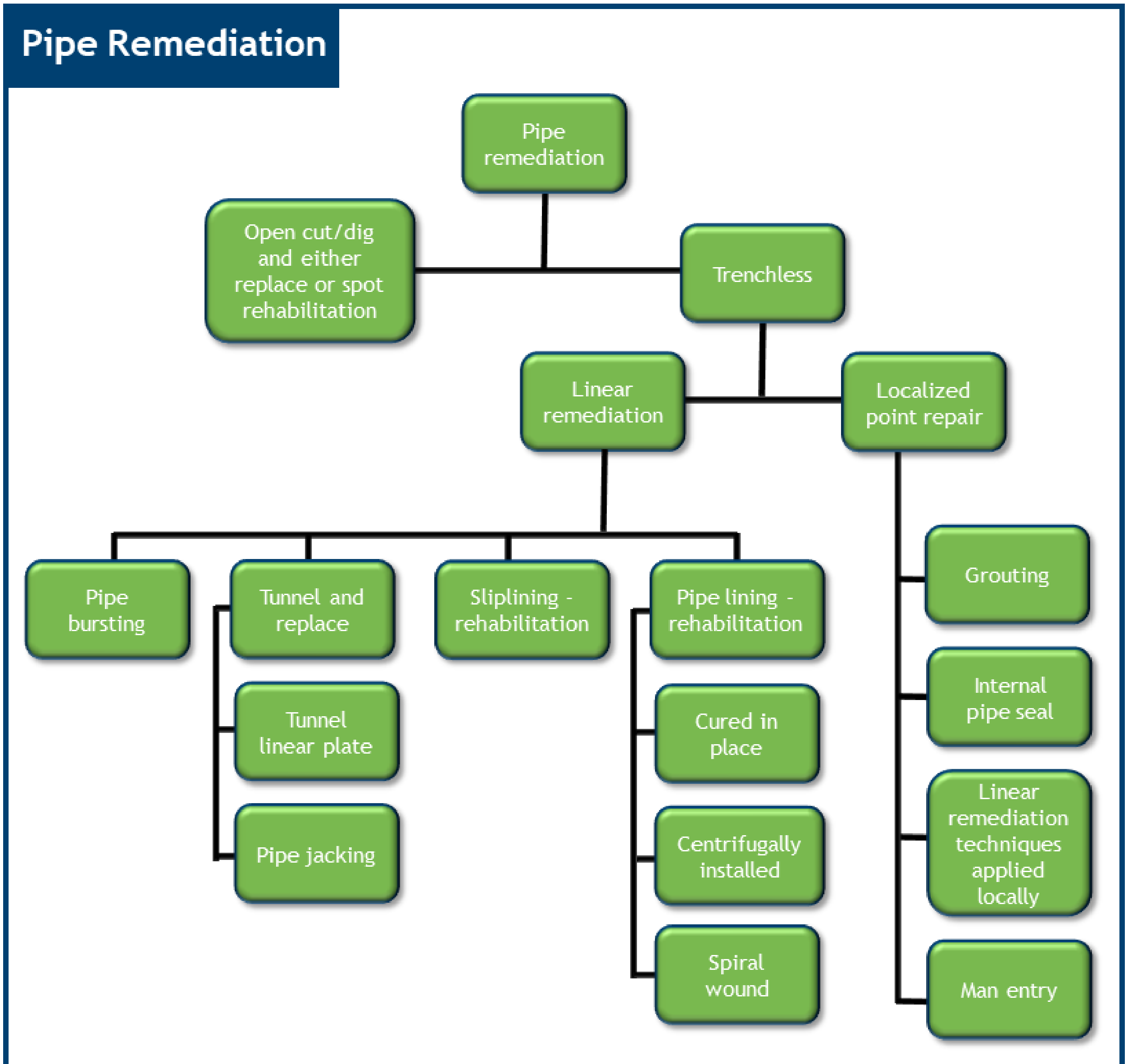


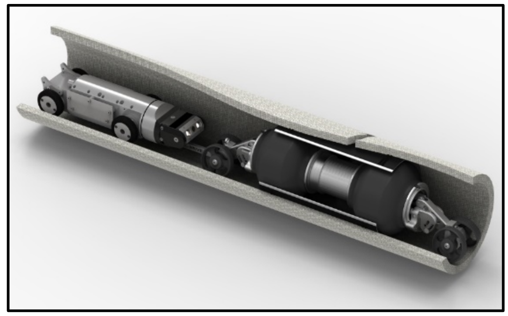
Figure 8-1

8.2 Localized Point Repair

Localized point repair is defined as the localized rehabilitation of a pipe defect. Performing these spot repairs avoids replacing entire sections of pipe or rehabilitating longer sections of pipe.

8.2.1 Mechanical Spot Repair

Mechanical spot repair is used to rehabilitate pipes that have localized damage and have not been structurally compromised. When structural damage is observed, mechanical spot repair can be used in combination with other structural repair methods to repair and seal the pipe. Mechanical spot repair is performed by using machines which enter the pipe to perform grouting, patching, or other sealing operations.



Robotic Packer. Image Courtesy of Sewer Robotics

8.2.1.1 Chemical Grouting

The most common mechanical spot repair performed is chemical grouting through use of a "packer" machine. The packer method involves a cylindrical packer with inflatable rubber end elements being inserted into the pipeline and positioned across a joint through use of video. The rubber end elements are inflated to isolate the damaged joint. Chemical grout is then forced through the open joint, lift holes, cracks, or fractures and into the surrounding soil where it solidifies with the soil to form a waterproof mass which cannot be pushed back into the storm sewer system. This water-tight collar adheres to the outer surface of the pipe or structure where it will stay until it is removed by excavation or deteriorates from site conditions. If groundwater pressures increase, the collar will be pressed more tightly against the structure, increasing its ability to stop leaks. There are many types of chemical grout available including urethane, acrylamide, epoxy, cementitious grouts, etc. Performing this repair can be difficult if the pipe is misaligned. This repair method is generally considered to have a service life of 10 years.

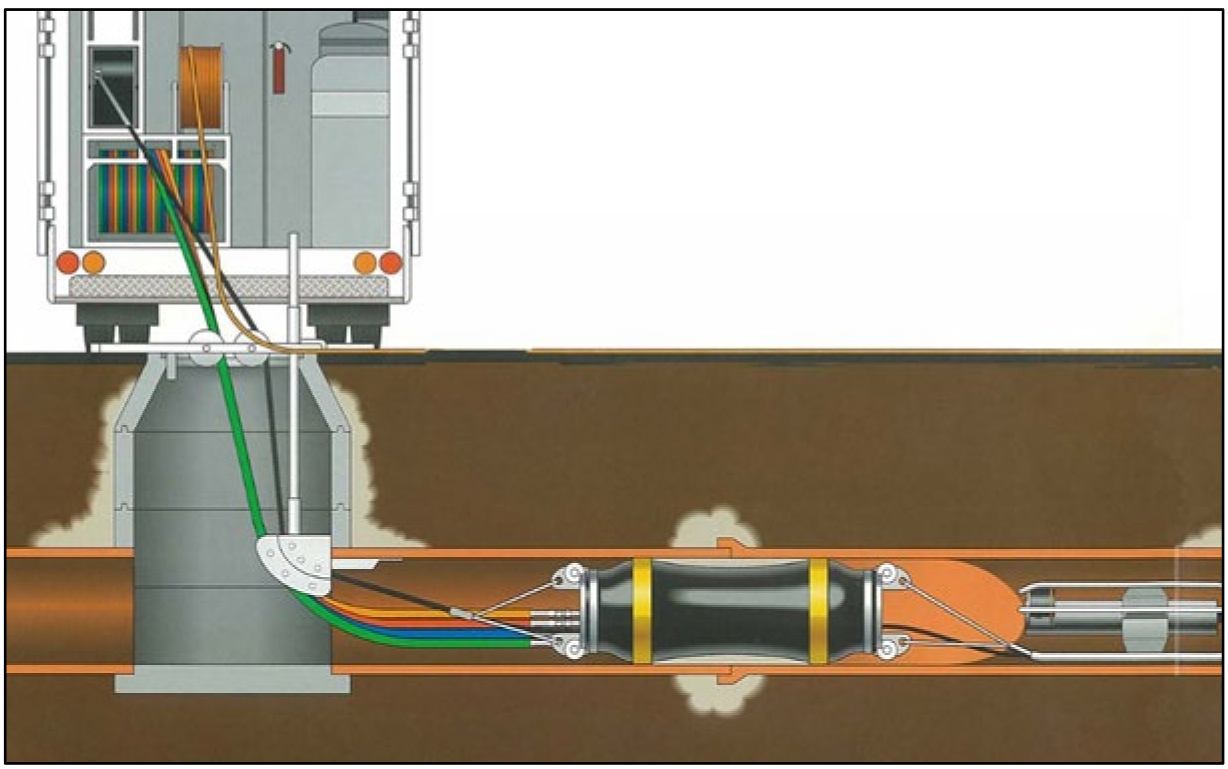


Diagram of Grouting. Image Courtesy of Standard Pipe Services

8.2.1.2 Internal Compression Seal

Utilizing an internal compression seal is another common localized point repair option. Typically, a flexible rubber seal is inserted at the location exhibiting infiltration or exfiltration and then compressed to the pipe wall to prevent the movement of water. The service life for these repairs generally varies based on manufacturer as well as environmental condition.

Internal Compression Seal. Image Courtesy of Envirosight

8.3 Linear Repair

Linear repairs occur along a length of the pipe segment to correct a variety of defects. There are multiple methods for linear pipe repairs.

8.3.1 Pipe lining

Pipe lining is a trenchless pipe repair process where an existing pipe is lined with a foreign material to create a new flow surface. The new continuous pipe lining eliminates infiltration and exfiltration at pipe joints and along the pipe walls. The liner may provide additional structural support depending upon the liner material and the liner's thickness. The new liner will have a smaller diameter than the host pipe; however, the resulting liner is typically smoother than the material of the host pipe to offset the resulting smaller pipe diameter's effect on flow capacity. Pipe linings attach to the existing pipe walls; therefore, this remediation method will not correct any misalignment issues present in the existing installation. There are multiple materials and techniques used to accomplish pipe linings.

Pipe Liner Installation. Image Courtesy of Standard Pipe Services

8.3.1.1 Cured-in-Place Lining

Cured-in-place pipe (CIPP) is the generic term used to describe a class of pipe lining technique whereby a pipe lining is directly cast against the wall of an existing host pipe. The CIPP rehabilitation method utilizes a thermosetting resin which is impregnated into a continuous felt tube. The tube is then inserted into the existing host pipe through use of various methods and techniques dependent on the CIPP material as well as the site access constraints. The tube is then pressure inverted against the wall of the host pipe from a suitable access point, and heated in-situ (using water, steam or air) to cure the resin, thus forming a structurally competent and continuous lining. Entire pipe runs can be rehabilitated, or short segments of pipe can be repaired utilizing this method. This process results in a seamless, jointless "pipe-within-a-pipe" with a smooth, continuous inner surface. CIPP liners can be used on various pipe sizes, shapes, and materials. Due to the liner's initial flexibility, the liner will conform to barrels that are longitudinally curved or sections that are displaced with open joints between them.

8.3.1.2 Spiral Wound

Spiral wound pipe rehabilitation is a pipe liner technique whereby a ribbed plastic strip is spirally wound by a winding machine to form a liner which is inserted into a defective pipeline. This technique was originally developed to address pipe repairs on existing systems where the diameter was either too small or too large for CIPP relining. Similar to CIPP liners, these liners can be used with various pipe sizes, shapes, and materials and will conform to barrels that are longitudinally curved or sections that are displaced with open joints between them.

8.3.1.3 Centrifugally Installed Liner

This liner technique utilizes a high-pressure nozzle on a pneumatic hose to shoot the new liner material onto the existing pipe wall. The liner material can vary based on manufacturer. The hydraulics of the system must be considered when utilizing this application as the liner will reduce the conduit diameter conduit. As a result, pipe capacity should be considered when utilizing this remediation method.

Centrifugally Installed Liner. Image Courtesy of Standard Pipe Services

Centrifugally Installed Liner. Image Courtesy of Centi-Lining

8.3.1.4 Fold-and-Form

Fold-and-Form lining is a pipe lining technique where a folded shape is pulled through the host pipe and then unfolded into place typically with heat from steam. The liner material is typically HDPE or PVC and is designed to fit tight against the host pipe. Folded shapes are flattened, C-or H-shaped, and coiled for delivery.

8.3.2 Pipe Sliplining

"Sliplining" is a trenchless method of installing a new pipe inside of an existing pipe. There are a wide variety of individual techniques that may be employed to perform a slipline; however, the process generally involves pulling a new liner pipe into the existing pipe with a winch cable or pushing into place with a choker strap and mechanical equipment. Once the new liner pipe is installed, the void space between the new and old pipe is filled by grouting.

Sliplining a pipe eliminates infiltration and exfiltration at pipe joints and along pipe walls. The liner may provide additional structural support depending upon the slipliner material and associated thickness. The new liner will have a smaller diameter than the host pipe; however, the resulting liner is typically smoother than the material of the host pipe to offset the resulting smaller pipe diameter's effect on flow capacity.

Pipe Sliplining. Image Courtesy of Downer PipeTech

Slipliners can be installed either segmentally or continuously. Segmental sliplining, which is also referred to as discrete sliplining, occurs when sections of the slipliner pipe are installed individually and then joined together. Continuous sliplining occurs when the slipliner pipe is installed as one continuous pipe segment.

8.3.3 Tunnel and Replace

Tunneling techniques can be utilized to repair or replace existing pipes. Their use in rehabilitation of existing pipes is limited; however, they are a valuable technique when full replacement is required and open cutting would result in large delays to the traveling public. The process can fail if there are obstructions surrounding the pipe. The proposed pipe material can vary based on the tunneling method chosen.

8.3.3.1 Tunnel Liner Plate

In this method, a new pipe is installed by creating a tunnel along the alignment of the proposed pipe. The stability of the tunnel is secured by utilizing tunnel liner plates. The tunnel is advanced by extending a tunneling shield which pushes off the existing segment of installed tunnel liner plate. Spoils from the tunnel are removed with a muck cart. A sending pit is required for spoil removal.

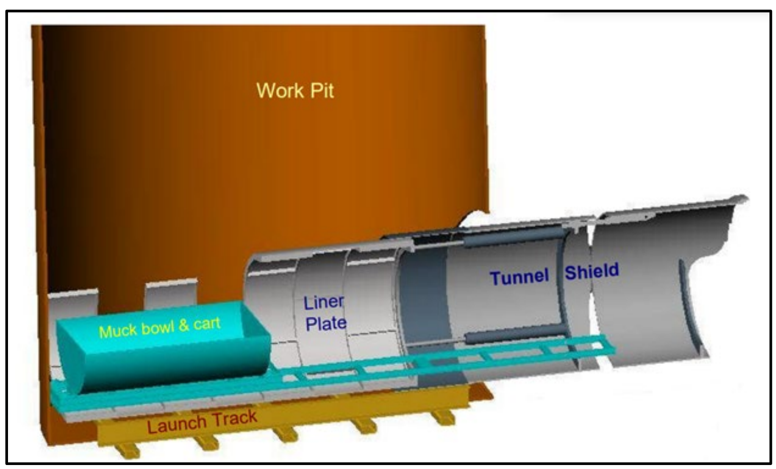
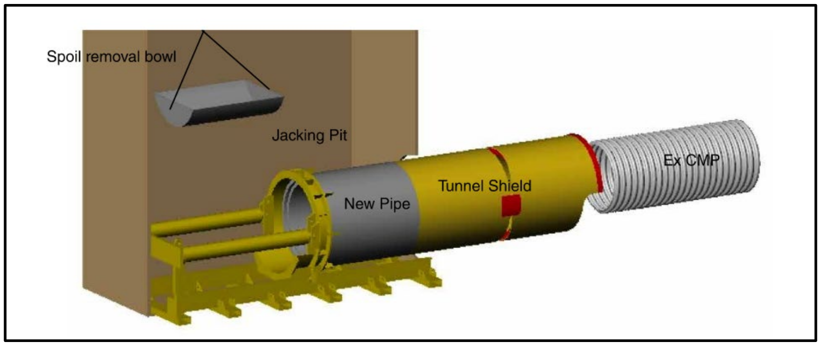


Diagram of Tunnel Liner Plate Operation. Image Courtesy of Tenbusch

8.3.3.2 Pipe Jacking

Pipe jacking is a tunneling technique for installing new pipe through use of hydraulic jacks. Typically, a "sending" and "receiving" pit is required for this technique. The new pipe is installed with a soil cutting shoe or cutter head which directs spoils inside the pipe which can be removed once installation of the pipe is complete. On longer installations, the spoils can be removed during the pipe jacking process. Various surveying methods are typically used during installation to ensure that proper alignment is maintained.

Pipe ramming is very similar to pipe jacking. Instead of using hydraulic jacks, pipe ramming utilizes percussion equipment to install the new pipe.



Pipe Jacking Operation. Image Courtesy of Tenbusch

8.3.4 Pipe Bursting

In the pipe bursting process, a new pipe is pulled through an old pipeline of equal or smaller size. The old pipeline is shattered as the new pipe is pulled through, with the pieces of the existing pipe displaced into the surrounding soil. The process is an effective technique to maintain or upsize the existing pipe. The process can fail if there are obstructions surrounding the pipe. Care must also be taken to avoid damage to surrounding structures.

8.4 General Guidelines for Remediation

Table 8-1 is included as a reference for applicable remediation methods available for the various pipe defects discussed in the applicable chapter of this guide.

Defect	Rehabilitation Method	Description
Open joints	Sealing	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Offset joint	Sealing	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Circumferential and longitudinal cracks	Sealing	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Multiple cracks and fractures	Sealing	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Broken Pipe Moderate	Point repair	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Broken Pipe Severe	Point repair	Techniques include pipe lining by various methods, pipe bursting, various tunneling methods, slip-liners, and man entry for large pipes
Collapsed Pipe	Point repair	Replace with open cut, pipe bursting, and various tunneling methods
Corrosion / Surface Damage	Repair and seal	Techniques include pipe lining by various methods, slip-liners, and man entry for large pipes
Misalignment	Point repair	Techniques include pipe lining by various methods, slip-liners, and man entry for large pipes
Lining failure	Lining, replace the pipe	Techniques include pipe lining by various methods, pipe bursting, slip-liners, various tunneling methods, and man entry for large pipes
Weld failure	Point repair	Techniques used include chemical grout, pipe liners, slip-liners, and man entry for large pipe
Deformed minor	Lining	Techniques include pipe lining by various methods, slip-liners, and man entry for large pipes
Deformed Severe	Replacement	Replace with open cut, pipe bursting, various tunneling methods

Table 8-1: Remediation Reference Guide