Michigan Department of Transportation

# DRAFT Preliminary Repair, Rehabilitation, and Replacement Options for Consideration for Culverts Report

HNTB

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# 1 EXECUTIVE SUMMARY

The *Preliminary Repair, Rehabilitation, and Replacement Options for Culverts Report* presents repair, rehabilitation, and replacement guidance for Michigan Department of Transportation (MDOT) culverts with a span less than 10 feet. HNTB compiled existing practice information by reviewing various MDOT manuals, standards, and other forms of documentation and reviewed documentation and guidelines from other agencies and DOTs to identify other potential practices.

This report outlines current fixes in Michigan for culvert repair, rehabilitation, and replacement strategies, and it describes additional industry best practices for consideration. It focuses on repair and rehabilitation strategies, and it provides an overview of cleaning and replacement activities. Industry best practices are presented for MDOT's consideration for adoption in the future. The preventative strategies and rehabilitation strategies presented contain multiple industry best practices options, and routine maintenance is explained in brief. Replacement strategies are included in this document as replacement occurs when the other options are not feasible. Repair and rehabilitation measures are essentially "fixes," so replacement measures were not the focus of this document. Furthermore, existing practices for culvert replacement are identified, but the literature review indicates MDOT already adopts most industry best practices for replacement measures.

# 2 INTRODUCTION

This report provides a comprehensive view of MDOT's current culvert repair, rehabilitation, and replacement practices and additional options and best practices for consideration. Repair strategies include localized repairs that are specific to one feature or one defect. Rehabilitation strategies refer to activities that address multiple deficiencies or a holistic culvert repair program. Replacement strategies address conditions where repairs and rehabilitation are no longer feasible. The preventative strategies and rehabilitation strategies presented contain multiple industry best practices options, and routine maintenance was explained in brief. Replacement strategies are included in this document as replacement occurs when the other options are not feasible. As repair and rehabilitation measures are essentially "fixes," replacement measures were not the focus of this document.

The industry best practices encompass a range of options that are not currently employed by MDOT for culvert repair and rehabilitation. This is due to design considerations, the potential alteration in the dimensions of the existing culvert, and various other factors that may arise from implementing such repairs.

## 2.1 Background

MDOT established the Ancillary Structures (AS) Program, which is an asset management program for ancillary structures, to develop and maintain a statewide inventory of MDOT-owned assets, including culverts, retaining walls, cantilever structures, trusses, poles, noise walls, mast arms, sign structures, and various towers. The AS Program aims to improve public safety by helping MDOT minimize risk from aging and deteriorating infrastructure. The AS Program includes culverts with a span of less than ten feet.

The AS Program developed the *Michigan Ancillary Structures Inspection Manual* (MiASIM) (2023) that provides guidelines for inspecting ancillary structures and recording work recommendations to initiate maintenance actions. Table 1 summarizes potential work recommendations.

**Table 1: Culvert Less than 10-feet Span Work Recommendations**

| Number | Description of Work Recommendation | Material Involved | Quantity/Unit of Measure |
|---|---|---|---|
| 1 | Channel – Install/Repair Scour Countermeasures | Rock or Articulated Concrete Block (ACB) | Cubic Foot |
| 2 | Channel – Monitor Scour | N/A | N/A |
| 3 | Substructure – Repair Abutment/Wings/ Headwall | Concrete | Cubic Foot |
| 4 | Repair/Replace End Treatment | End Treatment Material, as needed | Each |
| 5 | Repair Washouts/Erosion | Stone or Other, as needed | Cubic Foot |
| 6 | Approach Pavement Repair | Asphalt | Square Foot |
| 7 | Brush Cut | Brush | Cubic Yard |
| 8 | Culvert Cleanout | Sediment | Cubic Foot |
| 9 | Clean and/or Paint/Re-seal Concrete for Graffiti Removal | Concrete | Square Foot |
| 10 | Seal Barrel | Joint Sealer | Lineal Foot |
| 11 | Seal Cracks | Crack Sealer | Lineal Foot |
| 12 | Barrel Repair | Barrel Material, as needed | Square Foot |
| 13 | Install Culvert Liner | Liner | Lineal Foot |
| 14 | Replace Culvert | Culvert | Lineal Foot |
| 99 | Other | | |

*Source: MiASIM, September 2023, Table 8.2.16.*

## 2.2 Definitions

For the purpose of this report, the terms of repair, rehabilitation, and replacement are defined as follows, which were modified from the National Cooperative Highway Research Program (NCHRP) *Synthesis 303 Assessment and Rehabilitation of Existing Culverts* (2002). These terms also are defined in the Minnesota DOT (MnDOT) *Culvert Repair Best Practices, Specifications, and Special Provisions – Best Practices Guidelines* (2014). Routine and preventative maintenance are separated out in these documents and other literature that are included as references, and the definitions included below may be defined differently between agencies. However, the included definitions are how most DOT's define maintenance activities specific to culverts.

A **repair** is a maintenance task that is aimed at ensuring a culvert consistently remains in a good and safe condition. Repair strategies include routine and preventative maintenance.

- **Routine maintenance** is designed to address specific defects as they arise to make sure a culvert remains in a good and safe condition. This type of maintenance is often responsive to specific situations rather than being planned. Common activities associated with routine maintenance include clearing debris or sediment to restore the cross-sectional area of a pipe.
- **Preventative maintenance** is a cyclical maintenance approach that is designed to address early-stage deterioration and to stop it from worsening. It is usually scheduled and

typically involves activities like sealing joints, patching concrete, paving the invert, and repairing mortar.

**Rehabilitation** is a corrective action that uses the remaining usable components of a culvert to construct a reconditioned culvert. This action is undertaken to improve the pipe, nearly restoring it to its original condition. Rehabilitation is most suitable for culverts that have deteriorated to a point where preventative maintenance is no longer effective, but they have not reached a state of complete structural failure yet.

**Replacement** is the task of replacing the existing culvert with a completely new culvert to provide a new service life. It is typically accompanied by realignment, hydraulic, structural and safety improvements, and changes in culvert shape or material.

## 2.3 Culvert Types

The following list includes the types of culverts found in Michigan as included in Appendix A, MiASIM, (September 2023):

- Reinforced Concrete Pipe (RCP)
- Corrugated Metal Pipe (CMP)
- Box Culverts
- Clamshell Box Sections
- Arches/Multiplate Arch
- Natural Bottom Culvert (3-sided)
- Multi Barrel Culvert
- Smooth-lined Corrugated Plastic Pipe
- Other

The geometry of a culvert or the material can impact what types of deformations or issues are found and what types of repairs are necessary. For example, round culverts may be more susceptible to clogging with a reduced stream width at certain depths. These correlations were not investigated for this phase. However, data analyses can identify the correlations, which can be done in future phases, as discussed in the Conclusions and Next Steps section.

# 3 EXISTING WORK OPTIONS FOR CULVERT FIXES

MDOT repairs culverts in a variety of ways based on material type, culvert shape, dimensions, magnitude of distress, and other factors. This section focuses on the different culvert types, repair strategies MDOT already implements, including routine maintenance and preventative maintenance, and industry best practices.

## 3.1 Repair Strategies

Routine maintenance of a culvert keeps it in a reliable and sound condition by fixing certain defects as they appear. Work options are defined as “regular maintenance” in MiASIM, and they are assumed to be synonymous with routine maintenance activities. These activities typically consist of removing debris, sediment, or vegetation from the culvert barrel to mitigate blocking flow. Routine maintenance is briefly discussed in this report.

Preventative maintenance activities are geared towards preventing further propagation of existing culvert defects. These activities are important for extending the service life of the asset. Preventative maintenance is reported to be more extensive than routine maintenance. Examples of preventative maintenance include joint sealing, concrete patching, invert paving, scour prevention, mortar repair, and ditch cleaning and repair. Preventative maintenance does not contribute to improving the structural capacity of the culvert, rather it stops the deterioration of the culvert by preventing the conditions that would lead to such deterioration (Wyant 2002).

Existing work options are techniques that MDOT currently practices and are included below with associated references for routine and preventative maintenance practices.

## Routine Maintenance

The following lists MDOT's current culvert routine maintenance practices and corresponding references:

- Channel-Monitor Scour (Table 1, Work Recommendation #2)
  - MDOT Drainage Manual – Chapter 5: Culverts, page 61
  - MDOT Michigan Structure Inspection Manual – Chapter 6: Scour, page 5
- Brush Cut (Table 1, Work Recommendation #7)
  - MDOT Standard Specifications for Construction – Division 2: Earthwork, Section 201. Clearing, page 3
- Culvert Cleanout (Table 1, Work Recommendation #8)
  - MDOT Drainage Manual – Chapter 5: Culverts, page 60
  - MDOT Special Provision for Culvert Cleanout
- Clean/Paint/Reseal Concrete/Graffiti Removal (Table 1, Work Recommendation #9)
- Other (Table 1, Work Recommendation #99)
  - MDOT Road Design Manual – Chapter 4:Drainage, page 12 (Channel Cleanout)

## Preventative Maintenance

The following lists MDOT's current culvert preventative maintenance practices and corresponding references:

- Channel – Install/Repair Scour Countermeasures (Table 1, Work Recommendation #1)
  - MDOT Drainage Manual – Chapter 5: Culverts, page 61
  - MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts, page 10
- Substructure-Repair Abutment/Wings/Headwall (Table 1, Work Recommendation #3)
  - MDOT Michigan Structure Inspection Manual – Chapter 5: Routine and Condition based in-depth Inspection, page 165
  - MDOT Standard Specification for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts. Section 406. Precast Three-Sided, Arch, and Box Culverts.
- Repair/Replace End Treatment (Table 1, Work Recommendation #4)
  - MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts. Section 406. Precast Three-Sided, Arch, and Box Culverts.
  - MDOT Special Provision for Corrugated steel pipe arch end section replacement
  - MDOT Special Provision for Reinforced concrete elliptical culvert end section
- Repair Washouts/Erosion (Table 1, Work Recommendation #5)
  - MDOT Drainage Manual – Chapter 5: Culverts, page 61
- Approach Pavement Repair (Table 1, Work Recommendation #6)

    - MDOT Standard Specifications for Construction – Division 5: HMA Hot Mix Asphalt Pavements and Surface Treatments. Section 502 HMA Crack Treatment. Division 6: Portland Cement Concrete Pavements. Section 603. Concrete Pavement Restoration.
- Seal Barrel (Table 1, Work Recommendation #10)
    - MDOT Drainage Manual – Chapter 5: Culverts, page 61
    - MDOT Special Provision for Crack and Joint Sealing, applicable to most sizes and shapes of concrete culverts
    - MDOT Special Provision for Internal Mechanical Joint Sealing, applicable to most sizes and shapes
    - MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts; Division 7: Structures, Section 712. Bridge Rehabilitation — Concrete; Division 9: Materials, Section 909. Drainage Products and Section 914. Joint and Waterproofing Materials
        - Cold-Applied Pipe Joint Sealer
        - Fiber Joint Filler
        - Pressure Crack Injection for concrete
    - MDOT Special Provision for Chemical Pipe Joint Grouting
    - MDOT Special Provision for Expanding Polyurethane Foam Spray
    - Fiberglass Spot Repair (ASTM F1216) (MDOT-Personal communication)
- Seal Cracks (Table 1, Work Recommendation #11)
    - MDOT Special Provision for Crack and Joint Sealing
- Barrel Repair (Table 1, Work Recommendation #12)
- Other (Table 1, Work Recommendation #99)

## 3.2 Rehabilitation Strategies

If localized repair options are not adequate to maintain the culvert in safe and stable condition, then MDOT should examine rehabilitation options. The following list summarizes MDOT's current culvert rehabilitation practices and corresponding references.

- Install Culvert Liner (Table 1, Work Recommendation #13)
    - MDOT Drainage Manual – Chapter 5: Culverts, page 60
    - MDOT Presentation on Ultraviolet (UV) Hardened Culvert Slip Lining (UV Liners)
    - MDOT Special Provision for Cured-In Place Pipe (CIPP) Liner for Culverts
    - MDOT Special Provision for Slip Pipe Liner for Culverts
        - Snap-tite Lining System
        - Culvert Renew
        - A2 Liner Pipe
    - North Region Culvert Best Practices Memorandum
        - Sliplining
- Repair/Replace End Treatment (Table 1, Work Recommendation #4)
    - MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts
- Substructure Repair/Partial Culvert Replacement (Table 1, Work Recommendation #3)
    - MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 401. Pipe Culverts

- MDOT Standard Specifications for Construction – Division 4: Drainage Features, Section 406. Precast Three-Sided, Arch, and Box Culverts.
- MDOT Standard Specifications for Construction – Division 7: Structures, Section 706. Structural Concrete Construction
- MDOT Standard Specifications for Construction – Division 7: Structures, Section 712. Bridge Rehabilitation – Concrete

## 3.3 Replacement Strategies

Replacement options are considered when all other options have been ruled out. This document is focused on repair and rehabilitation strategies up to the replacement of a culvert; however, replacement is briefly included in this report. Furthermore, existing replacement strategies are presented, but industry best practices are not included. The existing replacement strategies are defined below.

- Repair/Replace Treatment (Table 1, Work Recommendation #4)
  - MDOT Standard Specifications for Construction
  - MDOT Special Provision for Corrugated Steel Pipe Arch End Section Replacement
  - MDOT Special Provision for Reinforced Concrete Elliptical Culvert End Section
- Replace Culvert (Table 1, Work Recommendation #14)
  - MDOT Standard Specifications for Construction
  - MDOT Special Provision for Pipe Bursting Culvert Rehabilitation
  - MDOT Special Provision for Culvert, Class V, 60 inch, Jacked in Place
  - MDOT Special Provision for Steel Casing Pipe, 20 inch, Jacked in Place
  - MDOT Special Conditions for Microtunneling (MT)
  - MDOT Special Conditions for Horizontal Directional Drilling (HDD)
  - MDOT Special Conditions for Horizontal Auger Boring (HAB)

# 4 INDUSTRY BEST PRACTICES

The industry best practices encompass a range of options that are not currently employed by MDOT for culvert repair and rehabilitation. This is due to design considerations, the potential alteration in the dimensions of the existing culvert, and various other factors that may arise from implementing such repairs.

The Industry Best Practice repair and rehabilitation options for culverts are not currently practiced by MDOT; the gray region on the left side of the page indicates unapproved options.

## 4.1 Repair Strategies

Routine and preventative maintenance are the two types of repair options. Routine maintenance best practices generally include cleaning out debris and managing vegetation growth in and around the culvert. The nature of routine maintenance involves taking care of issues as they arise, so routine inspections are recommended to keep up with maintaining the culvert. The MnDOT's *Culvert Repair Best Practices, Specifications, and Special Provisions – Best Practices Guidelines* (2014) document reinforces this idea. The manual organizes the routine maintenance mechanisms by various repair types, such as spalling repair. For all repair types, the overarching recommendation for routine maintenance includes regular inspections to meet routine maintenance goals. Overall, industry best practices for routine maintenance includes performing regular inspections, cleaning out debris, and vegetation control.

The following sections discuss preventative maintenance best practices as recommended by the California Department of Transportation (Caltrans), MnDOT, and South Carolina DOT (SCDOT), including joint repair techniques, spalling repair techniques, spot repair techniques, and other repair techniques. Some of these techniques also are covered under rehabilitation. The technique used depends on the magnitude of the repair needed, as preventative maintenance is limited to a localized repair, and rehabilitation typically includes the entire structure. Table 2 is a summary of industry best practices for preventative maintenance.

**Table 2: Summary Table of Industry Best Practices – Preventative Maintenance**

| Deficiency | Existing Work Rec.[1] | Best Practices/ Other Options | Associated Entity |
|---|---|---|---|
| Infiltration/exfiltration from joint deterioration | 10 | Joint grouting (internal grouting, chemical grouting, robotic grouting); grouting sleeves; internal packer sealers | Caltrans |
| Spalling | 3 | Apply mortar; chip and patch | Caltrans, MnDOT |
| Cracks, other concrete deterioration | 11 | Shotcrete | MnDOT |
| Slabbing | 3, 12 | Apply coatings | Caltrans |
| Erosion/scour | 1 | Slab-jacking; compaction grouting | MnDOT |
| Surface abrasion | N/A | Install corrosion-resistant coatings/materials | MnDOT |
| Invert corrosion and severe deterioration | 12 | Invert paving | MnDOT |
| Soil voids | N/A | Grouting voids | MnDOT |

[1] Refer to Table 1 for work recommendations.

## Joint Repair Techniques

Joint repairs depend on the diameter of the pipe. If the diameter of the pipe is 30 inches or less, grouting or lining (a rehabilitation strategy that is discussed later in the report) can be used. For diameters larger than 30 inches, joint repair methods including internal grouting, grouting sleeves, internal steel expansion ring gasket joint sealing systems, and lining methods, such as sliplining, are recommended. Small diameter culverts use robotic grouting techniques, and larger diameter culverts that allow for human entry for localized grouting techniques can be done by personnel. Caltrans and SCDOT's grouting techniques for joint repair are discussed below. Minnesota DOT (MnDOT) has a joint repair strategy, sealing with internal packers, that is also discussed as an option.

### California Department of Transportation (Caltrans)

Joint repair strategies depend on the type of issue, including misalignment, cracked, and separated joints. Misalignment usually happens due to settlement, and joint repairs are typically done after settlements are either completed or some other remediation is done to rectify the problematic soil conditions. Misalignment can also be the result of inadequate bedding during construction, and it can lead to infiltration and exfiltration of water and soil. To mitigate infiltration and exfiltration, cured-in-place lining (CIPP) or grouting are recommended. Grouting is the focus of this section as CIPP is considered a rehabilitation strategy and is discussed later in the document.

Chemical grouting is used to internally seal joints in structurally sound structures. This type of repair is not suitable for longitudinal or circumferential cracks or broken/crushed pipes. Materials used for chemical grouting include acrylamide gel, polyurethane foam, urethane gel, acrylic gel, and acrylate gel. Figure 1 shows a separation joint of an RCP that has been chemically grouted with polyurethane foam (Caltrans 2014).

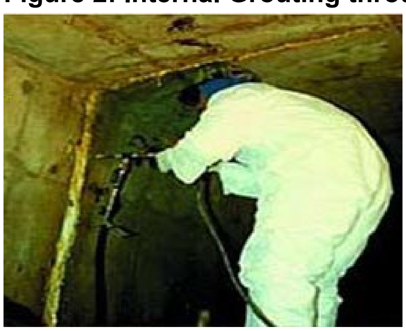
**Figure 1: Internal Side of a Chemically Grouted RCP**

*Source: Caltrans, 2014*

### South Carolina Department of Transportation (SCDOT)

Internal grouting with human entry involves filling internal cracks and joint voids using a specially formulated mix that aims to enhance the culvert's integrity and to minimize inflow and infiltration. This non-structural renewal method is suitable for larger-sized culverts, specifically those exceeding 30 inches in diameter (Figure 2). Traditional grout mixes use cement, while chemical grout finds widespread application for addressing leaking joints below the groundwater table. Traditional grout mixes involve the use of cement, while chemical grout, favored for treating leaking joints, encompasses several types of compounds. These chemical grouts effortlessly mix with water during application, ensuring excellent penetration into wet joints, cracks, and surrounding soils. They are available in various forms, including expanding polyurethane foam, which expands to fill the crack, gel, or in conjunction with a carrier medium such as oil-free oakum. (Peralta, et al. 2016).

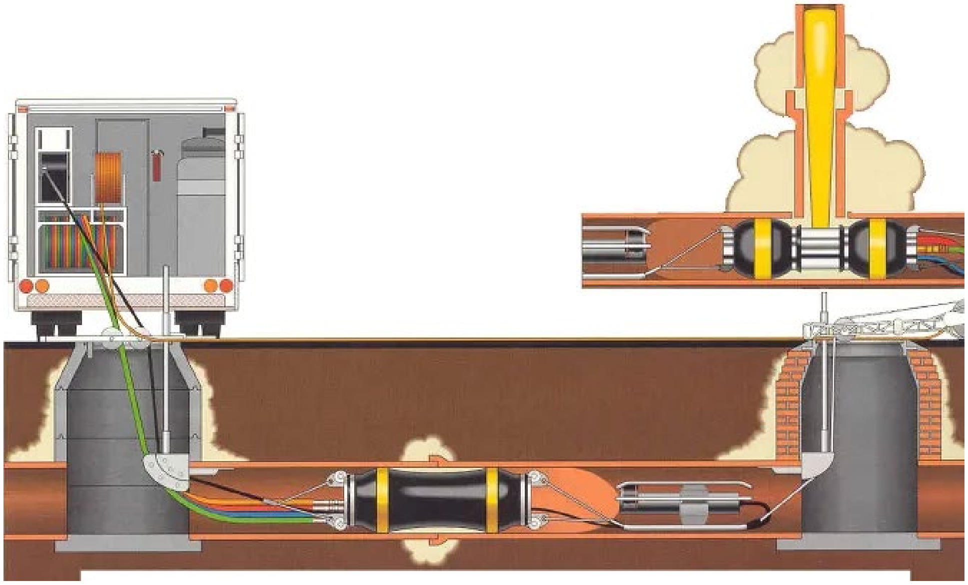
**Figure 2: Internal Grouting through Human Entry**



*Source: SCDOT, 2016*

Like internal grouting, robotic grouting is a non-structural renewal method. This technique involves pulling a sealing packer equipped with a closed-circuit television (CCTV) camera to the point of defect in small diameter culverts, less than 30 inches, using cables (Figure 3).

**Figure 3: Robotic Grouting**



*Source: SCDOT, 2016*

### Minnesota Department of Transportation (MnDOT)

Concrete culvert joints can be sealed with internal packers, which involves repairing culvert joints that are leaking and potentially depositing soil into the culvert. An internal packer is placed over the leaking joint and then inflated to allow chemical grout to be pumped into the joint. This method can be applied to culverts with pipes of diameters between 6 and 36 inches.

For CMPs, longitudinal seams that have defects may require structural strengthening. Structural members are placed over the weakened seams and welded into place (Wagener & Leagjeld 2014).

## Spall Repair Techniques

Spalling is a type of distress found in concrete structures where the concrete breaks down into smaller fragments. Spalling can be the result of multiple factors, such as quality of concrete, corrosion, freeze-thaw cycle wear and tear, and construction overloading or post-construction loading. The following are Caltrans and MnDOT's repair methods for spalling.

### California Department of Transportation (Caltrans)

Spalling from construction overloading is repaired by cleaning the area around the spall and applying a mortar patch. Cracks from spalling should be filled with grout. For crack widths over 0.01 inches, the width of the crack should be widened to a depth of 0.5 inches and then filled with grout. Post-construction loading that produces cracks is a significant issue, and Caltrans recommends reducing the load and replacing the pipe with a new one.

If reinforcing steel is corroding, the cause of the corrosion should be identified. If the corrosion's source is from the interior side of the culvert, the spall should be chipped back, the steel should be sandblasted to remove the rust, and a patch of mortar applied. In highly acidic environments, various coatings may be applied, or full-length sliplining (which is considered a rehabilitation measure and is discussed later in this report) may be required. If the source of corrosion is coming from the interior and exterior of the culvert, the interior side should be patched, and the culvert should be monitored to identify the rate of degradation (Caltrans 2014).

**Minnesota Department of Transportation (MnDOT)**

MnDOT's intervention for spalling aims at stopping further deterioration. The smallest diameter feasible for this intervention is 36 inches, as personnel must enter the barrel to perform the repair. First, the spalling concrete is removed. Then the surface should be prepared by establishing a surface profile by creating a roughness of 1/8 inches and cleaned. Lastly, repair mortars containing admixtures, such as epoxy, should be placed smooth and level with the surface (Wagener & Leagjeld 2014).

**Spot Repair Techniques**

Shotcreting can be a repair or rehabilitation technique depending on the magnitude of repair needed. MDOT has some form of shotcreting techniques, but these techniques were not found in standards for culverts, so shotcreting is included in this document as an industry best practice. MnDOT employs internal shotcreting through human entry and robotic shotcreting, which is similar to grouting techniques. These are explained below.

**South Carolina Department of Transportation (SCDOT)**

Internal shotcreting involves manually spraying concrete at a high velocity through a pneumatic hose to fix surface issues in large diameter RCP and CMP culverts (Peralta, et al. 2016). This method can be applied as either a non-structural or semi-structural renewal technique, as indicated by the Portland Cement Association (PCA 2015). Figure 4 shows human entry shotcreting.

**Figure 4: Internal Shotcreting through Human Entry**

*Source: SCDOT, 2016*

Robotic shotcreting involves the movement of a remote-controlled robot on a track that is equipped with CCTV cameras and a rotary applicator to enable the flow of concrete to the point of defect in the culvert (Figure 5). Robotic shotcreting can be used as either a non-structural or semi-structural renewal method.

**Figure 5: Robotic Shotcreting**

*Source: SCDOT, 2016*

## Other Repair Techniques

### National Cooperative Highway Research Program (NCHRP)

NCHRP guidance document dated 2010 (Allouche, et al. 2010) describes spot repair strategies, including mechanical repair sleeves. Mechanical repair sleeves are prefabricated stainless steel or polyvinyl chloride (PVC) sleeves that are inserted inside the pipe while folded, then expanded into shape using jacking (snapping) mechanisms (Figure 6). Grout is applied to fill the annular space between the sleeve and the pipe. These sleeves provide structural repair to damaged pipes and can restore missing sections without the need for excavation, simultaneously sealing joints against infiltration. The method is particularly effective in re-rounding distorted sections of CMPs.

Mechanical repair sleeves are available in different diameters and standard lengths, including 18, 24, or 36 inches. Sleeves are made of either stainless steel or rigid PVC. When flexibility needs to be retained in the repaired pipe, polyurethane grout is used to fill the annular space between the sleeve and the host pipe. For situations where joint flexibility is not necessary, cementitious grout provides a more economical alternative. PVC sleeves are suitable for human-entry culvert pipes with diameters ranging from 36 to 108 inches, and they can accommodate circular and non-circular pipes, such as teardrop, horseshoe, and oval designs. The rigid PVC sleeves can be adapted to most culvert designs, except for box culverts. However, stainless steel sleeves are applied in pipes ranging from 6 to 54 inches.

Mechanical repair sleeves offer a quick and straightforward structural repair without the need for excavation or expensive equipment. Setup and installation are efficient, requiring only a small, easily trained crew of three people.

**Figure 6: Mechanical Repair Sleeve: PVC Sleeve (left), Two Hydraulic Jacks to Expand Sleeve (middle), and Annular Space Grouting (right)**


*Source: NCHRP, 2010*

Case Histories are as follows:

- In Atlanta, Georgia, a 60-foot long, 47-inch diameter corrugated metal culvert underwent repair with a PVC sleeve measuring 45.5 inches in diameter in 2007.
- In Pentagon City, Virginia, a damaged high-density polyethylene (HDPE) culvert was repaired using a mechanical PVC repair sleeve.

**Minnesota Department of Transportation (MnDOT)**

MnDOT resources contained other preventative maintenance strategies, including:

- Invert Plating
- Spray-on Coatings and Linings
- Slab-Jacking
- Compaction Grouting
- Grout Applications for Voids

Invert plating involves welding plates made of steel, fiberglass, or other materials over deteriorated culvert inverts. This intervention is generally applied for culverts that have invert abrasion. Invert abrasion can happen from rough debris in the culvert flow. Plating is performed in culverts of large diameters where personnel can enter the culvert.

Spray-on coatings and linings can be applied to culverts at initial stages of deterioration to extend the service life of the culvert. This application aims to limit corrosion and deterioration. Sprayed coatings and linings are explained further under rehabilitation strategies.

Slab-jacking raises pavement sections that have dropped from ground loss around an existing culvert. This is achieved by either coring or drilling holes under pressure and placing a cementitious-based material in the drilled holes. The application of this material aims to fill voids and re-establish support for the pavement section.

Compaction grouting fills voids and re-compacts the ground that has loosened due to ground loss. The placement of low slump, low mobility soil or cement grout is inserted into the ground to establish support for the culvert.

Voids outside of a culvert that are identified during routine inspections can develop from invert erosion, corrosion, or piping. Piping occurs due to water runoff outside of the culvert that carries away parts of the soil envelope surrounding the pipe (erosion). The resulting voids can be filled with cementitious grout or foaming urethane grouts. Grout can be applied through three different measures: gravity flow above the void, grouting through a tremie pipe or tube, or pressure grouting.

The first technique, gravity flow, is the process by which the grout is applied above the void. The second technique is used when there is an issue with air entrapment in the grout. The grout is injected into the void through a tremie pipe where it fills the void from the bottom up. The third technique is suitable for culverts of any size because grout application can be applied inside or outside the culvert. Joints are filled behind the sidewalls of the pipe. If the joint is behind an open joint, the interior of the joint will need to be sealed, usually with a concrete mortar or a joint sealing system. Grout tubes are installed at the top and the bottom of the joint or void, and grout is pumped into the lower tube, air or water will flow out of the upper tube, and pure “watery” grout will flow out of the upper tube (Wagener & Leagjeld 2014).

**California Department of Transportation (Caltrans)**

Slabbing is a radial failure of concrete due to the straightening of the reinforcement cage, which breaks the concrete cover, causing spalling. Caltrans performs slabbing repair for reinforced concrete culverts by coating reinforcing steel for corrosion protection, cleaning the area around the damage and removing rust, or a combination of both. In highly acidic environments, the repair may be the application of various coatings or full-length sliplining. Full-length sliplining is a rehabilitation measure and discussed in Section 4.2.8. Other repairs may be done for slabbing depending on the root cause of the damage (Caltrans 2014).

Table 3 summarizes the preventative maintenance industry best practices for deficiencies and the existing practices MDOT uses for these types of repairs.

## 4.2 Rehabilitation Strategies

If localized repair options are not adequate to maintain the culvert in safe and stable condition, then MDOT should examine rehabilitation options. The following are industry best practices. Table 3 below is a summary of best practices for rehabilitation options discussed in the text.

**Table 3: Summary Table of Industry Best Practices – Rehabilitation Maintenance**

| Deficiency | Existing Work Rec.[1] | Best Practices/ Other Options | Associated Entity |
|---|---|---|---|
| Corrosion and culvert deterioration | 13 | Spirally Wound Liner | NCHRP, SCDOT, FHWA, MnDOT |
| Joint misalignment, infiltration, and defects; invert deterioration; structural damage; concrete surface spalling; cracks; or deformation | 13 | Fold and Form Liner | NCHRP, SCDOT, Caltrans |
| Deformation of the culvert cross-section | 13 | Deform-Reform Liner | NCHRP, SCDOT |
| Joint misalignment, infiltration, and defects; invert deterioration; cracking; insufficient flow capacity; corrosion and abrasion; leaks; concrete surface spalling; or degradation | 13 | Cured-In-Place Pipe (CIPP) Liner | NCHRP, MnDOT, Caltrans, WisDOT |
| Loss of structural integrity due to material degradation | 13 | Centrifugally Cast Liner (Spincast Liner) | NCHRP, SCDOT, WisDOT, MnDOT |
| Surface deterioration; erosion; corrosion; or abrasion | 13 | Sprayed-on Liners | NCHRP, WisDOT, CALTRANS, Ohio DOT |
| Invert corrosion and severe deterioration | 13 | Invert Paving | WisDOT, MnDOT, Caltrans |
| Joint misalignment, infiltration, and defects; cracks; corrosion and abrasion; or concrete surface spalling up to full deterioration | 13 | Sliplining | MnDOT, Caltrans, WisDOT, FHWA, Ohio DOT |

| Deficiency | Existing Work Rec.[1] | Best Practices/ Other Options | Associated Entity |
|---|---|---|---|
| Culvert pipe deterioration (up to full deterioration) | 13 | Close-Fit Liners | MnDOT |
| Culvert pipe internal surface deterioration | 13 | Shotcrete Liners | MnDOT |

[1] *Refer to Table 1 for work recommendations.*

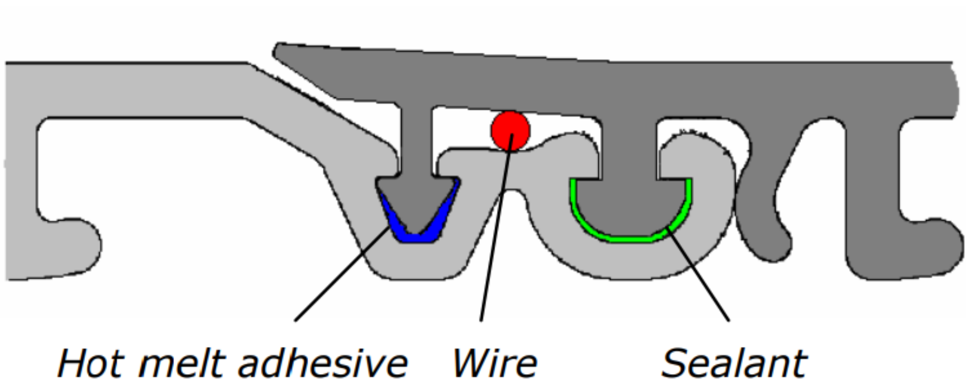
### *4.2.1 Spirally Wound Liner*

**National Cooperative Highway Research Program (NCHRP)**

The NCHRP *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption* (2010) outlines the spirally wound liners strategy.

Spirally wound liners are constructed on-site using a continuous thermoplastic strip that is characterized by one male and one female edge. As the helical winding process takes place, the male and female edges naturally self-interlock, creating a joint that is impervious to leaks (Figure 7). The strips used for the winding process can be crafted from either PVC or HDPE. The PVC strip can be manufactured with steel reinforcement. However, this practice is generally employed for larger diameter liners, typically those with a diameter of 30 inches or more. Federal Highway Administration (FHWA) (2010) mentioned that while joints are interlocked, a sealant is applied to create a tight seam, as seen in Figure 7. The spirally wound liner features a smooth-lined interior.

**Figure 7: Spirally Wound Liner: Self-Interlocking of Male and Female Edges During Spiral Winding**




*Source: NCHRP, 2010*

Spiral winding is classified as either stationary or mobile. In the stationary method, the winding machine is positioned at one end of the culvert. While in the mobile approach, a circular machine with hydraulic rams moves along the pipe's length (Figure **8**). Spiral winding is suitable for rehabilitating circular pipes with diameters ranging from 6 to 180 inches. The maximum drive length, which is subject to project specifics, is typically limited to 650 feet. Installation can be carried out in live-flow conditions.

**Figure 8: Spirally Wound Liner: Stationary (left) and Mobile (right) Winding Machines**

*Source: NCHRP, 2010*

Tightly-fitted liners (expandable diameter liners) typically do not require grouting unless specific conditions are met, such as the presence of extensive sections of missing pipe or significant offset of joints in the host culvert pipe. When grouting is required, it can be accomplished through pipes installed from the surface before liner winding, drilled through the installed liner, or via grouting through the bulkhead (Figure 9). According to NCHRP (2010), the standards ASTM F1697 and ASTM F1735 outline the specifications and testing procedures for materials, dimensions, workmanship, stiffness factor, extrusion quality, and a form of marking for extruded PVC profile strips used in the automated production of spirally wound pipe liners. ASTM F1697 provides tables for two different profile strip dimensions showing waterway wall thickness ranging from 0.040 inch to 0.15 inch, representing typical thickness of this type of liner.

**Figure 9: Spirally Wound Liner: Surface Grouting (left), Grouting Through Liner (middle) and Grouting Through Bulkhead (right)**

*Source: NCHRP, 2010*

Spiral winding presents key advantages, such as excavation elimination and quick and quiet installation, and it can efficiently handle bends and diameter changes. It is environmentally friendly, as it avoids chemical processes and potential contamination. The method is exclusive to circular pipes, which can be a limitation of this method.

Case Histories are as follows:

- Virginia DOT employed spiral winding for two 60-inch CMP culverts, each 60 feet long, with significant joint offsets.
- Caltrans successfully used spiral winding to repair two culverts under an existing highway. These RCPs, measuring 18 inches and 30 inches in diameter with a total length of 230 feet, were broken, leaking, and causing sags in the freeway pavement above them. The 18-inch culvert had a significant 8-inch hole expelling water with the force of a 15-foot water head. Spiral winding effectively spanned the hole and sealed the leak.
- Caltrans applied spiral winding in other culverts, such as a 24-inch culvert made of ribbed plastic that was approximately 200 feet long.
- Caltrans used spiral winding to rehabilitate a deteriorated 36-inch CMP, effectively addressing rusted invert and eroded bedding soil issues. Due to the deformations in the host pipe, the installation used a 30-inch fixed diameter liner.

### South Carolina Department of Transportation (SCDOT)

SCDOT *Best Practices for Assessing Culvert Health and Determining Appropriate Rehabilitation Methods: A Research Project in Support of Operational Requirements for the South Carolina Department of Transportation* (2016) references a spiral-wound lining strategy (Figure 10). In this strategy, the winding machine moves along the culvert, creating a semi-structural or fully structural liner that is leak-tight. This method is particularly well-suited for non-circular host culverts with limited access constraints, and it is applicable for different culvert shapes and tight curves. It does not require access pits.

**Figure 10: Spiral-wound Lining**

*Source: Trenchlesspedia, 2023*

### California Department of Transportation (Caltrans)

Caltrans *Design Information Bulletin 83.04 Caltrans Supplement to FHWA Culvert Repair and Practices Manual* (2014) references the spirally wound liners strategy. Caltrans' name for this technique is "lining with machine-wound plastic liner."

Lining culverts with machine-wound plastic liner is a method used to address corrosion, infiltration, or exfiltration. This method is not recommended in for culverts that have flows with debris and other materials that could cause abrasion. It involves inserting a machine-made, field-fabricated spirally wound PVC liner into the host pipe (can be either flexible or rigid). It is reported that this is most appropriate for pipes with diameters of 60 inches or less. In some cases, it can reach 120 inches if approved by the state.

After inserting the liner, one of the following techniques can be applied to it:

- Inserting a fixed diameter liner then expanding it against the interior of the existing pipe.
- Inserting a liner that is fixed in terms of dimensions into the host pipe without expansion, then grouting the annular space between the liner and the host pipe.
- Winding the liner against the walls of the host pipe by a machine that goes down the pipe.

The expanding system is used for smaller diameter pipes (i.e., 42 inches or smaller). The advantages of this method include a smaller construction footprint than sliplining, no need to grout for smaller diameters (i.e., 30 inches or less), and can be used in multiple shapes.

### *4.2.2 Fold-and Form-Liner*

**National Cooperative Highway Research Program (NCHRP)**

NCHRP document dated (2010) references the fold-and-form liner strategy.

Fold-and-form liners are PVC-based products that is delivered to the site in a flattened state, either as a "U" or "C" shape, before it is inserted into the host pipe (Figure 11, left). Alternatively, they can be folded into a "C" shape and coiled on large vertical drums. Some manufacturers produce liners in an "H" shape for sizes 15 inches and larger (Figure 11, right). The liner is drawn through the pipe, allowing it to extend beyond both ends of the host pipe (Figure 12, left). Once pulled into the culvert, the liner is re-rounded using steam and air pressure (Figure 12, right).

Liner thickness is determined based on the ASTM F1871 and ASTM F1504 in accordance with the applicable section of Test Method D2122 (Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings). According to NCHRP (2010), the standards ASTM F1871 and ASTM F1504 outline the specifications and testing procedures for materials, dimensions, workmanship, flattening resistance, impact resistance, pipe stiffness, extrusion quality, and a form of marking for folded PVC pipe for existing sewer and conduit rehabilitation. ASTM F1871 provides table for minimum wall thickness of formed pipe, ranging from 0.123 inch to 0.576 inch. ASTM F1504 provides table for minimum wall thickness of rounded pipe, ranging from 0.114 inch to 0.429 inch.

**Figure 11: Fold-and-Form Liner: Common Shapes of Folded PVC Liners - Flat (left) and "H" Shapes (right)**

*Source: NCHRP, 2010*

**Figure 12: Fold-and-Form Liner: Liner Protruding (left) and Steam Pressure to Re-round PVC Liner (right)**

*Source: NCHRP, 2010*

Case Histories explained in the NCHRP (2010) are as follows:

- The Georgia DOT (GDOT) successfully used fold-and-form liners in 2001 to rehabilitate seven deteriorated CMPs ranging from 15 to 30 inches in diameter and 40 to 80 feet in length, eliminating the need for excavation or chemical applications. GDOT used this method to rehabilitate 88 pipes, with lengths averaging about 50 feet and diameters ranging from 15 to 24 inches, by 2003. Additionally, according to the new product evaluation status report published by the GDOT in late 2023, the field test of the PVC Fold & Form Liner, manufactured by Dyna Liner, Inc., has been completed. It complies with ASTM F 1871-20, is specifically designed for the trenchless rehabilitation of sanitary, stormwater, and culvert systems. This thermoformed PVC liner undergoes a process where steam is utilized to heat and shape it, followed by cooling with air. Notably, it is styrene-free, and no VOCs (volatile organic compounds) are emitted during or after the installation process.

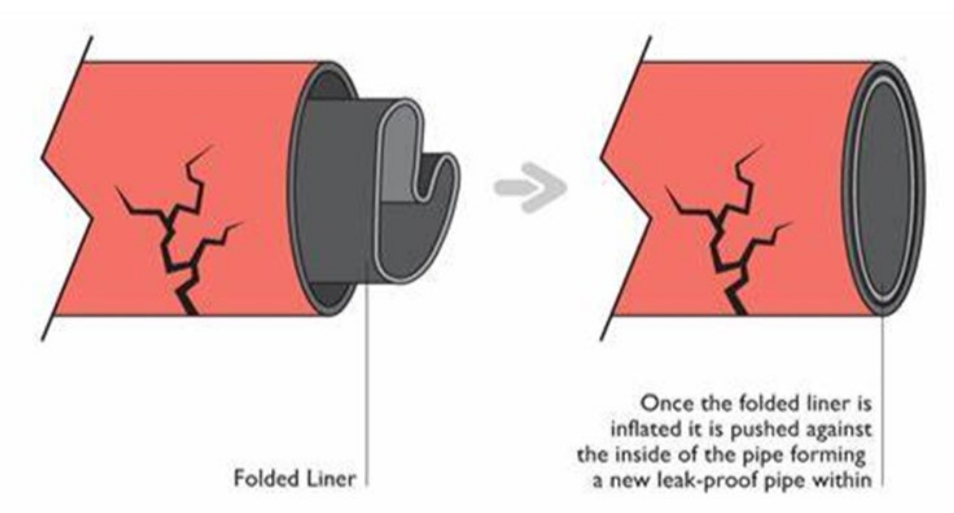
- The Kansas Turnpike Authority employed fold-and-form relining in 2008 to repair two corroded 32-inch diameter CMPs. They were approximately 70 feet long each, showed severe corrosion with approximately 40% metal loss at the invert, and they showed preliminary signs of buckling failure.
- City of Atlantic Beach, Florida used fold-and-form relining to repair an 18" x 29" elliptical CMP culvert that was 50 feet long, preventing its collapse. A 24-inch PVC liner, 0.75 inches thick, was employed.
- Jacksonville, Naval Air Station, Florida rehabilitated 12 RCP culverts (2,042 feet total length) between 6 and 30 inches in diameter using fold-and-form liners. A 0.5-inch-thick PVC liner was used for culverts smaller than 15 inches, while a 0.75-inch-thick liner was used for 15 inch and larger diameters.

### South Carolina Department of Transportation (SCDOT)

The SCDOT *Best Practices for Assessing Culvert Health and Determining Appropriate Rehabilitation Methods: A Research Project in Support of Operational Requirements for the South Carolina Department of Transportation* (2016) outlines the fold-and-form lining strategy.

The fold-and-form lining method involves the insertion of a folded liner, typically made of HDPE or PVC pipe, into the host culvert pipe. Subsequently, the liner is reshaped to its original form by applying hot water or steam, ensuring a snug fit within the host culvert (Figure 13). Once the liner has been reformed, it is cooled to maintain its shape, which results in a semi-structural renewal of a deteriorated culvert. This technique does not need grouting and is flexible enough to negotiate bends when necessary. Its limitations include toxic resins that can infiltrate flow, host culvert size and shape, and additional equipment that folds the pipe is required.

**Figure 13: Fold-and-Form Lining**




*Source: PUB, Singapore's National Water Agency, 2023*

### California Department of Transportation (Caltrans)

The Caltrans *Design Information Bulletin 83.04 Caltrans Supplement to FHWA Culvert Repair and Practices Manual* (2014) outlines the folded and re-formed PVC liner strategy.

Lining with folded and re-formed PVC liner involves the insertion of a continuously extruded, folded PVC liner into the host pipe. After that, the new pipe is reformed to adapt to the shape of the host pipe. This is achieved without excavation. Back when the bulletin was originally published, there was uncertainty about the durability and abrasion resistance of PVC compounds of this type. Also, the use of this intervention was limited to pipes with diameters of 24 inches or less. The liners are made of PVC compounds that are modified from those used in PVC pipes, and they are used for direct burial (e.g., standard ribbed PVC pipes).

### 4.2.3 Deform-Reform Liner

**National Cooperative Highway Research Program (NCHRP)**

The NCHRP's *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption* (2010) outlines the deform-reform liners strategy.

Deform-reform liners are HDPE pipes that are initially manufactured in a round shape with their memory set to remain round through cooling. Then, they undergo reheating with warm water, below the manufacturing temperature, and are deformed into a "U" shape using a former or a "heart" shape (Figure 14, left). This deformed shape is temporarily maintained by a sleeve or plastic bands (Figure 14, middle). Following the folding process, the pipe is coiled on large vertical drums for transportation to the job site (Figure 14, right). The flexible liner is unwound from the coil and pulled into the host pipe using a winching mechanism (Figure 15, left). Once pulled into the culvert, the liner is re-rounded by applying pressure to release the bands, allowing it to revert to its original shape (Figure 15, right). This re-rounding process can use pressurized steam, a combination of steam-generated temperature and pressure, or hot water. The installation cannot be performed in live flow conditions. Liner thickness is determined based on the ASTM F1533, covering requirements and test methods for deformed polyethylene (PE) liner for the rehabilitation of gravity flow and non-pressure pipelines.

**Figure 14: Deform-Reform Liner: "Heart" Shape of Folded HDPE Liner (left), Plastic Bands to Maintain the Shape (middle), and Coiled Pipe to Transport (right)**


*Source: NCHRP, 2010*

**Figure 15: Deform-Reform Liner: Winching Liner (left) and Steam Pressure to Re-round HDPE Liner (right)**

*Source: NCHRP, 2010*

Case Histories are as follows:

- Caltrans opted for deform-reform relining to rehabilitate an 18-inch diameter corrugated steel culvert/pipe (CSP) under a highway. The culvert was badly deteriorated and exhibited complete rusting at the bottom in multiple areas.
- Caltrans further utilized deform-reform relining to rehabilitate approximately 5,000 feet of culverts at various locations under Interstate 80 near Lake Tahoe, and under Interstate 5, with culvert diameters ranging from 18 inches to 56 inches.
- Oregon DOT successfully rehabilitated a 100-foot-long, 18-inch-wide, unreinforced concrete pipe (UCP) culvert using deform-reform relining.

Fold-and-form and deform-reform relining methods offer efficient culvert rehabilitation without excavation or grouting. They create a seamless, jointless product with a minimum 50-year service life, and they are installed quickly with minimal traffic disruption. The manufacturing process is controlled, using no hazardous chemicals, and materials require no refrigeration during transportation or storage. While the methods are diameter-limited (up to 30 inches) and require flow bypassing, they minimally reduce the pipe's cross-sectional area. The installation length is typically not an issue in culvert rehabilitation, but chemical grouting may be needed at the liner ends.

### *4.2.4 Cured-in-Place Pipe (CIPP) Liner*

**National Cooperative Highway Research Program (NCHRP)**

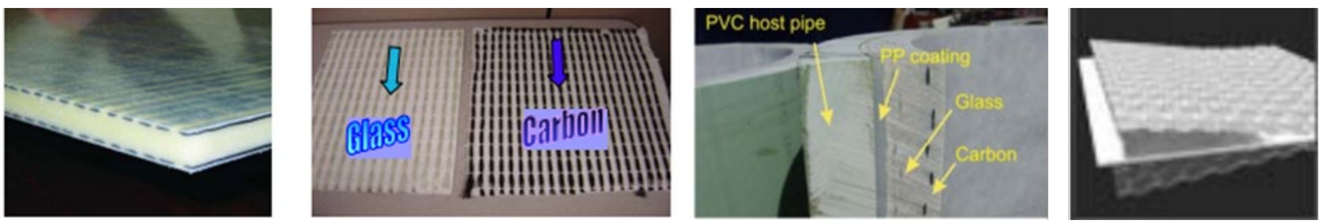
The NCHRP’s *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption* (2010) outlines the composite cured-in-place pipe (CIPP) liners strategy.

Composite cured-in-place pipe liners are constructed with high-strength fiber reinforcement, providing enhanced stiffness and strength. This results in thinner liner walls compared to traditional CIPP liners. These composite liners are specifically employed for the rehabilitation of medium to large culverts. They are cured at ambient or elevated temperature (via steam or hot water) or via UV-light.

One type of composite CIPP liner employs a tube made from conventional felt material that is sandwiched between layers that are reinforced with carbon and/or glass fiber (Figure 16, left). The reinforced layers are manufactured by stitching carbon or glass fiber tows onto thin layers of felt

(Figure 16, middle-left). Typically, glass is the preferred material for both layers in composite CIPP, while carbon is used for higher stiffness or in industrial settings requiring increased corrosion resistance. Additionally, a thermoplastic coating, such as polypropylene (PP), is applied to the tube for corrosion protection. The resin used is a standard isophthalic polyester resin. An illustrative example of the composite CIPP liner installed in a PVC pipe (Figure 16, middle-right) includes the following layers: PVC pipe, PP seam "tape" (the outer coated layer), a thin layer of standard felt, a glass fiber-reinforced layer, standard felt "core layers," a carbon fiber-reinforced layer, and a standard PP coated layer. The liner's total wall thickness is 14.0 mm (about 0.55 inches). Another type of composite CIPP liner uses a non-porous inner membrane that is positioned between two layers of structural fiberglass (Figure 16, right) and is securely bonded to them. The bonding of the inner membrane to the surrounding fiberglass layers is facilitated by felt fibers, and epoxy resin is used during the installation process.

**Figure 16: Composite CIPP: Sandwiched Tube (left), Glass and Carbon Fibers (middle-left), Cross-section of Composite CIPP Liner (middle-right), and Three-layer System with a Fiberglass Layer + Non-porous Felt/PVC Membrane + Fiberglass Layer (right)**




*Source: NCHRP, 2010*

Case Histories are as follows:

- The Texas DOT used a composite CIPP liner to reline a 660-foot-long, 48-inch diameter CMP in Dallas in 2007, with a total installed liner thickness of about 0.73 inches.
- The Vermont Agency of Transportation (VTrans) employed a composite CIPP liner to rehabilitate a 145-foot-long, 66-inch diameter CMP, achieving a total installed liner thickness of about 0.85 inches in 2008.
- The Florida DOT successfully rehabilitated a 70-foot-long, 30-inch diameter corrugated metal culvert under U.S. 98 in 2009.
- The City of Sylvester, Georgia, used a composite CIPP liner to rehabilitate a 24” x 72” double CMP under a busy highway, employing a liner that was pulled in place and cured with steam pressure.

**Minnesota Department of Transportation (MnDOT**)

MnDOT's *Culvert Repair Best Practices, Specifications, and Special Provisions: Best Practices Guidelines* (2014) outlines the CIPP liners strategy.

The most common resin types used are polyester and vinyl ester. Other applicable resins, which may be used for special projects and conditions, include epoxy. Pipes with diameters of 3 inches to over 96 inches were rehabilitated by the CIPP.

Similar to sliplining, this intervention can be used with culverts losing structural characteristics, up to fully deteriorated culverts (MnDOT 2014). However, the soil should be structurally sound, as otherwise replacement might be warranted.

**California Department of Transportation (Caltrans)**

Caltrans' *Design Information Bulletin 83.04 Caltrans Supplement to FHWA Culvert Repair and Practices Manual* (2014) outlines the CIPP liners strategy for concrete and metal pipes.

CIPP lining is a method used to reline culverts using the phenomenon of thermosetting or UV curing, resin impregnated flexible felt, or a tube of fiberglass. There is no standardization for the liner size, as these liners are designed and fabricated for the individual pipe to be rehabilitated in terms of size and shape. Candidates for this intervention includes concrete culverts subject to sulfate attacks and metal pipes in need of rehabilitation where reduction in pipe size is not feasible.

This rehabilitation method has historically been common for smaller-size pipes (less than 48 inches in diameter). There are culverts that are more than 400-feet long that have been CIPP-lined. The allowable length of the rehabilitated pipe varies by diameter.

If the method used for installation is inversion, a pre-liner is needed. Polyester resin is commonly used in CIPP, which does not stick to moist surfaces. As such, the pre-liner acts as a barrier and mold to things like open joints, damaged pipes, etc. Where a pre-liner is used, the liner consists of reinforced layers of non-woven, needled polyester fiber felt approximately 0.12-inch in thickness. These layers are formed into a seamed tube of the diameter required for the job. An inner membrane of impermeable plastic (polyethylene) is included. The plastic membrane keeps water or steam separate from the resin-impregnated felt during curing. When using the three resin types: epoxy, polyester, and vinyl ester, no grout is needed.

Caltrans allows American Society for Testing and Materials' (ASTM) F2019 specification, *Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Pulled in Place Installation of Glass Reinforced Plastic Cured-in-Place* (GRP-CIPP) *Using the UV-Light Curing Method*, for pulled-in-place installation of fiberglass and felt composite tubes, which can be cured by UV rays. In the case of pulled-in-place installation, Caltrans requires an impermeable inner layer and a sandwich-like combination of two liners, in which plastic is used on the inside and outside. This can be achieved using an inflatable bladder calibration hose.

### *4.2.5 Centrifugally Cast Concrete Pipe Liner (Spincast Liner)*

**South Carolina Department of Transportation (SCDOT)**

SCDOT's *Best Practices for Assessing Culvert Health and Determining Appropriate Rehabilitation Methods: A Research Project in Support of Operational Requirements for the South Carolina Department of Transportation* (2016) outlines the centrifugally cast concrete pipe (CCCP) lining strategy.

The process of CCCP lining, also referred to as a spincast liner, involves the use of a spincaster to apply thin layers of fiber-reinforced cementitious material onto the inner surface of a pipeline (Figure 17). This application creates a waterproof layer that significantly enhances the structural integrity of the pipe, tightly adhering to the original structure. The fiber-reinforced cement mortar, or Permacast mortar, serves the dual purpose of preventing corrosion and minimizing abrasion. The thickness of the coating is typically determined by specific engineering requirements and the need for structural support. CCCP is suitable to be applied to the host culvert with major corrosion, joint in/exfiltration, and invert deterioration. In comparison to the rehabilitation time required for a CIPP lining, this method is known for its shorter time frame and for providing lasting protection. However, it is essential to note that this technique is not suitable for application in temperatures below 45°F.

**Figure 17: Centrifugally Cast Concrete Pipe Lining**

*Source: SCDOT, 2016*

**Wisconsin Department of Transportation (WisDOT)**

WisDOT's *Facilities Development Manual: Chapter 13 Drainage* (2023) outlines the CCCP liners strategy.

WisDOT uses cementitious mortar or other materials centrifugally cast into a pipe's interior. The use is limited by WisDOT to pipes less than 48 inches in diameter unless additional reinforcement is provided, and where the strength of the pipe is not questionable. Some cementitious mortar systems involve fibers to enhance flexural strength. Non-cementitious systems are used when watertightness and corrosion resistance are favorable. Multiple passes might be warranted to arrive at the desired thickness.

**Minnesota Department of Transportation (MnDOT)**

MnDOT's *Culvert Repair Best Practices, Specifications, and Special Provisions: Best Practices Guidelines* (2014) outlines the CCCP liners strategy.

CCCP liners are applied by a rotating head that is either electric or air-powered (Figure 18). The liner is made of cementitious mortar or other materials as mentioned in other DOT applications. This is suitable for culverts with diameters of 30 up to 120 inches. This type of liner is usually applied to CSP culverts to improve their structural capacity and protect them from corrosion.

**Figure 18: Installation of Centrifugally Cast Liner**

*Source: Betcher, 2010*

### National Cooperative Highway Research Program (NCHRP)

NCHRP *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption* (2010) outlines the cement mortar lining by spincasting strategy.

In some centrifugal casting systems, additional trowelling or surfacing may not be necessary. For small diameter pipes, the equipment is remotely operated (Figure 19). For large diameter pipes, an operator can enter the pipe to control the mortar flow, travel speed, and rotation speed of the lining machine head (Figure 19). The centrifugal casting device moving through the pipe evenly applies a continuous, thin layer of cement mortar (typically ranging from 0.25 in. to 0.5 in. thick, and up to 2 in. thick when multiple layers are applied) onto the interior of a deteriorated culvert pipe.

**Figure 19: Spincast System Applies Material to Pipe Walls Using Centrifugal Force for Small Diameter Pipes (left) and for Large Diameter Pipes (right)**

*Source: NCHRP, 2010*

### 4.2.6 Sprayed-on Liners

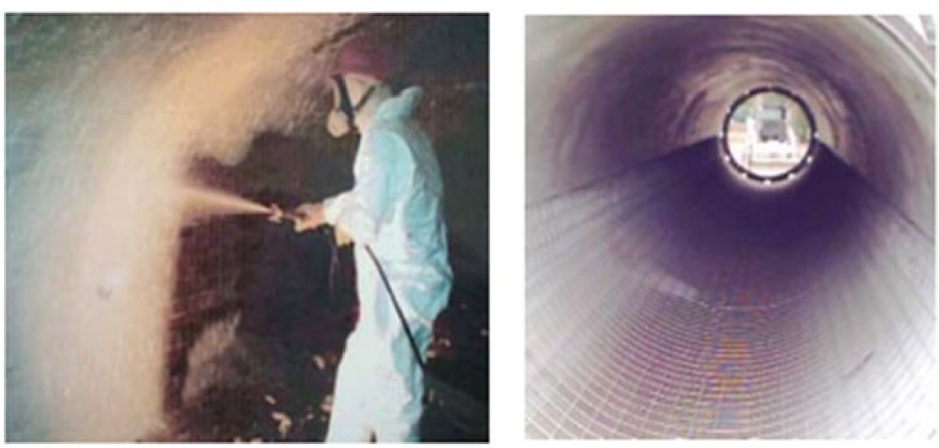
**National Cooperative Highway Research Program (NCHRP)**

NCHRP's *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption* (2010) outlines the sprayed-on liner strategy. NCHRP calls sprayed-on liner cementitious liner using the shotcreting technique. Shotcreting can be a repair method for a spot or a rehabilitation technique when used as liner. The liner method is described below.

*Cementitious Liner*

Cement mortar or concrete is pneumatically applied to the structure's surface at a high velocity, also called shotcreting (Figure 20, left). This process can be either wet mix (all ingredients, including water, are pre-mixed before introduction) or dry mix, known as gunite, (ingredients, excluding water, are mixed and fed into the delivery equipment with water added at the nozzle). The choice between the use of wet or dry mix is based on factors like project size, application rate, dust production, rebound, and required pumping length. Another technique, wire mesh reinforced cement mortar lining (Figure 20, right), involves applying two layers of cement mortar that is separated by a wire mesh. The first layer (0.5 inches thick) is conventionally applied using gunite, and the second layer (0.5 inches thick) is applied with a trowel over the wire mesh. The wire mesh helps provide support and prevent chips, cracks, and other problems from happening. This application can be used for culverts with cracks, spalling, and other forms of distress.

**Figure 20: Sprayed-on Liners: Spray Gun Application (left) and Wire Mesh Installation (right)**



*Source: NCHRP (2010)*

Various shotcrete materials are used for rehabilitation, including conventional and specialty types. Conventional shotcrete consists of Portland cement, aggregates, and chemical admixtures. Gunite, which is a type of shotcrete, is made from one part Portland cement and four parts sand. Specialty shotcretes may include polymer modifiers to inhibit corrosion and enhance chemical resistance.

Shotcrete can be reinforced with fibers, such as steel, glass, or synthetic fibers, to improve ductility, energy absorption, and impact resistance. The choice of shotcrete and fiber types depends on specific project requirements, with each type offering distinct benefits:

- Steel-fiber-reinforced shotcrete (SFRS) involves pneumatically projecting steel fibers onto a surface. Steel fibers can reduce or eliminate cracking.

- Glass-fiber-reinforced shotcrete (GFRS) improves flexural, tensile, and impact strength. Glass fibers enhance strength.
- Polypropylene-fiber-reinforced shotcrete (PFRS) uses polypropylene fibers to enhance strain capacity, toughness, impact resistance, and crack control. Polypropylene fibers control cracking and increase toughness.

The application methods, fiber lengths, and proportions vary, influencing the properties and performance of the shotcrete. The spray-up method for GFRS involves spraying a fluid concrete mixture and long fibers onto a form surface, creating large, lightweight panels. PFRS is known for its high-compressive strength, acid and abrasion resistance, and impermeability compared to ordinary concrete.

The spray-on shotcrete method is suitable for circular pipes with diameters ranging from 12 to 140 inches. However, it is specifically applicable in human-entry pipes. The maximum installation length varies, with about 650 feet feasible in robotic applications and approximately 50 to 60 feet in human-entry applications due to practical considerations and safety regulations. Although the corrugation in the pipe do not prevent the use of shotcrete, the pipe must be entirely empty, with no live flow conditions, and cleaned for the method to be effective.

Cementitious lining offers several advantages, including corrosion and abrasion protection, restoration of flow capacity, and structural repair potential with adequate material thickness — all without the need for excavation. However, the method has limitations, such as a relatively long setting time and slow strength gain for the installed liner. Additionally, the culvert must be entirely free of water, flow bypass may be necessary, and extensive surface preparation is typically required.

Case Histories are as follows:

- WisDOT relined 9,000 feet of 60-inch pipe with 0.5-inch-thick shotcrete using FRS.
- Colorado DOT relined a 36-inch diameter, 110-foot-long culvert in under two hours.
- Colorado DOT relined two 96-inch diameter, 85-foot-long CMPs in a day.

*Polyurea Liner and Coatings*

Polyurea coatings and liners, which are based on isocyanates/amines, offer rapid cure, even in low temperatures, and they are resistant to humidity. They provide high hardness, flexibility, tear and tensile strength, chemical and water resistance, and good weathering and abrasion resistance. In structural enhancement, the liner is sprayed in a "high build" manner with a thickness typically between 0.25 and 1 inch, and it is designed to resist soil and traffic loads along with hydrostatic groundwater pressure. Adhesion is less critical compared to protective coatings due to the liner's rigidity and shape.

The polyurea liner technology is versatile, suitable for all pipe shapes and types, including steel, concrete, PVC, cast and ductile iron, asbestos cement, wood, and CMPs. Polyurea coatings are approved for culvert and sewer rehab in 35 states. However, pipes must be empty, dry, and clean. Polyurea liner is effective in small diameter circular pipes, ranging from 3 to 36 inches, with a maximum distance of 700 feet. For human-entry pipes, it is applicable to any size and shape, typically limited to a 450 foot installation length, and subject to safety regulations.

Case Histories are as follows:

- Tucson Electric Power (TEP) used polyurea lining to rehabilitate 1,800 feet of 96 inch and 620 feet of 72-inch diameter steel pipes in Springerville, Arizona.

- Chicago, Illinois, rehabilitated a deteriorated 0.75-inch-thick semi-structural polyurea-lined concrete storm line with a 0.75-inch-thick semi-structural polyurea lining to address infiltration, joint seal degradations, radial cracks, and soil loss issues in 2000.
- Virginia Department of Transportation (VDOT) used polyurea lining for highway culverts (12- to 96-inch diameter) in 2005-2006.
- York Region, Canada rehabilitated a fully deteriorated elliptical CSP culvert under a busy road and bridge with minimal traffic disruption (IMC/Nukote Canada, 2023). The project design assumed the existing deteriorated pipe would not contribute to loads; however, all loads applied directly to the structural liner. The spray-applied lining system, a high-performance polyurea/ polyurethane hybrid coating, was selected for its durability, ductility, and load-bearing capabilities. A robotic application ensured precise and efficient coating, contributing to a fully structural and long-lasting outcome (Figure 21).

**Figure 21: Sprayed-on Liners: Polyurea Coating Application (left) and Robotic Liner System (right)**

*Source: IMC/Nukote Canada, 2022*

### Wisconsin Department of Transportation (WisDOT)

WisDOT's *Facilities Development Manual: Chapter 13 Drainage* (2023) outlines the spray-on liners strategy. WisDOT also uses cementitious mortars or other materials, which are centrifugally cast and are sprayed onto the interior of the pipe. Reinforcement is not needed in spray-on liners, and little-to-no structural capacity is added. WisDOT limits its use to pipes less than 48 inches in diameter, and where the strength of the pipe is adequate.

### California Department of Transportation (Caltrans)

Caltrans *Design Information Bulletin 83.04 Caltrans Supplement to FHWA Culvert Repair and Practices Manual* (2014) outlines the sprayed coatings for concrete and CSP culverts strategy.

Spray coatings are used to repair drainage structures or to form a continuous lining within a readily existing pipe. The materials can include concrete, concrete sealers, silicone, polyurethane (for concrete inlets and manholes), and vinyl ester. When non-cementitious systems are used, they aim at improving watertightness and corrosion resistance for concrete.

### 4.2.7 Invert Paving

**Wisconsin Department of Transportation (WisDOT)**

Invert paving involves placing reinforced concrete on the invert of the host culvert. The host pipe is not fully deteriorated, and its structural capacity is not compromised. Invert paving can only be done for pipes larger than 36 inches, as personnel entry is required for this type of repair (WisDOT 2018).

**Figure 22: Invert Paving of a Corrugated Metal Arch Pipe**

*Source: WisDOT, 2018*

**Minnesota Department of Transportation (MnDOT)**

The MnDOT manual states that invert paving is specified for concrete pipes and CSPs. Figure 22 depicts the rehabilitation of a corrugated metal arch pipe by paving its invert.

**California Department of Transportation (Caltrans)**

This intervention can be applied to CMPs and structural steel plate pipes. Paving can be achieved by reinforced concrete, shotcrete, or other approved materials. Paving thickness can range from 2 to 13 inches. The paved invert can achieve a maintenance-free service life of up to 50 years. The paved section can range from 90 to 180 degrees for the internal angle depending on the extent of invert deterioration (Caltrans 2014).

### 4.2.8 Sliplining

Sliplining consists of sliding a plastic liner or a new pipe into a deteriorated pipe then grouting the annulus. This option is usually preferred over total replacement because it costs less and is faster to install, especially when there are deep fills or when trenching would cause major traffic disruption. Sliplining can result in a significant extension of service life.

**California Department of Transportation (Caltrans)**

Sliplining is outlined in Caltrans' references. Caltrans refers to the *Highway Design Manual* (HDM) Topic 853, Index 855.2, and FHWA *Culvert Repair Practices Manual Volume 1*, pages 6-23 to 6-29. However, Caltrans determined the structural philosophy explained in Index 6.1.1 of the document and HDM's Index 853.2 supersedes any discussion by the FHWA regarding restoring structural strength with slipliners (Caltrans 2014).

The document cites the lack of soil-structure interaction as a “major deficiency” in sliplining as this relates to the structural integrity of the pipe. Soil structure interaction is crucial, especially for flexible pipes. Therefore, grouting the space between the original and the new pipe is necessary. For rehabilitation techniques, the host pipe should be structurally adequate to carry the loads (dead and live) by itself. If the structure is not structurally adequate, the pipe should be replaced. The method is most viable with culverts that are too small for human entry or invert paving (i.e., 36 inches or smaller in diameter).

If the soil envelope has voids or loose soil, grouting should be injected into the envelope. Chemical or Portland cement-based grouting is introduced into spaces either below the invert or within the backfill. Consideration should be given to the materials utilized and procedures followed.

When choosing material for sliplining, the environment and physical needs for installation should be considered. Some of the common materials of sliplining are high-density polyethylene and PVC in the form of either solid or corrugated walls. Although some materials are available for higher diameter pipes (e.g., polyethylene is available in diameters up to 120 inches), if the diameter exceeds 60 inches, some other repair methods could be more cost-effective.

**Wisconsin Department of Transportation (WisDOT**)

Wisconsin DOT also practices sliplining (WisDOT 2018). To fix the culvert with sliplining, the soil envelope around the culvert should be structurally sound as minimal intervention is applied to it. This trenchless method (i.e., a method that does not require continuous trenching) can be cost-effective compared to open-cut methods. This intervention is commonly used in metal-pipe culverts that have holes along the invert and is limited to culverts whose hydraulic capacity after lining would still be adequate.

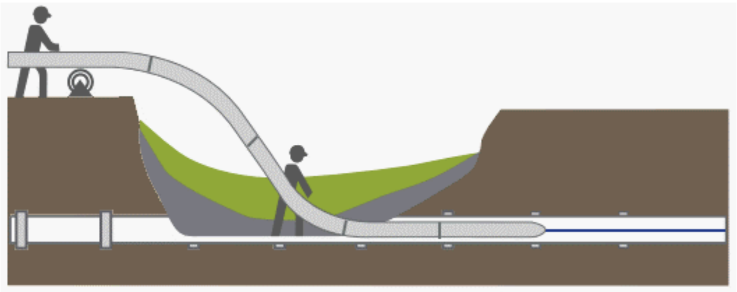
Sliplining is viable for pipe arches and box culverts, although there can be other cases. Lining box culverts requires coordination with the Statewide Drainage Engineers in the Bureau of Project Development, Roadway Standard Unit (RDSU), and the Bureau of Structures (BOS) for guidance.

Sliplining is divided into two main types: segmental and continuous. Segmental sliplining is lining the culvert with pieces that are less than the length of the culvert joined together. WisDOT guidance reports segmental sliplining as the primary sliplining practice. Continuous sliplining is where the liner runs the entire length of the culvert by pulling, pushing, or simultaneously pushing and pulling the new pipe into the host pipe (FHWA 2005). Figure 23 and Figure 24 show a graphical representation of continuous and segmental sliplining, respectively.

Some of the important design considerations include checking the internal clearance of the host pipe to verify whether any cleaning or fixing would be needed. Also, when the largest size pipe is needed, it is important to check that the host pipe can fit the liner. To allow space for grouting, the designer should assume that the liner would be at least 2 inches smaller in diameter than the host pipe.

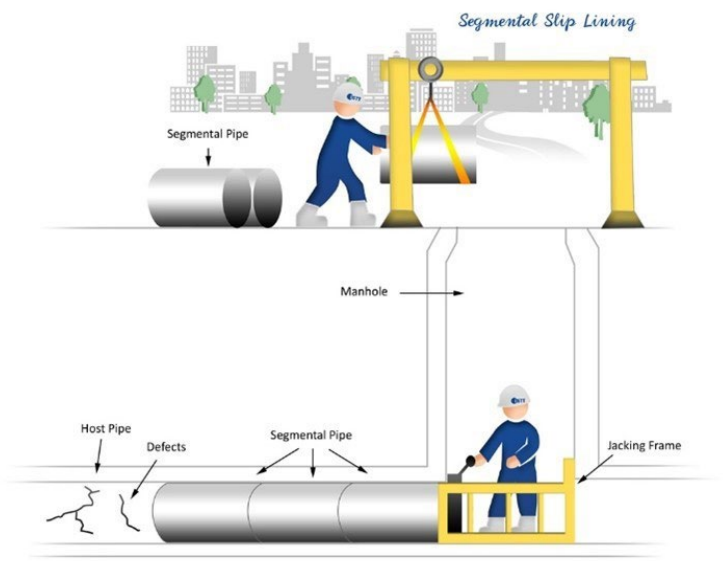
Another important consideration is the reduction in hydraulic capacity of the liner compared to the host pipe. Some liners are smoother than their host pipe, so flow through the culvert may improve and would offset the reduction caused by the smaller cross section. Nevertheless, this is only valid when the culvert is under outlet control. For culverts in inlet control, improving the inlet control may help offset the impact of the reduction in pipe size. As such, a hydraulic analysis should be performed to compare the conditions before and after lining.

**Figure 23: Continuous Sliplining**



*Source: Infra, 2020*

**Figure 24: Segmental Sliplining**




*Source: The International Society for Trenchless Technology, 2023*

Various materials can be used for pipe lining. WisDOT's approved list of materials includes dual-wall corrugated PVC, steel-reinforced polyethylene, and closed-profile or solid-wall HDPE. The specifications for these materials are, respectively, ASTM F949, AASHTO (American Association of State Highway and Transportation Officials) MP-20, ASTM D-3350, ASTM F714, and ASTM F894. Other materials WisDOT employs include smooth-lined CMPs and smooth-lined poly-coated CMPs, which are used for special applications.

**Minnesota Department of Transportation (MnDOT)**

Sliplining can be used when a culvert is structurally deficient (up to full deterioration), and it involves inserting a liner that is smaller in diameter into a deteriorated culvert by pulling or pushing.

Structurally, three design conditions are possible when sliplining:

- The host culvert is structurally adequate.
- The host culvert needs capacity enhancement by the liner.
- The host culvert is fully deteriorated, and the liner is required to carry all loads.

Design considerations differ between the three conditions, but generally, the second condition is the most difficult in terms of analysis and, if the existing culvert is difficult to assess, the conservative procedure could be to either replace the culvert or accept their condition as fully deteriorated (i.e., third condition, the load will be fully borne by the liner).

The chosen liner type and material depends on several aspects, including cost of material and pipe installation, structural capacity, load-bearing capacity, hydraulics considerations, and joint ability to prevent grout leakage. Culverts ranging from 18 to 160 inches in diameter can be sliplined.

MnDOT (2014) reports the pros and cons of some slipliner materials, including corrugated steel pipes, variations of high-density polyethylene pipes, variations of PVC pipes, and fiberglass sewer pipe culverts. For example, the advantages of using a corrugated steel pipe include material cost being lower than other options, availability of smooth interior pipe, and lightweight material properties. On the other hand, disadvantages include susceptibility to corrosion and abrasion and a high Manning's coefficient for pipes that do not have a smooth interior. The specifications used with each material are also included in the document.

### *4.2.9 Close-fit Liners*

**Minnesota Department of Transportation (MnDOT)**

Close-fit liner (FHWA 2005) is an intervention that can be used in smaller pipes (as small as 3 and up to 24 inches in diameter) and is sometimes referred to as modified sliplining. The outside diameter of the thermoplastic liner is the same size or slightly larger than that of the host pipe. A modified liner is placed and reformed and re-rounded to provide a close fitting with the existing culvert. When it's been reformed, grouting is not necessary due to the tight fit.

### *4.2.10 Shotcrete Liners*

**Minnesota Department of Transportation (MnDOT)**

Shotcrete liners use concrete that is pneumatically applied at a high speed. The compaction of the concrete happens due to the force of the application. The liner can be either reinforced or unreinforced. Reinforcement is typically welded wire fabric/fibers or reinforcing bar. This method is most appropriate for culverts with diameters of 60 inches or more as personnel are generally required to enter. Figure 25 shows the rehabilitation of a pipe by shotcrete lining. Shotcrete liners are typically applied within a thickness range of 0.5 inch to 5 inches to ensure a robust lining capable of withstanding environmental elements and the forces of flowing water (Standard Cement 2020; Conteches 2024).

**Figure 25: Shotcrete Lining**

*Source: Shotcrete + Pumping, 2019*

## 5 CONCLUSIONS AND NEXT STEPS

This report provides a summary of MDOT's existing culvert repair, rehabilitation, and replacement strategy documentation. A literature review identified additional industry practices that could potentially expand MDOT's repair and rehabilitation options. The following list summarizes strategies that reflect new or expanded options:

- Joint Grouting Techniques
- Spall Repair Techniques
- Spot Repair Techniques
- Other Repair Techniques (see Section 2)
- Spirally Wound Liner
- Fold-and-Form Liner
- Deform-Reform Liner
- CIPP Liner
- CCCP Liner (Spincast Liner)
- Sprayed-on Liners
- Invert Paving
- Sliplining
- Close-Fit Liners
- Shotcrete Liners

Further analysis, evaluation, and/or comparison of the additional strategies would help estimate the potential impact and support decision-making. Life-cycle analysis could identify fixes that last longer, the most economical alternatives, and the most appropriate strategies for different circumstances. Various types of deficiencies and the best strategies could be presented in the form of flow charts and visual aids to aid in decision-making, such as decision trees. Combining culvert inspection data analysis with cost analysis of the additional strategies could help develop and compare investment scenarios.

The AS program includes several types of culverts with different shapes and materials. Material type and geometry impacts what potential types of deficiencies are found and what maintenance activities are needed. Identifying this information could also assist in prioritizing maintenance activities.

Some fixes may require specialty, material and/or training. Workshops could be coordinated to determine current capabilities and the feasibility of new strategies.

Tables and figures from various sources that organize information in different ways to help with maintenance decision-making are presented in Appendices A, B, C, and D. The way the data is organized can be replicated for MDOT in future phases. Generally, the figures and tables show defects with repair options, benefits/disadvantages, or limitations, and low- to high-level indications for construction costs, materials, and applicable size ranges. How the data is displayed can be discussed in future interviews or workshops to determine what MDOT would be interested in seeing to help prioritize assets and maintenance decisions.

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