# Culvert Repair Best Practices, Specifications and Special Provisions – Best Practices Guidelines

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16. Abstract (Limit: 250 words)

This document contains the results of Task D, Best Practices Guidelines for the Culvert Repair Best Practices, Specifications and Special Provisions Guidelines Project. These guidelines will provide guidance to Minnesota Department of Transportation (MnDOT) engineers in making better decisions on culvert repairs. New materials specifications, special provisions, and standard details will ensure adherence to standardized practices and increase the effectiveness and longevity of repairs. Focus is on repair of centerline culverts of 24 inches to 72 inches in diameter.

This Task D document contains the best practices guidelines for replacement, rehabilitation and repair methods for deteriorating culverts. An overview of replacement methods is provided. Rehabilitation and repair methods are discussed in more detail. The methods discussed are the most common culvert rehabilitation and repair methods identified during governmental and industry surveys conducted during Tasks A and B. The final list for inclusion in this guideline was chosen by the authors and the Technical Advisory Panel (TAP).

Special provisions and standard details were prepared for the following methods: paved invert, cured-in-place pipe liner (CIPP), sliplining culvert pipe, centrifugally cast concrete culvert lining, spall repair, joint repair, and void filling outside the culvert.

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# Table of Contents

# List of Figures



# List of Tables

# 1 Introduction

This document contains the results of Task D, Best Practices Guidelines, for the Culvert Repair Best Practices, Specifications and Special Provisions Guidelines Project. These guidelines will provide guidance to Minnesota Department of Transportation (MnDOT) engineers in making better decisions on culvert repairs. New materials specifications and special provisions and standard details will ensure adherence to standardized practices and increase the effectiveness and longevity of repairs. Focus will be on repair of centerline culverts of 24 inches to 72 inches in diameter.

These guidelines are being developed in multiple tasks, as described below:

Task A—Minnesota Survey: Web surveys and interviews of personnel from MnDOT, Minnesota cities and counties, and contractors. Task A was completed in February, 2012.

Task B—Survey of other state's Department of Transportations (DOTs): Similar to Task A. Surveys were sent to the American Association of State Highway and Transportation Officials Research Advisory Committee (AASHTO RAC) list. Task B was completed in July 2012.

Task C—Research Synthesis: This Transportation Research Synthesis (TRS) contains the literature review of information provided in State Planning & Research (SP&R) Work Plan, Tasks A and B, and other sources described in the TRS. The results of Tasks A, B, and C are synthesized and recommendations are made on which methods should be included in the Best Practices Guidelines. Task C was completed in October 2012.

**Task D—Best Practices Guidelines**: Best Practices Guidelines, Special Provisions, and Standard details have been prepared based on the results of Tasks A, B, and C; discussions with the Technical Advisory Panel; and comments from other MnDOT personnel.

Task E—Feasibility Study: The feasibility study will include an examination of the feasibility of conducting a study to determine the long-term effectiveness and life cycle costs of different culvert repairs.

Task F—Outreach: CNA Consulting Engineers (CNA) will assist the Technical Advisory Panel with a plan for communication and distribution of the Best Practices Guidelines.

This Task D document contains the best practices guidelines for replacement, rehabilitation and repair methods for deteriorating culverts. An overview of replacement methods is provided. Rehabilitation and repair methods are discussed in more detail. The methods discussed are the most common culvert rehabilitation and repair methods identified during governmental and industry surveys conducted during Tasks A and B. The final list for inclusion in this guideline was chosen by the authors and the Technical Advisory Panel (TAP).

- The following methods are addressed in detail. Special provisions and standard details were prepared for these methods:

    - Rehabilitation of culvert, including:
        - Paved invert
        - Cured-in-place pipe liner (CIPP)
        - Sliplining
        - Centrifugally cast concrete mortar liner
    - Repair of culvert, including:
        - Spall repair
        - Joint repair methods
        - Filling voids outside the culvert

- The following methods are generally described:
    - Other rehabilitation methods
        - Spirally wound liners
        - Close-fit liners
        - Shotcrete
    - Other repair methods
        - Joint sealing with internal packers
        - Corrugated steel pipe (CSP) seam repair
        - Invert plating
        - Sprayed coatings and linings
        - Slab jacking
        - Compaction grouting
    - Replacement of culvert using open cut methods
    - Replacement of culvert using trenchless replacement methods, including:
        - Pipe jacking
        - Horizontal directional drilling
        - Pipe bursting

## 1.1 **Special Provisions and Standard Details**

The special provisions and standard details prepared as part of Task D are listed in Table 1.1 below. These are available upon request from:

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**Table 1.1 Special Provisions and Standard Details Prepared**

| Method | Special Provision Name | Standard Detail Name |
|---|---|---|
| Paved Invert | Paving Culvert Invert | 3X02 Paved Invert Repair - Corrugated Metal Pipe<br>3X03 Paved Invert Repair - Reinforced Concrete Pipe |
| Cured-in-Place Pipe (CIPP) | Cured-in-Place Pipe Lining | 3X06 Cured-in-Place pipe Liner - Corrugated Metal pipe<br>3X07 Cured-in-Place Pipe Liner - Reinforced Concrete Pipe |
| Sliplining Culvert Pipe | Sliplining Culvert Pipe<br>Grout Culvert Liner | 3X04 Sliplining Culvert - Corrugated Metal Pipe<br>3X04A Sliplining Culvert - Corrugated Metal Pipe<br>3X05 Sliplining Culvert - Reinforced Concrete Pipe<br>3X05A Sliplining Culvert - Reinforced Concrete Pipe |
| Centrifugally Cast Liner | Centrifugally Cast Culvert Lining | |
| Spall Repair | Culvert Patching | 3X03 Paved Invert Repair |
| Joint Repair | Repair Culvert Joint | 3X01 Pipe Joint Sealing - Reinforced Concrete Pipe |
| Void Filling Outside the Culvert | Filling Voids Outside of Culverts | 3X08 Culvert Void filling Detail - CSP and RCP Culverts |

## 1.2 **Definitions – Replacement, Rehabilitation, Repair**

For the purposes of this guideline, replacement, rehabilitation, and repair are defined as follows:

**Replacement**: Removal or abandonment of the existing culvert and replacing it with a new culvert pipe. This can be done by either open cut or trenchless construction methods.

**Rehabilitation:** The existing culvert pipe is returned to its initial condition or better. (Modified from National Cooperative Highway Research Program (NCHRP) Synthesis 303 Assessment and Rehabilitation of Existing Culverts (NCHRP, 2002)).

**Repair:** A maintenance activity that keeps the existing culvert in a uniformly good safe condition. (Modified from NCHRP Synthesis 303 Assessment and Rehabilitation of Existing Culverts (NCHRP, 2002)).

## 1.3 **Limitations**

This document is not a substitute for engineering knowledge, experience or judgment. Many of the guidelines given herein are subject to amendment as specific project conditions and experience may warrant. Special situations may call for variation from the procedures described.

# 2 Culvert Repair Process

The culvert repair process involves a number of steps, starting with problem identification and ending with maintenance after the repairs have been completed. The specific steps are listed below:

1. Identify the Problem.
2. Determine the Cause(s) of Deterioration.
3. Evaluate the Hydraulic Condition.
4. Evaluate the Structural Condition.
5. Evaluate Repair, Rehabilitation, and Replacement Options.
6. Implement the Design.
7. Maintain the Repairs.

Each of these steps is described in the following sections.

## 2.1 Identify the Problem

Culvert deterioration is generally identified and monitored during a HydInfra inspection. Other sources of identified culvert deterioration come from roadway project designers, or notifications from maintenance staff who observe roadway settlement, sinkholes or ponding water at the inlet structure.

HydInfra is MnDOT's culvert and storm drain management system, which is a database of information collected during field inspections, including culvert size, type, material and condition. HydInfra is described in full detail at http://www.dot.state.mn.us/bridge/hydraulics/hydinfra.html.

As a result of the HydInfra inspection, the culvert's overall condition is rated on a scale from 0 to 4, listed below.

0. Not able to rate, not visible
1. Excellent – like new condition
2. Fair – some wear, but structurally sound
3. Poor – deteriorated, consider for repair or replacement
4. Very Poor – serious condition

HydInfra's recommended frequency of a culvert inspection is based on the culvert's rated condition, as shown in Table 2.1.

**Table 2.1 Overall Culvert Condition Rating and Recommended Inspection Frequency**

| Overall Condition | Recommended Inspection Frequency (Years) | Comments |
|---|---|---|
| 4<br>Very Poor | 2 | Pipes where problem is not under the road |
| | 1 | Pipes where problem requires a repair under the road |
| 3<br>Poor | 4 | Most condition 3 pipes |
| | 2 | Pipes with piping or road void |
| 1 & 2<br>Like New and Fair | 6 | |
| 0<br>Can't Be Rated | 2 | |

It is strongly recommended that culverts with an overall condition rating of 3 or 4 receive some level of repair, rehabilitation or replacement. The timing will be influenced by the location of the deterioration and the potential for increased damage to the pipe and roadway above.

Determining the level of deterioration the culvert has sustained is an important part of deciding to repair, rehabilitate or replace it. Routinely monitoring the deterioration will assist in determining when repairs should be made, before rehabilitation or replacement is required. This is one of the main purposes of the HydInfra system. The HydInfra Inspection Manual includes rating guides for Plastic Pipe or Liners, Metal Pipe and Special Structures and Concrete Pipe and Special Structures.

Additional resources to assess the level of damage are provided by the national product organizations. These resources can be used to supplement the HydInfra Inspection Manual rating guides and provide additional background on condition ratings. Evaluation guidance for the primary culvert materials used in Minnesota – Reinforced Concrete Pipe (RCP) and Corrugated Steel Pipe (CSP), are listed below.

For evaluation of RCP culverts see the following documents available from the American Concrete Pipe Association (ACPA):

- "Evaluation and Repair Guidelines for New Drainage Pipe" (ACPA, 2012)
- "Post Installation Evaluation and Repair of Installed Reinforced Concrete Pipe" (ACPA, 2011)

For evaluation of CSP culverts see the following documents from the National Corrugated Steel Pipe Associations (NCSPA):

- Design Data 19 – Load Rating and Structural Evaluation of In-Service Corrugated Steel Structures (NCSPA, 1995)

A comprehensive assessment of the culvert's condition may need to be performed to allow for evaluation of the options and determination of feasibility and cost. The extent of the evaluation will depend on the level of deterioration and the consequences if the culvert fails.

When assessing the level of damage, it is important to consider the differences between rigid and flexible pipes, as this will influence which observed deficiencies require additional investigation and testing. Rigid pipe is designed to be substantially self-supporting and relies on the surrounding soil for only a small fraction of its overall strength. RCP is currently the only rigid pipe material used for culverts. Flexible pipe is designed using soil structure interaction, where the majority of the pipe's strength is derived from the quality of the backfill soils and compaction. Typical flexible pipe culvert materials include CSP, PVC, HDPE and fiberglass.

When assessing the level of damage a pipe has sustained, it is important to also consider the time in which this deterioration has occurred. Flexible pipes with relatively large deflections, typically in the range of 5%-7% and have been stable for a number of years will likely continue to be serviceable for a number of years, provided the soils surrounding the pipe and loading remain constant. Pipes such as CSP and RCP which are suffering from invert erosion will continue to deteriorate and should be routinely monitored and tracked to determine when repair or rehabilitation work should be completed.

Key items to measure, evaluate or test are included in Table 2.2. Much of this information may already be available through the HydInfra database. If detailed information is not available, additional field investigations will be required.

**Table 2.2 Key Culvert Observations**

| | |
|---|---|
| All Culverts | • Horizontal and vertical deflections of pipe<br>• Size and location of voids visible through separated joints and holes in the culvert<br>• Sounding the culvert interior with a hammer to listen for 'hollow' sounding areas indicating voids outside the culvert<br>• Width of separated or deflected joints<br>• Misalignment of pipe joints<br>• Camber (bend) or settlement of pipe alignment |
| Rigid Pipe Culverts | • Crack size, location, length and extent of reinforcement corrosion. Corrosion typically occurs in crack widths exceeding 0.02", especially in the presence of chlorides<br>• Depth of invert erosion. If reinforcement is exposed, amount of section loss<br>• Sound walls and invert to locate areas of delaminating concrete due to slabbing (radial tension failure) or corrosion of reinforcement |
| Flexible Pipe Culverts | • Composition and compaction of pipe bedding materials.<br>• Cracks or tears in pipe wall<br>• Crimping of pipe (CSP only)<br>• Tearing at bolt holes (CSP only) |

## 2.2 Determine the Cause(s) of Deterioration

Understanding the cause of deterioration is the key to developing a plan to replace, rehabilitate or repair a culvert. Every effort should be made to reduce or eliminate the source of deterioration, either by modifying the original design or selecting an alternative material that is less susceptible to the source of deterioration. Information from the HydInfra database will also assist in determining the cause. Establishing the rate and location of deterioration is also a key factor in determining the cause.

Table 2.3 is a brief summary of observed culvert deficiencies and likely causes:

**Table 2.3 Likely Causes of Culvert Deterioration**

| Observed condition | Likely cause |
|---|---|
| Invert and crown cracking width in excess of 0.10” in RCP culverts | • Dead and live loading on culvert exceeding culvert design capacity<br>• Increased loading on culvert due to increased soil or groundwater elevations |
| Slabbing (slabs of concrete "peeling" away from the sides of the pipe and a straightening of the reinforcement due to excessive deflection or shear cracks) in RCP culverts | • Dead and live loading on culvert exceeding culvert design capacity<br>• Increased loading on culvert due to increased soil or groundwater elevations<br>• Improper bedding of culvert |
| Deflections exceeding 7% in flexible culverts | • Dead and live loading on culvert exceeding culvert design capacity<br>• Increased loading on culvert due to increased soil or groundwater elevations<br>• Improper installation or selection of haunching materials or insufficient compaction<br>• Loss of soil through pipe wall or joints<br>• Piping of materials on exterior of culvert<br>• Excessive construction equipment loading with insufficient cover |
| Loss/erosion of invert | • Erosion of culvert material due to stream bed loading (All pipe materials)<br>• Corrosion or deterioration of culvert material due to pH of water, resistivity of soil, chemical attack, etc. (All pipe materials)<br>• Corrosion of reinforcement and resulting expansive forces resulting in delaminations of concrete (RCP)<br>• Freeze-thaw deterioration (RCP) |
| Joint separation and infiltration of soil | • Improperly seating of joint during installation<br>• Movement of pipe due to slope erosion, freeze-thaw or settlement<br>• Movement of pipe due to excessive deflection or structural deterioration<br>• Buoyancy of culvert with insufficient cover |

**Table 2.4 Likely Causes of Culvert Deterioration, cont.**

| Observed condition | Likely cause |
|---|---|
| Cracks or fractures in flexible pipe culverts | • Pipes damaged during installation by equipment or rock in direct contact with pipe<br>• Excessive loading on culvert<br>• Environmental stress cracking in pipe material |
| Piping of soil on exterior of culvert | • Water flowing past holes in the culvert or separated joints causes migration of soil particles<br>• High water head causing migration of soil particles around the outside of the culvert |

These observations can be used to assist in the plan to rehabilitate, repair, or replace the culvert and in selecting alternative materials. Consideration should be given to what other negative factors can be engineered out of a new installation to increase longevity of the new culvert. In addition, consideration can be given to upsizing the new culvert for future rehabilitation (e.g. sliplining).

### 2.3 **Evaluate Hydraulic Condition**

If there is a concern that the existing culvert size does not have adequate capacity, the culvert will need to be hydraulically evaluated. Changes in land use, drainage area, or precipitation since the culvert was installed could cause higher flows. The evaluation should follow the procedures described in the MnDOT Drainage Manual (MnDOT, 2000).

In addition to evaluating the hydraulics of the existing culvert, most culvert repair or rehabilitation methods will alter the hydraulics of the culvert to some degree. The Engineer needs to verify that the repaired culvert has adequate hydraulic capacity. Hydraulic analysis is generally recommended for rehabilitation methods that will reduce the internal diameter of the culvert, such as sliplining and CIPP. Hydraulic analysis will be necessary if it is not known if the existing culvert has adequate capacity.

In some cases, the culvert cross section can be reduced without reducing the capacity of the culvert. This occurs when the repaired culvert barrel roughness (typically represented by Manning's "n" value) is lower than the existing culvert for culverts operating under outlet control. A reduced barrel roughness increases the culvert capacity because there is less resistance to flow. For culverts operating under inlet control, the flow capacity is controlled by the upstream end of the culvert and not the culvert barrel. The reduced-size culvert needs to be checked to ensure that the culvert is still operating with inlet control.

Improved inlets can also increase the capacity of the culvert by allowing the flow to enter the culvert more easily.

## 2.4 **Evaluate Structural Condition**

Determining the structural capacity of a deteriorated culvert is not a simple and straightforward task. The residual structural capacity and resulting factor of safety is influenced by a number of factors such as culvert pipe material properties, quality of pipe installation and loading. There are numerous cases where a culvert remains generally stable when the condition indicates it should have failed. The reverse is also true, when culverts have excessive deformation or deterioration for no apparent reason. Examples of factors that may increase the residual structural capacity of deteriorated culverts include:

- The RCP culvert pipe yield and compressive strength of reinforcement and concrete exceeded minimum design values, resulting in additional capacity. For example, welded wire fabric specified under American Society for Testing and Materials (ASTM) A185 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete (ASTM A185, 2007) has a minimum specified tensile strength of 75 ksi, but the wire supplied may have an actual tensile strength of 90-100 ksi.
- The flexible and rigid pipe bedding conditions achieved during construction were better than assumed design bedding condition. Some designers specify a compaction level 5% higher than the design requires.
- The designer selected the next higher pipe class. For example, a RCP culvert design may have required a D-loading of 1500 lbs/ft x ft of diameter, but a Class IV pipe with a D-loading of 2000 lbs/ft x ft of diameter was specified, whereas a Class III only has a capacity of 1350 lbs/ft x ft of diameter.

Some examples of factors that may decrease the structural capacity of existing culverts and cause rapid deterioration and collapse include:

- The loss or reduction of soil support due to piping, or soil infiltrating through pipe joints, tears or holes
- The excessive deformation (> 10% deflection) of flexible culverts or reverse curvature of shape, leading to pipe buckling and collapse
- Tears in flexible culverts leading to rapid loss of support and collapse of the culvert
- Large cracks in RCP culverts, resulting in yielding of the culvert reinforcement
- Exposure and loss of reinforcement section in the invert of RCP culverts resulting loss of bending moment capacity

Typically a culvert with a HydInfra condition rating of 3 or 4 should be evaluated to determine whether a comprehensive structural evaluation of the culvert is required. The location and amount of deterioration in conjunction with the level of risk associated with a failure should be considered.

Localized deteriorations can typically be spot repaired and will not require a comprehensive structural evaluation. This recommendation is contingent on the condition that the pipe is not also suffering from excessive deflections or other severe deteriorations. Typical spot deteriorations not requiring a structural evaluation include the following conditions:

- Joint separations
- Small holes in the culvert
- Localized invert erosion
- Misalignment of joints
- Localized spalls or flaking

### 2.4.1 *Partially and Fully Deteriorated Culvert Condition*

For consistency in the use of the best practices and Special Provisions, culvert structural deterioration levels will be categorized as either partially or fully deteriorated. This terminology is modified from the CIPP industry and ASTM Standard F1216 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube, Appendix X1.1 (ASTM F1216, 2009).

For a partially deteriorated culvert condition, all of the following conditions must be met.

- The host culvert pipe can support the live and dead loads imposed on the culvert for the remaining service life of the rehabilitated culvert.
- The soil envelope around the pipe must be stable and capable of providing the necessary support to the rehabilitated culvert pipe.
- The internal deflection of the host culvert pipe must be less than 10% for culverts constructed from flexible pipe materials.
- Longitudinal crack widths in rigid pipe are less than 0.10” with no signs of reinforcement corrosion.

For a fully deteriorated culvert condition, the host culvert pipe is either structurally deficient or will become structurally deficient during the culvert’s remaining service life. In most cases metal pipe should be considered to be fully deteriorated. Table 2.5 below is a summary of culvert conditions that would be considered fully deteriorated.

**Table 2.5 Typical Fully Deteriorated Culvert Conditions**

| | |
|---|---|
| Rigid Pipe Culverts | • Longitudinal cracks in the crown or invert in excess of 0.20”<br>• Longitudinal cracks in the crown or invert in excess of 0.10” with signs of reinforcement corrosion<br>• Slabbing of the culvert wall<br>• Erosion of culvert invert with 20% or more exposure of reinforcement in 2 or more successive culvert segments<br>• Delamination of the concrete down to the reinforcement level |
| Flexible Pipe Culverts | • Deflections in excess of 10% or evidence of buckling<br>• Cracks or tears through culvert wall at more than 2 locations<br>• Crimping of culvert wall (CSP only)<br>• Tearing at bolt holes (CSP only)<br>• Erosion/corrosion of invert with 20% or more cross section loss<br>• A hole 1” or larger |

## 2.5 Evaluate Repair, Rehabilitation, and Replacement Options

Once the culvert problems have been identified and the causes of deterioration determined, the problems must be addressed. The options for addressing culvert problems include inspection, repair, rehabilitation, or replacement, as defined below:

- Inspect: Routinely and systematically inspect the culvert using the established condition assessment rating to determine whether the condition is degrading and if the original priorities need to be modified. This is part of the HydInfra process.
- Repair: These are maintenance activities that keep the existing culvert in a uniformly good safe condition. The do not necessarily enhance structural capacity.
- Rehabilitate: Rehabilitation will restore the culvert to its initial condition or better, including providing structural support.
- Replace: This involves installing an entirely new culvert by open cut or trenchless construction techniques.

Culverts determined to have a fully deteriorated condition should be rehabilitated or replaced. When evaluating the condition of a fully deteriorated structure, a qualified civil or structural engineer may be needed to determine if it can be rehabilitated or should be replaced. If the culvert is to be rehabilitated, consideration should be given to the following conditions:

- Stability of the culvert during construction to prevent additional distress to the culvert and provide worker safety.
- Transfer of load into the rehabilitated culvert section. If the culvert is not unloaded before rehabilitation, the rehabilitated culvert section will not see any load until additional loading is applied.

- Preventing live load from being applied to the culvert until rehabilitation work is completed and capable of carrying load.

Structural design for the various rehabilitation techniques are described in Chapter 4.

The Engineer must determine which of the potential options for repair, rehabilitation, or replacement should be selected. There is no specific methodology for making this determination, and in many cases several repair or rehabilitation options will be viable. Choosing a culvert repair or rehabilitation method is site specific. Culvert characteristics may point to one repair method but hydraulic requirements, geography and traffic needs may point to a different option. As discussed above, the key element is to first understand the conditions leading to the failure/deterioration of the existing culvert. Unless there have been significant changes in the upstream watershed, these conditions will likely persist and the selected repair strategy must be able to effectively counteract these conditions. (Modified from Caltrans Supplement to Federal Highway Administration (FHWA) Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011)).

Individual techniques, different fabricators, different chemical formulations, varying geotechnical conditions, condition of the host culvert, and installation techniques and procedures all are influential in the ultimate outcome of the repair technique. When designing and installing any of the various techniques, it is recommended that contact be made with suppliers, fabricators, or specialists to clearly ascertain the probability of success. Ultimately, only experience in varying situations and conditions will tell accurately what methods have the best potential for meeting the design objectives. (Modified from Caltrans Supplement to Federal Highway Administration (FHWA) Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011)).

Useful documents that aid in the decision-making process include the following:

- HydInfra suggested repairs reports and flow charts
- FHWA Culvert Assessment and Decision-Making Procedures Manual (FHWA, 2010)
- FHWA Hydraulics Toolbox (FHWA, 2012)
- Caltrans Supplement to FHWA Culvert Repair Practices Manual (Caltrans, 2011)

These publications are discussed in the following sections. Each of these can be used as a starting point for alternatives selection

### 2.5.1 *HydInfra Suggested Repair Methods*

It is recommended that MnDOT culvert designers start by looking at the HydInfra report for "Pipe Suggested Repair Method". The report gives recommended repair options for CSP, aluminum, and RCP culverts. The report takes into account culvert characteristics like size, shape, material and several condition and defect descriptors. The characteristics are sorted by a computer program based on the HydInfra Pipe Suggested Repair Method Flowchart. The designer must field review the culvert to verify the HydInfra data and look at site specifics that could affect the constructability of the chosen method, such as site access, staging area, and flow diversion requirements.

Flowchart outcomes can be joint repair, paved invert, CIPP liner, slipliner, open trench replacement, jacked pipe replacement, and resetting and tying end sections, depending on the culvert's characteristics, derived from inspection data. The suggested repair is a general recommendation based on the information available in HydInfra. The flow charts are developed primarily for planning purposes. The flowchart does not take into account hydraulic capacity and notes that additional factors must be taken into account before applying the suggested repair to an individual pipe. A repair must be chosen by taking into account the specific factors at the individual culvert.

### 2.5.2 *FHWA Culvert Assessment and Decision-Making Procedures Manual*

The FHWA Culvert Assessment and Decision-Making Procedures Manual (FHWA, 2010), contains a comprehensive system for assessing culverts and procedures for choosing among the various rehabilitation, repair, or replacement methods. Detailed decision-making flowcharts are provided. The Manual is a useful supplemental reference for MnDOT projects.

The Manual contains a Culvert Assessment Tool, which is similar to the HydInfra Pipe Suggested Repair Method. The purpose of the assessment tool is to provide FHWA Federal Lands Highway personnel with project-level guidelines for assessing the condition and performance of existing roadway culverts within the extents of a planned roadway project. The Level 1 assessment is intended for rapid assessment of a culvert's condition and performance. The Level 1 assessment procedure may identify the need for a more in-depth investigation, termed a Level 2 assessment. Level 2 assessments require the involvement of technical discipline specialists in hydraulic, geotechnical, structural or materials engineering, and may also require special equipment for access and inspection.

The Level 1 assessment procedure should lead to one of the following recommendations, for each culvert assessed:

1. The condition and performance appear to be acceptable, and no further action is needed with respect to the project being undertaken;
2. Level 1 maintenance (e.g. cleaning/clearing) is needed to remedy an observed performance problem and/or facilitate completing the Level 1 assessment;
3. Level 1 action is needed to repair or replace the culvert or appurtenances, with assistance from the decision-making tool portion of this procedure; or
4. An in-depth Level 2 assessment is required due to indicators identified by the Level 1 assessment.

The Manual also contains a Culvert Decision Making Tool, which is used to provide project-level decision-making guidance for post-assessment actions for existing roadway culverts. The procedure assists the user in making follow-up recommendations to the culvert assessments, which might include repair, replacement, and Level 1 and 2 activities. Guidance is also provided to assist with repair or replacement technique selection, following the assessor's preliminary recommendations. The decision-making tools include a set of flowcharts that outline the possible actions for the various culvert types.

The decision-making procedure begins after the termination of the culvert assessment procedure, with a rating having been assigned. The procedure then steps through a number of qualifiers intended to guide the user toward the appropriate action path, the options of which are no further action or a recommendation of Level 1 maintenance, Level 2 in-depth investigation, replacement, or repair. (Modified from FHWA Culvert Assessment and Decision-Making Procedures Manual (FHWA, 2010)).

### 2.5.3 *FHWA Hydraulics Toolbox*

The FHWA Hydraulic Toolbox (FHWA, 2012) is a suite of ten hydraulics software applications, some of which are applicable to culverts. The Culvert Assessment tool application makes culvert repair or rehabilitation recommendations that are generated by entering field assessment data on existing culvert condition and performance. The recommendation is based on the methodology of the FHWA Culvert Assessment and Decision-Making Procedures Manual (FHWA, 2010). Data from the HydInfra database or from procedures described in the FHWA Culvert Assessment and Decision-Making Procedures Manual can be used as input into the Culvert Assessment tool.

### 2.5.4 *Caltrans Supplement to FHWA Culvert Repair Practices Manual*

Table 8.1.1 of Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011) contains useful information that can be used to compare various repair and rehabilitation methods. The table lists repair and replacement methods, relative construction costs, applicable size range, advantages and limitations. A modified version of Table 8.1.1 is contained in Appendix A. Section 9.1 Replacement contains useful information on culvert replacement methods, including:

- Discussion of repair versus replacement
- Description of open cut and trenchless replacement methods
- Factors affecting selection of trenchless replacement alternatives
- A trenchless replacement methods overview that lists, method, primary applications, depth range, length range, diameter range, type of pipe, and accuracy
- Applicability of trenchless replacement methods in various soil conditions
- Cost range for trenchless replacement methods

## 2.6 **Implement the Design**

Once the rehabilitation, repair, or replacement method has been chosen, it should be designed to current design standards. Special provisions and standard details for some of the most common rehabilitation and repair methods have been prepared as discussed in Section 1.1.

## 2.7 **Maintain the Repairs**

In the years following a completed project, the work should be monitored and maintained as necessary. Most rehabilitation and repair techniques will require little ongoing maintenance. Some potential maintenance that may be required may include the following:

- Re-patching of concrete repairs such paved inverts, centrifugally cast liners, shotcrete liners, and spall repairs that may have spalled due to inadequate bonding to the culvert.
- Re-sealing of joints that have been repaired. Subsequent culvert movement may have caused joint separation or leakage.

# 3 Preparation for Rehabilitation or Repair

## 3.1 Environmental Protection

The culvert rehabilitation, repair or replacement method must not damage the surrounding environment. Procedures must be in place to protect waterways, adjacent land, flora and fauna. Permits will need to be obtained and their requirements followed. The permits required depend on the location and scope of the project and other permits may be required. Potential permits and notifications include the following:

- MnDNR Public Waters Work Permit (GP) 2004-0001
- Minnesota Pollution Control Agency (MPCA) Construction Site NPDES Permit
- MPCA 401 Water Quality Certification
- United States Army Corps of Engineers
- United States Coast Guard
- Watershed District Permits
- Wetland Conservation Act (wetland impacts)
- Local Floodplain Zoning Administration

Typical environmental procedures and permits are discussed below.

### 3.1.1 *Minnesota Department of Natural Resources (MNDNR)*

The MNDNR has issued MnDOT the General Public Waters Permit (GP) 2004-0001 (Minnesota DNR, 2008). This general permit has been issued to MnDOT for the repair or reconstruction of culverts, bridges, or stormwater outfalls impacting Minnesota's Public Waters. To aid in meeting the requirements of this permit, the MNDNR has prepared the "Best Practices for Meeting MNDNR General Public Waters Work Permit GP2004 -0001 (MnDOT Projects with Bridges, Culverts, or Outfalls)" (Minnesota DNR, 2011).This document contains the following chapters to address the various issues and meet MNDNR regulations. These guidelines shall be followed for any culvert project.

Chapter 1 Species Protection
Chapter 2 Hydraulic and Hydrologic Recommendations
Chapter 3 Methods of In-stream Construction
Chapter 4 Examples of Worksite Sediment and Erosion Control

### 3.1.2 *MnDOT Erosion & Sediment Control Design Guidance*

MnDOT has prepared the document "Erosion & Sediment Control Design Guidance" for MnDOT projects (MnDOT Office of Environmental Services, 2010). The recommendations of this document should be followed on culvert repair projects. The document contains guidance on the following:

- Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) and Municipal Separate Storm Sewer Systems (MS4) storm water permit programs
- Temporary erosion and sediment control best management practices (BMP's)
- Working in and near streams

- Permanent erosion control BMP’s
- Turf establishment
- Soil bio-engineered systems

Concrete truck washout procedures should also be followed as part of the NPDES Permit. MnDOT’s interpretation of the MPCA’s guidance on this subject is contained in the document “Best Management Practices (BMP) for Concrete Washout” (MnDOT, 2009). These guidelines should be followed for culvert repairs that involve cast-in-place concrete or grouting.

Environmental considerations for specific types of culvert rehabilitation or repair are discussed in methods descriptions in Chapters 4 and 5 and in the Special Provisions.

### 3.2 **Flow Diversion**

Many of the repair and rehabilitation methods require diversion of flow so that the work can take place in dry conditions. Flow could wash away unset concrete or grout when placing paved inverts and grouting slipliners and spirally wound liners. It could also prevent cured-in-place pipe (CIPP) resins from setting properly.

Each site will have different flow conditions. The Engineer should evaluate the feasibility of diversion options during project planning. The contractor should be required to submit a plan for diverting or controlling the culvert flow. This could be temporary conveyance of flow around or through the culvert or temporarily ponding flow upstream of the culvert. The chosen diversion method must not have adverse effects on the surrounding area. Chapter 3 of “Best Practices for Meeting MnDNR General Public Waters Work Permit GP2004 -0001 (MnDOT Projects with Bridges, Culverts, or Outfalls)” (Minnesota DNR, 2011) contains guidelines for flow diversion, including temporary stream block, culvert by-pass, by-pass channel, partial stream diversion, speed BMP, and winter work.

### 3.3 **Infiltration Control**

Just like flow in the culvert, infiltration can adversely affect the repair or rehabilitation work. It will need to be stopped prior to repair or rehabilitation work. Infiltration control usually involves one of the repair methods discussed in Chapter 5, such as joint repair with chemical grouts and oakum, joint injection with chemical grouts, or internal bands. These repairs would be done before infiltration-sensitive rehabilitation or repair.

### 3.4 **Cleaning**

In most cases, the culvert will need to be cleaned before the repair or rehabilitation work is completed. This is especially important for methods that require bond to the existing culvert. The cleaning method should be tailored to the repair or rehabilitation method chosen and site constraints. Cleaning should be done immediately before the culvert work is done to limit the amount of debris that reenters the culvert. Some rehabilitation and repair techniques will have more stringent cleaning requirements. For example, centrifugally cast liners require excellent cleaning to ensure good bond. MnDOT personnel should inspect the culvert after cleaning to ensure cleaning requirements have been achieved.

Cleaning should be done with high pressure water jet, vacuum trucks, reaming, push buckets, pull buckets, or brushing. If the culvert is large enough, personnel or equipment such as skid

steer loaders can remove debris. Horizontal directional drilling (HDD) equipment with barrel reamers, push buckets, pull buckets, and brushes is also effective.
Proper environmental controls need to in place to prevent debris and sediment from being released downstream. See section 3.1 for guidance.

### 3.5 **Check Culvert Clearance**

The culvert must be checked for obstructions or deformations that would prevent the culvert from being repaired or would reduce the flow capacity. This can be done visually, with a mandrel or cleaning device (pig) or a laser profiler. In the case of sliplining, selection of the liner must consider the effect on the liner diameter due to liner wall thickness and, in particular, the space requirements of the liner joints. The maximum exterior dimension of the liner must be able to be inserted through the existing culvert, while also considering deformations in the existing culvert, minor culvert bends, and any other disturbances in the bore of the existing culvert. These considerations make it imperative that the designer or contractor obtains accurate field measurements of the existing culvert to determine the minimum available clearance prior to selecting liner types and diameters. Be aware that manufacturers occasionally delete existing products and often bring new products to the market. Contact with industry representatives is encouraged to verify the availability of any products that will be specified. (Modified from Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011)).

If a contractor is performing the work, they should be required to certify that the proposed liner will fit. MnDOT Metro District owns a laser profiler that can be used to check the culvert clearance. Consideration should be given to utilizing this tool on specific culvert projects. The profiler and trained staff have limited availability but can be contracted for projects. A contractor should be required to conduct laser profiling on projects where MnDOT's profiler will not be available in a timely manner.

### 3.6 **Other Preparatory Work**

Sometimes more than one rehabilitation or repair may be required to complete a project. For example infiltration control by joint sealing or crack sealing may be required before a new liner is placed. This could be considered preparatory work. Another example would be invert paving or patching before placing a centrifugally cast liner. The work should be sequenced to provide the best final product.

### 3.7 **Safety**

Safety is the first priority on any work site and culvert projects are no different. Proper safety procedures must be followed when working in and around culverts. The following are some of the safety requirements and guidelines that may apply to a culvert repair project:

- The Occupational Safety and Health Administration (OSHA) Part 1910 Occupational Safety and Health Standards and Part 1926 Safety and Health Regulations for Construction (OSHA, Various)
- MnDOT Confined Space Program (MnDOT, 2011). This is document is available on MnDOT's internal website only.

- Chapter 2 of FHWA Culvert Assessment and Decision Making Procedures Manual (FHWA, 2010) contains general guidance for culvert entry procedures.
- MnDOT Specification and Special Provision 1706 Employee Health and Welfare
- Contractor's written safety program. MnDOT Special Provision 1706 requires the contractor to submit a written safety program at the preconstruction conference.

On projects performed by a contractor, the contractor shall be considered to be fully responsible for the development, implementation and enforcement of all safety requirements on the Project, notwithstanding any actions MnDOT may take to help ensure compliance with those requirements. This is a requirement of MnDOT Special Provision 1706.

### 3.7.1 *Safety Evaluation by a Competent Person*

A "competent person" should evaluate the hazards associated with each project. OSHA defines a competent person as:

> An OSHA "competent person" is defined as "one who is capable of identifying existing and predictable hazards in the surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them." From OSHA 29 CFR 1926.32(f). (OSHA).

### 3.7.2 *Confined Space Entry*

Besides the safety concerns in working on any construction site, confined space concerns should be addressed. Many culverts are considered confined space. Each culvert should be evaluated by a competent person to determine if the culvert can be entered and what safety procedures should be followed for entry. A confined space is defined as a space that has the following characteristics:

- Large enough and so configured that an employee can bodily enter and perform assigned work
- Has limited or restricted means for entry or exit
- Not designed for continuous employee occupancy

OSHA CFR 1910.146 uses the term "permit-required confined space" to describe a confined space that has one or more of the following characteristics: contains or has the potential to contain a hazardous atmosphere; contains a material that has the potential to engulf an entrant; has walls that converge inward or floors that slope downward and taper into a smaller area which could trap or asphyxiate an entrant; or contains any other recognized safety or health hazards. A culvert can have many of these characteristics. Permit-required confined space entry procedures (as specified in OSHA CFR 1910.146) should be followed for these culverts. These procedures include but are not limited, the following:

- Workers shall be trained in confined space entry procedures.
- Entry hazards shall be evaluated and workers shall be informed of these hazards.
- A written confined space entry plan shall be prepared.
- Before and during culvert entry, the atmosphere shall be tested for oxygen content, flammable gases, and toxic air contaminants.

- At least one attendant shall be provided outside the permit space into which entry is authorized for the duration of entry operations.
- Forced ventilation shall be supplied, if required.

In addition to the requirements of CFR 1910.146, the requirements of CFR 1926.800 "Underground Construction" and MnDOT's Confined Space Program (MnDOT, 2011) should be followed.

### 3.7.3 *Culvert-specific Hazards*

The following culvert-specific hazards should be addressed in addition to the ones associated with most construction sites.

- Hazardous atmosphere: This is of particular concern for blocked culverts. Air flow is restricted and dangerous gases can accumulate or be generated when sediment is disturbed.
- Culvert collapse: The culvert could collapse while workers are inside. Work activities could cause a marginally stable culvert to collapse. A competent person must evaluate these hazards before any work is performed.
- Water: High flow rates can create dangerous footing conditions. Falling into pools at the culvert ends is also a hazard.
- Animals: Animals, particularly snakes, in the culvert can be dangerous, especially if trapped.
- Entrapment: Deep mud can entrap personnel walking through it.

# 4 Culvert Rehabilitation Methods

The rehabilitation methods discussed in this chapter are intended to restore the culvert to its initial condition or better, including providing structural support. The common methods discussed in detail in this guideline include the following.

- Paved invert
- Cured-in-place pipe liner
- Sliplining
- Centrifugally cast liner
- Other methods

Other less common rehabilitation methods are briefly discussed or are not included in this guideline.

## 4.1 **Paved Invert**

For the purposes of this guideline, paved inverts involve placing reinforced concrete on the invert of existing culverts. Culverts with diameters greater than 36” can receive paved inverts since personnel entry is possible.

### 4.1.1 *Paved Invert for Reinforced Concrete Pipe Culverts (RCP)*

Figure 4.1 shows a typical paved invert rehabilitation detail.

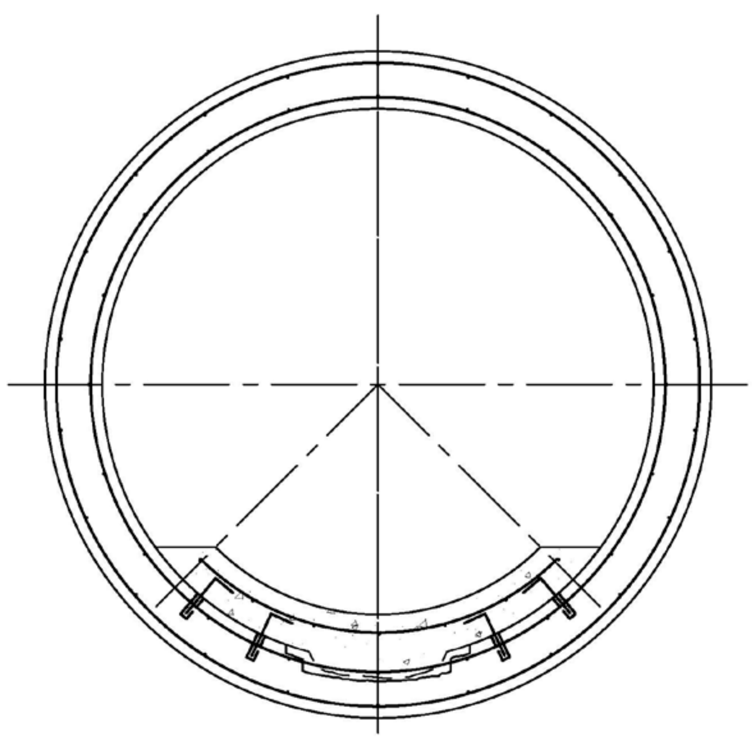

**Figure 4.1 Typical RCP Paved Invert Detail (CNA Consulting Engineers, 2013)**

#### *4.1.1.1 Shoring*

Fully deteriorated reinforced concrete pipe culverts selected for rehabilitation should be evaluated for safety and structural stability. If the structure is not safe for personnel entry, a shoring design should either be provided or the requirements included in the Special Provisions. In addition to safety concerns, it is difficult to achieve good load transfer between a paved invert and the host culvert unless the culvert is first shored and unloaded. Consideration should be given to prevent or limit live load on the culvert during rehabilitation work.

#### *4.1.1.2 Design*

The design of a paved invert for reinforced concrete pipe culverts can fall into two potential categories, partially or fully deteriorated. The definition of partially and fully deteriorated is discussed in Section 2.4.1.

When utilizing invert paving to rehabilitate partially deteriorated culverts, a structural review is not required. To rehabilitate a partially deteriorated invert involves sizing of reinforcement for crack control and sizing of dowel bars to prevent separation and curling of paved invert from the host culvert. Reinforcement, placed in a single layer, should be based on a minimum steel reinforcement ratio of 0.002 times the gross concrete cross sectional area.

When a culvert is fully deteriorated, the invert paving section, reinforcement, and connections between the paving and culvert should be structurally analyzed and designed to restore the culvert's capacity. Consideration should be given to having the Bridge Office or a qualified consultant perform the paved invert analysis and design. The flexural, diagonal tension and radial tension capacity of a fully deteriorated culvert can be evaluated using the software PIPECAR, available from the American Concrete Association or CANDE, which is available from FHWA. As noted above, the culvert should be substantially unloaded or shored, before the structural repairs are completed, otherwise the repair will not participate in carrying load until additional load is imposed on the culvert.

#### *4.1.1.3 Materials*

Selecting the right invert paving materials will play an important role in the constructability and durability of the paved invert.

For paved invert shrinkage and temperature reinforcement, consider the use of welded wire fabric, which concrete pipe fabricators can roll to the nominal inner diameter of culvert. The benefits of using welded wire fabric are: the length of fabric can be aligned with culvert joints, it develops strength quickly and it eliminates the labor to tie reinforcement. Welded wire fabric may also be used to replace lost reinforcement in a deteriorated invert. Many different wire sizes and spacings are available to meet reinforcement area requirements. Circumferential wire spacing, as small as 2 inches is readily available. If rebar is utilized, consider the use of more corrosion resistant reinforcement like MMFX steel and small diameter bars to facilitate field bending.

Once reinforcement is installed, post-installed anchors and solid plastic rebar chairs should be used to position and secure reinforcement. If reinforcement is not accurately positioned, the reinforcement may have insufficient cover and begin corroding.

Adhesively anchored dowel bars should be installed using structural adhesives that tolerate wet or damp holes during installation, are creep resistant and are suitable for constant immersion in water. While the flow will be diverted around the culvert during invert paving operations, the pipe walls may be saturated or there may be water seeping through the joints

The following characteristics should be considered when specifying a ready mix concrete for invert paving:

- Utilize Class A aggregates to increase abrasion resistance and improve durability.
- Add silica fume (micro silica) to increase durability and reduce permeability. Mixes containing silica fume will require the use of high range water reducing admixtures.
- Limit water cement ratio to 0.40, which will increase durability of concrete.
- Use a 3/8-inch maximum aggregate size where the encapsulation of existing reinforcement or welded wire reinforcement is required or where a two inch concrete hose is desirable for placement. Use a 3/4-inch maximum aggregate where a four inch concrete hose can be utilized for placement.
- The slump range should be designed to work well with the placement and forming methods for each project.

Potential MnDOT concrete classifications or mix numbers suitable for invert paving for placement through a two inch hose and four-inch hose are 3W27AMS and 3W23AMS, respectively. As an alternate, the performance requirements may be included in the Special provisionsand the final mix design may be submitted by the contractor and approved by the Engineer.

When a small concrete volume is required, a repair mortar extended with 3/8 inch aggregate can also be considered. Some repair mortars come prepackaged with the aggregate, while others can be extended for use in thicker applications. The value of using a repair mortar is that the material can be mixed on site and placed at a slower rate without exceeding the typical time constraint of 60 minutes for air-entrained ready mix concrete.

#### *4.1.1.4 Construction*

##### *4.1.1.4.1 Concrete Removal*

Use a hammer to sound the concrete culvert for areas of debonding, delamination or deterioration. Debonded or delaminated concrete will sound hollow or drummy. In addition to these areas, concrete areas that should be considered for removal include:

- Eroded concrete with exposed and corroded reinforcement. When exposed and corroded reinforcement is found, remove concrete until no signs of corrosion are evident on reinforcement. If more than 1/3 of the reinforcement bar diameter is exposed during the removal phase, remove concrete completely around the reinforcement. Removal should be ¼-inch plus maximum aggregate size included in the concrete or repair material. A reasonable minimum clearance around existing reinforcement bar is 3/4-inch.
- Concrete that is carbonated with a pH below 10. Concrete with a low pH does not provide corrosion protection to reinforcement. Concrete can be tested for carbonation by

applying phenolphthalein to a fresh concrete surface. If the concrete surface does not turn pink, the concrete is carbonated and should be considered for removal.

- Concrete that has an acid soluble chloride content by weight of cement that exceeds 1% at the reinforcement level. Existing concrete that has high chloride content and not removed may cause accelerated reinforcement corrosion zones around newly placed concrete or repair patches due to the differences in electrical potential. Existing concrete should be sampled and laboratory tested for acid soluble chloride content in accordance with ASTM C1218 Standard Test Method for Water-Soluble Chloride in Mortar and Concrete (ASTM C1218, 2008).

Prior to sawcutting activities, use selective demolition and a pachometer to locate reinforcement and verify existing concrete cover. Concrete culverts should have a minimum concrete cover of 3/4-inch over the existing reinforcement.

Sawcutting the perimeter of the proposed patch area is an important step to prevent feather edges, which are susceptible to failure. Key factors when performing sawcutting include:

- Determine depth to reinforcement to prevent cutting of existing reinforcement.
- Sawcut perpendicular to concrete surface.
- Sawcut perimeter of repair area into regular sided shapes. Opposite faces should be parallel.
- Do not overcut corners. Provide rounded corners if possible. Use small chipping hammers with sharp points to remove corners.

Once the removal perimeter is established by sawcutting, use mechanical equipment, such as chipping hammers to remove the concrete. Limit the size of demolition or chipping hammers to 15 pounds if possible. Larger hammers, up to 30 pounds may be used, but will cause microfracturing (bruising) of the surface. Microfracturing will limit or weaken the bond between the existing and new concrete or repair materials.

Remove concrete waste material from site on a daily basis, and consider environmental effects from high alkalinity runoff due to concrete removal operations.

#### *4.1.1.4.2 Surface Preparation*

Once the deteriorated concrete is removed, use sandblasting or high pressure water to remove damaged concrete. Sand blasting may also be required to remove corrosion from any exposed reinforcement. In addition to removing damaged concrete, sand blasting or high pressure water will provide a suitable surface profile necessary for proper bonding of concrete and repair materials.

Surface profiles (roughness) should be established in the Special provisionsand verified during the removal phase. Refer to the International Concrete Repair Institute (ICRI) guidelines or establish an equivalent sandpaper grit for comparison. A typical surface profile, with a 1/8-inch amplitude, should be adequate in most circumstances. When using repair mortars, the manufacturer data sheet should be reviewed to determine the required surface profile. Use high pressure, oil free air to blow the surface clean and remove any standing water. The concrete surface should be surface saturated dry (SSD) before concrete or repair materials are placed.

When a bonding agent is used to supplement the bond strength between the prepared concrete surface and new concrete or repair materials, carefully consider site and in-service conditions. If a latex bonding agent is used, use only an ASTM C1059 Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete (ASTM C1059, 2008) Type II, as other types may not be suitable for damp or wet in-service conditions.

As an alternative to a latex bonding agent, an epoxy bonding agent may be used to supplement the bond strength between the prepared concrete surface and the paved invert. A 100% solids, moisture insensitive, non-sag epoxy bonding agent meeting the requirements of ASTM C881 Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete (ASTM C881, 2010), Type V, Grade 3 or AASHTO M 235 Standard Specification for Epoxy Resin Adhesives (AASHTO, 2013) is suitable. The paved invert must be placed while the epoxy bonding agent is still tacky (open time), otherwise a second coat must be reapplied.

If existing culvert reinforcement is exposed during the removal phase consider using a corrosion inhibiting bonding agent but, limit the thickness of bonding agent to prevent loss of reinforcement bond due to loss of bar deformation. Also consider the time required to apply the bonding agent and the open time. If the bonding agent open time is too short and the bonding agent hardens, it will act as a bond breaker between the existing concrete and new concrete or repair materials.

#### *4.1.1.4.3 Placing Paved Invert*

Placement of paved inverts will require the use of a concrete pump and hose system for the majority of projects due to limited site access and space within the culvert. A screeding template and screed lines or pipes should be established prior to the placement of concrete. All reinforcement should be adequately supported and secured in place to prevent movement during concrete placement. Maintain 2 inches of clear cover to newly placed or existing reinforcement.

Prevent ground and surface waters from entering the culvert during concrete placement operations. Refer to Chapter 3 for discussions on flow diversion and infiltration control.

Properly cure concrete and repair mortars. Concrete mix designs and repair mortars containing silica fume (micro silica) require special attention for proper curing. Prevent flow of water over newly placed concrete for a minimum of 48 hours.

#### *4.1.1.4.4 Protective Systems*

Coatings, such as silanes and siloxanes, and cathodic protection are potential methods of extending the life of the paved invert. Coating environmental application requirements are difficult to achieve in the field. Cathodic protection can also be considered but all reinforcement must be bonded to be effective.

*4.1.1.4.5 Quality Control*
Ready mix concrete should be tested for temperature, slump, air content and compressive strength to verify conformance with the Special Provisions.

*4.1.1.5 Routine Maintenance*
Paved inverts should be routinely inspected and maintained. Routine maintenance could include cleaning debris accumulating at the inlet, sealing leaking culvert joints and repairing local spalls and erosion of the invert.

4.1.2 *Paved Invert for Corrugated Steel Pipe (CSP)*

*4.1.2.1 Design*
Paving CSP culvert inverts involves removing deteriorated steel and replacing it with new reinforced cast-in-place concrete. The design of a paved invert for corrugated steel pipe culverts is discussed in two sources, Corrugated Steel Pipe Design Manual (NCSPA, 2008) and ASTM A979 – Standard Specification for Concrete Pavements and Linings Installed in Corrugated Steel Structures in the Field (ASTM A979, 2009). Figure 4.2 shows a completed paved invert in CSP pipe.

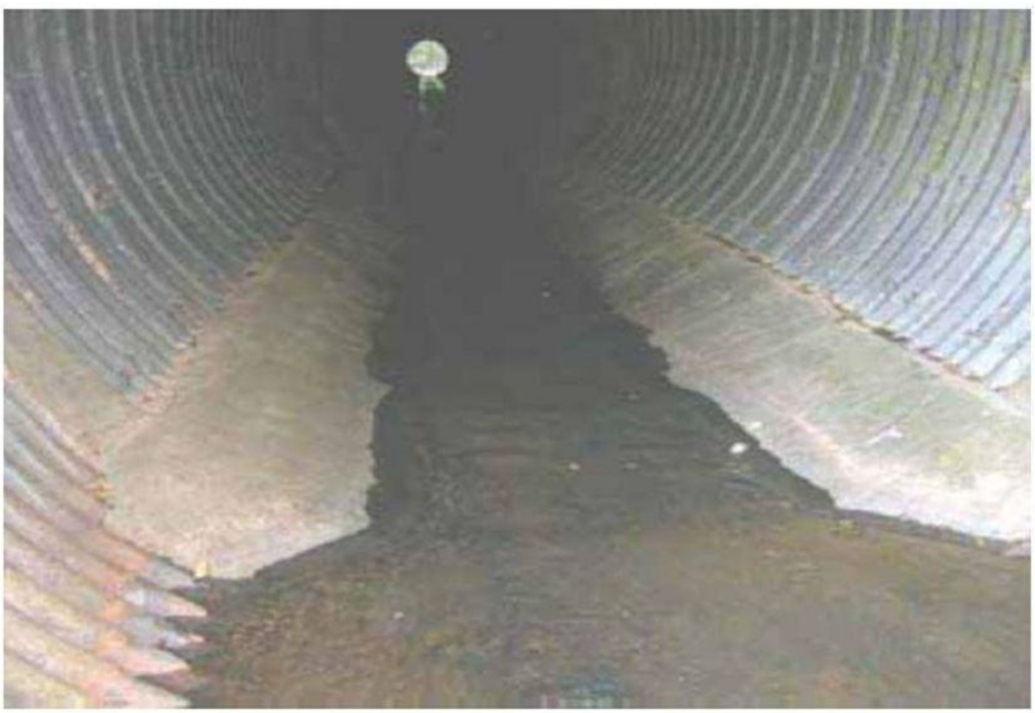

**Figure 4.2 Paved Invert in CSP (FHWA, 2010)**

For pipe culverts with partially deteriorated inverts, as defined in Section 2.4, the paved invert will only require minimum shrinkage and temperature reinforcement and moderately-spaced headed stud connectors to control movement and curling.

When a corrugated steel pipe culvert invert is fully deteriorated, as defined in Section 2.4.1, the paved invert analysis and design should be performed by the Bridge Office or a qualified consultant. The paved invert reinforcement and connections to the existing culvert should be sized to replace the structural capacity of deteriorated culvert section.

#### *4.1.2.2 Shoring*

Fully deteriorated corrugated steel pipe culverts should be evaluated for safety and structural stability. If the structure is not safe for personnel entry, a shoring design should either be provided or the requirements included in the Special Provisions. In addition to safety concerns, it is difficult to achieve good load transfer between a paved invert and the host culvert unless the culvert is first shored and unloaded. Consideration should be given to prevent or limit live load on the culvert during rehabilitation work.

#### *4.1.2.3 Materials*

See Section 4.1.1.3 Materials for recommendations on concrete, repair mortar, and reinforcement used in the construction of paved inverts for corrugated steel pipes.

Headed studs should be welded to the crest of the corrugations to assist in securing the paved invert to the existing corrugated steel pipe. Typical corrugations patterns result in welded stud spacing increments of 8” for 2-2/3” corrugation spacing and 9” for 3” corrugation spacing. Headed stud diameters in the range of 3/8-inch to 1/2-inch should be utilized. The recommended minimum plate thickness is 0.075” for 3/8-inch headed studs and 0.120” for 1/2-inch headed studs. It is recommended that 3/8-inch studs be used, unless the corrugated steel pipe wall thickness is verified to meet the1/2-inch stud recommended minimum base metal thickness. Headed stud manufacturers should also be consulted regarding the use of special ferrules for welding on curved surfaces. Discharge capacitor type studs may also be considered, as they limit the damage to existing coatings on the exterior of the culvert.

#### *4.1.2.4 Construction*

##### *4.1.2.4.1 Removal of Damaged or Corroded Culvert*

Severely corroded sections of the culvert invert should be carefully removed to facilitate placement of grout below the culvert. Any intact portions of the culvert invert should be left in place to assist in carrying the applied loadings.

##### *4.1.2.4.2 Surface Preparation*

The surface of the corrugated steel pipe should be thoroughly cleaned prior to placement of the paved invert. Corroded metal and loose rust on the culvert invert should be removed by high pressure water.

A bonding agent may be used to supplement the bond strength between the prepared steel surface and the paved invert. A 100% solids, moisture insensitive, non-sag epoxy bonding agent meeting the requirements of ASTM C881 Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete (ASTM C881, 2010), Type IV, Grade 3 or AASHTO M 235 Standard Specification for Epoxy Resin Adhesives (AASHTO, 2013) is suitable. One of the challenges with using an epoxy bonding agent is the short open time. The paved invert must be placed while the epoxy bonding agent is still tacky (open time), otherwise a second coat must be reapplied.

*4.1.2.4.3 Placing Paved Invert*

See Section 4.1.1.4.3 Placing paved invert for recommendations.

*4.1.2.4.4 Protective Systems*

Coatings, such as silanes and siloxanes, are potential methods of extending the life of the paved invert, however, typical coating application environmental requirements are difficult to achieve in the field.

*4.1.2.4.5 Quality Control*

See Section 4.1.1.4.5 Quality control recommendations.

*4.1.2.5 Routine Maintenance*

See Section 4.1.1.5 for maintenance recommendations.

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

Cured-in-place-pipe lining involves the insertion of a felt or fiber tube saturated with resin. There are two methods of installing CIPP liners, pulled-in-place and inversion. Figure 4.3 shows a CIPP liner installed by the inversion method, which is outlined in ASTM F1216 - Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube (ASTM F1216, 2009). Installation of CIPP liners by the pulled-in-place method is outlined in ASTM F1743 - Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP) (ASTM F1743, 2008). The most common resin types are polyester or vinyl ester. Other resin types including epoxy are available to accommodate special project conditions and constraints. Pipes with diameters ranging from 3 inches to greater than 96 –inches have been lined with CIPP.

**Figure 4.3 Cured-in-Place Pipe Installation by the Inversion Process (FHWA, 2010)**

### 4.2.1 *Design*

Design of cured-in-place-pipe liners (CIPP) installed by either the pulled-in-place or inversion method will follow the design equations outlined in ASTM F1216, Appendix X1. The design of the CIPP liner will fall into one of two categories, partially deteriorated or fully deteriorated. In lieu of determining the level of deterioration, the design can conservatively assume a fully deteriorated pipe condition.

In general, the CIPP installer or manufacturer will perform the final liner thickness calculations, based on the design requirements included in the Special Provisions. The final liner thickness will vary slightly by manufacturer, based on the manufacturer's specific liner tube materials, configuration and resin mechanical properties.

#### *4.2.1.1 Partially Deteriorated Design*

A partially deteriorated design is used when the existing culvert pipe is capable of supporting the design loads for the duration of its remaining service life. Refer to Section 2.4.1 for definitions of partially deteriorated flexible and rigid culverts.

The only design loading for partially deteriorated CIPP liner is the exterior water pressure on the culvert. This design value should be based on a maximum value, such as a 50 or 100 year flood elevation. When an exterior water pressure condition does not exist, the CIPP liner thickness should be sized to provide a maximum size to diameter ratio (SDR) of 100.

The design criteria listed in Table 4.1, as outlined in F1216 Appendix X1, will need to be established and included in the Special provisions to allow the CIPP manufacturer to perform the final liner design:

**Table 4.1 CIPP Partially Deteriorated Culvert Design Criteria**

| Design Variable | Recommended Value | Comments |
|---|---|---|
| Culvert Inside Diameter | Varies (in.) | Mean inside diameter of original culvert |
| Groundwater Pressure: P | Varies (psi) | Measured from culvert invert |
| Enhancement Factor: K | 7 | Minimum typical value |
| Long-term Modulus of Elasticity of the CIPP Liner: $E_L$ | 125,000 psi minimum | Use 50% of initial value. Minimum initial value is 250,000 psi. Consult with prospective CIPP manufacturers |
| Poisson's Ratio of the CIPP Liner: n | 0.3 | Average value |
| Culvert Deflection: Δ | Varies, field measured | A minimum recommended value of 2% should be specified. |

*4.2.1.2 Fully Deteriorated Design*

A fully deteriorated design is used when the existing culvert pipe is no longer capable of supporting the design loads now or during its remaining service life. A fully deteriorated CIPP design assumes the liner must carry all design loadings including soil, live and hydrostatic loads. The design criteria listed in Table 4.2 will need to be established and included in the Special provisionsto allow the CIPP manufacturer to perform the final liner design.

**Table 4.2 CIPP Fully Deteriorated Culvert Design Criteria**

| Design Variable | Recommended Value | Comments |
|---|---|---|
| Culvert Inside Diameter | Varies (in.) | Mean inside diameter of original culvert |
| Soil Density: w | 120 pcf, minimum | Consider choosing value based on specific soil conditions |
| Live Load: Ws | Varies (psi) | Follow AASHTO LRFD Bridge Design Specifications (AASHTO, 2012) Article 3.6.1.2.6 |
| Height of Water above Culvert Crown: Hw | Varies (ft.) | Use long term values, such as 100 year flood |
| Height of Soil above Culvert Crown: H | Varies (ft.) | Use maximum burial depth of alignment |
| Culvert Deflection: Δ | Varies, field measured | A minimum recommended value of 2% should be specified. |
| Modulus of Soil Reaction E’s | Varies (psi) | Follow AASHTO LRFD Bridge Design Specifications (AASHTO, 2012) Article 12.12.3.5.1 |
| Long-term Modulus of Elasticity of CIPP Liner: $E_L$ | 125,000 psi minimum | Use 50% of initial value. Minimum initial value is 250,000 psi per ASTM F1216, Table 1. Consult with prospective CIPP manufacturers for actual values. |
| Factor of Safety: N | 2 | A value of 2 is typical, other values can be selected. |

### 4.2.2 *Materials*

The following was modified from ASTM F1216 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube (ASTM F1216, 2009).

The CIPP tube should consist of one or more layers of flexible needled felt or an equivalent nonwoven or woven material, or a combination of nonwoven and woven materials, capable of carrying resin, withstanding installation pressures and curing temperatures.

The CIPP resin consists of a general purpose, unsaturated, styrene-based, thermoset resin and catalyst system or an epoxy resin and hardener. The resin must be able to cure in the presence of water and the initiation temperature for cure should be less than 180º F.

### 4.2.3 *Environmental Considerations*

CIPP installations involve the use of chemicals and temperatures that could be harmful to aquatic life. Studies have shown that styrene and other chemicals used in the CIPP resins are sometimes released in concentrations above toxicity thresholds. As a result, the installation of a CIPP liner requires careful planning and execution to reduce the potential for environmental impacts, especially to the downstream receiving waters. It is recommended that all process water used in the curing and post installation cleaning operations be captured. The captured waters should be transported to a local wastewater treatment facility capable of treating the impacted water. It is important to verify that the local wastewater facilities have the capabilities and capacity to handle the impacted water during the initial phase of design.

The following publications are recommended for additional discussion on the environmental implications of styrene and non-styrene based resins:

1. NASSCO CIPP Committee, 2008. Guidelines for the Use and Handling of Styrenated Resins in Cured-In-Place-Pipe (NASSCO CIPP Committee, 2008).
2. Moore, William, 2011. Non-Styrene Options For Cured-in-place Pipe. NASTT – No Dig (Moore, 2011).
3. Donaldson, Bridget M, Andrew J. Baker, 2008. Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology (Donaldson, Bridget M. and Baker, Andrew J., 2008).
4. Donaldson, Bridget M, 2012. Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners (Donaldson, Bridget M., 2012).
5. Tingberg, Fred Jr., “Green” Cured-in-place Pipe Utilization, Styrene Free Emerging Methods and Resin Systems,; Lanso Lining Services (Tingberg, Jr., 2012).

#### *4.2.3.1 Curing Methods*

Currently there are three methods used to cure out a CIPP liner: hot water, steam and ultraviolet light. Hot water is the most common method of curing with the longest history, but has the greatest disposal volume. Steam curing has not been used as long, but it does not produce as much water and cures the liner faster. Ultraviolet light is becoming more common but currently has limitations on culvert diameter. A liner that is not properly cured can release increased amounts of styrene and other harmful chemicals to the receiving waters, even if the process water is properly collected and disposed of. Section 4.2.4.5 and the Special provisionsdiscuss verification of proper curing and handling of process water that can prevent discharge of harmful chemicals to the environment.

#### *4.2.3.2 Thermal*

Water discharged from the cured liner will typically be above the ambient temperature of surrounding surface waters. Hot water or steam condensate discharged could result in a fish or aquatic life kill. In general, the internal water temperature is cooled down to 100º F or less before the water is slowly released from the liner so the liner is not cooled too quickly. Again, it is recommended that all process water be collected and properly disposed of.

### 4.2.4 *Construction*

#### *4.2.4.1 Removal of Damaged Culvert*

Any portion of the existing culvert protruding beyond the interior of the culvert should be removed to prevent loss of hydraulic capacity.

#### *4.2.4.2 Surface Preparation*
The interior of the culvert should be thoroughly cleaned prior the insertion of the liner. High pressure water is the most common method. In certain instances where high pressure water does not remove deposits or debris, hand operated power tools or mechanical equipment may be necessary.

#### *4.2.4.3 Repair Techniques and Material Installation*
Any voids in the invert will need to be filled prior to the installation of the CIPP liner. See Section 5.3 Void filling outside the Culvert. Small gaps and offsets in the pipe culvert joints can be bridged by the CIPP liner. Significant gaps and offsets should be repaired, as the condition that originally caused the damage will likely damage the CIPP liner. Significant invert damage in reinforced concrete pipe culverts should be repaired according to the recommendations outlined in Section 5.1 Spall Repair.

#### *4.2.4.4 External Void Filling*
External voids should preferably be filled prior to the placement of the CIPP liner, provided the existing culvert can withstand any increased loading due to the grout placement. When the culvert invert is fully deteriorated, consideration should be given to filling any external void after the installation of the CIPP liner. See Section 5.3 Void filling outside the Culvert.

#### *4.2.4.5 Quality Control*
Inspectors observing the installation of CIPP liners should have previous experience with this type of work or take the NASSCO cured-in-place-pipe inspector training class. Special provisionsshould require that the contractor hire an independent third party, NASSCO-trained inspectors to monitor the installation and curing.

Thermocouples should be installed at each end of the liner to verify that the curing recommendations from the manufacturer are achieved. In addition, samples should be prepared in accordance with ASTM F1216 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube (ASTM F1216, 2009) and then tested for conformance with the manufacturer’s final CIPP design values.

### 4.2.5 *Routine Maintenance*
CIPP liners should require very little maintenance. They should be routinely inspected as part of the HydInfra program. Things to watch for include eroded invert, deformation due to soil loading and other movement, and deterioration at the ends of the CIPP.

## 4.3 **Sliplining**
Sliplining involves inserting a pipe liner of smaller diameter directly into a deteriorated culvert. Liners are inserted into the host by either pulling or pushing the liner into place. After insertion, the annular space between the existing culvert and liner is generally grouted with a cementitious material providing a watertight seal. Annular space is the space between the outside diameter of the pipe being installed and existing culvert. Sliplining can further be categorized into segmental and continuous sliplining (FHWA, 2005). Culverts ranging from 18 inches to 160 inches can be sliplined. Figure 4.4 shows a slipliner grouted in place.

**Figure 4.4 PVC Slipliner and Grout Injection Pipes (FHWA, 2010)**

**Segmental Sliplining** consists of lining the deteriorated culvert with sections shorter than that of the existing culvert. A bell or spigot joint is commonly used to join culvert segments. Segments of the liner are assembled at entry points and forced into the host culvert. As each segment is added, the liner is forced further into the existing culvert until lining has been completed (FHWA, 2005).

**Continuous Sliplining** involves the lining of a deteriorated culvert with a continuous liner. Liners are generally made from polyethylene or high-density polyethylene pipe segments that are butt-fused together. The continuous liner is pulled, pushed, or simultaneously pushed and pulled into the host culvert. Once installed, the annular space is generally grouted and service connections are reopened (FHWA, 2005).

### 4.3.1 *Design*

#### *4.3.1.1 Structural*

Three design conditions are possible when evaluating a sliplined culvert rehabilitation:

1. The existing culvert has adequate structural capacity (partially deteriorated).
2. The existing culvert's structural capacity needs to be enhanced by the slipliner.
3. The slipliner is required to carry all loads (fully deteriorated).

Conditions 1 and 3 can be analyzed per AASHTO LRFD Bridge Design Specifications (AASHTO, 2012) Section 12 “Buried Structures and Tunnel Liners”. Condition 2 is difficult to analyze and most slipliner repair designs assume either condition 1 or 3. If the existing culvert is difficult to assess, the conservative approach is either replace the culvert or to assume condition 3. The Engineer can also use AASHTO LRFD Bridge Design Specifications Section 12 to check the structural capacity of the slipliner pipe.

Rehabilitating a fully deteriorated culvert by sliplining may require assistance from a civil or structural engineer experienced with culvert analysis and design. They may be able to provide assistance with selection of design values for modulus of soil reaction E’ based on the condition of the host culvert and soil conditions.

#### *4.3.1.2 Hydraulics*

The sliplined culvert will always have a smaller diameter than the existing culvert. In many cases, the slipliner will have a lower barrel roughness. The Engineer needs to verify that the sliplined culvert has adequate hydraulic capacity. See Section 2.3 for further discussion.

### 4.3.2 *Sliplining Materials*

There many different types of pipe that can be used for sliplining. Pipe choice is dependent on a variety of factors, including the following:

- Cost for both materials and installation
- Structural capacity
- Ability to withstand installation loads
- Hydraulics
- Pipe joint ability to prevent leakage of grout

Pros and cons of various sliplining materials are listed in Table 4.3 below:

**Table 4.3 Slipliner Material Advantages and Disadvantages**

| Pipe Material | Advantages | Disadvantages |
|---|---|---|
| CSP, MnDOT 3222 | Lower material cost, smooth interior pipe is available, lightweight, readily available, can be manufactured to any size, more dimensionally stable | Susceptible to corrosion and abrasion, high Manning's n for pipe without smooth interior, more difficult to slide into place due to corrugations– skids may be required |
| Solid Wall HDPE, ASTM F714 | Fused joints are watertight and can withstand pulling forces; impact, corrosion and abrasion resistant | Less dimensionally stable |
| Corrugated HDPE with Smooth Interior, AASHTO M294 Type S | Lightweight, impact, corrosion and abrasion resistant, watertight joints | Less dimensionally stable, more difficult to slide into place due to corrugations – skids may be required |
| Profile Wall HDPE, ASTM F894 | Lightweight, impact resistant, corrosion and abrasion resistant, watertight joints | More difficult to slide into place due to corrugations – skids may be required |
| Closed-profile HDPE | Smooth exterior makes installation easier, joints can withstand pulling forces, impact resistant, corrosion and abrasion resistant | Higher capital cost |
| Steel Reinforced HDPE, ASTM 2562 | High strength to weight ratio, corrosion and abrasion resistant | More difficult to install due to corrugations – skids may be required. Higher capital cost |
| Dual Wall Corrugated PVC, ASTM F949, AASHTO M304 | Lightweight, corrosion and abrasion resistant | Brittle in cold temperatures |
| Closed Profile PVC, ASTM F1803 | Lightweight, corrosion and abrasion resistant | Brittle in cold temperatures |
| Open Profile PVC, ASTM F794 | Lightweight, corrosion and abrasion resistant | Brittle in cold temperatures |
| Solid Wall PVC, ASTM F679, AASHTO M278 | Corrosion and abrasion resistant | Brittle in cold temperatures |
| Fiberglass Sewer Pipe (FSP), ASTM D3262 | More dimensionally stable, high strength to weight ratio, corrosion & abrasion resistant | Higher material cost |

#### *4.3.2.1 Pipe Dimensions*

As stated in Section 3.5, the slipliner, including joints, must be small enough to fit inside the culvert, which could be deformed, while leaving enough space for the minimum grout thickness. Appendix A of Culvert Repair Practices Manual, Pub. No. FHWA-RD-94-096 (FHWA, 1995) lists standard sizes of many types of pipe. Since new pipe types are constantly being developed, it is best to refer to manufacturer's literature for specific dimensions.

#### *4.3.2.2 Corrugated Steel Pipe (CSP)*

Along with reinforced concrete pipe (RCP), CSP is the most common culvert material installed in the state. CSP is a low cost, readily available pipe material. Damage during installation and corrosion of the pipe are concerns. Figure 4.5 shows a CSP liner grouted inside a CSP culvert.

**Figure 4.5 CSP Slipliner, Grouted inside CSP Culvert (FHWA, 2010)**

To assess corrosion, the St. Anthony Falls Laboratory conducted a MnDOT-commissioned study on factors affecting culvert service life in Minnesota. They stated "16-gage corrugated aluminized steel (CAS) should be the default CSP for Minnesota. CAS can be used in a similar range of pH and has a predicted service life of 3 to 8 times longer than galvanized CSP in both dry and wet conditions and CAS have fewer abrasive and installation damage concerns than polymer coated CSP" (St Anthony Falls Laboratory, University of Minnesota, 2012).

"Chapter 14 of AASHTO Highway Drainage Guidelines: Fourth Edition (AASHTO, 2007) states that aluminizing is effective for a pH range of 5.0 to 9.0 and a soil resistivity of greater than 1500 ohm-cm. Corrugated aluminized steel pipe (CAS) does not have appreciable abrasion resistance. Chapter 14 cites concrete invert paving is an effective abrasive resistant coating. Concrete thicknesses are typically between 3 and 6 inches" (St Anthony Falls Laboratory, University of Minnesota, 2012).

#### *4.3.2.3 High Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC) Pipe*

HDPE and PVC are flexible pipes that are corrosion and abrasion resistant. The following paragraphs describe these pipes. This discussion was modified from Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011):

Plastic pipe made of polyvinyl chloride (PVC) and high-density polyethylene (HDPE) is commercially available in a variety of diameters and styles that are adequate for the purpose of relining existing culverts. Many types of solid wall, profile wall and ribbed PVC and HDPE are manufactured that are also capable of performing the necessary function. No attempt is made to list every type of plastic pipe that could be used. The following information describes some of the most likely alternatives that are readily available.

The most economical types currently manufactured are PVC sewer pipe (AASHTO M-278/ASTM F679), PVC ribbed pipe (AASHTO M-304), Type C (corrugated interior) and Type S (smooth interior) corrugated HDPE (AASHTO M-294). HDPE solid wall fusion welded or Snap-Tite™ (ASTM F-714) is relatively expensive but has a variety of diameters and wall thicknesses. HDPE solid wall pipe is listed by Standard Dimension Ratio (SDR) classification (Standard Dimension Ratio given by the ratio of outside diameter to wall thickness with the lower SDR's having thicker walls). Also available is PVC profile wall sewer pipe (ASTM F-794 and F-949). Also relatively expensive, this smooth interior and smooth exterior pipe (closed profile) with an internal rib can be easier to install than other types and does not require couplers, belling, or other connectors that would increase the pipe diameter at the joints. Several pipe products are made specifically for sliplining with joint systems designed to maintain a constant outside and inside diameter. Some examples of these are the Contech A2 Liner Pipe™ (PVC), the Vylon PVC Slipliner Pipe™, and the Weholite™ Culvert Reline System (HDPE).

Pipe stiffness is a common term used in describing plastic pipe's resistance to deflection prior to placing any backfill. The higher the number, the stiffer the pipe, and the better the pipe's resistance to grouting pressure and handling. (Caltrans, 2011).

#### *4.3.2.4 Fiberglass Sewer Pipe (FSP)*

There are two basic types of fiberglass sewer pipe that can be used to slipline culverts, filament wound and centrifugal cast. Filament wound pipe is constructed by winding glass fibers or filaments coated with a polyester resin around a mandrel. Filament wound pipe is inside diameter controlled. Centrifugal-cast pipe is constructed by placing glass fibers, resin and a sand-resin mixture inside a spinning mold tube and thus is an outside diameter controlled. Centrifugal-cast pipe is also the most readily available pipe in this area. There are a number of different gasketed joint styles available including, FWC couplings, low profile bell-spigot, and flush bell-spigot. FSP is manufactured and testing in accordance with ASTM D3262 Standard Specification for

“Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) (ASTM D3262, 2011). Figure 4.6 shows the wall of a Hobas® pipe, which is a centrifugal cast FSP.

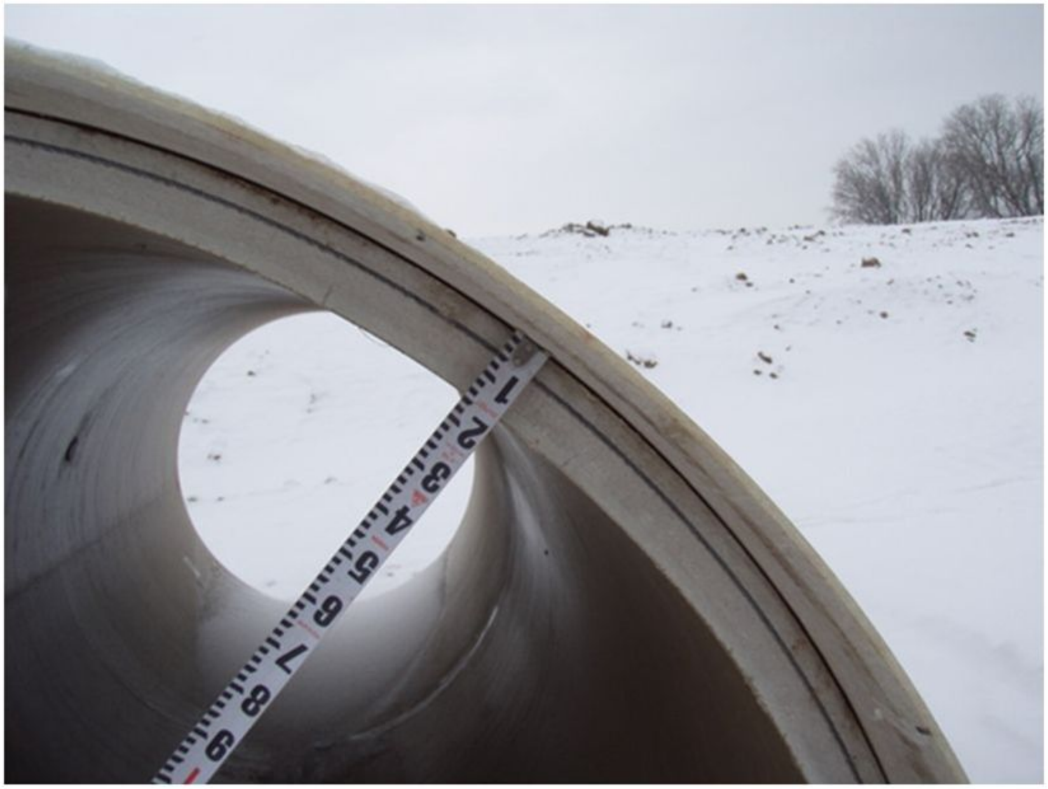

**Figure 4.6 Hobas FSP Pipe (CNA Consulting Engineers)**

FSP has good corrosion resistance. For sliplining applications, FSP is appropriate for larger diameter culverts where a higher strength slipliner is required. Fiberglass pipes are generally more expensive than the plain unreinforced plastic pipe and they are more routinely used to line pipelines.

FSP is currently not approved for MnDOT projects. It would need to go through an approval process before being used.

*4.3.2.5 Steel Reinforced Polyethylene (SRPE) Pipe*

SRPE pipe is constructed of steel reinforcing inside a HDPE resin. This design provides larger load carrying capacity than other types of plastic pipe and therefore allows for higher burial depths. It has good corrosion resistance since the steel reinforcement is covered with HDPE. For sliplining applications, it is appropriate for larger diameter culverts where a higher strength slipliner is required. Figure 4.7 shows the wall construction of an SRPE pipe.

SRPE pipe is currently not approved for MnDOT projects. It would need to go through an approval process before being used.

**Figure 4.7 DurroMaxx SRPE Pipe Wall (Contech Engineered Solutions)**

*4.3.2.6 Pipe Joints*

The following is modified from Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011):

In general, joints in pipes used for slipliners will not be subjected to the same performance requirements, as are joints in direct burial applications. The encasement provided by both the host culvert and the annular space grouting will typically isolate slipliner pipe joints from problems associated with infiltration/exfiltration, separation or misalignment. What is important is an understanding of the physical dimensions of various pipe joints to ensure that there is adequate space to both insert the liner pipe and feed in the annular space grout (at least 2 inches of space on all sides is desirable to ensure that the grout can completely envelop the slipliner), and to ensure that the joint is sufficiently tight to preclude migration of grout through the joint during the annular space grouting operation (which may have operating pressures of several psi). At a minimum, joints described as soil tight (up to 2 psi pressure without leakage) should be specified, and where it is anticipated that grouting pressures are likely to exceed 4 psi, joints meeting watertight requirements should be used.

Several manufacturers have developed modified joints for their pipes specifically for sliplining applications. This generally is accomplished by routing out male and female ends of the pipes and eliminating the bell end. As such, the increased external dimension of the bell is eliminated, minimizing the loss of host culvert cross sectional area. Several of these specially modified pipes are available in both PVC and HDPE. To date, however, one of the most commonly used plastic slipliners is solid wall HDPE. The sections of HDPE are typically "joined" via a fusion-welding machine, which results in a continuous pipe structure with no change in inside or outside dimension at the locations where pipe segments are fused. Butt fusion procedures for solid wall HDPE are described in Appendix A of Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011).

Also to be considered when specifying the type of pipe, and its joint type, is the likely method of insertion of the liner into the host culvert being rehabilitated. Most plastic joints used in sliplining applications have little to no ability to resist tensile forces. As such, they must be pushed, or jacked through the culvert being rehabilitated. Only fusion welded joints and some of the types with routed ends with overlapping tabs will allow a combination of pushing and pulling the liner through the host culvert. The ability to pull as well as push can be important where very long (or heavy) segments are being inserted, or where deflections, discontinuities or angle points in the host culvert increase the force needed to bring the liner into place.

#### *4.3.2.7 Grout*
Listed below are grout characteristics suitable for sliplining applications.

- Easily placed/pumpable over large distances.
- Flows easily/self-leveling so that it completely fills the annulus between the culvert and slipliner.
- Lower strength requirements. Compressive strength of 100 psi should be adequate in most cases.

Low density cellular concrete meets these requirements and is recommended. Benefits of cellular grout include:

- Buoyant forces on the pipe are less than those for normal weight grout.
- Placement pumping pressures are less than those for normal weight grout. Excessive pressures can collapse the slipliner.

If water is present during the grouting operation, the grout density should be higher than 70 pcf to ensure that the water is displaced.

A disadvantage of cellular concrete is that "standard concrete mixing equipment is not acceptable because the mixer does not combine the ingredients with the correct speed and mixing action. A high speed paddle mixer is preferable because it properly combines the ingredients and blends the preformed foam rapidly and efficiently to produce a uniformly consistent low-density cellular concrete mixture. Other mixers and processes the produce uniform mixtures include high-shear mixers" (ACI, 2006).

### 4.3.3 *Construction*

#### *4.3.3.1 Preparation*
The culvert must be checked and prepared as described in Chapter 3. In addition, resetting culvert end sections before sliplining may be desirable in some cases. These sections are commonly misaligned due to embankment movement or freeze/thaw. It has been found that it is

easier to excavate and reset these sections before sliplining rather than trying to line a misaligned culvert.

#### *4.3.3.2 Installing Liner*

The first step in installing the liner is preparing the insertion site to ensure there is adequate working area to install either the segmental or continuous slipliner. This may require improvement of the ground in front of the culvert to make it accessible for equipment.

The liners are either pushed or pulled into the culvert or some combination of pushing and pulling is used. In any case, the pipe joints need to withstand the installation forces. Corrugated or ribbed liners will be more difficult to install than smooth liners. The pipe manufacturer should be consulted about maximum push/pull forces or distances. The joint strength of various types of pipe may need to be enhanced for installation or grouting.

Use of skids is recommended to ease installation and to ensure minimum grout thickness. The minimum spacing and type of skids and bracing should be reviewed to ensure that the pipe is adequately supported. The pipe manufacturer or guides should be consulted. As an example for PVC pipe, The Handbook of PVC Pipe Design and Construction (PVC Pipe Association, 2012) Chapter 8, Table 8.6 lists support spacing for suspended horizontal PVC pipe filled with water. This table can be used for conservative estimate of support spacing when filling pipe with water when backfill grouting.

A bullet-shaped nose piece on the leading end of the slipliner, shown in Figure 4.8, can aid in the installation, especially if the culvert is deformed or not completely straight. It is common to cut v-notches in the end of HDPE slipliner and gather the end to make the bullet shape.

**Figure 4.8 Bullet-Shaped Nose on HDPE Slipliner (FHWA, 2010)**

Care needs to be taken when installing PVC liners since they can become brittle and crack in cold temperatures. Ribs on PVC need to be protected from cracking during handling and installation.

*4.3.3.3 Bulkheads*

Bulkheads are the seals at the ends of the slipliner in the annular space between the slipliner and culvert. Their purpose is to contain the grout. They will need to withstand grouting pressures without leakage. Various methods can be used. It is best to leave the sealing method to the contractor to adapt to conditions at each site. The bulkheads are commonly a cementitious grout or oakum and chemical grout seal. A resistant concrete cap should be placed in front of the bulkhead if the bulkhead material can erode or weather.

*4.3.3.4 Grouting*

Grouting the annular space between the culvert and slipliner is recommended for the following reasons:

- The slipliner is securely attached the culvert.
- The potential for joint leakage, piping, and void propagation outside the culvert is reduced.
- Soil-structure interaction is provided, which is important for flexible slipliners.

Grouting procedures are described in Appendix B-40 of Culvert Repair Practices Manual, Pub. No. FHWA-RD-94-096 (FHWA, 1995). Important considerations for grouting include:

1. The slipliner must be prevented from floating or displacing during the grouting operations. This can be prevented by:
    a. Increasing the weight of the pipe by filling with water or other material.
    b. Blocking the pipe. Blocking must be properly designed so that point loads are not placed on the slipliner.
    c. Placing the grout in lifts.

    It is best to leave these decisions to the contractor so that he can implement his preferred means and methods of installation. They should be required to submit the methods for resisting buoyancy along with appropriate calculations.

2. Grouting pressures must be kept below those which would damage the pipe. Pipe literature should be checked for maximum allowable pressures. Some grouting pressure guidance is listed below:
    a. The Handbook of PVC Pipe Design and Construction (PVC Pipe Association, 2012), Chapter 10 contains allowable grouting pressures for various PVC pipe types and stiffnesses.
    b. HOBAS Pipe (HOBAS Pipe, 2013)has recommended grouting pressures for their pipe based on pipe stiffness.
    c. Plastic Pipe Institute, Handbook of PE Pipe (Plastic Pipe Institute), Chapter 11 contains guidance on allowable hydrostatic pressures based on pipe stiffness.
    d. NCSPA Corrugated Steel Pipe Design Manual (NCSPA, 2008), Chapter 8, Section "Hydrostatic Buckling" contains guidance on calculating hydrostatic buckling of circular tubes under uniform external pressure.

    Pressures should be monitored during installation. It is preferable to locate pressure gauges near the bulkhead to provide readings that are most representative of pressures inside the culvert. Grout pressure in the lines between the gauge and insertion port needs to be added to the gauge reading if the gauge is at a higher elevation than the culvert. This must also be done to account for grade changes along the culvert.

It is desirable to place the grout from the downstream end and fill upstream. Vents should be placed at the crown of the upstream end. In this way, one can be sure that the annular space is completely full when grout is observed exiting the vent pipe.

#### *4.3.3.5 End Treatments*

After the slipliner has been placed, end treatments such as aprons, improved inlets, and outlet protection should be installed as required by the site and hydraulic requirements. Refer to the Drainage Manual for guidance. MnDOT Series 3000 Standard Plates contain details for aprons, rip rap, and other culvert materials. For hydraulic reasons, the slipliner should not project out of the culvert.

*4.3.3.6 Quality Control*
The following should be monitored during construction:

- Inspect the slipliner, particularly the pipe joints, for damage during installation.
- Take samples of grout for density and compressive strength.

### 4.3.4 *Routine Maintenance*
Slipliners should require very little maintenance. They should be routinely inspected as part of the HydInfra program. Things to watch for include eroded invert, deformation due to soil loading and other movement, and deterioration at the ends of the slipliner.

## 4.4 **Centrifugally Cast Liner**
Centrifugally cast liners are liners applied to the culvert interior by an electric or air powered rotating head, as shown in Figure 4.9. The liners can be constructed of cementitious mortar or other material. Cementitious mortars will be discussed in this guide. They are usually applied to CSP culverts to provide corrosion protection and to enhance the structural capacity. Pipes between 30 inches and 120 inches in diameter can be lined.

**Figure 4.9 Centrifugally Cast Liner Installation (Betcher, 2010)**

The thickness of the applied mortar is controlled by the speed at which the machine is pulled through the culvert. After the liner has been applied, rotating or conical drag trowels can be used to provide a smooth troweled finish, if required. Unless reinforced, cement-mortar spray-on lining adds little or no structural integrity to the existing culvert. Typically, fibers in the mix are used to enhance the flexural strength.

### 4.4.1 *Design*

#### *4.4.1.1 Structural*

The buckling capacity of these liners is calculated by assuming the liner is a thin tube that is under uniform radial external pressure. The equations can be found in Roark's Formulas of Stress & Strain, 7th Edition (Young, 2002) Table 15.2, case 19. The calculation is conservative in one way in that it assumes that the existing culvert provides no structural capacity. On the other hand, the assumption of uniform radial external pressure will need to be assessed by the Engineer for each specific project. It is likely that other load cases are possible due to protrusions and non-uniform support around the liner circumference.

Flexural strength is provided by fiber reinforcement, which may not be acceptable to MnDOT. It would need to go through an approval process before being used.

#### *4.4.1.2 Hydraulics*

The lined culvert will always have a smaller diameter than the existing culvert. The Engineer needs to verify that the lined culvert has adequate hydraulic capacity. See Section 2.3 for further discussion. Troweling the surface will provide better flow characteristics.

### 4.4.2 *Materials*

The scope of this document is limited to cementitious centrifugally cast liners. The mixes are proprietary and provide a high build, abrasion resistant, and corrosion resistant final product. Two suppliers of these materials are AP/M Permaform Centri-Pipe and Quadex, Inc. They typically incorporate fibers to enhance flexural strength. The two products mentioned above have the following properties:

- Flexural Strength ASTM C293, Min.1,080 psi
- Compressive Strength ASTM C109, 28 days, Min. 8,000 psi
- Shear Bond ASTM C882, 2,100 psi
- Freeze Thaw ASTM C666, no visible damage after 300 cycles

### 4.4.3 *Construction*

#### *4.4.3.1 Preparation*

The culvert must be checked and prepared as described in Section 3. The culvert surface must be thoroughly cleaned with a with high pressure water to ensure good bond. Any infiltration will need to be stopped, otherwise the mortar will not bond. Joint repairs may be required, as described in Section 5.2 Joint Repair. If there are abrupt changes in culvert shape or irregularities, it may be best to fill these in to make gradual transitions. In this way, the liner can be installed more uniformly. Alternatively, these can be repaired with mortar after the liner installation is completed.

#### *4.4.3.2 Invert Mortar Placement*

If the culvert invert is highly irregular or corroded, it is best to pave the invert before placing the liner. This provides a level surface for the machine’s skids to travel and has the added benefit of filling voids. The mortar should be high strength and free flowing.

#### *4.4.3.3 Liner Placement*

The high speed, rotating applicator is typically provided by the mortar supplier to certified contractors. Other equipment such as mortar mixers, compressors and pumps can be standard commercial models meeting the mortar supplier's specifications. The liner is placed by the rotating applicator as it pulled through the culvert. The rotation speed and rate of withdrawal are coordinated to provide the specified thickness. Multiple passes may be needed to place the specified thickness. The supplier's recommendations should be followed for mixing and application.

#### *4.4.3.4 Quality Control*

The following should be monitored during construction:

- Visual inspection. The liner should be visually inspected for deficiencies such as drop outs and irregular surfaces.
- Liner thickness. The best way to determine liner thickness is to conduct a survey with a laser profiler, which is attached to a pipeline camera. A ring of laser light is projected onto the internal pipe surface, perpendicular to the video camera's line of site. Software can then produce charts and cross sections of the pipe surface. Surveys should be done before and after lining to verify thickness. The Special provisions should require the contractor to perform laser profiling and submit the results.
- Compressive strength. Two-inch cubes should be cast and tested to verify compressive strength per ASTM C109 - Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens) (ASTM C109, 2012).

### 4.4.4 *Routine Maintenance*

Very little maintenance is required on a centrifugally cast liner installation. Periodic inspections should be conducted as required by the HydInfra program. Since this is a relatively uncommon repair method in Minnesota, more frequent inspections are recommended to confirm that the liners are performing as designed.

## 4.5 **Other Methods**

The methods discussed in this section can also be used to rehabilitate culverts. Brief descriptions are provided. Detailed guidance on these methods is beyond the scope of this Guideline.

### 4.5.1 *Spirally Wound Liners*

The following was modified from page 44 of Culvert Pipe Liner Guide and Specifications (FHWA, 2005):

Spirally wound lining uses interlocking profile strips, most commonly made from PVC and HDPE, to line a deteriorated culvert. Coiled, interlocking profile strips are fed through a winding machine that mechanically forces the strips to interlock and form a smooth, continuous, spirally wound liner. During the interlocking process, a sealant is applied to each joint to form a watertight seam. As the material is wound and snapped together, it is forced into the existing culvert, as shown in Figure 4.10.

**Figure 4.10 Spirally Wound Liner Installation (Caltrans, 2011)**

Generally, the liner is wound and inserted without excavation. For larger diameter culverts (larger than 36 inches), preformed panels are spirally wound, rather than profile strips. Grouting of the annular space is generally required when fixed diameter profile strips are used. If expandable profile strips are used, grouting is unnecessary.

Manufacturers of spirally wound liners include Danby, LLC and Sekisui-SPR Americas, LLC.

4.5.2 *Close-fit Liners*

The following was modified from pages 23 and 29 of Culvert Pipe Liner Guide and Specifications (FHWA, 2005):

Sometimes referred to as modified sliplining, close-fit lining involves the insertion of a thermoplastic pipe with an outside diameter the same or slightly larger than the inside diameter of the host culvert. As a result, the liner must be modified in cross section before installation. A modified liner is winched into place and reformed/re-rounded to provide a close-fit with the existing culvert. Once reformed, grouting is unnecessary due to the tight fit. Close-fit lining systems can be used in smaller pipes, generally between 3 inches and 24 inches in diameter. Close-fit lining methods can be categorized into two main groups based upon the method used for cross-sectional modification and reformation. These two groups are classified as symmetrical reduction systems and folded systems.

Symmetrical reduction methods use either a static die or a series of compression rollers that temporarily reduce the diameter of the liner. Once reduced, a winch is used to apply tension while the liner is pulled through the host culvert. After insertion, the tension applied by the winch is released and the pipe reverts to its original dimensions due to the material's molecular "memory." Pressure, generally provided by air, is sometimes used to speed up the reformation process.

Liners used in the folded method are generally folded into “C“-, “U“-, or “H”-shapes during manufacturing or by site-equipment before installation. Figure 4.11 shows an H-shaped liner. When shaped at the factory, liners are wound into a reel or coiled for ease of transportation. Unlike symmetrical reduction systems that dominantly rely on the “memory” of the material for reformation, folded systems are reformed by pressure or a combination of heat and pressure. Due to the materials and installation procedure associated with folded liners, they can typically be considered environmentally safe. The folded method can further be classified into the deformed/reformed method and the fold and form method.

**Figure 4.11 H-Shaped Fold and Form Liner (Utah DOT, unknown)**

### 4.5.3 *Shotcrete Liners*

Shotcrete is concrete that is pneumatically-applied at a high velocity onto a substrate. The concrete is compacted due to the force at which it is applied. It can be either unreinforced or reinforced. Reinforcement is typically reinforcing bar, welded wire fabric or fibers. It can be applied in multiple layers to build up the desired thickness. The shotcrete surface can be troweled to provide a smooth surface. The shotcrete nozzle can be hand held or robotic. The method would be most appropriate for culverts of at least 60 inches in diameter since personnel entry is generally required and the nozzle needs to be perpendicular to and offset from the culvert surface. Typically the shotcrete is applied to the sides and crown of the culvert. The invert would be repaired with cast-in-place concrete. Figure 4.12 shows shotcrete placement inside a utility tunnel.

**Figure 4.12  Shotcrete Placement over Reinforcing Bars (CNA Consulting Engineers)**

# 5 Culvert Repair Methods

The culvert repair methods discussed in this chapter are maintenance activities that keep the existing culvert in a uniformly good safe condition. The do not necessarily enhance structural capacity.

## 5.1 Spall Repair

Concrete can spall due to culvert movement, freeze/thaw cycles, structural distress, deicing materials, and corrosion of reinforcement. This section describes design and repair of spalled RCP culverts. Culverts greater than 36” diameter can be repaired since personnel entry is required.

### 5.1.1 *Design*

The majority of spall repairs will require no structural design. The primary focus of spall repairs or local patching of erosion is to stop further deterioration of the RCP culvert. Key items to consider when designing spall repair include:

- Limits of concrete removal
- Depth of concrete removal
- Whether reinforcement replacement is required or existing reinforcement should be supplemented. Most spalls will not require placement of additional reinforcement.
- Selection of materials or anchorage methods to keep patch intact with the host culvert pipe

### 5.1.2 *Materials*

Selecting the spall repair materials will play an important role in the constructability and durability of the repair. Consider material strength, modulus of elasticity and coefficient of thermal expansion. Patching materials need to act similar to host material to prevent debonding.

Replacement or supplemental reinforcement should be determined by the Engineer in the design phase. Provisions should also be made for adjustments made in the field, based on conditions observed after concrete removal operations. Consider use of welded wire fabric, which concrete pipe fabricators can roll to nominal inner diameter of culvert. The size of the reinforcement panels can be cut from the sheets and quickly positioned and secured in position.

Use post installed anchors and solid plastic rebar chairs to assist in positioning and securing supplemental or replacement reinforcement.

If rebar is utilized, consider use of more corrosion resistant reinforcement like MMFX steel.
If adhesively anchored dowel bars are utilized to secure the patching materials consider using structural adhesives that tolerate wet or damp holes during installation, are creep resistant and are suitable for constant immersion in water.

Use prepackaged epoxy modified repair mortars for repairs up to 2 inches thick. The benefits of using this type of material include:

- Improved bond strength between the host culvert and patching material
- Higher strengths in less time
- Decreased permeability and improved durability

For spall repairs and patches with thicknesses greater than 2 inches, the patching materials should contain a 3/8 inch aggregate, either prepackaged in the patching material or added on site in accordance with the manufacturer's recommendations.

### 5.1.3 *Construction*

#### *5.1.3.1 Concrete Removal*

For concrete removal procedures, see Section 4.1.1.4.1.

#### *5.1.3.2 Surface Preparation*

For general surface preparation procedures, see Section 4.1.1.4.2. In addition, concrete surface receiving repair material should be suitably prepared in accordance with the manufacturer's recommendations, including the following:

- Surface profiles (roughness) should be established. Refer to ICRI guidelines or equivalent sandpaper grit for comparison. Typically a roughness of 1/8 inch is suitable.
- Clean and provide a surface saturated dry (SSD) surface, if a bonding agent is not used, before repair material is placed. Use a high pressure, oil free air to blow surface clean and remove any standing water.

See Section 4.1.1.4.2 Surface preparation for bonding agents suitable for use in culvert spall repairs.

#### *5.1.3.3 Placement*

Repair mortars containing admixtures such as epoxy have a limited pot life before they reach initial set. As a result, the repair mortars should be mixed in limited quantities such that it can be placed before it sets. Repair mortars should be forced near the edge of the repair and worked towards the center. The surface should be finished smooth and level with the surrounding surface.

#### *5.1.3.4 Protective Coating*

Spall repair materials typically will not require protective coatings, as the patching materials have decreased permeability due to the admixtures.

#### *5.1.3.5 Quality Control*

Perform bond testing of repair material placed in mock-up repair areas to verify adequate bond is achieved between the base and repair material.

Mortar cubes can be prepared and tested for compressive strength. Repair mortars are typically not tested for air content, slump or temperature.

### 5.1.4 *Routine Maintenance*

Periodic inspections should be conducted as required by the HydInfra program. Spall repairs should be watched closely for delamination.

## 5.2 **Joint Repair**

One of the most common problems with culverts is infiltration and exfiltration at the joints. The main issue is that infiltration leads to ground loss into the culvert. This can cause surface settlement and loss of lateral support. Flexible pipe culverts such as CSP require support from the surrounding soil so loss of ground can cause culvert failure. This section describes some of the methods that can be used to repair culvert joints. Joint repair methods discussed herein can be done in culverts greater than 36" diameter since personnel entry is required. Other joint repair methods using remote methods can be performed in smaller pipes.

### 5.2.1 *Materials*

#### *5.2.1.1 Oakum & Wrethane Grout*

Oakum is a fibrous material derived from hemp or jute. It can be saturated with various materials and forced into joints to prevent or stop leaks. Oakum soaked with tar has been used for centuries to seal joints between timbers of ships. It is also used with molten lead to seal cast iron pipe joints. Oakum saturated with urethane grouts can be packed into culvert joints to stop infiltration. Dry, oil free oakum should be specified for use with urethane grouts, shown in Figure 5.1.

**Figure 5.1 Dry Oakum (Parsons Environmental Products)**

There are various types of urethane grouts that can be used. These grouts expand to many times their original volume when they react. Important properties of the grout are good adhesion, adequate strength, and flexibility. Flexibility is important because many culverts will experience some movement. Care must be taken when choosing the grout as there are many types to choose from. Some urethane grouts are not flexible or do not bond to the substrate. Either hydrophobic or hydrophilic, single component urethane grouts are recommended. Some hydrophobic grouts are not flexible and should not be used. Hydrophilic grouts will shrink if dried out, so a high solids grout is recommended because it will shrink less. Grout suppliers typically have different types of hydrophilic grouts. They should be consulted when choosing a high solids grout. Shrinkage characteristics should be discussed with them if drying shrinkage is a concern.

#### *5.2.1.2 Joint Injection*

Joints in RCP can be injected with urethane grout to seal them. The same grouts used with oakum, above, can be used.

#### *5.2.1.3 Internal Bands*

Internal bands can be installed on the culvert interior to stop infiltration. They can be used on most types of jointed pipe. Bands for smooth-walled culvert typically consist of a flexible rubber seal and stainless steel retaining bands as shown in Figure 5.2. The rubber seal spans the culvert joint and is sealed against the inside of the culvert by expanding the stainless steel bands on either side of the joint.

Internal bands for CSP typically consist of either one or two pieces of corrugated steel that has the same corrugations as the culvert. They may or may not have flexible rubber gaskets. Bands with gaskets are recommended for culvert repairs. The band spans the joint and is expanded with tightening bolts attached to the bands with steel angles.

**Figure 5.2 Internal Band (Trelleborg Pipe Seals Milford, Inc.)**

### 5.2.2 *Construction*

#### *5.2.2.1 Joint Preparation*

Joints should be thoroughly cleaned with high pressure water, brushes or other means. This is especially important for sealing methods that require a bond to the substrate.

#### *5.2.2.2 Joint Sealing*

##### *5.2.2.2.1 Oakum & Urethane Grout*

The following steps should be followed to seal the joint:

1. Soak the oakum with urethane grout.
2. If the joint is dry, pre-wet it with water. Water is required to activate some grouts.
3. Coat the joint with grout, especially if the joint is smooth. This will improve the adhesion.
4. Push the saturated oakum into the joint to completely fill the joint when the grout is expanded.

##### *5.2.2.2.2 Joint Injection*

Joints can be injected with grout either through holes drilled into the joint or needles pushed through a joint repaired with oakum. Disposable or reusable packers installed in 3/8-inch to 5/8-inch holes are commonly used in drilled holes. Figure 5.3 shows injection ports installed around a concrete crack. Installation at a pipe joint would look similar. The packers have a zerk or other type of fitting to which the grout lines are connected. Injection port spacing should be close enough for the grout to travel from hole to hole. Starting at a spacing of 18 inches is recommended. Decrease port spacing if required to get grout communication between ports. Grouting at an injection port can be stopped when grout is witnessed at an adjacent hole. After a few holes have been grouted, they should be re-injected to ensure complete grouting.

**Figure 5.3 Grout Injection Ports on a Concrete Crack (CNA Consulting Engineers)**

*5.2.2.2.3 Internal Bands*

Internal bands are simply expanded against the inside of the culvert. Expansion methods vary between manufacturers. It may be difficult to seal against offset or irregular joints. Other repair procedures should be considered if this is the case.

*5.2.2.3 Quality Control*

The joints should be inspected immediately after and again a few days after the repairs are completed to check for leaks. Any leaking joints should be re-grouted or repaired by other means.

### 5.2.3 *Routine Maintenance*

Periodic inspections should be conducted as required by the HydInfra program. More frequent inspections are recommended for joints sealed with urethane grouts because its life expectancy is not well understood.

## 5.3 **Void Filling Outside the Culvert**

Voids can develop outside the culvert due to piping, joint infiltration, and invert erosion/corrosion. Piping is a process of subsurface erosion in which water runoff flows along the outside of a culvert and, with sufficient hydraulic gradient, erodes and carries away soil around or beneath the culvert. This process is referred to as piping since a hollow similar to a pipe-shaped tube is often formed. The water may come from stream flow, surface flow, groundwater or leakage from inside the culvert (FHWA, 1995).

Joint infiltration occurs when groundwater or surface water flows into the culvert through joints that are not sealed. The culvert backfill is brought into culvert with the flow.

Invert erosion/corrosion is common in CSP culverts. The invert corrodes exposing the soil below. The soil is then eroded by the culvert flow.

Flexible pipes rely on support from the surrounding soil. Voids outside these culverts cause non-uniform loading conditions that can cause culvert failure.

Voids development is a serious condition. It can lead to dangerous roadway settlement and sinkholes. Such situations should be addressed immediately.

Voids can be filled from either inside or outside the culvert, so this work can be done on any size culvert.

### 5.3.1 *Grout Materials*

The grout material does not need to have the high strength of structural concrete. Grout with 100 psi compressive strength is adequate. Lower strength grouts have the benefit of being easily excavated in the future. In addition, high strength grouts can create undesirable point loads on the culvert. Both chemical and cement grouts can be used to fill voids.

#### *5.3.1.1 Cementitious Grout*

Portland cement based grouts, with or without admixtures, including lightweight cellular concrete can be used. The grout should have good flowability and should not segregate.

#### *5.3.1.2 Foaming Urethane Grouts*

Rigid foam hydrophobic urethane grouts are recommended for void filling. These grouts expand 10 to 30 times their original volume to completely fill the void. The grouts can be pre-mixed with water or react with water in the ground.

#### *5.3.1.3 Comparison of Chemical and Cementitious Grout*

- Cementitious grouts are less expensive than chemical grouts.
- Cementitious grouting from the surface may not require specialized contractors.
- Flowing water can wash away cementitious grout before it sets.
- Larger diameter (1”+) lines are required for placement of cementitious grout. Chemical grouts can be placed through 3/8” ports.
- Normal weight cementitious grouts can create point loads on the culvert.
- High strength cementitious grouts are difficult to excavate in the future.
- Expansion of hydrophobic urethane grouts will fill voids.

### 5.3.2 *Construction*

Appendix B-30 of Culvert Pipe Liner Guide and Specifications (FHWA, 1995) contains the following discussion of void grouting:

“The primary objective of completely filling the void can be accomplished by adequately studying site conditions and properly planning and executing the grouting operation. The principal problem to be avoided is entrapment of air or water in the void to be filled with grout. The procedure to be used for grouting must recognize this potential problem and provision must be made for air or water to be vented out of the void as grout is pumped into the void. Depending on the location of the void to be filled, the grout may be installed with a pressure pumping system or it may merely flow in by gravity.

Normally voids under corroded or undermined inverts may be filled by a gravity flow method. Voids behind the sides of culverts that are caused by piping or exfiltration will have to be pressure grouted to ensure that the void is properly filled. However, for certain situations where the void can be accurately located, it may be possible to fill side voids by gravity feed from the roadway surface.

**Procedures:**
There are basically three procedures for grouting:

1. Gravity Flow from Above the Void
   This concept involves merely pouring the grout into the void from above it. It is assumed that the fluid grout will completely fill the void without entrapping air and that any water in the void will be displaced as the heavier-than-water grout displaces it. Although this technique may work for a water-filled void, the grout will probably be dispersed in the water with the result that the void will not be properly grouted. It is much preferred that any water in the void be pumped out prior to grouting. Figure 5.4 shows grout that has been poured on a deteriorated CSP invert.

**Figure 5.4 Filling Voids below a CSP Culvert (Betcher, 2010)**

2. Grouting Through a Tremie Pipe or Tube
   For this gravity feed concept the grout is introduced into the void by pouring it into a tremie tube, so that grout fills the void from the bottom with an upward flow of the grout. The procedure may be warranted for some site conditions where there is a potential problem of entrapment of air in the grout.
3. Pressure Grouting
   This concept will normally be used to fill voids behind the sides of culverts. If the void is behind an open joint, it will be necessary to seal the interior surface of the joint, normally with a concrete mortar, or a joint sealing system, such as those described in Appendix B, Section 25 of the FHWA Culvert Repair Practices Manual, Pub. No. FHWA-RD-94-096 (FHWA, 1995).The most effective procedure for grouting will then involve installation of grout tubes at the bottom and the top of the joint or void. The grout is then pumped into the lower tube. Air or water will, at first, flow out of the upper tube, then a watery grout will flow out, and finally a pure grout will flow out of the upper tube. At this point it may be considered that the void is properly filled.

**Precautions:**

1. The grouting procedures should be designed so that air or water is not trapped in the void.
2. The grouting pressure should be monitored to prevent bursting of lines and/or displacement."

##### *5.3.2.1 Quality Control*

Cementitious grouts should be tested for compressive strength. Cellular grout density should be tested during placement to ensure the specified density is being supplied.

##### *5.3.2.2 Maintenance*

Periodic inspections should be conducted as required by the HydInfra program. The area around the culvert should be examined for settlement and piping to evaluate the completeness of void filling.

### 5.4 **Other Methods**

This section briefly discusses other methods that have been used to repair culverts and the surrounding ground.

#### 5.4.1 *Joint Sealing with Internal Packers*

Joint sealing involves the repair of culvert pipe joints that are leaking and potentially carrying soil into the culvert. An internal packer is pulled and positioned over the leaking joint. The packer is then inflated to allow chemical grouts to be pumped into the leaking joint. Closed circuit television cameras may be used to assist in positioning the internal pack. This method of repair is typically utilized in culverts from 6 inches to 36 inches where personnel access is limited due to size or environmental conditions. ASTM F2304 Standard Practice for Sealing of Sewers Using Chemical Grouting (ASTM F2304, 2010) may be referenced for additional information on joint sealing and testing requirements.

#### 5.4.2 *Corrugated Metal Pipe (CMP) Seam Repair*

CMP pipe longitudinal seams may occasionally require structural strengthening. Structural members, such as flat plate and round bar stock may be placed over the weakened seam and welded into place. Sizing of the structural members and welds should be performed by the Bridge Office or a qualified civil or structural engineer familiar with pipe design. Caltrans Supplement to FHWA Culvert Repair Practices Manual, DIB-83-02 (Caltrans, 2011) may be referenced for additional information on seam repair and strengthening.

#### 5.4.3 *Invert Plating*

Invert plating typically involves the placement of plates of steel, fiberglass or other material over deteriorated inverts. The plate segments could be either flat or matching corrugated culvert plate. Steel plates are usually welded in place. Welding of galvanized metal can also raise health concerns and should be considered when evaluating this repair method. Invert plating is typically performed in larger diameter culverts which readily allow personnel access. Caltrans Supplement to FHWA Culvert Repair Practices Manual, DIB-83-02 (Caltrans, 2011) may be referenced for additional information on invert plating.

#### 5.4.4 *Sprayed Coatings and Linings*

Sprayed coatings and linings can be applied to culverts at early stages of deterioration to increase the service life. Sprayed coatings and linings are primarily applied to limit corrosion and deterioration of culverts. For a more complete explanation of coatings and linings, see ASCE Engineering Practice No. 120 “Trenchless Renewal of Culverts and Storm Sewers” (ASCE, 2010).

#### 5.4.5 *Slabjacking*

Slabjacking or mudjacking can be used to raise and realign pavement sections that have settled due to a ground loss around an existing culvert. The process involves coring or drilling holes through the pavement section and placing a cementitious based material, under pressure, to fill voids and provide support for the pavement section. Specifications for slabjacking can be found under MnDOT Special provisionsSection S-140 (2301) Slabjacking (MnDOT, 2006).

#### 5.4.6 *Compaction Grouting*

Compaction grouting is the placement of low-slump, low-mobility soil/cement grout into the ground to fill voids and re-compact ground that has loosened due to ground loss. A grout bulb is pumped into the ground that displaces and compacts the soil. Compaction grouting should be considered when significant loosening of the soil has occurred. Care must be taken to not damage the culvert or heave the road surface during compaction grout placement.

### 5.5 **Other Important Culvert Features and Repairs**

#### 5.5.1 *Resetting and Retying End Sections*

End sections of culverts can become separated from the culvert barrel due to freeze/thaw, settlement, scour, undermining, and other similar causes. The resetting and retying of end sections is the salvaging and reuse of the section after work is performed to prevent the separation again. This repair is performed by removing the existing end section and then excavating down to sound material. After reaching the sound material, the excavation is backfilled and compacted. The salvaged end section is placed back onto the compacted material and then secured with new anchor rods to the culvert. Sometimes end sections are replaced instead of reused.

### 5.5.2 *Energy Dissipators*

Energy dissipators are used to reduce the velocity of water leaving the culvert. The reduction of water velocity prevents damage due to abrasion in all culverts and abrasion-related corrosion of metal culverts, scour and erosion of the streambed and surrounding land. Dissipators can be located inside the culvert-internal dissipators or outside-external dissipators. There are two types of internal dissipators, increased resistance or tumbling flow. Increased resistance dissipators use roughness elements to force the water to slow down in culverts operated under inlet control. Tumbling flow dissipators are used for high slope culverts and similar to increased resistance dissipators. External dissipators include riprap basins, impact basins, stilling wells and drop structures. Additional information and design criteria for energy dissipators can be found in Hydraulic Engineering Circular No. 14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* (FHWA, 2006), MnDOT *Drainage Manual*, Chaptor 6 (MnDOT, 2000), and MnDOT Standard Plate No. 5010 Reinforced Concrete Pipe Energy Dissipator (MnDOT, 2013).

### 5.5.3 *Trash Rack Maintenance*

Trash racks are metal grating that is placed on the outside of a culvert opening. Trash racks help to reduce the amount of debris that is allowed to flow into the pipe and prevent debris build up inside of the culvert, which maintains the hydraulic capacity. Trash racks need to be cleaned on a regular basis to help keep the inlet free and allow the culvert to flow at full capacity. Design criteria for trash racks can be found in the MnDOT Standard Plate Series 3000.

### 5.5.4 *Inlet and Outlet Protection*

Inlet and outlet protection treatments include headwalls, endwalls and wingwalls. A headwall is located at the inlet of the culvert, and an endwall is located at the outlet. Wingwalls are angled off of a headwall or endwall. The primary benefits of these structures are increasing hydraulic capacity, retention of the roadway embankment, and protecting the culvert. With certain hydraulic circumstances, a culvert's capacity can be increased dramatically, or justify the sliplining of the culvert with an improved inlet design that causes the water to be more efficiently channeled into the culvert. When the inlet channel is improved there is less contraction of the flow. Chapter 5 – End Treatment and Other Appurtenant Structure Repairs and Retrofit Improvements in FHWA Culvert Repair Practices Manual (FHWA, 1995), contains information and discussion on the installation and repair of these structures. MnDOT Standard Plate Series 3000 (MnDOT, Various) contain designs for different types of inlet/outlet protection structures.

### 5.5.5 *Apron/Cutoff Walls*

Aprons are rock or paved areas at inlets and outlets of culverts. They are used to prevent scour and undermining of culverts. Aprons also help to control the flow into the culvert like headwalls and wingwalls, but also contain a horizontal section and are generally a monolithic cast structure. While aprons are used to prevent undermining for culvert, they are also at risk of failing from this same problem. Aprons should be extended down below the streambed or use a cutoff wall. Cutoff walls are a structural element that is placed under culverts and aprons to help prevent undermining. The wall should be either concrete or protected metal sheeting. Apron Standard

Plates for different material culverts can be found in the 3000 Series of MnDOT Standard Plates (MnDOT, Various).

# 6 Replacement of Culvert using Open Cut Methods

If it is acceptable to close the roadway, open cut replacement of the culvert can be considered. It is beyond the scope of this guideline to discuss these procedures. MnDOT design and construction procedures should be followed for culvert design, culvert sizing, earthwork, and repaving. AASHTO LRFD Bridge Specifications (AASHTO, 2012), Section 12 – "Buried Structures and Tunnel Liners" contains design requirements for culverts.

## 6.1 **MnDOT Publications for Culvert Replacement**

Guidance for open cut is available in the following MnDOT publications.

### 6.1.1 *Drainage Manual*

The MnDOT Drainage Manual contains guidance on the following culvert design and construction issues:

- Hydrology and hydraulics
- Energy dissipation
- Outlet protection
- End treatments
- Aprons
- Multiple use culverts

### 6.1.2 *Standard Specifications and Special Provisions*

MnDOT Standard Specifications for Construction and Special Provisions contain specifications for the following:

- Culvert materials
- Earthwork
- Paving

### 6.1.3 *Standard Plates*

MnDOT 3000 series Standard Plates contain requirements for:

- Culvert pipe (CMP and RCP)
- Culvert joints (CMP and RCP)
- Aprons
- Connections
- Extensions
- Grates (in 4000 series Standard Plates)
- Inlet protection
- Rip rap outlets

### 6.1.4 *Other Manuals and Plans*

Other MnDOT manuals and plans that provide guidance for other aspects of open cut culvert replacement design and construction include but are not limited to:

- Grading and Base
- Lane Closure
- Minnesota Manual of Uniform Traffic Control Devices
- Pavement Design
- Seeding
- Standard Plans

# 7 Replacement of Culverts using Trenchless Methods

Trenchless culvert installation involves methods of construction where continuous trenches are not required for culvert installation, thus minimizing disruptions to the ground surface. Trenches are required only intermittently for pits were the culvert enters or exits the ground. Trenchless culvert replacement methods include conventional tunneling, pipe jacking, horizontal directional drilling (HDD), pipe ramming, horizontal auger boring and other methods.

## 7.1 MnDOT's Trenchless Culvert Replacement Specifications

MnDOT does not have Standard Specifications or Special provisionsfor trenchless roadway crossings. Current practice is to leave these trenchless methods to the contractor.

The construction industry standard is to conduct geotechnical analysis and prepare detailed plans and specifications, including a geotechnical baseline report. Specifically, the following work tasks are recommended when planning, designing, and specifying a trenchless roadway crossing:

- Take geotechnical borings to assess ground and groundwater conditions.
- Check for existing utility interferences.
- Confirm that adequate work sites are available.
- Evaluate appropriateness of various trenchless methods.
- Prepare a geotechnical data report (GDR) that provides the results of the geotechnical investigation.
- Prepare a geotechnical baseline report (GBR) that defines the subsurface conditions on which the contractor should base the bid. The GBR takes precedence over the GDR.
- Prepare plan and profile drawings of the crossing.
- Prepare drawing details and specifications for casing pipe and culvert pipe materials.
- Specify constraints on trenchless means and methods.
- Specify dewatering if required.
- Specify pre-grouting of the soil or rock if required for ground control, groundwater control, and/or settlement prevention.
- Prepare drawings and specifications for geotechnical instrumentation and monitoring to monitor settlement.
- Specify maximum allowable settlement and specify remedial action if settlement limits are exceeded.

Following these steps will help to ensure a successful installation and reduce the likelihood of construction claims.

## 7.2 **Conventional Tunneling**

Conventional tunnel refers to methods where tunnel support is erected at the tunnel face as the excavation progresses. In soils, this ground support is commonly steel liner plate or circular steel beams with wood lagging, shown in Figure 7.1. The soil can be excavated with hand tools or mechanized means. In rock, the ground support could also include rockbolts and shotcrete. Rock tunnels can also be driven without support if the rock is self-supporting.


**Figure 7.1 Conventional Tunnel, Circular Steel Beams and Wood Lagging (CNA Consulting Engineers)**

Any type of pipe can be installed inside the tunnel and grouted in place. Cast-in-place tunnel liners are also common.

## 7.3 **Pipe Jacking**

Pipe jacking is a method of tunnel construction where hydraulic jacks in a pit are used to push pipes through the ground behind a tunnel shield. Figure 7.2 shows the jacking system behind a jacking pipe. The shield has the same cross section as the pipe (almost always cylindrical) and contains steering equipment, face support, and excavation equipment. Personnel and equipment in the tunnel shield excavate the ground. Pipe jacking can be done in soil or rock.

**Figure 7.2 Pipe Jacking (CNA Consulting Engineers)**

**Microtunneling** is a type of pipe jacking where the steering and excavation equipment are operated remotely. No personnel enter the tunnel. Monitoring and control of slurry pumps (if used), cutter head drive motor, and hydraulic power for the jacks is performed at the surface. The ground is removed either by full diameter augers installed in the pipe or a pumped recirculating slurry. In slurry systems, the ground is mixed with and suspended in a slurry at the tunnel face. The soil particles are removed from the slurry at the surface. Figure 7.3 is a schematic of a microtunneling system. The term microtunneling is somewhat of a misnomer because microtunneling machines up to 10 feet in diameter have been constructed. Microtunneling is typically more expensive that other pipe jacking techniques. It can be done in soil or rock.

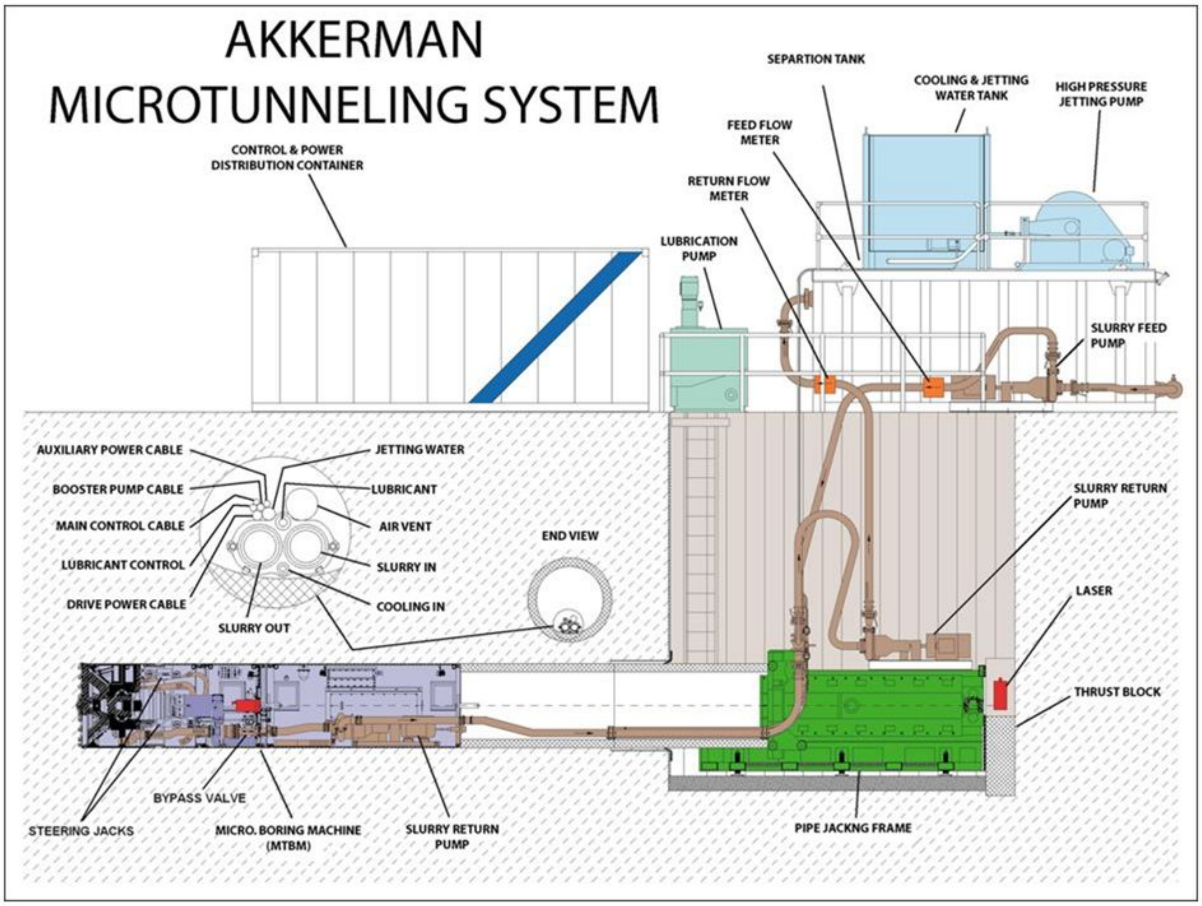


**Figure 7.3 Microtunneling System (Akkerman)**

**Auger Boring** is a pipe jacking method that uses full diameter augers installed in a steel casing pipe to remove the excavated ground. No personnel enter the tunnel. The system has limited steering capability. Auger boring is an inexpensive pipe jacking technique. It can be done in soil or soft rock.

Various types of face control equipment, excavating equipment, and cutter heads are available to prevent collapse of and to excavate the ground. Figure 7.4 shows a cutter head and augers that would be installed at the front of a jacked casing.


**Figure 7.4 Cutter Head and Augers used for Auger Boring (CNA Consulting Engineers)**

**Pipes for Jacking** include steel casings, RCP, and FSP because they can be designed to withstand the jacking forces. Vitrified clay and polymer concrete pipe are also used, but are less common in Minnesota. Joints are gasketed flush bell and spigot or steel banded. Steel casing can have welded or threaded joints.

## 7.4 **Pipe Ramming**

The pipe ramming method uses pneumatic percussive blows to drive a steel casing into the ground. The leading edge of the casing is usually open to allow the ground to enter the casing. The ground can be left in the casing until ramming is complete unless driving gets too difficult. If this is the case, ground can be removed from the casing during the ramming process to reduce the ramming force required.

**Figure 7.5 Pipe Ramming (CNA Consulting Engineers)**

The ramming tool is strapped to the steel casing with tensioning straps. An adaptor is installed between the ramming tool and steel casing to transfer ramming forces. Figure 7.5 shows the smaller diameter ramming tool attached to the end of the larger steel casing.

Sections of steel casing are added to the string as the casing enters the ground. Joints can either be welded or interlocking and designed to withstand jacking forces.

Pipe ramming is not steerable. It is becoming more and more common to first install a smaller guide pipe using steerable methods for the pipe-rammed casing to follow.

## 7.5 **Horizontal Directional Drilling**

Horizontal directional drilling (HDD) is a steerable installation method where pipe is installed along an arc. First, a pilot hole is drilled from a starting pit to a receiving pit. The hole is then back-reamed to enlarge the hole to the required size. Additional reaming steps may be required for larger pipes. The pipe is pulled through the back through the hole after the last reaming step.

Drilling fluid consisting of bentonite and/or polymers is used to remove cuttings, stabilize the borehole, cool the cutting head, and lubricate the hole for the pipe. A reclaimer removes the cuttings from the fluid so it can be reused.

Various types of guidance systems are used to locate the drill head to keep it on track. Various designs of drill heads are also available depending on the geotechnical conditions.

Pipes such as steel, PVC, HDPE, polypropylene, and ductile iron can be used. The pipe has to be able to withstand the bending forces during installation. The drill path must be designed so that the maximum bending radius of the pipe is not exceeded. Pipe joints must withstand the pulling forces.

## 7.6 Pipe Bursting

The following information was obtained from Guideline for Pipe Bursting (International Pipe Bursting Association, 2012).

In pipe bursting, the existing pipe is fractured or split by forcing a larger size expansion head through the pipe. The broken pipe is simply pushed into the surrounding ground. Figure 7.6 is a schematic of a pipe bursting operation.

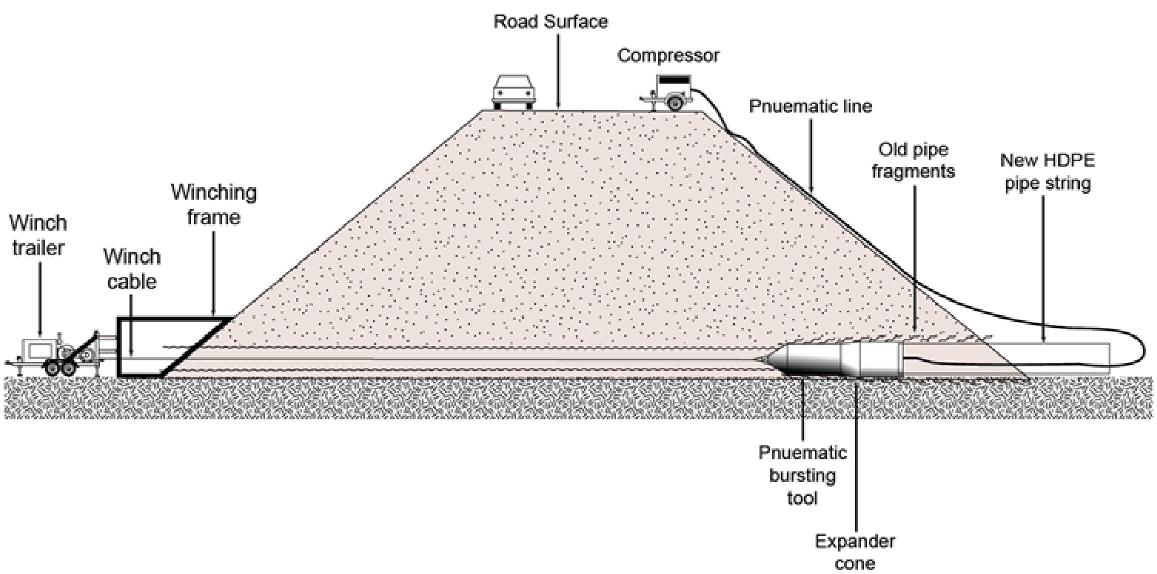


**Figure 7.6 Pipe Bursting Schematic (USDA Forest Service, 2005)**

The expansion head is advanced in one of two ways. One method uses a pneumatic hammer to drive the expansion head and break the pipe. The expansion head is connected to cable at the far end of the run to keep the expansion head centered. This method works on pipes that will fracture such as cast iron, clay, unreinforced concrete, and asbestos cement.

In the other method, a hydraulic unit pulls the expansion head through the existing pipe. This method can be used on non-fracturing pipe if a roller blade cutting wheel or pipe splitter is used. Ductile iron, steel, and plastic are examples of non-fracturing pipe.

CSP cannot be easily replaced by pipe bursting.

The back end of the expansion head is attached to the new pipe. Fusion-welded thermoplastic, including HDPE and fusible PVC works well with pipe bursting applications. Other pipe with mechanical locking joints can also be used, such as PVC, ductile iron, clay, concrete, and polymer concrete.

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# Appendix A  Table of Alternative Repair Techniques

Modified from Caltrans Supplement to FHWA Culvert Repair Practices Manual, Design Information Bulletin No. 83-02 (Caltrans, 2011)

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Sliplining with continuous or discrete pipe lengths | Med. | 18 inches - 120 inches | **Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration.**<br>Quick insertion; simple method requiring minimal investment in installation equipment and relatively little technical skill.<br>Multiple materials.<br>Provides a virtually new culvert comparable to replacement.<br>Continuous HDPE pipe has very few joints and is capable of accommodating large radius bends. Large range of diameters can be repaired depending on material used. Specialty liners are available in short lengths and constant O.D. (no bell or coupler) | Need fairly large area for liner insertion/jacking pit. Reduces cross section area because the annular space between the old and the new pipe must be grouted which may reduce hydraulic capacity. May increase velocity of flow. The environmental concern with this technique is the control of low density grout.<br>Labor intensive jointing for fusion welded HDPE. Difficult to reconnect laterals. |
| Fold and Form PVC | Med. To High | ≤ 15 inches | **Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration.**<br>Smaller construction footprint than sliplining. Easy to transport and handle.<br>Viable technique for storm drains and culverts in non-abrasive urban settings.<br>No annular space grouting required.<br>Capacity maximized. | PVC may become brittle in freezing temperatures. Specialized equipment and trained personnel needed.<br>Very limited sizes; little or no use for most projects. Cannot accommodate diameter variations and joint settlement.<br>Only circular shapes possible. |

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Cured-in-Place-Pipe (CIPP) Thermosetting resin-impregnated flexible fabric tube | High | 12 inches - 96 inches | Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration.<br>No annular space grouting required.<br>Very smooth interior surface may improve hydraulic- capacity. Capacity maximized.<br>Non-circular shapes can be accommodated.<br>No jacking pit required.<br>Eliminates pipe joints/seams and bridges all joints and irregularities on the interior surface of the host pipe.<br>Easy to transport and handle.<br>Good technique for storm drains; can access through MH or DI and can accommodate variations in cross section, minor pipe deformations and bends of up to 90 degrees. | Specialized equipment and trained personnel needed.<br>Site setup high proportion of cost on smaller projects.<br>Environmental concerns for disposal of waste water:<br>Water must be recaptured and trucked off site to a prearranged disposal site.<br>Groundwater infiltration may need to be controlled.<br>Lateral connections are easily handled but may require sealing after they have been cut. |
| External Grouting Voids | Low to High | All Sizes | **Voids behind culvert**<br>Prevents further distortion or collapse of culvert by re-establishing soil-pipe interaction. | Difficult to judge completeness of repair |
| Crack Sealing (RCP) Mortar/Epoxy | Low | > 36 inches | **Cracks in RCP**<br>Low resource commitment.<br>Protects reinforcing. | May be only a cosmetic repair if basic cause of the cracking is not determined and treated.<br>Requires human entry. |

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Invert Lining: with Concrete or Steel plate | Med.<br>Med. | > 36 Inches<br>≥48 inches | **Invert Repair for Concrete and Metal Pipe**<br>High strength concrete and/or hard aggregate/or steel plate provides abrasion resistance.<br>Can easily modify thickness to meet needs.<br>Limited to bottom third of pipe<br>Simple method requiring minimal investment in installation equipment and relatively little technical skill. If invert perforation is present, same equipment can be used for invert paving. | Human entry only.<br>Cement is subject to break down if runoff is acidic and concrete mix design is not modified.<br>May be difficult to attach wire mesh reinforcement or provide mechanical tie to host pipe.<br>Ventilation is needed for welding. |
| Internal Joint Sealing Steel Expansion Rings and rubber gaskets | Low | 15 Inches - 216 inches | **Infiltration/Exfiltration at Joints**<br>Low resource commitment.<br>Prevents further deterioration due to infiltration or exfiltration and loss of backfill. | More applicable to RCP than flexible pipe. If used on CMP or plastic, pipe must not be deflected beyond 10%.<br>Generally, pipe must be large enough for human entry. |
| Deform Re-form HDPE | Med. to High | ≤ 18 inches (Larger diam. Being evaluated) | **Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration**.<br>Smaller construction footprint than sliplining.<br>Easy to transport and handle.<br>Viable technique for storm drains and culverts.<br>No annular space grouting required.<br>Capacity maximized. | May be difficult to reform larger diameters with thick walls.<br>Specialized equipment and trained personnel needed.<br>Only circular shapes possible. Cannot accommodate diameter variations and joint settlement.<br>Range of available pipe diameters is limited. |

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Machine Spiral Wound PVC | High | <108 inches ≤ 30 inches for radially expanded method) | **Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration.**<br>Smaller construction footprint than sliplining and other methods because liner is formed on site and no pipe storage is necessary.<br>Easy to transport and handle.<br>Viable technique for storm drains and most culverts.<br>Can access through MH or DI<br>Annular space grouting not needed for radially expanded method.<br>Large range of diameters can be selected within the range of the winding machine. | May become brittle upon freezing.<br>Continuous interlocking joint system can be problematic if the host pipe diameter fluctuates.<br>Specialized equipment and trained personnel needed.<br>Reduction in hydraulic capacity can be significant for smaller diameter host pipes.<br>Annular space grouting required for some spiral wound methods. |
| Air placed concrete and Sprayed epoxy or polyurethane lining | High | N/A | **Drainage Structure Rehabilitation**<br>Will provide a corrosion barrier to reinforcing steel for concrete drainage inlets and manholes. | Limited to concrete drainage structures<br>Specialized equipment and trained personnel needed. |

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Cement Mortar Lining Cementitious mortar containing acrylic fibers | High | 12 inches – no upper limit for custom built spray machine | **Invert Repair for non-human entry pipes, Corrosion, Infiltration/Exfiltration.**<br>Cement in concrete prevents or significantly retards the oxidation of the interior base metal (rust) of CSP<br>Can accommodate bends and imperfections in host pipe<br>Large range of diameters can be selected within the range of the centrifugal mortar projecting machines.<br>Smooth interior surface may improve hydraulic characteristics by reducing roughness coefficient.<br>Lateral connections are easily handled | Specialized equipment and trained personnel needed.<br>Cement is subject to break down if runoff is acidic and/or contains sulfates and mix design is not appropriate.<br>Control of infiltration required. |
| Man-entry lining with pipe segments | High | 42 inches – 198 inches | **Invert Repair for Large Diameter Pipes, Corrosion, Infiltration/Exfiltration**<br>Can be manufactured in virtually any shape and length.<br>Lightweight and easy to handle.<br>Option for invert lining only.<br>Sections easily cut to form connections | Installation is labor intensive and slow.<br>Restraint system may be required during grouting.<br>Control of infiltration required |

| Technique and Materials | Const. Cost | Size Range | Problem Resolution and Advantages | Limitations |
|---|---|---|---|---|
| Internal Chemical Grouting (joints) Acrylamide gel, polyurethane foam, urethane gel, acrylic gel, and acrylate gel. | High | ≤ 24 inches | **Infiltration/Exfiltration at Joints**<br>Robotic sealing packer used to access small diameter pipes.<br>Can be used to stop severe infiltration prior to other repairs. | 20 years or less service life. Quality control difficult.<br>Acrylic gels limited for use in systems under the groundwater table. Success may depend on soil and moisture variability. Formulating the correct mixture may be dependent on trial and error on a case-by-case basis, rather than scientific principles. If conditions change, the grout may shrink. Grouting cannot be used for joints that are severely offset. It is also inappropriate for longitudinal cracks and severe circular cracks. Specialized equipment and trained personnel needed. |
| Invert steel Armor Plating | High | ≥ 24 inches | **Invert Repair for Concrete and Metal Pipe**<br>Provides abrasion resistance.<br>Can easily modify thickness to meet needs.<br>Limited to bottom third of pipe. | Difficult to attach to RCP or plastic.<br>May not be appropriate in highly corrosive environments. |
| Stainless Steel or PVC Repair Sleeve with expanding polyurethane grout | Low | 18 inches –54 inches (Stainless Steel)<br>18 inches –108 inches (PVC) | **Infiltration at Joints**<br>Remote installation for small diameter pipes.<br>Can be used to stop severe infiltration prior to other repairs.<br>Large range of diameters can be repaired.<br>Available in 18 inches, 24 inches and 36 inches individual lengths, which may be connected if, needed.<br>Can be used to repair deformed flexible pipe. | Local repairs only |