1.1 Introduction
This procedure discusses methods for inspecting, repairing, rehabilitating and replacing culverts and storm sewer using various trenchless techniques. The primary focus of the chapter is culverts and specifically the criteria for the design and specification of culvert rehabilitation by sliplining. Sliplining is sliding a pipe or pipe-like liner into an existing culvert that is exhibiting deterioration along its length. This practice has been successfully utilized by WisDOT on LET and maintenance projects for several years. In addition to sliplining, several other methods for in-situ rehabilitation of culverts and trenchless replacement of culverts are discussed. In some cases, these practices can be applied to storm sewer as well.

Other than sliplining, WisDOT has few documented specifications and practices for culvert rehabilitation. With the increased emphasis by WisDOT on asset management improvement types it is important to discuss various options as well as to develop and provide additional design guidance. The practices discussed in this procedure not only offer potential cost savings over traditional open trench replacement but can minimize disruption to the traveling public and reduce project liability such as those resulting from unknown hazardous materials, or significant erosion events during construction. As WisDOT's implementation of these practices are evolving, designers should revisit this section as needed to review updates, revisions, and additions.

1.2 Design Responsibility and Coordination
FDM 13-1-1.4 describes the roles and responsibilities of The Bureau of Structures (BOS) and Bureau of Project Development (BPD) in relation to hydraulic design of drainage structures. Design guidance for the rehabilitation and replacement of culverts as described in this part can be the responsibility of BPD, BOS, and/or Bureau of Technical Services Materials Management Section (MMS). Roles and responsibilities will differ based on the size and type of structure and the proposed method of rehabilitation or repair. Contact one of the Statewide Drainage Engineers in the Bureau of Project Development Roadway Standards Unit (RDSU) with questions regarding the guidance in this section. The Statewide Drainage Engineer will consult with BOS and/or MMS as necessary to determine the design and materials requirements specific to the project. Also, notify the Statewide Drainage Engineers when plans include:
- Sliplining of pipes > 60 inches
- Sliplining of box culverts, structural plate culverts or arches, arch pipes, or horizontal elliptical pipes
- Sliplining of culverts in a floodplain
- Sliplining with machine wound liners
- Replacement of culverts or storm sewers by trenchless methods
- Rehabilitation of culverts or storm sewer by cast in place pipe (CIPP), centrifugally cast or spray liners, trenchless placement or other similar methods requiring project unique special details and/or special provisions.

1.3 Definitions
For the purposes of this procedure; replacement, rehabilitation, and repair are defined as follows:

**Replacement** - Replacement of culverts can be accomplished by traditional open trench excavation or trenchless construction methods. The existing culvert is either removed or abandoned in place.

**Rehabilitation** - Rehabilitation of culverts involves returning the culvert to its initial condition or better.

**Repair** - Repair of culverts is intended to keep the existing culvert in a safe condition and inhibit further deterioration.

Note that the National Cooperative Highway Research Program (NCHRP) Synthesis 303, Assessment and Rehabilitation of Existing Culverts report further defines rehabilitation and repair of culverts. Refer to FDM 13-45-99.1 (Resources) for more details.

The following acronyms and definitions are used to describe pipe materials.

**ABS** - Acrylonitrile butadiene styrene

**CMP** - Corrugated metal pipe
Flexible Pipe Culverts - Corrugated metal, polyvinyl chloride and thermoplastic culvert pipes
HDPE - High density polyethylene
HDPP - High density polypropylene
PVC - Polyvinyl chloride

Rigid Pipe Culverts - Concrete pipe culverts
RCP - Reinforced concrete pipe
SRPE - Steel reinforced polyethylene

Thermoplastic Pipe - In this document primarily refers to HDPE or HDPP pipe but can also include composite pipe (PVC and ABS) as well as other forms of plastic piping.

5.1 Introduction
The following part describes design considerations for repairing, rehabilitating, and replacing culverts. The primary focus is on repair and rehabilitation because replacement has traditionally been addressed in other project development sections of this manual. Design considerations for culvert replacement by trenchless methods is further addressed in FDM 13-45-20. With any of these methods, consideration should be given to service life of the repair, rehabilitation, or replacement option and whether it is appropriate to the pavement treatment service life of the associated roadway project.

5.2 Evaluation
Determining the level of deterioration, coupled with the consequences of failure, of a culvert or storm sewer is essential to determining when to repair, rehabilitate, or replace the structure. Routine monitoring of the deterioration will assist in determining when repair, rehabilitation or replacement are required. In 2018 WisDOT initiated new culvert inspection and rating procedures to assist in this effort. Additional resources for evaluating culverts are provided in FDM 13-45-99.1. Regional maintenance staff are an excellent resource as are national product organizations such as the American Concrete Pipe Association (ACPA) and National Corrugated Steel Pipe Association (NCSPA). Pipe product suppliers can be resources in assessing the level of damage as well. Depending on the level of damage, experienced hydraulic and/or structural engineers may ultimately be needed to evaluate the structure.

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 support the circumferential soil and live loads with essentially no deflection and the pipe 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 CMP, PVC, HDPE and HDPP (Modified from MNDOT, 2014).

Table 5.1 and Table 5.2 are intended to assist in the evaluation of existing culverts and storm sewers when determining the need to repair, rehabilitate or replace them. Table 5.1 lists information that may be necessary to evaluate repair, rehabilitation and replacement options. Table 5.2 lists underlying issues that may have led to problems observed.
### Table 5.1 Key Culvert Observations

<table>
<thead>
<tr>
<th>Culvert Type</th>
<th>Observations</th>
</tr>
</thead>
</table>
| All Culverts          | - Pipe size and type including material, coatings, wall thickness  
- Past repairs, invert paving, sediment depth  
- Age  
- Horizontal and vertical deflection of pipe  
- Size and location of voids visible through separated joints and holes in the culvert  
- Sounding the culvert interior with a hammer to listen for ‘hollow’ sounding areas indicating voids outside the culvert (also useful to check for voids in slipline grouting)  
- Width of separated of deflected joints, backfill loss at joints  
- Misalignment of pipe joints  
- Camber (bend) or settlement of pipe alignment (can be determined by stringing the invert for sagging)  
- Localized distortions                                                                                     |
| 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  
- Depth of invert erosion. Amount of section loss for concrete, and reinforcement as applicable  
- Sound walls and inverts to locate areas of delaminating concrete                                      |
| Flexible Pipe Culverts| - Deflection of pipes  
- Composition and compaction of pipe bedding materials  
- Corrosion/Pitting  
- Cracks or tears in pipe wall  
- Buckling of pipe wall (CMP only)  
- Failure of lock or welded seams (CMP only)  
- Corrugation Pattern – Helical (run in a spiral-more common to WisDOT) or annular (circumferential pattern – often riveted)  
- Seam construction – rolled/locked, riveted, bolted  
- Tearing at bolt or rivet holes as applicable                                                                 |

*(Modified from MN DOT, 2014)*
<table>
<thead>
<tr>
<th>Observed Condition</th>
<th>Possible Cause</th>
</tr>
</thead>
</table>
| Loss/erosion of invert                          | - Erosion of culvert material due to stream bed loading (All pipe materials)  
- Corrosion or deterioration of culvert material due to pH and/or resistivity of water and soil, chemical attack, etc. (All pipe materials)  
- Corrosion of reinforcement and resulting expansive forces resulting in delaminations of concrete (RCP)  
- Freeze-thaw deterioration (RCP)                                                                                                                   |
| Joint separation and infiltration of soil      | - Improper seating of joint during installation  
- Movement of pipe due to slope erosion, freeze-thaw or settlement  
- Movement of pipe due to excessive deflection or structural deterioration  
- Buoyancy of culvert with insufficient cover                                                                                                         |
| Piping of soil on exterior of culvert          | - Water flowing past holes in the culvert or separated joints causes migration of soil particles  
- High water head causing migration of soil particles around the outside of the culvert                                                                 |
| Invert and crown cracking width in excess of 0.10” in RCP culverts | - Dead and live loading on culvert exceeding culvert design capacity  
- Increased loading on culvert due to increased soil or groundwater elevations  
- Excessive construction equipment loading with insufficient cover                                                                                   |
| Delamination or “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  
- Increased loading on culvert due to increased soil1. or groundwater elevations  
- Improper bedding of culverts                                                                                                                          |
| Deflections exceeding 7.5% of nominal pipe diameter in flexible culverts 2.       | - Dead and live loading on culvert exceeding culvert design capacity  
- Increased loading on culvert due to increased soil1. or groundwater elevations  
- Improper installation or selection of backfill materials or insufficient compaction  
- Loss of soil through pipe wall or joints  
- Piping of materials on exterior of culvert  
- Excessive construction equipment loading with insufficient cover                                                                                   |
| Cracks, buckling or separated seams in flexible pipe culverts | - Pipes damaged during installation by equipment or rock in direct contact with pipe  
- Excessive loading on culvert  
- Environmental stress cracking in pipe material                                                                                                     |
| Corrosion/Loss of section at crown of pipe     | - Chloride’s from road salt infiltration at centerline joints and at edge of pavement (aluminum CMP)                                                                                                           |

(Modified from MN DOT, 2014)

Notes:

1. Evaluate changes in fill (dead load) over the culvert due to changes in roadway profile from the original design. Profile changes during reconstruction or reconditioning without culvert replacement may exceed of maximum fill height. Maximum fill height generally decreases with larger pipe diameters and elliptical or arch shapes. A search of past projects or the presence of culvert extensions may give clues as to if additional fill has been placed on the culvert.

2. Due to the nature of flexible culverts, and in particular thermoplastic pipe, some deflection is normal with flexible pipe materials. Excessive deflection or point deflection should be evaluated however. If excessive deflection is a concern, consider mandrel testing per CMM 5-50.9 as an option. Newer technologies such as laser profiling are also an option to measure deflection without entry. Profiling can be coupled with video inspection. Where dewatering a pipe is not possible, sonar or similar methodologies is becoming increasing viable. Make careful observations as to sidewall buckling.
3. Localized distortions and similar damage can often be safely removed or repaired to provide clearance for rehabilitation methods such as sliplining. The extent, size, location of the damage or distortion should be noted.

5.3 Hydraulics
Hydraulic evaluation of rehabilitated and repaired culverts is required as most methods will alter the hydraulic capacity of the structure. In addition, the original design conditions (land use, drainage area, precipitation data) under which the culvert was installed could have changed. For areas in floodplains, with a history of localized flooding, or in other high-risk areas, a full hydrology and hydraulic (H&H) analysis may be necessary. When in doubt contact one of the Statewide Drainage Engineers in the Roadway Design Standards Unit (RDSU) for input. Further discussion regarding the hydraulics of slipliners can be found in FDM 13-45-10.4.1.2.

5.4 Structural Condition
Determining the structural condition of a deteriorated culvert is not a straightforward process. As a result, on culvert rehabilitation projects, WisDOT practice is to assume the host pipe is fully deteriorated and the rehabilitation (slipliner, CIPP) carries the full loading condition. In most cases rehabilitation practices that depend on the strength of the host pipe are discouraged except where done as preventative maintenance or a spot repair. At times, however, issues such as site access or maximum depth of cover may prohibit more conventional rehabilitation methods, such as sliplining. In these cases, contact one of the Statewide Drainage Engineers in RDSU for input on the proposed rehabilitation method. This should be done early in the project to allow RDSU to involve BOS and the MMS engineers in evaluating the proposed design assumptions and engineering design methodology employed to analyze the rehabilitation.

Where the structural integrity of the pipe is not in question, localized deterioration, or other issues may be spot repaired without the need to perform a structural analysis. Typical spot repairs can include; resetting endwalls, joint separation or misalignment, small localized holes, localized concrete spalls, and early stage invert corrosion.

Resources are provided in FDM 13-45-99.1 that can assist in determining when a culvert is in need of repair versus the need for full structural rehabilitation. As stated previously with the number of unknowns, such as backfill compaction and condition, culvert material properties and condition, etc. this is not a straightforward process and a conservative analysis should be employed. As-built plans and related installation records, if available, can be used to gain a better understanding of the culvert and backfill materials involved, the original versus current geometric shape, culvert’s age, and how a culvert was installed.

When considering a repair or structural rehabilitation of a culvert with areas of concern, consider if the proposed action will further degrade the condition of the culvert during construction. Will the operation cause the pipe to deflect, cause further separation of joints or cause collapse? Will inaction or delays in project initiation cause further degradation or collapse that could lead to failure prior to the repair operation? Such considerations need to be considered when determining if the repair or rehabilitation of a culvert can wait for the normal design and construction timeline of a standard LET project.

5.5 Cleaning and Verification of Clearance
WisDOT’s standardized special provision (STSP) for culvert slipliners includes a provision for contractor verification of the interior clearance of the culvert as a well as a separate STSP item for Cleaning Culvert Pipes for Liner Verification. The cleaning item should be included on most culvert rehabilitation and repair jobs depending on the conditions observed in the field. Cleaning methods will vary by the size of the culvert and can be left to contractor to determine means and methods. Regardless of the method of cleaning, controls should be in place to capture and dispose of debris and sediment. In many cases, however, it is important to determine clearance prior to the design of a culvert rehabilitation project. Waiting for construction to find out a proposed repair won’t work will lead to project delays and increased costs. Additional information regarding liner clearance can be found in FDM 13-45-10.4.1.1.

5.6 Environmental
Rehabilitation, repair, and replacement projects need to follow the same environmental processes as all WisDOT projects. Some specific considerations are covered in the following subsections.

5.6.1 Floodplains
Rehabilitation practices that reduce the culvert internal diameter, such as slipliners, require additional hydraulic modeling when in floodplain areas. The modeling must show that the upstream water surface elevation is not increased when compared to the host culvert. Bureau of Structure review and approval of the hydrology and hydraulics for the lined structure will be required in most cases regardless of whether the structure has a “B-” or “C-” number. Special liners, such as smooth lined CMP’s, or improved inlets can assist in meeting pre-lining
conditions. In these cases, special provisions specific to the project may be required to specify required Manning's roughness and internal diameter of the culvert. Construction details of improved inlets (bevels), if utilized, will also be required. Finally, often the liner will need to be set at a specific grade and the inlet and outlet to meet the modeled conditions of the floodplain. This will need to be detailed in the plan construction details and emphasized in the contract special provisions.

5.6.2 Aquatic Organism Passage
Rehabilitation practices can affect aquatic organism passage (AOP) in streams. Coordination with WDNR through the liaison process will be required to evaluate project impacts. Slipliners, for example, will often result in increased culvert velocities. In addition, the culvert inverts will be raised by at least the thickness of the liner. If a thick liner is specified this can create a "perched" condition of the culvert and further restrict aquatic organism passage. That said AOP concerns should not eliminate sliplining from consideration. Some slipliners may only raise the invert as much or slightly more than a cured in place or centrifugally cast liner and should not be eliminated from consideration as they provide a longer lasting structural solution for culvert rehabilitation.

5.6.3 Flow Diversion and Dewatering
Culvert rehabilitations and repairs may require flow diversion by bypass pumping, temporary impoundment or other means to keep water out of the work area. Dewatering may be required due to infiltration or high groundwater conditions. Coordination with WDNR through the liaison process will be required to evaluate the diversion or dewatering plans. Plan details may be required to detail this work and/or the project special provisions can require the contractor to develop and submit a dewatering or bypass plan. Special precautions are necessary when dewatering sites with contamination present. Contaminated water will require proper handling and disposal at a treatment plant or specialized facility. Contact the Bureau of Technical Services Environmental Services Section (BTS-ESS) for guidance.

5.6.4 Sediment and Debris
Debris and sediment removed from culverts should be captured and properly disposed of during cleaning operations. The environmental services section can provide guidance on proper disposal of sediments. Site erosion is also a concern. Most rehabilitation and repair methods will not involve trenching, but erosion and tracking is still a concern. For example, backhoes and other heavy equipment are used to install slipliners and bore pits are often excavated for trenchless culvert replacement. Cleaning sediment from a culvert may also involve removing accumulated sediment from the inlet and outfall ditchlines. A basic erosion control plan and material quantities should be included in project plans for account for these localized disturbances.

5.6.5 Additional Environmental Concerns
The materials used in culvert repair and rehabilitation can be of concern to the environment when not handled properly. Concrete and grout pumping and hauling equipment wash out needs to be controlled. Concrete washout and even slurry from sawing can contain metals and is caustic and corrosive, having a pH near 12. Caustic washwater can harm aquatic life. WisDOT will be developing additional guidance on concrete washout in response to the WDNR Construction General Permit first issued in 2018.

Joint repair and Cured in Place Pipe (CIPP) installations involve the use of chemicals 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. All process water used in the curing and post installation cleaning operations shall 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. If the local wastewater treatment plant can not take the water, contact BTS-ESS for disposal guidance. (modified from MNDOT 2014).

5.7 Safety
Safety is paramount on all WisDOT work sites. Standard Spec 107 requires the contractor to comply with all federal, state, and local laws governing safety, health, and sanitation, and to provide necessary safety devices, protective equipment, and safeguards. The contractor must also take all action reasonably needed to protect the life and health of employees on the job and the safety of the public. CMM 1-35 further describes construction safety.

Safety doesn’t only apply to construction sites however. Evaluating culverts presents a number of safety concerns including:

- 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.
- Water: High flow rates and deep water can create dangerous footing conditions. Falling into pools at the culvert ends is also a hazard.
- Animals in the culvert can be dangerous, especially if trapped.
- Entrapment: Deep mud can entrap personnel walking through it.
- Embankments: Steep slopes, loose cobbles, and wet or frozen ground can create dangerous footing conditions.

(Modified and supplemented from MNDOT, 2014)

Bureau of Structures has some additional guidelines for culvert inspection safety.

When inspecting storm sewers and appurtenances additional precautions are advised as it may meet the conditions of a “permit-required confined space”. Strongly consider remote operated inspection equipment when there is a need for inspecting storm sewer.

5.7.1 Safety Resources

Some additional safety resources are as follows:
- Part 1, Chapter 4 of the WisDOT Structure Inspection manual:
  https://wisconsindot.gov/Pages/doing-business/eng-consultants/cnslt-rsrcs/strct/inspection-manual.aspx#p4
- WisDOT Safety Directive 75 (Confined Spaces – access available to WisDOT staff only).

5.8 Access

The current WisDOT Standardized Special Provisions (STSP) for culvert liners requires the contractor to "obtain easements if necessary for installing long sections of pipe". This is not intended to relieve the designer of the responsibility of determining and securing the easements necessary to carry out culvert lining or other rehabilitation or repair operations. Right of way for construction staging and operations should generally be secured in the form of Temporary Limited Easements before project letting. Reliance on Construction Permits should be avoided. The STSP is intended to require the contractor to secure additional easements for unanticipated means and methods employed. Easements will vary by the type of operation. For culvert liners, on at least one end of the culvert, provide a minimum work area 45 feet long emanating on alignment with the end of pipe and 30-40 feet wide, with adequate access and limited obstructions. It is preferable that this area is available at both ends of the pipe to allow push or pull operations. Alternately a smaller work area of at least 10 feet x 10 feet should be available on the opposing end of the culvert. Trenchless construction can require similarly sized easements for boring pits or equipment staging areas.

5.9 Traffic

Culvert repair, rehabilitation, and trenchless replacement projects generally have significantly less impacts to traffic than open trench replacement. That said there are sometimes where short-term lane or shoulder closures may be necessary. During culvert lining material delivery and grout pumping equipment may need to operate from the shoulder due to limited access or steep embankments. Cured in place pipe lining (CIPP) requires support equipment such as CCTV inspection trucks, cleaning equipment, boiler or curing equipment, compressors, etc.

FDM 13-45-10 Culvert Rehabilitation by Sliplining

10.1 Introduction

Culvert lining, or sliplining, is sliding a pipe or pipe-like liner into an existing culvert, then grouting the void between the host pipe and the liner. Liners are inserted into the host pipe by either pushing or pulling the liner into place. Sliplining is frequently used on pipes that show deterioration along the whole length of the pipe. Metal culverts with holes along the inverts are the most common candidates for sliplining. Slipline repairs may be a cost-effective alternative to trenching in a new pipe but the use of sliplining is limited to culverts that will have adequate hydraulic capacity after the size reduction.

10.2 Types of Sliplining

Segmental sliplining consists of lining the deteriorated culvert with sections shorter than that of the existing culvert. 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). Segmental sliplining is the practice primarily
utilized by WisDOT. WisDOT has several approved segmental slipliners on the approved products list. 


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).

10.3 Sliplining Materials
Many types of pipe materials can be used for sliplining however WisDOT’s list of approved liners consist of the following:

- Dual Wall Corrugated PVC (ASTM F949)
- Steel Reinforced Polyethylene - SRPE (AASHTO MP-20)
- Closed Profile HDPE - Solid Wall HDPE (ASTM D-3350 /ASTM F714/ASTM F894)

Manning’s roughness (n) values for approved liners are laboratory tested specifically to the product and published with the approved list.

WisDOT employs other materials such as smooth lined corrugated metal pipes (CMP’s) and smooth-lined polycoated CMP’s for specialty applications. Refer to FDM 13-45-10.4.9 for more details.

![Figure 10.1 PVC Culvert Slipliner](image)

10.4 Slipliner Design Considerations

10.4.1 Liner Sizing
A slipliner needs to be sized for the hydraulic conditions of the site as well as sized to physically fit in the host culvert.

10.4.1.1 Liner Dimensions
As discussed in FDM 13-45-5.5 WisDOT’s standardized special provision (STSP) for culvert slipliners includes provisions for contractor verification of the interior clearance of the culvert as well as a separate STSP item for Cleaning Culvert Pipes for Liner Verification. The liner STSP also requires the contractor to verify the internal clearance of the culvert prior to ordering a liner to identify obstructions, deformations, or deflections that may require repair or special consideration. This does not absolve the designer from confirming host pipe dimensions and obstructions during the design process. Where hydraulics is critical, and the maximum sized liner is required, it may be necessary to confirm the host pipe can fit a liner by pulling a mandrel, laser profiling, or taking detailed direct measurements. In addition to variations in the pipe, the designer must consider the thickness of the liner wall, additional external liner thickness at joints (bells or flanges), while still allowing the minimum recommended clearance between the liner and host pipe. In absence of a recommended clearance,
the designer should assume at least 2 inches between the host pipe and outside of the liner to ensure effective grouting.

If needed, a separate special provision can be used to address areas in need of spot repair damage that would interfere with the intended lining. Examples of spot repairs include jacking or bracing an area of the host culvert to remove a bulge or repairing joints with specialty grouts or bands to control groundwater infiltration prior to sliplining.

WisDOT’s approved list of slipliners is found here:


Internal and outside diameter dimensions can be found at the associated manufacturer websites.

10.4.1.2 Liner Hydraulics

In the past WisDOT has only hydraulically analyzed culvert liners by performing a Manning’s calculation comparison for the roughened host pipe (often CMP) and the smooth liner. Often the reduction in Manning’s roughness of the smoother pipe can offset reducing the pipe diameter with a liner. This is only the case for culverts operating under outlet control (flow controlled by culvert barrel). For culverts in inlet control (flow controlled by the upstream opening, not the barrel), reducing the diameter will increase the headwater condition. Improving the inlet configuration may help offset the headwater increase by allowing flow to enter the culvert more efficiently (refer to FDM 13-45-10.4.7). In addition, the culvert may still perform adequately even with the reduction in opening size, but an analysis is required to confirm this.

At a minimum, a hydraulic analysis comparing the existing culvert to the lined condition should be performed. FWHA’s HY-8 free culvert hydraulics software can be used to analyze the headwater and velocity conditions of the existing and lined culvert. Assumptions regarding roughness of the existing pipe should be documented from a recognized resource such as the FHWA HDS-5 User Manual, an existing flood study, or other recognized publication. Attachment 3.1 provides an example of the minimum hydraulics analysis recommended for a liner project. As described in FDM 13-45-5.3 for areas in floodplains, with a history of localized flooding, or in other high-risk areas, a more detailed hydrology and hydraulic (H&H) analysis may be necessary. When in doubt contact one of the Statewide Drainage Engineers in the RDSU for input.

10.4.2 Invert Height Change

Lining a culvert will result in a rise of the culvert invert. At a minimum, this will be the thickness of the liner. Additional increase can result from the use of guides or rails used to install the liner, protruding bolts in a steel plate culvert or from increased external liner diameter (thickness) at joints. The rise in invert will typically be around 0.2 ft to 0.3 ft. This should be accounted for in the hydraulic analysis of the liner, especially when floodplain impacts are being considered. The designer should not only evaluate the change in headwater relative to the culvert. The raise in invert must be accounted for.

For example:

A 36-inch diameter host culvert has an invert of EL. = 800 ft and according to hydraulic analysis a 25-year design event depth of flow of 3.9 feet (EL. =803.9 ft). A 27-inch I.D. diameter slipliner is considered and results in a headwater of 3.75 feet. By all appearances the headwater has decreased.

In fact, when considering the change in elevation of the liner (in this case assume 0.25 ft) and the vertical datum the headwater has increased by 0.10 ft (Existing Invert EL. = 800 ft +0.25 ft + proposed Hw EL = 804.0 ft).
For a situation where the culvert is in a floodplain (see FDM 13-45-5.6.1) the change in headwater would not be allowed. For this situation, if we were to assume the 36-Inch culvert is not in a regulated floodplain, the headwater to depth (Hw/D) ratio of 1.5 for the host pipe still meets the requirements of FDM 13-15-5 Design Freeboard and Headwater-to-Depth Ratio and as long as no significant impacts resulted from the increased headwater, the 27-inch liner is assumed to meet the hydraulic needs of the site.

For situations with limited clearance the designer can evaluate the use of liners with specialty joints that have no increase in external diameter at the joint. A few WisDOT approved liners meet this condition. A special provision article can be used to modify the existing liner STSP to require a low-profile joint.

10.4.3 Installation Loads

The manufacturers of the culvert liners listed on WisDOT’s Approved Products List should provide recommendations for the maximum loads that can be placed on their products for push or pull installation and grouting operations. Contractors are to follow this guidance during installation. For special applications as described in FDM 13-45-10.4.9 it is advised that the designer evaluate the loading information for the intended product and consider including references to relevant information, special installation requirements, or precautions in the contract special provisions.

10.4.4 Pipe Joints In Liners

Segmental culvert liners have some form of watertight (gasketed) bell and spigot joints between pipe segments. These joints need to withstand pushing and pulling loads as well as grout pressure. If the contractor follows manufacturer guidance most gasketed joints can withstand normal grouting pressures. For nonstandard liner materials like CMP or structural plate culverts, additional restraint and/or joint sealing may be required to prevent leakage of grout.

As described previously the thickness of the liner at the joint needs to be accommodated as well. For example, a liner wall may be 0.2 ft thick resulting in a 0.4 ft difference between the inner and outer wall diameters, however at the joint the outer diameter increases another 0.2 ft due to the protrusion at the joint. Therefore, the true clearance required for the pipe is 0.6 ft larger than the nominal internal diameter. In addition, when assuming the new invert of the lined pipe this thickness at the joint should be considered, not the thickness of the outer wall of the pipe. As described above, in limited clearance situations liners are available without “bells” at the joint.

10.4.5 Liner Grouting

10.4.5.1 Liner Grouting

The annular space between the host culvert and liner should be completely grouted. Just bulkheading the ends of the pipe is not appropriate. Completely grouting the void forms the soil-structure interface important in developing the strength in flexible pipe systems. Annular space grouting has the additional benefits of reducing future movement of roadbed material through misaligned joints, distribution of vehicle load and dead loads on the liner, potential stabilization of voids surrounding the host culvert, and reduces the likelihood of damage or deflection from point loads should the host pipe someday collapse. The contractor’s grouting plan should include
locations for both grout injection and witness ports to confirm complete filling of the void space.

10.4.5.2 Grouting Materials

Materials for annular space grouting ideally are easily placed/pumped over large distances, flowable and self-leveling, and require minimal pumping pressures to mobilize. Two types of grout are typically used, flowable cementitious grouts or cellular grouts. Cementitious grouts are more commonly used due to cost reasons. Cementitious grouts for sliplining often are a mix of fly ash, cement, and water. Fly ash is added to reduce cured permeability and retard set time. Aggregates, when used, are small. Compressive strength can be low. The primary purpose of the grout is to form the structure-soil interface for the liner. An added strength of the liner due to the grout is secondary. Some research has suggested higher strength grouts can be a disadvantage as the grout cracks into larger pieces which can point load the liner. Cementitious grouts should be readily available and do not require specialized equipment. They also may be better suited for displacing groundwater infiltration. To date this has been the most common material used to grout culvert liners on WisDOT projects and may be the best alternative for small or remote projects.

Cellular grout is a mixture of cement and water which also employs foaming agents and/or low-density aggregate to reduce fluid loads during grouting. In general specialty contractors and equipment are required for this material. These grouts have low compressive strengths but high flowability. They will also tend to cause fewer issues related to pumping pressure and liner buoyancy and may be best suited for long culvert liner applications or situations with minimum annular space between the host pipe and liner.

WisDOT's standard STSP for culvert lining allows the contractor to select either cementitious or cellular grout. The designer may wish to consider a special provision article requiring one or the other mixes based on site conditions. Some considerations include:

- groundwater infiltration
- annular space size
- soil conditions
- liner length
- pressure capabilities of the liner and host pipe.
- weather/temperatures (PVC liners are more brittle in the cold)
- structure depth and access

As discussed in FDM 13-45-5.6.5, concrete and grout pumping and hauling equipment wash out needs to be controlled. Concrete washout and even slurry from sawing can contain metals and is caustic and corrosive, having a pH near 12. Caustic washwater can harm aquatic life. WisDOT will be developing additional guidance on concrete washout in response to the WDNR Construction General Permit first issued in 2018.

10.4.5.3 Grouting Pressures

Excessive pumping pressures can be an issue during sliplining. Pumping pressures need to be monitored during the grouting process especially for long or steep installations as discussed in FDM 13-45-10.4.6. For most liners recommended grouting pressure will be 5 psi or below. Excessive grouting pressure can cause joint leakage, joint deflection, liner floatation, and/or liner deformation.
Figure 10.3 Bulge at Liner Joint Likely from Excessive Pumping Pressure

10.4.5.4 Liner Floatation During Grouting
The slipliner must be kept from floating or deflecting during grouting. Grout will tend to be denser than the slipliner and can cause the liner to become buoyant and float or deflect and misalign. If there are obstructions or damage left in place in the host pipe these can damage the liner if it floats. Figure 10.4 shows an example of obstructions left in place that punched through a PVC liner that floated during grouting.
Liner floatation may also raise an invert higher than the designer intended and cause headwater concerns. Excessive grouting pressures will increase the likelihood of floatation.

The contractors grouting plan should describe the intended methods to prevent floatation. Grout staging is one of the best methods to prevent floatation and control loading on the liner from grouting. Some additional measures include bulkheading and filling the liner with water, blocking between the host pipe and liner, and installing jacks through holes in the liner, or through grout ports. The manufacturer should approve the methods of preventing floatation especially when blocking liners (point load concerns) or cutting holes for jacks or other bracing.
Figure 10.5 Floatation Bracing Examples with Blocking or Jacks (Photos courtesy of Contech)
10.4.6 Sliplining Long or Steep Culverts
Both long and/or steep culverts warrant additional consideration, especially during grouting operations. Long culverts can place additional stress on liner pipes during push or pull sliplining. Buoyancy forces during grouting, which normally may be analyzed by the supplier two dimensionally for a typical culvert, require additional consideration on a steep slope to accommodate additional uplift loads and non-uniform uplift loads being exerted along the liner. In addition to liner floatation, excessive grout pressures can be an issue and need to be considered. For long and/or steep pipes grouting should be performed in multiple lifts and pressures need to be monitored closely to avoid liner bulging, deflecting or misshaping joints, or otherwise damaging the liner. On steep pipes additional shoring of downstream bulkheads may be required and grouting should be performed in multiple stages to prevent excessive loading on the pipe during curing. Some manufacturers may recommend cellular grouts for especially long or steep culverts.

10.4.7 Improved Inlets for Culvert Liners
Culvert Liners shall not be allowed to extend beyond the host culvert unless the designs call for constructing a new headwall. This can result in inefficient inlet capacity of the culvert as it may behave like a “culvert projecting from fill”. Plan details or notes should be included when the inlet configuration of the slipline is critical to meet the intended hydraulic conditions. In some cases, a bevel-edged inlet can be formed between the host culvert and the slipline (Figure 10.6).

![Figure 10.6 Beveled Inlet Configurations (Source: FHWA HDS 5)](image)

FDM 13-15-5.7 describes improved inlet types. Regarding bevel-edged inlets it states, “The bevel-edged inlet is the most economical method of improving the capacity of a conventional culvert. The addition of bevels to a conventional culvert with a square-edged inlet increases culvert capacity by five to 20 percent. Note: Bevels should be used on all cast-in-place culvert entrance headwalls, both conventional and improved inlet types.”

In some cases, especially for larger diameter culverts, it may make sense to remove a deteriorated metal endwall and construct a concrete masonry endwall with a bevel-edged inlet. The designer should be mindful of roadside safety concerns for the new masonry endwalls.
10.4.8 Discharge Velocity
As described in FDM 13-45-10.4.1.2, when in outlet control, liner hydraulic capacity often depends on offsetting the reduction in culvert diameter by decreasing the Manning roughness of the pipe. As a result, the velocity of the flow in the pipe will increase. Additional downstream scour and erosion control measures may be necessary to offset the increased outlet velocity. For high outlet velocity conditions (typically >14 ft/s) riprap may not provide sufficient energy dissipation or right of way limits may limit placement of riprap. In these cases, energy dissipators may be necessary. FHWA HEC 14 Design of Energy Dissipators for Culverts and Channels can be used to evaluate energy dissipation at culverts. Fortunately, FHWA’s HY8 software has incorporated the HEC 14 process allowing for increased efficiency in design and evaluation of energy dissipation options.

10.4.9 Special Sliping Applications

10.4.9.1 Lining Pipe Arches
Steel plate and CMP pipe arches can be sliplined in some instances. In these cases, a project specific special provision will be required. The existing WisDOT Culvert Pipe Liner STSP cannot be used as it applies to round culverts. The designer may, however, use this STSP as a basis for a special provision for items of work such as verification, cleaning, grouting, or handling and installation.

It is important to perform detailed measurements of arch culverts when considering a rehabilitation project, especially for steel plate structures. Arches and especially plate structures may differ in radius in the haunches (corners) significantly between sizes even when compared to tables in historical industry or design manuals. Some plate structures may also have been specified with a slight vertical ellipse, especially in high fill situations. Good measurements, and where possible, review of as-built documentation, are important to the design process.

In general, round liners do not meet the hydraulic conditions required for sliplining pipe arches but they should be analyzed as a lower cost option for a site. For larger or multi-culvert installations, it may be worth evaluating the cost of using round slipliners in the host arch pipes and installing a “relief” culvert by trenchless methods to meet the hydraulics of the site. Although some manufacturers promote the practice, WisDOT does not allow the installation of thermoplastic liners that have been braced or otherwise deflected into an arch or horizontal elliptical (HE) shape for sliplining.

Figure 10.7 “Smooth-Lined” Poly-Coated CMP Arch used to Line Existing Steel Arch Culvert
For sliplining steel plate and CMP pipe arches WisDOT advocates the use of smooth lined CMP pipe arches (Figure 10.7). In these cases, the manufacturer fabricates an additional steel liner that covers the interior corrugations of the pipe. The Manning’s roughness of the liner is reduced closer to that of a concrete pipe. The reduction in Manning’s roughness compared to the host pipe in some cases will offset the reduction in pipe diameter. For additional longevity and protection from corrosion and abrasion, the liners can be polymer coated (Figure 10.8). In some cases, these smooth lined CMP pipe arch slipliners can also be manufactured in nonstandard sizes to meet the needs of specific applications. In special circumstances, arch pipes can also be lined with specialized field welded steel plate arch shaped liners.
As previously stated, the standard STSP for culvert liners cannot be used for “non-circular” pipe and a project specific special provision is necessary. Contact one of the Statewide Drainage Engineers in RDSU for guidance for analyzing and specifying slipliners for arch or HE culverts.

**Figure 10.8 “Smooth” Polymer Coated CMP**

### 10.4.9.3 Lining Box Culverts
Lining box culverts is possible in some cases but requires coordination with the Statewide Drainage Engineers in the RDSU and the BOS for guidance. Box culvert sliplining can be accomplished with specialized field welded steel plate box culvert liners, structural plate boxes or arches, or in some instances round culverts or steel plate culverts.

When considering lining a box culvert contact one of the Statewide Drainage Engineers in RDSU who will in turn provide guidance and engage BOS. A thorough hydrology and hydraulic as well as structural analysis will be required in most cases, especially when the culvert is located in a floodplain (see FDM 13-45-5.6.1).

### 10.4.9.4 Tunnel Plate Liners
Round, arched and box shaped culverts in some cases can be lined with tunnel liner plate. Tunnel liner plate, like steel plate pipe, bolts together in sections that form the culvert. Tunnel liner plate assembles from the inside allowing for it to serve as shoring during construction. The tunnel liner plate can also provide shoring to facilitate the complete removal of portions of a failing or severely deflected culvert while providing a safe working environment. Tunnel liner plates may have internal rings as part of the structure that should be considered as part of the hydraulic analysis of the liner.
10.4.9.5 Machine Wound Liners

Machine wound liners, often referred to as spiral wound liners, consist of strips of interlocking or continuously welded-seam thermoplastic pipe material (often PVC or steel reinforced HDPE) that are field fabricated by on-site machinery. The liners can be used to address corrosion or groundwater infiltration and are best suited for limited access installations where traditional slip lining is constrained. Often the machinery required can fit within a small-bore pit, manhole, or even the pipe itself. Some specialized equipment can travel down the pipe and wind the liner tight to the wall of the host pipe. Other methods allow the insertion of the liner at a fixed diameter where it is then expanded against the wall of the host pipe. Most often the expanding type of liner is done in smaller diameter pipes. For larger pipes or otherwise when the liner is not expended tight to the host pipe wall grout should be used to fill the annular space. Machine wound liner joints can be made watertight with machine applied sealants or welds during the installation process.

For installations with higher design loads steel reinforced thermoplastic strips are available. The steel reinforcement is added to the exterior ribbing of the field fabricated pipe so the resulting interior is smooth. The resulting annular space is grouted.

WisDOT does not have a standard item or STSP for machine wound liners. Coordinate with the Statewide Drainage Engineers when this type of liner is under evaluation for a project. The drainage engineer will involve BOS and the MMS as appropriate. General guidance for spiral wound and similar liners is as follows:

- Pipes 48” and less can be lined based on manufacturer-recommended empirical analysis for structural
capacity, stamped by a professional engineer registered in the state of Wisconsin and submitted to the project for review 14 days prior to delivery of the material.

- Pipes larger than 48" require a site-specific numerical (finite-element) structural analysis that incorporates soil boring data from the site and any additional anticipated loadings from dead, live, or adjacent foundation sources, stamped by a professional engineer registered in the state of Wisconsin and submitted to the project for review 30 days prior to the delivery of the material. It is recommended that a geotechnical subsurface investigation be performed during the design process and an initial liner analysis be performed by the design engineer to determine the feasibility of lining pipes greater than 48 inches in diameter using a spiral wound liner. The geotechnical subsurface investigation should provide the necessary level of detail to allow the accurate computational analyses of pipe lining design. The actual geology and site conditions will determine how many, and what spacing of, borings are required.

- The liner shall meet the hydraulic conditions of the site (see FDM 13-45-10.4.1.2).

10.4.10 Additional Sliplining Considerations and Restrictions

The following is a list of additional considerations and restrictions for sliplining culverts. Some of this material is repeated from previous sections for emphasis.

- Remember the exterior dimensions of a liner when considering a liner product. For example, steel plate liners not only need clearance for the exterior corrugations but an additional 1 inch or more of clearance may be lost to bolts.

- WisDOT’s STSP is only intended to be used for circular culverts. The STSP should not be used on culverts that are:
  - Located in a mapped floodplain unless culvert with liner is modeled to show upstream water surface elevation is not increased when compared to the existing culvert. (FDM 13-45-5.6.1)
  - Located in drainage districts unless the drainage board approves the installation of the liner. (FDM 5-15-1)
  - Located on a stream where aquatic organism passage is a concern unless WDNR agrees with the use of a liner. (FDM 13-45-5.6.2)
  - Crushed, collapsed, or have excessive deflection that may make liner installation impossible.
  - Horizontal elliptical or arch pipes. Project specific special provisions are required. (FDM 13-45-10.4.9.1)

- Do not line previously lined culverts. The liner must meet the hydraulic condition of the original host pipe, not that of a previously installed liner.

- Project plans must include characteristics of the existing culvert including material of construction, diameter, pipe slope, depth of fill and any additional loading requirements. Because of variation in liner size, do not show proposed liner diameters on the plans unless it is required to meet special hydraulic conditions such as maintaining a critical water surface elevation.

- Field verify culvert material of construction, size, shape and condition during design. Include a sufficient quantity under the Cleaning Culvert Pipes for Liner Verification bid item for the construction staff to confirm required liner dimensions before ordering material. Typically, the bid item is not needed for every liner on a multi-liner project but only for those likely to be under water or otherwise obscured by sediment or debris.

- When specifying liners for concrete pipe, designers should verify the hydraulic requirements of this special provision can be met.

- Perform a complete culvert hydrology and hydraulic analysis on culverts to be lined that have hydraulically sensitive structures and/or property upstream and in low cover areas where over topping may be a concern.

- The liner STSP states "Obtain easements if necessary for installing long sections of pipe". This IS NOT intended to relieve the designer of the responsibility of determining and securing the easements necessary to carry out culvert lining operations (FDM 13-45-5.8).

**LIST OF ATTACHMENTS**

**Attachment 10.1** Culvert Liner Hydraulic Analysis Example
15.1 Introduction
The following is a brief description of some additional repair and rehabilitation practices for culverts. These practices are not widely utilized by WisDOT and there are no standard items of work or STSP’s covering these methods. When one of these methods, or similar non-standard repair or rehabilitation is proposed for a project, notify one of the Statewide Drainage Engineers in the Bureau of Project Development, Roadway Design Standards Unit (RDSU). The Statewide Drainage Engineer will consult with the BOS and/or MMS as necessary to determine the design and materials requirements specific to the project and the appropriateness of the proposed method to the location in question.

15.2 Invert Paving
Invert paving involves placing reinforced concrete on the invert of an existing culvert. For culverts with partial deterioration, and where the structural capacity of the culvert has not been compromised, invert paving may be possible without a comprehensive structural review.

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 performing a 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. 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. (Modified from MNDOT 2014). Under most conditions a metal pipe requiring invert repair should be considered fully deteriorated.

15.3 Cured in Place Pipe Liner (CIPP)
Cured in place pipe lining involves inserting a resin impregnated fabric (often synthetic felt, commonly known as needle-punched geosynthetic) tube into a culvert or storm sewer. One of two methods is generally employed to install the liner, pulled-in-place or inversion. Depending on the method, the liner is placed and inflated, with air or hot water, and then is cured with hot water, steam, or more recently ultraviolet light. The liner will conform to the wall of the host pipe so any deflection or damage within the pipe will reflect through the liner, and if protruding, may damage the liner. This may require that areas of the culvert or storm sewer be repaired or replaced prior to insertion of the CIPP liner. Voids along the pipe will also need to be filled prior to CIPP lining.

Figure 4.1 Extending and Invert Paving a Structural Plate Pipe Arch (Photo courtesy of Contech)
15.3.1 Additional Environmental Considerations for Cured in Place Pipe Liner (CIPP)
Depending on the curing method, CIPP lining has the potential to create conditions harmful to aquatic life. Studies have shown that styrene and other chemicals can be released in concentrations above toxicity thresholds. Careful planning and execution of CIPP lining is critical to reducing the potential for environmental impacts, especially to the downstream receiving waters. Excessive temperatures from hot water or steam can also be a concern to aquatic life. Due to potential impacts to aquatic life, downstream receiving waters shall be protected from discharges from CIPP operations. Project specifications shall include provisions to capture process waters from the CIPP process. Further, the specifications shall require that the captured waters be transported to a local wastewater treatment facility capable of treating the impacted water. It is recommended that the designer may wish to verify with the local plant that it has the capability to handle the impacted waters during the design process. If the local wastewater treatment plant can not take the water, contact BTS-ESS for disposal guidance. Alternately, ultraviolet light curing is becoming more common and will significantly reduce the potential for construction discharges from a site. Unfortunately, ultraviolet curing is limited to smaller diameter pipe. Regardless of the method, 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.

15.4 Centrifugally Cast and Spray-on Liners
Lining systems are available where cementitious mortar or other material are sprayed or centrifugally cast to the interior of a pipe. Without additional reinforcement, spray-on lining may add little or no structural integrity to the existing culvert. Some cementitious mortar systems use fibers in the mix to enhance the flexural strength. Non-cementitious systems should only be considered where improved watertightness and corrosion resistance is
desired. Multiple passes may be necessary to reach the design thickness of the liner. Infiltration into the pipe will also need to be stopped prior to application.

WisDOT’s current position is that unless additional reinforcement is provided, in most cases this practice shall be limited to applications where the pipe diameter is small (<48-inch diameter) and the strength of the host pipe is not in question. With centrifugally cast products keep in mind that the culvert invert needs to be in sufficient condition for the applicator to travel across it.

**Figure 4.3 Spray-on Mortar Invert Repair and Cast Mortar Liner (Source FHWA and MNDOT)**

**15.5 Pre and Post Installation Inspection of Cured in Place Pipe Liners (CIPP), Cast, and Spray-on Liners**

Inspection of pipes both during the design phase and construction should be part of all culvert and storm sewer projects. However, with storm sewer projects or small diameter culverts access is limited and possibly dangerous. In those cases, consider requiring pre- and post-installation televising of the culvert or storm sewer as part of the contract special provisions. For storm sewer, this may help locate previously unidentified direct connections sewer pipe in spans between manholes. These connections may otherwise be inadvertently covered by the liner.

**15.6 Design Requirements for Cured in Place Pipe Liners (CIPP), Cast, and Spray-on Liners**

Prior to specifying cured in place pipe liners (CIPP), cast liners, spray-on liners, or other non-standard culvert repair or rehabilitation, the designer shall carefully verify that a conventional slipliner will not meet the needs of the site. Document the reasoning conventional sliplining will not meet the project DSR. As stated previously, if a non-standard repair or rehabilitation is ultimately proposed for a project, notify one of the Statewide Drainage Engineers in RDSU. The Statewide Drainage Engineer will consult with the BOS and/or MMS as necessary to determine the design and materials requirements specific to the project and the appropriateness of the proposed method to the location in question.

**15.6.1 Structural Design Requirements and Submittals for Cured in Place Pipe Liners (CIPP), Cast, and Spray-on Liners**

Claims that CIPP, spray liners or similar non-traditional methods of lining culverts “creates a structural pipe within a pipe” does not absolve the designer from verifying, or causing to be verified, the structural integrity of the repair. As with any culvert, minimum anticipated loading conditions need to be verified. The analysis should assume a fully deteriorated pipe and that the liner is carrying the full loading conditions of the site.
At this time, the following minimum design conditions shall be considered if a culvert or storm sewer is lined by methods other than slippining such as CIPP, Cast or Spray-on Liners:

- **Pipes 48-Inch Equivalent Diameter and less** can be verified by empirical analysis for structural capacity, stamped by a professional engineer registered in the state of Wisconsin and submitted to the project for review 14 days prior to delivery of the material. The analysis should assume a fully deteriorated pipe. For CIPP systems the structural analysis for pipes under 48-inches shall be performed using Appendix XI from ASTM F1216-16 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube. For other non-traditional methods of culvert rehabilitation, such as cast or spray-on liners, a manufactured-recommended empirical analysis for structural capacity can be utilized.

- **Pipes larger than 48-Inch Equivalent Diameter** cannot be lined with spray, cast or similar liner systems. CIPP installations larger than 48-inch equivalent diameter require a site-specific numerical (finite-element) structural analysis that incorporates soil boring data from the site and any additional anticipated loadings from dead, live, or adjacent foundation sources, stamped by a professional engineer registered in the state of Wisconsin and submitted to the project for review 30 days prior to the delivery of the material. MMS can assist with reviews if needed. It is recommended that a geotechnical subsurface investigation be performed during the design process and an initial liner analysis be performed by the design engineer to determine the feasibility of lining pipes greater than 48 inches in diameter using CIPP methods. The geotechnical subsurface investigation should provide the necessary level of detail to allow the accurate computational analyses of pipe lining design. The actual geology and site conditions will determine how many, and what spacing of, borings are required.

15.6.2 Hydraulic Design Requirements for Cured in Place Pipe Liners (CIPP), Cast, and Spray-on Liners

The hydraulics impacts of CIPP, cast, and spray liners needs to be evaluated by the designer. While these liners reduce the interior diameter less than a slippiner in most cases, the Manning’s roughness may not decrease as significantly. For example, when lining a corrugated metal pipe with CIPP, the CIPP may reflect the corrugations creating a Manning’s roughness higher than the 0.009 to 0.011 expected for a smooth lined pipe. For CIPP installation in concrete pipe a Manning’s roughness of 0.01 is to be used. For CIPP lining of corrugated metal pipe a Manning’s roughness of 0.018 is to be used. See FDM 13-45-10.4.1.2 for additional guidance on liner hydraulics.

![Figure 15.4 Roughness within CIPP Lined Culvert](image)

15.7 Cost Considerations for Cured in Place Pipe Liners (CIPP), Cast, and Spray-on Liners

On average CIPP, cast, and spray-on liners will cost more to install than a conventional culvert slippiner. The designer shall carefully verify the hydraulics of a conventionally slippined culvert will not meet the conditions of the site. A slight raise in headwater may be acceptable for culverts outside regulated floodplain areas so long as the impacts of the headwater increase are considered. CIPP and other non-traditional liners may become more cost effective where multiple culverts or a storm sewer system are lined where the cost of mobilizing specialized equipment is spread out. That said, the designer shall consider the life cycle and risk of these repairs versus
conventional slip lining where, in essence, a “new” pipe meeting intended design loads is placed.

20.1 Introduction

To this point this section has focused on repair or rehabilitation of culverts and storm sewers using trenchless methods. There are, however, trenchless methods of construction available to replace or install new culverts and storm sewer where traditional open-cut excavations are impossible or undesirable. The following is intended as an introduction to these technologies and to provide guidelines for WisDOT’s minimum project requirements for these installations. While one or more of these methods may meet the needs of a particular installation, each of these methods has its own advantages and limitations. As stated previously, when one of these methods, or similar non-standard repair or rehabilitation is proposed for a project, notify one of the Statewide Drainage Engineers in RDSU. The Statewide Drainage Engineer will consult with the BOS and/or MMS as necessary to determine the design and materials requirements specific to the project and the appropriateness of the proposed method to the location in question.

With the installation of new storm sewer or culverts through trenchless methods the primary design concern will be if the installed pipe can handle the installation loads. This is not just a matter of specifying a higher-class pipe or a “jacking pipe”. The pipe should be analyzed by a professional engineer registered in the state of Wisconsin to verify it can handle the intended construction and in place loading. For RCP used in jacked installations, consider requiring documentation and observation of quality control testing of the pipe that will be installed. It also must be determined whether a casing pipe should be installed. The need for a casing pipe should be determined based on the specific installation considering such factors as; the method of trenchless installation, risk of damaging a pipe driven without a casing, installation tolerance, risk of joint separation, the effects of abandoning and re-boring a new pipeline for installations stuck or severely off alignment, or other unanticipated events that may result in disruption to the overlying roadway. In most cases the trenchless installation of a culvert should include a casing and the annular space between the casing and carrier pipe should be grouted.

Another consideration is construction access. Trenchless construction often may still require excavation for bore and receiving pits and space is needed to stage materials and to set and brace trenchless equipment. Some additional considerations for trenchless construction include:
- Depth to groundwater
- Required dewatering
- Required geotechnical information
- Site constraints, space considerations, need for easements
- Potential obstructions
- Utility conflicts
- Monitoring of settlement and heave
- Monitoring of adjacent structures
- Monitoring of vibration, especially with pipe ramming
- Appropriateness of various trenchless methods

20.2 Environmental Considerations

FDM 13-45-5.6 describes various environmental considerations when planning a trenchless rehabilitation, repair or replacement project. For trenchless replacement, some additional considerations include preventing the discharge of spoils and lubricants (usually bentonite or polymer mixtures). “Frac-out, or inadvertent return of drilling lubricant, is a potential concern when the horizontal direction drilling (HDD) is used under sensitive habitats, waterways, and areas of concern for cultural resources. The HDD procedure uses bentonite slurry, a fine clay material as a drilling lubricant. The bentonite is non-toxic and commonly used in farming practices, but benthic invertebrates, aquatic plants, and fish and their eggs can be smothered by the fine particles if bentonite were discharged to waterways.” (AASHTO TC3). Contract documents should include provisions for the contractor to maintain a spill response plan which includes provisions for handling and storage of materials to address potential environmental concerns. WisDOT is in the process of developing such spill plan language for all projects.

20.3 Geotechnical Considerations

No proposal for the placement of a trenchless pipe installation should be made without performing a geotechnical subsurface investigation. The geotechnical subsurface investigation should provide the necessary
level of detail to allow the accurate computational analyses of pipe lining design. The actual geology and site conditions will determine how many, and what spacing of, borings are required. More complex projects may require a complete Geotechnical Baseline Report (GBR), dependent on project needs. It is advisable to secure recommendations within the geotechnical investigation regarding the feasibility of the concepts under consideration. Some additional considerations related to soils include: “Is the proposed [trenchless construction] equipment compatible with the anticipated soil conditions? Where is the water table? Can the equipment function in unstable ground conditions? Or, will the soil conditions need to be stabilized prior to the trenchless process being employed? If so, how? For example, will the soil need to be dewatered? Is dewatering reasonable at the specified project site? Are contaminated soils or groundwater anticipated? What is the likelihood of ground heaving or settlement? Need to establish allowable limits for ground movement and need to determine how ground movement will be measured” (Caltrans 2014).

20.4 Trenchless Construction Methods

20.4.1 Pipe Jacking

Pipe jacking is a method of tunnel construction where hydraulic jacks in a pit or drive shaft are used to push pipes through the ground, it is one of the first and most common trenchless methods of installing drainage facilities. On WisDOT projects pipe jacking is usually accompanied by a boring operation to excavate soils at the face of the operation and to remove the spoils. Space to configure jacking and receiving pits need to be of sufficient size to set and secure the jack and to stage materials. Jack and boring reinforced concrete pipe without a casing can be done considering the risks described in FDM 13-45-20.1. When jack and boring reinforced concrete pipe without a casing the driving ends of the pipe should be properly protected against spalling and other damage, and intermediate joints should be similarly protected. “The axial or thrust jacking loads are transmitted from one pipe section to another through the joint surfaces. It is essential that the pipe ends are parallel so that there will be a relatively uniform distribution of forces around the periphery of the pipe. Specifying a higher class of pipe provides little or no gain in axial crushing resistance” (Caltrans 2014).

As described in FDM 13-45-20.1, the voids between casing and carrier pipe should be grouted after completion of a jacking operation. Since the principal risk associated with trenchless methods is settlement of the overlying fill, additional consideration should be given to providing grout ports within the casing itself to allow the filling of any voids created by collapse while pushing the pipeline. “If there is a possibility of the excavation face collapsing, various soil stabilization techniques, including dewatering and grouting, may be required.” (AASHTO TC3).
20.4.2 Microtunneling

For long runs, where a high level of accuracy is required, and/or in soils with a higher risk of collapse at the excavation face, jacking operations can be coupled with microtunneling. Microtunneling is a type of pipe jacking where the steering and excavation equipment are operated remotely. This process provides continuous support to the excavation face. Spoils are generally removed by auger or mixed and pumped as a slurry.

Figure 20.1 Jack and Bore Operations (Source AASHTO TC3)

Figure 20.2 Microtunneling Machine (Source AASHTO TC3)
20.4.3 Pipe Ramming

With pipe ramming a pneumatic hammer pushes an open-ended steel casing that is cleaned out during and after completion of pipe installation. The ramming hammer is attached to the casing with tensioning straps and pneumatic percussive blows drive the casing. Depending on the situation, pipe ramming can be faster than jack and bore installations. Ramming is generally unguided and is not as accurate as other methods. In some special applications pipe ramming can be guided for greater accuracy. Pipe ramming does not have the same space requirements for installation equipment and can be used in difficult site conditions. When considering pipe ramming, the impact of the noise should be considered.

This method should only be used to install casing. Ramming of reinforced concrete pipe on WisDOT projects is not allowed.

20.4.4 Pipe Bursting

With pipe bursting, an expansion tool is guided through the old pipe and pushes it out of the way while a new pipe is guided through. This method works on pipes that will fracture such as cast iron, clay, and unreinforced concrete. CMP cannot be easily removed and replaced by pipe bursting. With CMP pipe, other methods should
be considered.

### 20.4.5 Pipe Swallowing/Pipe Crushing
Pipe swallowing and pipe crushing both involve installing a casing around the existing pipe. This may be advantageous where environmental or hydraulic considerations make it desirable to install the new pipe in exactly the same horizontal location as the existing. With pipe swallowing, an oversized casing is rammed over the existing culvert. After installation is complete, the old culvert and spoils are removed, and the new culvert can be inserted. Pipe swallowing may be advantageous in correction of an existing culvert that is perched or where a lowering of the invert of a culvert is desired for hydraulics, fish passage or other environmental considerations. Pipe crushing is primarily used with CMP culverts. Blades in the casing crush the existing pipe as the casing is driven. The old culvert and spoils can then be extracted from within the casing similar to pipe swallowing.

### 20.4.6 Horizontal Directional Drilling
Horizontal directional drilling, also known as directional boring, uses a steerable drilling rig to install primarily high-density polyethylene or a similar flexible conduit or pipeline. Some systems can install metal pipelines as well. The bore path can be monitored and adjusted according to the location of the proposed utility or obstacles that are encountered. The pipeline can be welded as it is installed, virtually eliminating joints within a run.

On WisDOT projects horizontal direction drilling is primarily used by private utility companies for associated utility relocates or replacements. It may have applications for installing non-drainage WisDOT systems such as conduit for communications or power cabling. HDPE pipe can be drilled up to 48 inches in diameter so there may be a site-specific drainage consideration when other trenchless methods do not meet the needs of the project.

### FDM 13-45-99 Resources and References

#### 99.1 Resources
The following is a brief list of useful resources for learning more about evaluating culverts, culvert liners and culvert repair in general.

**Assessment**

**Design**

**Repair and Rehabilitation**


NASSCO CIPP Committee (2008). Guidelines for the Use and Handling of Styrenated Resins in Cured-In-Place-Pipe.

**Trenchless Construction**

AASHTO TC3 Transportation Curriculum Coordination Council. Trenchless Technology (Online Course - 5.5 PDHs). This course provides an introduction to trenchless technology, including its purpose and history, and explains the applications, permitting considerations, construction practices, and inspection guidelines. The development of this course was provided by Iowa DOT in partnership with TC3. https://training.transportation.org/item_details.aspx?ID=3707

**99.2 References**

