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Large Corrugated Metal Pipe Repair Techniques: A Survey of Practice and Related Resources

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT. This TRS does not represent the conclusions of either CTC & Associates or MnDOT.

Introduction

MnDOT is interested in learning about effective practices and costs to structurally rehabilitate bridge-size large-diameter (10 feet or greater) corrugated metal pipe. Of particular interest are current practices of other northern cold-weather states for extending the life of a deteriorating CMP by performing a repair or rehabilitation that provides continued structural support for traffic. Examples of such repairs are the use of epoxy or cementitious sprayed-on liner, sliplining, or cured-in-place pipe. Any repair techniques found to be effective could be considered as alternatives to excavation and replacement of the deteriorating pipe.

To support this effort, CTC & Associates conducted a survey of transportation agencies and a literature search to identify practices for repairing large-diameter CMP.



Summary of Findings

This Transportation Research Synthesis is divided into two sections:

- Survey of Practice.
- Related Resources.

Survey of Practice

An email survey was distributed to representatives from state departments of transportation in 10 northern cold-weather states, three Canadian provinces and two national agencies to identify their experience, if any, with large-diameter CMP repair techniques.

Six state DOTs responded to the survey, with only five reporting experience with rehabilitation techniques for large-diameter culverts. In addition to the survey responses, a representative from New York State DOT provided information about two large-diameter repair projects in upstate New York.

The email survey gathered information in eight topic areas:

- Repair techniques.
- Frequency and extent of large-diameter repairs.
- Potential environmental concerns.
- Roadblocks precluding the use of certain repairs.
- Structural issues before repair.
- Structural issues after repair.
- Life-cycle cost-effectiveness.
- Pending research.

The following summarizes findings in each topic area.

Repair Techniques

The most commonly used technique among respondents is sliplining, used in Illinois, Indiana, New York and Ohio. Some respondents provided more detail than others about the specific method of sliplining used, with Indiana reporting the use of profile wall high-density polyethylene, smooth steel liners, spiral-wound liners and square ribbed metal pipe (the last three have had limited use). New York State DOT has also used smooth steel liners. The Illinois respondent described the agency's use of sliplining as "grouted insertion lining." Other rehabilitation practices used by respondents include cured-in-place pipe, concrete blanket, flowable fill and foam sealant (Michigan), concrete paved inverts (Indiana and Ohio), and spray-on liners (Indiana). While CIPP is used in Michigan for large-diameter repairs, the Indiana and Ohio respondents noted that size limitations preclude the use of CIPP on CMP with a diameter of 10 feet or more. This is consistent with guidance found in national and state publications.

Frequency and Extent of Large-Diameter Repairs

Most respondents were unable to provide data on the frequency of large-diameter repairs. Both Illinois and Indiana DOTs have completed relatively few such repairs, and in Indiana, practices other than sliplining have been used for no more than five years. In Michigan, liners have been in place for four years or less. In New York, over the past 10 years, one or two large diameter culverts have been sliplined every couple of years. While not providing data on the volume of these repairs, the Ohio DOT respondent did note that the agency intentionally oversizes culverts if the fill height is greater than 16 feet and/or if under a freeway for the sole purpose to slipline the culvert in the future.

Potential Environmental Concerns

None of the respondents reported concerns with environmental issues associated with a repair technique. The Indiana and Michigan DOT respondents mentioned concerns reported by Virginia DOT in connection with CIPP practices (research studies prepared for Virginia DOT on this topic appear in the **Related Resources** section of this report), but reported no specific concerns of their own. The New York State DOT respondent highlighted a series of potential adverse environmental impacts associated with culvert rehabilitation, noting that coordination with the agency's environmental group is done early in the design phase to identify potential impacts and opportunities for mitigation.

Roadblocks Precluding the Use of Certain Repairs

Both Indiana and Michigan DOTs reported a failed CIPP installation. In Indiana, problems occurred during the repair process; in Michigan, it is not clear what is causing the liner to pull away from the host pipe. In both cases,

the liner was or will be replaced. Indiana DOT has also identified issues with a cementitious spray-on liner product, including the possible excess accumulation of the sprayed-on material in the haunches of a pipe arch, and the need for multiple passes to fill corrugations and provide a smooth invert in the structure, which improves hydraulics.

The New York respondent also addressed hydraulics. A smooth steel liner was selected over other alternatives—lining with a round, smooth plastic liner or a smaller corrugated pipe arch—because both of these alternatives would decrease the hydraulic capacity of the repaired pipe.

Structural Issues Before Repair

Four respondents addressed the issue of when to repair a failing pipe:

- In Illinois, pipes are repaired when inspectors observe visual signs of distress such as excessive deflection, wall separation at riveted or bolted joints, severe section loss usually in the invert, or fill infiltration.
- Indiana DOT allows only structural lining methods, so there is no concern with the level of pipe deterioration prior to rehabilitation. The agency would consider full replacement if identifying significant undermining of the pipe or crushing of the structure. However, crushing or damage on the exposed portion of the host pipe can be removed and, if necessary, a pipe extension can be installed prior to lining.
- In Michigan, the agency considers rehabilitation or replacement when wall loss is apparent.
- The New York State DOT respondent noted that it may not be possible to push an adequately sized liner into a host pipe if the host pipe is partially collapsing or has other alignment issues. Routine inspection reports of culverts with a diameter or span width of 5 feet or more are used to identify large-diameter culverts in need of repair or replacement.

When a Pipe is Too Deteriorated for Repair

Two respondents identified circumstances under which repair may not be an option for a deteriorating pipe. In Indiana, full replacement may be required if there is significant undermining of the pipe or crushing of the structure. For New York State DOT, pipes that may not be good candidates for rehabilitation include those with significant deformation and/or settlement, severe corrosion and pitting, widespread section loss, backfill infiltration, and/or extensive undermining.

Structural Analysis of Failing Pipes

Illinois, Indiana and New York State DOTs allow only structural rehabilitation methods, which eliminates the need for a structural analysis of a failing pipe prior to repair. While Michigan does not appear to rely on structural rehabilitation methods, the Michigan DOT respondent provided information about visual inspections rather than formal structural analyses.

Parameters for Design, Construction, Inspection and Verification

Only two respondents—Illinois and New York State DOTs—provided a response to the survey question about parameters (design, construction, inspection and verification) associated with large-diameter CMP rehabilitation techniques:

- For Illinois, these parameters include the contribution allowed, if any, from the host pipe; minimum hydraulic capacity of the new liner relative to the existing pipe; minimum grout strength; installation procedures; and minimum experience required of the installation contractor (perhaps three projects of similar size and scope in the past five years).
- For New York, these parameters include hydraulic capacity, structural capacity, material specifications, environmental issues and permits, anticipated service life, required submissions for approval, construction details and procedures, testing and basis of payment. The maximum depth of cover for the pipe being relined, estimated modulus of soil reaction and the estimated water table must be noted on the contract plans.

Relevant information can also be obtained in special provisions and supplemental specifications available from Michigan and Ohio DOTs.

Structural Issues After Repair

When asked if rehabilitation methods provide adequate structural support, the Illinois, Indiana and New York State DOT respondents again noted that these agencies use only structural repair methods. The Michigan DOT respondent has questioned some of the manufacturer claims about the structural adequacy of a method or product.

Loading Introduced by Failing Pipe

Again citing the use of only structural repair methods, the Illinois, Indiana and New York State DOT respondents reported that problematic loading introduced by the failing pipe is not a concern. The Michigan DOT respondent noted multiple areas of concern, including the potential for uncalculated loading when the theoretical calculations are not correct due to an error in assumptions or inadequate coverage of secondary support material.

Bridge Load Ratings

Most respondents provided relatively little detail in response to the survey questions related to bridge load ratings (how to analyze a repaired pipe for a bridge load rating, the appropriate bridge load rating method and how the load rating is performed). The following summarizes initial survey responses and the results of follow-up contacts to selected respondents:

- Illinois DOT follows the AASHTO Load and Resistance Factor Design code, using the same bridge load rating method as the one applied to the existing host pipe.
- The Indiana DOT respondent indicated that to determine the structural integrity of spray-on liners, a finite element analysis, which Indiana DOT does not have the capability to perform internally, may be required. Determining structural integrity may also involve calculations of a strength coefficient to determine if the liner is structurally adequate.
- Michigan DOT requires that the liner designer provide the agency with signed load ratings, which are then checked by agency engineers. The agency was unable to provide sample manufacturer documents prepared in connection with large-diameter culvert rehabilitation projects.
- New York State DOT designs and specifies the pipe size, shape, gauge/thickness and material needed for lining a large-diameter culvert. For a recent project, the contractor was required to provide a Level 1 Load Rating Analysis certifying that the inventory and operating load rating was equal to or greater than that which was required in the contract documents.
- Ohio DOT's Supplemental Specifications address load ratings. The agency's Structures unit requests professional engineer-signed calculations from the manufacturer and accepts them as is.

Life-Cycle Cost-Effectiveness

Only the Illinois and New York State DOT respondents provided specific repair cost data; other respondents noted that costs vary based on a wide range of factors. Agencies did provide cost ratings for various rehabilitation methods. Two respondents rated the cost of CIPP as "high," and respondents had a clear difference of opinion on the cost of sliplining (one rating each for high, medium and low). The Indiana DOT respondent noted that costs for spiral-wound liners and spray-on lining fall between the costs for CIPP and sliplining.

Respondents were unanimous in their assessment of each rehabilitation technique costing less than replacement, and almost unanimous when asked if the addition to service life was worth the expense (the Michigan DOT respondent feels it is too early to make this determination).

Pending Research

Two agencies have research projects in progress. The projects will examine a triple-barrel spray cast process (Michigan) and the structural benefits of concrete paving of steel culvert inverts (Ohio).

Related Resources

Much of the research-oriented literature on rehabilitation methods for large-diameter CMP provides less detail about the structural effectiveness, installation practices and cost implications of the rehabilitation than MnDOT is seeking. Additionally, when research-based case studies are available, they typically address smaller-diameter CMP.

The publications highlighted in this report provide high-level information about the rehabilitation practices of interest to MnDOT or hold the promise of providing such information. For example, an NCHRP project in progress may offer guidance on rehabilitation practices for larger-diameter CMP. Other national guidance identifies and addresses in brief the rehabilitation methods that are appropriate for large-diameter repairs, which include segmental sliplining, high-density polyethylene formed-in-place pipe, spiral-wound liners and spray-on liners (cementitious or polyurea). State publications produced for Utah, Virginia and Wisconsin DOTs provide similar guidance that considers the advantages, disadvantages, application practices and costs for a range of pipe diameters. The focus is on the environmental implications of culvert repair in a series of publications prepared for Virginia DOT.

Perhaps the most extensive examination of rehabilitation practices for large-diameter CMP appears in magazine articles about repairs in New York, Indiana and Ohio. While not research-oriented, these articles describe states' experiences with relining large-diameter CMP culverts:

- A July 2015 article describes two projects in New York in which arched culverts (span and rise of 131 by 81 inches and 103 by 71 inches) were relined using custom-fabricated smooth-walled steel slipliners. The article details time and costs for both projects, emphasizing the agencies' combined cost savings of \$816,800 compared with cutting the roads and replacing the structures.
- A September 2012 article describes a relining effort in Indiana for large-diameter CMP (arched CMP structures with round equivalents of 114 inches for one pipe and 108 inches for two others) using centrifugally cast concrete pipe. At the time of publication, the rehabilitated pipes were the largest CMPs relined using CCCP technology in the United States.
- Ohio DOT's projects to rehabilitate culverts using two sliplining technologies—spiral-wound pipe and conventional sliplining—are highlighted in a March 2011 article. At the time of publication, the spiral pipe—a 132-inch spiral pipe lining installed in a 180-inch multiplate culvert—was the largest of its type installed in the United States. The second project involved the use of a culvert pipe liner that included the first hydro-bell structure to provide a larger, wider intake at the culvert entrance.

Additional publications offer a more general assessment of culvert repair practices, including various sliplining methods and newer technology such as honeycomb pipe liners.

Gaps in Findings

While the survey respondents provided useful information and introduced areas for further examination by MnDOT, the limited survey response cannot be considered an exhaustive review of rehabilitation practices for large-diameter CMP. Other agencies may have experience that could be of interest to MnDOT. The respondents who did participate in this survey provided varying levels of detail. In particular, survey questions about life-cycle cost-effectiveness failed to draw out the level of detail MnDOT is likely seeking. While acknowledging that the survey results represent a limited sample, it appears that some of the rehabilitation practices and products addressed in both national and state guidance have yet to be applied with sufficient frequency on large-diameter pipes for agencies to have identified the long-term effects of these practices.

Next Steps

MnDOT might consider the following as it continues its examination of large-diameter CMP repair techniques:

- Checking back with survey respondents to gather more information about areas of particular interest to MnDOT.
- Learning more about the application of three rehabilitation techniques used in recent projects by:
 - Contacting the New York State DOT Region 7 respondent to learn more about the recent rehabilitation projects using smooth steel liners.
 - Consulting with Indiana DOT to inquire about the agency's use of CCCP to rehabilitate two larger-size arched CMP structures.
 - Following up with Ohio DOT to discuss a 2011 rehabilitation effort using a 132-inch spiral-wound PVC liner.
- Examining in detail the specifications developed by Ohio DOT for a variety of culvert rehabilitation techniques.
- Consulting with the Spray Applied Non-Structural Pipe Liners Technical Committee of AASHTO's National Transportation Product Evaluation Program to learn more about efforts to investigate the structural component of spray-on liner products.
- Consulting with agencies using only structural rehabilitation methods (Illinois, Indiana and New York) and agencies using nonstructural methods (Michigan and perhaps Ohio) to identify advantages and disadvantages of each approach.
- Contacting Indiana DOT to learn more about the activities of its Pipe Committee in evaluating new rehabilitation products and techniques.

Detailed Findings

Survey of Practice

An email survey was distributed to representatives from the following transportation agencies in northern cold-weather states and selected Canadian provinces and national agencies to identify their experience, if any, with large-diameter CMP repair techniques:

State DOTs

- Illinois.
- Indiana.
- Iowa.
- Michigan.
- Nebraska.
- New York.
- North Dakota.
- Ohio.
- South Dakota.
- Wisconsin.

Canadian Provinces

- British Columbia.
- Ontario.
- Saskatchewan.

National Agencies

- Federal Highway Administration.
- Bureau of Land Management.

The survey consisted of the following questions:

General

1. What repair techniques have you used to structurally rehabilitate large-diameter (10 feet or greater) corrugated metal and structural plate pipe culverts used for bridges?
 - A. How frequently have you used each technique? Over what time period?
2. Can each technique be used equally effectively on all shapes and sizes of pipes? For example, is the technique appropriate for use with both round and arch pipes?
3. Have you identified potential environmental concerns associated with a repair technique?
 - A. Are these concerns associated with the repair process itself, the repaired pipe, or both?
4. Have you identified any roadblocks or other considerations that preclude your use of certain repair methods?

Structural Issues

Before Repair

1. How do you determine when to repair a particular large-diameter pipe?
 - A. Is there a point at which a pipe is considered too deteriorated for repair or rehabilitation?
2. How do you structurally analyze the integrity of a deteriorating pipe prior to repair?
3. What are the critical parameters that need to be addressed in specifications for design, construction, inspection and verification?

After Repair

1. Does each repair technique provide adequate structural support to the deteriorating pipe?
 - A. Is the strength of the repaired pipe adequate for a four-lane state highway?
 - B. Will a failing host pipe introduce loading that a liner or other repair material is not designed for?
2. How do you analyze a repaired pipe to demonstrate its structural adequacy to meet bridge load requirements?
 - A. What bridge load rating method is appropriate for repaired pipes?

B. How is the load rating performed?

Life-Cycle Cost-Effectiveness

1. What was the cost of each repair project?
2. How would you rate the cost of each repair technique you have used? Please rate each technique using the cost ratings *high*, *medium* and *low*.
3. Did repairing the pipe cost less than your estimate to replace the pipe?
4. For each repair technique, have you found that the repair expense can be justified by the expected addition to pipe service life?

Six agencies responded to the survey:

- Illinois.
- Indiana.
- Iowa.
- Michigan.
- New York State.
- Ohio.

Only five respondents reported experience with rehabilitation techniques for large-diameter culverts (Iowa DOT does not use structural plate or CMP bridge-size structures under its primary highway system). Of those responding, the Ohio DOT respondent chose to provide more limited information and did not specifically address the survey questions.

A follow-up contact made to a New York State DOT Region 7 staff member about a recent magazine article gathered additional information about the agency's practices. Information about these practices appears in the **Related Resources** section of this report (see page 38) and is included in the summary of survey results that follows, where applicable.

Summary of Survey Results

Survey respondents offered information about a range of rehabilitation techniques. The following are brief descriptions of many of these techniques to give some perspective to the information offered in survey responses. These descriptions are from MnDOT Report 2014-01, Culvert Repair Best Practices, Specifications and Special Provisions – Best Practices Guidelines, available at <http://www.dot.state.mn.us/research/TS/2014/201401.pdf>.

Cured-in-place pipe. 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. Pipes with diameters ranging from 3 inches to greater than 96 inches have been lined with CIPP.

Paved inverts. This rehabilitation method involves placing reinforced concrete on the invert of existing culverts. Culverts with diameters greater than 36 inches can receive paved inverts since personnel entry is possible. Paving corrugated steel pipe culvert inverts involves removing deteriorated steel and replacing it with new reinforced cast-in-place concrete.

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. Sliplining can be segmental or continuous.

Spiral-wound pipe. Spirally wound lining uses interlocking profile strips, most commonly made from PVC (polyvinyl chloride) 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.

Spray-on or centrifugally cast liners. Centrifugally cast liners are liners applied to the culvert interior by an electric or air-powered rotating head. The liners can be constructed of cementitious mortar or other material such as a polyurea spray.

The email survey gathered information in eight topic areas:

- Repair techniques.
- Frequency and extent of large-diameter repairs.
- Potential environmental concerns.
- Roadblocks precluding the use of certain repairs.
- Structural issues before repair.
- Structural issues after repair.
- Life-cycle cost-effectiveness.
- Pending research.

The full text of the survey responses begins on page 16 of this report. Following is a summary of findings by topic area.

Repair Techniques

Respondents were asked to identify the rehabilitation methods used on large-diameter CMPs and the methods' applicability to various pipe types. The table below summarizes survey responses.

Repair Techniques Used by Respondents			
Rehabilitation Method	Agency	Type/Product	Applicability to Various Pipe Types
CIPP	Michigan	N/A	Both Indiana and Ohio note that size limitations preclude the use of CIPP on pipes with a diameter of 10 feet or more.
Concrete blanket	Michigan	N/A	Techniques vary depending on pipe shape, connecting pipes that add liquid to deteriorating pipe, and the structural integrity left in the original pipe.
Concrete paved inverts	Indiana, Ohio	N/A	<i>Indiana.</i> More likely to be used on arches.
Flowable fill	Michigan	N/A	N/A
Foam sealant	Michigan	N/A	N/A
Sliplining	Illinois, Indiana, New York, Ohio	<i>Illinois.</i> Grouted insertion lining. <i>Indiana.</i> <ul style="list-style-type: none"> • Profile wall HDPE manufactured up to 132 inches. 	<i>Grouted insertion lining (Illinois).</i> Appropriate for round and arched pipes. <i>Profile wall HDPE (Indiana).</i> Liner can be flattened and strutted to allow close conformance. Depending on the hydraulics, can also be used in pipe

Repair Techniques Used by Respondents			
Rehabilitation Method	Agency	Type/Product	Applicability to Various Pipe Types
		<ul style="list-style-type: none"> • Smooth steel liner used for proposal only; size limitation may be near 132 inches. • Spiral-wound liner (PVC); requires filling the annular space between the host structure and the liner. • Square ribbed metal pipe used in an evaluation project only; no proposal for continued use. <p><i>New York.</i> Smooth steel liner; installation recently completed at the time of publication of this report.</p>	<p>arches. Can present a problem with hydraulic capacity in the haunch.</p> <p><i>Smooth steel liner (Indiana).</i> Welded to form so they can probably be used on arches; may be produced with limited loss in section except in the haunch. Concerns with lining a failing metal pipe with another metal pipe mitigated by use of smooth steel liner with a thicker wall.</p> <p><i>Smooth steel liner (New York).</i> Advantageous for sites with large embankment fills, long detours and heavy traffic. New pipe restores both the structural and hydraulic capacity of an existing pipe. Lining with a new pipe is effective for all sizes of round and arch pipes.</p> <p><i>Spiral-wound liner (Indiana).</i> Size limitations not known; typically used on round pipes; closely approximates the shape of the pipe.</p>
Spray-on lining	Indiana	Both cementitious and polyurea products.	Size limitations not known; no issue with pipe geometry.

Frequency and Extent of Large-Diameter Repairs

Respondents provided limited data on the frequency of large-diameter CMP repairs. Illinois DOT has completed one or two such rehabilitation projects over the past five years; the respondent noted that the agency does not have a lot of CMPs of 10 feet in diameter or larger, and even fewer that require repair. In Indiana, sliplining has been permitted for about 15 years. The other repair techniques identified in the table above have been used for no more than five years, and data on the extent and frequency of each technique is not readily available. The Indiana DOT respondent further noted that “[e]xcept for CIPP, everything else has been experimental, and I don’t know that we have had very many large diameter (120"+) structures lined anyway.” In New York, over the past 10 years, one or two large diameter pipes have been sliplined every couple of years.

While not specific to the frequency or extent of large-diameter culvert repairs, the Ohio DOT respondent noted that the agency intentionally oversizes culverts if the fill height is greater than 16 feet and/or if under a freeway for the sole purpose to slipline the culvert in the future.

Potential Environmental Concerns

None of the respondents reported experience with environmental issues associated with a repair technique. The Indiana DOT respondent mentioned a Virginia DOT ban on the use of CIPP due to the styrenic components getting into the waterway, noting that Indiana has no such prohibition. In Indiana, some liner installations are completed only during dry conditions, or coffer dams and pumping are used during installation to minimize any environmental impacts. The Michigan DOT respondent also highlighted the Virginia DOT concerns with CIPP, also noting that Caltrans reported similar issues. Noting that the environmental concerns appear to be most closely

linked to the repair process, the Michigan DOT respondent reported that the agency does not allow water from CIPP to be released to surface waters. The New York State DOT respondent noted that sliplining “has the potential for adverse environmental impacts on wetlands, in-stream habit, sediment dynamics, water/air quality, and general ecology and wildlife resources. Coordination with our Environmental Group is done early on in design in order to identify potential impacts and opportunities for mitigation.”

Roadblocks Precluding the Use of Certain Repairs

Both Indiana and Michigan DOTs reported a failed rehabilitation effort or concerns about a particular product used in a rehabilitation effort:

- An Indiana DOT CIPP installation failed. As the respondent noted, “The pressure built too high and the inflation fan was blown off causing the liner to partially deflate before initial cure. The contractor had to remove and replace the liner and CIPP vendors have been shy about bidding ever since.” An evaluation project that tested a polyurea spray-on lining also failed as the result of the contractor’s failure to follow the manufacturer’s recommendations. The agency also reported concerns with the use of a cementitious spray-on liner product.
 - If the rehabilitated structure is a pipe arch, more of the sprayed-on material can accumulate in the haunches of the structure, which can result in shrinkage cracking in these areas.
 - If the application process is unidirectional, one side of the corrugations can be coated more effectively than the other, particularly near the top of the structure.
 - Multiple passes may be needed to fill corrugations and provide a smooth invert in the structure, which improves hydraulics.

The Indiana DOT respondent also noted that, while profile wall HDPE is manufactured up to 132 inches in diameter, the agency only allows deformation on pipe with a ring stiffness class value of RCS 250 or greater. This affects the cost-effectiveness on large elliptical pipes and pipe arches. Hydraulics can be an issue when deciding on a rehabilitation technique, particularly for pipe arches.

- The Michigan DOT respondent reported that one of the agency’s initial test CIPP liner installations is beginning to fail and will require that the pipe be replaced before the 10 to 20 years that the liner was supposed to provide. Even though the installation process was reported to have gone well, the liner is pulling away from the pipe. The pipe is expected to be replaced in the next two years.

In New York, a smooth steel liner was selected over other alternatives—lining with a round, smooth plastic liner or a smaller corrugated pipe arch—because both of these alternatives would decrease the hydraulic capacity of the repaired pipe. The smooth bore of the smooth steel liner used for a recent rehabilitation mimics the arch shape of the host pipe and actually increases the hydraulic capacity due to the smooth bore. To address the increase in velocity of water in a repaired pipe, the agency instituted measures to avoid scour and erosion by stone-lining the outlet and inlet. If the installation had been on a fish-bearing stream, baffles could have been installed to help aquatic life transition through the repaired culvert.

Structural Issues Before Repair

When to Repair a Failing Pipe

Four respondents addressed the issue of when to repair a failing pipe:

- In Illinois, pipes are repaired when inspectors observe visual signs of distress such as excessive deflection, wall separation at riveted or bolted joints, severe section loss usually in the invert, or fill infiltration.
- Indiana DOT allows only structural lining methods, so there is no concern with the level of pipe deterioration prior to rehabilitation. The agency expects the host pipe will continue to deteriorate, with the

liner providing structural support. Indiana DOT would consider full replacement if identifying significant undermining of the pipe or crushing of the structure. However, crushing or damage on the exposed portion of the host pipe can be removed and, if necessary, a pipe extension can be installed prior to lining.

- In Michigan, bridge-width pipes are subject to a two-year rolling inspection. When wall loss is apparent, the agency considers rehabilitation or replacement.
- New York State DOT routinely inspects culverts with a diameter/span width of 5 feet or more. Inspection reports, which include condition ratings and other information, are used to identify the large culverts in need of repair or replacement. A second New York State DOT contact noted that it may not be possible to push an adequately sized liner into a host pipe if the host pipe is partially collapsing or has other alignment issues.

When a Pipe is Too Deteriorated for Repair

While the Michigan DOT respondent indicated that the point at which a pipe is too deteriorated for repair has not been well defined, other respondents offered circumstances under which repair may not be an option for a deteriorating pipe:

- The Indiana DOT respondent indicated that full replacement may be required if there is significant undermining of the pipe or crushing of the structure. However, crushing or damage on the exposed portion of the host pipe can be removed and a pipe extension can be installed before lining.
- For New York State DOT, pipes that may not be good candidates for rehabilitation are those with significant deformation and/or settlement, severe corrosion and pitting, widespread section loss, backfill infiltration and/or extensive undermining. The age of the pipe, remaining service life and costs are also considered.

Structural Analysis of Failing Pipes

Illinois, Indiana and New York State DOTs allow only structural rehabilitation methods, which eliminates the need for a structural analysis of a failing pipe prior to repair. The Indiana DOT respondent noted that a more significantly deteriorated pipe may require additional preinstallation preparation. In New York, inspection reports provide information regarding condition, and large-diameter pipe rehabilitations have been engineered to address structural concerns. While Michigan does not appear to rely on structural rehabilitation methods, the Michigan DOT respondent provided information about visual inspections rather than formal structural analyses.

Parameters for Design, Construction, Inspection and Verification

Only two respondents—Illinois and New York State DOTs—provided a response to the survey question about parameters (design, construction, inspection and verification) associated with large-diameter CMP rehabilitation techniques.

- For Illinois, these parameters include the contribution allowed, if any, from the host pipe; minimum hydraulic capacity of the new liner relative to the existing pipe; minimum grout strength; installation procedures; and minimum experience required of the installation contractor (perhaps three projects of similar size and scope in the past five years).
- For New York, these parameters include hydraulic capacity, structural capacity, material specifications, environmental issues and permits, anticipated service life, required submissions for approval, construction details and procedures, testing and basis of payment. The maximum depth of cover for the pipe being relined, estimated modulus of soil reaction and the estimated water table must be noted on the contract plans.

In lieu of a survey response, the Michigan DOT respondent provided a special provision for CIPP installation; a provision for structural flowable fill—another of the repair techniques cited by the Michigan DOT respondent—is

also available (see page 24 of this report). Similarly, Ohio DOT's Supplemental Specifications provide details of design specifications and installation practices for the following culvert repair methods:

- Conduit renewal using spray-applied structural liner.
- Conduit renewal using resin-based liner.
- Liner pipe.
- Conduit renewal using spiral-wound liner.
- Polyethylene liner pipe.
- Steel reinforced thermoplastic ribbed pipe.

Structural Issues After Repair

Structural Support Provided by Repair

When asked if rehabilitation methods provide adequate structural support, the Illinois, Indiana and New York State DOT respondents again noted that these agencies use only structural repair methods. Indiana DOT conducts an evaluation project before a method or product is approved for use. While these projects are developed and conducted based on manufacturer or vendor claims that the rehabilitation method is structural, the evaluation project includes the agency's own assessment. If it is determined that a rehabilitation method purported to be structural does not provide adequate support, that method would be removed from consideration on future projects. For New York State DOT, the lining pipe "is required to possess adequate structural capacity to carry the entire calculated dead and live load. It is assumed the host pipe possess[es] zero remaining structural capacity."

The Michigan DOT respondent noted that while manufacturers provide information about the structural adequacy of a method or product, she has questioned some of these claims. The agency has observed less-than-optimum attachment at some walls. Concerns about the strength provided by the spray-cast technique center on variations in thickness noted when the spray nozzle does not provide a consistent spray, which could affect the strength of the liner.

Loading Introduced by Failing Pipe

Again citing the use of only structural repair methods, Illinois, Indiana and New York State DOTs are not concerned with problematic loading introduced by the failing pipe. The Indiana DOT respondent observed that in cases where the annular space is required to be filled when repairing a failing pipe, the material used (cellular concrete grout) is designed to act similarly to soil.

The Michigan DOT respondent offered a different perspective, noting concern that soil and water infiltration that is not deterred properly and continues to flow behind the liner introduces unexpected additional loading. When the liner does not adhere to the host pipe, the area behind it could be full of air, decreasing strength. There is also potential for uncalculated loading when the theoretical calculations are not correct due to an error in assumptions or inadequate coverage of secondary support material.

Bridge Load Ratings

Most respondents provided relatively little detail in response to the survey questions related to bridge load ratings (how to analyze a repaired pipe for a bridge load rating, the appropriate bridge load rating method, and how the load rating is performed). Follow-up contacts sought additional information from selected respondents. The following summarizes survey responses and the results of follow-up contacts:

- The Illinois DOT respondent noted that the agency follows the AASHTO Load and Resistance Factor Design code, using the same bridge load rating method as the one applied to the existing host pipe.
- The Indiana DOT respondent initially reported that he was not aware that the repaired pipe is analyzed for a bridge load rating. In response to a follow-up contact, the respondent indicated that to determine the structural integrity of spray-on liners, a finite element analysis, which Indiana DOT does not have the

capability to perform internally, may be required. Determining structural integrity may also involve calculations of a strength coefficient to determine if the liner is structurally adequate.

At the time of publication of this report, no response was received to a follow-up contact to a staff person in the Indiana DOT Bridge Inspection unit requesting more information.

- In Michigan, such analysis depends on the pipe in question and whether the pipe is perpendicular to the road or at a skew. Michigan DOT requires that the liner designer provide the agency with signed load ratings, which are then checked by agency engineers. In response to a request for additional information about bridge load ratings provided by liner manufacturers, the agency was unable to provide sample manufacturer documents prepared in connection with large-diameter culvert rehabilitation projects.
- The New York State DOT respondent indicated that a liner pipe is designed to carry the entire calculated dead loads and HS-25 live loading. A bridge load rating is performed on bridge spans (culverts with a span of 20 feet or greater).

In response to a follow-up inquiry, the New York State DOT respondent provided the most detail among all respondents with regard to liner design and load rating analysis. A summary of these responses:

- New York State DOT designs and specifies the pipe size, shape, gauge/thickness and material needed for lining a large culvert. The design for a recent project is provided as [Appendix C](#). For this project, the contractor was required to provide a Level 1 Load Rating Analysis certifying that the inventory and operating load rating was equal to or greater than that which was required in the contract documents.
- Any span greater than 12 feet requires review and approval by the agency's deputy chief engineer of Structures in conjunction with the CANDE program, which is described as a "finite element computer program developed for the structural design and analysis of buried culverts and structures for all shapes and materials including corrugated metal, reinforced concrete and thermoplastics." The respondent was not aware of a culvert with a span over 12 feet or bridge (span of 20 feet or greater) that has been sliplined in his region.
- The respondent provided a link for the agency's specification that addresses load rating analysis for structural steel liners (see page 27 for **Culvert Lining with Structural Steel Plate Pipe**).
- Any load rating required given a culvert's classification as a bridge is part of the deliverables noted in Ohio DOT Supplemental Specifications. See page 30 of this report for a series of Ohio DOT Supplemental Specifications related to culvert repair methods. In response to a follow-up request for sample documents provided by liner manufacturers or internal agency standards, an Ohio DOT respondent indicated that the Structures unit will request professional engineer-signed calculations from the manufacturer and accept them as is. As the respondent noted, the agency "doesn't have any standards written to load rate this type of structure."

National Transportation Product Evaluation Program

A more general examination of the structural integrity of culvert liner products is being undertaken by the Spray Applied Non-Structural Pipe Liners Technical Committee of AASHTO's National Transportation Product Evaluation Program. The committee, which "oversees the work plan that covers the evaluation of non-structural cementitious and resin based spray applied liners for storm water conveyance conduits," initially sought information from industry representatives about how they test the structural component of their products. The committee found that manufacturers keep their calculations proprietary, and funding requested by the committee to further investigate these issues has not been provided. Currently, the committee is reviewing the laboratory structural testing conducted on concrete pipe to determine if there is a correlation to CMP.

Life-Cycle Cost-Effectiveness

Respondents were unable to provide much in the way of specific cost data when asked about life-cycle cost-effectiveness (the Ohio DOT respondent opted not to address these questions). The table below summarizes survey responses about repair costs and extended service life.

Respondents' Observations about Repair Costs and Extended Service Life					
Rehabilitation Method	Agency	Repair Cost	Cost Rating	Cost Less to Repair Than Replace	Addition to Service Life Worth Expense
Sliplining	Illinois	\$324,000 for 360 lineal feet.	High	Yes	Yes
	Indiana	N/A	Low	Yes	Yes
	New York	\$2,700 per linear foot (2015 repair). \$2,000 per linear foot (previous projects).	Medium	Yes	Yes
		Under \$50,000 (2013 repair).	N/A	Yes	Yes
CIPP	Indiana	N/A	High	Yes	Yes
	Michigan	N/A	High	Yes	Not yet
Spiral-wound liner	Indiana	N/A	Medium	Yes	Yes
Spray-on lining	Indiana	N/A	Medium	Yes	Yes

Some respondents provided additional perspective on repair costs and other factors contributing to a decision to repair or replace a failing pipe.

Cost comparisons.

- The cost for the recent rehabilitation in Natural Bridge was estimated at \$700,000; the cost to replace with a new bridge was estimated at \$1.5 million (New York).

Cost variations.

- Costs vary widely based on the size of the structure, the liner method selected, the location, the ease of entry and other factors (Indiana).
- Cost varies by length of pipe, how many other pipes tie in, locational challenges, difficulty in removal and disposal of curing materials, whether it is a single-barrel or multibarrel repair, location of materials and hauling/shipping fees (Michigan).

Lower-cost options.

- Corrugated steel plate lining and HDPE lining would have cost less than the welded straight-seam structural steel plate arch pipe recently installed in Natural Bridge, but the lower-cost methods were not viable options for the project (New York).

Availability of cost data.

- Formal cost data for the more recently evaluated methods such as spiral-wound and spray-on lining will not be available until these methods are used with more frequency (Indiana).

Decision to repair or replace.

- While pipe lining is almost always less expensive than replacement, the choice to reline instead of replace is often made based on disruption to traffic (Indiana).
- Costs are high on all repairs. Even with repair, metal culverts have a limited life. With the high cost of repair for some types of culverts—for example, a triple-barrel metal culvert—it may be more cost-effective to replace with an actual bridge than to repair or replace the host pipes (Michigan).

Extended service life.

- The anticipated service life of a recently installed structural steel plate arch pipe liner is 70 years (New York).

Pending Research

Two agencies—Michigan and Ohio—have research projects in progress:

- In Michigan, a triple-barrel spray cast maintenance project will be starting soon.
- An Ohio DOT project in progress is examining the structural benefits of concrete paving of steel culvert inverts.

Survey Results

The full text of survey responses is provided below. For reference, an abbreviated version of each question is included before the response. The full question text begins on page 7 of this report.

Illinois

Contact: Gary M. Kowalski, Policies, Standards & Specifications Unit Chief, Bureau of Bridges and Structures, Illinois Department of Transportation, gary.kowalski@illinois.gov, 217-785-2914.

General

1. **Repair techniques:** Grouted insertion lining.
- 1a. **Frequency and over what time period?** Once or twice over the past 5 years, we don't have that many 10 feet or larger CMPs, and even less that need repairs.
2. **Technique used for all shapes and sizes?** The only method we have used is appropriate for both round and arched pipe.
3. **Potential environmental concerns?** No.
- 3a. **Concerns with the repair process, after the repair is completed, or both?** N/A.
4. **Roadblocks preclude use of certain repair techniques?** No.

Structural Issues

Before Repair

1. **When to repair pipe?** Typically, when visual signs of distress (i.e., excessive deflection, wall separation at riveted or bolted joints, severe section loss usually in the invert, or fill infiltration) [are] observed.
- 1a. **Point when pipe too deteriorated for repair?** There might be, especially if you wait too long to address the issues.
2. **How to structurally analyze pipe prior to repair?** We don't; the liner is designed assuming no contribution from the host pipe.
3. **Parameters for design, construction, inspection and verification:** Contribution allowed, if any, from existing host pipe; minimum hydraulic capacity of the new liner relative to the existing; minimum grout strength; ask for installation procedures, specify a minimum experience required, like say 3 projects of similar size and scope in the past 5 years.

After Repair

1. **Does repair provide adequate structural support?** We require that the liner assume no contribution from the existing host pipe.
- 1a. **Strength adequate for state highway?** Yes.
- 1b. **Failing host pipe introduce problematic loading?** No.
2. **How to analyze repaired pipe for bridge load rating?** We follow the AASHTO [Load and Resistance Factor Design] code.
- 2a. **Appropriate bridge load rating method:** Same as original.
- 2b. **How load rating is performed:** Not sure.

Life-Cycle Cost-Effectiveness

1. **Cost of each repair?** \$324,000 to do 360 lineal feet.
2. **Rate cost of each repair technique:** High.
3. **Repair cost less than replacement?** Yes.
4. **Expected addition to pipe service life worth expense?** Yes.

Indiana

Contact: Bill P. Schmidt, Senior Hydraulics Engineer (Acting Hydraulics Manager), Bridge Design, Inspection, Hydraulics & Tech Support, Indiana Department of Transportation, wpschmidt@indot.in.gov, 317-232-5148.

Note: Bill Schmidt was the initial contact at Indiana DOT. When contacted for additional information, Schmidt recommended that another Indiana DOT staff member, Kenny Anderson, provide more detailed responses. Anderson's survey response follows Schmidt's response.

General

1. **Repair techniques:** We have used concrete paved inverts, steel pipe sleeves, spiral-wound products. We tried a cured-in-place once on an 8-foot pipe and it failed. Also CPI Supply has [high-density polyethylene] pipes up to 120 inch inside diameter (127.72 outside).

- 1a. **Frequency and over what time period?** [No response.]
2. **Technique used for all shapes and sizes?** Paved inverts are more likely to be used on arches and the pipes and spiral wound on round. The steels are welded to form so they can probably be used on arches as well. HDPE can be used on both because they can be squished. We hydraulically analyze each to see if they work.
3. **Potential environmental concerns?** No.
- 3a. **Concerns with the repair process, after the repair is completed, or both?** N/A.
4. **Roadblocks preclude use of certain repair techniques?** See #1 for cured in place.

Other Comments

Cost: Generally HDPE is the cheapest. We had one even bigger that HDPE wouldn't work (plus we lost too much hydraulic area with HDPE). The choices were between spiral wound and steel sleeve. The steel sleeve turned out cheaper.

Indiana

Contact: Kenny Anderson, Materials Services Engineer, Highway Management, Indiana Department of Transportation, kbanderson@indot.in.gov, 317- 610-7251, ext. 203.

General

1. **Repair techniques:** I cannot speak to all technologies used, but I can tell you what we have either applied or have begun to evaluate. Solid wall (ASTM F714) HDPE can only be used up to about 66". Profile wall HDPE (ASTM F894) is manufactured up to 132". These are the only sliplining products used. We do allow profile wall PVC (AASHTO M304/ASTM F949), but my understanding is that this is only manufactured up to 36". We also allow CIPP, but I have been told it is only produced up to an equivalent 120" round. As Bill mentioned, we did have a 96" round equivalent that failed, so the CIPP suppliers have been averse to bidding on projects ever since. Spiral wound PVC (Sekisui and Danby) is also an option that requires filling the annular space between the host structure and the liner. I do not recall the diameter limitation on this technology. There are also two spray-on technologies. Again, I do not know the diameter limitations, but there are cementitious products (CentriPipe and GeoSpray) and polyurea products (Hydratech PolySpray FS-250 and SprayRoq). We have evaluated CentriPipe and recently had a trial installation of GeoSpray. We did have one evaluation project with PolySpray, but the contractor failed to observe the manufacturer's recommendations and the installation failed. We have had a proposal on smooth steel liners and I believe the limitation is again near 132", though I am not certain. We have also had a proposal on square ribbed metal pipe (ASTM A760, Type IR). Although we have allowed an evaluation project, none has been proposed. We also have concerns with lining a failing metal pipe with another metal pipe. We do not have the same concern with the smooth steel liner because it has a thicker wall.
- 1a. **Frequency and over what time period?** We have allowed sliplining for approximately 15 years. The other techniques are under evaluation and have varying periods in service. These date back in the last 5 years or so. I do not know the extent or frequency of use. This will require considerable effort to compile, but if necessary I can look into it.
2. **Technique used for all shapes and sizes?** Round and elliptical pipes are not typically an issue. For solid wall HDPE and profile wall HDPE, the liner can be flattened and strutted to allow close conformance. Depending on the hydraulics, these can also be used in pipe arches. The problem lies in the hydraulic capacity losses in the haunch. If this can be overcome through velocity increase without significant increase in the backwater elevation, this practice is allowed. Obviously the spray-on technologies do not have an issue with pipe geometry. The spiral wound PVC also closely approximates the shape of the pipe. The metal pipes cannot accomplish this, but the smooth steel can be produced with limited loss in section except in the haunch, so it is viable. It may even be produced to mimic the shape of the host pipe,

but I am not certain of that.

3. **Potential environmental concerns?** I am not aware of any. I think Virginia banned the use of CIPP due to the styrenic components getting into the waterway. Indiana has no such prohibition. I do believe in some cases lining is done during dry conditions or coffer dams and pumping used. This minimizes any environmental impacts.
- 3a. **Concerns with the repair process, after the repair is completed, or both?** [See above.]
4. **Roadblocks preclude use of certain repair techniques?** As Bill and I mentioned, we did have one failed CIPP installation. The pressure built too high and the inflation fan was blown off causing the liner to partially deflate before initial cure. The contractor had to remove and replace the liner and CIPP vendors have been shy about bidding ever since. As mentioned, the PolySpray failure was a result of the contractor attempting to install the product themselves. Had a subcontractor with experience been used, this may not have been an issue. The contractor in question was installing their first such liner. The vendor has not found another contractor to bid with their product since. Our Pipe Committee had some concerns with the CentriPipe liner. We have allowed GeoSpray to perform an evaluation installation after the vendor addressed concerns posed by the Pipe Committee after observing the CentriPipe liners in place. While profile wall HDPE [is] made up to 132", we only allow deformation on pipe with a RSC value of 250 or greater. This affects its cost-effectiveness on large elliptical pipes and pipe arches. Also, as mentioned above, hydraulics can be an issue particularly on pipe arches.

Structural Issues

Before Repair

1. **When to repair pipe?** Rehabilitation is determined by Department maintenance during structure inspection or as part of a road project where full depth pavement replacement is not being performed, but the life cycle of the structure is nearing its end. I do not know the specific parameters that are used in making this determination. As the Department allows only structural lining methods, there is no concern with the level of deterioration and in fact the host pipe is expected to continue to deteriorate such that the liner will function as the structure in whole. Considerations for full replacement would be significant undermining of the pipe or crushing of the structure. If crushing/damage occurs on the exposed portion of the host pipe, this can be removed and, if necessary, a pipe extension can be installed prior to lining.
- 1a. **Point when pipe too deteriorated for repair?** [See above.]
2. **How to structurally analyze pipe prior to repair?** As we do not allow nonstructural methods, I do not believe this is performed. The selected repair method may require additional prep work if the invert or other areas are more deteriorated than expected, once construction commences. In severe cases, the repair method may need to be changed. To the extent possible, the contractor is allowed to select a liner product among those approved. Alternate methods may be proposed by the contractor as long as hydraulic analysis accompanies the proposal. The Hydraulics Section then reviews the calculations before approving the alternative.
3. **Parameters for design, construction, inspection and verification:** I am not sure I understand this question. Please clarify or provide examples of the parameters that may be considered.

After Repair

1. **Does repair provide adequate structural support?** For those methods approved, structural support is provided. While the evaluation projects are based on manufacturer/vendor claims that the rehabilitation method is structural, the evaluation would include this determination. If at any point in time it is determined that an allegedly structural method does not provide adequate support, it would be removed from consideration on future projects.
- 1a. **Strength adequate for state highway?** See previous response. Nonstructural liner products are not allowed.

- 1b. **Failing host pipe introduce problematic loading?** As the liner is required to be structural, this is not anticipated to be an issue. The host pipe is expected to continue to deteriorate to complete disintegration. Where annular space is required to be filled, the material placed (cellular concrete grout) is designed to act similarly to soil.
2. **How to analyze repaired pipe for bridge load rating?** I am not aware that this is performed. Consultation with Bridge Inspection or Bridge Design may be required to determine this.
- 2a. **Appropriate bridge load rating method:** [See above.]
- 2b. **How load rating is performed:** [See above.]

Life-Cycle Cost-Effectiveness

1. **Cost of each repair?** This varies widely based on the size of the structure, the liner method selected, the location, the ease of entry and other factors. With lining having been performed for at least 15 years, it is difficult to ascertain the cost of each type of project. If necessary, additional research can be performed, but it will require extensive effort.
2. **Rate cost of each repair technique:** Sliplining is the cheapest alternative, with CIPP being the most expensive. The technologies currently being evaluated appear to fall between these methods, but this cannot be accurately determined until they are approved and used in reasonable quantity.
3. **Repair cost less than replacement?** Pipe lining is almost always less expensive than replacement. However, the choice to reline instead of replacement is often made based on disruption to traffic.
4. **Expected addition to pipe service life worth expense?** Again, without detailed cost analysis, this will be qualitative. Because the treatments are structural only, the expected life span is 50+ years. In many cases, the host structure [is] 40 years old or less, so the treatment effectively provides an additional life cycle without the need to open cut for full replacement. [In a follow-up response, Anderson added: Of course, given that this is relatively new technology, there is no way to determine that this will be the case.]

Other Comments

Installation Issues

The following summarizes Anderson's response to a follow-up inquiry about concerns with regard to a CentriPipe liner:

The Indiana DOT Pipe Committee identified several concerns in connection with a CentriPipe installation that were communicated to another vendor seeking a field trial of a similar product. These issues include:

- When rehabilitating pipe arches, more material can accumulate in the haunches of these structures than over the remainder of the structure interior, leading to shrinkage cracking in these areas.
- If the application process is unidirectional, one side of the corrugations can be coated more effectively than the other, particularly near the top of the structure. The coating process must ensure an even distribution of material.
- Multiple passes may be needed to provide a smooth invert in the structure, which will improve hydraulics.

When asked how the various rehabilitation treatments compare, Anderson also noted that “[e]xcept for CIPP, everything else has been experimental, and I don’t know that we have had very many large diameter (120"+) structures lined anyway. Until we have more large structures lined with the alternative methods, I can’t really state how they compare.”

Structural Adequacy and Bridge Load Ratings

In response to a follow-up inquiry about how liner manufacturers provide proof of the structural integrity of the

liners they provide, Anderson noted that for Indiana DOT, culverts below 20 feet in diameter are considered a small structure, not a bridge. For spray-on liners, the thickness of a spray-on liner is important if the liner will provide structural integrity, and calculations must be done to determine the appropriate thickness. This determination could require a finite element analysis, which Indiana DOT does not have the capability to perform internally, or may involve calculations of a strength coefficient to determine if the liner is structurally adequate. A staff member in the Indiana DOT Bridge Inspection unit did not respond to requests for additional information at the time of publication of this report.

National Transportation Product Evaluation Program

Anderson recommended investigating the work of AASHTO's National Transportation Product Evaluation Program to learn more about the structural adequacy of culvert rehabilitation methods. The Spray Applied Non-Structural Pipe Liners Technical Committee "oversees the work plan that covers the evaluation of non-structural cementitious and resin based spray applied liners for storm water conveyance conduits."

From the NTPEP website:

This work plan (located under Documents on the right side menu) is intended to determine the material, durability, application properties, and the composition properties of each liner. Acceptability of each material, based upon the data generated as a result of the testing and evaluation in this practice, is the responsibility of the user. Structural design methodologies of spray applied liners are not covered under this standard practice.

While the current form of its work plan does not address structural liners, the committee did address structural adequacy in its May 2015 annual meeting (see **Related Resources** below for meeting minutes) and is considering an expansion of the work plan to include structural liners. Action items for the committee include:

- Speaking with industry about how they test the structural component of their products.
- Exploring funding available through NCHRP to determine if a recommended test protocol for structural testing on spray-applied liners is available or can be provided.
- Discussing the verification of design calculations.

Karen Byram, the chair of the Spray Applied Non-Structural Pipe Liners Technical Committee, was contacted to learn more about the committee's activities. Byram indicated that the committee has learned that manufacturers keep their calculations proprietary. The committee requested funding to further address the issue of manufacturers' proof of structural integrity, but the request for funding was not granted. Even with the absence of this funding, the committee will continue its work in addressing these questions and is currently reviewing the laboratory structural testing that is conducted on concrete pipe to determine if there is a correlation with CMP.

Contact: Karen Byram, Product Evaluation Administrator, Florida Department of Transportation, karen.byram@dot.state.fl.us, 850-414 - 4353.

Related Resources:

Certification for Profile Wall HDPE Liner Pipe/Certification for Solid Wall HDPE Liner Pipe, Indiana Department of Transportation, undated.

<http://www.in.gov/dot/div/contracts/standards/Thermoplastic%20Liner%20Pipe%20Certification%20forms.pdf>

Indiana DOT uses this document to certify the profile wall and solid wall liner pipes used in sliplining.

Spray-Applied Non-Structural Pipe Liners (SAPL), Technical Committee Meeting Notes, Working Session #6, 2015 Annual NTPEP Meeting, National Transportation Product Evaluation Program, May 2015.

http://www.ntpep.org/Documents/Technical_Committee/SAPL/Minutes/SAPL%202015%20Minutes%20and%20Attendance.pdf

These meeting minutes summarize the NTPEP technical committee's interest in verifying the structural adequacy of spray-applied pipe liners.

Work Plan for NTPEP Evaluation of Spray Applied Non-Structural Pipe Liners for Storm Water Conveyance, AASHTO Designation SAPL-01-15, National Transportation Product Evaluation Program, undated.

http://www.ntpep.org/Documents/Technical_Committee/SAPL/Documents/Spray%20Applied%20Pipe%20Liners%20Work%20Plan.pdf

From the scope:

This work plan covers the requirements and testing criteria for the National Transportation Product Evaluation Program (NTPEP) evaluation of non-structural cementitious and resin based spray applied pipe liners for storm water conveyance conduits. The National Transportation Product Evaluation Program (NTPEP) serves the member departments of the American Association of State Highway and Transportation Officials (AASHTO).

The results of this program may be used for product quality verification by individual member Departments. If used for quality verification, a letter of certification from the cementitious or resin based spray manufacturer indicating testing was conducted by NTPEP that supports published values may be required by member Departments.

Iowa

Contact: Dave Claman, Preliminary Bridge Engineer, Office of Bridges & Structures, Iowa Department of Transportation, david.claman@dot.iowa.gov, 515-239-1487.

The respondent provided the following in response to the survey questions:

The Iowa DOT does not utilize structural plate or CMP bridge-size structures under our primary highway system. We only utilize small CMP pipes (72" diameter or less) for field entrances and driveways.

Therefore, the Iowa DOT does not have any experience with repair techniques for large-diameter corrugated metal pipe culverts.

Michigan

Contact: Therese R. Kline, Flexible Pipe Specialist, Special Structures, Bridge Design, Michigan Department of Transportation, klinet@michigan.gov, 517-241-0082.

General

1. **Repair techniques:** We have used CIPP, something that our Bay City region calls "The Super Goo" (foam sealant), concrete blanket, flowable fill in the flowline.
- 1a. **Frequency and over what time period?** We have been using these techniques more frequently as our culverts age and there is little to no money for replacements. I do not have accurate data on these type repairs.
2. **Technique used for all shapes and sizes?** Techniques used vary depending on pipe shape, connecting pipes that add liquids to the deteriorating pipe, the type of deterioration showing and structural integrity

left in the original. Shape matters as well when determining structural integrity.

3. **Potential environmental concerns?** We have followed the Virginia and Caltrans CIPP concerns closely. Currently MDOT does not allow water from CIPP to be released to surface waters.
- 3a. **Concerns with the repair process, after the repair is completed, or both?** The concerns seem to center around the repair process.
4. **Roadblocks preclude use of certain repair techniques?** Money has been our issue: why spend major amounts of money for a five-year band aid? Replace the failing pipe once and done.

Structural Issues

Before Repair

1. **When to repair pipe?** For our bridge-width pipe we have a two-year rolling inspection. When wall loss is apparent, we consider rehabilitation or replacement.
- 1a. **Point when pipe too deteriorated for repair?** Yes, however that point has not been well defined. A rough definition of failure we have been grappling with is: “What goes [through] it no longer can, OR traffic can no longer safely travel over it.” This is a very loose definition. Generally, if the inspector has any question I get a call to come take a look.
2. **How to structurally analyze pipe prior to repair?** First we view it. Then we use a survey pole to poke that area. Does the metal, concrete or plastic crumble easily? That is not good. When poked, does water and/or soil move into the void? That is really not a good thing. Are the shoulders of the road holding up? Are there sinkholes in the shoulder or pavement? Are the lanes solid or starting to deflect? Does it appear that the concrete lanes have bridged over the soil loss around the culvert? The more of these issues we find, the lower the grade given to the culvert. We use the NBI condition rating codes for our culverts of bridge width.
3. **Parameters for design, construction, inspection and verification:** Please see attachment Cured in Place [see Related Resources].

After Repair

1. **Does repair provide adequate structural support?** According to the manufacturers, yes. My experience says not so much.
- 1a. **Strength adequate for state highway?** According to the manufacturers, yes. But we have not seen good attachment at some walls, and do not feel that some of the technologies provide strength advertised. My personal greatest concern is the spray-cast technique and the strength provided. Thicknesses of the coating covering vary because the nozzle does not seem to spray at optimum. If the coating is not the correct thickness, the protection promised does not occur, and the strength that the sprayed-on material is supposed to provide is theoretically compromised.
- 1b. **Failing host pipe introduce problematic loading?** In my opinion, yes. Example: The soil and water infiltration is not deterred properly and continues behind the liner giving the liner unexpected additional loading. Also when the liner does not adhere to the host pipe, the area behind it is a void potentially of air that does not lend strength. When the theoretical calculations are not correct due to some error in assumption or inadequate coverage of secondary support material, there is potential for uncalculated loadings.
2. **How to analyze repaired pipe for bridge load rating?** MDOT relies on the liner manufacturer to provide us with signed calculations, which are then checked for accuracy. I find this to still be rather worrisome with potential for inaccuracies.
- 2a. **Appropriate bridge load rating method:** This depends on the pipe in question, and if it is perpendicular to the road or at a skew. Again we require that the liner designer provide MDOT with signed load ratings, which are then checked.

- 2b. **How load rating is performed:** It is theoretically calculated by the liner designer, and checked by an MDOT engineer.

Life-Cycle Cost-Effectiveness

1. **Cost of each repair?** This varies by length of pipe, how many other pipes tie in, the difficulty in location, difficulty in removal and disposal of curing materials, if it is a single-barrel repair or a multibarrel repair, location of materials and hauling/shipping fees. Also if it is an emergency repair or if it is more of a maintenance technique.
2. **Rate cost of each repair technique:** In my opinion, costs are high on all repairs. MDOT was quoted \$3 to \$4 million dollars for a triple-barrel metal culvert maintenance repair. We realize that instead of replacing these culverts with like in the future, this area will require an actual bridge, which is much more costly. However, to perform that replacement now will result in a longer lived piece of infrastructure. These metal culverts have limited life left even with the liner repairs. Additionally, we are seeing more rainfall and greater flows. The triple barrel necks down the flows, and even further with the liners in place. The cost for a bridge only escalates in the future, and in my opinion, money is better spent on infrastructure that will last, not merely moving the issue down the calendar.
3. **Repair cost less than replacement?** At this time, yes.
4. **Expected addition to pipe service life worth expense?** Not yet. We have not had liners in for more than 4 years at some sites, and less at others. One of the initial test liner installations is beginning to fail and will require that the pipe be replaced before the assumed 10 years that the liner was supposed to provide.

[The respondent provided the following in response to a follow-up question about the failing liner installation: “This liner was installed for a county. I was not on site for the installation and have to rely on what others have said about it. I’ve been told by the installer that this is one of their best installations; pipe walls were dry and everything went smoothly. County employees back this up; pipe walls were dry, things seemed to go very well for the installer. Both agree that the liner is pulling away from the wall of the pipe. The installer says that it’s a pipe issue, not their product. The county feels they did not get a good installation. Either way, the county is looking at replacing the pipe in the next two years—not quite the minimum 10 years to 20 years they were hoping for/counting on.”]

Other Comments

Pending Research

When submitting her survey response, the respondent mentioned research that will be starting soon on a triple-barrel spray cast maintenance project. The project has been delayed by attempts by the supplier to obtain research funding. The pipes that will be the subject of the project are, as the respondent indicated, “not in terrible shape. I’d score them a 5 on the NBI structural evaluation scale.” The research will be conducted in conjunction with maintenance of the pipe. The respondent has offered to inform MnDOT of progress on the project.

Manufacturer Claims

When asked about issues or concerns related to manufacturer claims, the respondent noted:

MDOT is open to using these materials and we try to take lowest bidder, which I think is problematic. We have been told that issues experienced have been due to pipe walls not completely dry and/or clean, curing issues (timing, deplying), and nozzle not spraying at optimum. The most helpful thing we have found is to get it in writing: guarantees, warranties included.

Structural Adequacy and Bridge Load Ratings

A follow-up contact to the survey respondent sought additional information about the liner manufacturers’ proof of the structural integrity of the liners they provide, including calculations for bridge load ratings. The survey respondent referred the question to a colleague, Dave Gauthier, who indicated that he had no information to provide on rehabilitation projects on CMP with a diameter of 10 feet or more.

Contact: Dave Gauthier, Grading and Drainage Engineer, Michigan Department of Transportation, gauthierd@michigan.gov, 517-322-5710.

Related Resources:

Special Provision for Cured-in-Place Pipe for Culverts and Storm Sewers, Michigan Department of Transportation, December 1, 2014.

See [Appendix A](#).

From the description of the special provision:

This work consists of providing all labor, equipment and materials necessary for the design and installation of the cured-in-place resin impregnated felt liner into an existing culvert or storm sewer by hydrostatic inversion or by the direct pulled-in-place method at the locations specified on the plans. Cure the liner in place so that the finished installation is continuous, provides structural support and is tight fitting to the existing pipe. The manufacturer of the liner system must provide the design, installation and inspection of the liner and must have an authorized representative on site during installation.

Special Provision for Flowable Fill, Michigan Department of Transportation, August 19, 2011.

See [Appendix B](#).

From the description of the special provision:

This work consists of developing a mix design, producing a trial batch and placing flowable fill as indicated on the plans or as directed by the Engineer. All requirements for flowable fill and related work will be according to the standard specifications and this special provision. This specification is not intended to address non-structural flowable fill used for abandoning pipes and miscellaneous structures or other non-structural applications.

New York

Contact: Kevin P. Eager, Job Manager, Region 7 Design, New York State Department of Transportation, kevin.eager@dot.ny.gov, 315-785-2351.

General

1. **Repair techniques:** Mostly lining with new pipe is done to restore both structural and hydraulic capacity of an existing pipe.
 - 1a. **Frequency and over what time period?** Maybe one or two sliplines of large-diameter pipes every couple years over the past 10 years.
2. **Technique used for all shapes and sizes?** Lining with a new pipe is effective for all sizes of round and arch pipes.
3. **Potential environmental concerns?** Sliplining has the potential for adverse environmental impacts on wetlands, in-stream habit, sediment dynamics, water/air quality, and general ecology and wildlife resources. Coordination with our Environmental Group is done early on in design in order to identify potential impacts and opportunities for mitigation.
 - 3a. **Concerns with the repair process, after the repair is completed, or both?** Generally both.
4. **Roadblocks preclude use of certain repair techniques?** Condition/shape of existing pipe, hydraulic capacity and environmental impacts can be roadblocks to sliplining.

Structural Issues

Before Repair

1. **When to repair pipe?** NYSDOT routinely inspects large culverts (5 ft. in diameter/span width and greater) and produces an inspection report for each culvert to provide information and ratings in regards to condition. These inspections help determine if the large culverts are in need of repair or replacement.
- 1a. **Point when pipe too deteriorated for repair?** Generally when the pipe is showing significant deformation and/or settlement, severe corrosion and pitting, widespread section loss, backfill infiltration, and/or extensive undermining. The age of the pipe, remaining service life and costs are also considered.
2. **How to structurally analyze pipe prior to repair?** The inspection report and ratings provide the information regarding condition and the need to repair or replace the pipe.
3. **Parameters for design, construction, inspection and verification:** Hydraulic capacity; structural capacity; material specifications; environmental issues and permits; anticipated service life; required submissions for approval; construction details and procedures; testing; and basis of payment. The maximum depth of cover for the pipe being relined, estimated modulus of soil reaction, and the estimated water table need to be noted on the contract plans.

After Repair

1. **Does repair provide adequate structural support?** The lining pipe is required to possess adequate structural capacity to carry the entire calculated dead and live load. It is assumed the existing host pipe possess[es] zero remaining structural capacity.
- 1a. **Strength adequate for state highway?** The pipe lining can be design[ed] to have the strength to adequately carry a four-lane state highway.
- 1b. **Failing host pipe introduce problematic loading?** No. The liner pipe is designed assuming the existing host pipe possess[es] zero remaining structural capacity.
2. **How to analyze repaired pipe for bridge load rating?** Liner pipe is designed to have adequate structural capacity to carry the entire calculated dead loads and HS-25 live loading. It is assumed the existing host pipe possess[es] zero remaining structural capacity.
- 2a. **Appropriate bridge load rating method:** Unless it is a bridge (span of 20 feet or greater), a bridge load rating is not performed.
- 2b. **How load rating is performed:** [No response.]

Life-Cycle Cost-Effectiveness

1. **Cost of each repair?** Lining the large arch pipe in Natural Bridge with a welded straight-seam structural steel plate arch pipe (Infrasteel) will cost about \$2,700 per linear foot. Lining other large pipes with new corrugated structural steel plate pipes over the past few years have cost around \$2,000 per linear foot.
2. **Rate cost of each repair technique:** Would rate the cost of lining a large pipe with a welded straight-seam structural steel plate arch pipe (Infrasteel) like the one in Natural Bridge as medium. Corrugated steel plate lining and HDPE lining cost less than the Infrasteel lining but they were not viable options for the pipe in Natural Bridge.
3. **Repair cost less than replacement?** Lining the large corrugated steel plate arch pipe in Natural Bridge with a welded straight-seam structural steel plate arch pipe (Infrasteel) and all the other necessary associated work was estimated @\$700,000. Replacement of the large arch pipe would have required building a 38-foot-long single-span bridge to comply with USACE Nationwide Permit requirements regarding “bank-full” width. A new bridge with all the necessary associated work was estimated @\$1.5 million.

4. **Expected addition to pipe service life worth expense?** The anticipated service life of the sliplined pipe in Natural Bridge is 70 years.

Other Comments

Structural Adequacy and Bridge Load Ratings

We asked the respondent to further address the issue of structural adequacy in a series of follow-up questions:

Q: Generally, how do the manufacturers indicate that the liner they have designed for a particular project will provide adequate structural capacity?

A: NYSDOT actually designs and specifies the pipe size, shape, gauge/thickness and material needed for lining a large culvert. In the case of the recently sliplined arch culvert with a steel arch pipe from Infrasteel, the contractor had to submit a Level 1 Load Rating Analysis certifying that the Inventory and Operating Load Rating was equal to or greater than that which was required in the contract documents.

Q: For liners used for bridge spans (as you indicate in the survey, for NYSDOT these are spans of 20 feet or greater), does the manufacturer provide signed calculations for bridge load ratings that are then checked for accuracy by an NYSDOT engineer?

A: As per attached specification, any span greater than 12 feet would require review and approval by our Deputy Chief Engineer [of] Structures in conjunction with the Culvert ANalysis and DEsign (CANDE) program. Currently, I am not aware of any culvert having a span over 12 feet or bridge (span 20 ft. or greater) that has been sliplined in our Region.

Q: If yes, might you be able to share samples of the manufacturer's documents? Or is the load rating analysis for a liner conducted solely by NYSDOT?

A: NYSDOT does load rating analysis for Lining With Steel Structural Plate Pipe [see **Related Resources**].

Related Resources:

Culvert Lining Design Detail with Notes, New York State Department of Transportation, March 2015. See [Appendix C](#).

This is the design detail for a sliplining project recently completed in Natural Bridge using an Infrasteel liner. The 0.75-inch-thick liner is estimated to provide a 70-year service life for the repaired pipe.

Culvert Lining with Structural Steel Plate Pipe, Item 602.9xyynn07, New York State Department of Transportation, September 2015.

<https://www.dot.ny.gov/spec-repository-us/602.92100107.pdf>

This specification was used in connection with the recently completed sliplining project in Natural Bridge, New York, and provides for the load rating analysis that must be submitted by the contractor providing the liner.

From the specification:

The contractor must submit a Level 1 Load Rating Analysis (NYSPE stamped) certifying that the Inventory and Operating Load Rating will be greater than or equal to that which is required in the contract documents. Any proposed span greater than 12 feet will require review and approval by D.C.E.S. in conjunction with the CANDE program.

The document also specifies the installation practices expected of the contractor.

CANDE: Culvert ANalysis and DESign, American Association of State Highway Officials, undated.
<http://www.candeforculverts.com/home.html>

From the website:

CANDE is a special-purpose, finite element computer program developed for the structural design and analysis of buried culverts and structures for all shapes and materials including corrugated metal, reinforced concrete and thermoplastics.

First introduced in 1976 under sponsorship of the Federal Highway Administration (FHWA), CANDE's capabilities have steadily grown over the years. In 2005, the American Association of State Highway Officials (AASHTO) sponsored additional enhancements in the version called CANDE-2007, which is maintained by the Transportation Research Board (TRB). In 2011, AASHTO/TRB sponsored more upgrades producing the currently official version called CANDE-2007 with 2011 upgrade.

Chapter 8, Design Guidelines for Rehabilitation of Culvert and Storm Drain Pipe, Revision No. 61, Highway Design Manual, New York State Department of Transportation, March 2011.

<https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/rev61.pdf>

This document provides additional information about New York State DOT's practices for lining culverts.

Ohio

Contact: Jeffrey E. Syar, Administrator, Office of Hydraulic Engineering, Ohio Department of Transportation, jeffrey.syar@dot.state.oh.us, 614-275-1373.

The respondent provided the following in response to the survey questions:

While culverts with spans measured 10 feet and larger are considered bridges, many of the culvert rehabilitation and repair methods are applied for smaller sizes as well (if practicable). Many of your answers will come from the following document [Designer Guidelines for Trenchless Culvert Repair and Rehabilitation; see Related Resources].

In general, most of the techniques can be used for any size culvert. Some of the listed techniques would not be applicable due to size limitations of the repair method. Examples would include CIPP liners or internal bands. Two of our more popular methods are to apply a concrete invert paving to CMP structures or to install a liner pipe into a host conduit. The size and shape of these can range from smaller sizes up to sizes larger than 10 feet with a variety of different shapes. We intentionally oversize our culverts if the fill height is greater than 16 feet and/or if it's under a freeway for the sole purpose to slip-line in the future.

Any load rating required due to the culvert being a bridge is part of the deliverables from the Supplemental Specifications.

Research

We have active research that is evaluating the structural benefits of concrete invert paving [see Related Resources].

In addition, we recently completed a field test that applied concrete invert paving to half of the length of a metal pipe arch. We then load tested the invert paved side and the nonpaved side to evaluate the structural benefits of invert paving. The final report is in the work[s] by our "On-Call" researcher.

Other Comments

Structural Adequacy and Bridge Load Ratings

A follow-up contact to the survey respondent sought additional information about the information provided by liner manufacturers with regard to the structural integrity of the liners they provide. The survey respondent referred the question to a colleague, Matt Cozzoli, who provided this response:

Structures doesn't have any standards written to load rate this type of structure. For now they probably just ask the manufacturer [to] provide PE [professional engineer] signed calculations and accept them as it is.

Contact: Matt Cozzoli, Assistant Administrator, Roadway and Bridge Hydraulics, Ohio Department of Transportation, matt.cozzoli@dot.state.oh.us, 614-466-3152.

Related Resources:

Research in Progress: Structural Benefits of Concrete Paving of Steel Culvert Inverts, Ohio Department of Transportation, expected completion date: March 2017.

http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Pages/active.aspx?View=%7bd7c72556-2abc-4830-bdff-6c02603a792b%7d&SortField=Research_x0020_Organization&SortDir=Asc&FilterField1=Research%5Fx0020%5FOrganization&FilterValue1=Ohio%20University (Scroll down to the project title and click on "Click Here.")

From the project abstract:

Over time, a steel culvert invert will experience invert material loss due to corrosion and abrasive flow. The material loss progresses from minor perforations to ultimate invert loss if corrective action to protect the culvert invert is not taken. Invert material loss can lead to erosion of the supporting backfill which is an integral component for the structural integrity of a steel culvert. A common corrective maintenance action is to place 4-6 inches of concrete onto the invert of the steel culvert for the bottom 1/3 of the rise of the culvert. Light reinforcing mesh is attached to the culvert and concrete is poured and shaped to the bottom of the barrel in most applications. If total invert loss or significant backfill erosion has occurred and the exiting shape is unaffected, additional measures may be required such as: additional reinforcing steel and replacement of the backfill with cementitious materials.

This corrective maintenance action is cost effective and widely used because it seals the culvert invert, prevents backfill loss, and provides a protective layer between the abrasive flow and the steel material. However, the impact of this corrective maintenance action on the structural integrity of the culvert is unknown. Additionally, it is unknown if additional reinforcement is required when there is total invert loss and the existing shape is unaffected. While it is clear that the pipe has been weakened by the loss of the steel section, it is unclear if the stiffness of the added concrete compensates and restores the culvert to its original strength. Furthermore, once the floor is sealed with concrete, inspectors are unable to visually confirm additional damage to the remaining steel. This could adversely impact load capacity ratings causing some culverts to receive a higher load rating than is actually warranted. Research is needed to verify the viability of this practice and provide engineers with scientifically-based guidance on its proper application.

The goal of this research is to enhance the understanding of the mechanics of steel culverts and the impact that this common corrective maintenance action has on the structural integrity of the steel culvert. The objectives of this research are to: (1) determine and quantify the influence the repair has on the structural integrity of the culvert system, (2) determine if additional reinforcing steel is required when there is total invert loss, and (3) develop a scientifically-based, cost effective, repeatable methodology engineers can use to evaluate repairs to steel culvert inverts with deteriorated inverts. The results of this research may influence ODOT's current standard specifications for metal culverts (item 611.11). The findings will enable engineers to make more informed decisions on which culverts are ripe for the invert rehabilitation and the most appropriate application of this practice.

Designer Guidelines for Trenchless Culvert Repair and Rehabilitation, Ohio Department of Transportation, July 19, 2013.

<http://www.dot.state.oh.us/Divisions/Engineering/Hydraulics/Location%20and%20Design%20Volume%202/Designer%20Guidelines%20for%20Trenchless%20Culvert%20Repair%20a/Designer%20Guidelines%20for%20Culvert%20Repair%20and%20Rehabilitation.pdf>

These guidelines provide remediation alternatives for steel and aluminum pipe, identifying different techniques for structurally sound and nonstructurally sound pipes. The remediation alternatives do not specify pipe diameter. The tables that appear on page 2 of the guidelines are reproduced below.

Flexible Pipe

Steel & Aluminum Pipe

Generally structurally sound pipe

PROBLEM	REMEDATION
Corrosion – Light No Invert Perforations	Invert paving with portland cement concrete CMS 611.11, SS834 Conduit Renewal Using Resin Based Liner
Corrosion – Heavy Perforations to the Pipe and/or Invert	Invert paving with portland cement concrete CMS 611.11 with SS834 Conduit Renewal Using Resin Based Liner, spray on liner (structural), cement mortar lining, shotcrete, cured-in-place-pipe (CIPP), SS837 Liner Pipe, SS841 Conduit Renewal Using Spiral Wound Liner, SS937 Polyethylene Liner Pipe, SS938 Steel Reinforced Thermoplastic Ribbed Pipe
Infiltration / Exfiltration	Portland cement grout, chemical grouting, cured-in-place-pipe (CIPP), SS837 Liner Pipe, SS841 Conduit Renewal Using Spiral Wound Liner, SS937 Polyethylene Liner Pipe, SS938 Steel Reinforced Thermoplastic Ribbed Pipe

Nonstructurally sound pipe

PROBLEM	REMEDATION
Structurally Deficient Requiring Total Conduit Rehabilitation / Replacement	SS837 Liner Pipe, SS841 Conduit Renewal Using Spiral Wound Liner, SS937 Polyethylene Liner Pipe, SS938 Steel Reinforced Thermoplastic Ribbed Pipe, structural steel pipe liner, spray-on Liner (structural), tunnel liner plate, pipe jacking

Note: Below are Ohio DOT Supplemental Specifications for some of the rehabilitation techniques referenced in the tables reproduced above. The specifications address design requirements, preparations for installation, installation procedures and activities required postinstallation.

Supplemental Specification 833, Conduit Renewal Using Spray Applied Structural Liner, Construction & Material Specifications, Ohio Department of Transportation, July 17, 2015.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/833_07172015_for_2013.pdf

From the Ohio DOT website and the Supplemental Specification:

This specification may be used for relining existing conduit that is 36-inch diameter or greater in size.

This work consists of conduit lining with spray applied, factory blended cementitious, geopolymer or resin based material. The term “host pipe” refers to the conduit being renewed with the spray applied structural liner system.

The specification identifies the minimum property requirements for the cementitious or geopolymer-based liner material used in this process.

Supplemental Specification 834, Conduit Renewal Using Resin Based Liner, Construction & Material Specifications, Ohio Department of Transportation, July 17, 2015.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/834_07172015_for_2013.pdf

From the Ohio DOT website and the Supplemental Specification:

This specification may be used for relining existing conduit that is 36-inch diameter or greater in size.

This work consists of renewing a conduit by lining it with a spray applied, resin based material. The term “host pipe” refers to the conduit being renewed with the resin based liner system.

Among the approved products are PolySpray SS100 from HydraTech and SprayShield Green II from Sprayroq.

Supplemental Specification 837, Liner Pipe, Construction & Material Specifications, Ohio Department of Transportation, January 17, 2014.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/837_01172014_for_2013.pdf

From the Ohio DOT website and the Supplemental Specification:

This specification is for using liner pipe to rehabilitate existing conduits.

Design the liner pipe according to the Location and Design Manual, Volume 2, Drainage Design. This work consists of furnishing, installing and grouting liner pipe into existing conduits shown on the plans.

The specification provides guidance for use of the following as liner pipe:

- Corrugated steel spiral rib pipe.
- Corrugated polyethylene smooth lined pipe.
- Polyvinyl chloride corrugated smooth interior pipe.
- Polyvinyl chloride profile wall pipe.
- Steel casing pipe.
- Polyethylene liner pipe.
- Steel reinforced thermoplastic ribbed pipe.

Supplemental Specification 841, Conduit Renewal Using Spiral Wound Liner, Construction & Material Specifications, Ohio Department of Transportation, July 17, 2015.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/841_07172015_for_2013.pdf

From the Ohio DOT website and the Supplemental Specification:

This specification may be used for relining existing conduit for the sizes shown in the table shown [see the table below].

This work consists of rehabilitating a conduit by lining it with an extruded polyvinyl chloride (PVC) profile strip that is spiral wound into the existing conduit (the host pipe). The extruded PVC profile strip mechanically locks together to itself. The work also includes grouting the annular space between the liner and host pipe.

Conduit Shape	Minimum Size	Maximum Size
Round	42" (1067 mm)	240" (6096 mm)
Elliptical	Short Axis 42" (1067 mm)	Long Axis 240" (6096 mm)
Box	42" × 42" (1067 mm × 1067 mm)	8' × 12' (2438 mm × 3658 mm)
Pipe-Arch	42" Rise (1067 mm)	240" Span (6096 mm)

Supplemental Specification 937, Polyethylene Liner Pipe, Construction & Material Specifications, Ohio Department of Transportation, October 16, 2015.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/937_10162015_for_2013.pdf

From the Ohio DOT website and the Supplemental Specification:

This specification should be used in conjunction with SS 837.

This specification covers Type B polyethylene liner pipe with heat fusion or plain end extrusion weld joints. The inside diameters range from 18 to 132 inches.

Supplemental Specification 938, Steel Reinforced Thermoplastic Ribbed Pipe, Construction & Material Specifications, Ohio Department of Transportation, April 16, 2010.

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specification%20Files/938_04162010_for_2013.PDF

From the Ohio DOT website and the Supplemental Specification:

Use this specification in conjunction with SS 837 when installed as a liner pipe.

Steel reinforced thermoplastic ribbed pipes are also used as liner pipes where the steel reinforced thermoplastic pipe is inserted into an existing conduit and grouted in place.

Related Resources

The citations below are organized in the following sections:

- National Research and Guidance.
- State Research, Guidance and Experience in the Field.
- Additional Resources.

National Research and Guidance

Research in Progress: Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption, NCHRP Project 14-19.

<http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1634>

This research project was originally scheduled for completion on June 30, 2014. The NCHRP website indicates that the project is still in progress, with the contractor's Phase 2 interim report pending.

From the project website:

The objective of this project is to develop a handbook that provides up-to-date guidance to assess the existing condition of culverts; provides assistance in the selection and design of suitable rehabilitation options; and provides information on various methods of construction associated with culvert rehabilitation. The emphasis

of the handbook should be on culvert rehabilitation that minimizes disruption to traffic and the road surface, while maximizing hydraulic capacity of the rehabilitated culvert.

Culvert repair methods to be considered should include liners, local repairs, grouting of voids, joint seals, and other applicable methods. Details at termination of liners should be considered. Identify the method of estimating the service life of rehabilitated culverts for each repair method.

Decision Analysis Guide for Corrugated Metal Culvert Rehabilitation and Replacement Using Trenchless Technology, Forest Service, U.S. Department of Agriculture, December 2012.

<http://www.fs.fed.us/t-d/pubs/pdfpubs/pdf11771810/pdf11771810Pdpi72.pdf>

This publication's flowcharts provide assistance in selecting the appropriate rehabilitation practice, and case studies describe methods used by other agencies for similar conditions. The authors cite a 2002 publication that offered a brief discussion of a Maine DOT project that applied segmental sliplining with reinforced concrete pipe (see page 29 of the report, page 37 of the PDF):

The existing corrugated metal pipe, 1,048 feet long and 144 inches in diameter, was relined with a 108-inch reinforced concrete pipe structure. The reinforced concrete pipe segments were installed by pushing in place the segments inside the corrugated metal pipe. A special cart was fabricated to drive the precast concrete segments inside the pipe. Jacks were used to lift the segments off the ground while the cart was pushed along the existing tunnel with a Bobcat loader. At the target location, the jacks were lowered and the pipe homed with the previously positioned pipe using two 6-ton come-alongs anchored in two holes that were later used for pumping grout between the old metal and new concrete pipes. The process was repeated for each pipe segment.

Culvert Assessment and Decision-Making Procedures Manual for Federal Lands Highway, Central Federal Lands Highway Division, Federal Highway Administration, September 2010.

<http://flh.fhwa.dot.gov/innovation/td/hydraulics/culvert-assessment/> (The PDF for the entire document appears to be corrupted. Individual chapters of the manual are available at this website.)

Appendix E includes a liner selection matrix (see http://flh.fhwa.dot.gov/innovation/td/hydraulics/culvert-assessment/12_Appendix_E_Culvert_Decision_Making_Matrices.pdf) that summarizes properties, advantages and disadvantages of liner rehabilitation options. Diameter limits are indicated to permit identification of liners appropriate for large-diameter culverts. These include:

- Sliplining (segmental)—up to 158 inches; up to 72 inches common.
- Spiral-wound liner—up to 120 inches, depending on type.

Localized man-entry repairs that do not have maximum size limits include grouting voids and invert lining.

This publication identifies the diameter limits for CIPP as 12 inches to 108 inches, with 48 inches or less most common, which removes CIPP from consideration for the type of large-diameter repair of interest to MnDOT.

State Research, Guidance and Experience in the Field

Research and Guidance

Kentucky

Research in Progress: Culvert Slip Lining Guidance, Kentucky Transportation Cabinet.

Project description: <http://www.ktc.uky.edu/files/2014/01/KYSPR-13-466.pdf>

This project was originally scheduled for completion on June 30, 2014, but is classified as a current project on the Kentucky Transportation Center website.

From the project description:

Objectives: The objective of this study is to develop a culvert slip lining guidance manual for Kentucky. The guidance manual will provide information on the appropriate locations to use slip lining as a rehabilitation alternative.

Background: Slip lining a culvert is a cost effective way of remediating a currently deficient facility by inserting a smaller diameter solid wall HDPE pipe into a larger diameter pipe. Slip lining has been used in Kentucky, but the structural and hydraulic designs were performed by consultants outside of Kentucky. This research project will look at current slip lining standard practices across the country and develop a guidance manual to be used by the Kentucky Transportation Cabinet (KYTC) and consultants in Kentucky for the repair or maintenance of pipe culverts.

Utah

Culvert Rehabilitation Practices, Utah Department of Transportation, undated.

<https://www.udot.utah.gov/main/uconowner.gf?n=1128117589169310>

This manual was developed to “provide a brief description of each method and its installation procedure and highlight the advantages and disadvantages of each method.” A table on page 14 of the manual (page 16 of the PDF), reproduced in part below, indicates that sliplining, cement-mortar spray-on lining and spiral-wound liner are appropriate methods to rehabilitate culverts with a diameter of 10 feet or more. All of these methods restore structural integrity and increase flow velocity, which may cause scouring at outlets.

TABLE 1. SUMMARY OF TRENCHLESS REHABILITATION METHODS					
Method	Diameter (inches)	Length (feet)	Material*	Advantages	Disadvantages
Sliplining	4 to 158	Up to 5,248	HDPE, PE, PP, PVC, GRP	<ul style="list-style-type: none"> • Capable of large radius bends • Flow diversion not necessary during installation • Simplistic method • Low cost/less training • Applicable to all types of existing culvert materials 	<ul style="list-style-type: none"> • Excavation required for access pits • Grouting necessary for annular space • Existing culvert must be longitudinally uniform
Cement-mortar spray-on lining	3 to 276	Up to 1,476	Cement, Mortar	<ul style="list-style-type: none"> • Does not block lateral and service connections • Protects against corrosion • Low cost 	<ul style="list-style-type: none"> • Flow bypass is required • Existing culvert must be completely dry prior to applying the cement • Long curing time (up to

TABLE 1. SUMMARY OF TRENCHLESS REHABILITATION METHODS					
Method	Diameter (inches)	Length (feet)	Material*	Advantages	Disadvantages
					seven days) <ul style="list-style-type: none"> • Generally fails to enhance the structural integrity of the existing pipe • Application of cement-mortar may be inconsistent
Spiral-wound liner	4 to 120	Up to 1,000	PE, PVC, PP, PVDF	<ul style="list-style-type: none"> • Liner formed on site • No or little excavation • Flow bypass may not be necessary • Accommodates diameter changes • Grouting not required if expandable liner is used 	<ul style="list-style-type: none"> • Trained personnel required • Grouting may be required if fixed diameter is used • High material and training cost • Continuous fusion or sealant for joints required

* See the definitions below:

GRP: Glass-fiber-reinforced polyester
 HDPE: High-density polyethylene
 PE: Polyethylene

PP: Polypropylene
 PVC: Polyvinyl chloride
 PVDF: Polyvinylidene chloride

In-Situ Culvert Rehabilitation: Synthesis Study and Field Evaluation, Travis Hollingshead and Blake Paul Tullis, Utah Department of Transportation, June 2009.

<http://www.udot.utah.gov/main/uconowner.gf?n=9732720543913757>

This publication also includes Table 1, Summary of Trenchless Rehabilitation Methods, that is reproduced in connection with the citation above (see page 17 of the report; page 26 of the PDF), describing advantages and disadvantages of rehabilitation methods for large-diameter CMP of interest to MnDOT. The authors provide a brief description of repair methods and installation procedures, and highlight the advantages and disadvantages of each. Costs and structural requirements are also addressed in brief.

Virginia

Chapter 8 – Culverts, VDOT Drainage Manual, Virginia Department of Transportation, July 2014.

<http://www.virginiadot.org/business/resources/LocDes/DrainageManual/drain-manual-chapter-08.pdf>

See page 8-23 of the manual (page 30 of the PDF) for Section 8.3.6.7, Pipe Rehabilitation, which addresses issues to be considered in the initial decision-making process of whether to install new pipe or line the existing pipe. A decision matrix on page 8-25 of the manual (page 32 of the PDF) aids the user considering installation of a flexible liner given the existing pipe material, noted deficiencies of the existing pipe and site limitations.

Water Quality Implications of Culvert Repair Options: Cementitious and Polyurea Spray-on Liners, Bridget M. Donaldson and Andrew J. Whelton, Virginia Department of Transportation and Federal Highway Administration, November 2012.

<http://ntl.bts.gov/lib/46000/46700/46781/13-r3.pdf>

Researchers evaluated two spray-on liner options available for use by Virginia DOT: a polymer-enhanced cement mortar (or cementitious) spray-on liner and a polyurea spray-on liner.

From the abstract:

For the cementitious spray-on liner evaluated, pH and alkalinity exceeded specified Virginia water standards in laboratory tests but pH and other evaluated compounds were within the acceptable range in water flow and

immersion tests. For the polyurea spray-on liner evaluated, elevated water quality indicators (i.e., biochemical oxygen demand, chemical oxygen demand, total organic carbon, and total nitrogen) in laboratory tests suggested that contaminants were released from the polyurea liner, particularly during its initial contact with water, but water quality impacts were not detected in the other tests. Water flow, dilution, and volatilization appear to play an important role in reducing water quality impacts from contaminant leaching.

The study recommends that VDOT specifications include protective controls for spray-on liners to prevent exceeding water quality standards or toxicity thresholds for aquatic species in receiving waters with low flows and little dilution potential.

Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners, Bridget M. Donaldson, Virginia Department of Transportation and Federal Highway Administration, November 2012.

http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r2.pdf

In this study provides an environmental evaluation of two CIPP technologies: vinyl ester-based (styrene-free) CIPP and styrene-based ultraviolet (UV) CIPP.

From the abstract:

For the vinyl ester based CIPP liner evaluated, concentrations of the primary resin constituent exceeded toxicity thresholds for aquatic species in six subsequent water sampling events. Adherence to VDOT's CIPP specifications for styrene-based liners is expected to minimize contaminant leaching from the installation and use of this product. Following UV CIPP installations, no water quality impacts were documented from culvert outlets with water flow but styrene concentrations following one of the installations exceeded toxicity thresholds for aquatic species in standing water.

The study recommends that VDOT consider revising its current CIPP specifications such that styrene-based CIPP requirements also apply to non-styrene-based CIPP installations. Because the water quality evaluations conducted in this study could not capture the range of potential field scenarios and installation variables, the VDOT specification that requires the collection and analyses of water and soil samples following CIPP installations would provide VDOT with additional sampling results from liners installed in varying field conditions and help ensure that VDOT is using this lining technology with appropriate environmental safeguards.

Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology, Bridget M. Donaldson and Andrew J. Baker, Virginia Department of Transportation and Federal Highway Administration, May 2008.

http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-r16.pdf

This study examined the environmental impacts of practices to apply cured-in-place rehabilitation of failing pipe culverts. Focusing on seven CIPP installations in Virginia, researchers examined installations that applied forced steam through the lining tube to press the liner to the inside dimensions of the host pipe and harden the styrene-based resin-impregnated liner material.

Evaluation of water samples collected from each site identified that five of the seven CIPP installations showed detectable levels of styrene, with styrene concentrations generally highest in water samples collected during and shortly after installation. Findings indicate that elevated styrene levels could have resulted from one or more of the following:

- Installation practices that did not capture condensate containing styrene.
- Uncured resin that escaped from the liner during installation.
- Insufficient curing of the resin.
- Some degree of permeability in the lining material.

As a result of this study, Virginia DOT suspended the use of styrene-CIPP for pipes that convey surface or stormwater. Reinstatement of statewide CIPP installations was planned for May 2008 after instituting:

- Modifications to the agency's specifications.
- An inspector training program.
- Increased project oversight.
- Water and soil testing prior to and after CIPP installation.

Wisconsin

Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Structures, Sam Salem, Mohammad Najafi, Baris Salman, Diego Calderon, Rahul Patil and Deepak Bhattachar, Wisconsin Department of Transportation, August 2008.

<http://wisdotresearch.wi.gov/wp-content/uploads/08-30trenchlesstech-f.pdf>

The scope of this report is "trenchless renewal of culverts and drainage structures with a diameter or equivalent diameter range of 12 to 144 inches." Summaries of each technique address the product's main characteristics, advantages and limitations, installation and quality assurance/quality control. Technologies identified as appropriate for pipes with a diameter of 120 inches or greater include:

Sliplining (segmental).

- *Diameter*: 24 to 160 inches.
- *Grouting*: Requires a thin, coarse mortar.
- *Liner material*: Polyethylene, polypropylene, PVC and glass-reinforced pipe.

Spiral-wound pipe.

- *Diameter*: 12 to 120 inches.
- *Grouting*: Sometimes required (cementitious grout).
- *Liner material*: Polyethylene, PVC, polypropylene, polyvinylidene chloride.

Panel lining.

- *Diameter*: 42 inches and larger.
- *Grouting*: Cementitious.
- *Liner material*: PVC.

Formed-in-place pipe.

- *Diameter*: 8 to 120 inches and larger.
- *Grouting*: Cementitious polymer mortar.
- *Liner material*: HDPE.

Coatings and linings.

- *Diameter*: 8 to 177 inches.
- *Grouting*: Not required.
- *New material*: Cement mortar or polymers.

Experience in the Field

“Stormwater Rehab in New York: Coordinated Effort Saves Taxpayers \$816,800,” Cullom Walker III and Shanna St. Clair, *Trenchless Technology*, pages 26-28, July 22, 2015.

<http://trenchlessonline.com/stormwater-rehab-new-york-coordinated-effort-nysdot-st-lawrence-county-ny-saves-taxpayers-816800/>

This magazine article describes a collaborative effort between New York State DOT and the St. Lawrence County Department of Highways to repair two large-diameter arched culverts using smooth-walled steel slipliners that were custom-fabricated to match the existing culvert dimensions. The state’s existing culvert had a 131-inch span and an 81-inch rise, while the county’s culvert was 103 inches by 71 inches. By rehabilitating rather than replacing these culverts, the agencies together saved more than \$816,800.

The Infrasteel liner used in this rehabilitation effort matches the exact shape of host pipe to maximize the area of flow. Manufactured in 8- to 10-foot lengths with wall thicknesses up to 1 inch, a standard 0.500-inch wall thickness was chosen for these installations. The vendor has developed a method of measuring and gathering information about the host pipe so that the manufactured liner is sized with exact rise and span measurements that will allow it to be sliplined into place.

Project managers considered other options, including paving the invert, and concluded that the Infrasteel liner’s strength and thickness, coupled with the grouting of the annular space (the space between a rehabilitation structure and the host structure) would improve the structural integrity of the repaired pipe. The bottom section of the liner has an inverted bevel, allowing for welding to be done from within the pipe; the top and sides are welded on the outside. Grouting is done from within the structure through 2-inch grout ports cut into the liner at top center. The life expectancy of the rehabilitated pipe is estimated at 50 to 100 years.

Note: Ernest Olin, the resident engineer for New York State DOT Region 7 identified in the article, provided additional information about the state DOT portion of this project. The following summarizes Olin’s responses to a series of questions about the project described in the *Trenchless Technology* article and general rehabilitation practices employed by New York State DOT.

Contact: Ernest Olin, Resident Engineer, Region 7, New York State Department of Transportation, ernest.olin@dot.ny.gov, 315-265-2320.

The liner described in the article was delivered in September 2013 and the installation was completed in early October 2013. The Infrasteel liner provided a smooth invert for the arch shape of the host pipe, increasing the culvert’s hydraulic capacity at a reasonable price (under the agency’s \$ 50,000 discretionary limit). Olin estimates that the 0.5-inch liner will provide 50 years minimum extended service life. A culvert rehabilitation now underway in Natural Bridge (upstate New York) will use a 0.75-inch thick liner, and the agency’s engineers estimate a 70-year service life for the repaired pipe.

(Olin noted that his region has used only a few of the different types of liners available, using primarily products that are on an agency contract or products with a cost under the discretionary purchasing limits and obtainable through the agency’s purchasing rules.)

The 2013 rehabilitation project was completed as a maintenance repair that had to be completed before losing the road (the invert of the corrugated host pipe was completely rusted out). The current project has been fully engineered to address structural concerns. Olin said that when examining failing pipes for possible repair, it is important to recognize that it may not be possible to push an adequately sized liner into the host pipe if the host pipe is partially collapsing or because of other alignment issues. Hydraulics may dictate installation of a new, larger culvert if the host pipe is severely undersized.

According to Olin, arched culverts were traditionally lined with a round, smooth plastic liner or smaller corrugated pipe arch, with both options decreasing the hydraulic capacity of the repaired pipe. Because the agency could not afford to lose capacity by downsizing, other alternatives were investigated. Olin learned of a smooth bore alternative offered by the Infrasteel liner that mimics the arch shape and actually increases the hydraulic capacity due to the smooth bore.

With the 2013 repair, velocity of water in the pipe increased, which led the agency to institute measures to avoid scour and erosion by stone-lining the outlet and inlet. If the installation site had been a fish-bearing stream, baffles could have been installed to help aquatic life transition through the culvert.

Olin recommends considering sliplining when it is a cost-effective alternative compared to other rehabilitation solutions or replacement, noting that the economy of scale for sliplining becomes more advantageous for sites with large embankment fills, long detours and heavy traffic. Maintenance and protection of traffic are usually minimal with the sliplining rehabilitation projects completed by the agency.

“Massive Spincast Culvert Rehab for INDOT,” Jeff Griffin, *Underground Construction*, Vol. 67, No. 9, September 2012.

<http://centripipe.com/portals/0/docs/Massive%20Spincast%20Culvert%20Rehab%20For%20INDOT.pdf>

This magazine article about an Indiana effort to reline 43 culverts ranging in diameter from 24 to 114 inches along a 63-mile stretch of Interstate 74 focuses on relining with centrifugally cast concrete pipe. At the time of publication, the three culverts with round equivalents of 114 inches and 108 inches that were relined with CCCP were the largest corrugated metal pipes relined using this technology in the United States. This rehabilitation technology can be used on pipes with diameters from 30 to 120 inches. CentriPipe is the product used in the Indiana DOT installations.

Installation Process

Setting the stage for an effective installation involves determining the condition of the host pipe and taking accurate measurements. Installers use a remote-controlled spincaster to apply concrete coating inside the existing pipe. The material is described as a “high-strength, abrasion- and corrosion-resistant fiber-reinforced mortar.” The spincaster travels at a speed to ensure uniform thickness of concrete; the device can be started and stopped as needed. For the Indiana DOT installations, crews set up a bypass system to divert water because no water can pass through the culvert during installation.

The installation process began with cleaning the host pipe. Crews repaired damaged inverts by pumping in self-consolidating mortar to permanently seal the bottom of the pipe to provide a new floor. The spincaster was placed in the center of the pipe at the downstream end. Crews applied varying lifts of 0.25 inch to 0.75 inch, with one application per day. A curing compound was applied to the surface of the rehabilitated structure after the final lift. The entire installation took about 2.5 weeks. The final product is expected to have the same service life as a concrete pipe section of the same diameter and thickness.

“Two Methods of Culvert Repair Successful in Indiana,” *Underground Construction*, Vol. 66, No. 3, March 2011.

<http://ucononline.com/2011/03/15/two-methods-of-culvert-repair-successful-in-indiana/>

This article’s title is misleading. The contractor is from Indiana, but the project—a rehabilitation effort using a 132-inch spiral-wound PVC liner—was completed in Ohio for Ohio DOT.

From the article:

Contractor Indiana Reline Inc. recently rehabilitated two culverts for the Ohio Department of Transportation that illustrates the benefits of two types of sliplining technologies: spiral wound pipe and conventional sliplining.

Indiana Reline Project Manager/Estimator Karl Bates said the spiral pipe project represented the largest Sekisui SPR PVC spiral wound pipe [ever] installed in the United States. The other project, Bates said, used ISCO Snap-Tite culvert pipe liner and included the world’s first hydro-bell structure to provide a larger, wider intake at the culvert entrance.

The SPR liner project was with 132-inch spiral pipe lining installed in a 180-inch multi-plate culvert which had been installed in the 1950s to carry the flow of a creek under two-lane State Road 101 outside Tiffin, OH. Bates said the project originally called for the culvert to be relined with 132-inch HDPE liner, but ODOT District 2 issued an addendum that allowed 132-inch machine spiral wound PVC liner in addition to HDPE.

....

SPR is a spiral wound liner utilizing steel reinforced, monolithic, interlocking PVC profile strip that is grouted in place with specified cementitious grout. SPR has the capability to negotiate bends and rehabilitate odd shaped pipelines because of the adaptability of the profile.

The basic installation process is to position a winding machine at the base of an access point of the host pipe and spirally wind monolithic panels of PVC into the host pipe to form a continuous, low-weight, watertight liner with high stiffness.

....

Indiana Reline personnel cleaned the host culvert, installed bracing and blocking between the liner and the host to prevent displacement during grouting, and the SPR liner was installed. No pits were required. In addition, Indiana Reline built two 14-cubic-yard bulkheads, installed internal bracing and pumped 620 cubic yards of 350 psi light-weight cellular grout in the annular space between the host and liner pipes per the project specifications.

The project began in September of 2010 and was completed in November 2010.

Additional Resources

“Decision-Making Guidance for Culvert Rehabilitation and Replacement Using Trenchless Techniques,”

He Jin, Kalyan R. Piratla and John C. Matthews, *Pipelines 2015: Recent Advances in Underground Pipeline Engineering and Construction*, pages 1443-1451, August 2015.

<http://ascelibrary.org/doi/abs/10.1061/9780784479360.132>

From the abstract:

Culverts which are typically located under roadways and embankments for the passage of water are designed to support the super-imposed earth and live loads from passenger vehicle and trucks as well as the internal hydraulic loading from the stream flow. Many of the existing culverts in the U.S. are in a deteriorated state having reached the end of their useful design life, making them vulnerable to failures with potentially catastrophic consequences. Traditionally, deteriorated culverts have been replaced by the conventional open-cut construction method. Due to higher costs, adverse environmental and societal impacts associated with

open-cut method, particularly in high population and busy roadways, transportation agencies are increasingly looking to adopt trenchless techniques for addressing their culvert problems. This paper reviews several trenchless rehabilitation and replacement techniques investigating their suitability to address different defects, and their compatibility with various host pipe materials and diameters. With focus on reinforced concrete pipe (RCP), corrugated metal pipe (CMP) and high density polyethylene (HDPE) culvert materials, easy-to-use decision-making flowcharts are presented in this paper. State transportation agencies, U.S. Forestry Service and other local government agencies that manage culvert infrastructure will benefit from this paper.

“Role of Grout Strength and Liners on the Performance of Slip-Lined Pipes,” Trevor Smith, Neil A. Hoult and Ian D. Moore, *Journal of Pipeline Systems Engineering and Practice*, April 2015.

Citation at <http://trid.trb.org/view.aspx?id=1350985>

From the abstract:

As infrastructure built during the 20th century reaches the end of its service life, engineers and managers are increasingly turning to rehabilitation rather than replacement to potentially reduce costs. For corrugated steel pipes and culverts, one such rehabilitation alternative is to use slip lining where a liner (new pipe) is placed inside the existing deteriorated pipe and the space between them is grouted. The current research seeks to better understand the performance of slip-lined systems by (1) characterizing the properties of a low-strength and a high-strength grout; (2) conducting a series of pipe tests to determine the load-carrying capacity and stiffness of a corrugated steel pipe and pipes that have been rehabilitated with slip liners; (3) understand the impact of grout strength and the liner on pipe stiffness and strength; and (4) determine the level of composite action in the pipe system by using a plasticity approach to estimate the load-carrying capacity of the system. The pipes rehabilitated with low-strength grout had increased strength (three times greater) and stiffness (eight times greater) versus an unrehabilitated pipe, whereas the specimens rehabilitated with high-strength grout showed higher increases in both load-carrying capacity (ten times greater) and stiffness (50 times greater) over the unrehabilitated pipe. The high density polyethylene (HDPE) liner had no impact on the load-carrying capacity of the specimens with high-strength grout and required large diameter changes to enhance the load-carrying capacity of low-strength grout specimens. A plasticity approach was used to estimate the load-carrying capacity of the specimens and indicated that for these tests, composite behavior between the grout and the corrugated steel pipe was developed.

“Recent Advances in Repair of Culverts and Pipes,” Mo Ehsani, *TRB 91st Annual Meeting Compendium of Papers DVD*, Paper #12-2950, 2012.

Citation at <http://trid.trb.org/view/2012/C/1130042>

From the abstract:

There is a large inventory of deteriorated culverts worldwide. In many cases the loss of strength in these structures causes safety hazard to the traveling public. However, there are few effective techniques to restore the integrity of these structures. This paper reviews some of the existing methods for spot and full length repair of culverts. Among the materials used are Fiber Reinforced Polymer (FRP) products. The development of a new honeycomb pipe is discussed. This pipe takes advantage of a technology that has been used for decades in the aerospace industry. It is demonstrated that these honeycomb pipes can offer unique cost-effective solutions to repair of culverts when the liner is expected to carry the traffic and soil loads that can no longer be resisted by the failing culvert.

“State-of-the-Art Literature Review on In-Situ Pipe Repairs and Durability,” Fazil Najafi, Brad Cooney and Adnan Javed, *TRB 90th Annual Meeting Compendium of Papers DVD*, Paper #11-1269, 2011.

Citation at <http://trid.trb.org/view/2011/C/1091856>

From the abstract:

For any aging infrastructure, its probability of failure increases with time. There is a multitude of ways to repair and rehabilitate deteriorating pipes, and as the infrastructure system continues to age, there is a need for less invasive pipe renewal techniques. The focus of the paper is to examine the methodology, advantages, disadvantages, applications and factors affecting the durability of the five most common in-situ repair

methods: sliplining, cured-in-place-pipe, structural spray on lining (sprayed-in-place-pipe), spiral wound lining (grout-in-place-pipe), and fold and form lining (formed-in-place-pipe). A summary of the findings for each method is presented in tabular form at the end of the paper. The factors that affect the durability of various pipe materials typically used in the pipe repair methods mentioned above were also researched. After an extensive literature review, it can be concluded that, when compared to the traditional open cut pipe replacement method, in-situ technologies cause less disruption to the surrounding environment, less inconvenience on the community, and in appropriate applications are more cost effective.

MICHIGAN
DEPARTMENT OF TRANSPORTATIONSPECIAL PROVISION
FOR
CURED-IN-PLACE PIPE FOR CULVERTS AND STORM SEWERS

CFS:DMG

1 of 2

APPR:SJU:DBP:12-01-14

a. Description. This work consists of providing all labor, equipment and materials necessary for the design and installation of the cured-in-place resin impregnated felt liner into an existing culvert or storm sewer by hydrostatic inversion or by the direct pulled-in-place method at the locations specified on the plans. Cure the liner in place so that the finished installation is continuous, provides structural support and is tight fitting to the existing pipe. The manufacturer of the liner system must provide the design, installation and inspection of the liner and must have an authorized representative on site during installation.

Provide video inspection of the culverts and sewers before (after cleaning) and after lining. All culvert and sewer cleaning, maintaining flow, bypass pumping, and site preparation is included in this work.

b. Materials. Use tube and resin material that meets the requirements of *ASTM F 1216* and *ASTM F 1743*, as applicable.

Design the liner for HS-20 live loading. Design the required cured-in-place liner wall thickness in accordance with *appendix X1 of ASTM F 1216*. Use the formulas assuming a fully deteriorated pipe condition and the water table at the ground surface.

Provide documentation to the Engineer indicating the proposed design liner thickness for each run of pipe, all component materials and that the liner meets the minimum chemical resistance requirements listed in *appendix X2 of ASTM F 1216* prior to installation.

Provide a tube consisting of one or more layers of flexible needled felt or equivalent woven or nonwoven material capable of carrying resin and withstanding installation pressures and curing temperatures. Ensure the tube is compatible with the resin system used. Ensure the tube material is able to stretch to fit irregular culvert or sewer sections. Ensure the outside layer of the tube is plastic coated with a material that is compatible with the resin system used. Fabricate the tube to the required size to fit the inside diameter for the full length of the existing culvert or sewer when cured. Ensure allowance is made for circumferential stretch during the hydrostatic inversion method and for longitudinal stretch during the direct pulled-in-place method.

c. Construction. Provide a minimum of 10 work days notice to the Engineer prior to starting the work. Electronically submit all required documentation to the Engineer for approval prior to starting the work. Do not begin work until approval is received from the Engineer.

Video inspect the existing and lined pipe in accordance with subsection 402.03.K of the Standard Specifications for Construction. Thoroughly clean the existing pipe prior to videotaping. Dispose of all debris in accordance with subsection 205.03.P of the Standard Specifications for Construction.

Propose a corrective action to eliminate any obstruction revealed by pre-installation inspection that

cannot be removed by conventional pipe cleaning equipment and that prevents the cured-in-place liner from being installed properly. Ensure the proposed corrective action is approved by the Engineer prior to commencement of the work.

Maintain flow around the run of pipe designated for lining as necessary. Ensure the bypass pumping system can provide adequate capacity to handle the existing flow plus any additional flow that may occur during periods of rainfall. Electronically submit a bypass pumping plan containing all necessary details to the Engineer for approval a minimum of 10 work days prior to conducting the work.

Continuously monitor all pumps and equipment. Follow local noise ordinances if pumping is required on a 24 hour basis.

Install the cured-in-place liner in accordance with the manufacturer’s guidelines and *ASTM F 1216* or *ASTM F 1743*, as applicable. Ensure the finished liner is continuous over the entire length of pipe and is free from visual defects, such as foreign inclusions, dry spots, pinholes, lifts, and delamination. Wrinkles or other flaws in the cured liner that reduce the hydraulic capacity of the pipe are unacceptable. Correct any deficiency found at the Contractor’s expense, utilizing a method approved by the Engineer. Remove and dispose of excess resin and other materials generated from the installation.

For all types of resin and installation methods, capture and dispose of any process water and wastewater resulting from the installation and flushing of the cured-in-place liner. Ensure the captured water is disposed of at a local wastewater treatment facility or as otherwise approved by the Engineer in accordance with applicable federal, state and local regulations and permit requirements. Provide written permission for acceptance of this water from the local wastewater treatment facility to the Engineer prior to starting the work. Ensure process water is not discharged directly or indirectly to a ditch, storm sewer, surface water body or other unapproved location.

Prepare and test samples for each lined run of pipe using either method described in *ASTM F 1216*, section 8.1.

Provide a certification, sealed by a Professional Engineer licensed in the State of Michigan, verifying that the lining system has been designed, manufactured and installed in accordance with the applicable *ASTM standards* and this special provision.

d. Measurement and Payment. The completed work, as described, will be measured and paid for at the contract unit price using the following pay item:

Pay Item	Pay Unit
Cured-In-Place Pipe Lining, __ inch.....	Foot

The cost for the work to remove an obstruction that cannot be removed with conventional pipe cleaning equipment will be paid for separately in accordance with the contract.

MICHIGAN
DEPARTMENT OF TRANSPORTATIONSPECIAL PROVISION
FOR
FLOWABLE FILL

C&T:JFS

1 of 2

C&T:APPR:JAB:DBP:08-19-11

a. Description. This work consists of developing a mix design, producing a trial batch and placing flowable fill as indicated on the plans or as directed by the Engineer. All requirements for flowable fill and related work will be according to the standard specifications and this special provision. This specification is not intended to address non-structural flowable fill used for abandoning pipes and miscellaneous structures or other non-structural applications.

b. Materials. Provide flowable fill consisting of a mixture of Portland cement, granular material or fine aggregate, fly ash and water. The optional addition of ground granulated blast furnace slag, air entraining admixture and performance enhancing admixture is allowed.

Use either Type I or IA Portland cement conforming to section 901 of the Standard Specifications for Construction and Class F or C fly ash as specified by ASTM C 618 except that there is no limit on loss on ignition.

Use granular material Class II conforming to section 902 of the Standard Specifications for Construction except that 100 percent must pass the 1/2 inch sieve. Use 2NS material for the fine aggregate.

If a performance enhancing admixture is used it must be included in the mix design and trial batch, and must be used according to the manufacturer's recommendation.

c. Mix Design. Submit mix design documentation to the Engineer for review a minimum of 7 days prior to placement. The mix design must include source and type or class of materials and batch proportions.

d. Strength Requirements. The compressive strength of the flowable fill must be a minimum of 50 psi at 3 days, and 75 to 150 psi at 28 days. If an air entraining admixture or performance enhancing admixture is used, the air content of the flowable fill must not exceed 35 percent by volume.

e. Trial Batch. Produce a trial batch using the approved mix design and test to verify that the mixture is capable of obtaining the required compressive strength. Mold and cure four 6 by 12 inch cylinders. Test two cylinders at 3 days and test two cylinders at 28 days. Determine air content of the trial batch if an air entraining admixture or performance enhancing admixture is used. Submit all trial batch test results to the Engineer.

f. Construction. Provide for 24 hours from start to start of each flowable fill placement. Produce and deliver the flowable fill at a minimum temperature of 50 degrees F. Do not place flowable fill if ambient air temperature of 35 degrees F or less is anticipated in the 24 hour period following proposed placement.

Use batching equipment equipped to measure the quantities of each component material. Provide sufficient mixing to ensure uniform consistency of the mixture. Do not add water to the flowable fill mixture after batching. Maintain water content to achieve specified compressive strengths and a uniform, self-leveling mixture.

Secure all pipes and conduits within the backfill area to counteract the buoyant effect of flowable fill. Tightly seal pipes, manholes and other areas not intended to be filled. Place the material evenly around manholes and in utility trenches to avoid dislocating pipes and conduits.

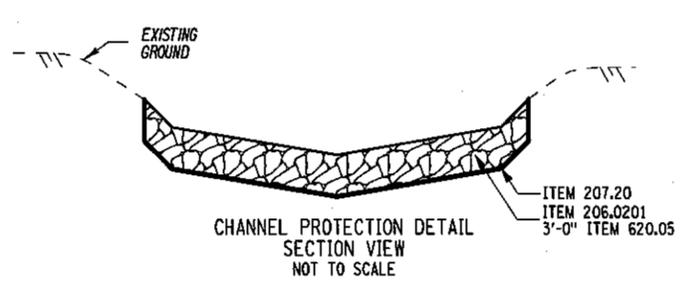
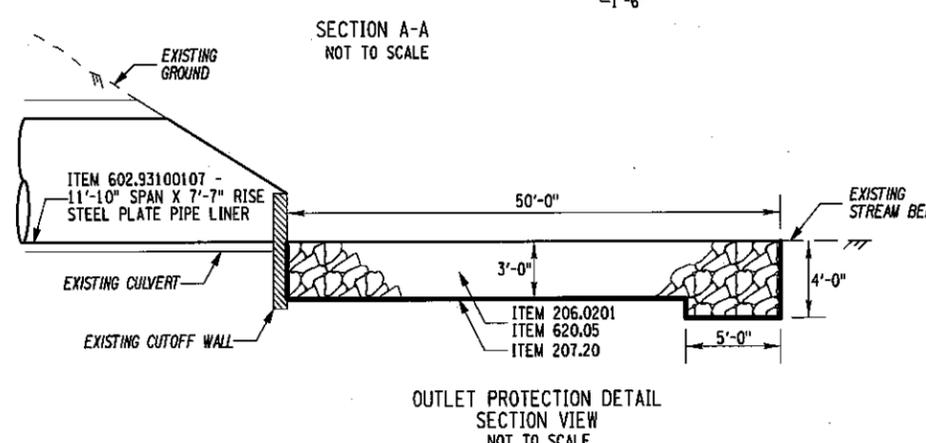
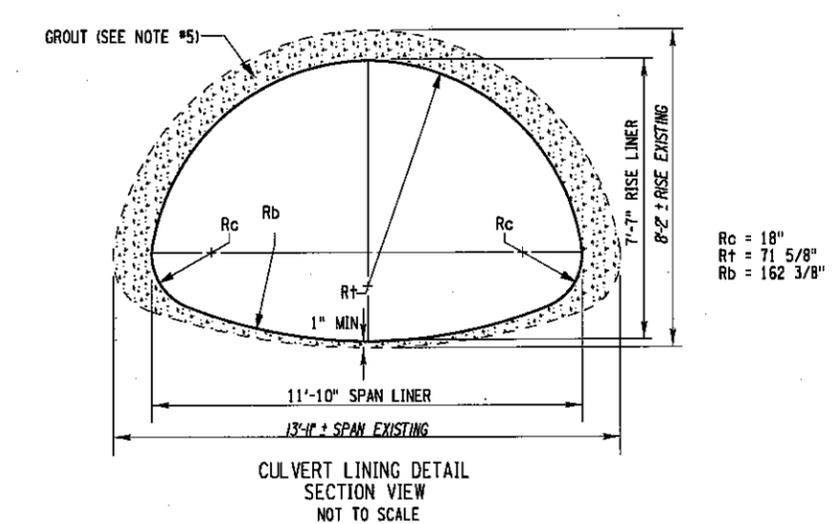
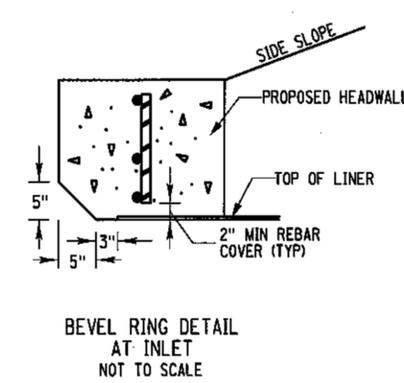
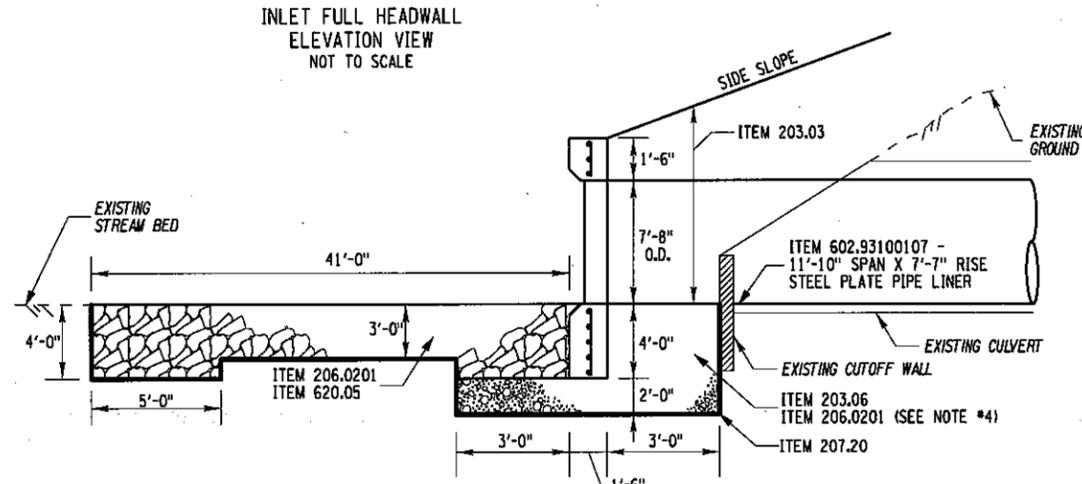
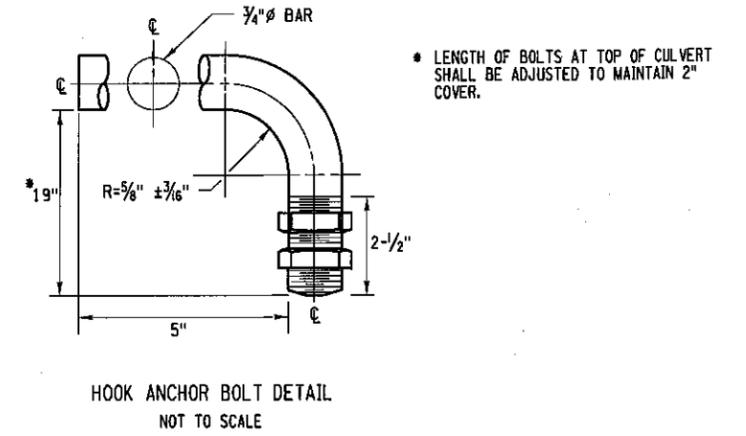
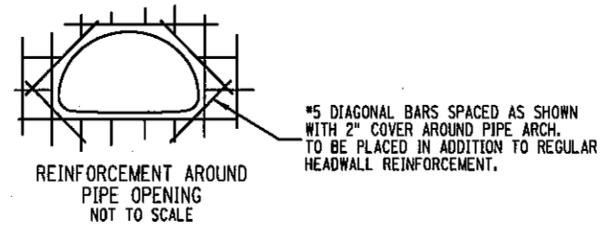
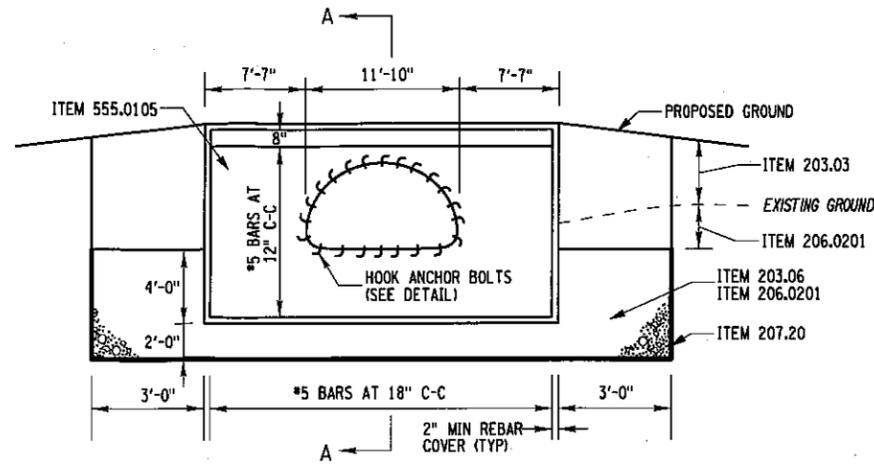
For each day of production, mold two 6 by 12 inch cylinders and store at the job site for the first 24 hours. Store cylinders in a shaded area or keep covered. The Department will transport the cylinders to the laboratory designated by the Engineer. Testing for 28-day compressive strength will be according to ASTM C 39, except specimens will be air cured in their molds until they are to be tested.

e. Measurement and Payment. The completed work, as described, will be measured and paid for at the contract unit price using the following pay item:

Pay Item	Pay Unit
Flowable Fill	Cubic Yard

Flowable Fill includes all producing and placing the trial batch, preliminary testing, furnishing the mix design, and all materials, equipment and labor necessary to complete the work as described.

Appendix C



- NOTES
- ALL EXPOSED EDGES OF HEADWALL SHALL BE CHAMFERED 1"
 - ANCHOR BOLTS:
 - A) HOOK BOLTS SHALL CONFORM TO ASTM SPECIFICATION A36.
 - B) BOLTS AND NUTS SHALL BE GALVANIZED AFTER FABRICATION TO MEET CURRENT ASTM SPECIFICATION A153.
 - C) NUTS SHALL CONFORM TO ASTM SPECIFICATION A563, HEAVY HEX BOLT SPACING 18" C-C MAXIMUM.
 - D) THE NUTS AND BOLTS SHALL BE ASSEMBLED SO THAT IN THE FINAL ASSEMBLY, THE BOLTS AND ONE OF THE NUTS FACE EACH OTHER, AND SECURE THE CULVERT BETWEEN THEM.
 - E) ANCHOR BOLTS SHALL BE PAID UNDER ITEM 602.93100107.
 - A BEVEL RING SHALL BE FORMED AROUND THE ENTIRE CIRCUMFERENCE OF THE INLET. SEE BEVEL RING DETAIL.
 - ANY UNDERMINING OF EXISTING PIPE AND OR CUTOFF WALL SHALL BE BACK FILLED USING CONTROLLED LOW STRENGTH MATERIAL (CLSM) (NO FLY ASH) MEETING THE REQUIREMENTS OF SECTION 204 OF THE STANDARD SPECIFICATIONS. COST TO BE INCLUDED IN ITEM 206.0201.
 - GROUT SHALL BE DESIGNED SO THAT IT FLOWS INTO VOIDS OF THE ANNULAR SPACE AND SETS UP SUFFICIENTLY WITHIN 24 HOURS TO ALLOW PLACEMENT OF ADDITIONAL MATERIAL. COST TO BE INCLUDED IN ITEM 602.93100107.
 - CONTRACTOR SHALL FIELD MEASURE THE EXISTING ARCH CULVERT TO VERIFY THE RISE, SPAN, AND LENGTH; AND TO DETERMINE THE TOP, CORNER AND BOTTOM RADII BEFORE ORDERING THE STEEL PLATE PIPE LINER. COST TO BE INCLUDED IN ITEM 602.93100107.
 - GEOTEXTILE BEDDING (ITEM 207.20) SHALL BE STRENGTH CLASS 2 WITH APPARENT OPENING SIZE B.
 - OUTLET END OF STEEL PLATE PIPE LINER SHALL BE MITERED TO MATCH THE EXISTING SLOPE (AOBE), COST TO BE INCLUDED IN ITEM 602.93100107.
 - THE PIPE LINER IS REQUIRED TO POSSESS ADEQUATE STRUCTURAL CAPACITY TO CARRY THE ENTIRE CALCULATED DEAD LOAD AND HS-25 LIVE LOADING. DEPTH OF COVER OVER THE CULVERT BEING RELINED IS 7.4 FT., THE SURROUNDING SOIL HAS AN ESTIMATED MODULUS OF SOIL REACTION "E" VALUE OF 1000 PSI, AND THE WATER TABLE IS ESTIMATED AT 11 FT. BELOW ROADWAY GRADE.
 - IN ADDITION TO THE STEEL LINER PIPE THICKNESS REQUIRED FOR STRUCTURAL ADEQUACY, AN ADDITIONAL SACRIFICIAL STEEL THICKNESS OF 0.14 INCH SHALL BE PROVIDED FOR ASSUMED METAL LOSS OF 2 MILS PER YEAR FROM ABRASION THROUGHOUT THE ANTICIPATED 70 YEAR SERVICE LIFE OF THE PIPE LINER.

CULVERT QUANTITIES			
CULVERT	ITEM 555.0105	ITEM 556.0201	ITEM 602.93100107
	CONCRETE FOR STRUCTURES, CLASS A	UNCOATED BAR REINFORCEMENT FOR CONCRETE STRUCTURES	CULVERT LINING WITH STRUCTURAL STEEL PLATE PIPE
C740168	16 CY	562 LB	98 LF

AFFIX SEAL: KEVIN P. EAGER
ON: 3/10/2015

ALTERED BY:
ON:



AS-BUILT REVISIONS DESCRIPTION OF ALTERATIONS:	FARGO - NATURAL BRIDGE, SH 8190	PIN 7805.51	BRIDGES	CULVERTS	ALL DIMENSIONS IN FT UNLESS OTHERWISE NOTED	CONTRACT NUMBER D262927
	NATURAL BRIDGE - HARRISVILLE PART 1, SH 8130	NYS RTE 3	BIN 1027490	C740168		
		UTILITY QUALITY LEVEL C			CULVERT DETAILS	DRAWING NO. CD-1
					NYS ROUTE 3 OVER BLANCHARD CREEK	SHEET NO. 13

IT IS A VIOLATION OF LAW FOR ANY PERSON, UNLESS THEY ARE ACTING UNDER THE DIRECTION OF A LICENSED PROFESSIONAL ENGINEER, ARCHITECT, LANDSCAPE ARCHITECT, OR LAND SURVEYOR, TO ALTER AN ITEM IN ANY WAY. IF AN ITEM BEARING THE STAMP OF A LICENSED PROFESSIONAL IS ALTERED, THE ALTERING ENGINEER, ARCHITECT, LANDSCAPE ARCHITECT, OR LAND SURVEYOR SHALL STAMP THE DOCUMENT AND INCLUDE THE NOTATION "ALTERED BY" FOLLOWED BY THEIR SIGNATURE, THE DATE OF SUCH ALTERATION, AND A SPECIFIC DESCRIPTION OF THE ALTERATION.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION REGION
DOCUMENT NAME: 780551_CPH_MTD_CD.DGN,LNK.CPH....

FILE NAME = 12-MAR-2015 11:06
DATE/TIME =
USER = jlaclair

PROJECT MANAGER D.M.H.
CHECK P.J.W.
DRAFTING J.A.L.
CHECK K.P.E.
DESIGN J.A.L.
JOB MANAGER K.P.E.
DESIGN SUPERVISOR E.J.R.