



TRANSPORTATION RESEARCH SYNTHESIS

Minnesota Department of Transportation
Office of Policy Analysis, Research & Innovation
Research Services Section
(651) 366-3780
www.research.dot.state.mn.us

TRS1209
Published October, 2012

Culvert Repair Best Practices, Specifications, and Special Provisions: Task C Research Synthesis

Introduction

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

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

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

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

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

Task D—Best Practices Guidelines: Best Practices Guidelines, Special Provisions, and Standard Details will be prepared based on the results of Tasks A, B, and C; discussions with the technical advisory panel; and comments from other MnDOT personnel.

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

Task F—Outreach: CNA will assist the technical advisory panel with a plan for communication and distribution of the Best Practices Guidelines.

This TRS contains references to the documents that were collected. Refer to these documents for complete information:

1. Culvert Repair Best Practices, Specifications and Special Provisions, Task A – Minnesota Survey Results, February, 2012.
2. Culvert Repair Best Practices, Specifications and Special Provisions, Task B– Other State Survey Results, August 13, 2012.

The following sections are included in this TRS:

1. Summary
2. Online Surveys – A description of the online surveys conducted in Tasks A and B.
3. Interviews– A description of the interviews conducted in Tasks A and B.
4. Literature, Specifications, Drawings, and Cost Information Review – A list of the information collected, along with brief descriptions.
5. Findings Summary – A listing of findings, primarily from the Tasks A and B online surveys and interviews.
6. Culvert Repair Methods Recommended for Preparation of Specifications and Drawings – Recommended methods to be included in Task D.

Summary

This TRS involved the synthesis of the following tasks, the results of which are described in detail in other sections of this TRS.

1. Online Surveys. These were online base surveys, conducted in Tasks A and B using SurveyMonkey™ online survey software.
2. Interviews. Phone interviews were conducted in Tasks A and B.
3. Literature, Specifications, Drawings, and Cost Information Review. Literature related to culvert repair was collected before and during previous tasks. Literature was requested during the online surveys and interviews. Additional literature was collected from sources provided by MnDOT and CNA Consulting Engineers.

Online Surveys

Online surveys were conducted with the following agencies:

1. Task A surveys included MnDOT District personnel and offices and Minnesota Cities and Counties.
2. Task B surveys included other State's DOT's. Surveys were sent to the American Association of State Highway and Transportation Officials Research Advisory Committee (AASHTO RAC) list.

The surveys were conducted using SurveyMonkey™ software. The goals of the surveys were to:

1. Determine what types of culvert repairs the agencies have done.
2. Obtain specifications, standard details, and cost information for culvert repair methods.
3. Obtain contact information for culvert repair contractors and suppliers.
4. Identify concerns with the various repair methods.

The surveys included questions about the following repair methods:

1. Cured-in-place pipe (CIPP).
2. Sliplining.
3. Fold and form liners.
4. Spirally wound liners.
5. Pipe bursting.
6. Paved invert.
7. Joint repairs.
8. Spincast liners.
9. Crack sealing.
10. Spall repair.
11. Filling voids outside the culvert.
12. Other.

The reports for Task A and B contain a summary of information gathered.

Interviews

Personnel were selected for interviews based on their responses to the online surveys and recommendations from MnDOT. The following interviews were conducted during Tasks A and B.

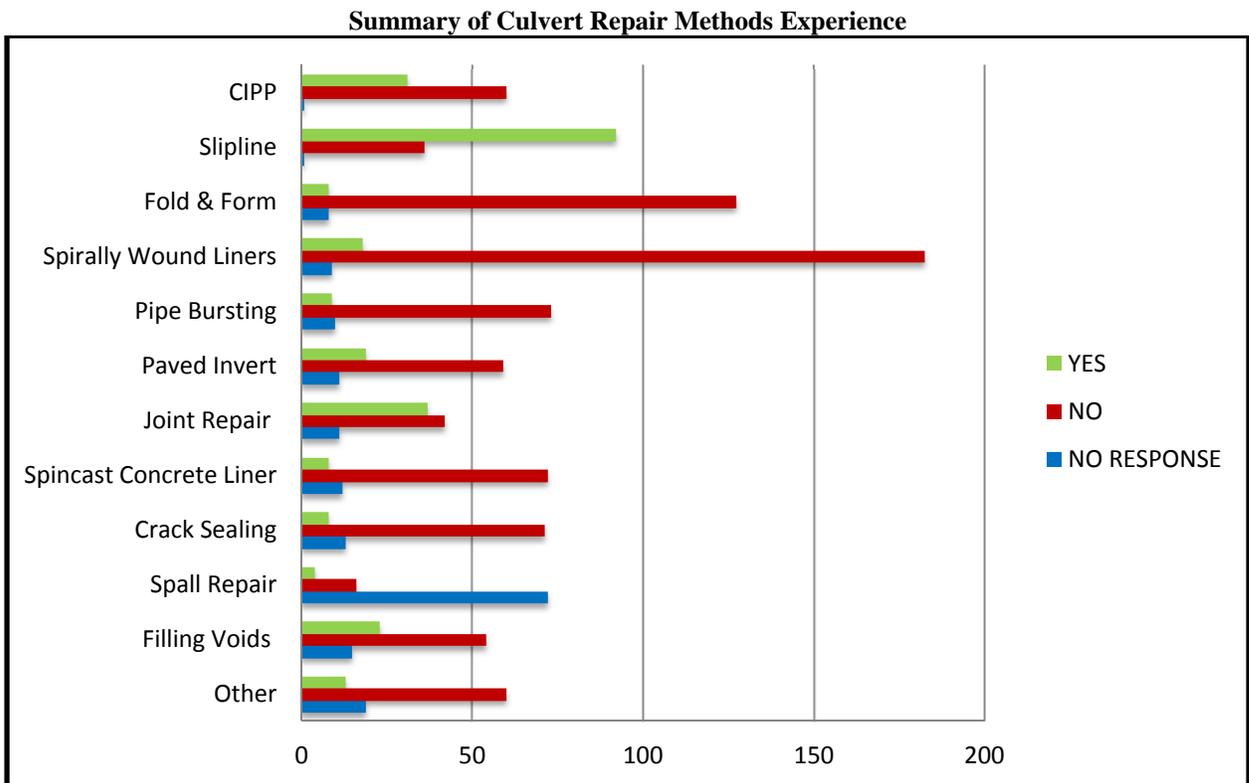
1. Task A interviews included the following:
 - a. Ten maintenance and hydraulics personnel from seven MnDOT District offices.
 - b. Two key MnDOT experts.
 - c. Nine Minnesota cities/county personnel.
 - d. Four culvert repair contractors.
2. Task B interviews included ten personnel from other state's DOT's and one person from the Saskatchewan Highways and Infrastructure Department.

The interviews included questions similar to those listed for the online surveys, above. The reports for Tasks A and B contain a summary of information gathered.

Findings Summary

1. Experience with the Various Culvert Repair Methods.

The chart below shows the experience the survey respondents had with the various culvert repair methods.



Of the methods asked about in the surveys, respondents had significant experience with sliplining, cured-in-place pipe (CIPP), and joint repair. There was relatively little experience with fold and form liners, spirally wound pipe, pipe bursting, paved invert, spincast concrete liners, crack sealing, filling voids outside the culvert, and spall repair.

Other methods respondents identified were:

- a. Insulation foam to fill voids - quick fix
- b. Strips of high density polyethylene (HDPE) and foam insulation to cover holes in liners
- c. Internal bands
- d. Excavate and re-lay the culvert

- e. Replace the culvert or sections
 - f. Spray on liners
 - g. Composite material for invert of liner
 - h. Invert repair using metal liner plates
 - i. Shotcrete lining to repair large diameter pipes
2. General Comments on Culvert Inspection and Repair Methods
- a. Culvert Inspections
 - i. MnDOT: In general, the districts try to follow Hydinfra guidelines, which are to inspect Condition 4 culverts yearly and Condition 3 every other year. In addition, culverts are routinely inspected as part of an upcoming roadway project. Many said that resource limitations make it difficult to keep up with inspections.
 - ii. Minnesota cities and counties: A couple of the cities are working on implementing an inspection program to identify problem culverts and track inspections. McLeod County uses GIS for tracking culvert inspections. Other practices included checking certain culverts after major rain events and also before major road work or resurfacing. Culverts over 10 feet in size are inspected by MnDOT.
 - b. Culvert Materials: In Minnesota, reinforced concrete pipe (RCP) and corrugated metal pipe (CMP) are by far the most common.
 - c. Culvert Sizes: In Minnesota, 15-inch to 48-inch diameter are most common.
 - d. Piping along the outside of the existing pipe is a big concern. Piping is difficult to note without flowing water. Piping can occur with both concrete and metal culverts. Piping becomes a problem to roadway user safety during flash floods as culverts with piping are more likely to wash out than those with no defects.
 - e. Cleaning ditches can cause flushing that reveals more defects.
 - f. Repair Methods Comments and Concerns. The following concerns were noted about some of the methods:
 - i. Many methods do not address voids or piping outside the culvert. Voids need to be filled for a proper repair.
 - ii. Cured-in-Place Pipe:
 - 1. Many respondents have had success with this method.
 - 2. Need to make sure that the space at the inlet between the host pipe and CIPP liner is filled.
 - 3. Styrene release to waterways is a concern. Some agencies do not allow styrene-based resins. Virginia DOT placed a moratorium on use of styrene-based resins.
 - 4. Higher cost than other methods.
 - iii. Sliplining:
 - 5. The annular space between the culvert and liner needs to be grouted.
 - 6. Cement grout temperature needs to be controlled. One project recorded grout temperatures of 140 degrees F.
 - 7. Cellular Concrete CLSM Concerns:
 - a. Expensive - Not enough competition.
 - b. Needs a washout agent when water is present.
 - c. Needs a sanded mix when water is present.
 - 8. Concern that grout doesn't completely fill the annulus. They found this was the case on one cellular grout project, probably due to water being present.
 - 9. Mixes that are less flowable require high grouting pressures. This can damage the liner.
 - 10. Grout can float the liner if it is not blocked properly.
 - 11. Freezing of grout placed in the winter can be an issue.
 - 12. Grout spills are an environmental issue.
 - 13. Culvert might have a reduced hydraulic capacity after liner is placed.
 - 14. Culverts that are inlet-controlled need improved inlets to improve the hydraulic efficiency of the sliplined culvert.
 - iv. Fold and Form Liners
 - 15. One respondent does not specify this method due to limited diameter range; that can be repaired with need to "stretch" the PVC.
 - v. Spirally Wound Liners
 - 16. Higher cost than other methods.
 - 17. Concern about consistency of final product.

- 18. Concern about quality assurance.
- vi. Pipe Bursting
 - 19. One MnDOT respondent had experience with pipe bursting. His comments are paraphrased below:
 - a. Pipe bursting needed to be done with over 8 ft of cover to prevent bulging of the roadway. Poor subgrade or water caused the area around the pipe to turn to mush. Then energy transferred to soil rather than pipe and it quit working. Did not work on CMP as claimed as metal pipe folded up creating large void around host pipe.
 - 20. Contractor Comments:
 - a. HDPE, PVC and steel replacement pipes have been used.
 - b. Existing couplings and fittings can make pipe bursting difficult.
 - c. The method requires flow bypass.
 - d. Equipment is expensive.
 - e. Good geologic and existing pipe information is important.
 - f. Pipe bursting does not work on all pipe types.
- vii. Paved Invert
 - 21. Some considered this a temporary repair, however, one noted repair has lasted more than 25 years.
 - 22. Specifying high strength concrete with durable aggregate is recommended.
 - 23. Choosing a good method of mechanically tying the concrete paving to the host pipe is important.
- viii. Joint Repair
 - 24. Mortar repairs may crack or spall with time.
 - 25. One respondent did recommend mortar repairs if water is flowing through the joints.
 - 26. Use of internal rubber gaskets can be problematic on significantly deflected flexible pipe.
 - 27. Joint preparation and attention to detail is very important.
 - 28. No change in diameter is a benefit.
 - 29. Allows for sliplining or other lining technique later.
 - 30. Voids outside existing pipe are potentially filled.
 - 31. Rubber bands need to be tight or they will not stay in place.
 - 32. Joint problems in RCP are typically on ends of culverts. If space allows, sections are dug up, tied with external galvanized ties, fabric placed around joint and then backfilled.
- ix. Spincast Liner
 - 33. Fiber reinforcing could enhance product performance.
 - 34. Surface preparation is very important.
 - 35. Final surface is not smooth.
 - 36. There are temperature restraints during application.
- x. Filling Voids Outside the Culvert
 - 37. May require involvement of geotechnical staff.
 - 38. One respondent typically uses a contact grout as opposed to compaction grouting due to concern over excess pressure generation and potential for damaging the host pipe. As a result, it's difficult or nearly impossible to assess the resulting soil compaction level and accurately analyze pipe structure.
 - 39. This has to be done on a Unit Price basis since the volume of grout needed is unknown.
 - 40. Chemical grout prices vary. A 3:1 expanding grout could be a cheaper result than a 10:1 expanding grout as using more of a cheaper product maybe as cost effective as the greater expandable material. The specific gravity of the product is important so that it mixes with the soils, adheres to the culvert and does not float to the surface due to water or freeze conditions.
 - 41. High grout pressures can damage the culvert.
 - 42. Grout can migrate into other nearby utilities.
- xi. FRP Invert Liner and Fish Weirs: These were preformed panels and weirs that were set in place, fastened to side walls of existing culvert and grouted. Advantages over concrete liner: quicker in-stream construction, less invert elevation change.

Literature, Specifications, Drawings, and Cost Information Review

Literature, specifications, drawings, and cost information related to culvert repair was collected before and during Tasks A and B. Guidelines, specifications, details, and cost information was requested during the online surveys and interviews. Additional literature was collected from sources provided by MnDOT and CNA Consulting Engineers, including the following sources:

- State Planning & Research (SP&R) Work Plan.
 - NCHRP 14-19 Culvert Rehabilitation to Maximize Service Life while Minimizing Direct Costs and Traffic Disruption. This is ongoing work being conducted by Trenchless Technology Center at Louisiana Tech University and CNA Consulting Engineers.
 - Hydrinfra information and flowcharts.
 - Other information provided by MnDOT Research and MnDOT Hydraulics.
2. Guidelines and Reports. The following culvert repair guidelines and reports have been collected during Tasks A and B. These will be reviewed and incorporated into the work of Task D as appropriate. Information that has been received, but deemed not useful is not included in the list below.
- a. *Culvert Repair Best Practices Manual*, FHWA-RD-94-096, May, 1995, 651 pages, http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=true&keyword=008
This manual has been developed to provide guidance to highway agencies on procedures that may be used to repair a wide variety of types of problems that beset metal and concrete culverts of all types. Many of the procedures are also applicable to the repair of timber and stone masonry culverts. Procedures are also presented on ways to improve the inlet and outlet ends of culverts as well as the streambed channels leading to and from them.
 - b. *Caltrans Supplement to FHWA Culvert Repair Practices Manual*, CALTRANS Design Information Bulletin No. 83-02, August 20, 2011, 174 pages. <http://www.dot.ca.gov/hq/oppd/dib/dib83-02.htm>
The primary purpose of this Design Information Bulletin (D.I.B.) is to supplement the 1995 Federal Highway Administration Publication 'Culvert Repair Practices Manual-Volumes 1 and 2', highlight areas of general concern, and reference other appropriate documentation to provide information, guidelines and alternatives for the cost-effective repair, rehabilitation, strengthening or retrofit upgrade of culverts and storm drains as described in Indices 806.2 and 838.1 of the Caltrans Highway Design Manual (HDM).
 - c. *Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Structures*, Midwest Regional University Transportation Center, Project 07-15, August, 2008, 171 pages. http://www.wistrans.org/mrutc/files/07-15_FR.pdf
This report provides a comprehensive study and decision making procedures for asset management using trenchless technologies to address the construction, renewal, renovation, and inspection of culverts and drainage infrastructures.
 - d. *Pipe Liners and Linings for Culvert Rehabilitation*, California Highway Design Manual Topic 853.
This manual addresses various pipe liner and lining materials intended for culvert repairs, including host pipe structural philosophy, problem identification, alternative pipe liner materials, cementitious pipe lining, invert paving, and structural repairs with steel liner plate.
 - e. *Culvert Pipe Liner Guide and Specifications*, FHWA-CFL/TD-05-003, July, 2005. 169 pages. http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?sort=Publication_title&archived=false
Colorado State University (CSU) was contracted to establish guidelines and specifications for the use of culvert liners. Task 1 involved a thorough literature review to collect information describing the state-of-the-practice in culvert pipe lining. Task 2 involved the development of a decision-making methodology for choosing appropriate culvert liners based on various factors. Task 3 required CSU to prepare and submit a final report whereby providing guidance to both the Design and Construction Branches of the FHWA and to State DOTs.
 - f. *Assessment and Rehabilitation of Existing Culverts*, NCHRP Synthesis 303, 2002, 82 pages. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_303.pdf
This study was initiated to determine the state of the practice in pipe assessment and in the selection of appropriate repair and/or rehabilitation methods. In addition, the study was undertaken to determine how

- pipe assessment and corrective work fit into the larger transportation management system and what efforts, research or otherwise, are needed to implement a pipe management system. This synthesis had the following six objectives:
- i. To determine what guidelines were being used by transportation agencies to assess the conditions of pipes.
 - ii. To determine what guidelines were being used to select the methodology to repair or rehabilitate a damaged pipe.
 - iii. To determine what methods were being used to store inspection and maintenance records.
 - iv. To determine what management systems were being used with an agency's assessment program.
 - v. To determine what methods were being used by agencies to predict the service life of pipes.
 - vi. To determine what material specifications were being used during repair or rehabilitation of pipes.
- g. *Culvert Rehabilitation to Maximize Service Life while Minimizing Direct Costs and Traffic Disruption*, NCHRP 14-19, not yet completed.
The first phase of this three-phase project has been completed. Phase I is a 217-page long literature review completed in July, 2010. It contains a literature review of condition assessment procedures and culvert rehabilitation methods. Phases 2 and 3 will develop a culvert rehabilitation handbook.
- h. *Culvert Renewal*, MnDOT Report No. MN/RD92-02, April, 1992, 49 pages.
Several different culvert repair options were placed in culverts on I-35 near Hinckley, Minnesota, in an effort to find an inexpensive and less disruptive alternative to removal and replacement of deteriorated culverts. Seven different reliners were placed in concrete and metal pipe, and five joint repair options were placed in concrete pipe. These reliners and repairs were compared using costs, skills and resources required, time, culvert preparation, traffic disruption, work area requirements, placement problems, and grouting procedures. Field performance of the reliners and joint repairs was checked visually after one year to evaluate the short term effects of climate. At this point in time all reliners appeared to be performing adequately. Relining and joint repair should be considered as an inexpensive, time saving, and minimally disruptive alternative to removal and replacement of deteriorated culverts. Smooth reliners are inexpensive, flexible, easy to install and perform better hydraulically than corrugated or ribbed reliners. Savings can be significant in both money and time with very little disruption to the driving public.
- i. *Chapter 14-Culvert Inspection, Material Selection, and Rehabilitation*, AASHTO Highway Drainage Guidelines, 4th Addition, 2007 , <https://bookstore.transportation.org/>
Chapter 14 contains discussions of inspection, factors influencing service life, material selection, and culvert repair, and replacement methods. The 14-page repair methods section includes paving and plating invert, sliplining, CIPP, fold and form, PVC pipe lining system, pipe bursting, joint sealing, cement mortar lining, and epoxy lining.
- j. *Policy and Guidelines for Culvert Rehabilitation Using Sliplining and Other Trenchless Techniques*. Maine DOT, February, 2004, 20 pages.
This document contains guidance for sliplining, paved inverts, CIPP, and fold and form liners.
- k. *Flexible Liner Selection Guidelines*, Virginia DOT Instructional and Informational Memorandum IIM-LD-244.1, Draft June 4, 2012. This is a short guide for selection of pipe rehabilitation methods, listing general rehabilitation categories.
- l. *Culvert Rehabilitation Practices*, Utah DOT, 20 pages.
<http://www.udot.utah.gov/main/uconowner.gf?n=1128117589169310>
This report contains brief descriptions of various culvert repair methods.
- m. *Segmental Culvert Liner Installation*, Utah DOT, 26 pages.
<http://www.udot.utah.gov/main/uconowner.gf?n=1134120956863828>
This report describes sliplining installation techniques.
- n. *Trenchless Technology Hydraulics Manual*, Oregon DOT, Chapter 16, 33 pages.
ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf

Chapter 16 of the Oregon DOT Hydraulics Manual addresses trenchless technology. It gives a brief overview of a variety of culvert repair methods. It contains tables that identify the appropriateness of the various methods with regard to depth, length, soil conditions, and pipe type. It includes a table of costs per foot for the various methods and pipe diameter.

- o. *Culvert Sleeving (Rehabilitation)*, Saskatchewan Highways and Infrastructure Technical Bulletin 2000-1, November 1, 2004, 9 pages.
This guideline discusses sliplining considerations, materials, and installation guidelines.
- p. *Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology*, VTRC 08-R16, Bridget Donaldson and Andrew J. Baker, Virginia Transportation Research Council, May, 2008.
This report discusses contamination of streams due to chemicals used with cured-in-place liners.
- q. *Project Report: Centripipe, MnDOT District 6*, Contacts: Ruth Betcher and Carl Miller, October 28, 2010.
This report describes a culvert repair using centrifugally cast concrete (CCCP) in a 36-inch diameter, 80-ft long CMP culvert near Wabasha, MN. It is a useful description of a culvert repair method that has been rarely used in Minnesota.
- r. *Culvert Failure Report and Photos*, MnDOT District 6, Ruth Betcher, 2010.
This report describes culvert failures and highlights the need to repair aging culvert infrastructure.
- s. *Pipe Repair Method: Paved Invert*, MnDOT District 1, Jon Bergstrand.
This report describes a 25+ year old paved invert repair under TH 23 east of Banning Junction, MN that is performing well.
- t. *Cured in Place Pipe (CIPP) Liner Design Considerations and Pipe Wall Thickness Design*. CIPP Corp.
This information includes CIPP liner design considerations and Excel spreadsheets for calculating CIPP liner thicknesses based on host pipe condition, depth, dead load, live load, and external water pressure, based on ASTM F1216 “Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube.”
- u. *Concept Development of a Hybrid Composite Bridge Culvert Rehabilitation System*, University of Maine Advanced Structures & Composites Center, AEWG Report 09 – 43, Project 683, May 15, 2009, 14 pages.
This report documents the development of a fiber-reinforced polymer (FRP) structural invert liner that is attached to the host pipe with shear nails and grouted.

3. Specifications

The following culvert repair specifications were collected during Tasks A and B. These will be reviewed and incorporated in the work of Task D as appropriate. Specifications that have been received, but deemed not useful are not included in the lists below.

- a. MnDOT Specifications and Special Provisions. The following specifications or special provisions were provided by MnDOT personnel. These will be useful in preparing the special provisions in Task D:
 - i. (2501) Chemical Grout
 - ii. (2501) Lining Culvert Pipe
 - iii. (2501) Repair Culvert Joint
 - iv. (2506) Repair Drainage Structure
 - v. (2507) Culvert Liner
 - vi. (2519) Cellular Concrete – Controlled Low Strength Material
 - vii. (3249) Culvert Liner Materials
- b. Caltrans Specifications
 - i. 15-6.02 Fill Culvert Voids
 - ii. 15-6.03 Contact Grouting
 - iii. 15-6.04 Concrete Invert Paving Invert
 - iv. 15-6.10 Plastic Pipe Liners
 - v. 15-6.11 Cured-in-Place Pipeliners

- vi. 15-6.12 Deformed and Reformed HDPE Liner
- c. Maine DOT Specifications
 - i. Section 603 Culvert Sliplining (Plastic Pipe)
 - ii. Section 502 Annular Space Grouting
 - iii. Section 502 Structural Concrete Culvert Invert Lining
 - iv. Section 502 Structural Concrete Culvert Invert Lining (Shotcrete)
 - v. Section 509.73 Composite Invert Lining Option (Furnishing and Installing Composite Invert Liner)
 - vi. Section 502 Structural Concrete Culvert Invert Lining (Cast-in-Place Method) – Smyrna Dunn Brook Bridge Project
 - vii. Section 502.325 Structural Concrete Culvert Invert Lining (Composites Method) Smyrna Dunn Brook Bridge Project
 - viii. Section 502 Structural Concrete Culvert Invert Lining (Shotcrete Method) Smyrna Dunn Brook Bridge Project
- d. Michigan DOT
 - i. Cured-in-Place Pipe For Culverts and Storm Sewers
 - ii. HDPE Culvert Rehabilitation Liner
 - iii. Pipe Bursting Culvert Rehabilitation
 - iv. Culvert Joint and Crack Sealing
 - v. Chemical Pipe Joint Grouting for Sewers and Culverts
- e. Missouri DOT
 - i. Section 735 Culvert Pipe Liner
 - ii. Section 1046 Pipe Liner
- f. New York DOT
 - i. Revisions to Standard Specifications 602- Rehabilitation of Culvert and Storm Pipe
- g. Ohio DOT
 - i. Supplemental Specification 837 Liner Pipe, April, 2008.
- h. Oregon DOT
 - i. Section 00446 Culvert Installation by Pipe-Bursting
 - ii. Section 00410 Pipe Lining
- i. Texas DOT
 - i. TxDOT 659-51-50 Liner Pipe, Polyethylene, June, 2009.
- j. Virginia DOT
 - i. Special Provisions for Pipe Culvert Replacement or Rehabilitation, Draft May 1, 2012.
This specification contains requirements for smooth wall and corrugated steel pipe liners and flexible pipe liners.
- k. Supplier and Contractor Specifications
 - i. Cured-In-Place (CIPP) Lining of Existing Sewers. CIPP Corp.
- 4. Drawings

The following culvert repair drawings were collected during Tasks A and B. These will be reviewed and incorporated in the work of Task D as appropriate. Drawings that have been received, but deemed not useful are not included in the lists below.

 - a. Maine DOT. These drawings contain invert lining details.
 - i. Amherst Hancock County West Branch Bridge, State Project 15642.00. Fish Weir Details
 - ii. T4 Indian Purchase Highway Rehabilitation, State Project 15646.00. Invert Rehabilitation with Fish Weirs

- iii. Smyrna Aroostook Dunn Brook Bridge, Federal Aid Project No. STP-1787 (800)X. Invert Lining Details
5. Cost Data. Very little cost data was obtained in Tasks A and B. MnDOT and other DOT bid results could be mined for this information. The cost data collected is listed below:
- a. The City of Duluth, MN provided bid prices for CIPP projects in 2011.
 - b. Four Minnesota counties provided bid prices sliplining projects between 2009 and 2011.
 - c. Culvert Pipe Liner, Admin Minnesota, Materials Management Division, Contract Release: C-592 (5), March, 2011.
This contract release contains pricing for both groove press-on joint and threaded joint high density polyethylene (HDPE) pipe liner material.
 - d. *Trenchless Technology*, Hydraulics Manual, Oregon DOT, Chapter 16, 33 pages.
ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf
Chapter 16 of the Oregon DOT Hydraulics Manual addresses trenchless technology. It includes a table of costs per foot for the various methods and pipe diameter.

Culvert Repair Methods Recommended for Preparation of Specifications and Drawings

Based on the originally proposed scope and the results of Tasks A, B, and C, we recommend that the following be prepared in Task D:

- 1. Best Practices Guidelines. The Best Practice Guidelines will address the following major methods and submethods of culvert repair. A flow chart or other form of decision tree will be created.
 - a. Replacement using open cut methods.
 - b. Replacement using trenchless methods. Common methods :
 - i. Pipe jacking
 - ii. Augering
 - iii. Directional drilling
 - iv. Pipe bursting
 - c. Repair of existing culvert:
 - i. Cured in place liner (CIPP).
 - ii. Sliplining
 - iii. Paved invert
 - iv. Joint repair methods
 - v. Spincast concrete liner
 - vi. Resetting and tying end sections
 - vii. Crack sealing
 - viii. Spall repair
 - ix. Filling voids outside the culvert
- 2. Specifications and details will be prepared for the following methods. These were identified as the most commonly used methods and had a relatively large amount of previously prepared information.
 - a. Cured in place liner (CIPP).
 - b. Sliplining and grouting of annular space between culvert and slipliner
 - c. Paved invert
 - d. Joint repair methods
 - e. Spincast concrete liner
 - f. Spall repair
 - g. Filling voids outside the culvert