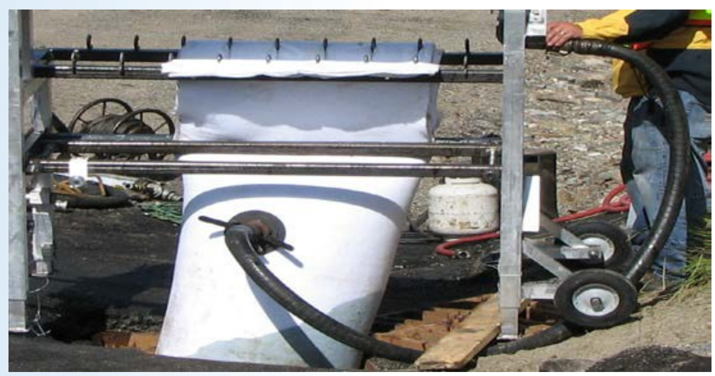
Montana Demonstration Project: Innovative Culvert Rehabilitation Using Trenchless Technologies

Final Report
June 2009

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.



U.S.Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. “Innovations” is an inclusive term used to encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community’s culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decisionmakers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is available at www.fhwa.dot.gov/hfl.

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16. Abstract
As part of a national initiative sponsored by the Federal Highway Administration (FHWA) under the Highways for LIFE (HfL) program, the Montana Department of Transportation (MDT) was awarded a grant to demonstrate the use of trenchless technologies in rehabilitating 10 deteriorated culverts on U.S. 12 over MacDonald Pass in Powell and Lewis and Clark Counties. This report documents the entire work effort, including the use of two innovative techniques to rehabilitate the corrugated steel pipe culverts. These innovative techniques included a cured-in-place pipe (CIPP) lining and a sliplining system using high-density polyethylene pipe (HDPEP) liners.

The rehabilitation effort was a great success. By using trenchless technologies, MDT was able to perform the work without closing any lanes or interfering with traffic flow. The benefits of using CIPP and HDPE included the following:

- Virtually eliminated traffic delays and lane closures
- Provided a safer environment for the traveling public and workers by eliminating exposure to traffic and construction activities
- Potentially improved quality because work was done in a controlled environment
- Eliminated costs associated with traffic control and roadway excavation
- Attained user satisfaction.

17. Key Words
CIPP, cured-in-place pipe, HDPE, high-density polyethylene, Highways for LIFE, innovative culvert rehabilitation, sliplining, trenchless technologies

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ACKNOWLEDGMENTS

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway Administration Highways for LIFE Team Leader Byron Lord and Program Coordinators Mary Huie and Kathleen Bergeron, who served as the Technical Panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team also is indebted to Jeff Patten of the FHWA Montana Division for his effective coordination effort, and to Montana Department of Transportation Project Manager Jim Divies and Craig Abernathy Research Project Manager, who provided construction information that shaped this report and was instrumental in making this HfL project a success.

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ABBREVIATIONS AND SYMBOLS

ADT	average daily traffic
CIPP	cured-in-place pipe
CSP	corrugated steel pipe
dB(A)	A-weighted decibel
DOT	department of transportation
FHWA	Federal Highway Administration
HDPEP	high-density polyethylene pipe
HfL	Highways for LIFE
IRI	International Roughness Index
NHS	National Highway System
MDT	Montana Department of Transportation
OBSI	on-board sound intensity
OSHA	Occupational Safety and Health Administration
PVC	polyvinyl chloride
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—may provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than $5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how agencies can manage the highway project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications in fiscal years 2006, 2007, 2008, and 2009. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, and contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management Team; the Division offices; and the HfL team. After evaluating and rating the applications and supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
  - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
  - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
  - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.

- **Construction Congestion**
  - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
  - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
  - Queue length during construction—A moving queue length of less than 0.5 mile (mi) (0.8 kilometer (km)) in a rural area or less than 1.5 mi (2.4 km) in an urban area (in both cases, at a travel speed 20 percent less than the posted speed).

- **Quality**
  - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.

- Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

- **User Satisfaction—**An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a rating of 4 or more points on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Montana Department of Transportation's (MDT) HfL demonstration project, which involved rehabilitation of 10 24-inch (in) (609.6-millimeter (mm)) corrugated steel pipe (CSP) culverts using innovative trenchless technologies. MDT managed to rehabilitate these culverts without closing any lanes and without interfering with the flow of traffic. The report presents project details relevant to the HfL program, including the use innovative, rapid culvert rehabilitation techniques using trenchless technologies, description of the materials and methods used in the process, HfL performance metrics measurement, and an economic analysis.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

Ten of the corrugated steel pipes under U.S. 12 near Helena were in poor structural condition with deteriorated inverts and badly in need of replacement. Sand and debris were accumulating in these culverts, reducing their capacities and requiring constant care by maintenance forces. The poor condition of the culverts prompted MDT to take immediate mitigating measures. MDT had two options to address the problem. Option 1 was to excavate and replace the culverts, which would have required lane closures that interfered with traffic flow. Option 2 was to reline the culverts using trenchless technologies without impeding traffic flow. After exploring the two alternatives and evaluating project and user costs, MDT selected the trenchless technologies to rehabilitate the culverts under U.S. 12. The rehabilitation strategies included the following innovative techniques:

- Cured-in-place pipe (CIPP) lining system, a trenchless rehabilitation technique used to restore structural integrity of the existing deteriorated pipes with a seamless, jointless liner. Five of the 10 culverts were rehabilitated using the CIPP methodology.

- Sliplining system, a simple technique consisting of inserting a new smaller diameter pipe, normally made of polymeric, thermoplastic-type material, into a deteriorated culvert and filling the annular space between the existing culvert and the new liner with cementitious materials. The five remaining culverts were rehabilitated using the sliplining system.

By using trenchless technologies, MDT virtually eliminated the need for lane closures, thereby eliminating traffic congestion due to the work zone and the costs associated with maintenance and protection of traffic control and roadway excavation. The use of the CIPP system and high-density polyethylene pipe (HDPEP) liners substantially improved safety for both the traveling public and workers in the work zone by eliminating the roadway users' exposure to construction activities. The new pipe linings improved the structural integrity of the pipes while maintaining similar hydraulic capacities and improved passage of sediments through the pipes.

DATA COLLECTION

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to demonstrate that trenchless technologies can be used to achieve the HfL performance goals in these areas.

No worker injuries or motorist incidents were reported during construction, which means MDT exceeded the HfL requirements for worker safety. No motorist incidents have been reported since the rehabilitation of the pipes.

Although the quality of the pipes' rehabilitation potentially was improved because the work was done in a controlled environment, the rehabilitation process had no impact on the quality of the pavement surface with respect to noise and smoothness. The existing corrugated culverts trapped sediment at the bottom of the culverts. Both CIPP and HDPEP liners provide a smooth surface, which enhances the flow of the sediments through the culvert to the sediment basins at the outfall and maintains similar hydraulic capacities.

The HfL performance goal criteria for construction congestion were attained , as the project had no impact on traffic flow since the work was done beyond the shoulder edge. Traffic was continuous during culvert rehabilitation, with no impact on trip time or queue length through the construction zone.

ECONOMIC ANALYSIS

The benefits and costs of using the innovative trenchless technologies to rehabilitate the deteriorated culverts were compared with the traditional excavation and replacement approach. Although the cost of using liners was higher for this project, it was the first time MDT used such innovative features in rehabilitating pipes. As a result, the agency did the project on a highway with a lower average daily traffic (ADT) to gain experience. In higher trafficked areas, where lane closures and traffic delays are not permitted, the trenchless technology could totally eliminate interference with traffic flow and be economically feasible by resulting in much lower user costs.

LESSONS LEARNED

Because of the success of this project, MDT plans to use trenchless technologies more routinely to rehabilitate deteriorated pipes, especially on heavily trafficked highways where lane closure would adversely affect community residents and businesses.

Public Involvement

Based on the survey questionnaire returned, it appears that most of the traveling public on U.S. 12 did not notice the rehabilitation of the pipes because the construction activities were inconspicuous.

CONCLUSIONS

The rehabilitation of the deteriorated culverts using trenchless technologies was a great success. MDT easily met the HfL performance goals on the safety of motorists and workers, construction congestion, quality, and user satisfaction. By using CIPP and HDPEP liners, MDT was able to repair all 10 of the deteriorated culverts effectively in a matter of hours instead of days, without excavation of the roadway, and with no traffic flow interference.

PROJECT DETAILS

BACKGROUND

Using trenchless technologies to rehabilitate deteriorated culverts is gaining popularity because it provides transportation agencies with a versatile, cost-effective alternative to traditional culvert rehabilitation methods. By incorporating culvert liners, these technologies allow an agency to repair aging concrete or metal culverts cost effectively in hours instead of days, without excavating the roadway, and with little or no disruption to traffic flow. Generally speaking, there are five trenchless methods of rehabilitating culverts:

1. Sliplining
2. Close-fit lining
3. Spirally wound lining
4. CIPP lining system
5. Spray-on lining

As part of the HfL demonstration project, MDT used two methods—sliplining and CIPP lining systems—to rehabilitate deteriorated culverts on U.S. 12 near Helena. For the sliplining method MDT used seam-welded HDPEP, and for the CIPP lining it used resin-impregnated polyester felt.

PROJECT DESCRIPTION

The project involved rehabilitating 10 24-in (609.6-mm) CSP culverts along a 10-m (16-km) stretch of U.S. 12 in Powell and Lewis and Clark Counties over MacDonald Pass near Helena (see figure 1). U.S. 12 at this location is a mountainous, undivided four-lane National Highway System (NHS) roadway with an ADT of 2,670 and 12.1 percent trucks.

The poor structural condition of the culverts at this location prompted MDT to rehabilitate them in a manner that did not interfere with the flow of traffic. MDT used two innovative methods, CIPP and HDPEP liners, to achieve this goal. Five culverts were rehabilitated using the CIPP lining system, and the other five were rehabilitated using HDPEP liners. The locations of these culverts and the treatments they received are shown in table 1.

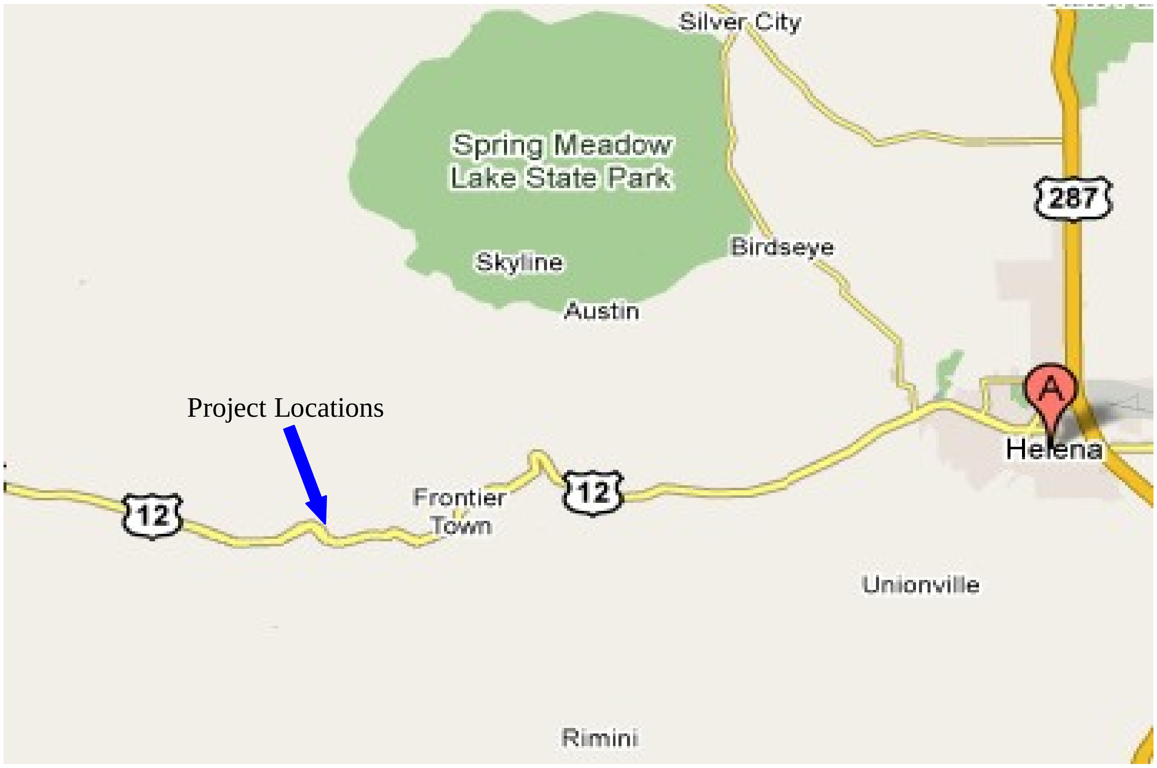

Figure 1. View of the project site.

Table 1. CIPP and HDPE site locations.

Method	Stationing
1. HDPE	184+18
2. HDPE	189+47
3. CIPP	194+99
4. CIPP	199+97
5. CIPP	206+44
6. HDPE	209+71
7. CIPP	213+29
8. HDPE	216+98
9. CIPP	221+61
10. HDPE	230+58

Sliplining

Sliplining is a simple technique consisting of inserting a new pipe, normally made of a polymeric, thermoplastic-type material, into a deteriorated culvert. Liners are inserted into the existing culverts either by pulling or pushing. After insertion, the annular space between the existing pipe and the new liner is filled with a relatively slow flow rate cementitious grout material. This method of rehabilitating culverts provides a versatile and cost-effective alternative to traditional excavation and replacement. If installed properly, the sliplined pipe functions like a new installation. Several different lining materials can be used in sliplining, including high-density polyethylene, polyethylene, polypropylene, polyvinyl chloride (PVC), and ethylene propylene diene monomer. For this project, MDT used 18-in (457-mm) outside diameter HDPEP with a smooth interior and exterior and a wall thickness of about 0.75 in (19 mm). Before the pipes were inserted, debris was removed from the existing pipes (figure 2) using a high-pressure jet wash and a truck-mounted vacuum, as shown in figure 3.

Figure 2. Existing condition of a typical culvert at the project site.

Figure 3. Cleaning and removal of debris from the existing CSP.

The HDPEP sections were delivered to the job site in 25-foot (ft) (7.6-meter (m)) segments. The pipe sections were welded together to a proper length using a device called a plastic pipe fuser (figure 4). Before the fusing phase, the ends of the pipes were trimmed with a special rotary cutting tool equipped with three razors to remove any imperfections, dirt, or grease and ensure a good-quality weld.

Figure 4. View of the pipe fuser apparatus.

Next, a preheated round electric iron with an average temperature of 425 degrees Fahrenheit (°F) (218 degrees Celsius (°C)) was placed between the two pipe sections (figure 5). The pipes were compressed against the heated iron for about 2 to 3 minutes until the pipes started to melt and form a circular bead (figure 6).

The size of the bead indicates when the HDPEP is at the temperature required to fuse the pipe sections. The ends are allowed to cool in place and, depending on the ambient temperature, the average time to complete the weld ranges from 15 to 20 minutes. According to the manufacturer's specifications, a properly fused seam is structurally stronger that the pipe itself.

After all the sections were fused together to a proper length, spacers were attached along the pipe at intervals of 8 to 10 ft (2.4 to 3 m). The primary purpose of the spacers is to facilitate efficient insertion of the new pipe and placement of the cementitious grout, which was pumped between the existing CSP and the new liner. Figure 6 shows the formed bead after fusion and the spacers. Figure 7 shows the welded pipe liner ready for installation.

Before the liner was inserted, a PVC tube was attached along the entire length of the pipe to allow pumping of the cementitious grout material from the pumping station. As the grout was pumped, completely filling the space between the liner and the existing pipe, the PVC tube was pulled back slowly until the grouting was complete. Figure 8, 9, and 10 illustrate the operation.

The grout, which was made of a low-density cellular material had a compressive strength specified between 100 and 300 psi. The primary purpose of the lining was to restore the structural integrity of the pipes. However, it was also important to maintain the hydraulic capacity of the pipes. According to the Montana DOT's Research Project Manager, two of the pipes were completely cologged and several were filled with debris reducing the capacity anywhere from 30 to 40 perceent.

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Figure 5. View of the preheated iron during the fusion process.

Figure 6. View of the welded pipes and spacers.

Figure 7. View of the welded HDPEP liner ready for installation.

Figure 8. Pulling the liner and PVC tube into the existing pipe.

Figure 9. View of the pumping apparatus.

Figure 10. Fully installed HDPEP and the cementitious materials.

Cured-In-Place Pipe

The CIPP lining system is used to restore the structural integrity of deteriorated pipes with a seamless, jointless liner. Similar to sliplining, CIPP does not interfere with the flow of traffic because it does not require work zone traffic control. The lining does not come in standard sizes, but is designed specifically for the individual pipe to be rehabilitated, with variable diameters and shapes (e.g., round, elliptical, oval) and wall thicknesses.

When necessary, a minimum liner thickness is specified to provide resistance in abrasive conditions and to improve the longevity of the liner. Unlike sliplining, no grouting is required because there is no annular space between the existing culvert and the liner. The CIPP liner system creates a close-fit “pipe within a pipe” that conforms to the contour of the inside surface of the existing culvert and, for the most part, retains the original culvert’s capacity.

The CIPP liner installation at MacDonald Pass involved inserting resin-impregnated polyester felt into the existing pipes through an inversion process. The resin impregnation was done offsite at the installer’s facility, and the liner was placed in a refrigerated truck for delivery to the job site (figure 11).

Figure 11. View of the refrigerated truck and the liner.

Since curing begins as soon as the resin is applied, it is imperative to keep the resin-impregnated polyester at temperatures below 20 °F (6.6 °C). This retards the setting process until the liner is ready for insertion and final curing. Inversion is achieved using either compressed air or pressurized water. For this project, compressed air was used in installing all CIPP liners.

The following procedures and materials were used in relining the culverts for this project:

- The CIPP liners, specified to proper length and diameter by MDT, were delivered to the jobsite in a refrigerated truck. Several layers of ice bags were placed on the truck bed to ensure the temperature of the liner was kept low enough to impede setting until the steam curing phase.

- The nonresin-impregnated liner system has three separate layers, with the outer layer having a denser weave than the two inner layers. Once cured, all layers are bonded together, forming a monolithic layer that becomes the new interior surface of the existing culvert. Figure 12 shows a closeup of the three layers of the nonresin-impregnated polyester.

Figure 12. Closeup of the nonimpregnated polyester liner.

- A propane heated core was used to place a 3-in (76.2-mm) diameter hole in the liner, for attaching a bracket and an air hose to the liner (figure 13). In preparation for installation, the contractor cut slots in the liner layers to be hooked onto the inversion apparatus, facilitating the inversion of the liner. All five CIPP liners were inserted at the intake or upstream ends of the culverts.

Figure 13. Inserting a circular hole into the liner using a heated core.

- The inversion apparatus is equipped with two rows of hooks to hold the liner in place while the liner is pressurized for its travel through the existing CSP culvert. Figure 14 shows the process of attaching the liner to the hooks of the inversion apparatus.

Figure 14. View of the inversion apparatus.

- To invert and force the liner through the CSP culvert, compressed air at an average pressure of 12 pounds per square inch (psi) (82.7 kilopascals (kPa)) was applied through the bracket into the liner. Figure 15 shows application of the compressed air and a completely inverted liner at the culvert's intake.

- Figure 16 shows a fully exited liner at the culvert's outlet releasing the air pressure, which had forced it through the culvert (see the yellow arrow). Since the liner was inverted at the culvert's intake, it provided a natural plug through the entire inversion process.

- Once fully deflated, as shown in figure 17, the liner was ready for the curing phase. On average, for a 130-ft (39.6-m) CSP culvert like the ones at MacDonald Pass, it takes about 30 minutes to invert the liner from the intake to the outlet of the culvert.

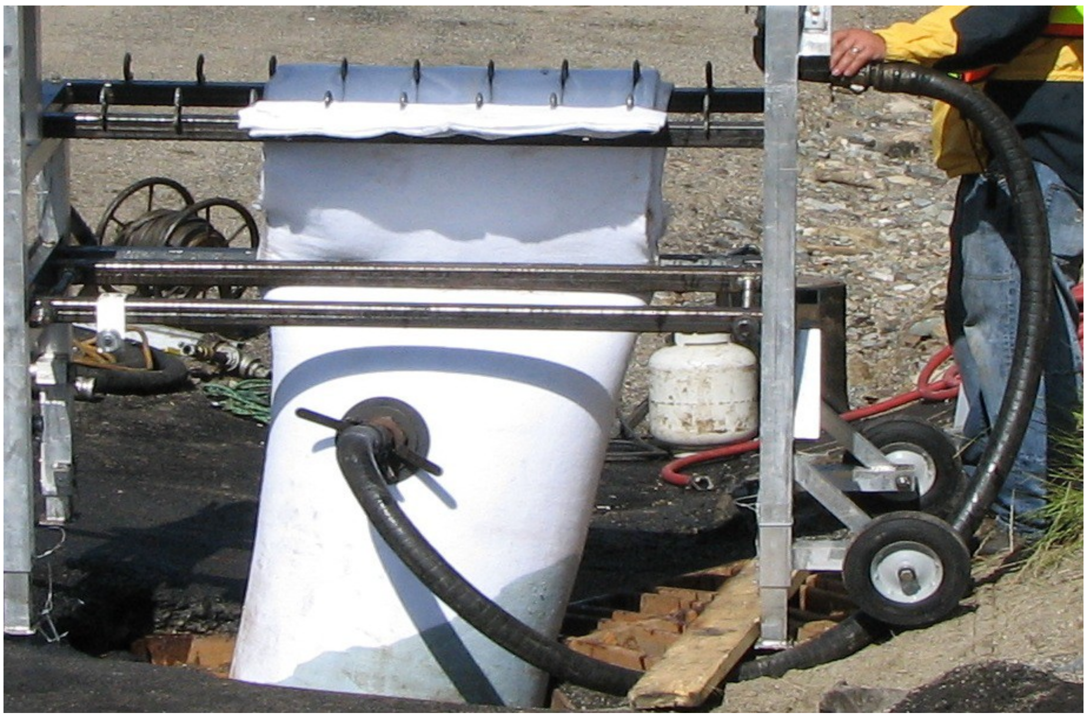


Figure 15. Closeup view of compressed air application and fully inverted liner.

Figure 16. Fully exited liner at the outlet end.

Figure 17. Fully deflated liner at the outlet.

- The next step in the operation, the curing phase, entails the application of air and steam. A large-diameter rubber plug was placed inside the liner at the outlet. The plug was equipped with two connections, which allowed attachment of an air line (red arrow) and steam line (yellow line). Figure 18 shows the rubber plug attached to the air and steam lines.

- Air was applied to inflate the liner to conform to the interior of the existing CSP culvert. Once fully expanded, steam was applied at an average temperature of 235 °F (112.7 °C) and at a rate of about 5 psi (34.4 kPa).

- Figure 19 shows steam exiting at the intake end of the culvert. Curing can take place at ambient temperature, but using steam can accelerate the curing time. Applying steam reduces the curing time from several weeks to 1.5 hours.

- A close-up view of a fully cured CIPP liner is shown in figure 20. All three polyester layers of the liner are bonded, forming a composite monolithic rigid layer with an average thickness of 0.625 in (15.8-mm).

Figure 18. View of the rubber plug with air and steam line connections.

Figure 19. View of steam exiting at the intake end of the culvert.

Figure 20. View of a fully cured CIPP.

- After the application of the steam, the CIPP was allowed to cool. The rubber plug was removed, and the excess CIPP at the intake and outlet was trimmed to a proper length.

- Fiber meshed grout was used to seal the interface of the CIPP liner and the existing culvert at its intake and the outlet ends (figure 21).

- As shown in figure 22, the installation of the CIPP liner was monitored and inspected remotely by a tractor-mounted closed-circuit television camera to ensure proper placement.

Figure 21. View of a fully installed CIPP liner (Note intimate contact of the liner with the pipe).

Figure 22. Remote monitoring and inspection.

DATA ACQUISITION AND ANALYSIS

Data collection and analysis on the MDT project consisted of acquiring and comparing data before, during, and after construction to provide sufficient performance information to support the feasibility of the proposed innovation and to demonstrate that innovative trenchless culvert rehabilitation technologies can be used to do the following:

- Achieve a safer environment for the traveling public and workers.
- Reduce construction duration and minimize traffic interruptions.
- Achieve better quality because work is done in a controlled environment.
- Attain user satisfaction.

SAFETY

The traditional culvert removal and replacement process involves excavating the roadway and removing the existing culvert, which requires lane closures and traffic control while pipes are being removed and replaced. This causes significant traffic disruption and exposes both the traveling public and workers in the work zone to safety hazards. One attribute of trenchless technologies is that they do not require lane closures during installation. As a result, these technologies provide no impact to traffic flow and a substantially safer environment for both the traveling public and workers.

Figure 23 shows a roadway during culvert rehabilitation using CIPP. No worker injuries or highway user incidents were reported during the rehabilitation of the culverts on MacDonald Pass. Overall, MDT exceeded all the safety performance goals set by HfL.

Figure 23. Typical CIPP liner installation.

CONSTRUCTION CONGESTION

The HfL performance goal criteria for construction congestion were easily attained because the project had no impact on traffic flow. All work was accomplished beyond the outside edge of the shoulders.Traffic was continuous during culvert rehabilitation, with no impact on trip time or queue length in the construction area.

QUALITY

The IRI and the tire-pavement interface noise at the project site were not impacted because innovative trenchless technology was used to rehabilitate the CSP culverts without disturbing the driving surface. Both CIPP and the HDPEP liners improve the structural integrity of the existing culverts and have a life expectancy beyond 50 years. The new lining system provides a smooth surface that reduces abrasion, enhances the flow of sediments through the culvert to the sediment basins, and maintains the culvert's hydraulic capacity. Cleaning the new catch basins will be easier, requiring less equipment and fewer workers than cleaning the bed load from the existing approximately 130 ft. long CSP culverts.

USER SATISFACTION

Because the trenchless culvert rehabilitation techniques did not interfere with traffic flow, MDT received no negative comments from the traveling public about the project and perceived that the public did not notice any work being done during the culvert rehabilitation process. Therefore, MDT's score for user satisfaction on a Likert scale is greater than 4 for both the approach used to rehabilitate the culverts and the final product. A questionnaire developed by MDT was sent to residents; for the results of the user satisfaction survey, see Appendix A.

ECONOMIC ANALYSIS

Based on the information furnished by MDT, the cost for the innovative trenchless technologies used on this project were about $75,000 higher than the costs for traditional subexcavation and pipe replacement. Because this was the first time MDT employed such innovative features to rehabilitate pipes, the agency chose a project on a highway with lower ADT to gain experience. In higher trafficked areas where lane closures and traffic delays are not permitted, the trenchless technology could eliminate interference with traffic flow and be economically feasible by resulting in much lower user costs.

For this economic analysis, MDT supplied the costs for both methods of rehabilitating the pipes, as shown below.

Estimated Cost for Subexcavation and Replacement

1,419 linear feet (LF) of 24-in drainpipe at $85.00/LF		= $120,615.00
322.2 yd^3 of CBC at $30.00/$yd^3$		= $ 9,666.00
83.4 tons of commercial plant mix at $125/ton		= $ 10,425.00
20 days of traffic control at $2,500/day		= $ 50,000.00
Road user cost		= $ 3,500
	Total	**= $194,206.00**

Actual Costs for Pipe Lining

661 LF 24-in pipe liner at $190/LF		= $125,590.00
758 LF 18-in pipe liner at $190/LF		= $144,020.00
Traffic control (two temporary signs)		= $ 14.00
	Total	**= $269,624.00**

APPENDIX A: USER SATISFACTION SURVEY

A questionnaire consisting of four questions was sent to 151 residents around the project construction:

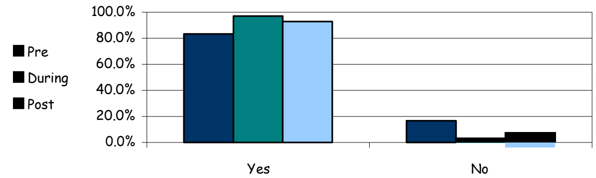
1. Have you traveled MacDonald Pass during the recent construction?
2. Was traffic control easy to follow through the construction zone?
3. Did traffic control seem safe?
4. Please rate your overall travel experience through the construction zone.

Ninety-seven questionnaires were returned (about a 63 percent rate of return). The figures and tables on the following page document the results of surveys before, during, and after construction. Also included are the comments received from all respondents.

2008 MacDonald Pass Construction Survey Results

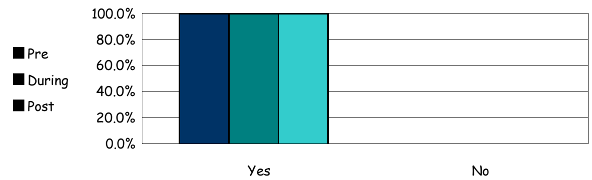
1. Have you traveled MacDonald Pass during the recent construction?

	Pre		During		Post	
Yes	30	83.3%	32	97.0%	26	92.9%
No	6	16.7%	1	3.0%	2	7.1%
Total Responses	36		33		28	
Mean	1.17		1.03		1.07	
Standard Deviation	0.38		0.17		0.26	



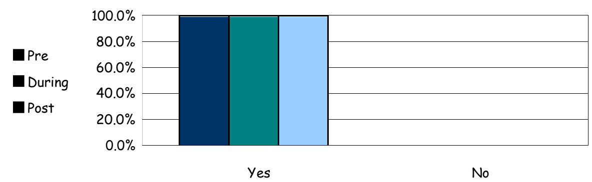
2. Was traffic control easy to follow through the construction zone?

	Pre		During		Post	
Yes	30	100.0%	31	96.9%	25	100.0%
No	0	0.0%	1	3.1%	0	0.0%
Total Responses	30		32		25	
Mean	1.00		1.03		1.00	
Standard Deviation	0.00		0.18		0.00	



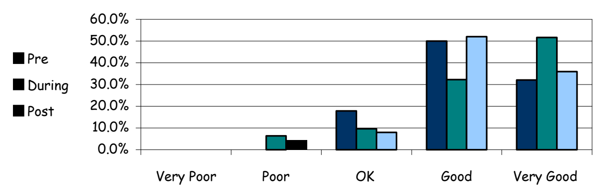
3. Did traffic control seem safe?

	Pre		During		Post	
Yes	29	100.0%	32	100.0%	25	96.2%
No	0	0.0%	0	0.0%	1	3.8%
Total Responses	29		32		26	
Mean	1.00		1.00		1.04	
Standard Deviation	0.00		0.00		0.20	



4. Please rate your overall travel experience through the construction zone.

	Pre		During		Post	
Very Poor	0	0.0%	0	0.0%	0	0.0%
Poor	0	0.0%	2	6.5%	1	4.0%
OK	5	17.9%	3	9.7%	2	8.0%
Good	14	50.0%	10	32.3%	13	52.0%
Very Good	9	32.1%	16	51.6%	9	36.0%
Total Responses	28		31		25	
Mean	4.14		4.27		4.20	
Standard Deviation	0.71		0.90		0.76	



Special Notes:
The response rate from this mailed survey was 63.4% (51 sets of surveys mailed, with 97 surveys returned).
The population of regular drivers who travel on MacDonald Pass during a given time is unknown and the number of surveys distributed/collected is small, so it cannot be said if this sample is representative of the MacDonald Pass driver population.

Comments Before Construction

1. The only construction that I'm aware of so far has been the highway painting. I didn't drive the pass during that work.
2. I went over the pass on June 4, but did not notice any construction at that time.
3. I've traveled over the pass quite a bit, but didn't see any construction.
4. Drove the pass on 6/11/08, we had lots of snow but the road was not plowed at all, multiple accidents. Also the advisory sign always says drive safely and buckle up rather than updates on the road condition (for the past 2 years by the way).
5. Remove signage when construction is completed. Seems like signage is up sometimes and no work.
6. There was 1 day where it wasn't clear that up ahead were workers, even though there were markers on the road.
7. Intrusion is minimal and speed zone is reasonable…nothing more frustrating than <u>MILES</u> at 45 mph when you're only repairing a couple hundred feet of bridge.
8. It was just fine. No particular problems at all.
9. The only recent construction I recall was the tree removal. The portion across from Frontier Town was in a tricky area for cars headed east. As I recall it is a sort of blind curve until you are right on it. Anyway, it seemed well marked and as safe as you could make it for drivers who are paying attention. Thanks for asking. I live west of Helena and travel the pass 2-3 times weekly.
10. I haven't seen any culvert work yet. Right now the work crews are putting up railing. Could you replace the reflectors also? In a snow storm up there, sometimes that is how I see to stay on the road.
11. This response related only to the west side of pass with blacktop crack repair. It might be good to have electronic signs tell of construction ahead and speed limits.
12. All in all, very smooth construction project. Surprisingly easy!
13. Traffic seemed to move pretty smoothly but the speed limit signs seemed to be up when no work was being done.

Comments During Construction

1. I recently traveled the pass but saw no construction, but saw signs. I guess that's great.
2. MDT staff and highway contractors do a superior job. Thank you.
3. The construction workers deserve congratulations on their speedy work and good job.
4. I did not encounter any construction, only the warning signs.
5. I just have to remember to leave earlier to allow for construction/delays.
6. We had no problems getting through.
7. That was a loooooong construction zone from the base of the pass to Avon and when you were chip sealing! Also why the long zone near the bridge over the river and railroad track approaching Garrison? I've been through there 6 times lately and there has either been no construction or only very little.
8. Please consider restricting one lane traffic to down grades. The heavy truck, camper and motor home traffic on Mac Pass results in 15-25 mph commutes.
9. Traffic was slow and was stopped for more than 20 minutes.

10. The new guardrails look spindly and the end cap (not the black and yellow side) startles me some mornings. In a certain light it looks like a deer. Just the one at the far end going east on the west side of the pass.
11. All things considered, the traffic flow was good.
12. Keep the speed low rather than low, resume normal and 5 minutes later low again!
13. Really concerned about new metal guardrail after being in a head-on wreck and the heavier past guardrail saved me from going over the ledge. I am concerned about this experimental metal guardrail. Thanks to the Mac Pass road crew! They do an exceptional job keeping roads cleared and travelable.
14. I travel at night regularly so I am anxious to see if visibility of the guardrails is better during whiteouts. I depend on reflectors to stay on the road!
15. The new guardrails and reflectors are wonderful. Thanks!
16. I think everything has been handled as well as it could!
17. DOT does a great job!
18. Didn’t experience any delays. Traveling by motorcycle and still was safe, easy trip.
19. I know this is not the proper forum, but there are some nasty holes right in the drive grooves—front end work could be costly.
20. Keep up the good work

Comments After Construction

1. Thanks!
2. I have traveled the pass, but <u>still not seen</u> construction! What construction?!
3. I sat there for 45 minutes wasting gas waiting for the pilot car.
4. Flaggers were very polite. Delays were short.
5. MDT does a great job! Thanks!
6. Slow down zone near bridge over railroad seems excessively long on the Avon end. I have noticed many drivers ignoring the speed reduction, I suspect because they don’t see a risk.
7. I go early enough that sometimes the crew is just setting up.
8. Some people were passing in the work zone near the bridge when it was 45 mph. Suggest “no-passing area” as vehicles were moving slow and pulling out.
9. It is a fine job, actually.
10. Sand on road in between wet and dry days seems excessive and poses other hazards if not cleaned up quickly.
11. No construction?
12. It wasn’t as big of a project as I thought it would be—not much inconvenience at all!
13. When there was another road turnoff from the highway it was hard to tell if you were to stay in the same lane or move to the next lane. Keep the speed the same from the start to the end of the construction, not 35, 60, back to 35 and then 60 again.
14. We thought there would be more work than was done—so was minimal (paving??)—we’re thinking the paved ditches will cause more rock to roll onto highways (not stopped by soft ground)—given we’ll find out as we observe.