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IN-SITU CULVERT REHABILITATION: SYNTHESIS STUDY AND FIELD EVALUATION

Prepared For:

Utah Department of Transportation
Research Division

Submitted By:

The Utah Water Research Laboratory
Utah State University

Authored By:

Travis Hollingshead
Dr. Blake P. Tullis

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RESEARCH



Utah Department of Transportation - Research Division
4501 South 2700 West, Box 148410 - Salt Lake City, Utah 84114-8410

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| 16. Abstract This synthesis study evaluated culvert rehabilitation (repair) methods involving trenchless technologies that may be appropriate for use in Utah. This report is not intended as a replacement for installation manuals provided by the manufacturers but rather provides a brief description of each method, installation procedures, and highlights the advantages and disadvantages of each. Segmental lining is cost effective in Utah and the most common method of culvert rehabilitation in most western state highway culverts. Cured-in-place pipe and fold-and-form methods are also common but the costs are higher than segmental lining. DOT maintenance personnel can often carry out segmental lining, while contractors with specialized skills and equipment are required for all other methods. This report also presents a survey of culvert relining project costs (western states) and a discussion on burial depth limitations and end treatments. The information provided was obtained through a literature review, surveys of various western State DOTs and interaction with the Utah Department of Transportation (UDOT). A flip chart and installation video were developed for segmental lining as part of this study, with the majority of effort coming from UDOT personnel. Table 1 at the end of the report summarizes the main disadvantages, advantages, and limitations for each culvert relining method. | | | | | |
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1.0 Executive Summary

A review of six trenchless culvert relining technologies or methods (i.e., segmental lining, fold-and-form, cured-in-place, cement-mortar spray-on lining, deformed-reformed, and spiral-wound liner) with potential for application in the state of Utah is presented in this report. It also includes maximum culvert relining size, liner material types, culvert length limits, installation requirements (e.g., specialized training and/or equipment), cost, maximum burial depths, and general advantages and disadvantages for each rehabilitation method. As there are distinct advantages and disadvantages associated with each method, the culvert rehabilitation method best suited for individual projects will vary by project. The aim of this synthesis report is to provide designers and project managers with a general culvert relining knowledge base to aid in the decision making process.

Based on a cost survey of culvert relining projects in Utah and surrounding states, segmental lining is typically the least expensive relining method of the six reviewed. No specialized equipment is required and most department of transportation (DOT) maintenance crews can be trained to do the work. In an effort to aid in the training of segmental-liner installation crews, UDOT and Utah State University personnel produced a training video and pocket-reference flip chart, which are available at <http://udot.utah.gov>. Relative to segmental lining, fold-and-form and cured-in-place methods are preferable when the host or existing culvert contains bends, pipe offsets due to misaligned joints, junctions, or when the cross-sectional area of the rehabilitated culvert needs to be maximized. Due to the relatively short history associated with culvert rehabilitation, insufficient data are available for distinguishing variations in the expected life of the different relining techniques/materials.

No data were found specific to the structural strength of relined culverts. Consequently, the new culvert direct burial depth limits associated with various western DOTs are presented for the same (or similar) materials used in relining. In general, the composite structural strength associated with a segmental lining and host culvert, joined via a grouted annular space, likely exceeds the burial depth limit of the liner's direct-burial depth. In the absence of specific relined

culvert load limit data, designing rehabilitated culvert burial depth limits based on direct-burial limits likely represents a conservative approach.

2.0 INTRODUCTION

2.1 Study Objectives

The purpose of this report is to provide pertinent information regarding trenchless culvert rehabilitation (repair) methods that may be applicable in Utah. This manual is not meant to replace the installation manual provided by the manufacturer, but rather to provide a brief description of each method, installation procedures, and highlight the advantages and disadvantages of each method. This manual was developed based on a literature review, interaction with the Utah Department of Transportation (UDOT), and survey data provided by other western DOTs. A glossary of terms can be found at the end of the report, providing definitions for the bold-face terms throughout the report.

2.2 Background

Many aging culverts in the State of Utah and elsewhere have deteriorated to the point where replacement or repair is warranted. As a rule-of-thumb, it is typically more cost effective to repair over replace when the average daily traffic exceeds 1000 vehicles, the maximum cover over a culvert is more than 4 feet, and/or the detour drive time is greater than 20 minutes (UDOT, 2008).

Prior to making a culvert replacement vs. rehabilitate decision, the structural integrity of the host pipe should be made. In many cases, if the existing or host pipe is incapable of sustaining design loads, it should be replaced rather repaired (see Figure 1).



Figure 1. Example of collapsed culvert
(www.mnr.gov.on.ca/images)

In cases where the host culvert cross-section is deformed, as shown in Figure 2A, the culvert can still be relined, particularly when using liners that adapt to the shape of the host culvert (i.e., fold-and-form or cured-in-place). A rigid-pipe segmental **liner** can also be used, however, the diameter of the new liner pipe will have to be appreciably smaller than the host culvert, relative to the original, a non-deformed, host pipe diameter (see Figure 2B), significantly reducing the discharge capacity.



Figure 2A. Deformed culvert



Figure 2B. Round culvert with rusted invert

Like traditional culverts, rehabilitated culverts can operate under inlet or outlet control depending on the culvert slope, end treatments and flow conditions. When a culvert is relined, the cross-sectional area reduces relative to the host pipe. If the slip-lined culvert is hydraulically smoother than the host pipe and operates under outlet control, the decreased flow area will likely be offset by the reduction in flow resistance, resulting in a similar discharge capacity.

If the slip-lined culvert operates under inlet control, then an improved end treatment may be required to minimize the amount of flow reduction associated with the smaller diameter inlet. Currently, most slip-lined culverts have projecting end treatments with squared off ends. Little information is currently available regarding the hydraulic characteristics of end treatments specific to slip-lined culverts; however, in many cases they may not be considerably different from traditional projecting inlets (see Figure 3).



Figure 3. Inlet of segmental-lined culvert

3.0 GENERAL CULVERT REHABILITATION

Culvert rehabilitation is typically much faster, easier, and more economical than culvert replacement, particularly when deep fills or large traffic volumes are present. Deteriorated culverts are most commonly rehabilitated by inserting a rigid-wall or flexible liner pipe inside the existing culvert barrel, with the liner held in place by either grout (rigid-wall liner) or a pressure/heat-based curing process (flexible liner). The following six culvert relining techniques represent the common methods currently applied in practice.

1. Segmental Lining
2. Spiral Wound Lining

3. Cured-In-Place Lining
4. Fold-and-Form PVC Lining
5. Deformed-Reformed HDPE Lining
6. Cement-Mortar Spray-On Lining

An overview of each method is provided in this report and summary information (e.g., liner materials and advantages/disadvantages of each technique) is presented in Table 1. Note that segmental lining is typically the only relining method that may not require a contractor with specialized training and equipment. With a minimum amount of training, DOT maintenance personnel can typically handle segmental liner culvert rehabilitation projects in-house.

Prior to relining, the project site must be cleared to provide appropriate access to the culvert inlet and outlet; the host culvert must also be cleared of debris. A vacuum truck is recommended for most culvert cleaning operations, however, a small section of pipe, capped on one end and attached to a rope via a three-point connection, can be pulled through the host culvert to remove debris (see Figure 4) if a vacuum truck is not available. If man-entry is possible and appropriate from a safety standpoint, visual inspection is recommended to check for obstacles or irregularities (e.g., misaligned joints, evidence of excessive piping, junctions, etc). Culvert cleaning should take place within a few days of relining to prevent further debris from collecting in the host culvert.



Figure 4. Optional cleaning device for culverts

3.1 Segmental Lining

Segmental lining uses a rigid-walled pipe as the liner for the host culvert. Two types of liner pipe are commonly used, pipe with bell-and-spigot joints or butt-welded joints. In most cases, the liner pipe is moved into the culvert one section at a time. With butt-welded pipe, the entire unit may be prefabricated on site and installed as a single pipe. The liner is pushed or pulled with jacks or construction machinery. Rigid-walled liners with smooth exteriors are typically easier to insert when the host pipe has a corrugated interior wall profile. Host culvert alignment variations can become control or pinch points for the insertion process. If alignment variations exist and the segmental liner technique is used, the diameter of the liner may have to be significantly reduced, relative to an optimal relining project. When slip-lining a host culvert with alignment variations, a “pulling head” or “nose cone” is recommended (see Figure 5A and 5B) to help facilitate the insertion process. When the liner is in place, the **annular space** is grouted. Almost any type of culvert can be slip lined with an appropriately sized liner pipe. The specifications, materials, advantages, and disadvantages of slip lining are summarized in Table 1.



Figure 5A. Cutting out nose cone



Figure 5B. Nose cone

Grouting of the annular space is recommended to reduce seepage, further deterioration of the host culvert, soil migration, as well as create a structural connection between the liner and the host pipe. For host culverts with rusted-inverts or mis-aligned joints, voids in the embankment materials often develop. In cases where the soil loss is not sufficiently extensive to warrant a

culvert replacement, the grout will typically fill those voids, improve the culvert/embankment structural connection, and reduce the risk of sink-hole development.

Prior to grouting, the annular space must be sealed at both ends using **bulkheads**. Bulkhead seals keep the grout in and water, if present, out. Cement-mortar bulkheads are common and usually require a curing time of several days prior to grouting. When water is present within the culvert (e.g., live stream or wetlands), **Oakum** soaked in water-activated urethane sealant can be used as the bulkhead material (see Figures 6A and 6B). The hydrated Oakum requires only a few minutes to cure.



Figure 6A. Oakum being soaked in urethane sealant



Figure 6B. Inlet sealed with Oakum

Grout may be either gravity fed or pumped through a hose or small diameter pipe (1-1/2 in to 2 inch PVC) placed in the annular space. The grout is typically a low-density foam concrete consisting of Portland cement and **fly ash**. This mix allows the grout to flow easily and fill the entire annular space (see Figure 7). If standing water is present in the annular space, a higher-density grout may be required to displace the water. Grouting in lifts is recommended when using high-density grout or when grouting a culvert with a significant change in elevation between inlet and outlet to avoid collapse of the liner via excessive external loads from the grout.

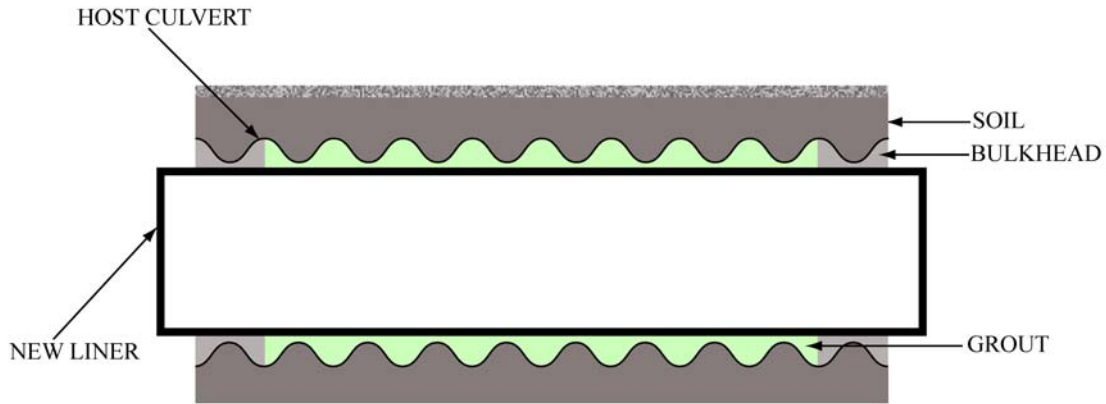


Figure 7. Model of CMP lined with HDPE liner

When preparing to pump grout, these steps are recommended: Three grout feed tubes should be used running 75%, 50%, and 25% of the total length of the liner. The number and lengths of feed tubes can vary depending on the culvert length. The grout feed tubes of differing lengths are strapped to the exterior of the liner pipe segments using metal banding. Short pieces of dimensional lumber (e.g., 2x4 blocks) are placed adjacent to the tubes and under the metal bands to minimize direct pressure on the grout tubes from the banding. Air tubes are placed at approximately the three, nine and twelve o'clock positions in each bulkhead to expel air during the grouting process. The grouting process is stopped when grout discharges from all of the air vents. Following grouting, the air and grout feed tubes are capped (see Figure 3). A two dimensional schematic of the grouting assembly is shown in Figure 8.

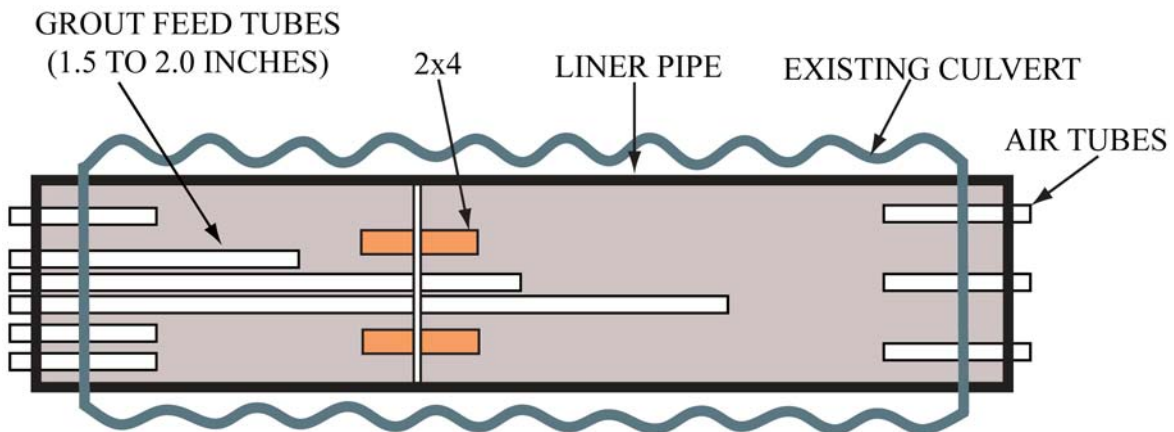


Figure 8. Plan view of model setup for grouting process.

3.2 Spiral-Wound Method

The Spiral-Wound method is another solid-wall liner technique. It differs from the segmental liner method in that the liner is formed on the site as a continuous liner. Inter-locking polyvinyl chloride (PVC) profile material is fed through a winding machine that mechanically forces the material to interlock, forming a smooth, continuous, spirally-wound liner (see Figure 9). During the interlocking process, a sealant is applied to make the seam watertight. As the material is wound, it is fed into the existing culvert as shown in Figure 9.

There are two common types of spiral-wound liners:

- A) *Expanding liner*: Inserted as a fixed diameter and then expanded until it presses against the interior surface of the existing pipe.
- B) *Fixed-diameter liner (PVC or Steel Reinforced)*: Inserted into the host culvert and the annular space is grouted.

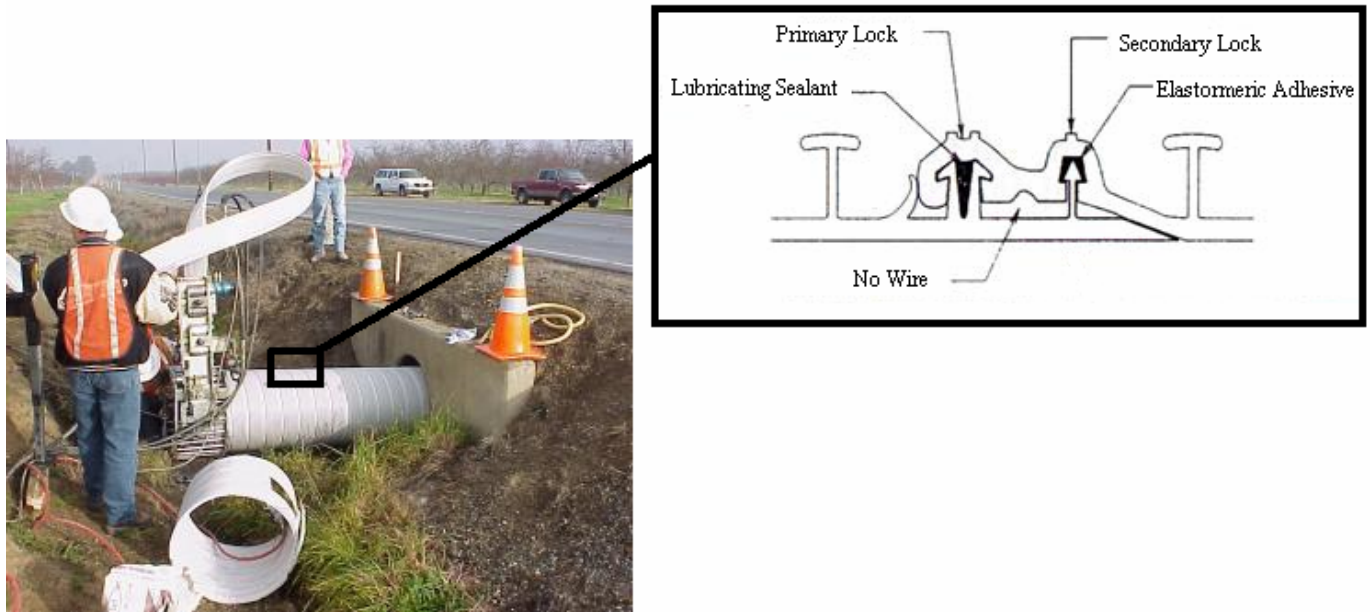


Figure 9. Rib Loc lining system
Left: (www.dot.ca.gov), Right: (www.cflhd.gov)

3.2.1 Expanding liner

The spiral-wound liner is inserted as a fixed-diameter pipe. When the liner reaches the termination point of the host culvert, the liner is expanded one of two ways (depending on the type of liner used); either a wire that runs through the entire spiral joint is pulled, allowing the liner to expand (see Figure 10) or a rotating machine is run through the inside of the liner (see Figure 11A). This expanding liner system utilizes a water activated polyurethane adhesive joint sealant. Steel reinforcement can be added to the liner wall to increase the structural strength of the liner. No annular space grouting is required (no annular space), however, the ends of the liner are often grouted into place. Both flexible and rigid pipes can be rehabilitated with this system.

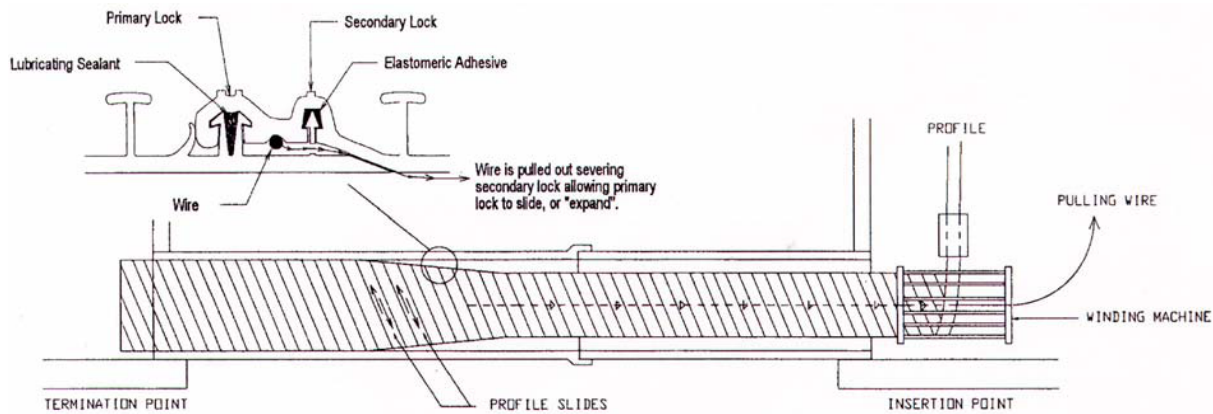


Figure 10. Spiral wound expanding system
(www.cflhd.gov)

3.2.2 Fixed-Diameter Liner (PVC or Steel Reinforced)

The fixed-diameter liner system creates a PVC pipe with a ribbed external profile. This produces an integrated structure with the PVC liner "tied" to the original pipe through the grout similar to a segmental liner. A steel reinforced PVC lining system is also available, which includes a continuous strip of profiled reinforcing steel added to the outside of the plastic pipe (see Figure 11B). The resulting liner has a smooth plastic internal surface with increased stiffness from the steel reinforcing profile. Both flexible and rigid pipes can be rehabilitated with this system. The specifications, materials, advantages, and disadvantages of spiral wound lining are discussed in Table 1.



Figure 11A. Full-bore expanding machine
(www.dot.ca.gov)



Figure 11B. Steel Reinforce Lining
(www.prsrohrganierung.de)

3.3 Cured-In-Place Lining

Cured-in-place lining installations involve the insertion of a flexible fiber tube coated with a thermo-setting resin into the host culvert. The tube is pushed into the host pipe using compressed air (inverted method) or pulled into place using a winch.

Cured-in-place linings are available in felt-based, woven hose, and membrane type tubes. Felt-based liners are produced from non-woven polyester felt and coated on one face with a layer of elastomer. The wall thickness of the felt-based tubes can be varied to accommodate various application requirements. In some cases, two liners are inserted, one inside the other. Woven hose systems, manufactured out of a circular, woven, seamless, polyester fiber hose and coated on one face with a layer of elastomer, are primarily designed to rehabilitate pressure pipelines. Membrane linings are composed of very thin elastomers and are commonly used to rehabilitate existing or protect new low-pressure gas mains.

For the pulled-in-place method, a winched cable is placed inside the host pipe. The resin-impregnated liner is connected to the free end of the cable and pulled into place between drainage structures or culvert ends. The cable is disconnected, the ends plugged, and the liner is inflated and cured with hot water or steam (see Figure 12A).

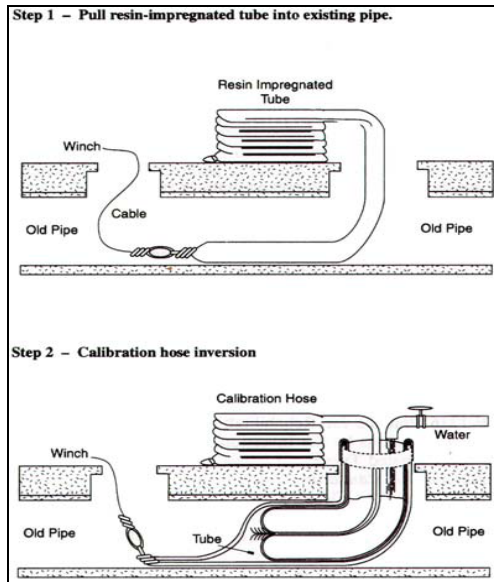


Figure 12A. Pulled-in-place method
(www.cflhd.gov)

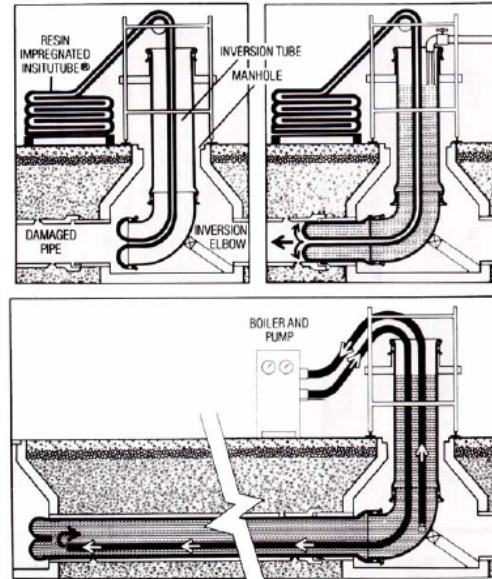


Figure 12B. Inverted method
(www.cflhd.gov)

For the inverted installation method, the polyester felt tube saturated in a liquid thermo-setting resin is inserted inside-out using compressed air as shown in Figures 12B and 13. Following insertion, the thermo-setting resin layer is on the outside of the liner. Next both ends are plugged and pressurized hot water or steam is used to expand the flexible liner until it conforms to the inside of the host pipe wall. The heated water/steam also activates the thermo-setting resin, causing the flexible liner to harden and maintain its expanded shape.



Figure 13. Outlet end of inverted liner

If water is used for curing the liner, a water source must be accessible at

the site and the water must be heated continually and circulated during the curing process. The resin will harden in a few hours, forming a jointless pipe-within-a-pipe. When required, remote controlled cutters can be used to trim the liner to reinstate host pipe junctions and laterals. Once cured, the resins become the primary structural component of the cured-in-place system and are categorized as unsaturated polyester, vinyl ester or epoxy. Unsaturated polyester resins are the most widely used resins in cured-in-place lining systems.

Some thermo-setting resins contain styrene. Due to potential environmental concerns associated with styrene (particularly with fish), a capture and disposal system may be required for the styrene-contaminated water. The specifications, materials, advantages, and disadvantages of cured-in-place lining are discussed in Table 1.

3.4 Fold-and-Form Lining

The fold-and-form lining method uses a PVC liner that has been folded (*flat* and *H-shapes* are common, as shown in Figure 14), manufactured to length, and delivered to the job site on reels. The flat-shape is used for lines in the 4- to 12-inch diameter range (diameter dimension corresponds to the liner when the cross section is round). The H-shape is used for liners in the 15- to 30-inch diameter range.



Figure 14A. Flat-shape liner
(4- to 12-inch) (www.ultraliner.com)



Figure 14B. H-shape liner
(15- to 30-inch)

The liner is inserted by covering the coiled liner with a tarp and pre-heating it with steam until malleable. A winch cable is fed through the host pipe, attached to the end of the liner, and the liner is pulled through at a rate of 40 to 50 feet per minute depending on field conditions. Once



Figure 15A. Cutting liner



Figure 15B. Pneumatic plug

through, the spool-end of the liner is cut and both ends are sealed with pneumatic plugs (see Figure 15). Pressurized steam is supplied to the liner via a port in the pneumatic plug until the liner expands tightly against the inside wall of the host pipe. The steam is replaced by compressed air to cool the liner while maintaining its shape. Once cooled, the ends of the liner are trimmed to the desired length (typically projecting some distance beyond the end of the host pipe as shown in Figure 16). This overall process typically requires roughly one full work day per installation. The time required to heat the liner (twice) will vary with ambient temperature conditions and the length of the liner. The specifications, materials, advantages, and disadvantages of cured-in-place lining are discussed in Table 1.



Figure 16. Inlet of fold-and-form rehabilitated culvert

3.5 Deformed-Reformed Lining

The deformed-reformed lining method, which is similar to the fold-and-form method, uses a high density polyethylene (HDPE) solid wall pipe which is deformed by mechanical force. If the nominal diameter of the HDPE liner is 18 inches or smaller, it is delivered to the job site folded on a spool as shown in Figure 17A. Larger diameters are brought to the job site in individual sections and then butt-fused or welded and deformed onsite into a *U-shape* by means of thermo-mechanical deforming equipment as shown in Figure 17B. Each pipe is made specifically for the culvert so grouting is unnecessary.



Figure 17A. Liner on a spool



Figure 17B. On-site deforming equipment

(www.htliners.com)

After the liner is pulled or pushed through the existing culvert, the ends are plugged and heat is introduced into the folded liner using pressurized steam to expand it tightly against the inside wall of the host pipe (see Figure 18). A remote controlled cutter reconnects laterals without excavation. The specifications, materials, advantages, and disadvantages of deformed-reformed lining are discussed in Table 1.



Figure 18. Steam being introduced into a 30 inch HDPE liner
 (www.htliners.com)

3.6 Cement-Mortar Spray-On Lining Method

Cement-mortar spray-on liners consist of lining the inside of the host pipe with cement mortar. This method is usually applied to steel and iron pipe to provide protection against corrosion. For small diameter pipe, mortar is supplied via a high-pressure hose and applied by the rotating head of an electric or air-powered machine (see Figure 19A). A lining of uniform thickness is applied as the machine travels through the existing culvert at a constant speed. The thickness of the liner applied is directly related to the travel speed of the machine. After the lining has been applied, rotating or conical drag trowels provided a smooth troweled finish. Unless reinforced, cement-mortar spray-on lining adds little or no structural integrity to the existing culvert.



Figure 19A. Lining machine for non-man entry culverts
 (www.dot.ca)



Figure 19B. Large diameter cement-mortar lining
 (www.cflhd.gov)

TABLE 1. Summary of trenchless rehabilitation methods.^α

| Method | Diameter (inches) | Length (feet) | Material | Advantages | Disadvantages |
|-------------------------------|--------------------------|----------------------|---------------------------------------|--|---|
| Segmental Lining | 4 to 158 | Up to 5248 | HDPE, PE, PP, PVC, GRP | -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 | -Excavation required for access pits -Grouting necessary for annular space -Existing culvert must be longitudinally uniform |
| Cured-in-Place Pipe | 4 to 108 | Up to 3000 | Thermosetting Resin/ Fabric Composite | -Access pits not required -Capable of bends and varying diameters within the pipe -Grouting not required -Minimal or no reduction in flow capacity -Non-circular shapes possible -No joints | -Flow bypass is required -Tubing must be specifically constructed for each project -Styrene monomer-based resins used in curing the liner are toxic to fish when discharged |
| Fold-and-Form | 4 to 30 spool | Up to 1000 | PVC | -Little excavation -Minimal or no reduction in flow capacity -Few or no joints -Fast installation -No grouting required -Capable of large bends | -Flow bypass is required -High material and training cost -Pipe must be specifically constructed for each project |
| Cement-Mortar Spray-on Lining | 3 to 276 | Up to 1476 | Cement, Mortar | -Does not block lateral and service connections -Protects against corrosion -Low cost | -Flow bypass is required -Existing culvert must be completely dry prior to applying the cement -Long curing time (up to seven days) -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 1000 | PE, PVC, PP PVDF | -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 | -Trained personnel required -Grouting may be required if fixed diameter is used -High material and training cost -Continuous fusion or sealant for joints required |

α (Purdy, 2005)

Table 1 Acronyms

| | | | |
|-------|----------------------------------|-----|--------------------|
| CIP: | Cast Iron Pipe | PE: | Polyethylene |
| PVDF: | Poly-Vinylidene Fluoride | PP: | Polypropylene |
| RCP: | Reinforced Concrete | PVC | Polyvinyl Chloride |
| GRP: | Glass-Fiber-Reinforced Polyester | | |
| HDPE: | High-Density Polyethylene | | |

Reinforced cement-mortar spray-on lining is limited to large diameter culverts (see Figure 19B). Installations are limited by pipe diameter, valve locations, bends, and length of supply hose. The specifications, materials, advantages, and disadvantages of cement-mortar lining are discussed in Table 1.

4.0 STRUCTURAL REQUIREMENTS

As a culvert degrades, the structural strength (ability of the culvert to support external loads) degrades also. By relining a deteriorating host culvert with a new rigid pipe liner, the structural integrity of the host culvert is increased. No maximum external load data, however, have been found specific to the various rehabilitated culvert techniques. Since many of the culvert lining materials are consistent with traditional culvert materials [i.e., HDPE, PVC, Corrugated Metal Pipe (CMP), etc.], a survey of various DOTs was taken to identify burial depth limits for the various culvert materials. A summary of this information is presented in Figure 20. Until rehabilitated culvert-specific burial depth data becomes available, use of the data in Figure 20 is recommended as a guide. It is possible that the structural strength rehabilitated culverts could exceed that of new culverts of the same material due to the combined influence of the liner, host pipe, and any annular space grouting that may take place.

Insituform CIPP has a design guide calculator on their website for burial depth (*Insituform*, February 2009), which calculates how thick the new liner will need to be. State DOTs do not have specifications for this particular material and it therefore was not included in Figure 20. CIPP, according to *Insituform*, can be placed at any burial depth and extra layers can be added to give the new pipe more structural strength.

Figure 20 shows how burial depth specifications vary by state and by culvert material. These specifications were obtained from the respective DOT websites. The burial depth data survey was limited to states in the western region of the United States. Not all states have specifications available on their websites for all culvert materials. For the CMP culverts, the wall thickness requirements varied from state to state, which influenced the recommended maximum burial depth.

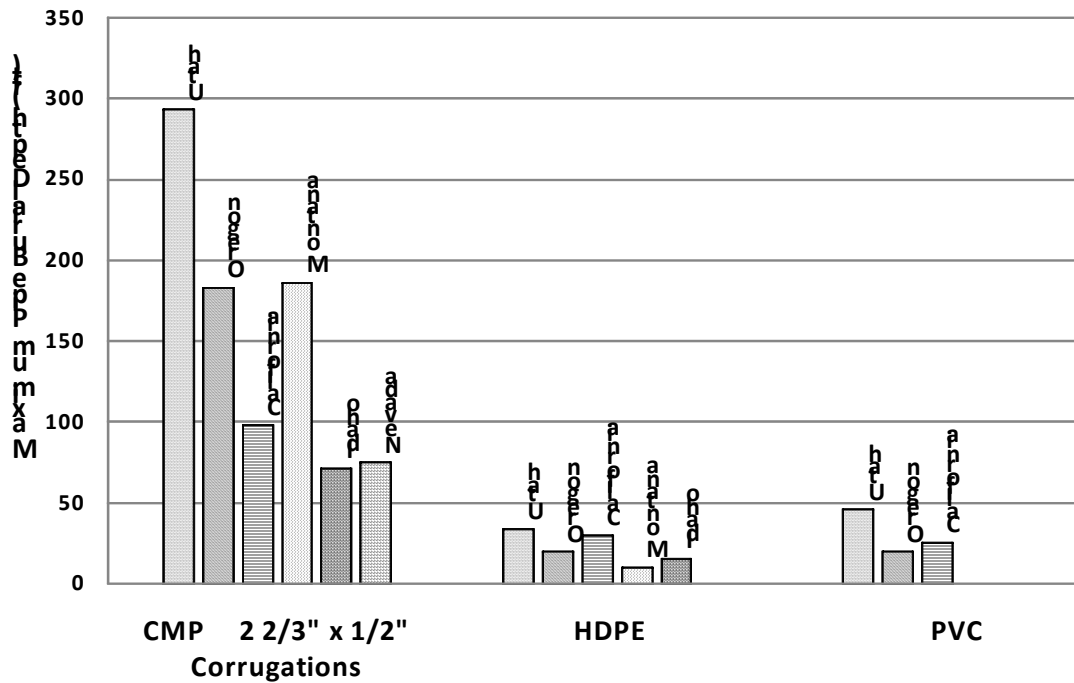


Figure 20. Maximum culvert burial depth based on State and culvert type (see “Burial Depth Specifications” in references)

5.0 END TREATMENTS

The end treatments for most segmental slip-lined culverts are generally projected a short distance beyond the end of the host culvert, as shown in Figure 3. *Poly Systems* recommends to their contractors that the liner project 6 to 12 inches beyond the host pipe (*Poly Systems, 2009*). In some cases the liner is cut off flush with the headwall. For CIPP, *Insituform* recommends that at least 4 inches of liner projects on each end, but it is up to the contractor to do what they think is necessary (*Insituform, January 2009*). No end treatment specification was found for the fold-and-form liner. Where appropriate, the end sections for both fold-and-form and the cured-in-place liners could be flared into a bell shape by placing pneumatic plugs, used to seal the liner during the curing process, at the appropriate locations while the liner is still malleable. There is very limited information regarding rehabilitated culvert end treatments, specifically regarding their hydraulic efficiency. Consequently there are no specifications for end treatments thus far for repaired culverts in Utah, but the topic warrants further study.

6.0 COST ANALYSIS

A limited Western States DOT cost survey of culvert rehabilitation was conducted; the results are compiled in Table 2. Data were provided by the DOTs on a cost-per-foot of culvert length basis. For all liners, the cost increases with increasing diameter. According to the data in Table 2, cured-in-place-pipe is generally the most expensive alternative. As a general rule, the installation cost/ft tends to decrease with increasing culvert length (compare CDOT 24-in vs. MDOT 24-in in Table 2). The project location can also have a bearing on the cost (distance from supplier, weather factor, etc.) The cost in general can vary due to labor, ease of installation, delays, and other factors

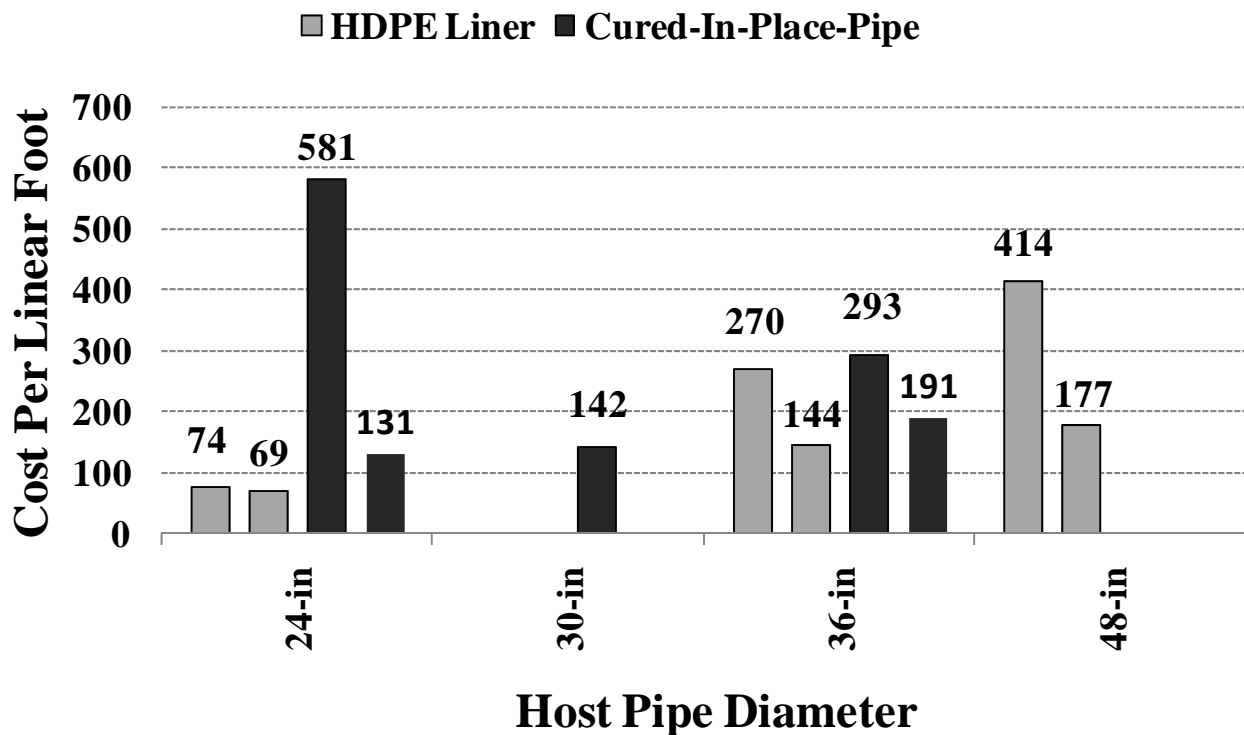


Figure 21. Total cost/foot of projects from Table 1

Table 2. Culvert relining cost comparison summary

| Method of Rehab | Host Pipe and Size | Pipe Length (ft) | Reference | Liner \$/ft | Total \$/ft |
|--|---------------------------|-------------------------|------------------|--------------------|--------------------|
| Concrete liner in bottom of pipe; placed | TRPL.-137" x 87" SSPPA | 220 | MDT (2008) | 87 | |
| Cured-in-Place-Pipe | 18-in Liner Pipe | 661 | MDT (2008) | 190 | |
| Cured-in-Place-Pipe | 24-in CMP | 185 | CDOT (2004) | 381 | 581 |
| Cured-in-Place-Pipe | 24-in CMP | 187 | UDOT (2009) | | 131 |
| Cured-in-Place-Pipe | 24-in CMP | 758 | MDT (2008) | 190 | |
| Cured-in-Place-Pipe | 30-in CMP | 507 | UDOT (2009) | | 142 |
| Cured-in-Place-Pipe | 36-in CMP | 632 | UDOT (2008) | | 293 |
| Cured-in-Place-Pipe | 36-in CMP | 512 | UDOT (2009) | | 191 |
| Cured-in-Place-Pipe | 54-in CMP | 600 | CDOT (2004) | 635 | |
| Fold-and-Form | 24-in CMP | 200 | UDOT | 135 | |
| Fold-and-Form | 24-in CMP | 245 | UDOT | 135 | |
| HDPE Liner | 24-in CMP | 75 | UDOT | 56 | 74 |
| HDPE Liner | 24-in CMP | 85 | UDOT | 53 | 69 |
| HDPE Liner | 36-in CMP | 237 | CDOT (2004) | 180 | |
| HDPE Liner | 36-in CMP | 65 | Caltrans | 111 | |
| HDPE Liner | 36-in CMP | 281 | UDOT (2009) | | 144 |
| HDPE Liner | 36-in CMP | 80 | UDOT | 100 | 123 |
| HDPE Liner | 36-in CMP | 80 | UDOT | 125 | |
| HDPE Liner | 48-in CMP | 596 | CDOT (2004) | 290 | 414 |
| HDPE Liner | 48-in CMP | 196 | UDOT (2009) | | 177 |
| HDPE Liner | 78-in CMP | 224 | CDOT (2004) | 500 | |
| Shotcrete | 36-in CMP | 335 | CDOT (2004) | 136 | |
| Shotcrete | 36-in CMP | 224 | CDOT (2004) | 126 | |
| Shotcrete | 72-in CMP | 241 | CDOT (2004) | 200 | |

Figure 21 shows the total cost/ft of six projects. This gives a general idea of the total costs for CIPP and segmental lining for the different diameters of pipe with the given lengths from Table 2.

7.0 CONCLUSION

Culvert rehabilitation is becoming more common in Utah. Segmental lining is cost effective in Utah and the most common method of rehab in most states. Cured-in-place-pipe and fold-and-form methods have been used and are effective, but costs are higher. Contractors with specialized skills and equipment are required for all method other than segmental lining. DOT maintenance crews can be trained to carry out segmental lining culvert repair projects. A survey of existing culverts, site conditions and cost considerations will help determine which rehabilitation method is most appropriate.

8.0 RECOMMENDATIONS AND IMPLEMENTATION

There are no recommendations in this manual. A flipchart and installation video for segmental lining are products of this study and contain suggestions for this method of rehabilitation. These documents can be found at <http://udot.utah.gov>.

9.0 REFERENCES

Caltrans. (2003). "General Culvert Barrel Rehabilitation Techniques." DIB 83-01 – 6.1-6.1.3.8
<www.dot.ca.gov/hq/oppd/dib/dib83-01-6.htm>

Central Federal Lands Highway Division. (2005). "Culvert Pipe Liner Guide and Specifications."
<www.cflhd.gov/techDevelopment/completed_projects/hydraulics/culvert-pipe-liner/>

Hydro Tech Inc. www.htliners.com, July 17, 2009.

Insituform Technologies. <<http://www.insituform.com/designguide/DesignGuide.aspx>>, February 3, 2009.

Insituform Technologies. Evans, Chantel. Personal Communication, January 21, 2009

Isco Industries Inc. Snap-Tite. <www.culvert-rehab.com>

Poly Systems. Boswell, Julie. Personal Communication, January 28, 2009.

Purdy, Diane. Penn State. 2005. *Trenchless Technology Alternatives for Pipe Rehabilitation*. LTAP Technical Information Sheet #116, Spring 2005.

Utah Department of Transportation. Burns, Kelly. Personal Communication, March 11, 2008.

Ultraliner Inc. <www.ultraliner.com>

References specific to State DOT burial depth specifications

Utah: <http://www.dot.state.ut.us/main/f?p=100:pg:2646153128037418:::V,T:1945>

Nevada: http://www.nevadadot.com/business/contractor/standards/index/pdfs/english/r1_3_1_2.pdf

Oregon: http://www.oregon.gov/ODOT/HWY/ENGSERVICES/roadway_drawings.shtml#Roadway_300__Drainage

California: <http://www.dot.ca.gov/hq/oppd/hdm/pdf/chp0850.pdf>

Montana: http://www.mdt.mt.gov/other/roaddesign/external/montana_road_design_manual/17_drainage_and_irrigation_design.pdf

Idaho: http://itd.idaho.gov/manuals/Online_Manuals/Current_Manuals/Design%20Manual/600.pdf

10.0 GLOSSARY

Annular space – Space between two telescoped pipes.

Bulkhead – Walls that are placed at the end(s) of a culvert to seal the annular space.

Cured-in-place-pipe – A resin-impregnated flexible tube cured with heat.

Deformed-reformed – A HPDE pipe folded that is reformed by heat.

Fly ash – The powdery residue that remains after burning coal in a power plant.

Laterals – Smaller pipes that flow into larger pipes.

Liner – A material that serves as a lining inside of a host pipe.

Oakum - Loosely twisted hemp or jute fiber for caulking seams.