FOLD AND FORM / DEFORM AND REFORM

Metal Culvert Overview Flowchart
Structural Defects Flowchart (Metal)
Bedding Deficiencies Flowchart (Metal)
Hydraulic Capacity Flowchart (Metal)

1. OVERVIEW

Two lining procedures involve the insertion of a thermoplastic pipe with an outside diameter slightly larger than the inside diameter of the host culvert pipe. The liner pipe is "folded" for easy winching into the host culvert pipe where it is subsequently expanded to closely fit the size and shape of the host pipe (Figure 1, Figure 2). These liners are categorized as either fold and form liners or deform-reform liners. While they are often referred to as "close-fit liners", this term is not used here since other lining processes produce close-fitting liners (e.g. CIP and helically wound liners).

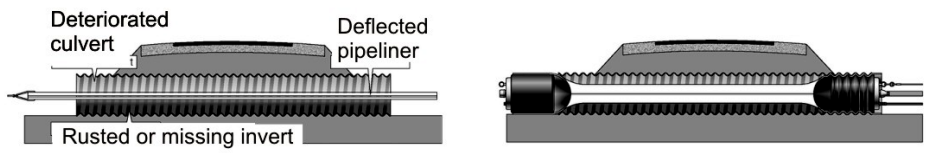

Figure 1. Two step installation. Left: A folded liner is pulled in. Right: A folded liner is expanded forming a tight-fitting new pipe (Roads and Bridges, 2001)

Figure 2. Cutout of a culvert pipe rehabilitated with a fold-and-form liner (Roads and Bridges, 2001)

2. MATERIALS USED

2.1. FOLD AND FORM LINERS

Fold and form liners are PVC-based products that are delivered to the site flattened (folded into a "U" or "C" shape prior to insertion into the host pipe) or folded into a "C" shape and coiled on large vertical drums. One manufacturer makes liners folded into an "H" shape for sizes 15 in. and larger (Figure 3). After being pulled into the culvert, the liner is re-rounded using steam and air pressure.

Figure 3. Common shapes of folded PVC liners: flat shape and "H" shape (Munson, 2008)

2.2. DEFORM-REFORM LINERS

Deform-reform liners are HDPE pipes that are manufactured in a round shape and cooled to set the memory to round, then reheated with warm water to a temperature lower than manufacturing and deformed into the "U" shape (the pipe is pushed through a former that folds it into a "U" shape or, as some call it, a "heart" shape, Figure 4), and this shape is temporarily held by a sleeve or plastic bands (Figure 5). Once the pipe is folded, it is coiled on large vertical drums and shipped to the job site (Figure 6). After being pulled inside the culvert, the liner is re-rounded by applying pressure to snap the bands that hold the deformed shape allowing the liner to revert back to its original shape. Either pressurized steam (i.e., a combination of steam generated temperature and pressure) or hot water can be used.

Figure 4. An HDPE pipe deflected into a "heart" shape (Subterra, 2008)

Figure 5. Plastic bands hold a deflected pipe in shape (Long, 2005)

Figure 6. Deflected HDPE pipe with restraining bands, and coiled on a large vertical drum (Long, 2006)

2.3. METHOD APPLICABILITY

Whittle (2009) showed diameter range, DR range and max installation length for four fold-and-formed systems and one deform-reform system in the US (Table 1). Circular pipes ranging in diameter from 6 in. to 24 in. are routinely rehabilitated. Non-circular culvert shapes can also be rehabilitated, e.g. elliptical (see Example case histories). Lengths up to 1,500 ft can be relined.

Table 1. Technical envelope for four different fold-and-form liners on the US market (Whittle, 2009)

	PVC1	PVC2	PVC3	PVC4	HDPE
Diameter range	6 in.-12 in.	3 in.-24 in.	3 in.-15 in.	6 in.-16 in.	3 in.-24 in.
For "common" diameter: D DR range & typical DR Max length	 8 in. 32.5-26.0 (32.5) 1,500 ft	 8 in. 41.0-26.0 (35.0) 1,500 ft	 8 in. 41.0-32.5 (35.0 1,500 ft	 8 in. 34.0 (34.0) 500 ft	 8 in. 21.0-35.0 (32.5) 1,500 ft
For max diameter: D DR range & typical DR Max length	 12 in. 32.5-26.0 (32.5) 500 ft	 24 in. 50.0-60.0 (55.0) 650 ft	 15 in. 41.0-35.0 (35.0) 800 ft	 16 in. 34.0 (34.0) 250 ft	 24 in. 32.5-35.0 (35.0) Butt-fused

Applicability is not limited by culvert pipe type or condition unless the pipe has already collapsed (these liners can rehabilitate deteriorated pipes with ovality up to 10%, soil voids, and with offsets and bends). Deep pipes exceeding 30 ft have been rehabilitated. Fold-and-form and deform-reform liners can be can't be installed in live flow conditions.

3. CONSTRUCTION ISSUES

3.1. INSTALLATION PROCEDURE

The following are steps that are normally required for both fold and form and deform-reform liners (modified from Thornton et al., 2005):

- Test the air in the pits for the presence of toxic or flammable vapors or the lack of oxygen.
- Clean the existing culvert structure using high-velocity jet cleaners.
- Inspect culverts for protrusions, sags, collapsed sections, etc, that may hinder liner installation and remove any obstructions found.
- Setup flow bypass.
- Heat the coil or reel containing the folded liner prior to insertion, if recommended by the manufacturer.
- Insert a containment tube into the culvert by winching and inflate with low pressure and heat, if recommended by the manufacturer.
- Insert the deformed liner by winching.
- Expand the folded liner using heat and pressure. A rounding device may also be used in combination with heat and pressure. Maintain the temperature and pressure as required.
- Cool down the liner as required and relieve the expansion pressure.
- Trim down the terminating ends

- Inspect the completed installation (CCTV)
- Carry out leakage or other testing, as required
- Reconnect connections
- Restore flow if bypass was required and initiate site cleanup.

3.2. FOLD AND FORM LINER INSERTION, FORMING AND COOLING

Dayton (2008a, b) provided construction details for one fold-and-form relining system. The spool is placed into a hotbox where low pressure steam (280°F) from a boiler truck is used to heat the material to soften it until it is sufficiently pliable (i.e., as wet leather) to be pulled through the pipe (Figure 7). The liner is heated to a temperature recommended by the manufacturer, usually around 110°F, which takes about 1 hour. For winching, the "pulling nose" is made by folding the liner flat in half and drilling two opposing holes approx 12 in. from the edge, through which the chain is fed and hooked onto the cable. The liner is pulled through the pipe allowing it to protrude on both ends of the host pipe (Figure 8). A flow-through plug is inserted at one end of the liner and steam under low pressure is introduced into the liner. The liner material heats relieving stress induced from pulling, which is indicated by movement of the liner end with the plug (the opposite end of the liner is locked by the pulley system). The process continues until no liner movement can be observed. The stress relief process is then repeated at the opposite end of the liner.

Figure 7. Heating the liner with steam before insertion (Dayton, 2008a)

Figure 8. Liner protruding beyond the brick catch basin after being winched in (Dayton, 2008b)

Figure 9. Steam pressure being inserted (Dayton, 2007)

Dayton (2008a, b) also described steps that involve the PVC liner expansion and forming, and its cooling to ambient temperature. The liner is further heated using low-pressure steam until it is pliable enough for expansion. Heating time is determined by the length and SDR of the liner. At the end of the heating time, the process is switched from steam to compressed air. The pressure is increased to 18 psi thus inflating the liner to conform tightly against the host pipe. Once the liner is expanded, the pressure is reduced to 12 psi to hold it in place while an after-cooler blows in air at 80°F. The temperature at the exhaust end is monitored and when it drops to 100°F, the liner is hard enough not to collapse and the pressure is turned off. Depending on diameter and length, the liner cools in 1 to 2.5 hours. Water may be introduced into the compressed air during the cooling process to reduce the cooling time. The liner can be reheated, extracted and reinserted if any mistake has been made. After cooling, the liner is trimmed to a minimum of 3 inches beyond the culvert for possible shrinkage during the process of cooling it to ambient temperature.

3.3. DEFORM-REFORM LINER INSERTION AND RE-ROUNDING

Deform-reform liners do not require pre-heating for installation (Long, 2006). The flexible liner is pulled off the coil and winched into the host pipe (Figure 10). Once in place, the ends of the pipe are closed off and a flow-through plug is inserted (Figure 11). Steam generated from a boiler truck is sent through the pipe causing the liner to expand and fit tightly to the inside of the host pipe (Griffin, 2007).

Figure 10. Insertion of a deformed liner from a drum (Griffin, 2007)

Figure 11. Pressurized steam expands and re-rounds the PE pipe (Long, 2006)

4. QA/QC CONSIDERATIONS

Whittle (2000) reviewed material characteristics that affect quality assurance, the window of field instability, as well as the structural capacity of pipeliner materials. The paper also outlined the engineering requirements that differ from traditional "direct burial" design. ASTM standards relevant for quality control procedures often used at manufacturing facilities were listed.

Kampbell and Whittle (2003) reviewed the fundamentals of good QA/QC for these liner technologies and provided guidelines for knowledgeable monitoring of the QA/QC results. As these liners are pre-manufactured products, quality control is simplified. All structural properties are established under ASTM prescribed QA/QC protocols common to all plastic pipe production and are confirmed on a specified sampling rate by batch, lot, or production run. The liners must merely be expanded to fit the ID of the host pipe. Preliminary wall thickness confirmation can be achieved prior to installation, and post-installation confirmation of the finished wall thickness (SDR) is easily and inexpensively accomplished (a restrained sampling technique per ASTM F 1871, F 1504, or F 1533, with laboratory testing). Post-installation QA/QC inspection is important to identify any stretch marks, thin spots, blow holes, waviness, lumpiness (not to be confused with conformance to host pipe anomalies), or discoloration from stretching, which could lead to further liner inspection and/or testing.

NASTT (2006e) summarized the QA/QC material verification, proper installation practices and post-installation procedures and practices, and listed ASTM standards that provide reference on accepted installation practices of thermoformed pipeliners.

5. STANDARDS AND SPECIFICATIONS

5.1. FOLD AND FORM LINERS

ASTM D1784 covers rigid PVC compounds and chlorinated PVC compounds for use in extruded or molded form like pipe and fitting applications. (Material standard)

ASTM F1871 and **ASTM F1504** cover the requirements and test methods for materials, dimensions, workmanship, flattening resistance, impact resistance, pipe stiffness, extrusion quality, and a form of marking for folded PVC pipe for existing sewer and conduit rehabilitation. (Product standards)

ASTM F1867 and **ASTM F 1947** cover the procedures for the rehabilitation of sewer lines and conduits by the insertion of a folded/formed PVC pipe that is heated, pressurized, and expanded to conform to the wall of the original conduit. (Installation standards)

Additional standards and specifications associated with fold and form relining are listed in Thornton et al. (2005).

5.2. DEFORM-REFORM LINERS

ASTM D3350 covers the identification of polyethylene plastic pipe and fitting materials (cell classification of materials). (Material standard)

ASTM F1533 covers requirements and test methods for deformed polyethylene (PE) liner for the rehabilitation of gravity flow and non-pressure pipelines. **(**Product standard**)**

ASTM F1606 covers the requirements for the installation of deformed polyethylene (PE) liner for pipeline rehabilitation. This practice applies to the rehabilitation of 3 to 18 in. diameter pipe in terms of installation (Installation standard)

Additional standards and specifications associated with deform-reform relining are listed in Thornton et al. (2005).

6. EXAMPLE CASE HISTORIES

6.1. FOLD AND FORM LINERS

The Georgia DOT (GDOT) used fold-and-form liners for the rehabilitation of corrugated metal culverts in 2001. Seven deteriorated culverts in the roadbed ranging from 15”-30” in diameter and 40 ft-80 ft in length were successfully relined. GDOT selected this method because it involved no digging, no chemicals were used, there was never need to block more than one lane of traffic for more than four hours, and it was the least expensive method identified by GDOT at that time ("Hard…" *Roads and Bridges*, Jan 2001).

The GDOT continued using this technology and by 2003 has rehabilitated 88 corrugated metal pipes in Georgia’s District One. The average length was about 50 ft, although the length of some exceeded 200 ft, and the diameters varied between 15”-24”. The thickness of new liner varied between 0.35”-0.55”. The tensile strength of the finished liner was reported to be 4,100 psi and the structural strength rated at 155,000 psi ("Keeps…" *Public Works*, Jan 2003).

Kansas Turnpike Authority (KTA) used fold-and-form relining to repair two corrugated metal culverts under roadway near Lawrence, KS in the fall of 2008. The culverts were 32” in diameter and approx 70 ft long, showing extreme corrosion (one culvert had approx 40% of metal in the invert lost) and buckling (personal communication with Ed Patterson, KTA).

City of Atlantic Beach, FL used fold-and-form relining to repair an 18”×29” elliptical CMP culvert, 50 ft long in the residential area that was on a verge of collapse. A 24” PVC liner ¾-inch thick was used (Dayton, 2008. "Ultra…").

6.2. DEFORM-REFORM LINERS

Caltrans had a corrugated steel culvert under a highway near Big Sur, CA rehabilitated using deform-reform relining in 2007. The culvert was 18” in diameter and was badly deteriorated, with the bottom rusted completely in many places (Griffin, 2007)

Caltrans had approx 5,000 ft of culverts at various locations under Interstate 80 near Lake Tahoe, CA, and under Interstae 5 near Redding, CA, rehabilitated using deform-reform relining. The culverts were ranging in diameter from 18” to 56” (Griffin, 2003).

7. ADVANTAGES AND LIMITATIONS

The main advantages of fold-and-form and deform-reform relining include the elimination of the need for excavation and grouting, and the one piece (jointless) final product with an expected minimum 50-year service life. Installation is straight-forward and fast, with minimal traffic disruption. The liner is manufactured in a controlled environment under stable conditions and the installation process does not

change the physical properties of the liner material. No hazardous chemicals are used and no refrigeration is required during transportation of materials or for their storage. Reduction of cross area of culvert pipe is minimal, while flow capacity remains the same or is even improved due to the liner's smooth surface.

The main limitations of this method are diameter limitation (up to 30 in. diameter) and the need for flow bypassing (installations can't be performed in live flow conditions). Installation lengths are limited by pull-in forces or coil length (however, this is typically not an issue in culvert rehabilitation). Chemical grouting may be required at liner ends.

8. REFERENCES

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