CURED IN PLACE PIPE (CIPP)

[Plastic Culvert Overview Flowchart] [Structural Defects Flowchart (Plastic)]
[Bedding Deficiencies Flowchart (Plastic)] [Hydraulic Capacity Flowchart (Plastic)]

1. OVERVIEW

Cured-in-place (CIP) relining is a method in which a flexible material (typically a tube) saturated with thermosetting resin is inserted into the deteriorated culvert by inversion or winching, expanded via air or water pressure, and the resin is subsequently cured at ambient or elevated temperature (by means of steam or hot water) or by means of UV-light. The final product, which is often referred to as Cured in Place Pipe (CIPP), has minimal or no annular space, thus eliminating the need for grouting (Figure 1).

The CIP liners can be categorized into conventional CIPP and composite CIPP (based on their material composition, see 2). Composite CIP liners are high-strength fiber-reinforced CIP liners (fiber reinforcement provides increased stiffness and strength resulting in thinner liner walls compared to conventional CIP liners) and are used to rehabilitate medium to large sewers, drains and culverts.

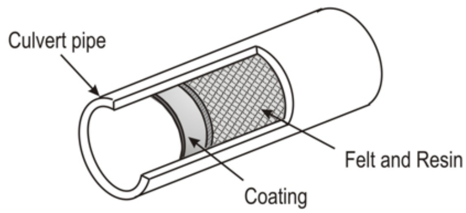

Figure 1. Components of CIP liners

Figure 2. CIP relined culvert (McClanahan, 2009)

2. MATERIALS USED

2.1. CONVENTIONAL CIPP

In conventional CIP lining, the fabric tube is typically made of needled felt or equivalent woven or non-woven material and a thermosetting resin is usually unsaturated polyester, epoxy vinyl ester, or epoxy with catalysts. Simonson and Peterie (2002) indicated that roughly 95% of CIP liners are made with polyester, 4% with vinyl ester and 1% with epoxy resins. A protective layer of non-porous fabric (reinforced PVC or PE) is often added to the outside of the tube (after installation is completed, it faces the pipe interior if the liner is inserted by inversion or it stays between the CIPP and the host culvert if the liner is pulled into place).

In addition, fiberglass and resin systems are available that are cured with ultraviolet (UV) light. The most commonly used fiberglass is ECR-glass, which has mechanical properties similar to E-glass but enhanced corrosion resistance (Lance Brown Import-Export, 2009). The resin used in these systems (polyester, vinyl ester, or non-styrene resins) comes with a UV initiator. A UV-cured CIP liner typically consists of several layers: (1) an outer foil, i.e., there would be no bonding to the host pipe, (2) a water resistant layer, (3) the resin impregnated layers of fiberglass, and (4) an inner foil that would be removed after the curing so as not to hinder future cleaning operations, e.g., high-pressure water jetting (Sain and Montemarino, 2009).

3. COMPOSITE CIPP

Shearer (2007) described one type of composite CIP that utilizes a tube made of conventional felt material sandwiched between layers reinforced with carbon and/or glass fiber liner (Figure 3). The reinforced layers are manufactured by stitching carbon or glass fiber tows[1] onto thin layers of felt (Figure 4). Typically, glass is the material of choice for both layers in the composite CIP and carbon is used when a higher stiffness composite is required or in industrial settings where higher corrosion resistance is needed. In addition, a coating made of thermoplastic material, e.g., polypropylene (PP) is added to the tube for corrosion protection. The resin used is standard isophthalic polyester resin. An example of the composite CIP liner installed in a PVC pipe (Figure 5. the liner's total wall thickness of 14.0 mm) comprises of the following layers: PVC pipe, PP seam "tape" (the outer coated layer); thin layer of standard felt, glass fiber reinforced layer, standard felt "core layers", carbon fiber reinforced layer, and standard PP coated layer.

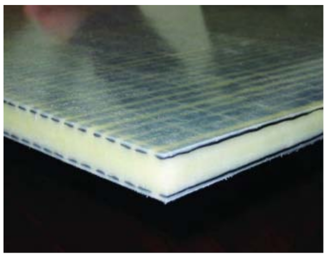

Figure 3. Sandwiched tube material used for one composite CIP (Shearer, 2007)

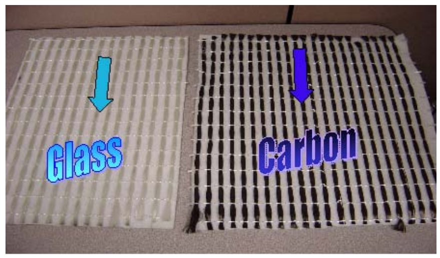

Figure 4. Carbon and glass fiber tows stitched onto thin layers of felt (Shearer, 2007)

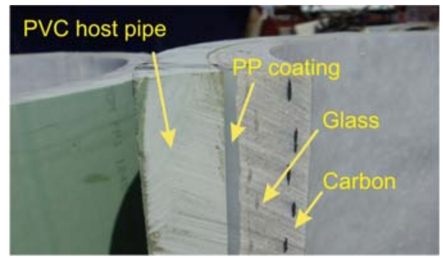

Figure 5. Cross-section of a composite CIP liner installed in a PVC host pipe (Shearer, 2007)

In another composite CIP liner, a non-porous inner membrane is sandwiched between two layers of structural fiberglass (Figure 6) and bonded to them. Felt fibers allow bonding of the inner membrane to the surrounding fiberglass layers with epoxy resin during installation. Beside this three-layered system, multilayered systems comprising up to four inner membranes between five layers of fiberglass can be made. Depending on the number of layers, the thickness of the pre-saturated liner ranges between 3.0 mm and 6.0 mm. With increased thickness, the physical properties improve considerably, e.g., flexural modulus per ASTM D790 increases from 600,000 psi to 1,000,000 psi (Poly-Triplex Technologies, 2009a). Third-party testing (SWL, 2004) in accordance with ASTM C497 D demonstrated a significant increase in culvert pipe strength after CIP relining with a composite CIP liner made with four layers of fiberglass, non-porous membranes in-between, and epoxy resin, compared to the original culvert pipe (Figure 7).

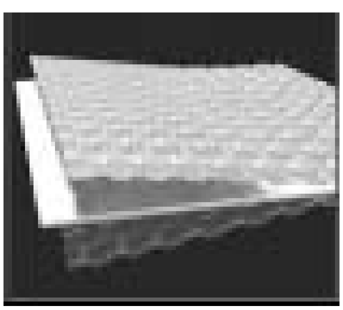

Figure 6. Three-layer system comprising a fiberglass layer, a non-porous felt/PVC membrane, and a fiberglass layer) (Robert Putnam, Poly-Triplex Technologies, personal communication)

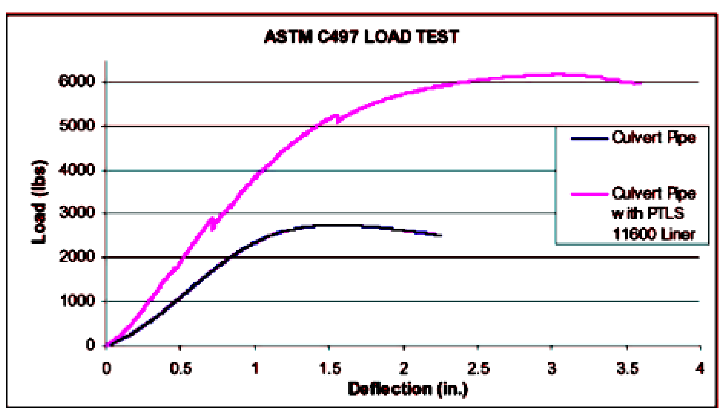

Figure 7. ASTM C497 load test of galvanized corrugated metal pipe before and after CIP relining (SWL, 2004)

[1] *The term "tow" means a loose untwisted rope.*

3.1. METHOD APPLICABILITY

CIP liners can be installed in pipes of any material and shape (circular or non-circular), with or without corrugations on the inside surface of the pipe.

Conventional CIPP is applicable in diameters between 6 in. and 108 in., and installation lengths range from 10 ft to 2,850 ft (Simonson and Peterie, 2002; McClanahan, 2007). Smaller diameters (e.g., 4 in. pipes) can also be CIP relined (WERF, 2006). Composite CIPP is used in pipes typically 48 in. in diameter or larger, although can be used in 36 in. pipes as well.

4. CONSTRUCTION ISSUES

4.1. INSTALLATION PROCEDURE

Thornton et al. (2005) outlined the general installation procedure for conventional CIP relining:

- Test the atmosphere (in the insertion pits) for presence of toxic or flammable vapors, or the lack of oxygen
- Thoroughly clean the existing culvert using high-velocity jet cleaners
- Inspect the existing culvert (identify any protrusions, collapsed sections, deflected joints, etc)
- Clear line obstructions (excavate to remove and repair the obstructions if needed)
- Vacuum-impregnate the insertion tube with the specified resin under controlled conditions. Lubricate the tube before installation (apply lubricant to the fluid in the standpipe or directly to the tube).
- Setup flow bypass
- Invert the resin-impregnated tube (with hydrostatic head or air/steam pressure)
- Let the resin cure (while circulating hot water or steam throughout the liner with approved equipment; maintain the recommended pressures throughout the curing process)
- If heated water was used to cure the resin, drain the heated water from a small hole made in the downstream end and replace with the introduction of cool water into the inversion standpipe. Cool the liner to a temperature below 100°F before relieving the static head in the inversion standpipe. If air/steam was used to cure the resin, drain the air/steam through a small hole made in the downstream end and replace with the introduction of cool water into the guide chute. Cool the liner to a temperature below 113°F before relieving the pressure within the section.
- Cut and seal the termination ends with a resin mixture compatible with the installed liner if the liner does not fit tightly against the original pipe.
- Inspect the completed installation (CCTV or visually in man-entry pipes)
- Perform leakage or other testing to specifications
- Reconnect laterals and service connections with a robotic cutting device or manually where the diameter permits man-entry.
- Restore flow and initiate site cleanup.

Additional notes: A pre-installation video is typically made. The liner tube can be resin impregnated in the regional wet-out facility or on site.

Composite CIPP utilizes the same installation procedure (the liner is resin pre-impregnated and inserted by inversion or pull-in into the host pipe where it cures into the final product). However, one composite CIP liner is installed (Jerry Trevino, Protective Liner Systems, personal communication) by first manually applying resin directly onto the surface of the host pipe and then pressing the liner cloth into the resin (thus impregnated the cloth with the resin inside the host pipe; multiple layers can be applied), which is followed by the resin cure.

4.2. LINER INVERSION OR PULL-IN

For inverting resin-impregnated liner tubes, air inversion is typically used for smaller diameters, i.e., 6 to 24 in. (Figure 8) and water inversion for diameters over 24 in. Water inversion can be carried out by either creating hydrostatic head with a tower (Figure 9) or applying simulated head through water pressure (Gearhart, 2008). Special inversion drums can also be used for inverting smaller diameters liners (WERF, 2006). Alternatively, the resin-impregnated liner tube can be pulled into the culvert using a winch (Figure 10). A calibration hose is then inverted into the center of the pulled-in tube using hydrostatic water pressure or pressurized air/steam.

Figure 8. Air pressure inversion (Jaques, 2008b)

Figure 9. Water inversion (Jaques, 2008b)

Figure 10. Liner being winched into the culvert (McClanahan, 2009)

4.3. RESIN CURE AND COOL DOWN

Ambient temperature cure can take a long time and the process can be accelerated by circulating hot water, air or steam through the pipe (Figure 11, Figure 12). In small diameters, once water reaches approximately 180ºF and interface temperatures are appropriate, curing takes approx 2 to 3 hours for water cure and 15 to 60 minutes for air cure. In large diameters, curing times can be 12 to 18 hours. Once cured, the liner is cooled to 100ºF. The pressure is then released and the ends are cut out (McClanahan, 2008).

UV-light resin cure utilizes a mobile light source that contains several UV lamps that operate at steady radiation intensity (wavelength range of 360 to 420 nm) and are optimally placed in the liner during the curing process so that the liner is evenly lit even with varying channel diameters and line profiles. The curing process with UV light is very fast, e.g., curing speeds of 5 ft/min are possible (WERF, 2006)

Figure 11. Hoses for delivering hot water (McClanahan, 2009)

Figure 12. Steam cure (McClanahan, 2009)

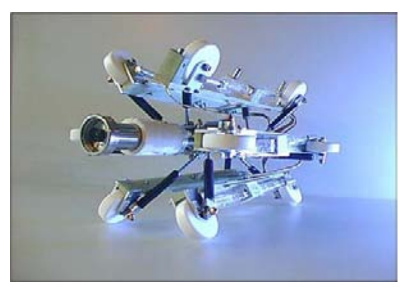

Figure 13. UV-light cure (McClanahan, 2009)

4.4. SET-IN-PLACE CIP LINERS

One composite CIP liner made of fiberglass cloth (E-type glass) and modified epoxy resin system (the resin has imbedded fibers for increased tear resistance of the liner) is installed as set-in-place rather than by inversion or winching. The application requires man entry into the pipe. With this system, mastic is applied first at approx thickness of 0.1 in. The fiberglass fabric is then cut into the required dimensions and pressed, using a putty knife, into the mastic to achieve full wetting of the fabric. With subsequent applications of the fabric, the edges are overlapped. Epoxy is applied between the overlapped edges to assure a monolithic construction. The fabric is top-coated with the mastic to insure complete saturation and encapsulation of the fabric. The finish lining systems has a minimum thickness of 0.125 in. The epoxy cures in 3 to 4 hours at 70°F to approx 75% of its strength (at this time the structure may return to service) and to its full strength in 4 to 5 days. Higher temperatures reduce the cure time and lower temperatures increase it (Jerry Trevino, Protective Liner Systems, personal communication).

5. QA/QC CONSIDERATIONS

Kampbell and Whittle (2003) reviewed the fundamentals of good QA/QC for CIP liners and provided guidelines for knowledgeable monitoring of the QA/QC results. CIP liners are manufactured in place and it is important that a sample of the finished wall section be obtained and analyzed for the specified finished thickness and material properties. Restrained samples, or flat plate samples, subjected to the in situ curing pressures and heating cycle are a must for assessing the structural properties of the finished liner. Sampling rates should be sufficiently frequent and line segments should be targeted for sampling based upon quality assurance needs and concerns. Line segments exhibiting early or incomplete curing, or resin slugs, or those at high risk of resin washout may deserve particular attention. Lines installed with significant deviations from the planned temperature and pressure schedules may also warrant testing. Visual inspection can help to identify discoloration, blisters, delamination, dry spots, etc. to target line segments for additional inspection and/or testing.

Kampbell (2005) reviewed the design parameters and the installation parameters necessary for long lasting cured in place pipe (CIPP).

NASTT (2006) summarized QA/QC issues for CIPP liners saying that QA/QC should address both the component products (the resin and the tube) and its design and installation. The ability of the CIPP to withstand buckling was recognized as the key design consideration in CIPP design. ASTM standards for proper installation by insertion or pull in were listed.

6. STANDARDS AND SPECIFICATIONS

The following ASTM standards are associated with conventional CIPP relining:

ASTM D5813 covers specification, evaluation, and testing of materials used in the rehabilitation of existing pipes by the installation and cure of a resin-impregnated fabric liner. (Material standard)

ASTM F1216 and **ASTM F1743** describe the procedures for the reconnection of pipelines and conduits by the installation of a resin-impregnated, flexible tube which is inverted by use of a hydrostatic head or air pressure (F1216) or the pulled-in-place (F1743) into the existing conduit. (Installation standards)

ASTM F2019 is the third generic ASTM standard for CIPP liners (installation standard) that covers a tube composed of a fiberglass-reinforced material. It describes procedures for the reconstruction of pipelines and conduits 4 to 48 in. in diameter by pulled-in place installation followed by inflation with compressed air. The resin/fabric tube is cured by mixed air and steam.

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

7. EXAMPLE CASE HISTORIES

Gwinnett County, GA completed a total of 136 culvert CIP lining projects up until April 2009 (Table 1). The majority of the lined pipes were of the corrugated metal classification, and the rest were clay, concrete and plastic pipes. Since April 2009, 12 CIP culvert lining projects were completed, all of which were cured using steam rather than hot water. (Frank Matticola, Gwinnett Co, personal communication).

Table 1. Culvert CIP lining projects in Gwinnett County, GA between Dec 2005 and Apr 2009

Item	Diameter	CIPP Liner Thickness	Cumulative Length
1	15 in.	7.5 mm	516 ft
2	18 in.	8.0 mm	5997 ft
3	21 in.	10.0 mm	2,021 ft
4	24 in.	10.0 mm	5,531 ft
5	30 in.	12.5 mm	5,098 ft
6	36 in.	16.0 mm	5,607 ft
7	42 in.	18.0 mm	3,332 ft
8	48 in.	21.0 mm	2,266 ft
9	54 in.	24.0 mm	1,649 ft
10	60 in.	28.5 mm	1,030 ft
11	66 in.	30.0 mm	223 ft
12	72 in.	32.5 mm	221 ft

8. ADVANTAGES AND LIMITATIONS

The main advantages of CIP relining are elimination of the need for excavation and grouting, and installation of a one piece (jointless) product that provides structural renewal with an expected 50-year service life. CIPP is a proven technology (it has been in use for 30 years), may be cost effective, and causes minimal traffic disruption. Small diameter installations can be completed in as little as one day.

The main limitations of this method are the need for flow bypass (unless the culvert pipe is empty at the time of rehabilitation), custom made tube is required for each installation, trained personnel are required, prolonged liner cure is needed for large diameters, there is potential for thermal pollution (if hot water was used to accelerate resin cure) and there is potential for adverse environmental impact (if styrene-based resins are used).

9. REFERENCES

Gearhart, S., 2008. "Tutorial: Cured in Place Pipe," *UCT 2008*, Atlanta, GA, Jan 29-31, 2008, paper T1A-05, 38p

Jaques, J., 2008b. "Old Montreal Avoids Infrastructure Trauma," 31st Annual Conference HWEA 2008, Honolulu, HI, Feb 19-21, 2008, Hawaii Water Environment Association (HWEA), 56 slides

Kampbell, E., 2005. “Cured In Place Pipe Designed To Last,” *NASTT NO-DIG 2005*, Orlando, FL, April 24-27, 2005

Kampbell, E., and L.G. Whittle, 2003. "QA/QC for Trenchless Pipeliners," white paper, http://www.ultraliner.com, downloaded on 04/22/2004, 10p

McClanahan, D., 2007." Tutorial: Cured-In-Place Pipe," *UCT 2007*, Atlanta, GA, Jan 29-31, 2007, T1B-1, 21 slides

McClanahan, D., 2009. "CIPP Installation, Curing and Repair," a presentation given at the CO Municipal Users’ Forum,” Littleton, CO, Mar 10, 2009, 28 slides

NASTT, 2006. "QA/QC for Trenchless Methods: Cured-in-Place-Pipe (CIPP)," *NO-DIG 2006*, Nashville, TN, Mar 27-29, 2006

Poly-Triplex Technologies, Inc: *Poly-Triplex® Technologies*, product brochure, 8 p, Poly-Triplex Technologies, Inc, Bonifay, FL.

Sain, D. and R. Montemarino, 2009. “Adopting UV Fiberglass CIPP in Sewer and Stormwater Rehabilitation Bid Specifications,” *Intl NO-DIG 2009*, NASTT/ISTT, Toronto, ON, Canada, Mar 29-Apr 3, 2009, paper F-3-04, 6p.

Shearer, N., 2007. “Next Generation Trenchless Technologies,” a presentation given at the ArkLaMiss Municipal Users’ Forum, Ruston, LA, Nov 24, 2007, 28 slides

Simonson, J. and T. Peterie, 2002. "Tutorial: Cured-In-Place-Pipe Basics," *UCT 2002*, Houston, TX, Jan 15-17, 2002, 43 slides

SWL, 2004. *D-Load Bearing Tests of Poly-Triplex PTLS-11600 Liner*, WO: POL056-04-28-57624-1, 04/30/2004, Southwestern Laboratories (SWL), Houston, TX, 2p.

Thornton, C.I., M.D. Robeson, L.G. Girard, B. A. Smith, 2005. *Culvert Pipe Liner Guide and Specifications*, FHWA-CFL/TD-05-003, Federal Highway Administration (FHWA), McLean, VA, July 2005, 169p

WERF, 2006. *Methods for Cost-Effective Rehabilitation of Private Lateral Sewers*, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436p.

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