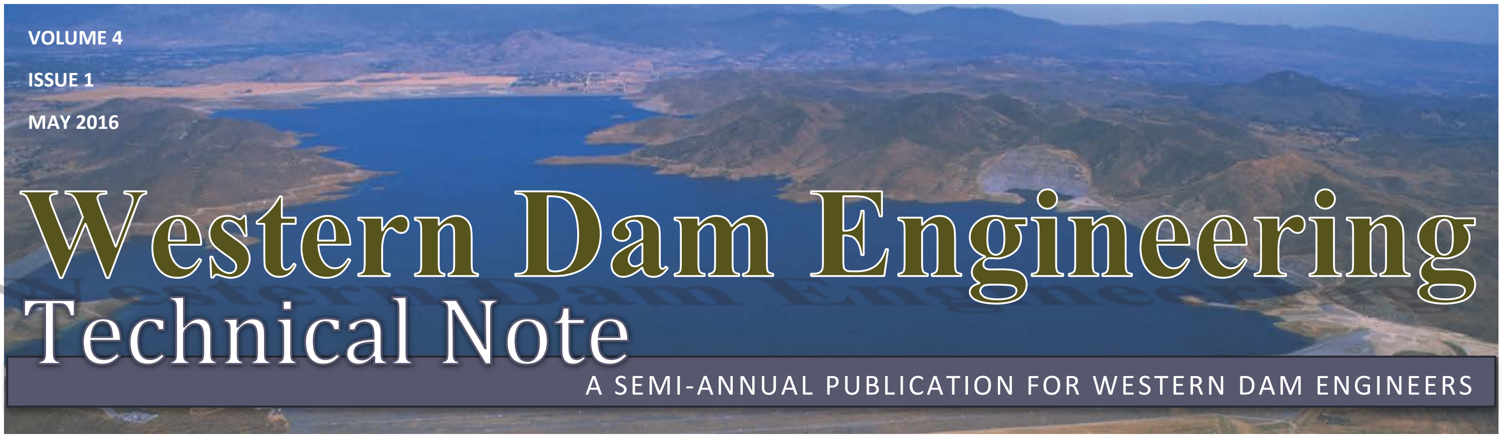


VOLUME 4
ISSUE 1
MAY 2016

Western Dam Engineering
Technical Note

A SEMI-ANNUAL PUBLICATION FOR WESTERN DAM ENGINEERS

In this issue of the ***Western Dam Engineering Technical Note,*** we present articles on **mobile applications for dam engineers,** considerations for pipe rehabilitation using **cured-in-place pipe (CIPP)**, and a **first on a series of seepage** articles. This semi-annual newsletter is meant as an educational resource for civil engineers who practice primarily in rural areas of the western United States. This publication focuses on technical articles specific to the design, inspection, safety, and construction of small to medium sized dams. It provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

The Western Dam Engineering Technical Note is sponsored by the following agencies:

- Colorado Division of Water Resources
- Montana Department of Natural Resources
- Wyoming State Engineer's Office

This Technical Note was compiled, written, and edited by AECOM in Denver, Colorado

Funding for the Technical Note has been provided by the FEMA National Dam Safety Act Assistance to States grant program.

Article Authors:
AECOM: Taylor Rawlinson, Ph.D., Aaron Neff, Bob Waddell, P.E., Dan Johnson, P.E., Jennifer Williams, P.E.

Good to Know

FEMA Training Aids for Dam Safety (TADS): A Self-Instructional Study Course in Dam Safety Practices

Upcoming ASDSO Webinar Dam Safety Training:

- **Strength Selection for Static Slope Stability Analysis** *John France, P.E., and Christina Winckler, P.E.; May 10, 2016 (On Demand)*
- **Cracking and Hydraulic Fracturing in Embankment Dams and Levees** *by Debora J. Miller, Ph.D., P.E.; June 14, 2016*

Upcoming ASDSO Classroom Technical Seminars

- **Inspection and Assessment of Dams***, Omaha, NE., May 25-27, 2016.*
- **Inspection and Assessment of Dams***, Jackson, MS, June 7-9, 2016.*

ASDSO Training Website Link

In this Issue

You Down with CIPP? – Yeah! You Know Me!

Introduction

Cured-in-place pipe (CIPP) is becoming a more common method used to rehabilitate deteriorated outlet piping on dams, and offers many benefits over other pipeline rehabilitation methods. CIPP has been successfully used in renovating deteriorated pipelines, drain pipes, and conduits through levees and has been used for conduit renovation through embankment dams since about the mid-1990s [5]. The CIPP system consists of a flexible fabric tube and a resin system that is hardened by a curing method. The resin is the primary structural component of the system. A fabric tube is used as a means to install and temporarily support the resin until it is cured in place. The CIPP liner resin is typically injected into the fabric ("wet-out") at the manufacturing facility for quality control and shipped to the project site, where it is cured after installation. The fabric tube and resin systems vary depending on the CIPP manufacturer and the design of the CIPP. Some common fabric tube materials are polyester felt and glass fiber composite cloth. Some common resin systems are unsaturated polyester, vinyl ester, and epoxy. CIPP is installed inside an existing pipeline by either an inversion method or a pulled-in-place method. After the CIPP is installed, it is cured in place using one of several available techniques and forms to the shape of the existing pipe, including minor irregularities. This article presents some considerations for selecting and designing an effective CIPP system for pipeline rehabilitation.

CIPP Selection Considerations

Selecting the right rehabilitation method needs to consider the cause of the deficiency prompting the repair. Pipeline repair can range from isolated repairs of a leaky joint or crack, to more global rehabilitation of a deteriorated pipe. A known construction defect that resulted in an open joint could warrant isolated repair using expandable bands or grout; whereas, deterioration due to general aging of the pipe would warrant a more global rehabilitation. CIPP is most often considered as a global rehabilitation method. Although segment lining is possible (lining only a portion with CIPP), it induces greater hydraulic irregularities within the pipe and cost inefficiencies associated with an isolated repair as compared to other alternatives. Global rehabilitation with CIPP can be compared to other common methods such as remove-and-replace using cut-and-cover techniques or slip lining. See the previous Western Dam Engineering article for additional considerations on outlet conduit rehabilitation: Low-Level Conduits - Rehab or Replace?. Table 1 summarizes a few key considerations when initially screening the viability of CIPP as a potential rehabilitation method.

Table 1. Considerations for Evaluating Suitability of CIPP as a Viable Pipe Rehabilitation Method

Conditions	Considerations
Pipe Pressure	CIPP can be a good option for pressurized pipes because of the jointless installation but both internal and external pressures need to be taken into account during the design.
Host Pipe Alignment	CIPP is suitable for pipes with gentle bends; however, certain curing methods work better under certain conditions. Steam curing is best for long runs of steeply sloping pipe to avoid excessive hydrostatic pressure. Water curing is best for pipes with bellies since steam condensation can accumulate in bellies, preventing proper curing due to cooling at those locations. CIPP is not suitable for pipes with significant bends or changes in diameter.
Flow Conditions	Pipes should be fitted with proper venting to prevent cavitation and negative pressures that could damage the lining.
Degree of Pipe Deterioration	Can be used for partially to fully deteriorated pipes; however, not well-suited for deformed/collapsed pipes.
Pipe Size	CIPP can be installed in pipes from 4 to 108 inches in diameter and up to 3,000 feet in length. Liners on the upper end of this range have practical limits due to material handling and transportation limitations as the liner needs to be shipped in one piece.
Access	Access to both ends of the pipe is typically required, regardless of curing method. Site access for equipment mobilization and efficient installation are also considerations as different curing methods require significantly different equipment.
Climate	May influence selection of curing methods and related resin.

Advantages of CIPP

The advantages of selecting the CIPP outlet conduit rehabilitation method include:

- CIPP is a trenchless pipeline rehabilitation process
  - The embankment does not need to be excavated to install the CIPP.
  - The CIPP is installed directly inside the existing pipe.
- No grout is needed of the annulus between the CIPP liner and host pipe.
  - With proper installation, the CIPP lining fits tight against the existing pipeline and should not require grout for a watertight seal.
- Typically no joints are required and installation is rapid
  - The CIPP is installed in one continuous process, extending from one end of the pipe to the other; and does not require joints.
  - Long lengths can be installed quickly, but proper curing is required before recommissioning the pipeline.
  - After curing is complete, the ends of the CIPP liner are cut flush with the ends of the existing pipe and treated to create a seal. End treatments can consist of mechanical seals, grinding the ends of the CIPP smooth, and using epoxy.
  - No thermal or contraction joints are required because CIPP is installed in one continuous piece.
- The CIPP lining decreases the interior diameter of the pipeline, but the smooth interior surface of the CIPP lining usually improves the roughness coefficient, resulting in increased flow capacity in some cases.
- Noncircular pipes can be rehabilitated with CIPP.
- The CIPP lining is capable of accommodating bends, minor changes in cross section, and other slight shape variations in the pipeline.
- The cost of CIPP can be competitive with other rehabilitation methods for longer lengths of pipe (e.g. several hundred feet), but may not be cost-effective for shorter lengths of pipe due to higher installation costs.

Design Considerations

The American Society for Testing and Materials (ASTM) Standards F1216, F1743 and F2019 provide design standards for CIPP. Manufacturers also provide guidelines for designing their individual CIPP products. Most manufacturers specialize in certain CIPP systems, thus ensure the proper CIPP system is selected and understood independent from the manufacturer. Thickness of the CIPP lining depends on the diameter of the existing pipe, the type of CIPP resin system, discharge requirements, condition of the existing pipeline, and loading. Liner thickness typically ranges from about one half inch for smaller pipes to over 2 inches for larger pipes under external loads. CIPP typically has up to a 50-year design life and can be used to rehabilitate pipes ranging in diameter from 4 to 108 inches with insertion lengths of up to 3,000 feet. One limiting factor is weight restrictions for transporting the liner from the manufacturer to the jobsite, as it must be transported in one piece.

CIPP can rehabilitate aging pipes that range from partially to fully deteriorated, as the liner provides improved structural integrity. A fully deteriorated pipe has lost most of its structural capacity and thus the liner needs to provide structural support for the pipe, as well as a water tight seal. The liner thickness can be designed and fabricated to meet the necessary structural criteria for most applications. A partially deteriorated pipe may have sufficient structural capacity to support soil and surcharge loads and the primary function of the liner is to create a water tight seal and slow further deterioration. However, regardless of the degree of deterioration of most host pipe materials, the CIPP should be designed assuming the host pipe provides no support. This more robust design of a self-supporting CIPP improves the longevity of the rehabilitated pipe for a small incremental cost.

Pipes deteriorated to the point of impending collapse may not be a candidate for CIPP, as proper installation is likely infeasible.

Careful attention must be paid to design parameters when determining if CIPP is the best option for an outlet rehabilitation. One of the critical design parameters for CIPP is the liner thickness and resin material required to withstand external and internal pressures. Internal pressures can be induced by static head pressures from the reservoir as well as positive and negative pressures under dynamic flow conditions. Outlet control configurations on gravity piping and pressurized flow within outlets connected to supply, treatment or distribution systems are cases that can induce significant internal pressures. Proper venting of the pipe is also required to prevent collapse of the CIPP lining due to internal vacuum pressures that can develop during operation. See the previous Western Dam Engineering article on pipe venting: Design Considerations for Outlet Works Air Vents

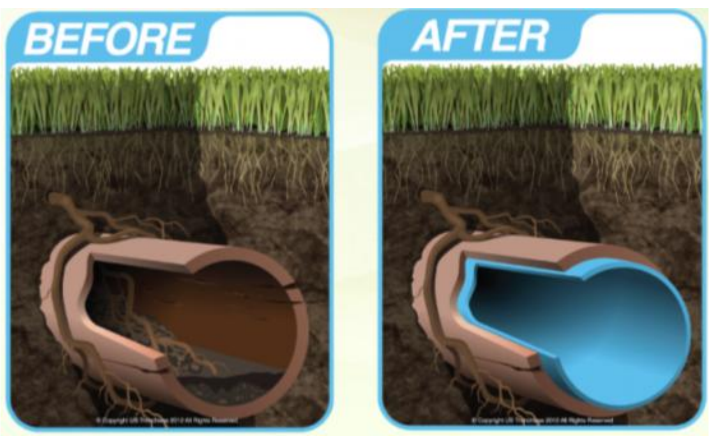


Figure 1 – CIPP Installed inside Existing Pipeline [8]

The minimum required initial modulus of elasticity of the cured liner, per the ASTM Standards, is 250,000 lb/in^2. Typically steam and water cure methods provide an initial modulus of elasticity ranging between 250,000 to 450,000 lb/in^2 and ultraviolet cure methods provide an initial modulus of elasticity ranging between 1,015,000 to 2,600,000 lb/in^2 (see Liner Materials and Curing Methods section for curing procedures). However, the CIPP liner needs to be designed for the long term modulus of elasticity. Typically the long term modulus of elasticity used for a 50-year design life is 50% of the initial modulus of elasticity.

Resins used for CIPP are the most important component to the performance of the CIPP including parameters such as strength, chemical resistance, and creep. Thermoset resins used for CIPP generally fall within one of three categories: polyester, vinyl ester and epoxy resins. Polyester or vinyl ester resins are also formulated for cure by UV. In general epoxy and vinyl ester resins are higher performance products compared to polyester resins. They have higher strength, elongation, elevated thermal and chemical resistance compared to polyesters. Mineral fillers, such as aluminum trihydrate or calcium carbonate, can be added to resins to significantly increase the modulus (i.e. stiffness) of the CIPP without decreasing the strength or the chemical resistance. [7] As may be expected, the higher performance products come at a higher cost, and some projects may not warrant higher performance parameters.

The fabric tube material will also influence the mechanic properties of the combined resin/tube material. Depending on the type of tube fabric, it can either enhance or reduce the mechanical (e.g. strength) properties of the raw resin.

Beside resin type and liner thickness for loading considerations, other key design parameters include entrance and terminal structures, selection of diameter considering both heat-induced shrinkage as well as potential circumferential stretching, and selection of appropriate curing system considering environmental, access, and climate considerations.

Installation

For proper installation of CIPP, both upstream and downstream access to the pipeline is required. The two installation methods are the inversion method (ASTM F1216), in which the liner is installed by progressively turning it inside-out from its initial as-shipped configuration, and the pulled-in-place method (ASTM F1743 and F2019). The installation method is chosen based on site conditions and design of the CIPP resin and curing system. During installation, the CIPP lining is inflated and pushed tight against the host pipe, compressing the fabric and resin against the interior of the host pipe. Once cured, the CIPP resin bonds to the host pipe to prevent sliding of the CIPP lining.

Prior to Installation

- Inspect the pipeline to determine if the pipe is clear of toxic materials in accordance with local, state, and federal safety regulations.
- Clean the pipeline with hydraulically or mechanically operated equipment and clear the pipeline of any debris.
- Perform a second inspection when the pipeline is clean, to determine the location of any conditions that may prevent proper installation, including:
    - Seepage inside the pipe
    - Protruding objects inside the pipe
    - Crushed or collapsed pipe

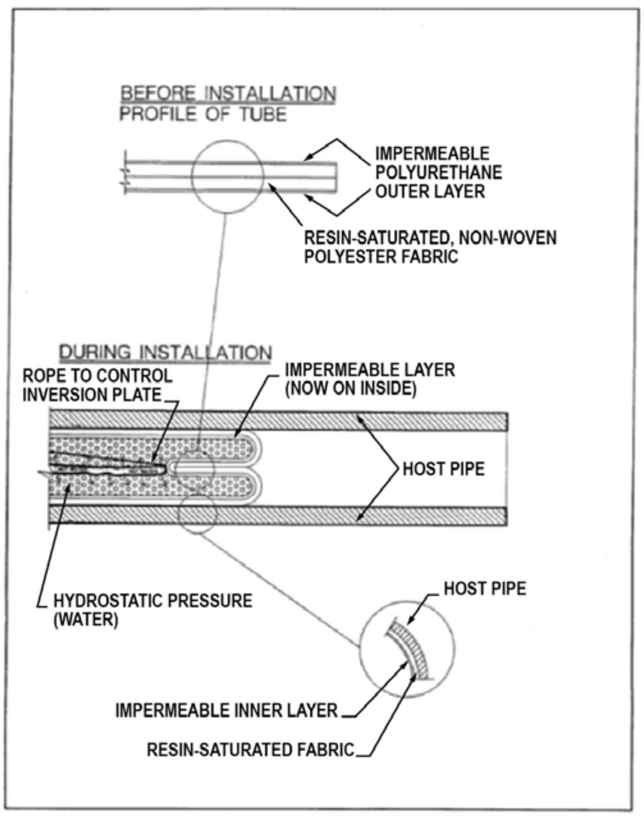


Figure 2 – Inversion Installation Method [5]

Inversion Method

- The CIPP liner is shipped inside-out with the resin already impregnated. Once on site, it is then attached to an inversion standpipe so a leak proof connection is created. The smooth, un-impregnated side if left on the outside for ease of handling.
- Then, either air, steam, or water is pushed into the CIPP liner, inverting it (turning it inside-out) and pushing it into the host pipeline for its entire length. Once inverted, the resin side is directly against the inside of the host pipe, and the smooth side is in the flow area. Compressed air is typically used for inversion in the steam curing application and water is typically used in the hot water curing method.
- The CIPP manufacturer determines the minimum and maximum air or water pressure required to push the CIPP liner tight against the existing pipe without damaging the fabric tube of the CIPP.
- Inversion is the most common installation method, and water is the most common fluid used to invert the liner.

Figure 3. CIPP liner exiting from an existing conduit via the hydrostatic inversion method [5]

Pulled-in-Place Method (also called Winch-in-Place)

- Pulled-n-place liners are typically used for (a) short, large diameter pipes, (b) long CIPP runs where inversion pressures would be overly high, (c) where inversion equipment would have difficult access, or (d) for UV light cured resin applications.
- A pulling tape or cable is first threaded through the host pipe. (This process has its own set of challenges!) The CIPP liner is attached to the cable or tape and to a winch or other mechanically operated device to pull the lining in place.

- Special care needs to be taken when pulling the liner in place so it is not damaged due to friction.
- Liners used for this type of installation require a second inner calibration tube or bladder to inflate the resin-impregnated tube.
- After the CIPP liner is in place, a calibration hose is inverted inside the liner and water or air is forced into the liner, expanding it, and holding it tight against the existing pipe.
- The CIPP manufacturer determines the minimum and maximum air or water pressure required to push the CIPP liner tight against the existing pipe without damaging the fabric tube of the CIPP.

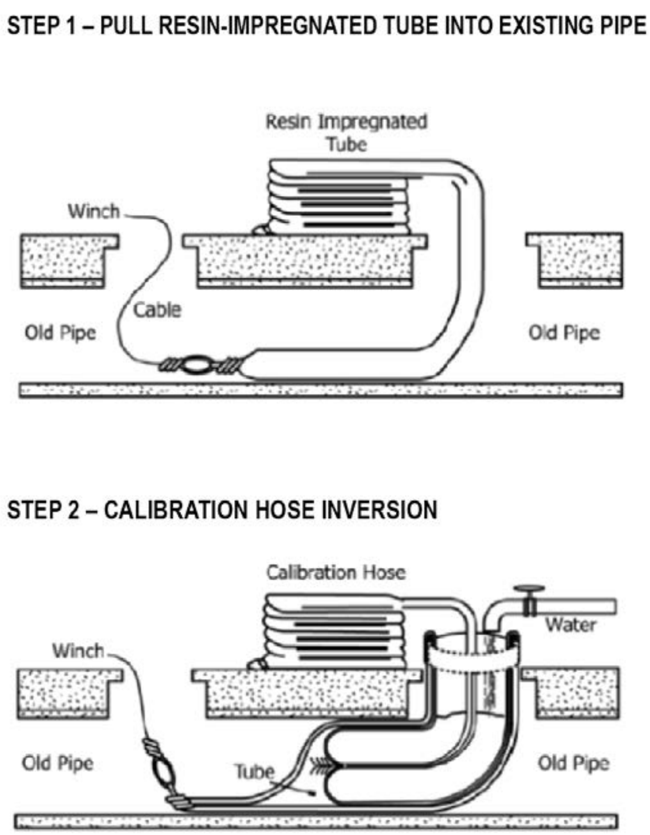


Figure 4 – Pulled-in-Place Installation Method [2]

Post-Installation

The CIPP liner should be inspected by trained personnel following installation. If the CIPP-lined conduit is too small for man-entry inspection, video inspection methods should be used. No dry spots, lifts, delamination, pinholes, wrinkles, twists or infiltration of groundwater should be present and the CIPP liner should be in a fully expanded condition. Some installation and curing systems, such as certain UV systems, have provisions for video inspecting the installation once inflated and prior to curing. This is preferred as installation deficiencies can be corrected prior to curing of the CIPP.

Liner Materials and Curing Methods

Curing of the liner refers to the process of hardening the resin through polymerization induced by either thermal or UV light exposure. Selection of the resin and curing method are interdependent, as the curing methods will dictate the resin to be used. The curing of each liner utilizes a delicate balance of resin catalyst level, curing temperature and time of exposure to maximize the installed physical properties [6].

Proper transportation of the CIPP lining materials is critical, especially for thermally-cured resins in hot climates. Care needs to be taken to avoid damage to the fabric and prevent premature curing of the resin while being transported. Most CIPP resin systems are thermosetting and the resin starts to cure when exposed to heat; therefore, it should be transported in a refrigerated truck. Ultraviolet (UV) light can also be used to cure CIPP and these liners should be transported in light-tight packaging, but have a significantly longer shelf life with no need for refrigeration.

The common curing methods are heated water, steam, ambient, and Ultra Violet light (UV). All curing methods require an internal pressure to press the liner tight against the host pipe before and during curing. Recommended pressures should be maintained throughout the curing process. The curing process used will be based on available resources, access, transportation distance, climate, and the manufacturer's recommendation for the specific resin system. For thermosetting (steam/hot water) curing methods, the CIPP should be cooled in a controlled manner after the curing process is complete.

Circulating Heated Water

Cool water is used initially to invert the pipe to prevent premature curing until the liner is fully installed, and the water inside the liner is subsequently heated. As the liner is inverted, a hose is inserted with the CIPP tube and is subsequently used to circulate hot water from a boiler through the inside of the water-filled liner, heating the water and resin-impregnated liner, causing the resin to cure. Heated water can be circulated throughout the installed CIPP at the required temperature to initiate cure of the resin. The water temperature should be constantly monitored to maintain it above the required cure temperature for the minimum time required. The initial cure will be complete when the exposed CIPP is hard and temperature sensors show the resin has reached the required temperature. After the initial cure, the water temperature should be raised to the required post-cure temperature for the time recommended by the manufacturer.

Steam

The use of steam to cure CIPP liners is most often used for installing liners within pipes from about 6 to 36 inches in diameter. The steam cure method is normally faster than hot water cure, as heat transfer from steam occurs more rapidly. Steam is used in conjunction with pressurized air that inflates the liner against the host pipe and distributes the steam from one end of the liner to other. After the liner has been placed in the host pipe, steam cans, or other similar equipment, are attached at each end of the pipe to distribute steam uniformly throughout the CIPP. Steam with compressed air is then passed through the liner, pressing the liner tight against the host pipe and heating the resin until cure is complete.

The steam generating system should be constantly monitored to maintain the steam temperature above the required cure temperature. The initial cure will be complete when the exposed CIPP is hard and temperature sensors show the resin has reached the required temperature. After the initial cure, the steam temperature should be raised to the required post-cure temperature for the period of time recommended by the manufacturer, then cooled in a controlled manner as described below. Steam is not recommended for pipes that have bellies or vertical bends (such as siphons), as the steam may condense and pool in low areas preventing that portion of liner from reaching the required curing temperature. Condensation also collects at the downstream end of the pipe; therefore, a fitting with a drain hole is usually installed at the downstream end.

Steam curing is two to three times quicker than water curing and is better with restricted-access installations. Steam is also better for steeply-sloping pipes to avoid excessive hydrostatic pressure that can result with water-cured procedures.

Cool-Down

With both the heated water and steam curing methods, the temperature should be cooled below 100°F in a controlled manner before relieving the internal pressure on the CIPP to avoid unwanted shrinkage. The manufacturer will provide the recommended cooling process and temperature drop intervals based on the fabric, resin, and pipe size. The most common cool down process circulates cool water throughout the CIPP. The air or fluid pressure inside the CIPP should be monitored and relieved in a controlled manner so an internal vacuum does not occur and damage the CIPP.

Environmental

Some thermoset resins (e.g. vinyl ester) can contain up to 33 parts per million (ppm) of styrene. Styrene-contaminated resins and water must be disposed of properly and cannot be discharged into stormwater systems because of concerns with its odor and volatile organic compound (VOC) emissions. There are some newer formulations of thermoset vinyl ester resins that reduce VOC emissions. Epoxy resins are naturally VOC-free, but are generally more costly and must be mixed and applied on-site rather than in a controlled factory setting.

UV

There are resin systems that can be cured with UV light. These resins do not react to temperature but rather contain a photo-initiator that reacts to certain UV light wavelengths. UV-curable liners use a nonwoven glass fiber tube, rather than other nonwovens, because the translucent glass fibers permit light transmission through the liner's thickness. A UV light is pulled through the CIPP at the required wavelengths initiating cure of the resin. UV cure is recommended in colder temperatures where heat cure would be more expensive and less efficient. UV may also be a beneficial alternative for remote locations with long transport times, as these products have a much longer shelf-life without refrigeration and do not begin to cure if properly protected from light. Resins cured with UV light can also be used to avoid the environmental impact of some thermoset resins. UV cured resins do not contain styrene but they are more expensive than styrene-based resins. Since UV curing is not heat dependent it has less shrinkage than hot water and steam cure. UV cured CIPP has less than 0.5% shrinkage and hot water and steam cured CIPP can have up to 12% shrinkage. However, UV liners are limited in thickness and diameter because the thicker the liner and the farther its surface is from the light source, the less intense, and less effective the light is at curing the resin. Typical UV liners are limited to about 0.5- to 0.6-inch thick and about 50 inches in diameter.

Ambient

This method of curing is generally not recommended because it takes longer for the resin to cure and the temperature is not as easily controlled resulting in a lower quality product. The CIPP can be cured at ambient temperatures above 65 degrees Fahrenheit, or at the temperature recommended by the resin manufacturer. However, ground temperatures within dams are typically below 60 degrees limiting the effectiveness of this technique.

Termination and End Seals

After the curing process is complete, the ends of the CIPP liner are trimmed flush with the ends of the existing pipe, as needed, and any air vents or other service connections are cut and smoothed and the ends of the CIPP are treated. The ends of the CIPP can be treated using mechanical seals, grinding the ends of the CIPP smooth, or using epoxy. With smaller diameter pipe, where access inside the pipeline is limited, a robotic remote controlled device can be used inside the pipeline to make the necessary cut outs. As required by the contract or purchase agreement, samples of the CIPP can be tested for flexural and tensile strength and chemical resistance. Thermosetting setting resin systems have different shrinkage properties, both radially and longitudinally. The design length of the as-shipped CIPP liner should consider the potential for longitudinal shrinkage.

Table 2. Comparison of Curing Methods

	ADVANTAGES	CONSIDERATIONS
Hot Water	• Historically proven method • Ability to address sags/standing water • One uniform temperature throughout pipe • Accommodates long lengths/large diameters	• Consumption of Water to inflate/cure • Height access for inversion towers • Steep slope limit due to weight of water
Steam	• Less time to complete curing • Higher degree of cure = higher properties • Allows for steep slope installations • Limited water supply and access required	• Safety considerations of steam use • Length and thickness limitations • Potential of coating to blister from heat
UV	• Glass fiber allows for reduced laminate thicknesses • Accommodates both polyester and vinylester resins • Styrene barriers minimize environmental impact • Shelf life up to six months; no refrigeration • Ability to view liner before it is cured • Ability to accommodate and control pipe seepage during installation	• Size limitation of 6-48" • Typically slightly higher cost compared to felt CIPP • Minimal expansion capability for abnormal pipes
Ambient	• Minimal curing equipment • Less expensive	• Requires ambient temperatures above 65°F, which is uncommon in dam outlet works pipes. • Longer cure duration and limited temperature controls may lead to reduced quality

Adapted from inliner™ technologies [6]

Case Studies

Project 1

CIPP was used on one project to rehabilitate an old bituminous coated 48-inch corrugated metal pipe (CMP). The downstream portion of the old CMP was replaced with a new reinforced concrete pipe (RCP) and the upstream portion of the old CMP was slip lined with CIPP. The CIPP was installed through an access point at the gate tower and cured with circulating hot water.

Figure 5 – CIPP installed through gate tower (White pipe is the CIPP and black pipe is used to circulate hot water for curing)

After installation and curing was complete, it was noticed that the CIPP did not fit tightly against the existing CMP and there were gaps between the two pipes. Portions of annular space between the CIPP and the old CMP had to be grouted to fill these gaps. The problems with this installation were thought to be caused by the larger size of the original pipe (48-inch) and the distance from the CIPP manufacturing point to the project site. It was speculated that because of the long travel distance to the site, the CIPP began to cure enroute.

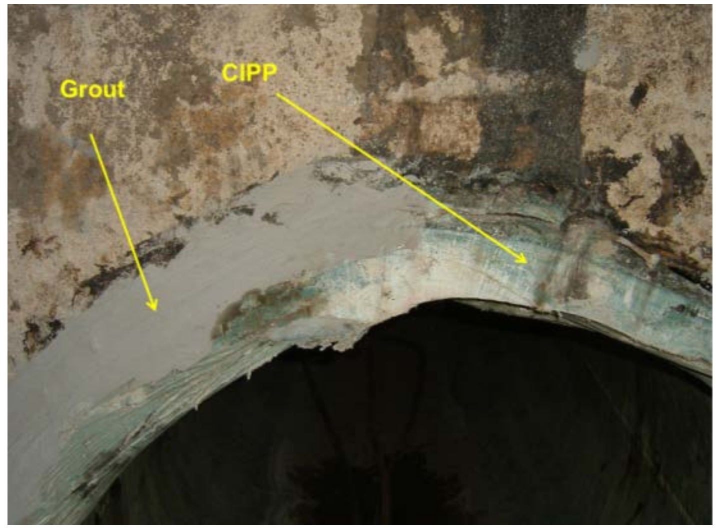


Figure 6 – Loose-fitting CIPP against Old CMP. (Portions of the pipeline had to be grouted.)

Project 2

In this case, CIPP lining was used to rehabilitate a 24-inch CMP successfully. The CIPP fit tightly to the existing CMP and no issues were noted. The difference between the two projects was that Project 2 had a smaller diameter pipe and the project site was close to the manufacturing location.

Figure 7 – CIPP Being Installed to Rehabilitate 24-inch CMP

Figure 8 – CIPP after Installation

Lessons Learned

- The location of the project and travel time from the manufacturing location need to be considered when determining if CIPP is the best option and selecting the appropriate CIPP resin and curing system. CIPP may not be the best option for remote project locations.
- CIPP may be difficult to install in large diameter pipes, particularly those with non-uniformities, and this possibility should be taken into account during the design and installation processes.

Project 3

This project involved the successful CIPP lining of an existing 12-inch CMP outlet conduit. An inspection of the existing CMP pipe showed the pipe needed to be repaired based on the amount of corrosion and seepage into the pipe. The CIPP manufacturer in this case recommended using UV curing identifying the advantages of UV cure; stronger material, thinner walls, and UV/pressure curing allowed the seepage into the existing pipe to be controlled better during installation. The CIPP was installed using the pulled-in-place method and inflated tight against the existing pipe with air pressure. After installation the UV light string was pulled through the CIPP lining for curing. Once curing was complete the ends of the CIPP were cut flush with the existing pipe and Xypex was used to seal the ends of the CIPP. Due to the small diameter of the pipe, a cutter robot was used to go inside pipe and cut out all existing laterals.

Figure 9 – UV-cured CIPP lining installed inside the existing 12-inch CMP

Common Pitfalls of CIPP

While there are many advantages to using CIPP, there are also common pitfalls and disadvantages.

- Successful, high-quality design and installation of CIPP requires a company and personnel with expertise in CIPP and specialty equipment to ensure strength requirements are met.
  - The installation of CIPP is not a common procedure; a company with expertise in CIPP will ensure the CIPP is not damaged during the shipping or installation process, and that resulting installation will meet quality standards.
  - Special equipment is required for a proper cure; curing system equipment must be robust, reliable, and operable by the installing crew.
  - Pressure and temperature need to be monitored constantly throughout the installation and curing processes for most common curing methods.
- While transporting and prior to installation, thermally-cured CIPP needs to be kept in a cool environment so early cure of the CIPP does not occur.
  - Some resins can be sensitive to installation in hot climates.
  - As shown with the case studies, travel distance from the CIPP manufacturer to the project site should be taken into account.
- CIPP installation and curing equipment can include water tanks and boiler trucks for the

hot water and steam cure processes. Such equipment may be difficult to get to remote dam sites.

- CIPP liners with damage from shipping or poor installation techniques including punctures, breaks, or abrasions must be replaced and should not be repaired in the field.
- Infiltration and/or seepage into the existing pipeline need to be controlled prior to installation of the CIPP.
- If the CIPP is not correctly sized, it will not fit properly inside the existing pipeline.
  - Wrinkles can occur if the CIPP is too large.
  - Voids can occur between the CIPP and the existing pipe if the CIPP is too small.

References

[1] American Society for Testing and Materials, *F1216 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube*, ASTM International, 2009.

[2] American Society for Testing and Materials, *F1743 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)*, ASTM International, 2008.

[3] American Society for Testing and Materials, *F2019 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Pulled in Place Installation of Glass Reinforced Plastic (GRP) Cured-in-Place Thermosetting Resin Pipe (CIPP),* ASTM International, 2009.

[4] Dawson, Donna. Composites World. 30 November 2012. *Cured-in-Place Pipe: Trenchless Trends.* [ONLINE} Available at: http://www.compositesworld.com/articles/cured-in-place-pipe-trenchless-trends. [Accessed 29 March 2016].

[5] Federal Emergency Management Agency, *Technical Manual: Conduits through Embankment Dams Best Practices for Design, Construction, Problem Identification, and Evaluation, Inspection, Maintenance, Renovation, and Repair*, FEMA 484, September 2005.Available at: FEMA.gov

[6] Inliner Technologies. 2015. *Curing Methods*. [ONLINE] Available at: http://www.inliner.com/en/products/curing-methods.aspx. [Accessed 16 April 2016].

[7] Lanzo Lining Services, Inc. 2010. *Engineering Design Guide For Rehabilitation With Cured-In-Place Pipe*, Second Edition. [ONLINE] Available at: http://lanzo.net/pdf/lanzo-lining-guide-2410.pdf. [Accessed 16 April 2016].

[8] U.S. Army Corps of Engineers, *Guidelines for Trenchless Technology: Cured-in-Place Pipe (CIPP), Fold-and-Formed Pipe (FFP), Mini-Horizontal Directional Drilling (Mini-HDD), and Microtunneling*, Construction Productivity Advancement Research (CPAR) Program Report No. CPAR-GL-95-2, Waterways Experiment Station, 1995d. Available here: http://www.dtic.mil/dtic/tr/fulltext/u2/a304645.pdf

[9] US Trenchless General Engineering & Plumbing. 2015. *Cured-in-Place pipe liners*. [ONLINE] Available at: http://www.ustrenchless.com/services/pipe-lining/. [Accessed 18 March 2016].

Is Your Embankment Dam under Pressure – Underseepage Impacts

Introduction

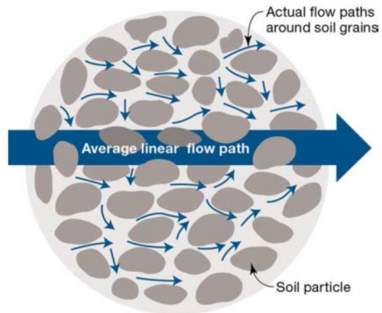
A simple truth: every embankment dam that retains water also seeps water. This is due to the nature of soils and rock that constitute earth dams and porous dam foundations that have a potential to allow flow of water. The question will always be — Does the mechanism, location, and volume of seepage cause concern for the safety of the dam? How does one identify acceptable versus unacceptable seepage? These are lofty questions that dam engineers, top academics, and research agencies have been studying for decades, resulting in a continuous evolution of the understanding of seepage mechanics of earth dams during the past 100 years.

The majority of U.S. dams are more than 50 years old and were designed and built prior to the current understanding of internal erosion control. One of the common challenges of evaluating an existing structure is recognizing what the surface expressions may be telling us about the internal mechanisms at work, (i.e., when a potentially hazardous condition may be developing). This concept is especially applicable to earth dams that are composed of and founded upon natural materials.

Giving dam owners, operators, engineers, and regulators the knowledge and tools to monitor, detect, and evaluate observed seepage is an enduring task. This article introduces the extensive, yet critically important topic of seepage and focuses on the mechanics, monitoring, and investigation of seepage through the soil foundations of earth dams. More importantly, the article provides guidance as to when observed foundation seepage should be a concern. Future articles will focus on other aspects of earth dam seepage including embankment seepage, emergency response to seepage incidents, and long-term remedial measures.

Basic Seepage Knowledge

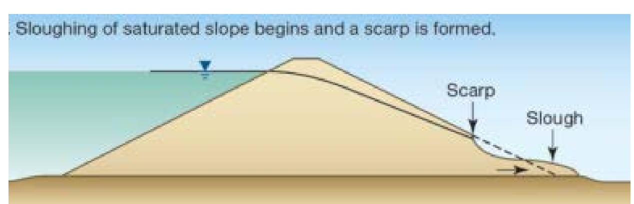
Seepage is defined as the flow of a fluid (water) through the porous space within a soil mass. Although on a micro scale the seepage follows an irregular path



around the solid particles, engineers generally think in terms of the average linear flow path. Much work has been completed on the topic of seepage, and Cedergren's *Seepage, Drainage, and Flow Nets* [1] is an excellent book on the characteristics of flow under and through dams. Most current seepage approaches are based on his assessments.

Seepage that simply results in water loss is not necessarily a dam safety issue. It can, however, be an economic or societal issue, as retaining or storing water is the dam's primary function. If the structure is not good at that, then cost and social impacts of the water loss may warrant improvements. Clean seepage from a dam may result in an inadvertent creek or pond downstream of the dam, unintentionally feeding distant aquifers, or causing settlement of nearby roads or structures—but these may not significantly affect the integrity of the dam structure itself.

When seepage velocity is great enough, erosion of the soil can occur because of the frictional drag exerted on the soil particles. Dam safety engineers are focused on seepage that erodes the soil material of the dam or its foundation. This type of seepage-induced erosion can be considered in two broad categories; surface erosion and internal erosion. **Surface erosion** due to seepage initiates at the point of the seepage exit. The scour caused by the exiting flow of water can progressively destabilize embankments by removing materials which provide external support to the structure.



Internal erosion occurs within the soil mass as soil particles within an embankment dam or its foundation are carried downstream by seepage flow. Internal erosion can progressively deteriorate the integrity of the structure by eventually creating large voids or "pipes" within the dam or foundation, ultimately leading to loss of the reservoir.