



**ENGINEERING DESIGN GUIDE FOR
REHABILITATION WITH CURED-IN-PLACE PIPE**
Second Edition



LANZO COMpANy HISTORy

Lanzo has been a leading competitor in the construction industry for over 45 years. Lanzo was founded in Roseville, Michigan with offices presently in Detroit, Michigan, Atlanta, Georgia and Deerfield Beach, Florida. Lanzo employs a highly diversified staff of over 400 people providing a full range of construction services with contracting capabilities including:

Professional Services

- Construction Management
- Engineering Design/Build

Trenchless Technologies

- Cured-in-Place Pipe Lining
- "Over the hole" Application
- Noncircular, Box Culvert and Large Bore CIPP
- NSF61 Certified Waterline Rehabilitation
- Air Duct/Plenum Reconstruction
- Lateral Rehabilitation
- Interface seal technology

Heavy Construction

- Road & Highway Construction
- Site Work/Civil Construction
- Water Transmission
- Wastewater Collection Systems
- Water/Wastewater Treatment Facilities
- Marine Construction
- Demolition

Land Development

- Acquisitions
- Design Build

At Lanzo, we value our employees and the residents of the communities within which we serve. Our mission at Lanzo is to provide safe, high quality, cost-effective and on-time construction. Lanzo is an equal opportunity employer meeting all Federal, State and Municipal health & safety regulations. We hold the highest level of ethics and are committed to ensuring the safety of our employees along with both the convenience and safety of the residents of the communities we service.



Trenchless renovation in storm drain application



Environmentally friendly "Green Resin Formulations"

FORWARD

At the time of this publication, Lanzo Lining Services marks seventeen years serving the municipal, industrial, and public works rehabilitation marketplaces with a quality cured-in-place pipe (CIPP) liner. Having installed over 6,000,000 linear feet of sanitary sewer, force main, storm drain, NSF 61 potable water transmission, large diameter, and non-circular CIPP, we offer this newly revised second edition of the Lanzo Lining Services Design Guide as continued confirmation of our experience with design and application.

With millions of feet of CIPP in service throughout the world, it is not necessary to state the applicability or validity of CIPP as a proven rehabilitation technology. Over the years the industry has witnessed the introduction of many new products competing for a portion of the pipeline rehabilitation market. Several seemingly logical technologies have dissipated due to a number of reasons that include short term failure, lack of marketplace support, poor installation practices, and inexperienced contractors. Some products have failed in aggressive environments unanticipated by the designer or installer.

Lanzo Lining Services success can be attributed to five primary directives:

1. An emphasis on safety
2. Consideration of the community.
3. Quality installation by experienced crews.
4. A conservative design approach and superior resins.
5. Third party testing of each liner run.

DAILY THIRD PARTY TESTING vs. CATEGORIC LONG-TERM TESTING

The mere use of long-term testing for product selection is inadequate. The participation in a long-term testing program, while notable, does not insulate the customer from workmanship flaws, inferior resin or batch irregularities, or day-to-day jobsite fluctuations. There is no better way to prove quality and product reliability than to take a test specimen from the actual installation being lined and have it tested by a third party laboratory. For instance, the ability to retrieve samples from CIPP installations with properties in excess of 350,000 psi flexural modulus demonstrates that the submitted design basis has been validated. This additionally proves out the quality of the liner wet out, the adherence by the installer to ASTM installation practices, and the quality of the resin actually used on the day of the installation. The existence of over six million feet of Lanzo installed CIPP in service throughout the United States and Canada may serve to qualify our technology as viable, conservative, and safe.

INNOVATION

Our service is the daily solution of problems and pursuit of a quality installation. This is not simply the installation of a product, but rather the accomplishment of a complete sequence of events ranging from resin preparation and wet out to installation, utility reinstatement and jobsite cleanup with minimal disruption to the surrounding community. In the evolution of our company, many new product developments, installation tools, and refined practices have combined to make the use of our service a practical occurrence. Our conservative use of the highest design standards and field proven methods have been applied to diameters as large as 120", circular and non-circular storm drain applications, pressure rated force main and NSF 61 certified water main "stand alone" pipe liner installations.

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INTRODUCTION

OBJECTIVE OF THE mANUAL

This manual is intended to serve both as a general reference as well as an educational tool for the owner or project engineer designing infrastructure rehabilitation projects. The technology presented includes cured-in-place pipe, NSF61 certified water main transmission and potable water distribution pipeline rehabilitation, lateral lining, large diameter circular and non circular structural pipeline repair as installed by Lanzo Lining Services.

Cured-in-place pipe is prepared and installed by first saturating a specially fabricated tube with a thermosetting resin. The flexible, resin-saturated tube is installed by pulling it in place or inverting the liner into itself directly through the host pipe using either an existing or constructed access point. With the use of a static head of water, steam pressure, or pressurized air; the resin-saturated tube is pressed tightly against the existing "host" pipe. The water or steam is then continuously circulated through a heater in order to quickly polymerize the thermoset resin which forms a new pipe within the existing "host" pipe. Lateral connections are easily identified where the liner dimples and may quickly be reinstated robotically. All of these steps are typically accomplished without the need to excavate demonstrating truly trenchless technology.

Members of both the public and private sectors are finding the benefits of cured-in-place pipelining immeasurable. This trenchless rehabilitation technology allows placement of pipe within a pipe with "stand alone" structural characteristics while eliminating infiltration and exfiltration at a lower cost, in less time, and with fewer inconveniences to the owners and the communities served.

LANZO LINING SERVICES CONSTRUCTION EXPERIENCE

Lanzo Lining Services is among a handful of companies proven competent in the use of a wide array of cured in place pipelining technologies to rehabilitate deteriorated water, sewer, and drainage pipelines.

Lanzo Lining has successfully installed over six million (6,000,000) linear feet of cured-in-place pipe throughout the United States and Canada, in pipe sizes ranging from 6" to 144". Our specialties include large diameter, non-circular, pressure, high temperature, and corrosive environments in collection, transmission, treatment plant, industrial, NSF 61 potable water main, environmentally sensitive, "green" and storm drain applications. [1,2].

Lanzo Lining Services has installed over 1,000,000 feet of large bore CIPP, of which over 250,000 feet has been placed using "over the hole" wet out/installation technology; where factory liner preparation or transport to the remote jobsite location was not possible. We have installed non-styrenated polyester, non-styrenated vinyl ester, and epoxy resin impregnated tubes where environmentally sensitive, potable water transmission or air plenum ventilation application prohibits the use of styrene or other VOC's.



"Over the hole" wet out and installation of large bore circular, non-circular, and box culvert applications

THE CORROSIVE PIPELINE ENVIRONMENT

Accelerated aging caused by hydrogen sulfide-related corrosion has generally caused premature failure of our nation's sanitary sewer infrastructure. Awareness of the existence of corrosion and concern about its effect on the sewer system has been an issue since concrete and ductile iron first started displacing clay and brick as the primary materials in sanitary sewer construction. Even though it was known that some corrosion would take place, precautions taken in the sewer design and pipe thickness were intended to produce the 100+ year life expectancy of the sewer system [3]. However, within the last 25 years, hydrogen sulfide-related corrosion has accelerated at an alarming rate throughout the U.S. and has been documented by the Environmental Protection Agency (EPA) in a number of studies [3,4,5,6]. The primary cause of the accelerated corrosion has been attributed to the proliferation of several strains of *Desulfiobrio* bacteria in response to the reduction of cyanide and other heavy metal pollutants regulated by the EPA [3,4]. An anaerobic bacteria living in the slime layer on the lower hemisphere of the pipe reduces sulfur-containing compounds to hydrogen sulfide (H_2S). An aerobic strain living in the slime on the crown of the pipe oxidizes hydrogen sulfide to sulfuric acid (H_2SO_4). Routine wastewater pH measurements often indicate the effluent to remain in a range of pH 5-8, which would not ordinarily be of concern. However, the area of most concern with materials having low acid resistance is in the slime layer itself where the aerobic bacteria live. The aerobic bacteria have been observed to produce sulfuric acid up to 5% by weight (i.e., pH ~ 0.28) and remains viable in concentrations as high as 7% (i.e., pH < 0.15) [4,7]. At these acid concentrations unprotected concrete or ferrous metals are readily decomposed, producing holes in the top of the pipe commonly found during inspection.

ADMINISTRATIVE ORDER/CONSENT DECREE

Sewage overflow restrictions, overflow monitoring, and stiff penalties for non-compliance imposed by the EPA and state water agencies have motivated municipal sanitation departments to develop aggressive programs to maintain and/or rehabilitate their systems [4]. These programs have fostered the growth and acceptance of number of trenchless pipe rehabilitation techniques, as well as creative maintenance solutions [4,6,8]. The most popular current ongoing maintenance program utilized by many sanitation districts is the development of chemical treatment protocols and inventive application techniques to control hydrogen sulfide corrosion [4,6,8]. Depending on the program objectives, regular addition of one or more chemicals can reduce existing hydrogen sulfide, neutralize the acids, temporarily shock the bacteria, or accomplish all three. Chemicals commonly used for this purpose includes strong oxidizing agents (i.e., hydrogen peroxide, sodium hypochlorite (active ingredient in bleach), chlorine, potassium permanganate), weak oxidizing agents (i.e., oxygen and air injection), acid neutralizing bases (i.e., sodium hydroxide), and iron salts [4,6]. Use of magnesium hydroxide has been utilized as a thick alkaline chemical coating on the crown of cementitious pipe in order to neutralize the acid gases and kill the acid forming bacteria.

In general, this nation's sanitation system has changed dramatically within the last several decades and will continue to evolve. Studies demonstrate that decreased flows related to water conservation efforts increase the corrosive environment in sewer systems [9]. It is suggested that municipal efforts to reduce inflow and infiltration (I/I) through rehabilitation will also increase hydrogen sulfide-related corrosion and concentrate all other chemical agents present [10]. These and other unpredictable changes may necessitate lining to fortify existing pipelines against an increasingly aggressive corrosion environment [11].

Finally as the nation's infrastructure becomes tighter and additionally rehabilitated; the concentration of the many chemicals contributing to system deterioration will naturally increase. This will further emphasize the need to completely renovate our systems and finish the job started.

ALLOWABLE LEAKAGE By SPECIFICATION



Infiltration & inflow reduction



Maximum flow capacity

As a continuous and joint free pipe material, CIPP has been part of a “Green Revolution” even before the environmental community first coined this phrase. The evolution of specified materials has allowed the Engineering Community to reduce the allowable passage of effluent through the joints of newly installed or rehabilitated pipelines, thus improving the overall environment. As late as the 1980’s a leakage level of 200 gallons per inch-mile-day was commonly found in new vitrified clay pipe installations and this has now been reduced to a level of 50 gallons per inch-mile-day available with Unibell installations of PVC pipe today. The impact of a zero leakage system such as CIPP should prove instrumental as efforts to move towards a “greener” society remain emphasized. CIPP offers the luxury of a “pressure rated” sewer pipe where leakage either in or out of the system was previously commonplace in new installations.

CIPP BACKGROUND AND APPLICATION



NSF 61 Certified water main rehabilitation



ASTM F1743 Pull & invert technology

The full technology development of cured-in-place pipe as an industry is attributed to Insituform Technologies back in the early 70’s in the United Kingdom. As the technology grew, installation techniques, materials advancements and product marketing were all combined to spawn the international multibillion-dollar business it is today. Recent estimates place the total number of cured in place pipe feet installed at over 100 million feet worldwide. At the present time the North American market has become the largest in the world for CIPP as for many other trenchless technologies.

Cured-in-place pipe has achieved wide popularity and acceptance because it is one of the most versatile methods of trenchless pipeline renewal that exists today. Many of the key features of CIPP are summarized as follows:

1. CIPP is able to span a diameter range of 4 inches to over 120 inches.
2. CIPP has been used to rehabilitate sections of pipe over 3000 feet in length.
3. CIPP can rehabilitate non circular pipe configurations such as ovals, boxes, bends and transitional diameters without digging.
4. Used to rehabilitate partially, as well as, fully deteriorated pipe.
5. Used for gravity, internal pressure and vacuum applications.
6. CIPP is used in extremes of temperature and pH.
7. Specialized products meet NSF61 certification for potable water pipe distribution, green resin applications in sensitive environmental areas, and ventilation applications where styrene use is prohibited
8. CIPP eliminates inflow and infiltration, as well as exfiltration.
9. The smooth inner surface of CIPP increases the flow capacity of the existing pipe.
10. CIPP has ASTM F1216 [12] and ASTM F1743 [13] installation specifications.
11. CIPP tube and resin materials are specified by ASTM D5813 [14].

CIPP INSTALLATION DETAILS

In this section of the manual a general description of the various installation techniques will be described for both the direct inversion and pulled-in-place installation techniques. The descriptions and figures detailed are not intended to encompass all aspects of any given installation. Variable job site, underground piping, and climatic conditions may necessitate a variety of modifications to these descriptions that are intended to produce the same installed product. The basic categories involved with CIPP installation involve the following steps:

1. Inspection
2. Pipe and job site preparation
3. Tube preparation
4. Tube installation
5. Tube curing and cool down
6. Lateral reinstatement and finishing steps

Inspection - Initially before any lining tubes are prepared the existing pipe must be CCTV inspected for debris, roots, damage, offset joints or any other anomaly that does not allow for proper CIPP installation. Inspection also involves measurement of the pipe diameter, pipe length, manhole depths and records of pipe location and other job site conditions (i.e. overhead power lines, or railway, backyard easement, excessive sewerage flows, etc.) that can be properly planned for to help the project proceed efficiently. CIPP can easily be installed over dirt and debris, through severely offset joints or around protruding laterals, and in multiple bends as severe as 90°. CIPP will not eliminate existing pipe defects, but rather will contour the configuration of the host pipe being lined. It must be determined that later inspection with CCTV or water jet cleaning may occur and that bumps or fins in the liner will not disallow equipment from passing through the rehabilitated pipeline.

Pipe Preparation - Preparation for lining may involve internal mechanical cleaning and grinding to remove roots, protruding laterals, or other obstructions in the pipe. Collapsed pipe or severely offset joints (i.e. 40% of the diameter) typically require point excavations at those locations. Loose dirt, debris, or tuberculation may require high pressure water or mechanical cleaning with a final pre-lining inspection showing the full circumference of the pipe.

Tube Preparation - After the engineered tube of proper diameter and thickness for the pipe being rehabilitated has been matched to the host pipe length; it is ready for resin-impregnation. Most liner preparation and resin saturation takes place in the controlled environment of a workshop where the resin and tube temperatures are controlled to desired conditions. The resin and resin-saturated tube may be refrigerated to slow the chemical reaction and provide an additional factor of safety during the transportation and installation of the liner. The tube is prepared by first evacuating the air from it to create a condition for vacuum impregnation. Secondly, the catalyzed resin is introduced

into the tube under vacuum so that air is completely displaced with resin while saturating the fabric. The tube is moved through pinch rollers calibrated to the proper thickness so that a controlled amount of resin is introduced into the tube. The tube is then loaded into a refrigerated truck for transportation to the job site. For projects where either the diameter is large and/or the length of the liner is long, this process will take place at the construction site and the liner will go from wet out directly into the pipe being rehabilitated. When properly handled and stored, resin-saturated tubes can be stable for up to a week or more.

Tube Installation - The following installation descriptions are intended to be a generalized overview of common direct inversion and pulled-in-place installations. Since there are so many variables associated with each project and the job site conditions on projects, an overview is provided here to familiarize the reader with general knowledge of this technology. While direct inversion and pulled-in-place installations are performed in a different manner and require different equipment, the decision to choose one installation method over another is related to the project, job site and piping conditions. On a single project it may be advantageous to use both techniques, as well as variations of each to maximize quality and efficiency of the installed product. Both techniques have been used successfully for pipe diameters from 4 inch to greater than 120 inch. The installation techniques described below use water as the installation and curing media since it is by far the most common and reliable method of installing CIPP. However, steam and air pressure may also be used as job conditions dictate. Each technique can be considered a tool in the toolbox of a CIPP installer. As such, each one has its place at the appropriate time to successfully complete a project safely, on time and within budget.

Direct inversion of CIPP is installed to meet or exceed the requirements of specification ASTM F1216. Initially the tube is attached to a top ring or pulled through a column and turned inside out and attached to an elbow. In both cases, the tube is turned inside out with the use of a hydrostatic head of water as shown in Figure 1. As the water is carefully introduced into a column, the resin-saturated tube is allowed to invert upon itself and progress longitudinally through the pipe in a continuous and controlled manner.



figure1: Direct inversion installation per ASTM F1216

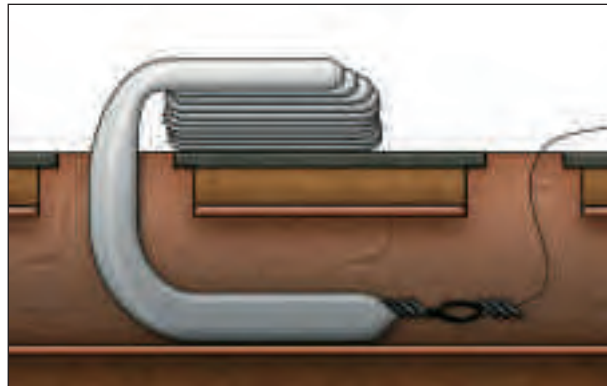


figure 2: Liner pulled-in-place per ASTM F1743

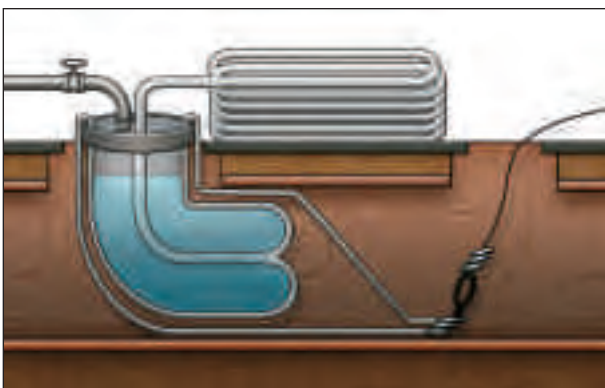


figure 3: Calibration hose or pre liner utilization

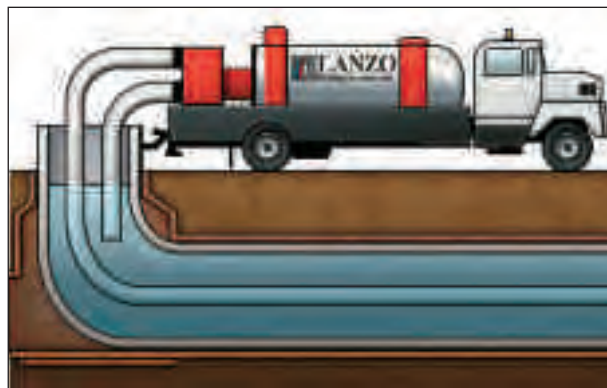


figure 4: Curing liner with hot water or steam

The direct inversion method is the most popular method, available in virtually all sizes, and especially suited to the “over the hole” technique.

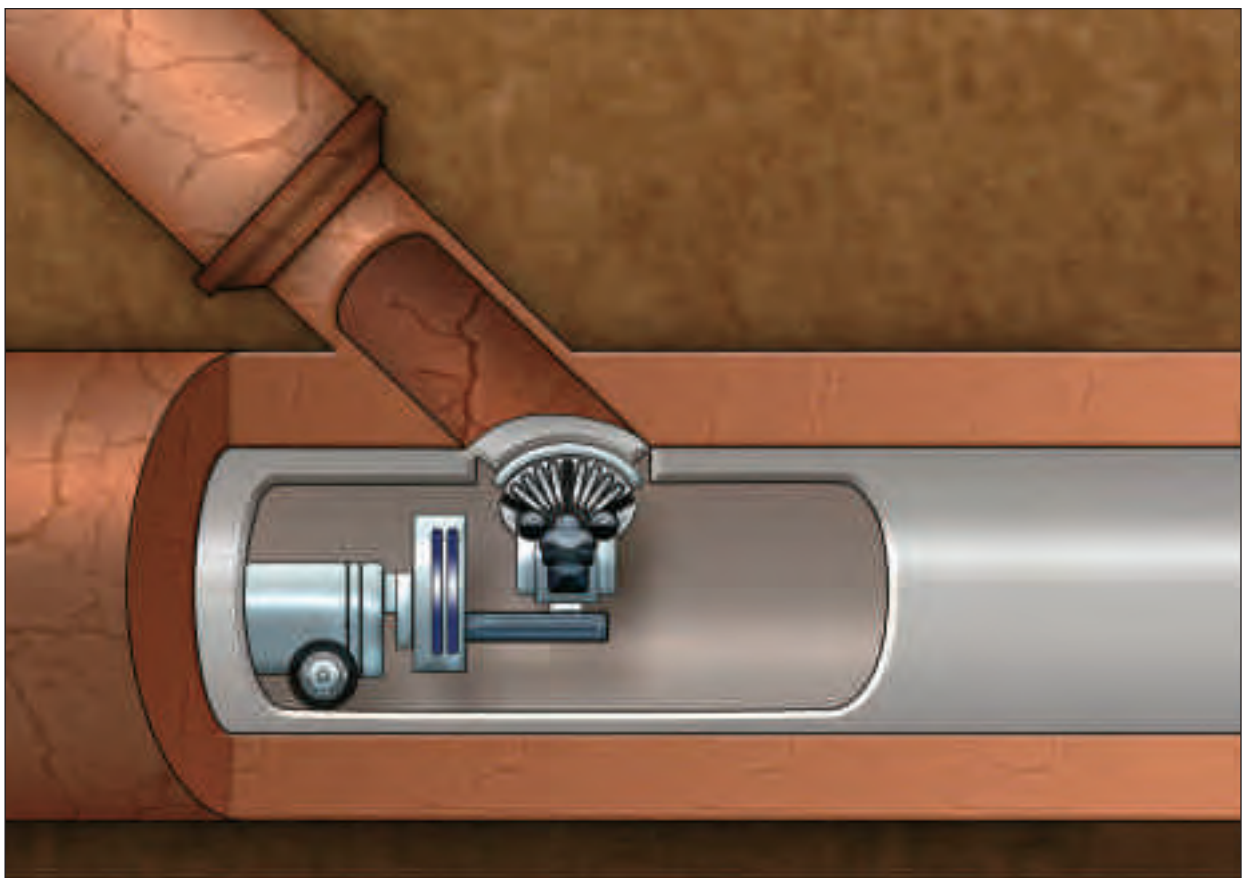
Pulled-in-place CIPP installation is installed to meet or exceed the requirements of specification ASTM F 1743. For this technique a cable is strung through the existing pipe and attached to the tube. Once attached, the tube is carefully pulled into position as shown in Figure 2. In order to reduce potential friction between the pipe and the liner, hydrant water may be introduced into the pipe through the manhole, allowing the tube to easily slide down the pipe. Through the choice of tube materials and careful pulling techniques, pulling forces rarely exceed 10-20% of the maximum tensile properties of the fabric tube. Tube stretch is less than the maximum 5% specified in ASTM F1743, but is usually less than half that value. For a more detailed estimation of maximum tensile strength of a tube and estimated pulling forces, contact Lanzo Lining Services.

Pull in place employs a second installation step. A calibration or retractable hose is inverted into the center of the resin-saturated tube by a hydrostatic head of water. This hose sequentially inflates the resin-saturated tube from one access point to another and holds it tight against the existing pipe as shown in Figure 3. Any residual water trapped in the pipe is directed downstream as the calibration hose inflates and longitudinally progresses within the tube sequentially from one end of the pipe to the other.

Pull in place is extremely instrumental in the many special applications such as Pressure pipe, transitional sizes, NSF 61 water main, ventilation plenum rehabilitation, and large diameter applications where particular placement challenges exist.

CIPP Curing and Cool Down - Once installed by direct inversion or pulled-in-place the tube is cured through the use of circulating heated water, introduction of steam, or the use of an ultraviolet (UV) light.

When water is used, it is taken into the water heater from the column and discharged out into the center of the installed tube at the downstream end. The heated water circulates back to the column at the upstream end where the cycle in



Robotic reinstatement of house connection or “lateral” sewer

continued throughout the curing process as shown in Figure 4.

When steam is used as a heat source, the steam is typically introduced at one end and flows through the length of the liner and out the downstream end through a specialized manifold that helps control temperature and internal pressure. New innovations in steam generation technology allow for dryer steam and can also allow the installer to cure at much higher temperatures than circulating hot water.

UV light is a third method of curing CIPP and requires specialized resins and photo sensitive initiators. UV light curing technology is relatively new in North America, but has been used for many years overseas and is proving to have advantages for many different applications. Liners can be stored and transported without refrigeration and still be viable months. When the lights are turned on, curing takes place within minutes.

Whether cured with water or steam, the process must be carried out in a controlled manner with the temperature monitored at both ends of the tube with thermocouples placed between the liner and the host pipe. In addition, the water/steam temperature is monitored at the heater and may also be monitored at the downstream end of the liner. Where intermediate access points exist, the curing process of the tube may also be monitored at those locations also.

Most often the tube is cured in a two-staged heating process and cooled down in a controlled manner to a temperature below 100F. The times and temperatures of these different stages are highly variable based on tube diameter, length, thickness, resin type, catalyst formulation, size of the water heater, environmental and job site conditions. In general, thick tubes require extended curing and cooling times, while thinner tubes may be cured more rapidly. The variable cure times and tube thickness relate to the slow heat transfer into and out of the tube, as well as the requirement to control the exothermic (i.e. heat producing) reaction that occurs when the thermoset resin in the tube polymerizes.

Lateral Reinstatement and Finishing Steps - Once installed, cured and cooled down the CIPP is fully opened on both ends while any lateral connections leading to the pipe are then reinstated. When the pipe is too small for a man entry, CCTV is used to re-locate lateral connections and remotely operated cutting machines are used to re-open the lateral connection. At the manhole connections an end sealing procedure may be utilized which helps eliminate infiltrating water from tracking down or around the host pipe and/or CIPP and re-entering the collection system at the manhole. Where there is heavy groundwater some type of lateral sealing technology is recommended where the lateral connects to the main line. Top hats or interface seals may be applied remotely from inside the liner using a robot without the need to introduce a cleanout or other above ground access. Other trenchless sealing techniques include chemical grouting, lateral lining at the connection and/or up the entire lateral, or robotic placement of polymer putty. Alternatively, laterals may be opened and sealed by making a point excavation to place a new saddle connection at each lateral.

Final Inspection - As with any project, final CCTV inspection provides the documentation for the project engineer that the CIPP was properly installed. Ideally CIPP is smooth and wrinkle free throughout the length of the installation. However, CIPP cannot eliminate piping irregularities and will mirror pre-existing problems in a defective pipe being lined to eliminate I/I, exfiltration, or improve structural integrity. In addition, fins in the CIPP can occur when the pipe diameter decreases to less than the nominal diameter of the existing pipe. During the engineering and design phase of a contract, tubes are commonly specified with an undersized diameter (i.e. 4-8% undersized) to anticipate host pipe diameter changes and moderate bends. When encountering crushed pipe, PVC pipe used for point repairs, and clay pipe the host pipe diameter can decrease to the point where these measures cannot prevent fins. Fins are also unavoidable in sharp bends where the inner radius bunches going around the bend. Wrinkles such as these are cosmetic defects in an otherwise defective host pipe and prevalent in all CIPP construction. Since most all fins run along the length of the pipe they typically increase the physical properties like that of a built-in I-beam and do not affect flow. Typically fins in the CIPP are of little concern to the overall performance objectives of the rehabilitation project.

CIPP PROJECT SPECIFICATION

To insure the desired results from a CIPP rehabilitation project, proper specifications must clearly outline the objectives. With any rehabilitation project it is recommended that the collection system be evaluated as a whole and pipeline sections be segregated for repair using the appropriate rehabilitation technology(s) most suited for the stated project objectives. A project may be put out to bid with multiple technologies (i.e. CIPP, sliplining, open cut replacement, lateral lining) to achieve the desired end result. Exclusive rehabilitation with CIPP is recommended in areas where any or a combination of the following conditions may exist:

1. Suspect structural characteristics in the host pipe are manifested in the form of radial or longitudinal cracks, offset and/or displaced joints.
2. Ovality sufficient to preclude sliplining or folded and re-formed products from reaching a full round configuration consistent with ring compression support theory (see Design Section).
3. Pipes where sections are completely missing.
4. Pipe subject to highway loading in shallow or live loads.
5. Deeply buried pipe where high external hydrostatic pressure may exist.
6. Pipe with line and/or grade differentials (i.e. existing bellies in the pipe run) that may produce friction for sliplining and/or not allow folded products to reach their fully rounded state after installation.

Once it has been determined that CIPP is the proper choice for pipeline rehabilitation there are many aspects of specification that will determine the success and quality of the completed project. Prequalification factors such as threshold contractor experience, minimum installed footage, same liner size or larger, key employee resumes and local wet out facility are significant items that may be taken into account prior to bid. Contact Lanzo Lining Services for a sample specification that can be used as a template for your specific CIPP project.

ASTM SPECIFICATION

ASTM standardization is extremely important to insure consistency in materials and installation practices, while minimizing owner liability in ongoing construction work. It may take as long as five (5) years to obtain a ratified specification. After initial publication ASTM standards are kept current through a mandatory review process that is required every seven years. If there is no interest to review a standard it is dropped from publication. Standards exist for virtually every pipe rehabilitation product, including CIPP. ASTM does not purport to cover all the details of every project or installation, but does provide a valuable framework and set of guidelines that are absolutely necessary for the underground rehabilitation industry in general.

ASTM D5813 "Specification for Cured-In-Place Thermosetting Resin Sewer Pipe" covers material requirements for the resins and fabric tube materials used for CIPP. ASTM D5813 also outlines test methods for evaluating installed CIPP.

ASTM F1216 "Practice for the Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube" provides guidelines for the installation of CIPP with the direct inversion method.

ASTM F1743 "Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)" is an installation standard practice for the pulled-in-place method of installation. ASTM F1743 references both ASTM F1216 and ASTM D5813 for designing and specifying CIPP.

As with any technology there are critics within and outside the CIPP industry regarding the validity of the aforementioned standard practices. Two areas that have come under extreme scrutiny are the design criteria and pre-qualifying materials for chemical resistance testing. CIPP gravity sewer design is divided into "Partially and Fully" deteriorated existing piping criteria. Based on the pipe classification, the CIPP is designed to either withstand hydrostatic loading only, or

all possible external loads that the CIPP may be exposed to. In addition, some municipalities have developed their own chemical resistance and design criteria, which is much more severe than that specified in ASTM (i.e. The California Green Book [15]). Proponents and supporters of these specifications argue that CIPP has performed admirably in the U.S. for over 40 years and has not failed as a technology because the approach taken has been conservative and aimed at long term performance for the product(s).

Lanzo Lining Services supports the more conservative approach to specification selection. With over six million (6,000,000) feet of failure free installation, primarily in fully deteriorated design basis, serves as testimony to the confidence attainable in a conservative approach.

CIPP APPLICATION GUIDELINES

Since the publication of our premier Design Guide ten (10) years ago there has been an absolute transformation within the CIPP marketplace with respect to comfort with this technology and a relative boom in the range of application for composite felt/resin liner systems.

Lanzo has remained an innovator and pioneer installer of CIPP in many cutting edge applications such as:

- I/I reduction in sanitary collection systems
- Large Diameter and Non Circular sewers, storm drains, and box culverts
- "Over the Hole" wetout and installation
- High temperature chemical concentrations and industrial sewers
- Pressure rated force main sanitary sewer transmission
- NSF 61 certified water main rehabilitation
- Green resin utilization in wetland or environmentally sensitive areas
- Air duct ventilation repair and vacuum pressure line
- Contaminated soil remediation prevention
- Flood control structure rehab
- Submerged or canal enclosure pipeline rehabilitation

CIPP has been installed by Lanzo in diameters ranging from 6" through 144".

The utilization of direct inversion, pull in place, and hand lay-up methods are application dependant but generic in terms of the design parameters presented in this guide. Additionally, both gravity and pressure rated design is presented herein, while an abundance of information has been accumulated on each of these methods available for informational or specification writing purposes by contacting Lanzo.

COMPETING TRENCHLESS PIPELINE REHABILITATION TECHNOLOGIES

In general, trenchless pipeline rehabilitation technologies have proliferated and gained extraordinary acceptance because of the changing chemical environment previously described, enforcement of the clean water regulations, inadequacies of traditional piping materials, and the rising social costs of traditional dig and replace methods. Social costs include the direct and indirect costs that will impact the community surrounding the project. These costs might include destruction of old trees, disturbance of a wetland habitat, disruption to businesses, and impact of traffic congestion on side streets as people are forced to take alternative routes. A number of experts and engineering firms have studied this more closely to develop generalized costs [16]. Pipe repair alternatives include chemical grouting, point repairs/excavation, internal robotic repairs, sectional liners, sliplining, CIPP liners, fold and form liners, and pipe bursting. Acceptance of new technologies has increased competition and pushed the cost down to the point where the cost of a trenchless repair is generally less costly than trenching, even without taking social costs into consideration.

Table 1. Generic costs of Pipeline Construction and Repair methods [16].

method	Cost/Inch Diameter/Foot	Type of Installation
Sliplining	\$4-\$6	Rehab
Grouting	\$4-\$6	Rehab
Cured-In-Place Pipe	\$4-\$8	Rehab
Pipe Bursting	\$8-\$10	Rehab
Over the Hole large diameter CIPP	\$10-\$28	Rehab
Trenching	\$15-\$30	Rehab or New
NSF 61 Water main CIPP rehab	\$20-\$30	Rehab
Sectional CIPP Liner	\$50-\$85	Rehab

Each method of repair has a niche where it is most applicable. These technologies are briefly reviewed with the understanding that the included summary cannot encompass the full scope of each technology.

Chemical Grouting - Chemical grouting is a technique primarily used to seal leaks in pipes or lateral connections in pipe diameters typically in the range of 6 inch to 24 inch. It has been used for years and includes material selection options such as acrylamide gel, acrylic additives, urethane gels or foam. These products are typically injected under pressure with a specialized packer that forces the liquid grout through the hole in the pipe into the surrounding soil envelope. There it polymerizes to form a solid or semi-solid gel that pervades the soil envelope serving to non-structurally seal the pipe. Grouting is economical and effective but temporary in sealing leaks and not a structural repair to a damaged pipe. The estimated effective lifetime of various grouts is an ongoing point of debate which points to a range from 3 to 7 years.

Sectional or Part Liner – Developed as a repair technique for CIPP defects, this method has seen expanded application and is perhaps “over used” to repair damaged pipe. It can be designed as a structural repair to a fully deteriorated host pipe. This method is essentially a short CIPP repair that may be furnished in lengths ranging from 3 feet to as long as necessary, depending on diameter and location of the repair. The primary issue in electing to utilize this technology is the selection of an adequate repair length. Pre video inspection reports revealing target defects do not offer insight into the underlying cause of the failure or extent of soil envelope deterioration. Consequently, a seemingly adequate repair may not prevent crack propagation outside of the limits of the sectional repair after a relatively short time. It is judicious to select a sectional repair length which takes this phenomenon into account by extending the repair to several joints in either direction beyond the target defect. Additionally, a maintenance program should exist to monitor these repairs over time as post cure shrinkage as well as other effects may cause movement of the short liner.

This method is most typically used for pipes 8 inch to 24 inch in diameter, but is available in diameters as large as 120". Fabric tubes constructed of woven and/or non-woven materials (i.e. polyester felt and/or fiberglass) are manufactured for the project and saturated with a variety of resins which have been modified for a reactive cure with low heat or UV light. The sectional liner is typically pulled into position on a carrier or packer which is then pressurized causing the short CIPP segment to expand tightly against the host pipe then allowed to cure in place.

A practical alternative to this method is an installation technique called a “blind shot” or a sectional CIPP liner section which only requires access to the pipe at one end for a starting point. Although Part Liners typically do not run manhole to manhole, this variety of sectional pipe repair offers the additional benefits of:

-
- a solid connection to a manhole-pipe interface
- a repair which is readily visible from the manhole
- the ability to line past the defect by several joints thus clearing the suspect soil envelope by a more conservative distance

Service Connection Reinstatement, Repair, Interface Seal and Lateral Lining Lanzo has become proficient in providing several technologies to repair lateral connections and lateral pipes both remotely from within the mainline, as well as, from a cleanout located at the property line. These repair technologies require specialized liner materials and equipment, but can successfully seal the lateral-mainline connection and rehabilitate the smaller lateral pipe up to the house or business. These methods require experienced field technicians with an understanding of varying host pipe materials, resin cure, remote camera and robotic equipment operation, variable temperature, flow and piping conditions to complete a successful time sensitive repair.

Different technologies exist in the marketplace which utilizes either water or air as placement media with either water, steam, or UV light for curing the resin systems. There exist several proprietary technological approaches while the end user should be cautious to insulate themselves from sole source specification which may drive cost unduly higher as they become embroiled in trade issues such as full wrap vs. lateral region adhesion, or minimum length of interface seal dimension.

An interface seal is intended to eliminate annular space or shear condition, while lateral lining serves to seal and structurally repair the lead to a determined length within the service. Although certain lateral lining technologies may be remotely launched from within the main, a cleanout is routinely necessary to insure the removal of root manifestation and mineral deposits while visually inspecting defects within the lateral to be rehabilitated. The notion that a lateral may be routinely lined without a cleanout is therefore flawed.

Robotic Repairs - This is a highly specialized technology that can also be used as a trenchless point repair method to seal cracks and leaking lateral connections. Through the use of grinding tools and epoxy resins or chemical grouts a wide variety of pipe defects can be repaired. Widespread use of this method has been hampered by the initial purchase and maintenance expense of the robotic equipment employed which also requires highly trained personnel for a small portion of the repairs typically being addressed in a comprehensive system rehabilitation project.

Repairs consist of employing a remote cutter head to ream, gouge, or machine a channel into an existing defect which then is more receptive to an epoxy which may be robotically troweled or pumped into place. Typical repairs apply to pipes in the 8-inch to 24 inch robotic equipment are repaired with these techniques.

Point Excavation for Repair - When a pipe is severely damaged or crushed it may be most cost effective to dig at that location to repair the section of pipe. This method is often used in conjunction with trenchless lining techniques to replace collapsed sections so the existing pipe may then be inspected, cleaned and subsequently lined from manhole to manhole. All sizes, shapes, and varieties of pipe have been repaired with this method to effect a conventional open cut repair.

Sliplining and Segmental Sliplining - These methods can be used to either pull or push new plastic or composite system into the existing host pipe. Traditional or "discrete" sliplining typically either pulls a high-density polyethylene (HDPE) pipe or pushes a reinforced thermoset resin (RTR) or reinforced plastic mortar (RPM) through one access pit to another. Depending on site conditions, sections of pipe of 1000 feet or more may be pulled or pushed at one time. The pull method of pipe repair is most typically used on pipe 8 inch to 24 inch in diameter, but larger sizes have been installed. In 48 inch and larger applications, segmental sliplining with thermoplastic or composite pipe can become more cost effective depending on site conditions at the entry and receiving pit along with the costs associated with bypass pumping.

Segmental sliplining is performed by lowering individual sections of pipe into an access pit and hydraulically jacking each into the host pipe towards a receiving pit while maintaining pipe flow.

Hard pipe material slipline methods are limited by the frictional forces of the slipline material against the host pipe, which will determine the shot length or allowable distance between pits.

Sliplining reduces the overall hydraulic radius significantly and may reduce the capacity of the pipe rehabilitated. Factors such as pipe joint articulation, mineral deposits, bends and line obstructions must be thoroughly investigated prior to method selection. Reinstatement of lateral connections requires external point excavations.

Pipe Bursting - Pipe bursting is a technology where the existing pipe is sheared or cracked while a new pipe is pulled behind (sliplining) a specialized bursting tool. Many types of tools have been developed with hydraulic or pneumatic bursting capability and include pulling only, pulling and pushing, and so on. This method enables the owner to actually increase the size of the existing pipe by one or more diameters and actually increase the hydraulic radius. Pipe bursting has been used to up-size 8 inch to 10 inch or 12 inch and has been used to increase pipe up to 36 inch or larger, from smaller diameters. The technique works most efficiently on brittle host pipe materials, such as clay, concrete, asbestos cement and "pit" cast iron. HDPE is most often used as the replacement pipe, but PVC, composite pipe, and even clay have been used. The limitations to this technology involve use of the bursting tools when the pipe is close to structures such as foundations or utilities that cross the line being burst. Where these structures can be point excavated, bursting can proceed without incident. Reinstatement of lateral connections requires external point excavations.

Fold and Form Lining - This process uses plastic pipe that has been folded into a "U" shape allowing it to be steam softened then pulled into the existing pipe. Using steam heat and internal pressure the liner is reshaped to meet the existing pipe. Fold and form has been attempted in diameters ranging from 6 inch to 24 inch, but is most applicable in the range of 8 inch to 12 inch. HDPE and modified PVC are the piping products used for fold and form. This method is a low cost rehabilitation technology that is used where the existing pipe can provide structural support to the liner for gravity flow applications. Potential problems exist where the liner does not fully unfold, making it susceptible to collapse under external groundwater pressure. For some products the modified PVC materials are often experimental in nature without extensive long-term property research behind them. Therefore, prior to use the owner should review all products carefully. In most cases lateral connections can be reinstated by remote cutting tools, but may require point excavation and typically require grouting to guard against flow tracking through an annular space. There is no reliable "adhesion" or "mechanical bond" between a thermoplastic material and a host pipe.

Pipe Preparation - Most of the technologies listed have the common need for pre-installation inspection, cleaning, and other forms of preliminary pipe preparation. For most applications by pass pumping is of minor concern in diameters up to 15 inch. In the range of 18 inch and above by pass pumping can become a significant portion of project planning and cost. Depending on site conditions pipes greater than 48 inches may be rehabilitated during flow diversions and using techniques that minimize the reliance on by pass pumping.

Lanzo Lining Services brings experience with dig and replace, new pipe construction and multiple rehabilitation technologies while adding value to the project. The Lanzo Companies can combine construction capabilities to optimize the allocation of municipal dollars while streamlining coordination efforts on any given project.

CIPP ENGINEERING AND COMPOSITE MATERIAL PROPERTIES

Since 1993, Lanzo Lining Services representatives have actively participated in national organizations such as ASTM, NASTT, AWWA, APWA and NASSCO in an effort to assist owners, municipal and plant engineers maintain the most current material specifications. Lanzo Lining Services' objective is to provide a competitive CIPP product that will meet or exceed the EPA mandated fifty-year design life. To satisfy ASTM and municipal/industrial specifications it is critical to select tubes, resin, and catalyst products from qualified suppliers providing the highest quality materials and services. Lanzo Lining Services only uses the finest quality manufactured products and supplies from ISO 9000 certified sources. In the following sections, minimum and typical property values for the fabric and resin products are provided. In order to remain competitive while providing the highest quality CIPP; Lanzo Lining has continued to review and update the following published criteria, as the industry and job conditions necessitate.

FABRIC TUBE MATERIALS

The flexible fabric tube is one of several key elements of the CIPP process. The materials used to construct tubes must possess chemical resistance, flexibility, an ability to stretch and conform to irregular piping, and be durable to withstand the rigors of underground construction. Currently, the most commonly used fabric tube material in North America is composed of thermoplastic polyester fibers needled into a dense felt. However fabric tubes made of combinations of needled polyester and polypropylene fibers and needled polyester with various fiber reinforcements are also available. Depending on fiber orientation, liners constructed of fiberglass tubes can easily produce a flexural modulus that would exceed 1,000,000psi and flexural strength values over 15,000psi. At the time this criteria was placed in the referenced ASTM specifications the targeted material(s) were needled polyester felt and coated polyester felt. Many coatings may actually enhance the properties of a tube. Table 2 includes typical values for plain polyester felt and coated polyester felt.

Table 2. Typical tensile properties for polyester felt and plastic coated felt.

material	% Elongation at Failure	Ultimate Tensile Strength
Felt	85-95	800-1000 psi
Plastic coated felt	70-75	1200-1500 psi

THERMOSET RESINS

Resins Overview and Properties

The thermosetting resins used for CIPP are the most important component to the short- and long-term performance of the product. First, there is a distinction between initial or short-term properties and the long-term performance that dictates the life span of a product. Short-term properties include parameters such as flexural, tensile, and compressive properties. Long-term properties include parameters such as chemical resistance, creep, and strain corrosion. Most all these parameters are important for the qualification, design, and performance of CIPP.

There are three main groups of thermoset resins used for CIPP and they consist of polyester, vinyl ester and epoxy resins. Within each of these three categories exist hundreds of combinations of products with their own characteristics that distinguish their performance. A number of papers have been published that generally review the short- and long-term performance of these three classifications of thermoset resins. 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. However, not all pipe rehabilitation applications require the elevated performance of a vinyl ester or epoxy resin. The vast majority of standard gravity flow sewer pipe rehabilitated has been accomplished with polyester resins. However, since there are so many types of products within each category typical properties provided are given as a range of values that could be expected. Table 3 provides some typical properties of neat resins formulated for CIPP that have 'not' been combined with any fabrics or specialty fillers.



Frontal view of 60 inch diameter direct inversion



Finished outfall product at the headwall

Table 3. Typical neat physical properties.

Test Property	Epoxy Resin	Epoxy Vinyl Ester	Isophthalic Polyester
Flexural Modulus ¹ , psi	500,000-550,000	500,000-570,000	500,000-570,000
Flexural Strength, psi	15,000-25,000	15,000-25,000	10,000-18,000
Maximum Strain, %	4-7%	4-7%	3-5%
Tensile Modulus ² , psi	490,000-540,000	490,000-560,000	490,000-560,000
Tensile Strength, psi	8,000-10,000	8,000-10,000	5,000-8,000
Tensile Elongation, %	4-7%	4-7%	2-5%

1 Flexural properties determined by ASTM D790

2 Tensile properties determined by ASTM D638

Resin/Felt and Resin/Fiber Composite Properties

When the aforementioned thermoset resins are combined with the flexible fabric of a tube, material properties can be dramatically changed, as previously overviewed in the FABRIC TUBE MATERIALS section. The following discussion will focus primarily on the effects of needled polyester felt tubes on the material properties of a thermoset composite. There are several reasons for the observed effect on physical properties. First, the randomly oriented needled fibers of a felt tube are not oriented in a manner that can become load bearing. Therefore, modulus or stiffness and strength values are often reduced 30-50% compared to the neat resin properties. However, it is not as simple as it appears, since fiber types, sizes, orientation, and felt density can also affect material properties. In addition, felts made of combinations of polyester, polypropylene, and/or polyethylene fibers have varying performance due to the level of resin adhesion to the fiber(s). Polyester fibers tend to slightly solvate when exposed to styrene based resins (i.e. polyester and vinyl ester) and bond extremely well. Tubes made with a combination of polyester felt and fiberglass fibers or entirely with fiberglass can produce extremely high physical properties. By so doing, the designer can produce CIPP with a reduced wall thickness, but still perform extremely well for either external hydrostatic pressure or internal pressure applications.

The resin component of the resin/felt or resin/fiberglass composite can also be modified with fillers to effect the processing parameters and the mechanical properties of the composite. The viscosity of thermoset resins developed for CIPP are modified with specialty fillers called thixotropes. Thixotropic fillers are added at small levels (i.e. 1-3%) to increase the viscosity of the resins so that they stay in the tube fabric during processing and installation and do not drain out of the tube and into the host pipe, ground, lateral connections, etc. Thixotropes typically do not effect physical properties since they are added at such low quantities.

Other mineral fillers such as aluminum trihydrate (ATH) are also added to resin to enhance the overall material properties. Newer formulations with calcium carbonate and calcium carbonate/ATH combinations have been developed and have recently been introduced to the market. ATH and other fillers are added to significantly increase the modulus (i.e. stiffness) of the overall composite without diminishing the resins' processability, or decreasing the strength or the chemical resistance of the CIPP. Increasing the modulus of the composite can provide some cost advantages when designing CIPP and this is reviewed in the ENGINEERING DESIGN section of the manual. In addition to design advantages, resins with fillers have an increased thermal conductivity and therefore heat up more uniformly through the entire thickness of the tube which is especially helpful when working in cold climates. Fillers reduce resin and tube shrinkage during curing and cool down, which provides a tighter fit to the host pipe after the CIPP is installed. To illustrate the effects of resin/felt composite properties in Table 4 is provided with typical properties. As consistent with Table 3, these properties are generated from experimental panels made in laboratory conditions and should not be misconstrued to be typical of all installed CIPP.

Table 4. Typical property ranges for resin/felt composites consistent with CIPP construction.

Test Property	Epoxy Resin Data	Epoxy Vinyl Ester Data	Isophthalic Polyester Data	Filled Isophthalic Polyester Data
Flexural Modulus, psi	480,000-550,000	480,000-570,000	480,000-570,000	550,000-750,000
Flexural Strength, psi	10,000-12,000	10,000-12,000	7,000-9,000	7,000-8,500
Maximum Strain, %	3-5%	3-5%	2-4%	2-4%
Tensile Modulus, psi	490,000-540,000	490,000-560,000	490,000-560,000	550,000-750,000
Tensile Strength, psi	7,000-10,000	7,000-10,000	6,000-9,000	5,000-8,000
Tensile Elongation, %	2-4%	2-4%	1-3%	1-3%

minimum Recommended Design Properties

Typical properties of neat and resin/felt composites produced in the laboratory are not typical of the product produced in the field. When all the parameters of the preparation, installation, curing, and sampling are carefully monitored and controlled the properties of installed CIPP fall within the median range of data provided in Table 4. However, there are many uncontrollable variables of an underground construction project that can negatively affect the end product. The net overall result is that variability is increased and the variability in the test data also increases. Therefore, minimum property values have been established within the industry to provide a conservative minimum value for flexural and tensile properties of installed CIPP. Table 5 provides recommended minimum design values for standard CIPP. The values in Table 5 are relatively low compared to the values of Table 4, but the median value of installed CIPP is typically 15-25% higher than minimums. However, cold weather, high groundwater, poor water or steam circulation and/or equipment failure can produce reduced properties just above the minimum standards. In effect, the majority of all CIPP installed essentially has an additional factor of safety due to the conservative design practices that have been adopted in ASTM standards. Minimum properties are given for both flexural and tensile properties, but it should be pointed out that tensile properties are only used in the design of fully deteriorated (stand-alone) internal pressure pipe.

Although not emphasized in this design guide, minimum properties using fiberglass reinforced liners might be specified with a flexural modulus that would exceed 1,000,000psi and strengths that would exceed 10,000psi for gravity flow applications. With proper fiber orientation, tensile properties can also be greatly enhanced for internal pressure applications like NSF 61 potable water pipe rehabilitation and/or sewer force mains.

Table 5. minimum recommended design properties for CIPP.

Test Property	Epoxy Resin Data	Epoxy Vinyl Ester Data	Isophthalic Polyester Data	Filled Isophthalic Polyester Data
Flexural Modulus, psi	250,000-300,000	350,000-450,000	250,000-350,000	400,000
Flexural Strength, psi	5,500	5,500	5,500	5,500
Tensile Strength, psi	3,000-5,000	3,000-5,000	3,000-5,000	3,000-5,000

Creep Properties of Thermosetting Resins

Engineering materials of all kinds deform when placed under a load and this is a basis for careful engineering and design for any structural application. When materials such as thermoset and thermoplastic resins are subjected to low loads relative to their ultimate breaking point they will experience incremental deformation occurring over a period of time. These deformations occurring over the design life of a product is referred to as creep. Creep is affected by many factors that include the type of material being analyzed, the degree of cure (for thermoset resins), environmental conditions (temperature, chemical agents), and the amount of load applied. For the thermoset resins used for CIPP creep is an important design parameter that must be taken into account to provide an adequate factor of safety over the design life of the pipe. Loading on CIPP occurs when it is installed under the water table and uniform hydrostatic pressure pushes uniformly around the circumference of the CIPP. Additional forces can occur where CIPP is installed in unstable soil conditions and/or live loads act

on the pipe. In these cases the loads may not be uniform, but would push down on the upper half of the CIPP creating a combination of complex loading conditions.

In order to understand long-term creep performance of common resin/felt composites mechanical tests have been developed to characterize the performance of CIPP. The typical expected design life of CIPP is fifty (50) years so testing is performed in a way to estimate long-term performance and produce a safety factor that can be applied to the design of CIPP. Tests include hydrostatic buckling and three point bend tests performed under constant loading conditions. Tests are typically performed over a time period of 10,000 hours. The data is statistically fit to a line and extrapolated out to fifty (50) years for the design life of the CIPP. The reduction of stiffness due to creep is applied to the short-term flexural modulus (as given in Table 5) to estimate a long-term modulus (EL). Many confidential research projects have been conducted without publication until Louisiana Tech University carried out a research program to evaluate the long-term performance of a number of pipe lining products [17]. The results of this study have been highly controversial due to criticism over uncontrolled variables and statistical data treatment. However, this research created a basis for additional analysis and comparison between hydrostatic testing and three-point bend testing as specified in ASTM D2990 [18].

Published results of the aforementioned testing indicate factors like degree of cure, loading level, thermal and chemical environment, and type of resin and/or reinforcement will affect the amount of creep that may be experienced over the life of installed CIPP. Therefore, test results have been analyzed to develop a conservative recommendation for creep. When all conditions are set equal it is generally understood that there are differences between resin types. Therefore, the minimum recommendations in Table 6 given for the different resin categories used for CIPP are multiplied times the short-term modulus or strength to obtain the estimated EL (long-term modulus), sL (long-term flexural strength), or stL (long-term tensile strength) used for long-term CIPP design. For special applications such as pressure pipe, industrial chemical exposure, and/or elevated temperature consult Lanzo Lining for creep recommendations.

Table 6. Recommended minimum factors for creep

	Epoxy* Resin	Epoxy Vinyl Ester	Isophthalic Polyester	Filled Isophthalic Polyester
Creep Factor	0.25 - 0.6	0.5 - 0.6	0.4 - 0.5	0.4 - 0.5

*The creep factor of epoxy resins is quite variable depending on the curing agent chosen. Consult Lanzo Lining technical services for proper recommendations.

Thermal Properties of Thermoset Resins

The thermal properties of thermoset resins are measured by the heat distortion temperature (HDT). The HDT is not the only method of determining the performance of resins at elevated temperature, but is a commonly used indicator. Thermoset resins have what is called a glass transition temperature (Tg) where their properties changing from a glassy or rigid state to a softer or rubbery state. When the temperature reaches and goes beyond the Tg of a particular resin its physical properties diminish significantly. However, as temperatures approach the HDT physical properties remain fairly constant. The Tg and HDT of resins are determined by the inherent chemistry of the resin and the degree of cure. Typical HDT values are provided for the different categories of thermoset resins in Table 7. When pipe rehabilitation products will be required to perform continuously at elevated temperatures alternative resins and/or additional factors of safety may be required to compensate for the resulting reduction of stiffness and/or strength.

Table 7. Typical heat distortion temperatures (HDT) for thermoset resins used for CIPP.

	Epoxy Resin	Epoxy Vinyl Ester	Isophthalic Polyester	Filled Isophthalic Polyester
HDT	150-225F	200-245F	190-225F	190-225F

Chemical Resistance Properties of Thermosetting Resins

By the nature of the application, most CIPP will be exposed to some type of chemical environment. Since most applications involve a combination of chemicals at varying concentrations it is difficult to evaluate all the possibilities that may be necessary to define the exact performance. To simplify this analysis standard chemicals are chosen at higher than normal concentrations. Testing can also be done at elevated temperatures to accelerate the effects of these chemicals on the resin/felt composites. To date there is no defined test method for specifically evaluating CIPP composites. The standard practice currently used is to adopt a modified version of ASTM C581, which was developed for fiberglass/resin composites. By so doing, four resin/felt coupons are submerged into the chemical of interest. At intervals of 30, 90, 180 and 360 days a coupon is removed from the chemical, weighed, measured, and tested for flexural properties. At the end of one year these separate evaluations are compared to a control coupon that was not exposed to the chemical. The one aspect of this test method that can create anomalies arises when the test coupons are not uniform. In other words, all five coupons should initially have identical physical properties before the testing starts. If one or several coupons had significantly higher or lower physical properties initially, this may adversely effect of the outcome of the protocol with an anomalous data point(s). For such cases it is common to eliminate that data point from the data set and use the remaining data as an indication of the overall performance.

Table 8 provides a set of chemical resistance performance for the different types of thermoset resins used for CIPP in a number of different chemicals. This set of chemical data was performed at an elevated temperature of 120F. The one-year data was statistically fit and extrapolated out to obtain a prediction of performance at 25 years. From the data it is clear that different resin categories perform differently in groups of chemicals. Isophthalic polyester resins generally perform extremely well in acidic chemicals (i.e. sulfuric, nitric, hydrochloric acids), but perform moderately in oxidizing agents (i.e. sodium hypochlorite, potassium permanganate, hydrogen peroxide), and poorly in basic chemicals (i.e. ammonium hydroxide, sodium hydroxide). Epoxy resins generally perform extremely well in basic chemicals, but also can withstand acidic and oxidizing chemicals. Epoxy vinyl ester resins have excellent overall chemical resistance to all three categories of chemicals.

Table 9 provides an estimate of the retention of physical properties of resin/felt composites using the chemical agents specified in ASTM F1216. The data obtained in Table 9 was run at room temperature and evaluated for a period of one (1) year. Several different resin types were tested and the 1, 3, 6 and 12 month data was averaged to obtain an overall estimate of the one-year retention of physical properties. This set of tests indicates a high level of chemical resistance to all the chemicals when evaluated at the aforementioned conditions. There also appears to be no significant difference between the standard polyester and the filled polyester resins.

When specifying a resin for CIPP it is obvious one must consider the chemical environment of the application. Since most sewerage applications are acidic in nature, isophthalic polyester resins typically are adequate and work well in this environment. However, it is often difficult to predict what may be introduced into a municipal sewer or industrial piping system. For example, odor-reducing chemicals commonly used in municipal sewers could be potentially damaging to polyester resins, while not affecting epoxy or epoxy vinyl ester resins. As the environment and managing personnel change over years, common practices also change, thereby changing the requirements of the CIPP.



Large bore trenchless renovation in "tight quarters"

Table 8. Chemical Resistance of Thermoset Resins Used for CIPP. Estimated Percent Retention of Flexural Properties.

		Percent Retention of Flexural Properties					
Chemical Tested	Flexural Property	Epoxy Vinyl Ester		Epoxy		Isophthalic Polyester	
		1 year Actual	25 years Estimated	1 year Actual	25 years Estimated	1 year Actual	25 years Estimated
2.5% Sodium Hypochlorite	Modulus	100	99	30	42	0	0
	Strength	100+	100+	42	45	0	0
5% Hydrogen Peroxide	Modulus	96	94	76	84	75	65
	Strength	100	100	66	84	83	76
5% Potassium Permanganate	Modulus	100+	100+	90	83	84	77
	Strength	98	97	83	60	62	49
5% Sodium Hydroxide	Modulus	74	65	78	88	0	0
	Strength	79	71	75	72	0	0
5% Ammonium Hydroxide	Modulus	76	65	66	65	35	22
	Strength	72	61	64	54	38	25
25% Sulfuric Acid	Modulus	100+	100+	93	93	92	89
	Strength	97	95	90	100+	93	91
20% Hydrochloric Acid	Modulus	100+	100+	93	89	84	78
	Strength	100+	100+	99	95	79	70
5% Nitric Acid	Modulus	100+	100+	91	85	86	79
	Strength	100+	100+	100+	82	82	75

Note: 100+ indicates the curve fit would predict physical property retention greater than 100%.

Table 9. Average Chemical Resistance of Typical Thermoset Resins Evaluated for One year Using Chemicals Specified in AS m F1216.

		Percent Retention of Flexural Properties		
Chemical Tested	Physical Property	Epoxy Vinyl Ester	Isophthalic polyester	Filled Isophthalic Polyester
10% Sulfuric Acid	Modulus	92	98	90
	Strength	90	87	94
5% Nitric Acid	Modulus	98	95	86
	Strength	93	87	99
10% Phosphoric Acid	Modulus	87	94	87
	Strength	89	90	99
100% Gasoline	Modulus	101	98	90
	Strength	94	94	95
100% Vegetable Oil	Modulus	102	99	95
	Strength	100	94	100
Tap Water	Modulus	92	95	85
	Strength	90	85	99
0.1% Detergent	Modulus	110	94	90
	Strength	108	90	94
0.1% Soap	Modulus	99	93	85
	Strength	95	89	98



CIPP installation at Joe Louis Arena – Home of the Detroit Red Wings



Rehabilitation of 900 feet of 72-inch sanitary trunk sewer at "The Joe"

STRUCTURAL DESIGN OF CIPP

In the previous sections of this Engineering Design Manual ASTM specifications F1216 and F1743 have been reviewed and the design equations utilized in this manual will conform to the requirements of these specifications. Alternative designs for CIPP have merits and potentially offer more accurate predictions of performance. However, it is not the purpose of this Design Manual to advocate or implement the use of these alternative design equations until they have been accepted and adopted by specifying organizations such as ASTM. In order to provide a basis for these design models a review of the development of the design theory used in the ASTM standards will be discussed. To put these theories into perspective an overview of some recently introduced modeling alternatives will also be discussed in this manual.

DESIGN BACKGROUND

The objective of buried pipe design evolves around the ability to develop a set of equations that can take forces of ground water, soil loading and other pressures such as live loads into consideration. Through practical experience and scientific study it was determined that cylindrical structures such as tubes or pipe failed by buckling when exposed to an external load. Some of the earliest proven buckling theories published were carried out by Timoshenko and others in the early 1900's [19]. This work focused on buckling behavior of thin wall tubes. These equations were subsequently modified to take into account long tubes having a practical thickness consistent with the building materials available at the time. One of the first practical applications of this work was the successful development of the first submarines. The unrestrained buckling equation that was developed for long thin tubes is given as follows:

$$P_w = \frac{2 E t^3}{(1 - \nu^2) D_m^3} \quad (1)$$

where, P_w	=	Hydrostatic water pressure
E	=	Modulus of elasticity of the pipe
t	=	Pipe wall thickness
ν	=	Poisson's ratio, typically = 0.3
D_m	=	Mean pipe diameter ($D_o - t$)
D_o	=	Mean outer CIPP diameter

In the 1940's Spangler published work that was conducted on flexible piping systems[20]. This work was the basis by which pipe stiffness of flexible pipes was derived. The measurement of pipe stiffness has been standardized with ASTM D2412[21] and is determined at a pipe deflection of 5%. This is a relatively simple test and is performed on free standing, unsupported pipe placed between two parallel plates that are pressed towards each other at a controlled rate. Spangler's also developed a model for the deflection of buried flexible pipe that took into account factors such as dead load forces, pipe bedding, and soil modulus[20].

Work by these early pioneering engineers was extremely important in laying the foundation that is the basis of the design equations used for CIPP. However, it is important to understand that there is very little similarity between the loading experienced by installed CIPP and that of buried rigid or flexible pipe. CIPP is installed into existing pipe that has typically been buried for many years. As such, the soil has long since consolidated and the soil pipe system is typically very stable. Therefore, installed CIPP is supported by the soil pipe system and subsequent pipe deflections can be expected to be minimal. When CIPP is installed into an existing pipe the surrounding pipe provides constrained ring support to the CIPP under the influence of uniform hydrostatic water pressure. When CIPP is exposed to this type of loading the CIPP is under compression. If the load increases to a critical level the CIPP will eventually deform and fail by buckling. Hydrostatic buckling experiments carried out by Aggerwal and Cooper[22], Lo and Zhang[23], and Kleweno[24] have clearly demonstrated practical ranges of the enhancement that can be obtained by the support

provided by the host pipe. These studies demonstrated that supported CIPP can buckle at pressures that are seven to fifteen times greater than that of unrestrained CIPP. In order to account for this support in the development of buckling equations used in the design of CIPP this phenomenon was characterized as an enhancement factor and assigned the variable "K". The enhancement factor is the ratio between the restrained buckling pressure and the unrestrained buckling pressure. By applying a statistical treatment of the data generated by Aggerwal and Cooper the value of K was assigned a value of seven (7). In other words, there is high statistical confidence that the restrained buckling pressure will be at least seven times greater than the unrestrained buckling pressure. By applying the enhancement factor and appropriate safety factors to the buckling equation attributed to Timoshenko, CIPP can be designed to easily withstand the hydrostatic forces that are prevalent around the pipe. In most practical applications, CIPP is installed in conditions where the hydrostatic pressure is significantly less than the critical buckling pressure. As such CIPP failure may still occur, but would occur over a very long period of time. This type of long-term buckling failure occurs as a result of plastic creep deformation. Materials such as thermoset and thermoplastic resins will undergo slight deformations over time when exposed to a constant load, such as hydrostatic water pressure. Given enough pressure and a long enough period of time, the CIPP can deform to the extent that it will produce catastrophic failure by buckling. In order to take the long term effects of creep into account the modulus of elasticity in the buckling equation attributed to Timoshenko was modified to a long-term modulus. In addition, a safety factor and correction for pipe ovality was also added to obtain the restrained buckling equation. By substituting the dimension ratio (DR) for the mean diameter and rearranging, the equation reduces as given below:

$$P_w = \frac{2KE_L}{(1 - \nu^2)} \frac{1}{(DR - 1)^3} \frac{C}{N} \quad (2)$$

where, E_L = Long-term modulus of elasticity of the pipe material
 K = Enhancement factor, typically $K = 7$
 DR = D_o/t , D_o = mean outside diameter of the CIPP
 N = Safety factor
 C = Ovality correction factor (See Appendix Table 12)

$$C = [D_{\text{omin}}/(D_{\text{omax}})^2]^3 = [(1 - q/100) / (1 + q/100)^2]^3 = (r/re)^3 \quad (3)$$

$$q = 100 \times \frac{(D - D_{\text{min}})}{D}, \text{ or } 100 \times \frac{(D_{\text{max}} - D)}{D} \quad (4)$$

where, C = Ovality reduction factor
 q = Percentage of ovality of the original pipe
 D = Inside diameter of the original pipe
 D_{min} = Minimum inside diameter of the original pipe
 D_{max} = Maximum inside diameter of the original pipe

The effects of long-term hydrostatic buckling of installed CIPP was studied by the Trenchless Technology Center (TTC) at Louisiana Tech University by Guice in 1994[17]. The study carried out by the TTC was an investigation into the long-term structural performance comparing the critical buckling behavior of several pipe rehabilitation systems (i.e. five cured-in-place pipe (CIPP) and one PVC fold and form (FNF)) from a number of commercial product manufacturers. These pipe rehabilitation products were installed in sections of round steel pipe that were sealed with gaskets on the ends.. The annular space between the steel pipe and the liner were pressurized with water at a number of different pressures and monitored over time as the products crept, deformed, and eventually failed by buckling. Although the report was extensive the data produced had significant scatter and has been the subject of many subsequent papers

that questioned the inability to control experimental variables. Subsequent reports and presentations (McAlpine, 1996[25], 1996[26]) have pointed out the flaws of the testing program. These flaws include: 1) testing carried out in perfectly round steel pipe, 2) the CIPP was manufactured above ground under highly controlled conditions, 3) tested under controlled temperature and humidity conditions, 4) no influence of chemicals typically found in sanitary sewer conditions, and 5) lack of detailed statistical analysis. In recent years long-term tests have been extensively analyzed in an attempt to develop experimental protocols that can carefully control variables for long- and short-term hydrostatic buckling. In addition, there has been considerable research to define the relationship between E and K , and/or to develop alternative buckling models that correlate more closely with data. The model developed by Glock[27] has gained considerable support (Guice & Li, [28], Schrock & Gumbel, [29]) as a more accurately representing existing data. New models being proposed are refinements that can represent pipe imperfections (Moore[30]) and ovality (Omara[31]) more accurately. With all the potential problems pointed out by a number of authors regarding the modified buckling equation that is currently used in ASTM F1216 and ASTM F1743, this equation appears to be providing a conservative design basis for pipe lining systems as evidenced by the lack of failures over the 30+ years of its use.

Since there is currently no single design equation that can be used for all the different conditions that must be taken into account for the proper design of CIPP it is necessary to divide these conditions into different groups. For both gravity flow and internal pressure design equations have been divided into categories of “partially deteriorated” and “fully deteriorated” conditions of the existing pipe to be rehabilitated. These piping conditions are defined as follows:

Partially Deteriorated Piping Condition

A partially deteriorated gravity flow pipe is one in which the existing pipe may have displaced joints, cracks or corrosion, but is structurally able to support all soil and surface loads. In this case the existing pipe is intended to provide structural support over the full circumference of the CIPP. When assuming a pipe is partially deteriorated, the CIPP will be designed to withstand uniform hydrostatic pressure over the full circumference of the CIPP. In addition, as a conservative approach, this design does not assume that the CIPP is attached to the existing pipe in any way.

A partially deteriorated pressure pipe is one in which the existing pipe may also have minor corrosion, leaking joints, and/or small holes, and should be free of any longitudinal cracks. In this case the existing pipe is assumed to be able to withstand the specified internal design pressure over the expected lifetime of the pipe. When assuming a pressure pipe is partially deteriorated, it is assumed that the CIPP will conform tightly against the host pipe everywhere (i.e. in bends or diameter changes, etc.) and uses the strength of the existing pipe to support the stresses. The thickness of the CIPP can be compensated to span small holes or leaking joints, but will not be of sufficient thickness to withstand design pressures. In addition, if the partially deteriorated pressure pipe is assumed to be leaking the designer must also be aware of external hydrostatic pressure to insure that the minimum CIPP thickness is sufficient to withstand these forces over the design life of the product.

Fully Deteriorated Piping Condition

A fully deteriorated gravity flow pipe is one in which the existing pipe has insufficient strength to support all soil and surface loads. A fully deteriorated pipe is characterized by severe corrosion, missing pipe, crushed pipe, longitudinal cracks, and severely deformed pipe. When assuming a pipe is fully deteriorated, the CIPP is designed as a pipe able to withstand all hydrostatic, soil, and live loads that may exist in the CIPP-soil system with adequate soil support.

An alternative strategy for fully deteriorated gravity flow pipes is available to the designer in areas where there are isolated sections of missing or severely offset pipe that would otherwise cause it to be classified as fully deteriorated. In these areas it may be possible to carry out point repairs, and rehabilitate the pipe as a partially deteriorated classification. However, each situation must be considered separately.

A fully deteriorated pressure pipe is one in which the existing pipe has failed and/or has insufficient strength to operate at specified design pressures. A pipe may also be classified as fully deteriorated if it is determined that it will not be able to withstand design pressures at some point during the expected lifetime. A fully deteriorated pressure pipe is characterized by significant loss of wall thickness due to severe corrosion, large holes, missing sections of pipe, and leaking longitudinal cracks. When assuming a pipe is fully deteriorated, the CIPP is designed as a stand alone pipe able to withstand all internal pressure. In addition, the designer must also be aware that fully deteriorated CIPP pressure pipe must be capable of withstanding external hydrostatic pressure.

PARTIALLY DETERIORATED GRAVITY FLOW CIPP DESIGN

When rehabilitating existing pipe that has been classified as partially deteriorated in a gravity flow condition the restrained buckling condition applies. In this case the classical buckling equation that has been described previously is re-arranged to solve for CIPP thickness as follows:

$$t = \frac{D_o}{\left(\frac{2KE_L C}{P_w N (1 - v^2)} \right)^{1/3} + 1} \quad (5)$$

where, D_o	=	Mean outer CIPP diameter, inches
K	=	Enhancement factor, typically $K = 7$
E_L	=	Long-term modulus of elasticity of the pipe material
C	=	Ovality correction factor (See Appendix Table 12)
P_w	=	External water pressure measured above the pipe invert (See Appendix Table 13)
N	=	Safety factor, typically $N = 1.5 - 2.0$
v	=	Poisson's ratio, typically $v = 0.3$

For partially deteriorated design conditions where the groundwater is below the invert of the pipe the hydrostatic pressure is equal to zero and the restrained buckling equation cannot be used to calculate CIPP thickness. For this special design case the calculated thickness of the CIPP must be equal to or greater than that which will produce a maximum dimension ratio of $DR = 100$. When this special design condition exists, CIPP thickness is determined by the following equation:

$$t = D_o/100 \quad (6)$$

When designing for circular partially deteriorated pipe the CIPP is under constant compressive hoop stresses. If the existing pipe is out of round or has localized ovalization, bending moment forces may predominate on the CIPP. For this special case the CIPP must be checked to insure that the bending forces do not exceed the long-term flexural strength of the CIPP. To make this determination the bending stresses on the CIPP are determined by the following equation:

$$\frac{S}{P_w N} = [1.5q/100 (1 + q/100)DR^2] - [0.5(1 + q/100)DR] \quad (7)$$

where q is defined by Equation 4 and the other parameters have been defined previously.

Partially Deteriorated Design Example

Determine the minimum wall thickness required of the following piping condition:

- 1) Existing pipe classification = Partially deteriorated
- 2) Mean outer CIPP diameter (D_o) = 24 inches

- 3) Minimum pipe diameter (D_{min}) = 23.1 inches
- 4) External water above invert = 8 feet
- 5) Minimum CIPP modulus (E) = 350,000 psi
- 6) Minimum CIPP strength (s) = 5,500 psi
- 7) Long-term modulus (E_L) = 175,000 psi
- 8) Long-term strength (s_L) = 2750 psi

A. Determine hydrostatic pressure acting on CIPP

$$P = 8 \text{ ft} \times 0.433 \text{ psi/ft water} = 3.46 \text{ psi}$$

B. Calculate the pipe ovality

Determine q using Equation 4.

$$q = 100(24 - 23.1)/24 = 3.75\%$$

Determine ovality reduction factor using Equation 3

$$C = [(1 - 3.75/100)/(1 + 3.75/100)^2]^3 = 0.715$$

C. Determine minimum CIPP design thickness using buckling Equation 5

$$t = \frac{24}{\left(\frac{2(7)175,000(.715)}{(3.46)2(1 - .32)} \right)^{1/3} + 1} = 0.36 \text{ inches}$$

D. Because the pipe is out of round, bending stresses must be calculated to insure they do not exceed the long-term flexural strength of the CIPP

Determine S using Equation 7

$$DR = D_o/t = 24/0.36 = 66.6$$

$$S/(3.46)2 = [1.5(3.75/100)(1 + 3.75/100)66.6^2] - [0.5(1 + 3.75/100)66.6]$$

$$S = 1552.2 \text{ psi}$$

E. The minimum CIPP design thickness is 0.36 inches because the bending stresses are less than the long-term CIPP flexural strength. However, if the bending stresses had exceeded the long-term flexural strength then this equation would control the design. In this case solving for the proper thickness can be accomplished by trial and error. Start by choosing dimension ratios (DR) that are smaller than previously used until the bending stress is less than the long-term flexural strength of the CIPP.

FULLY DETERIORATED GRAVITY FLOW CIPP DESIGN

When rehabilitating existing pipe that has been classified as fully deteriorated in a gravity flow condition ASTM F1216 and ASTM F1743 specifies the use of a design equation from AWWA C950 that has been modified by adding the ovality reduction factor, and the consideration of long-term effects due to creep. In this case the modified AWWA C950 equation from ASTM F1216 has been re-arranged to solve for CIPP thickness as follows:

$$t = .721 D_o \left(\frac{(NP_t)^2}{CE_L R_w B' E'} \right)^{1/3} \quad (8)$$

- where, P_t = Total pressure due to water, soil and live load acting on pipe, psi
- R_w = Buoyancy factor, dimensionless
- B' = Empirical coefficient of elastic support, dimensionless
- E' = Modulus of elasticity of adjacent soils or soil reaction, psi

The CIPP designed by the modified AWWA C950 formula is required to have a minimum stiffness (EI/Do^3) which is 50% of the specification. The AWWA C950 specification calls for EI/Do^3 to be equal to 0.186 and 50% of this value is 0.093. In the following equation this means that pipe designed with a flexural modulus of elasticity $E = 350,000$ psi would have a dimension ratio equal to 67 for fully deteriorated pipe. If the CIPP stiffness is too low, the wall thickness must be increased accordingly to insure that the following design condition is met:

$$EI/Do^3 = E/12(DR)^3 \geq 0.093 \quad (9)$$

where, E = Flexural modulus of elasticity of the CIPP, psi
 I = Moment of inertia, in^4 , $in = t^3/12$

When designing fully deteriorated CIPP where the existing pipe is out of round or the CIPP may have localized ovalization, bending moment forces may predominate on the CIPP. For this special case of the fully deteriorated design the CIPP must be checked to insure that the bending forces do not exceed the long-term flexural strength of the CIPP. To make this determination the bending stresses on the CIPP are determined by modifying Equation 7 and substituting total pressure (P_t) to produce the following equation:

$$\frac{S_L}{P_t N} = [1.5q/100 (1 + q/100)DR^2] - [0.5(1 + q/100)DR] \quad (10)$$

where q is defined by Equation 4 and the other parameters have been defined previously.

Total External Pressure on CIPP

Several new parameters are introduced for the design of fully deteriorated gravity flow pipe. This manual is intended to provide simplistic explanations of these design parameters that have not been provided in ASTM F1216 or other design guides currently available. When determining fully deteriorated designs all loads acting on the CIPP must be estimated to determine the total pressure (P_t). This is accomplished by estimating the contribution of each individual load and adding them together. The total load is typically made up of hydrostatic water pressure (P_w'), buoyancy corrected soil load (P_s), superimposed or live loads (P_L), and other loads such as vacuum (P_v). Loading due to vacuum is a special case and will not be handled here. Consult Lanzo Lining Services for recommendations related to vacuum loading. The total pressure acting on the pipe can be represented as follows:

$$P = P_w' + P_s + P_L + P_v \quad (11)$$

Hydrostatic Water and Soil Loads

Initially, groundwater and soil heights must be determined or estimated to begin the design process. For the fully deteriorated design condition be careful to note that groundwater and soil heights are determined from the top of the pipe and not the invert. The hydrostatic pressure is determined as follows:

$$P_w' = H_w (.433 \text{ psi/ft water}) \quad (12)$$

where, H_w = Water height above the top of the pipe, ft

The contribution related to soil loading involves many different parameters. The soil prism loading pressure is determined as follows:

$$P_s = wH_sR_w/144\text{in}^2/\text{ft}^2 \quad (13)$$

where, w = Soil density, lb/ft³ (See Table 14 for soil types and densities)
 H_s = Soil height above top of pipe, ft.
 R_w = Water buoyancy factor, dimensionless

$$R_w = 1 - 0.33(H_w/H_s) \geq 0.67 \quad (14)$$

Other related design parameters are the modulus of soil reaction or elastic support (E') and the coefficient of elastic support (B'). The modulus of soil reaction values used for CIPP design should typically represent stable undisturbed soils that would have E' values in the range of 700 to 3000 psi. Most typically a value of 700 psi is recommended for unknown soil conditions. Where the pipe is buried deep and the soil condition is stable values of 1000 to 1500 psi may be applicable. In areas known to have weak and unstable native soils a value of 200 psi may be appropriate. The coefficient of elastic support (B') is determined with the following relationship:

$$B' = 1/(1 + 4e^{-0.065H_s}) \quad (15)$$

Superimposed or Live Loads

For the fully deteriorated design condition dynamic live load pressures occur frequently and are a standard design condition for the parameter PL. Live loads may be classified as either concentrated or distributed, depending on the soil pipe conditions and the depth the pipe is buried. In some cases the live load may be characterized by impact factors. Impact loading is generally only applicable for pipes that are relatively shallow (i.e. 2-5 ft). A number of maximum live load conditions have been studied and recommended for pipe buried beneath highways, railways, and airport runways. The generally accepted guidelines for determining these live loading conditions are provided by the ASSHTO Standard Specifications for Highway Bridges[32], HS-20-44 highway loading, American Railway Engineers Association (AREA) Cooper E-80 loading, and the Federal Aviation Agency criteria. The most frequently encountered design condition is that for pipes buried under active roads or highways. For highway HS-20 loading the live load becomes insignificant beyond seven feet of soil height cover over the top of the pipe. Live load pressures (PL) associated with the aforementioned piping conditions are given in Table 18.

Fully Deteriorated Design Example

Determine the minimum wall thickness required of the following piping condition:

- | | | |
|---|---|--|
| 1) Existing pipe classification | = | Fully deteriorated |
| 2) Mean outer CIPP diameter (D_o) | = | 48 inches |
| 3) Minimum pipe diameter (D_{min}) | = | 47.04 inches |
| 4) External water above pipe (H_w) | = | 8 feet |
| 5) Depth of soil cover above pipe (H_s) | = | 15 feet |
| 6) Type of soil | = | Ordinary Clay (120lb/ft ³) |
| 7) Soil Modulus (E_s) | = | 700 psi |
| 8) Live load | = | Live load HS-20 |
| 9) Minimum CIPP flexural modulus (E) | = | 350,000 psi |
| 10) Minimum CIPP flexural strength (s) | = | 5,500 psi |
| 11) Long-term modulus (E_L) | = | 175,000 psi |
| 12) Long-term strength (S_L) | = | 2750 psi |

A. Determine the total load

Hydrostatic water pressure

$$P_w = 0.433(H_w) = .433\text{psi/ft}(8\text{ft}) = 3.46 \text{ psi}$$

Soil load

$$P_s = w_s R_w / 144\text{in}^2/\text{ft}^2$$

$$R_w = 1 - 0.33(H_w/H_s) \geq 0.67 = 1 - 0.33(8\text{ft}/15\text{ft}) = 0.824 \text{ which is } > 0.67$$

Ordinary clay soil density = 120lb/ft³

$$P_s = 120\text{lb/ft}^3(15\text{ft})0.824/144\text{in}^2/\text{ft}^2 = 10.3 \text{ psi}$$

The soil pressure can also be determined by multiplying the Buoyancy Correction Factor (R_w) times the Soil Prism Pressure give in Table 17.

$$P_s = 0.824(12.5) = 10.3 \text{ psi}$$

Live load (P_L) (Table 18) ~ 0 psi

Total pressure load applied to the CIPP

$$P_t = 3.46 \text{ psi} + 10.3 \text{ psi} = 13.76$$

B. Calculate coefficient of elastic support

$$B' = 1/(1 + 4e^{-0.065H_s})$$

$$B' = 1/(1 + 4e^{-0.065(15\text{ft})}) = 0.40 \text{ (Table 16)}$$

C. Calculate pipe ovality using Equation 4

$$q = 100(48 - 47.04)/48 = 2.0\%$$

Determine ovality reduction factor using Equation 3

$$C = [(1 - 2.29/100)/(1 + 2.29/100)^2]^3 = 0.84 \text{ (Table 12)}$$

D. Determine the minimum CIPP thickness for buckling

$$t = .721 D_o \left(\frac{(NP_t)^2}{CE_L R_w B' E'} \right)^{1/3} = .721(48) \left(\frac{(2.0(13.76))^2}{(.84)(175,000)(.824)(.4)(700)} \right)^{1/3}$$

$$t = 0.975 \text{ inch}$$

E. Check for minimum pipe stiffness

$$DR = 48/0.975 = 49.2$$

$$350,000/12(49.2)^3 = .26 \geq 0.093$$

F. Check for pressure limited due to bending stresses (Equation 10)

$$S_L = 13.76(2)[1.5(2)/100(1 + 2.0/100)48^2] - [0.5(1 + 2/100)48]$$

$$S_L = 1920 \text{ psi}$$

G. The calculated bending stress (i.e. 1,920psi) is less than the estimated long-term bending strength of the resin (i.e. 2,750psi) so bending stress does not control the design thickness for this example.

Therefore, the final design thickness for the CIPP is:

$$t = .975 \text{ inch}$$

PARTIALLY DETERIORATED INTERNAL PRESSURE PIPE

When designing for internal pressure, it is critical to obtain a proper evaluation of the condition of the pipe being evaluated. Secondary to this is the requirement to understand the proper operating pressure. The third consideration for the design of pressure pipe is an understanding of test pressures, surge pressures and/or water hammer that may significantly exceed the standard operating or test pressures of the pipe. In addition, the project engineer and contractor must be aware that pipe requiring heavy cleaning may change the condition of the pipe from a partially to a fully deteriorated condition. After cleaning it is recommended that pipe classified as partially deteriorated be tested for the operating or test pressure to verify the condition of the pipe prior to lining. If the pipe is able to maintain the specified pressure then it can be classified as partially deteriorated without question. However, this may not always be possible due to the presence of small holes in the pipe that will not allow it to maintain pressure. When the condition of the pipe and/or the operating parameter is not well defined, it is recommended that the pipe be classified as fully deteriorated. Pressure pipe presents a higher risk application of CIPP and it is recommended that the contractor have experience in this area of technology to insure success[33].

The partially deteriorated design equation for internal pressure pipe given in ASTM F1216 was derived with the assumption that the CIPP acts like a uniformly pressurized round flat plate with fixed edges covering an existing hole in the pipe. The CIPP is designed with the assumption that the aforementioned condition prevails and that bending stresses at and around the hole (if one exists) control the design thickness. This design assumption is more conservative than that of a square or rectangular plate.

The equation given in ASTM F1216 has been incorrectly derived with the term DR-1 in the derivation instead of the correct term DR. Although it may be argued that the difference is negligible to the outcome of the calculated thickness, the technically correct derivation will be advocated for use in this engineering design guide. The technically correct derivation for pressure acting on a flat circular plate covering a hole is given below. This equation has been rearranged to solve for CIPP thickness:

$$t = \frac{D_o}{[5.33/P_i (D_o/D_h)^2 (S_L/N)]^{0.5} + 1} \quad (16)$$

where, D_o	=	Mean outer CIPP diameter, inches
P_i	=	Internal pipe pressure, psi
D_h	=	Hole diameter in the pipe, inches
S_L	=	Long-term flexural bending strength for the CIPP, psi
N	=	Safety factor, $N = 2$ minimum

In order for the circular flat plate design condition to be valid the following criteria must be met. If this condition is not met then the CIPP cannot be considered a circular flat plate and ring tension or hoop stress will dominate. For this condition the internal pressure condition is designed as a fully deteriorated internal pressure pipe.

$$D_h/D_o \leq 1.83(t/D_o)^{0.5} \quad (17)$$

The variables used in Equation 17 have been previously defined.

Once the CIPP thickness has been calculated this value must be compared with the thickness calculated from Equation 5 to confirm that external hydrostatic water pressure does not dominate the design condition. The larger thickness is then selected for the design. Since design Equation 17 is conservative it may at times lead to a greater CIPP thickness than if the CIPP is evaluated in ring tension as an unrestrained, stand-alone pipe. Any internal pressure pipe application is higher risk so it is recommended that a Lanzo Lining Services representative be contacted for assistance in pressure pipe design assistance.

Partially Deteriorated Internal Pressure Pipe Design Example

1) Determine the CIPP thickness for the following piping conditions:

2) Existing pipe classification	=	Partially deteriorated
3) Existing pipe inner diameter (D)	=	15 inches
4) Existing pipe maximum diameter (Dmax)	=	15.2 inches
5) Internal pressure (Pi)	=	80 psi
6) External water (Hw)	=	5 ft above top of pipe
7) Maximum pipe hole diameter (Dh)	=	1 inch
8) Minimum CIPP flexural modulus (E)	=	350,000 psi
9) Minimum CIPP flexural strength (s)	=	5,500 psi
10) Minimum long-term modulus (E _L)	=	175,000 psi
11) Minimum long-term strength (S _L)	=	2,750 psi
12) Minimum long-term tensile strength (S _{tl})	=	1,750 psi

A. Determine the pressure pipe thickness using Equation 16.

$$D_o = \frac{D + D_{max}}{2} = \frac{15.0 + 15.2}{2}$$

$$D_o = 15.1 \text{ inches}$$

$$t = \frac{15.1}{[5.33/80(15.1/1.0)^2(2,750/2.0)]^{1/2} + 1}$$

$$t = 0.10 \text{ inches}$$

B. Check thickness with Equation 17.

$$1/15.1 \leq 1.83(0.1/15.1)^{1/2}$$

$$0.066 \leq 0.149$$

The condition of Equation 17 is met

C. Check the thickness for external pressure using Equation 5.

$$q = 100(15.2 - 15.0)/15.0 = 1.33\%$$

$$C = [(1 - 1.33/100)/(1 + 1.33/100)^2]^3 = 0.89$$

$$P_w = 5(.433) = 2.2 \text{ psi}$$

$$t = 0.18 \text{ inches}$$

The thickness for external pressure is greater than that required for internal pressure and the DR = 84, which is less than 100, as specified in Equation 6.

D. Since the pipe is slightly out of round, the bending stresses must be checked using Equation 7.

$$S_L = 2.2(2.0)[[1.5(.0133)(1 + .0133)84^2] - [0.5(1 + .0133)84]]$$

$S_L = 440$, which is less than the long-term flexural strength of the CIPP. Therefore, the final CIPP thickness is $t = 0.18$ inches.

FULLY DETERIORATED INTERNAL PRESSURE PIPE

As discussed previously, it is critical to understand the physical conditions of the pipe and the operating parameters of the system when designing for the fully deteriorated pressure condition. This pipe classification assumes the existing pipe has no capability to hold any of the pressure and the CIPP must be designed of a proper thickness to hold all internal and external pressure.

For the design of pressure pipes it may assumed that pipes are either thick or thin walled cylinders with uniform pipe wall thickness. Internal pressure produces an internal ring tension loading condition and tensile strength of the resin/fabric matrix used to construct the CIPP is important to the design. As reviewed in the Materials section of the Engineering Design Guide, high performance resins such as vinyl esters and epoxy resins are recommended for pressure applications due to their high tensile strength and elongation properties. Contact Lanzo Lining technical services for recommendations concerning the design and materials selection for pressure pipe.

The design equation for fully deteriorated pressure pipe given in ASTM F1216 assumes pressure pipe is a thick walled cylinder as given below:

$$P_i = \frac{2s_{tl}}{(DR - 2) N} \quad (18)$$

The equation for a thin walled cylinder is given as follows:

$$P_i = \frac{2s_{tl}}{(DR - 1) N} \quad (19)$$

When rearranged to solve for thickness Equation 19 becomes:

$$t = \frac{D_o}{[(2s_{tl}/P_i N) + 1]} \quad (20)$$

The variables used in Equation 20 have previously been defined.

Although the differences are relatively small, the solution for a thin walled cylinder is a more conservative approach than ASTM F1216. Therefore, design Equation 20 for a thin walled pressure cylinder will be used for fully deteriorated pressure pipe. When the pressure pipe is underground the CIPP thickness for internal pressure should be checked against Equations 8 and 9 for fully deteriorated gravity flow pipe. The greatest thickness is chosen for the pressure pipe.



Fully Deteriorated Internal Pressure Pipe Design Example

Determine the CIPP thickness for the following pipe design conditions:

1) Existing pipe classification	=	Fully deteriorated
2) Existing pipe inner diameter (D)	=	15 inches
3) Existing pipe maximum diameter (Dmax)	=	15.2 inches
4) Internal pressure (Pi)	=	80 psi
5) External water (Hw)	=	8 ft above top of pipe
6) Soil height (Hs)	=	15 ft above top of pipe
7) Soil type	=	Ordinary Clay (120lb/ft3)
8) Soil modulus (E')	=	700 psi
9) Minimum CIPP flexural modulus (E)	=	350,000 psi
10) Minimum CIPP flexural strength (s)	=	5,500 psi
11) Minimum long-term modulus (EL)	=	175,000 psi
12) Minimum long-term strength (sL)	=	2,750 psi
13) Minimum long-term tensile strength (stL)	=	1,750 psi

A. Determine the CIPP thickness using Equation 20.

$$D_o = 15.1 \text{ (From previous example)}$$

$$t = 15.1 / [(2(1750)/80(2)) + 1] = 0.66 \text{ inches}$$

B. Check the CIPP thickness against the fully deteriorated gravity flow design condition for external buckling (Equation 8).

Determine the total pressure

$$P_t = P_w + P_s + P_L = 3.46 + 10.3 + 0 \text{ (see previous Fully Deteriorated example)}$$

$$P_t = 13.76$$

Determine pipe ovality (see previous example)

$$q = 1.33\% \text{ (Equation 4)}$$

$$C = 0.89 \text{ (Equation 3, Table 12)}$$

Determine CIPP thickness using Equation 8.

$$R_w = 0.824 \text{ (Table 15, see previous example)}$$

$$B' = 0.40 \text{ (Table 16)}$$

$$t = .721 D_o \left(\frac{[(NP_t)^2]}{CE_L R_w B' E'} \right)^{1/3} = .721(15.1) \left(\frac{((2.0)(13.76))^2}{(.89)(175,000)(.824)(.4)(700)} \right)^{1/3}$$

$$t = 0.30 \text{ inch}$$

Since 0.30 in $\leq$ 0.66 inch internal pressure dominates the design.

C. Check the CIPP thickness for minimum pipe stiffness using Equation 9.

$$DR = 15.1/0.66 = 22.9$$

$$350,000/12(22.9)^3 \geq 0.093$$

$$2.43 \geq 0.093$$

D. Since the pipe is slightly out of round, the bending stresses must be checked using Equation 10.

$$S_L = 13.76(2.0)[[1.5(1.33)/100(1+1.33/100)22.9^2] + [0.5(1+1.33/100)22.9]]$$

$$S_L = 612 \text{ psi, which is less than } 2750 \text{ psi}$$

E. All checks indicate that internal pressure dominates the design of this fully deteriorated pressure pipe and the specified thickness is $t = 0.66$ inches.

HyDRAULIC DESIGN OF CIPP

GRAVITY FLOW

The installation of CIPP typically improves the flow characteristics of the pipe being rehabilitated. Flow is improved because the inner surface of CIPP is extremely smooth and continuous, without any joints or discontinuities that create friction to flow. Typically the Manning equation is used to predict flow in gravity or open channel piping conditions as follows:

$$Q = VA = \frac{1.486 AR^{2/3} S^{1/2}}{n} \quad (21)$$

where, Q	=	Flow rate, cfs
V	=	Velocity, fps
A	=	Flow Area
n	=	Manning coefficient of roughness (see Table 10)
R	=	Hydraulic radius, ft = A/P
P	=	Wetted perimeter of flow, ft
S	=	Slope of grade line, ft(slope)/ft(pipe)

When the pipe is circular and the flow is full as in a surcharged situation the Manning equation may be modified to the following form:

$$Q = \frac{0.463 D^{8/3} S^{1/2}}{n} \quad (22)$$

where, D = pipe internal diameter, ft.

For circular pipe flowing full the Manning equation can be abbreviated to produce an easy comparison of flow capacity between CIPP and different piping materials as given below:

$$\% \text{ Flow Capacity} = \frac{Q_{\text{CIPP}} \times 100}{Q_{\text{exist}}} = \frac{n_{\text{exist}}}{n_{\text{CIPP}}} \left(\frac{D_{\text{CIPP}}}{D_{\text{exist}}} \right)^{8/3} \times 100 \quad (23)$$

Manning coefficients provide a relative comparison of the resistance to flow for different types of pipe and coefficients for several piping materials have been provided in Table 10. There is a large variation in the coefficients for different materials and even variation for the same piping product because these coefficients are dependent on the condition of the pipe evaluated. A conservative average Manning coefficient for CIPP in relatively smooth concrete, clay, or steel pipe is an 'n' of 0.010. However, this coefficient might be subject to change over time as slime and/or debris build up in uncleaned pipe over time.

Gravity Flow Design Example

Problem: Determine the change in flow capacity when a circular 24 inch concrete pipe is flowing full and is lined with a 12 mm thick CIPP.

1. Select Manning coefficients for the piping materials (Table 10).

a) n' for CIPP = 0.010

b) n' for concrete = 0.015

2. Determine inside pipe diameters.

a) Existing concrete pipe $D = 24$ inches

b) New CIPP $D = 24 - 2(12/25.4) = 23.1$ inches

3. Determine increased flow capacity using Equation 23.

$$\% \text{ Flow Capacity} = \frac{0.015}{0.010} \left(\frac{23.1}{24.0} \right)^{8/3} \times 100 = 135\%$$

Therefore, it was determined that the CIPP increased the flow of the pipe approximately 135% compared to the existing concrete pipe. This increase in flow was realized even though the inside diameter of the CIPP was slightly smaller than the existing concrete pipe.

PRESSURE FLOW

For pressure flow the Hazen-Williams equation is commonly utilized for determining the flow rate of the pipe. For pressure flow CIPP also increases the flow capacity of a pipe because of the inherent smoothness of the inner surface. The Hazen-Williams equation is given as follows:

$$Q = 1.318 C R^{0.63} S^{0.54} A \quad (24)$$

where, Q	=	Flow rate, cfs
C	=	Hazen-Williams coefficient (see Table 11)
R	=	Hydraulic radius, ft = A/P
A	=	Flow area, ft ²
P	=	Wetted perimeter of flow, ft
S	=	Slope of grade line, ft(slope)/ft(pipe)

As shown previously, the Hazen-Williams equation can be simplified to provide a comparison of flow capacity between CIPP and the existing pipe as follows:

$$\% \text{ Flow Capacity} = \frac{Q_{\text{CIPP}} \times 100}{Q_{\text{exist}}} = \frac{C_{\text{CIPP}}}{C_{\text{exist}}} \left(\frac{D_{\text{CIPP}}}{D_{\text{exist}}} \right)^{8/3} \times 100 \quad (25)$$

The Hazen-Williams coefficients for different piping materials, or age of materials are provided in Table 11. Determination of flow capacities of CIPP in a pressure application relative to other existing piping materials is calculated in the same manner as given in the gravity flow design example.

APPENDIX

Table 10. manning Coefficients for Typical Piping materials.

Pipe material	manning 'n' Coefficient	Recommended manning 'n'
Cured-In-Place Pipe	0.009 - 0.012	0.010
Vitrified Clay	0.013 - 0.017	0.013
Concrete	0.013 - 0.017	0.015
Corrugated Metal	0.019 - 0.030	0.025
Brick	0.015 - 0.017	0.016

Table 11. Hazen-Williams Coefficients for Typical Piping materials.

Pipe material/Condition	Recommended Hazen-Williams 'C' Coefficient
Cured-In-Place Pipe	140
New steel or ductile iron (less than 1 year old)	120
Cement lined new steel or ductile iron	140
Steel (2 years old)	120
Steel (10 years old)	100
Cast Iron (5 years old)	120
Cast Iron (18 years old)	100
Tuberculated Steel or Cast Iron	80

Table 12. Ovality reduction factor, C.

$C = [D_{omin}/(D_{omax})^2]^3$										
Percent Ovality	1	2	3	4	5	6	7	8	9	10
Reduction Factor, C	0.91	0.84	0.76	0.70	0.64	0.59	0.54	0.49	0.45	0.41



Easement installation of subdivision sewer rehab



Subaqueous installation of CIPP into storm drain

Table 13. Partially Deteriorated Gravity Flow CIPP Design Thickness.

CIPP Thickness (mm) for each Pipe Diameter (Inches) at the given Depth (feet)																		
Water Depth	Water Pressure	6	8	10	12	15	18	21	24	27	30	36	42	48	54	60	66	72
1	0.44	1.1	1.5	1.8	2.2	2.8	3.3	3.9	4.4	5.0	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2
2	0.87	1.4	1.8	2.3	2.8	3.5	4.2	4.8	5.5	6.2	6.9	8.3	9.7	11.1	12.5	13.8	15.2	16.6
3	1.30	1.6	2.1	2.6	3.2	3.9	4.7	5.5	6.3	7.1	7.9	9.5	11.1	12.6	14.2	15.8	17.4	19.0
4	1.73	1.7	2.3	2.9	3.5	4.3	5.2	6.1	6.9	7.8	8.7	10.4	12.2	13.9	15.6	17.4	19.1	20.8
5	2.17	1.9	2.5	3.1	3.7	4.7	5.6	6.5	7.5	8.4	9.4	11.2	13.1	15.0	16.8	18.7	20.6	22.4
6	2.60	2.0	2.6	3.3	4.0	5.0	6.0	6.9	7.9	8.9	9.9	11.9	13.9	15.9	17.9	19.9	21.8	23.8
7	3.03	2.1	2.8	3.5	4.2	5.2	6.3	7.3	8.4	9.4	10.4	12.5	14.6	16.7	18.8	20.9	23.0	25.1
8	3.46	2.2	2.9	3.6	4.4	5.5	6.5	7.6	8.7	9.8	10.9	13.1	15.3	17.4	19.6	21.8	24.0	26.2
9	3.90	2.3	3.0	3.8	4.5	5.7	6.8	7.9	9.1	10.2	11.3	13.6	15.9	18.1	20.4	22.7	25.0	27.2
10	4.33	2.3	3.1	3.9	4.7	5.9	7.0	8.2	9.4	10.6	11.7	14.1	16.4	18.8	21.1	23.5	25.8	28.2
11	4.76	2.4	3.2	4.0	4.8	6.1	7.3	8.5	9.7	10.9	12.1	14.5	17.0	19.4	21.8	24.2	26.6	29.1
12	5.20	2.5	3.3	4.2	5.0	6.2	7.5	8.7	10.0	11.2	12.5	15.0	17.5	19.9	22.4	24.9	27.4	29.9
13	5.63	2.6	3.4	4.3	5.1	6.4	7.7	9.0	10.2	11.5	12.8	15.4	17.9	20.5	23.0	25.6	28.1	30.7
14	6.06	2.6	3.5	4.4	5.2	6.6	7.9	9.2	10.5	11.8	13.1	15.7	18.3	21.0	23.6	26.2	28.8	31.5
15	6.50	2.7	3.6	4.5	5.4	6.7	8.0	9.4	10.7	12.1	13.4	16.1	18.8	21.5	24.1	26.8	29.5	32.2
16	6.93	2.7	3.7	4.6	5.5	6.8	8.2	9.6	11.0	12.3	13.7	16.4	19.2	21.9	24.6	27.4	30.1	32.9
17	7.36	2.8	3.7	4.7	5.6	7.0	8.4	9.8	11.2	12.6	14.0	16.8	19.6	22.3	25.1	27.9	30.7	33.5
18	7.79	2.8	3.8	4.7	5.7	7.1	8.5	10.0	11.4	12.8	14.2	17.1	19.9	22.8	25.6	28.5	31.3	34.1
19	8.23	2.9	3.9	4.8	5.8	7.2	8.7	10.1	11.6	13.0	14.5	17.4	20.3	23.2	26.1	29.0	31.9	34.8
20	8.66	2.9	3.9	4.9	5.9	7.4	8.8	10.3	11.8	13.3	14.7	17.7	20.6	23.6	26.5	29.5	32.4	35.4
Minimum Practical Thickness		4.5	6.0	6.0	7.5	9.0	10.5	10.5	12.0	12.0	13.5	15.0	16.5	18.0	21.0	24.0	27.0	28.5

For determining the CIPP thickness in Table 13 the following variables were utilized in the calculations: $E_L = 175,000$ psi, $S_L = 2750$ psi, 2% Ovality, Safety Factor = 2.0, Enhancement Factor $K = 7.0$, Poisson's Ratio = 0.3

Table 14. Soil Types and Densities.

Soil Type	Density, w (lb/ft ³)
Sand & Gravel	110
Saturated Topsoil	115
Ordinary Clay	120
Saturated Clay	130

Table 15. Water Buoyancy Factor, *R_w*.

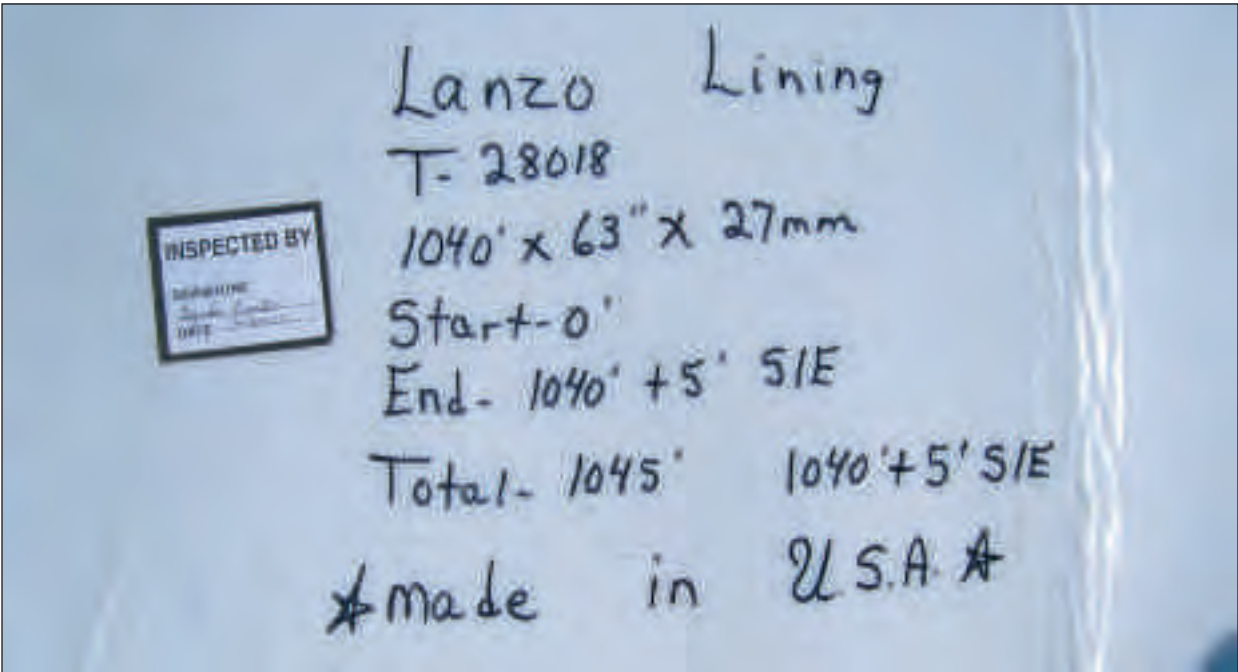
$R_w = 1 - 0.33(H_w/H_s) \geq 0.67$

Ratio <i>H_w/H_s</i>	Factor <i>R_w</i>
0	1.00
0.05	0.98
0.1	0.97
0.15	0.95
0.20	0.93
0.25	0.92
0.30	0.90
0.35	0.88
0.40	0.87
0.45	0.85
0.50	0.84
0.55	0.82
0.60	0.80
0.65	0.79
0.70	0.77
0.75	0.75
0.80	0.74
0.85	0.72
0.90	0.70
0.95	0.69
1.00	0.67

Table 16. Coefficient of Elastic Support, *B'*

$B' = 1/(1 + 4e^{-0.065H_s})$

Soil Height <i>H_s</i> , ft	Elastic Support <i>B'</i>
0	0.2
1	0.21
2	0.22
3	0.23
4	0.24
5	0.26
6	0.27
7	0.28
8	0.30
9	0.31
10	0.32
11	0.34
12	0.35
13	0.37
14	0.38
15	0.40
16	0.41
17	0.43
18	0.45
19	0.46
20	0.48
22	0.51
24	0.54
26	0.58
28	0.61
30	0.64



All materials are rigorously inspected for quality while Lanzo Lining Services emphasizes materials “Made in America”

Table 17. Soil Prism Pressure as a Function of Water or Soil Height and Soil Density.

Height of Water, Hw or Soil, Hs, ft	Hydrostatic Pressure Pw', psi	Soil Prism Pressure, psi Soil Density, w, lbs/ft ³				
		100 lbs/ft ³	110 lbs/ft ³	115 lbs/ft ³	120 lbs/ft ³	130 lbs/ft ³
1	0.43	0.7	0.8	0.8	0.8	0.9
2	0.87	1.4	1.5	1.6	1.7	1.8
3	1.30	2.1	2.3	2.4	2.5	2.7
4	1.73	2.8	3.1	3.2	3.3	3.6
5	2.17	3.5	3.8	4.0	4.2	4.5
6	2.60	4.2	4.6	4.8	5.0	5.4
7	3.03	4.9	5.3	5.4	5.8	6.3
8	3.46	5.6	6.1	6.4	6.7	7.2
9	3.90	6.3	6.9	7.2	7.5	8.1
10	4.33	6.9	7.6	8.0	8.3	9.0
11	4.76	7.6	8.4	8.8	9.2	9.9
12	5.20	8.3	9.2	9.6	10.0	10.8
13	5.63	9.0	9.9	10.4	10.8	11.7
14	6.06	9.7	10.7	11.2	11.7	12.6
15	6.50	10.4	11.5	12.0	12.5	13.5
16	6.93	11.1	12.2	12.7	13.3	14.4
17	7.37	11.8	13.0	13.6	14.2	15.3
18	7.79	12.5	13.8	14.4	15.0	16.3
19	8.23	13.2	14.5	15.1	15.8	17.2
20	8.66	13.9	15.3	16.0	16.7	18.1
22	9.53	15.3	16.8	17.5	18.3	19.9
24	10.4	16.7	18.3	19.2	20.0	21.7
26	11.3	18.1	19.9	20.8	21.7	23.5
28	12.1	19.4	21.4	22.3	23.3	25.3
30	13.0	20.8	22.9	24.0	25.0	27.1



Trenchless CIPP rehabilitation of a pipe running under a busy highway during rush hour traffic

Table 18. Live load Pressure and Impact Factors for Surface Load Impact.

Soil Height	Highway HS-20		Railway E-80		Airport	
Hs	Load, psi	Impact	Load, psi	Impact	Load, psi	Impact
0-1	>15.1	0.3	N/A	0.4	N/A	0.5
1	15.1	0.3	N/A	0.4	N/A	0.5
2	10.9	0.2	26.4	0.36	13.2	**
3	5.3	0	23.6	0.28	12.3	**
4	2.2	0	18.4	0.24	11.3	**
5	1.7	0	16.7	0.2	10.1	**
6	1.3	0	15.6	0.16	8.8	**
7	1.1	0	12.2	0.12	7.9	**
8	1.0	0	11.1	0.08	6.9	**
9	*	0	9.4	0.04	6.5	**
10	*	0	7.6	0	6.1	**
12	*	0	5.6	0	4.7	
15	*	0	4.2	0	2.5	

*Insignificant, less than 1.0psi

**Consult FAA requirements for ground conditions

Table 19. Fully Deteriorated Gravity Flow Condition for High Groundwater at Grade.

CIPP Thickness (mm) for each Pipe Diameter (Inches) at the given Depth (feet)

Soil Depth	Water Depth	6	8	10	12	15	18	21	24	27	30	36	42	48	54	60	66	72
6	6	2.5	3.0	3.7	4.5	5.6	6.7	7.9	9.0	10.1	11.2	13.5	15.7	17.9	20.2	22.4	24.7	26.9
8	8	2.5	3.2	4.0	4.7	5.9	7.0	8.1	9.2	10.2	11.3	13.5	15.7	17.9	20.2	22.4	24.7	26.9
10	10	2.5	3.3	4.1	5.0	6.1	7.7	8.8	10.0	11.3	12.4	14.6	16.9	19.0	21.2	23.5	25.9	28.2
12	12	2.8	3.7	4.6	5.5	7.1	8.4	9.7	11.0	12.3	13.7	16.1	18.5	21.1	23.4	25.8	28.0	30.2
16	16	3.2	4.2	5.3	6.3	8.0	9.6	11.1	12.6	14.1	15.6	18.5	21.4	24.3	27.1	29.9	32.6	35.2
20	20	3.5	4.7	5.8	7.0	8.9	10.6	12.3	14.0	15.6	17.3	20.6	23.8	27.0	30.3	33.4	36.5	39.5
25	25	3.9	5.2	6.4	7.7	9.8	11.7	13.6	15.4	17.3	19.1	22.8	26.5	30.1	33.6	37.2	40.7	44.2
30	30	4.2	5.6	7.0	8.4	10.6	12.6	14.7	16.7	18.7	20.8	24.8	28.8	32.7	36.6	40.5	44.3	48.2
minimum Practical Thickness		4.5	6.0	6.0	7.5	9.0	10.5	10.5	12.0	12.0	13.5	15.0	16.5	18.0	21.0	24.0	27.0	28.5

For determining the thickness of the CIPP in Table 19 the following variables were used: $E_L = 175,000$ psi, $S_L = 2750$ psi, 2% Ovality, Safety Factor = 2.0, Soil Density = 120 lb/ft^3 , Soil Modulus = 1000 psi, HS-20 Highway Loading at shallow depths

Table 20. Fully Deteriorated Gravity Flow Condition for Groundwater at 50% of Soil Depth.

CIPP Thickness (mm) for each Pipe Diameter (Inches) at the given Depth (feet)																		
Soil Depth	Water Depth	6	8	10	12	15	18	21	24	27	30	36	42	48	54	60	66	72
6	3	2.5	3.0	3.7	4.5	5.6	6.7	7.9	9.0	10.1	11.2	13.5	15.7	17.9	20.2	22.4	24.7	26.9
8	4	2.5	3.1	3.7	4.5	5.6	6.7	7.9	9.0	10.1	11.2	13.5	15.7	17.9	20.2	22.4	24.7	26.9
10	5	2.5	3.3	4.0	4.7	5.7	6.8	7.9	9.0	10.1	11.2	13.5	15.7	17.9	20.2	22.4	24.7	26.9
12	6	2.7	3.5	4.3	5.1	6.3	7.4	8.6	9.7	10.8	12.1	14.3	16.4	18.7	20.7	22.9	24.9	26.9
16	8	3.0	3.9	4.8	5.7	7.1	8.4	9.8	11.1	12.4	13.7	16.3	19.0	21.5	23.9	26.4	28.8	31.2
20	10	3.3	4.3	5.3	6.3	7.8	9.3	10.8	12.3	13.8	15.3	18.2	21.1	23.9	26.8	29.5	32.3	35.0
25	12.5	3.6	4.7	5.8	6.9	8.6	10.3	11.9	13.6	15.2	16.9	20.1	23.3	26.5	29.7	32.8	36.0	39.0
30	15	3.8	5.0	6.3	7.5	9.3	11.1	12.9	14.7	16.5	18.3	21.8	25.4	28.9	32.3	35.7	39.1	42.5
Minimum Practical Thickness		4.5	6.0	6.0	7.5	9.0	10.5	10.5	12.0	12.0	13.5	15.0	16.5	18.0	21.0	24.0	27.0	28.5

For determining the thickness of the CIPP in Table 19 the following variables were used: $E_L = 175,000$ psi, $S_L = 2750$ psi, 2% Ovality, Safety Factor = 2.0, Soil Density = 120 lb/ft³, Soil Modulus = 1000 psi, HS-20 Highway Loading at shallow depths



Lanzo Lining Services crew preparing liner for direct inversion installation of CIPP

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28135 Groesbeck Highway
Roseville, Michigan 48066
Phone: (586) 775-5819
Fax: (586) 775-2328

Website: www.lanzo.net

Please direct all technical questions to Fred Tingberg, Jr. (fredt@lanzo.org)

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