UCT UNDERGROUND CONSTRUCTION TECHNOLOGY

The Underground Utilities Event | July 13-15, 2021 | Music City Center | Nashville, TN

Pipeline Rehabilitation Technologies: Evolution from Gravity-Flow to Pressure Pipe

David P. Kozman, P.E.

Senior Product Engineer

HAMMERHEAD TRENCHLESS

Introduction

Overview of Technologies → **Design Considerations** → **Industry Resources**

Overview of Technologies
- Lining processes and applications
- Historical timelines

Design Considerations
- ASTM F1216
- AWWA M28
- Structural classifications

Industry Resources
- Standards
- Publications
- Committee Activity

Pressure Pipe Rehabilitation Technologies

Designed to accommodate a wide range of host pipe materials, conditions and applications:

- Potable water
- Raw water
- Sewer force mains
- Fire suppression
- Industrial settings

Lining systems can be grouped into one of the following processes:

- Cement mortar lining (CML)
- Spray-on polymer lining (PL)
- Cured-in-place pipe lining (CIPP)
- Close-fit lining (CFL)
- Sliplining (SL)
- Carbon fiber reinforced polymer (CFRP)

Rehabilitation/Replacement:

- Pipe bursting or splitting

UNDERGROUND CONSTRUCTION TECHNOLOGY

The Underground Utilities Event | July 13-15, 2021 | Music City Center | Nashville, TN

Pressure Pipe Rehabilitation Historical Timeline

1652: Wood pipe first used in Boston, MA

Wood stave pipe used

1804: First cast iron pipe put into service in Philadelphia, PA

1832: First US welded steel pipe plant opened in Philadelphia, PA

1930: AC pipe introduced into the North American market

1933: Spray-applied CML first utilized in the USA

1940s: Traditional sliplining developed

1942: PCCP first introduced

1950s: PE pipe introduced

1955: Introduction of ductile iron pipe; first PVC water pipe installation in the US

1959: Pipe splitting developed

1960s: Glass reinforced pipe introduced

1970s: Widespread use of internal linings in manufactured DIP and CIP

1971: CIPP developed in UK for gravity sewers

1980s: CIPP utilized in low-pressure sewer apps

Spray-on epoxies first utilized

1983: Pipe bursting developed

1980s-90s: Development of close-fit lining systems

1992: HDPE water mains installed in Indianapolis, IN

1997: CFRP utilized to strengthen PCCP

1998: Introduction of CIPP for water line rehab into North America

2000s: Polyurea linings first introduced

Cement Mortar Lining

Applications:
- Internal sealing and corrosion protection for water lines
- Most common non-structural spray lining technique to improve water quality and hydraulic characteristics

AWWA Class I

Composition:
- Type I/II or type V Portland cement is typically used
- Specialty cements are available to withstand aggressive environments

Installation Methods:
- Remote application for 3”-24” diameter
- Man-entry methods for >24” diameter

Historical Timeline:
- 1905 – First used in trowel-on applications in Australia
- 1930 - Albert G. Perkins filed for US patent for centrifugal spray cement mortar lining of pipes
- 1931 – Tate of Australia patents mandrel method of cement mortar lining pipes.
- ***1933 – First underground test of the centrifugal spray method was performed on a 72” steel pipe in Jersey City, New Jersey***

Sliplining

Applications:
- Gravity-flow sewers
- Water and sewer pressure pipelines

AWWA Class IV

Material Composition
- HDPE, PVC, FRP and VCP

Installation Methods:
- Traditional sliplining
  - Segmental or continuous
  - Grouting of annular space between liner and host pipe is usually required
- Modified sliplining
  - Roll-down
  - Swagelining
  - Fold and form PVC; deformed/reformed HDPE
  - Close-fit lining methods (no annulus grouting)

Historical Timeline:
- ***Circa 1940s – Traditional sliplining first developed***
- ***1950s – Development of PE pipe***
- Circa 1960s – Full length grouting of traditional sliplining implemented
- ***1980s-90s – Development of close fit lining systems***
  - *1983 – Stewarts and Lloyds patent roll-down process*
  - *1986 – British Gas files UK patent for Swagelining*
  - *1990s – Development of fold and form PVC and HDPE processes*

Pipe Bursting / Splitting

AWWA Class IV

Applications:
- Gravity-flow and pressure pipelines. Same path technology.

Pipe Materials:
- HDPE, PVC, VCP and DIP

Installation Methods:
- Pneumatic (2"-42")
- Static pull (2"-24")
- Brittle pipe materials are most suitable for bursting (VCP, cast iron, AC, unreinforced concrete, some RCP and some plastics)
- Pipe splitting is commonly used on ductile iron, PVC, plastic liners and steel

Historical Timeline:
- ***1959 – William Lindsay of Madisonville, KY creates "pipe splitter and spreader"; patents filed***
- 1964 – Reg Handford utilizes an early form of pipe expansion and replacement
- 1981 – British Gas patenting of "pipe insertion method" jointly with D.J. Ryan
- 1982 – IPD Systems Ltd develops pipe expansion and replacement method; UK patent filed
- 1983 – Expand-A-Line develops concept of pipe upsizing in Texas; US patent filed
- ***1983 – First British Gas upsizing performed; British Gas "pipe bursting" patent filed in the UK in 1984***
- 1991 – Handford develops the Controlled Line and Grade (CLG) process to restore the line and grade of a pipeline; US patent filed
- 1993 – Al Tenbusch develops Tenbusch Insertion Method to push in rigid segmental pipe while performing pipe expansion; US patent filed

Cured-In-Place Pipe (CIPP)

Applications:
- Gravity-flow sewers
- Water and sewer pressure pipelines

Material Composition:
- Felt-thermosetting resin composite for gravity sewers
- Fiberglass or carbon fiber reinforced liners for pressure applications

Design Parameters:
- Generally up to 108" diameter (circular and non-circular) in various thicknesses and lengths; size transitions can be accommodated
- Cured with hot water, controlled steam, UV or LED light

Historical Timeline:
- ***1971 - Eric Wood of Insituform develops CIPP process; first installation in the UK***
- 1973 – Inversion process patented in the UK
- 1975 – US patent filed for inversion process
- ***1980s – First low-pressure sewer applications installed (sewer force mains)***
- 1984 – Eric Wood of Insituform files patent for UV cure in UK
- 1984 – Development of static resin mixing system
- 1986 – US patent issued to Eric Wood of Insituform for UV cure
- 1986 – KMG develops pull-in-place installation method in Germany
- 1989 – Development of ASTM F1216
- 1989 – Pull-in-place method introduced into the USA
- 1990 – Insituform develops and files patent for eversion pressure chamber in US
- ***1998 – First North American installation of CIPP for potable water in Canada***
- 2004 – UV cure process introduced into the US market

AWWA Class III

AWWA Class IV

Polymer Lining (PL) – Epoxies

AWWA Class I

AWWA Class II

Applications:
- Gravity-flow and pressure pipelines
- Sewer, water and industrial applications
- Used for corrosion protection and to improve water quality and hydraulic performance

Material Composition:
- 100% solids (solvent free) epoxy polymer
- Materials can be used as non-structural and semi-structural applications as determined by lining thickness

Design Parameters:
- Application via specialty plural component spray equipment, trowel or roller
- 3"-36" diameter pipelines; man-entry methods for >24" diameter

Historical Timeline:
- 1930 – The first epoxy developed in Germany
- Late 1930s – The type of epoxy utilized for marine and industrial applications was patented simultaneously in Switzerland and the United States
- ***1970s – In situ lining of water mains first developed by UK water authorities***
- 1993 – First reported US epoxy lined pipe trial in Chester, PA increased Hazen-Williams coefficient of roughness from 22 to 114
- Mid-1990s – UK converts all water line rehabilitation projects to epoxy
- 2000s – Epoxies used in water line rehabilitation in the US

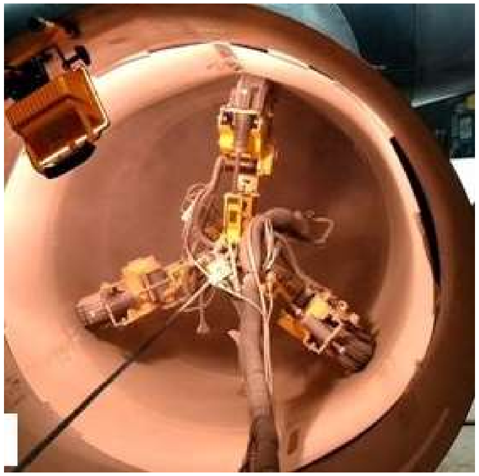
Polymer Lining (PL) – Polyureas

Applications:
- Gravity-flow sewers
- Water, sewer and industrial pressure pipelines

Material Composition:
- Thermosetting polymeric resins, NSF-61 certified for potable water

Design Parameters:
- 5" to 120" diameter applications
- Follows ASTM F1216 design; thicknesses vary by application
- Cures in seconds to minutes, depending on chemistry

Historical Timeline:
- 1980s – Polyurea developed for spray applications
- ***Mid-2000s – First use of polyurea for water main rehabilitation***



AWWA Class I

AWWA Class II

AWWA Class III

Carbon/Glass Fiber Reinforced Polymer (CFRP/GFRP)

Applications:
- Pressure (mostly CFRP) and gravity (mostly GFRP) pipelines

Materials:
- Carbon and glass fiber fabrics
- Saturating resin (usually engineered epoxy)
- Tack coat (adhesive)
- Topcoat (corrosion protection)
- Epoxy based or cementitious fillers (as necessary)

Installation Methods:
- Wet layup (cured-in-place) – can be applied internally or externally
- Prefab systems available for sliplining mainly large sewers

AWWA Class III

AWWA Class IV

Historical Timeline:
- 1988 – First conference presentation (Transportation Conference in Iowa) on rehabilitating infrastructure with CFRP based on the experimental work done at the University of Arizona (Saadatmanesh, H. and Ehsani, M.)
- 1990 – First real-life projects on rehabilitation of infrastructure (mainly bridges) with CFRP
- ***1998 – First known application of CFRP in a large diameter (PCCP) pipe by QuakeWrap at the Palo Verde Nuclear Power Plant in Arizona***
- 2000-2018 – Many applications in pipelines across the United States mainly by Fyfe, Structural Technologies, and QuakeWrap
- 2012 – First application of FRP to rehabilitate approximately 1 mile of pipe by QuakeWrap at the El Canto Hydroelectric Power Plant in Costa Rica
- 2018 – AWWA C305 design standard for CFRP renewal of PCCP with CFRP was published

Pressure Pipe Lining Design

ASTM F1216

"Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube"

- First introduced in 1989; last updated in 2016
- Appendix X1 – most common method utilized for pipe lining design in North America
- Gravity flow sewer and pressure pipe design checks for:
  - **Partially deteriorated host pipe**
  - **Fully deteriorated host pipe**
- Evolution and design concepts based on:
  - Unbonded, close-fit liners
  - Isotropic (homogeneous) materials
  - Low pressure sewers

No correlation between them

AWWA Manual of Practice No. M28

Rehabilitation of Water Mains

- First edition published in 1987 with subsequent releases in 2001 and 2014
- Structural classifications of pressure pipe linings are loosely defined in Appendix A:
  - **Class I:** Non-structural, corrosion barrier
  - **Class II-III:** Semi-structural (host pipe interactive)
  - **Class IV:** Fully structural
- No design guidance provided

Pressure Pipe Lining Design

Testing

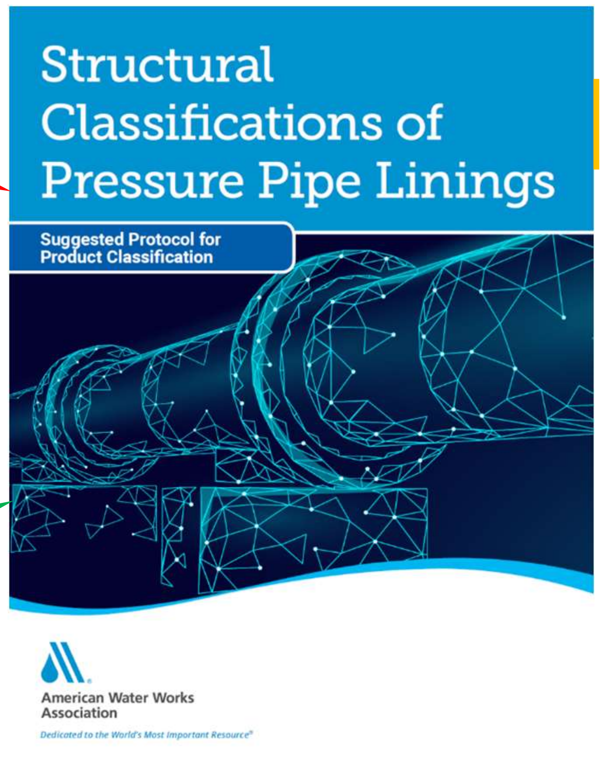
Type

Demonstration

Acceptance

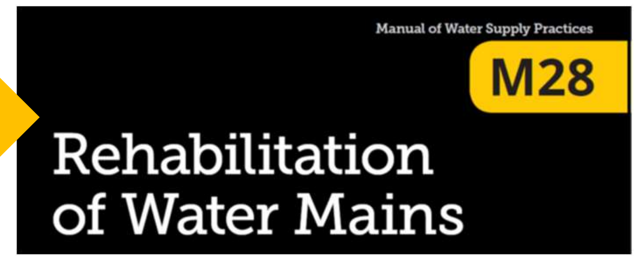
Design

2019 Committee Report



Content Integration

4th Edition (In Progress)



Addresses All Class I-IV Linings:

- Cement mortar lining (CML)
- Spray-on polymer lining (PL)
- Cured-in-place pipe lining (CIPP)
- Close-fit lining (CFL)
- Sliplining (SL)
- Carbon fiber reinforced polymer (CFRP)

Pressure Pipe Lining Design

AWWA SCPPL

- Establishes more concrete definitions, design, testing and acceptance criteria for Class I through IV pressure pipe lining systems
- Each structural classification presented as a sequential building block

Lining System Characteristic	Non-Structural	Semi-Structural (Interactive)		Fully Structural
	Internal Coating	*Hole span*	*Hole span + ring stiffness*	*Structural Resistance for all specified loads (internal & external)*
	Class I	Class II	Class III	Class IV
Internal corrosion protection	✔	✔	✔	✔
Long-term adhesion to the host pipe	See Note 1 Below	✔	See Note 2 Below	See Note 2 Below
Hole span at MAOP		✔	✔	✔
Inherent ring stiffness (hydrostatic pressure or vacuum loads only)	See Note 1 Below	See Note 1 Below	✔	✔
Water tightness (positive connection to service taps and sealed at termination points or other discontinuites)		✔	✔	✔
Inherent ring stiffness (all static and dynamic external, hydrostatic and vacuum loads)				✔
Pressure rating of lining ≥ MAOP of host pipe				✔
Lining survives anticipated host pipe failures				✔

[1] The Owner/Engineer must specify whether vacuum loads exist. This is addressed through reliable adhesion to the host pipe, which is a characteristic of all Class II and some Class I linings, or inherent ring stiffness.

[2] For Class III and IV linings, adhesion is not required to develop ring stiffness. However, it may be necessary to achieve a watertight seal (for example, at services and lining terminations). There are also situations where adhesion is not desirable, such as applications with broad temperature swings and in Class IV linings where the host pipe is anticipated to experience brittle failure modes.

Pressure Pipe Lining – Industry Publications

AWWA

- Committee Report, "Structural Classifications of Pressure Pipe Linings – Suggested Protocol for Product Classification"
- Manual of Practice No. M28, *Rehabilitation of Water Mains*
- C305, *CFRP Renewal and Strengthening of Precast Concrete Cylinder Pipe (PCCP)*
- C620, *Spray-In-Place Polymeric Lining for Potable Water Pipelines, 4 in (100 mm) and Larger*
- C622, *Pipe Bursting of Potable Water Mains, 4 in (100 mm) to 36 in (900 mm)*
- Standards in progress: CIPP, sliplining, applied linings

ASTM

- F1216, "Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube," Appendix X1

ASME

- NM.1 – Thermoplastic Piping Systems
- NM.2 – Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems

ISO

- ISO 11297: *Plastics piping systems for renovation of underground drainage and sewerage networks under pressure*
- ISO 11298: *Plastics piping systems for renovation of underground water supply networks*

THANK YOU!

David P. Kozman, P.E.
Senior Product Engineer
(614) 832-2860
dkozman@hhtrenchless.com

HAMMERHEAD® TRENCHLESS