Trenchless Technology for Drainage Structures

Richard S. Willammee, Jr., MSCE, P.E.
District Materials Engineer
Fort Worth District
TxDOT

2011 Transportation Short Course  October 11, 2011
INTRODUCTION

There are textbooks and manuals that describe renewal techniques for sanitary sewers and many of the described techniques are suitable for the renewal of culverts and storm sewers.

However, the literature is lacking in detailed guidance for those in search of information on renewal techniques specifically for culverts and storm sewers. This applies to our highway structures.
Provide a *comprehensive decision making procedure for the selection of appropriate trenchless technology methods* for:

→ **Construction,**
→ **Renewal,**
→ **Renovation (collectively called renewal), and**
→ **Maintenance**

of culverts and drainage structures

by reviewing...

geo-environmental and mechanical factors

<table>
<thead>
<tr>
<th>Range of application</th>
<th>Construction requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter restrictions</td>
<td>Design life</td>
</tr>
<tr>
<td>Type and geometry</td>
<td>Life-cycle-cost</td>
</tr>
<tr>
<td>Diameter</td>
<td>Chemical and mechanical properties</td>
</tr>
<tr>
<td>Cross sectional reduction</td>
<td>Maintenance issues and</td>
</tr>
<tr>
<td>Structural capability</td>
<td>Requirements</td>
</tr>
<tr>
<td>Hydraulic analysis</td>
<td>and other important parameters</td>
</tr>
</tbody>
</table>
What is Trenchless Technology

• Trenchless Technology –
  Methods of pipe installations with **minimum** surface excavation.
  – **Characteristics include:**
    • Less excavating and trenching
    • Less surface footprint
    • Environmentally friendly
    • Enhanced safety
    • Increased productivity
    • More cost-effective
Why Trenchless Technology

• Benefits of Trenchless Technology
  – Reduce disruptions to traffic, business, etc.
  – Reduce danger to existing underground facilities
  – Reduce easement requirements
  – Reduce environmental impacts
  – Reduce potential for settlement damage
  – Reduce potential of injuries due to open excavations
  – Reduce required time and costs
Trenchless Culvert Construction

Trenchless Methods

Construction Methods
- Utility Tunneling
- Pipe Jacking
- Horizontal Earth Boring
  - Horizontal Auger Boring
  - HDD
  - Pilot Tube Microtunneling
  - Microtunneling
  - Pipe Ramming
  - Compaction Methods

Renewal Methods
- Cured-in-Place Pipe
- Close-fit Pipe
- Thermoformed Pipe
- Sliplining
- Modified Sliplining
- In-line Replacement
- Localized Repair
- Lateral Renewal
- Coatings & Linings
- Manhole Renewal
Trenchless Technology Methods

• Pipe Jacking
  – Combines the excavation and pipe installation into one step.
  – Product pipe sizes 42” and larger.
  – Limitations on length and size based on logistical considerations and safety.
Trenchless Technology Methods

- Horizontal Earth Boring

Methods in which borehole excavation is accomplished through mechanical means without workers being inside the borehole.
Trenchless Technology Methods

• Horizontal Auger Boring
  – Performed in two steps:
    • Excavation and installation of the casing pipe
    • Installation of carrier pipe and filling annular space with grout
  – Available with:
    • Dynamic grade control
    • Dynamic line and grade control
Trenchless Technology Methods

• Horizontal Directional Drilling (HDD)
  – Performed in two steps:
    • Drilling of pilot hole using a steerable drill head and guidance system
    • Backreaming to increase pilot hole diameter and pullback of product pipe
  – Product pipe sizes up to about 60”.
Trenchless Technology Methods

• Microtunneling
  – Also known as remote controlled pipe jacking.
  – Product pipe sizes 12” and larger.
  – Uses automation for processes performed by workers within the tunnel on pipe jacking.
    • Remote controlled excavation and spoil removal
    • Remote controlled guidance system
Trenchless Technology Methods

• Pipe Ramming
  – Performed in two steps:
    • Installation of the casing pipe by using an air hammer from a drive pit
    • Use open-end casing for pipes >8” and use clean spoil from the casing after drive completed
    • Installation of a carrier pipe and filling annular space with grout
Trenchless Methods

- Construction Methods
  - Utility Tunneling
  - Pipe Jacking
  - Horizontal Earth Boring
    - Horizontal Auger Boring
    - HDD
    - Pilot Tube Microtunneling
    - Microtunneling
    - Pipe Ramming
    - Compaction Methods

- Renewal Methods
  - Sliplining
  - Cured-in-Place Pipe
  - Spiral Wound
  - Close-fit Pipe
  - Thermoformed Pipe
  - Panel Lining
  - Formed-in-Place
  - In-line Replacement
  - Coatings & Linings
  - Others
Trenchless Culvert Renewal

- Sliplining
  (Source: Terrafix Geosynthetics Inc.)
- Cured in place pipe (CIPP)
  (NASSCO, 2007)
- Spiral wound pipe
- Close-fit pipe
  (Source: Insifuform Technologies)
- Thermoformed pipe
- Formed in place pipe
**Introduction and Background**

One of the earliest and simplest forms of trenchless culvert renewal methods and can be used for structural or nonstructural renewal processes.

- cost-effective
- minimum disruption of service
- surface traffic
- minimum property damage

Used for more than 60 years.

Although sliplining decreases the total cross sectional area of a culvert, using a smoother pipe material with a lower Manning’s Roughness coefficient may eliminate this problem.

(Source: Terrafix Geosynthetics Inc.)
## Sliplining

### Product Main Characteristics

<table>
<thead>
<tr>
<th>Method</th>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>Liner material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segmental</td>
<td>24-160</td>
<td>200 – 2000</td>
<td>Requires a thin, coarse mortar.</td>
<td>Polyethylene, Polypropylene, PVC, Glass Reinforced Pipe</td>
</tr>
<tr>
<td>Continuous</td>
<td>12 - 63</td>
<td>200 - 2000</td>
<td>Requires a thin, coarse mortar.</td>
<td>Polyethylene, Polypropylene, PVC</td>
</tr>
</tbody>
</table>

Can be used to install a new culvert of up to 10 percent smaller diameter compared to the host culvert.

The culvert should be clean; free from sediment and debris.

In many cases, where culverts are too deep to make replacement practical, slightly reduced hydraulics may be an acceptable tradeoff to an expensive replacement.
# Sliplining

**Advantages and Limitations**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inexpensive specialized equipment is used</td>
<td>Host diameter is typically reduced by ~10%; however, due to the liner pipes’ good flow characteristics; the hydraulic capacity is frequently improved</td>
</tr>
<tr>
<td>A simple technique</td>
<td>Grouting is required</td>
</tr>
<tr>
<td>Can be used for both structural and nonstructural purposes</td>
<td>Segmental installations; cannot typically push through angle points greater than 1 to 3 degrees (depends on diameter and clearance)</td>
</tr>
<tr>
<td>Existing flow does not restrict the process</td>
<td></td>
</tr>
</tbody>
</table>
Cured In Place Pipe (CIPP)

*Introduction and Background*

Was the first truly trenchless full pipeline renewal process.

Invented in 1970.

As of 2008, it is estimated that over 25,000 miles of CIPP have been installed worldwide.
# Cured In Place Pipe (CIPP)

## Product Main Characteristics

<table>
<thead>
<tr>
<th>Method</th>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Resin</th>
<th>Liner material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverted with air</td>
<td>12 - 108</td>
<td>3000</td>
<td>Polyester and vinyl ester resins</td>
<td>Polyester felt material, fiberglass reinforced or similar</td>
</tr>
<tr>
<td>Winched at place</td>
<td>12 - 100</td>
<td>1500</td>
<td>Polyester and vinyl ester resins</td>
<td>Polyester felt material, fiberglass reinforced or similar</td>
</tr>
</tbody>
</table>

Generally involves manufacturing a fabric tube of the length and diameter of the host pipeline.

The fabric tube is saturated with a liquid thermosetting resin, inserted into the host pipeline and inflated with air or water pressure.

The resin is then cured by one of several different methods (hot water, hot air, steam, UV light or at ambient temperature) resulting in a new tight-fitting plastic pipe within the host pipe.
# Cured In Place Pipe (CIPP)

**Advantages and Limitations**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouting is not necessary</td>
<td>The tube is custom made for each project</td>
</tr>
<tr>
<td><strong>Smooth interior surface enabling an increase in flow capacity</strong></td>
<td>Successful installation depends highly on the curing process</td>
</tr>
<tr>
<td>Lining noncircular shapes is possible</td>
<td><em>Existing water flow must be diverted</em></td>
</tr>
<tr>
<td>Lining can be accomplished even in the presence of bends</td>
<td><em>It can be expensive</em></td>
</tr>
<tr>
<td>Design life of 50 – 100 years</td>
<td></td>
</tr>
<tr>
<td>Corrosion resistant</td>
<td></td>
</tr>
<tr>
<td>Relatively quick installation</td>
<td></td>
</tr>
<tr>
<td>A structural solution</td>
<td></td>
</tr>
<tr>
<td>Small cross-section reduction with increased flow capacity</td>
<td></td>
</tr>
</tbody>
</table>
**Spiral Wound Pipe**

*Introduction and Background*

Utilizes a rigid plastic profile that is closely formed inside an existing pipe by interlocking the continuous strips winding machine or by manually locking.

A spiral wound lining system can be designed and installed either for corrosion protection or as a fully structural renewal for existing pipelines.
Spiral Wound Pipe

**Product Main Characteristics**

<table>
<thead>
<tr>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>Liner material</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 - 120</td>
<td>Unlimited</td>
<td>Some times required.</td>
<td>PE, PVC, PP, PVDF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Cementitious Grout)</td>
<td></td>
</tr>
</tbody>
</table>

6 inch diameter and non-round pipes from 42 inch and upwards.

The Spiral Wound Lining System is able to rehabilitate round pipes, square and rectangular box section pipes, as well as horseshoe shaped pipes.
# Spiral Wound Pipe

## Advantages and Limitations

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large bends can be accommodated</td>
<td>Skillful personnel are needed</td>
</tr>
<tr>
<td>Pipes are not stored on the job site</td>
<td>Annular space should be grouted</td>
</tr>
<tr>
<td>Mobilization costs are low</td>
<td><strong>Dependency on a special winding machine</strong></td>
</tr>
<tr>
<td></td>
<td>Reduction of sectional area; however an improvement in the roughness coefficient will compensate for this size reduction in most cases</td>
</tr>
</tbody>
</table>
Close-Fit Pipe

Introduction and Background

Involves the insertion of a thermoplastic pipe with an outside diameter the same or slightly larger than the inside diameter of the host culvert.

Generated by modifying the cross sectional area of polyethylene pipes, inserting them to the host pipe and returning the cross sectional area to the normal by applying pressure.

In this type of renewal, the pipe is manufactured before being brought to the job site, which increases the quality of the finished product.

Source: Insifuform Technologies
Close-Fit Pipe

Product Main Characteristics

<table>
<thead>
<tr>
<th>Close-fit pipe</th>
<th>Mechanically folded liners (MFL)</th>
<th>Reduced diameter pipes (RDP)</th>
</tr>
</thead>
</table>

- Diameter range (in): 12 - 24
- Maximum installation (ft): 1000
- Grouting: Not necessary
- Liner material: HDPE, MDPE

Mechanically folded liners requires site-based equipment that cold-folds the liner in a U-shape.

Reduced diameter method rearranges the molecular structure of the plastic pipe by the use of a cold rolling machine or by thermal methods.
## Close-Fit Pipe

*Advantages and Limitations*

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>The new pipe is produced at a controlled environment</td>
<td>The diameter and installation range is limited</td>
</tr>
<tr>
<td>Minimal reduction in the existing pipe area</td>
<td>A large working space is needed</td>
</tr>
<tr>
<td>Mechanically folded pipes can accommodate 45 degree bends</td>
<td>Usually the water flow needs to be bypassed</td>
</tr>
<tr>
<td>Few or no joints</td>
<td>Existing culvert must be longitudinally uniform</td>
</tr>
<tr>
<td>No grouting is required</td>
<td>Relatively complex method requiring special machinery</td>
</tr>
</tbody>
</table>
Thermoformed Pipe

Introduction and Background

Was first installed in 1988.

As of 2007, production of HDPE folded pipeline has ceased in North America.

Folded Thermoplastic (HDPE or PVC) Pipe liners are utilized to rehabilitate small size (30in. and under) culverts.

• Cross sectional area is temporarily altered to enable insertion,
• The pipeline is pulled through one access point to the next,
• After insertion, pipe liners are heated and thermoformed to fit tightly inside the old pipe.
Panel Lining

Introduction and Background

In 1979, the Water Research Center (WRc) UK performed a 5-year research in methods and materials for structural renewal of large-diameter noncircular sewers.

This procedure can also be used to renew culverts that have noncircular cross sections such as pipe arch or elliptical, box sections or multiple barrels.

In this type of renewal, workers enter the pipe and install the panels manually.
Panel Lining

Product Main Characteristics

One of these methods is fiberglass liner, also called fiberglass reinforced polyester panel (FRPP). Glass-fiber liners can be manufactured to fit any size or shape.

The liner pipes are made of various combinations of fiberglass mats, glass fibers, polyester, vinyl ester, epoxy resin, and sometimes silica sand.

<table>
<thead>
<tr>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>Liner material</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 in. and larger</td>
<td>N/A</td>
<td>Cementitious or polymer</td>
<td>PVC Or Combinations</td>
</tr>
</tbody>
</table>

Panel liners can be designed and constructed as self-supporting.
# Panel Lining

**Advantages and Limitations**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel lining can be used in any shape of pipe</td>
<td>Only worker entry pipes can be renewed by this method</td>
</tr>
<tr>
<td>Chemical and abrasive resistant liners can be installed</td>
<td>Grouting must be applied to the annular space</td>
</tr>
<tr>
<td>It can be installed under restricted flow conditions</td>
<td>Reductions in the cross sectional area may be significant</td>
</tr>
<tr>
<td>Changes in pipe diameter can be negotiated with prefabricated transition panels</td>
<td></td>
</tr>
</tbody>
</table>
Formed-in-Place Pipe

Introduction and Background

Developed in Germany in the early 1990s.

Over 1 million linear feet installed around the world.

The essential component of the FIPP rehabilitation technique is the HDPE panel with V-shaped embedment anchors.
Formed-in-Place Pipe

**Product Main Characteristics**

<table>
<thead>
<tr>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>Liner material</th>
</tr>
</thead>
<tbody>
<tr>
<td>8in. to 120in. and larger</td>
<td>600’ (up to 40in.)</td>
<td>Cementitious polymer mortar</td>
<td>HDPE</td>
</tr>
<tr>
<td></td>
<td>400’ (up to 50in.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200’ (up to 80in.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: A.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The portion of the HDPE panels exposed at the ends of the culvert must contain UV protection such as carbon black.

The grout utilized with the FIPP technology is a low-viscosity, quick and ambient-curing, expansive, cementitious polymer mortar of high strength.

HDPE panels are coiled on reels and the grout is bagged for shipping and storage convenience.

The HDPE FIPP installation and design are governed by existing European standards with ASTM standards under development.
## Formed-in-Place Pipe

**Advantages and Limitations**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be used in any shape (circular, oval, vertically sided, symmetrical, or nonsymmetrical)</td>
<td>Significant reduction in cross-sectional area of the culvert is possible</td>
</tr>
<tr>
<td>Can serve for both corrosion control and structural purposes</td>
<td>Access shafts or great clean out process may be required</td>
</tr>
<tr>
<td>Can be used for long-drive length where access is limited</td>
<td>The annular space must be grouted</td>
</tr>
<tr>
<td>Nonstandard shapes up to 12 ft in diameter are possible</td>
<td></td>
</tr>
<tr>
<td>Improved hydraulic capacity by providing a lower coefficient of friction</td>
<td></td>
</tr>
<tr>
<td>Is abrasive resistant and chemical resistant</td>
<td></td>
</tr>
</tbody>
</table>
In-line replacement technology originated in the 1970s.
It is most cost-effective if a new culvert with a larger diameter is required.
Virtually all types of culvert materials can be replaced using this technique.
Method I. A cone-shaped tool is inserted and forced through it, fracturing the pipe and pushing its fragments into the surrounding soil.

At the same time, a new pipe is either pulled or pushed.

Method II. Pipe removal (also known as pipe eating) is a replacement technique, which is based on horizontal directional drilling (HDD) or microtunneling (MT) technology.

This method excavates the existing pipe in fragments and removes them rather than displacing them into the surrounding ground.

<table>
<thead>
<tr>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>New material</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 to 48</td>
<td>300 to 400</td>
<td>Not required</td>
<td>PE, PVC, Ductile Iron, Vitrified clay</td>
</tr>
</tbody>
</table>
## In Line Replacement

*Advantages and Limitations*

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A wide range of existing pipe types and diameters are possible to replace</td>
<td>Bypassing of water flow is usually required</td>
</tr>
<tr>
<td>The new pipe will follow the alignment of the existing culvert</td>
<td>Ground movements, vibrations, and possibility of damaging nearby utilities and existing structures must be evaluated for specific conditions of each project</td>
</tr>
<tr>
<td>In pipe bursting, the existing culvert is left underground eliminating the need for its disposal</td>
<td>There is a risk of disturbing the pavement surface above the existing culvert</td>
</tr>
<tr>
<td>No cleaning necessary</td>
<td></td>
</tr>
</tbody>
</table>
Underground Coatings and Linings

Introduction and Background

Developed at the dawn of the 20th century in Allentown, Pennsylvania. Coatings and linings have been used to renew water and sewer infrastructure for decades; however, they can also be used to renew culverts and storm sewers.

High-tech polymer coatings and composite lining methods are used to restore, protect, repair and renew a wide range of concrete, masonry, and steel structures.

Reinforced spray mortars are effectively used for man-entry culverts; non-man entry culverts require the lining to be applied with a centrifugal lining machine.

As the machine moves through the culvert, a uniform thickness liner is applied.
Underground Coatings and Linings

Product Main Characteristics

Primary materials used:
• cementitious,
• polymers,
• sheet liners, and
• cured-in-place liners

Adhesion is generally regarded as a required attribute of coatings.

<table>
<thead>
<tr>
<th>Diameter range (in)</th>
<th>Maximum installation (ft)</th>
<th>Grouting</th>
<th>New material</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 to 177</td>
<td>1400</td>
<td>Not required</td>
<td>Cement-mortar or polymers</td>
</tr>
</tbody>
</table>
# Underground Coatings and Linings

**Advantages and Limitations**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variations in cross section can be readily accommodated</td>
<td>Relatively slow installation for cement-mortar lining</td>
</tr>
<tr>
<td>Relatively low cost for cement-mortar lining</td>
<td>Requires safe conditions for worker entry</td>
</tr>
<tr>
<td>Quick installation, thus higher production in polymers</td>
<td>High-level operator skill is required</td>
</tr>
<tr>
<td>Polymers do not wear for longer life</td>
<td>Water pH sensitive for cement-mortar lining</td>
</tr>
<tr>
<td>No pH effect for polymer coatings</td>
<td>Control of infiltration is required to prevent procure lining disbondment or collapse</td>
</tr>
<tr>
<td>Protects against corrosion</td>
<td>Slightly higher cost when using polymers</td>
</tr>
<tr>
<td>Some reinforcement can be used</td>
<td></td>
</tr>
</tbody>
</table>
Case History No. 1:
Sliplined Corrugated Metal Pipe (CMP)
FM 981 in Collin County
in the Dallas District
CSJ 6152-70-001

Before
Distressed Pavement from CMP

After
Case History No. 2A:
Pipe Jacking of 3-36” Reinforced Concrete Pipe (RCP)
US 82 in Montague County in the Wichita Falls District
CSJ 0044-04-044
RTI Implementation Project 5-9042-01 with UT Arlington
Case History No. 2B:
Installation of 1- 6’x4’ Single Box Culvert (SBC)
US 287 in Wilbarger County in the Wichita Falls District
RTI Implementation Project 5-9042-01 with UTArlington
Case History No. 2B:
Installation of 1- 6’x4’ Single Box Culvert (SBC)
US 287 in Wilbarger County in the Wichita Falls District
RTI Implementation Project 5-9042-01 with UT Arlington
SUMMARY

- Sliplining
- Cured in place pipe (CIPP)
- Spiral wound pipe
- Close-fit pipe
- Thermoformed pipe
- Panel lining
- Formed-in-Place Pipe

- In line replacement
- Coatings and linings

- Introduction and background
- Product main characteristics
- Advantages and limitations
Conclusions

Trenchless methods are viable options for culvert renewal and repairs.

Specific requirements in the selection of correct method and installation process are required during the design phase.

A current Implementation Project is looking at the available installation techniques to make the process easier and less costly for our highway drainage needs.