Polytechnic University
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COnstruction iNterference COst Reduction Demonstration – CONCORD –

Inter-agency Technology Assessment Committee

ConEdison NYCDEP NYCDDC Keyspan Energy

Trenchless Technology Solutions for Professional Training Sessions

Prepared by:

The Urban Utility Center

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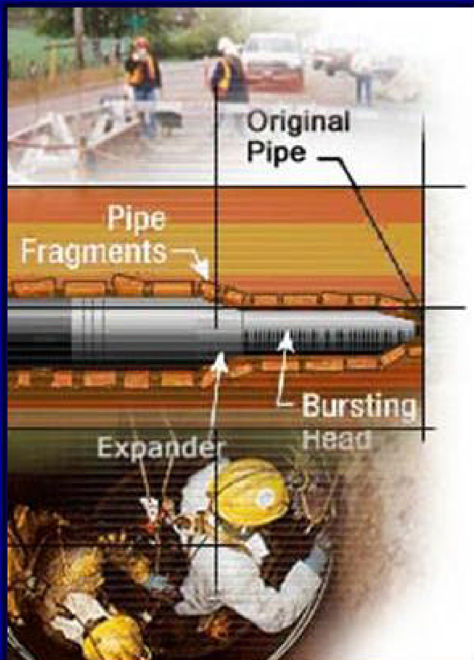
August 2005

COnstruction iNterference COst Reduction Demonstration

– CONCORD-



Polytechnic University
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URBAN UTILITY CENTER

Development & Demonstration of Innovative Technologies to Reduce Utility Interference / Construction Costs.

COnstruction iNterference COst Reduction Demonstration
- CONCORD -

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Sponsored by

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June 1st, 2004

Scope of work:

- Creating an Advisory Board with NY City Agencies and utilities
- Resolving barriers to the utilization of Trenchless Technologies
- Conducting cooperative research and sharing results of on going projects with City Agencies and utilities
- Conducting cooperative field demonstration projects Conducting technology transfer and professional training programs
- Conducting technology transfer and professional training programs

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PART ONE: INTRODUCTION

These guidelines address the need for development of technology assessment criteria and recommendations for selecting trenchless methods as alternative solutions to conventional water-main replacement. It also provides the engineering rationale for the evaluation of current design procedures, QA/QC, construction inspection requirements, contract specifications and post-construction monitoring for infrastructure performance assessment.

The NYC Water Distribution System

The NYC water distribution system, exclusive of that portion previously owned by Jamaica, consists of a grid network of water mains of various sizes. It contains approximately 6,134 miles of pipe, 94,358 mainline valves and 98,812 fire hydrants. Some pipe was installed before 1870 and approximately 7.1% is over 100 years old. The following tables set forth distribution of pipe by size and age, based on the City's 1999 computerized mapping information. Totals may vary due to rounding.

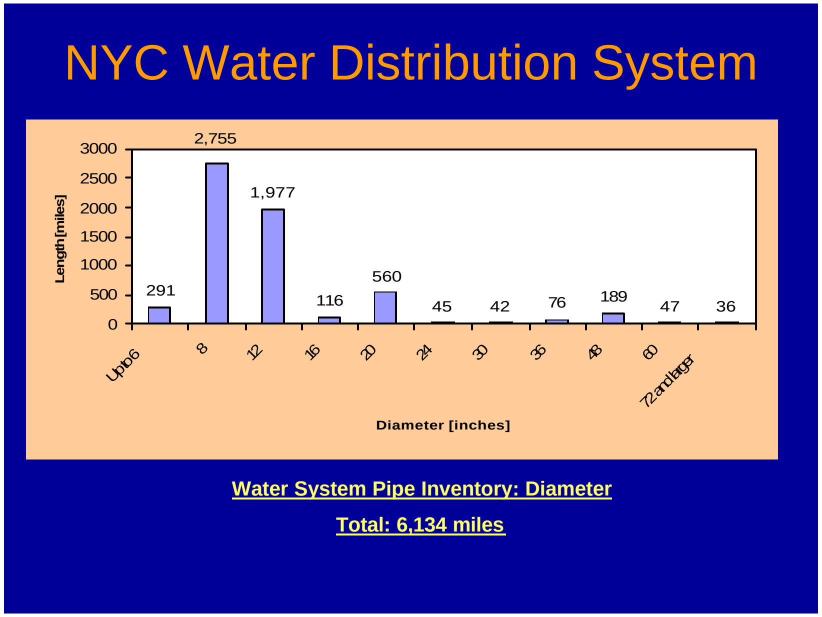


Figure 2 – NYC Water Distribution System Inventory: Size

Of the 6,134 miles of pipe in service, about 2,168 miles are unlined cast iron laid before 1930. Pipe laid between 1930 and 1969 is cement-lined cast iron and comprises about 2,396 miles of the Distribution System. Pipe laid after 1970 is cement-lined ductile iron and comprises about 1,570 miles of the Distribution System. The Distribution System also includes over 94,358 mainline valves, about 98,812 hydrants, four distribution facilities, 16 gatehouses, 15 pump stations and 11 maintenance and repair yards. This is illustrated in Figure 3.

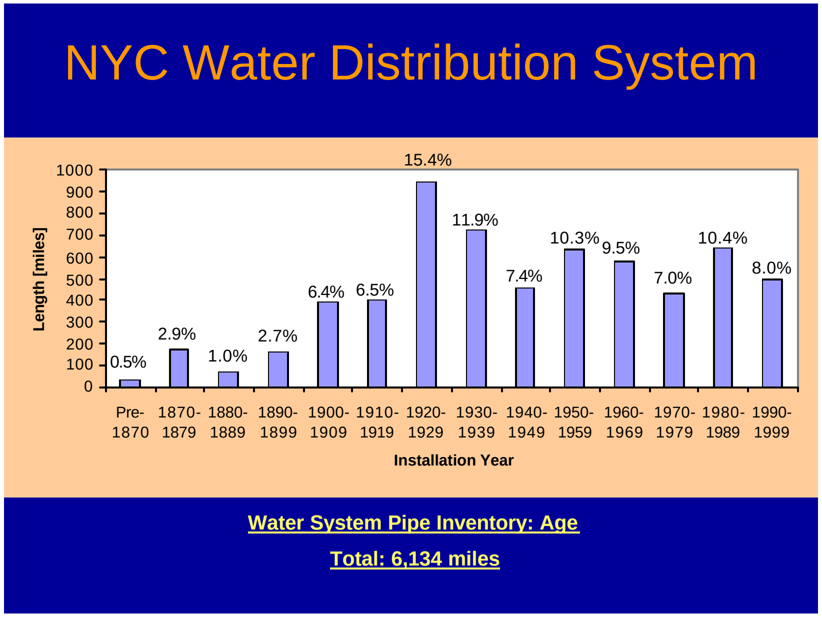


Figure 3 – NYC Water Distribution System Inventory: Age

Technology Solutions

Before considering any trenchless technology method it is wise to implement a systematic approach to plan and construct a cost-effective rehabilitation of the old pipeline.

A few steps to consider:

- Identify the pipeline sections with the greatest risk and consequences of failure
- Compare the costs of several rehabilitation options with the direct and social costs of future repairs, including the liability related to additional failures
- Analyze the costs and benefits of trenchless rehabilitation alternatives
- Investigate the availability of utility co-founding to reduce the cost to all parties
- Plan to implement the most cost-effective, non-disruptive technology

To analyze the condition of the pipeline and identify those sections with the greatest risk of failure, the project team has to develop a plan to guide the fieldwork. In order to effectively define the problem, the team has to begin a review of the pipeline records (if available), including the original plans and specifications, construction and repair records, leak history, and corrosion reports, while asking the following questions:

- What is the water quality and capacity?
- Is there joint leakage?
- Is there joint leakage with structural failure?
- Are there other major structural failures?
- Is there utility interferences?

Using the record as a guideline, the team has to identify sections that might serve as a representative sample of the condition of the entire pipeline. Soil conditions, external loading factors, and repair history may be evaluated to select the pipeline segments for inspection. Balancing statistical reliability with affordability, the team has to make the decision how and where to conduct internal and external inspections of the pipeline. Most importantly, the team should:

- Check the history of the main
- Perform a visual inspection
- Take test samples if in doubt

Figure 4 provides a summary table of typical water main problems which may be encountered and the consequences and potential solutions for each.

Typical Water Main Problems

Problem	Typical Consequences	Lowest Cost Commercial Solutions
Mild Internal Corrosion And Tuberculation	Poor Water Quality And Flow Restriction	Cement Or Epoxy Spray Lining
Severe Internal Corrosion	As Above Plus Leakage And Structural Failure	Thin PE Hose And Cipp Liners
Joint Failure	Leakage	Internal Joint Seals Thin PE Hose And Cipp Liners
Localized External Corrosion	Leakage And Localized Structural Failure	Thick PE (Thin PE Hose And CIPP Liners In Some Cases)
Extensive External Corrosion	Major And Extensive Structural Failure	PRP, Thick PE

Figure 4 – Typical Water Main Problems

Assessing the Risks and Consequences of Pipeline Failure

A risk-of-failure value should be assigned based on the likelihood of failure before and after rehabilitation. Consequences have to be assessed based on the direct costs and social costs of pipeline failure include the following:

Direct Costs:

- Planning
- Design
- Contracting cost
- Permanent reinstatement
- Professional Charges

Indirect Costs

- Damage to adjacent property
- Diversion of existing facilities
- Reduction in road pavement life
- Increase in road maintenance requirements
- Disruption to businesses

Social Costs:

Environmental loss (noise, vibration, air pollution)

- Loss of amenity
- Disruption to traffic
- Increased levels of traffic accidents
-

To evaluate the likely cost of future repairs (with and without rehabilitation), the direct costs of repairing recent pipeline failures should be investigated along with the estimated social costs. In densely populated or high traffic areas, the total cost of a pipeline failure can be three or four times the direct costs of repair.

Evaluating the Alternatives

Selecting the optimal solution for a specific problem is a complex process involving both technical and economic considerations. Typically the pipeline does not operate at full hydraulic capacity, so options that reduce the pipe diameter could be considered. Spot or local repairs may also be considered instead of complete rehabilitation. Each rehabilitation option has to be evaluated according to its appropriateness to the project, including:

- Materials and geometry of the water main
- The length of time the main can be taken out of service
- Size, pressure, capacity
- History of technology
- Construction access and disruption
- Availability of materials and the capability of contractors
- Cost per linear foot of each option

Technical Solutions

Trenchless Technologies can be classified into four types of applications: investigation, localized repair, on-line replacement, and new installation. Choice of trencless technologies is influenced by a wide range of factors, including project needs, subsurface soil and groundwater conditions, pre-existing obstructions, and density of lateral utility connections. In many cases, a common trenchless technology will need to be adapted to address a particular set of site-specific condition. Public and private utilities such as electric, gas, and telecommunications companies, as well as city agencies should consider using trenchless methods when possible to install and repair their own property. This will result in fewer utility cuts, a reduced rate of pavement failure, and cost savings for the city.

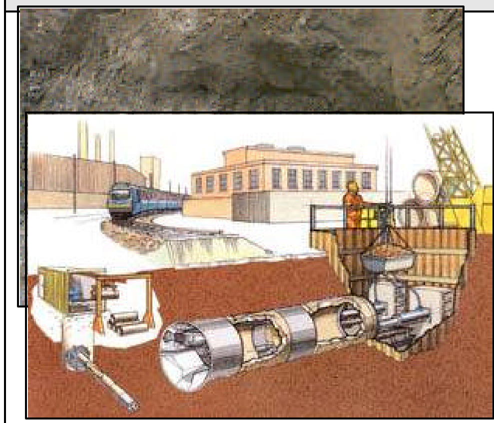
Installation Alternatives

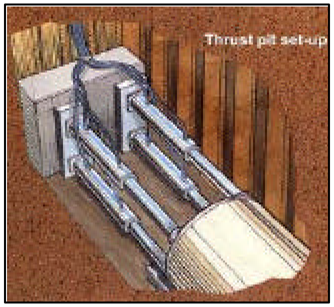
In the last 20 years, a number of methods and technologies have emerged which allow us to install and rehabilitate our pipe and cable infrastructure without digging a trench. Set out below is a brief summary of the main techniques used for new installation, on-line replacement and rehabilitation of existing pipes.

I. New installation

The following trenchless construction techniques can be used for the below ground installation of new pipes and cables which might previously have been installed by open-cut trenching.

Name	Description
	A piercing tool or impact mole is a tool that comprises a percussive hammer within a suitable casing, generally of torpedo shape. The hammer may be pneumatic or hydraulic. During operation the soil is displaced, not removed. An unsupported bore may be formed in suitable ground, or a pipe drawn or pushed in, behind the tool. Cables may also be drawn in. Because piercing tools are generally unstirred, the technique is most suitable for shorter bores: a straighter bore can often be maintained more easily at larger diameters. Diameters range from about 45 to 200 mm depending on the pipe or cable being installed. Piercing tools can be a very cost-effective method of installing small to medium sized pipes, ducts and cables for a broad range of utilities including gas, electricity, water and telecommunications. The technique is in common use for simple road crossings and the installation of service connections between main lines and individual properties. Moles are relatively easy to use, monitor and maintain in the field. Many utility companies carry these systems as standard equipment for every team on installation and service vehicles.
Directional Drilling (1)	A steerable system is used for the installation of pipes, conduits and cables using a surface or pit-launched drilling rig powering drill rods. The direction of the drilling head can be adjusted at any stage during the bore to steer around obstacles or to provide a curved path under highways, rivers or railways. Machines range from compact rigs suitable for small bores and operation in restricted spaces, to extremely large units designed for large diameter, long distance crossings. Installation of the product pipe or duct is usually a two-stage operation. A pilot hole is first drilled along the required path, and the bore is then back-reamed to a larger diameter to accommodate the product pipe. During this second pullback stage, the product pipe is pulled into the enlarged bore as the drill string is withdrawn.

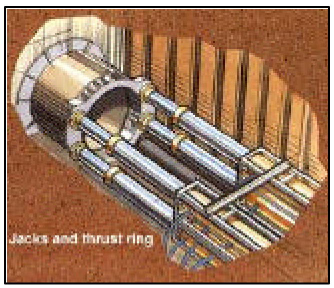
Name	Description
	Directional drilling has been used mainly for the installation of pressure pipes and cable ducts, where precise gradients are not usually required. Directional drilling is arguably the fastest growing new installation technique worldwide. Introduced as recently as the mid eighties, there are probably now 10,000 guided drilling machines worldwide. Because of the restoration savings, this method is directly cost competitive with open-cut trenching in streets.
Pipejacking & Microtunnelling	Pipe jacking, generally referred to in the smaller diameters as microtunnelling, is a technique for installing underground pipelines, ducts and culverts. Powerful hydraulic jacks are used to push specially designed pipes through the ground behind a shield at the same time as excavation is taking place within the shield. The method provides a flexible, structural, watertight, finished pipeline as the tunnel is excavated. There is no theoretical limit to the length of individual pipejacks although practical engineering considerations and economics may impose restrictions. Drives of several hundred meters either in a straight line or to a radius are routine. A number of excavation systems are available including manual, mechanical and remote control. Pipes in the range 150mm to 3000mm, can be installed by employing the appropriate system. Construction tolerances are compatible with other tunnelling methods, and the pipe jacking method generally requires fewer overbreaks than segmental tunnels, providing better ground support. Excavation methods are similar to those employed in other forms of tunnelling using either manual or machine excavation. Shields, excavation and face support can be provided for a wide variety of ground conditions.



In order to install a pipeline using this technique, thrust and reception pits are constructed, usually at manhole positions. The dimension and construction of a thrust pit may vary according to the specific requirements of any drive with economics being a key factor. Mechanized excavation may require larger pits than hand excavated drives, although pipe jacking can be carried out from small shafts to meet special site circumstances.

A thrust wall is constructed to provide a reaction against which to jack. In poor ground, piling or other special arrangements may have to be employed to increase the reaction capability of the thrust wall. Where there is insufficient depth to construct a normal thrust wall, for example through embankments, the jacking reaction has to be resisted by means of a structural framework constructed above ground level having adequate restraint provided by means of piles, ground anchors or other such methods for transferring horizontal loads.

High-pressure jacks driven by hydraulic power packs provide the substantial forces required for jacking concrete pipes. The ram diameter and stroke of the jack may vary according to an individual contractor's technique. Short stroke jacks with multiple spacer blocks, medium stroke jacks with shorter length pipes or long stroke jacks, which can push a full length pipe at one setting may be used.

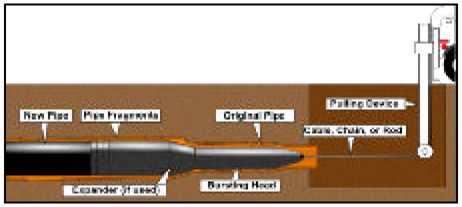
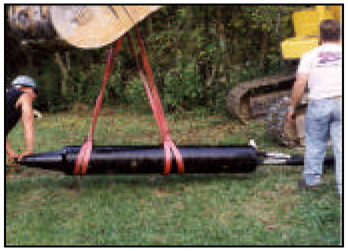
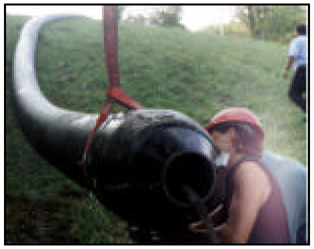


To ensure that the jacking forces are distributed around the circumference of a pipe being jacked, a thrust ring is provided of a design dependent on the number of jacks being used. The jacks are interconnected hydraulically to ensure that the thrust from each is the same. The number of jacks used may vary because of the pipe size, the strength of the jacking pipes, the length to be installed and the anticipated frictional resistance.

A reception pit of sufficient size for removal of the jacking shield is normally required at the completed end of each drive. The initial alignment of the pipe jack is obtained by accurately positioning guide rails within the thrust pit on which the pipes are laid. To maintain accuracy of alignment during pipe jacking, it is necessary to use a steerable shield, which must be frequently checked for line and level from a fixed reference. For short or simple pipe jacks, these checks can be carried out using traditional surveying equipment. Rapid excavation and remote control techniques require sophisticated electronic guidance systems using a combination of lasers and screen based computer techniques.

II. On-line replacement

Where there is a need to replace an existing pipe we can simultaneously remove the old pipe and install a new one by techniques such as:

Name	Description
Pipe Bursting/Splitting   	Pipe bursting is a technique for breaking an existing pipe by brittle fracture, using mechanical force from within. The remains are forced into the surrounding ground. Simultaneously a new pipe, of the same or larger diameter, is drawn in behind the bursting tool. The pipe-bursting device may be based on a pneumatic impact tool, which converts forward thrust into a radial bursting force, or, by a hydraulic device inserted into the pipe and expanded to exert direct radial force. The pneumatic bursting tool is inserted inside the new polyethylene pipe. A proper sized bursting head is then attached to the new PE pipe. A winch cable is then hooked to the tool that will help keep it on line as it progresses through the existing line. As the pneumatic tool moves forward the assembly is simultaneously winched. The action bursts the existing pipe and pushes the pieces of old pipe into the surrounding soil no further than the outside edge of the bursting head, as the new PE pipe is pulled into place. The pneumatic tool is protected inside the new pipe and the steel burst head is the leading edge used to fracture the old pipe. When the bursting head has reached its destination, the stake down unit and winch cable are removed, then the tool is placed into reverse. The reverse action of the tool helps to back it out of the new line all the way to the launch pit. The bursting head is cut off and removed. The installation of the new pipe is now complete and ready for connection. Pipe bursting is widely used for the renewal of gas and water mains and for the replacement of old and undersized sewers. Significant increases in size are possible. Sewer bursting operations are typically in the diameter range 150 to 375 mm, although larger pipes have been replaced by this method. This technique has proved to be cost effective when compared with digging a trench for renewing a pipe.

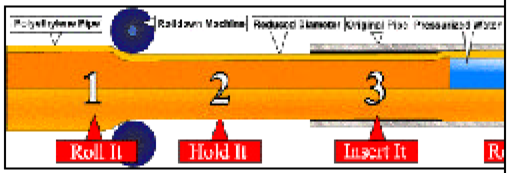
II. Rehabilitation of existing pipelines

The rehabilitation of existing pipelines by repairing or renovating the existing pipeline has seen major developments both for gas and water as well as for sewer pipes. Rehabilitation is carried out from inside the pipe without digging a trench.

Methods include:

Name	Description
Lining the Host pipe Sliplining	Pipeline rehabilitation techniques are used when the existing pipe is to remain in service but has scattered defects to preclude the use of point repair techniques. These techniques will renew the existing pipe to various levels and can provide structural solution as well as leakage reduction (McArthur, 1997). This class includes semi and fully structural solution renovation of the pipe. The host line bears the internal pressure, which therefore, should be structurally sound this is due to the fact that the liner is at least one order of magnitude less rigid than the host pipe (Heavens, Insituform). However, the liner is expected to carry the load at restricted holes and defect in the pipe. A fully structural system, which is capable of sustaining the maximum allowable operating pressure of the host pipe, is also available and this liner should temporarily endure the loading associated with the burst of the host pipe. This group of techniques involves the installation of polymeric lining tightly bound to the host pipe. Based on a temporary deformation of the polyethylene liner in order to reduce its cross section to allow insertion in the host pipe, after which the liner is adjusted to its designed shape and size so it is tightly fit into the host pipe. Slip lining is the simplest technique for renovating non-man-entry pipelines. Basically, it entails pushing or pulling a new pipeline into the old one. Although, in theory, any material can be used for the new pipe, in practice flexible polyethylene (PE) is the most common choice for pressure lines. Not only is this material well established in the potable water and gas industries, it is also abrasion resistant and sufficiently flexible to negotiate minor bends during installation. It can be butt-fused into a very long continuous length prior to being winched into the host pipe. For slip lining sewers, rigid pipes are used and can be of a variety of materials.

Close-fit liners

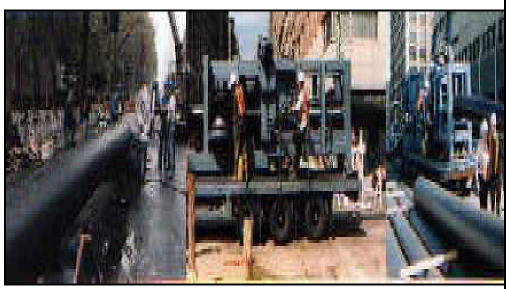


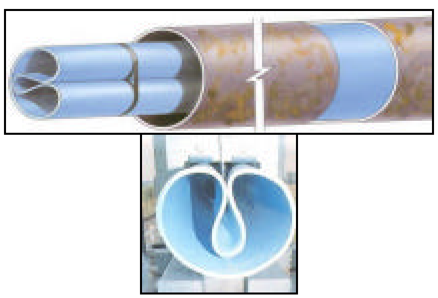
Rolldown (Pim Corporation, Subterra)

The terms "close-fit liners" or "modified slip-lining" refer to liners that are deliberately deformed prior to insertion, and then reverted to their original shape once in position so that they fit closely inside the host pipe. These techniques are a logical development of the basic sliplining described in the previous section, and can be applied to both gravity and pressure pipes. However, some polymeric pipe materials have an in-built memory.

The temporary on-site reduction is achieved by passing the liner pipe through rollers. It is used for water and gas transmission and distribution, sewer pumping mains and industrial water pipeline.

The pipe is formed into a U or C shape, after which insertion the pipe is transformed to fit into the host pipe by using heat and air pressure or hydrostatic pressure. The pipe thickness should be carefully selected to withstand the required pressure.





Subline (Pim Corporation, Subterra)

Cured-in-place liners

The polyurethane liner is pulled through adjustable squeeze rollers and placed into a pressure box in a layered manner.

After polymerization of the adhesive, the pipeline is ready for pressure testing or service installations.

A polyester fiber reinforced polyethylene pipe is available (Heavens, Insituform) which can achieve independent pressure rating of 150 psig at a few mm thicknesses. This process is being used in the UK and a full renovation of 650 ft pipe was achieved in just a few hours.

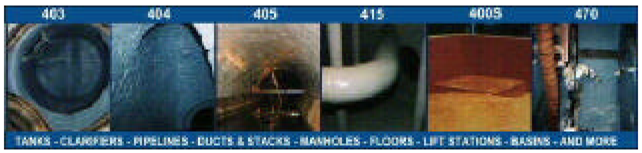
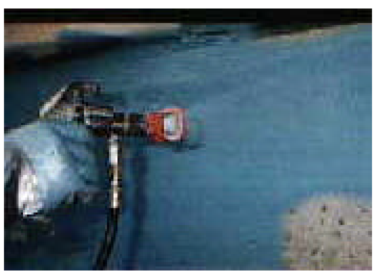
This method is based on the original cured-in-place well known and widely used sewer renovation method. It utilizes a glass fiber reinforced felt tube which is impregnated with epoxy resin. The tube is installed by means of water pressure as described above for woven liner. These liners are available in different thickness and diameter.

These processes were found to have the widest range of application in terms of size and shape of the pipe in the case of sewer application (Dennis, 1999).

The main alternative to slip lining and its variants is cured-in-place lining, sometimes referred to as 'in-situ lining', 'soft lining' or 'cured-in-place-pipe' (CIPP). These linings have dominated the non-man-entry sewer renovation market in many countries for over twenty years.

Although several competitive systems are now available, the common feature is the use of a fabric tube impregnated with polyester or epoxy resin. The tube is inserted into the existing pipeline and inflated against the pipe wall, then cured either at ambient temperature or, more commonly in all but the smallest diameters, by re-circulating hot water or steam. Some variations use ultra-violet light to cure the resin.

As well as minimizing bore reduction, an inherent advantage of cured-in-place liners is their ability to conform to almost any shape of pipe, making them suitable for relining non-circular cross-sections.
CIPP has proved to be a cost-effective alternative when renovating deteriorating sewer pipes. To renovate with CIPP reportedly costs 40-50% of open cut costs.

Name	Description
Cement Mortar **&** **Epoxy Spray Lining** Spray-on linings  	A widely used method for the short-term repair of pipes that are basically structurally sound and are locally corroded or tuberculated (tuberculation – sediment, encrustation and corrosion by-products on the inside of pipes that, in time, effectively block the free passage of water). The method involves the deposition of a thin layer of cement mortar or epoxy resin on the clean inner surface of the pipe. This layer separates the pipe wall from the flow stream and is designed to prevent further internal corrosion and deterioration of the pipe. The cement method is based on the alkaline activation of the pipe to prevent corrosion whereas the epoxy layer provides a thin film, which is water-resistant. Often with water pipelines the principal objective is to remove scale and corrosion, and then apply a coating, which will inhibit further deterioration and may seal very minor leaks. The most common materials used for this purpose are cement mortar or epoxy resin. These are applied by a robotic spraying machine, which is winched through the pipe at a constant, predetermined rate. In larger sewer pipes, allowing man entry, techniques of mortar spraying such as shotcrete can be used to provide a structural liner.

To conclude, a large variety of different pipe relining systems is now available for the rehabilitation of short sections of pipe as well as complete pipeline runs. Both pressure and non-pressure pipe relining systems are available. These methods can provide a lining that will have the equivalent operating life of a new pipe.

There are four generic types of relining systems:

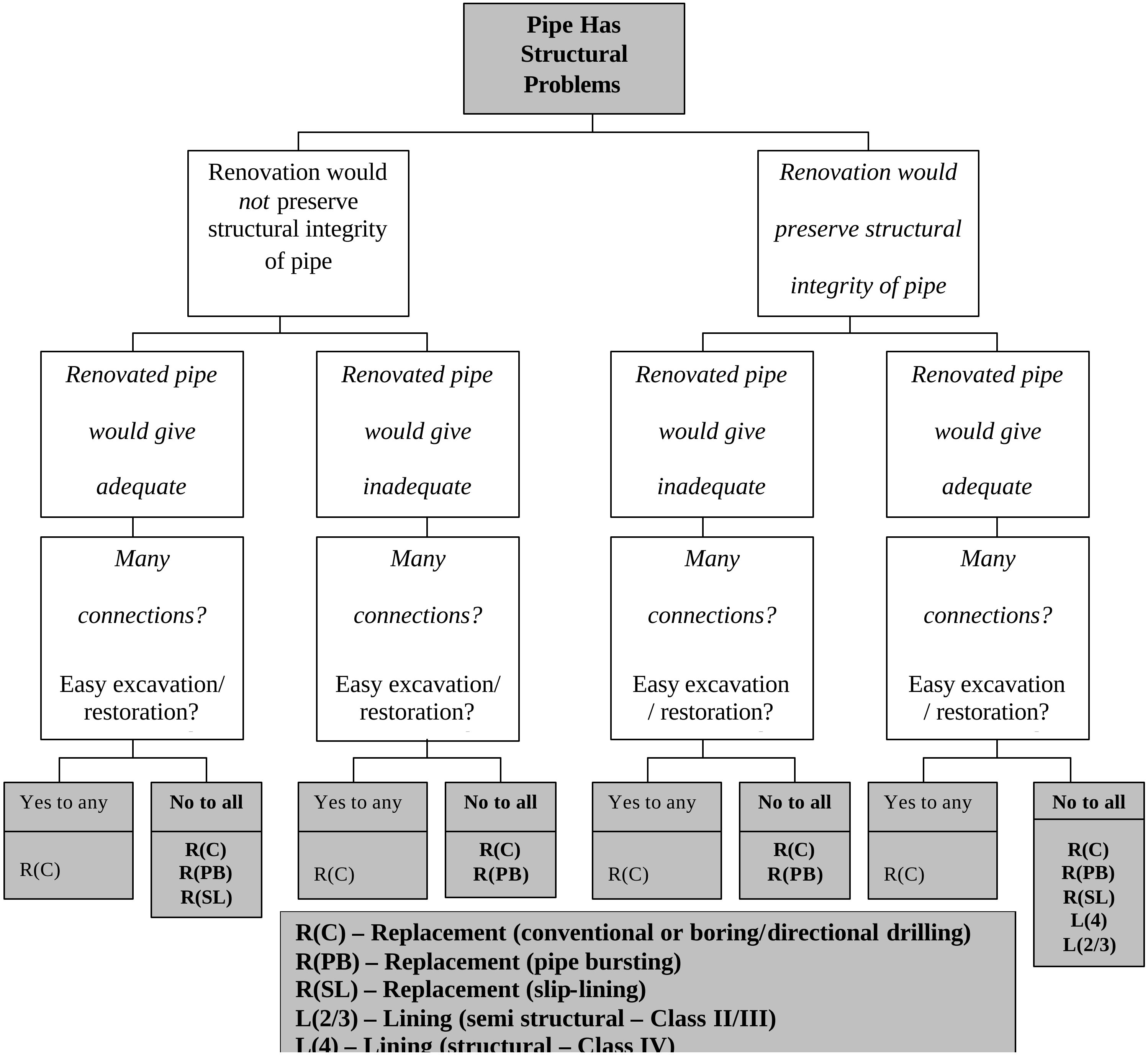
- Sliplining
- Close fitting liners
- Cured-in-Place linings (CIPP)
- Sprayed lining systems

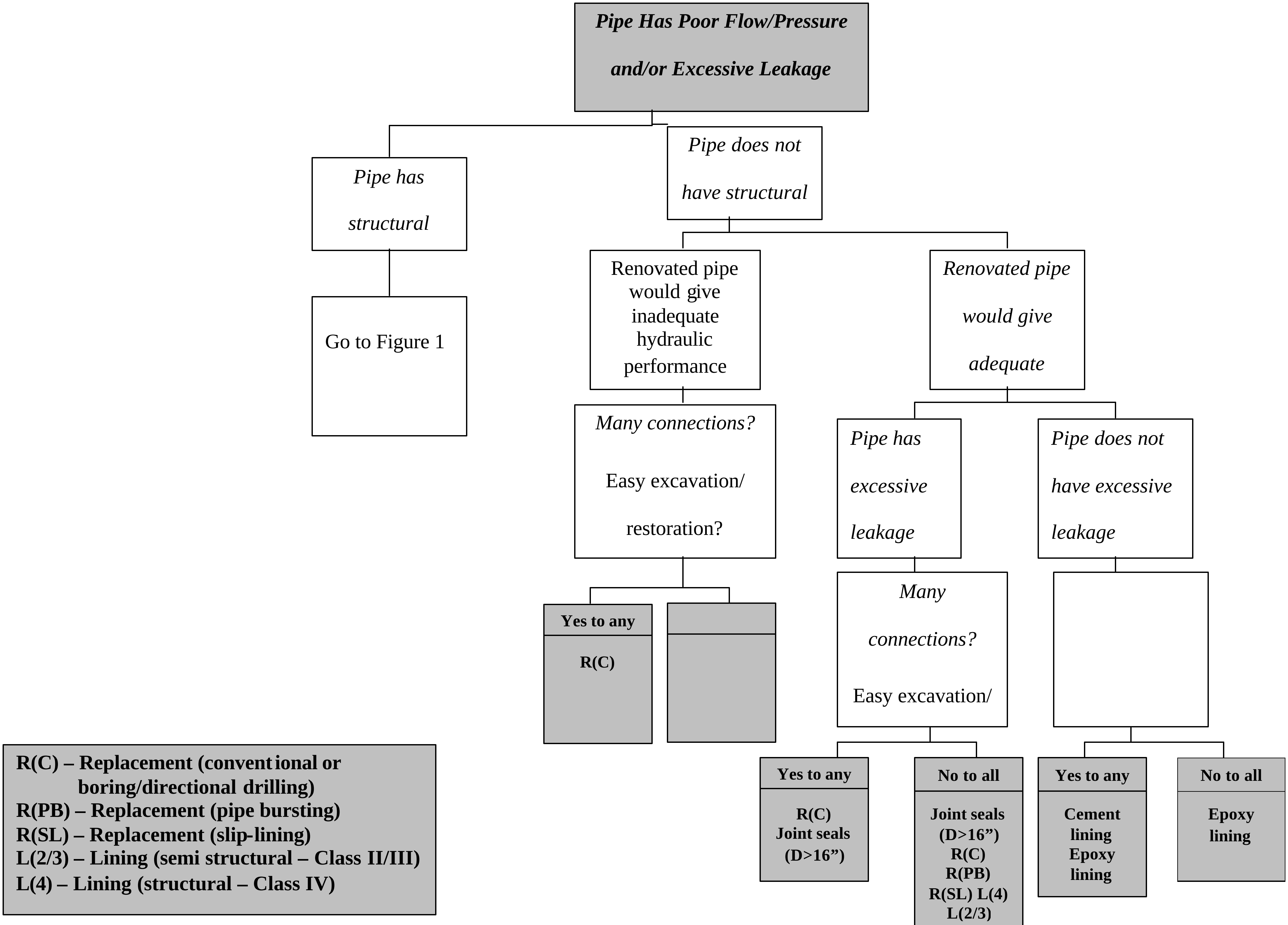
Table I shows how these generic lining systems can be selected to solve typical water main problems. Furthermore, Figure 1 provides a decision tree which can be used to select a rehabilitation technique, assuming the pipe has structural defects. In a similar fashion, Figure 2 if it is noted that the pipe has flow, pressure and/or leakage problems which necessitate rehabilitation measures.

Table I – Typical Water Main Problems and Minimum Liner Structural Functionality

Problem	**Typical Consequences**	**Minimum Liner Class Required (See AWWA Manual M28 in Appendix A)**	**Lowest Cost Commercial Solutions**
Mild internal corrosion and tuberculation	Poor water quality and flow restriction	Class I	Cement or Epoxy Spray Lining
Severe internal corrosion	As above plus leakage and structural failure	Class II/III	Thin PE Hose and CIPP liners (PRP)
Joint failure	Leakage	Class II/III	Thin PE hose and CIPP liners
Localized external corrosion	Leakage and localized structural failure	Class IV preferred but class III may be acceptable	PRP thick PE (thin PE hose and CIPP liners in some cases)
Extensive external corrosion	Major and extensive structural failure	Class IV	PRP, thick PE

Figure 1: Selection of rehabilitation techniques to resolve structural problems




Pipe Has Poor Flow/Pressure and/or Excessive Leakage
Pipe has structural
Pipe does not have structural
Go to Figure 1
Renovated pipe would give inadequate hydraulic performance
Renovated pipe would give adequate
Many connections?
Easy excavation/ restoration?
Pipe has excessive leakage
Pipe does not have excessive leakage
Yes to any
R(C)
Many connections?
Easy excavation/
Yes to any
R(C) Joint seals (D>16”)
No to all
Joint seals (D>16”) R(C) R(PB) R(SL) L(4) L(2/3)
Yes to any
Cement lining Epoxy lining
No to all
Epoxy lining
R(C) – Replacement (conventional or boring/directional drilling)
R(PB) – Replacement (pipe bursting)
R(SL) – Replacement (slip-lining)
L(2/3) – Lining (semi structural – Class II/III)
L(4) – Lining (structural – Class IV)

Structural Classification of Lining Techniques

Lining systems used to rehabilitate potable water pipelines can be classified into four groups according to their effect on the performance of the lined pipe when subjected to internal pressure loads.

Class I Linings

Class I linings are essentially nonstructural systems used primarily to protect the inner surface of the host pipe from corrosion. They have no effect on the structural performance of the host pipe and have a minimal ability to bridge any existing discontinuities, such as corrosion holes or joint gaps. Hence, they have minimal effect on leakage. Their use is indicated in pipes suffering from internal corrosion or tuberculation but still in structurally sound condition and where abatement of current or future leakage is not an issue. Examples of Class I linings are cement-mortar lining and epoxy resin lining.

Class II and III Linings

Class II and III linings are both interactive and semi structural systems. When installed, the liners closely fit the host pipes, and any remaining annulus is rapidly eliminated when internal operating pressure expands the lining. Since the stiffness of such a lining is less than that of the host pipe, all internal pressure loads are transferred to the host pipe, leading to their classification as interactive. Such a lining is required only to independently sustain internal pressure loads at discontinuities in the host pipe, such as corrosion holes or joint gaps, or if the host pipe is subject to structural failure.

A liner is considered to be in Class II or III if its long-term (50-year) internal burst strength, when tested independently from the host pipe, is *less than* the maximum allowable operating pressure (MAOP) of the pipeline to be rehabilitated. Such a liner would not be expected to survive a burst failure of the host pipe, so it cannot be considered as a replacement pipe. However, Class II and III liners are designed to bridge holes and gaps in the host pipe on a long-term basis, and various systems can be further classified in terms of the magnitude of the holes and gaps they can bridge at a given MAOP. Some systems are capable of bridging holes and gaps of up to 6 inches (52 mm) on a long-term basis at an MAOP of 150 psi (1,034 kPa).

The separation of these systems for spanning holes and gaps into two classes is based on their inherent resistance to external buckling forces and dependence on adhesion to the host pipe wall. Class II systems have minimal inherent ring stiffness and depend entirely on adhesion to the pipe wall to prevent collapse if the pipe is depressurized. Class III liners have sufficient inherent ring stiffness to be at least self-supporting when depressurized without dependence on adhesion to the pipe wall. As explained later, Class III liners can also be designed to resist specified external hydrostatic or vacuum loads.

Use of Class II or III linings may be indicated where the host pipe is suffering from one or more of the following conditions:

1. Severe internal corrosion leading to pinholes and leakage

2. Leakage from faulty joints

3. Localized external corrosion resulting in pinholes and leakage

Although the liner will not prevent further external corrosion, it will prevent leakage at corrosion holes. This capability guards against the associated effects of that leakage on the exterior of the pipe and the corrosivity and support offered by the surrounding soil.

Class IV Linings

Class IV linings, termed *fully structural* or *structurally independent*, possess the following characteristics:

1. A long-term (50-year) internal burst strength, when tested independently from the host pipe, equal to or greater than the MAOP of the pipe to be rehabilitated

2. The ability to survive any dynamic loading or other short-term effects associated with sudden failure of the host pipe due to internal pressure loads

Class IV linings are sometimes considered to be equivalent to replacement pipe, although such linings may not be designed to meet the same requirements for external buckling or longitudinal/bending strength as the original pipe. Also, they may be of smaller internal diameters. Class IV linings can, of course, be used in circumstances similar to those for Class II and III, but their use is essential for host pipes suffering from generalized external corrosion where the mode of failure has been, or is likely to be, catastrophic longitudinal cracking.

As explained later, some available renovation technologies can offer both Class II and III and Class IV linings, while a given lining system may be rated as Class IV for MAOP levels up to a threshold value and Class II and III for higher pressures.

Additional Design Considerations

In addition to internal pressure loads, linings may also be required to sustain external buckling loads during periods when the host pipe is depressurized, as well as transient vacuum loads. Some systems (Classes III and IV) can be designed to offer significant inherent resistance to such external loads, while others (Class II) depend solely on adhesion to the host pipe wall. Inherent resistance to external buckling normally varies with increased lining thickness and hence cost. Care should therefore be taken to ensure that such performance requirements are accurately defined.

The hydraulic performance of the lined pipe will be determined by the thickness of the liner, its closeness of fit to the host pipe, and its internal smoothness (C value). The lining process is usually preceded by extensive cleaning, which will itself restore the original flow cross section of the pipe. Liners of plastic materials are significantly smoother than the inner surface of a deteriorated host pipe, and they may even be smoother than the original pipe. In addition, many lining systems provide essentially joint-free coverage over long sections, so they offer less disturbance to flow than jointed sections of pipe. In general, close-fit plastic lining systems with SDR of 26 or more normally retain the original flow capacity of the pipe.

Reinstatement of Fittings after Structural Lining

All Class II, III, and IV linings block or otherwise interfere with the function of in-line fittings such as service connections, branch pipelines, and valves. Lining installers must remove branch connections, valves, reducers, and similar fittings at local excavations prior to lining. The liner then terminates on each side of the fitting location with suitable end seals, and crews then reinstate or install replacement fittings after lining.

Crews handle service connections in a similar manner. After accessing the connection fitting via a small local excavation prior to lining, workers disconnect the communication pipe, then they generally remove the fitting prior to lining. In an installation of a thick, polyethylene-based Class IV lining, workers commonly break out all or part of the existing pipe at the location of the service connection, line through the gap, and then install a new electrofusion or mechanical saddle connection.

For a Class II or III or thin Class IV lining, workers normally enlarge the hole left by the removal of the original connection, line over it, and then install a service connection adapter through the lining. Some lining technologies involve proprietary systems for such connections, and fittings manufacturers also offer ferrules suitable for a number of lining technologies. In some cases, ferrules can be installed under pressure so that new connections can subsequently be added to a lined pipe with minimum customer disruption.

End seals must be installed to prevent leakage between the liner and the pipe wall at any location where the liner is terminated. Both internal and external specialized seals are available. Some external seals incorporate flanges for easy reconnection to fittings. The seals vary in their capabilities for withstanding longitudinal forces and liner movement due to thermal and other effects, and these characteristics should be considered in selecting seals. Where sections of pipe have been removed to facilitate access for the lining process, a spool piece must be installed to bridge the gap after lining and end-seal installation.

The availability of reliable techniques for reinstating fittings is a vital element in the renovation of pipelines with structural linings. Options should be discussed in detail with contractors offering the lining systems. This choice also has implications for water companies, which must maintain inventories of specialized fittings for subsequent modifications or repairs to lined pipes. Procedures and costs required for repairs of lined pipes damaged by third-party actions should also be agreed with the contractor at the time of lining installation.

PART TWO: SOCIAL COSTS

INTRODUCTION

According to C. J. F.P. Jones (Newcastle University, UK; "Policy, incentives and barriers to the use of Trenchless Technology in the UK"), before considering the incentives and barriers to the use of trenchless technology in the UK and worldwide, it is necessary to identify the overall costs of public utility works. These can be considered under three headings: direct costs, indirect costs and social costs.

- Direct Costs include the planning, design, contracting costs, permanent reinstatement and professional charges.

- Indirect Costs include diversion of existing facilities, reduction in road pavement life, the increase in road maintenance requirements, and damage to adjacent property and disruption to businesses directly involved with the works.

- Social Costs include environmental loss associated with air pollution, noise, vibration, the loss of amenity and the disruption to commercial and private traffic, sometimes on a wide scale, together with increased levels of traffic accidents.

Factoring in the social costs when using trenchless technology involves looking at the possible construction methods available to rehabilitate, replace, or install new pipeline. It involves understanding the total cost of installing the pipeline. This total cost includes the direct cost of the materials, labor, and equipment, and also the indirect cost of its impact on the community.

In the United-Kingdom and in many cities in the United-States, the diversion of existing facilities (gas, electric, telephone) or the cost to protect these facilities from adjacent excavation is the responsibility of the municipality installing sewer or water mains (part of the direct cost). In New York City, the gas, electric and telephone utilities are responsible to relocate or protect their facilities when they are in interference with water or sewer construction projects. Consequently, the cost to the private utilities may be considered an indirect cost to municipal construction projects or perhaps included as a social cost. By whatever name, these utility costs are ultimately passed on down to the residents of New York in the form of higher utility bills.

Figure 1
Urban Street with

Figure 2.
Utility Networks

The New York City resident is therefore best served by the selection of construction methods that offer the lowest total cost (direct, indirect and social).

Likewise the New York City resident is best served by the methods of construction that cause the least disruption to traffic, loss of business, noise, dust, environmental concerns and quality of life issues. Selecting construction methods that reduce or eliminate the relocation of other facilities is desirable to minimize the scope and duration of a project and thereby reduce the total cost and improve quality of life for the New York City resident.

The majority of studies on social costs related to construction projects have been performed in the U.K and Europe. The following discussion of these issues is based on a presentation by James C. Thomson, Chairman of Jason Consultants, at a "Life Extension Technologies" (LET) seminar co-sponsored by the Urban Utility Center in New York.

Professional Background

Jason Thomson is the Chairman of Jason Consultants a leading international consultant in the underground infrastructure. Jason has offices in Geneva, London, Washington, D.C. and San Diego.

He is an acknowledged international authority in all forms of non-disruptive underground techniques for the installation and rehabilitation of pipes, cables, and structures. His expertise in the specialized field goes back to 1958, when he pioneered the development and use of pipejacking and auger boring techniques in the U.K. and other countries.

James Thomson is an innovator of design concepts for constructing all types of underground installations without causing surface disruption or damage to existing structures. These include not only the installation and rehabilitation of utilities but also for larger structures such as pedestrian and traffic underpasses, subway lines and stations.

He has been directly concerned with new technology for underground installation as it has developed, including pressure balance tunneling, micro-tunneling, guided boring, directional drilling and techniques for on-line replacement and the in-situ renovation of pipes and cables. He has managed trenchless technology and underground projects ranging from research and development, through engineering and design, to analyzing the economic and marketing potential of various systems.

He has written more than 80 technical papers and lectured to engineering groups and learned societies in many countries. He is the author of the book "Pipejacking and Micro-tunneling" and co-author of "An introduction to Trenchless Technology".

Worldwide Experience and Best Practices in Mitigating Disruption from Utility Installation

James Thomson C. Eng.
Jason Consultants International

Community Disruption and Utility Works

Traditionally we have recognized that our streets have to serve a dual role:

- The surface is used by pedestrians and vehicles as they go about their business.
- The space below the street is a location for the pipes and cables essential to society.

Increased traffic and growing demands on utilities to install, replace, reinforce or rehabilitate pipes and cables have resulted in a clash of interests between community and utility. This clash will continue to escalate as traffic and utilities compete for limited road space. We need to consider whether the changing needs of society require us to rethink the priorities of the dual roles of these users as well as how to mitigate the disruption. Perhaps the replacement, renovation and maintenance of utilities should be carried out with the community and overall economy in mind and not just the requirements of a utility and its program.

If you could take someone who lived in New York 100 years ago and transport that person through time to the same city streets today, there would be astonishment at the changes in the skyline and the number of vehicles and their speed. On the other hand, the person would feel quite familiar with the methods utilities are using to install pipes and cables in the streets. Equipment would have improved—hydraulic backhoes rather than steam shovels, for instance—but the approach would be the same.

However, in the last 20 years we have seen the emergence of a series of non-disruptive installation and rehabilitation methods, which are generically called *trenchless technology*. When correctly used, trenchless methods of rehabilitating and installing utilities can help reduce many traffic problems caused by utility works.

Before we can make any informed decision about the method of installation or rehabilitation to be employed, we have to define all the elements of the problem.

In this presentation, we shall look at four main issues:

1. What is the true cost of a utility installation?
2. If a trenchless option proves to be the most economic solution, what alternative methods do we have?
3. What constitutes current best practice in the use of trenchless technology?
4. What can we learn from trenchless practices used in other countries?

1. What is the Real Cost of Utility Installation?

Depending on whom you ask, the answer to this question is likely to vary. A utility person will probably list the direct costs of carrying out the work.

These would include:

- Payments to contractors
- Permanent reinstatement
- 3rd party plant diversions
- 3rd party damage
- Costs of traffic management

However, if you speak to the authorities responsible for the operation of the street, they will add:

- Higher accident costs
- Reduced highway life
- Damage to public and private property

Automobile users or people going about their business will add:

- Additional vehicle operating costs
- Additional costs of traffic and pedestrian delay
- Loss of business revenue and profit
- Loss of public amenity

And if you speak to environmentalists, they will throw in:

- Street tree damage
- Air pollution
- Additional use of natural resources

How costs are estimated

Utilities are rarely required to make contributions to anything but the direct costs. As we will see, these direct costs are probably less than the indirect cost burden borne by the city and the community

For some of these impacts it is difficult to attribute a monetary cost. Such items as loss of public amenity, tree damage, air pollution and use of natural resources are in this category. However difficult they are to assess in money terms they are a real cost as far the public is concerned.

In other cases the data or the agreed means of calculating the financial cost either does not exist or is inadequate. There is no accepted rule for considering the cost of damage to third party property, including damage to existing utilities. Nor is reduced highway life part of a general formula, although some US studies have suggested that pavement life can be reduced by 15 to 30%. These figures are disputed, but if anything approaching these percentages were to be established, they would add a very large cost to the bill.

No doubt everyone here would agree that utility operations in highways are extremely disruptive to the economic and social fabric of New York. Probably the most significant cost is the cost attributable to disruption and delays to traffic. The question is what is this cost?

Traffic disruption costs

Despite the magnitude of the problem, surprisingly little work has been done to obtain some means of measuring the costs caused by traffic disruption.

Jason conducted a major study (Jason Consultants, 1992) for the UK Department of Transport to evaluate the social cost of utility installation in UK. We undertook a series of site surveys of various types of roadwork. By using cameras, we were able to measure the delays incurred by vehicular traffic at these sites. I should add that no attempt was made to evaluate the extra distance traveled or the time lost by diverting the route away from the works. We then took data from our surveys plus data from other studies of social costs to produce a range of ratios of traffic costs to construction cost.

The social costs of traffic delays at the sites surveyed together with the direct construction cost value were summarized. Social costs were expressed as a percentage of direct construction costs. The range of the ratio extended from 70% to 493% of the actual cost of the traditional trenched jobs. Across the board, we arrived at an average ratio of 1.3%. That is to say, on average, the cost of delay to traffic is 30% greater than the cost to the utility.

We were also able to draw on other research work, where an even higher level of ratios had been established. (*Peters, 1984*). In a busy town, this study in a busy town had identified some sewer work that generated a high ratio of over 10. The average ratio in Peter's study was 3. A summary of the ratios for the two research projects is given in Table 1.

Jason's Mean Values		Peter's Mean Values	
Overall	**1.3**	**Overall**	**3.0**
Upper 80%	**1.7**	**Upper 80%**	**3.5**
Lower 80%	**0.6**	**Lower 80%**	**2.1**

It is important to emphasize two things:

- The number of sites surveyed was insufficient for final conclusions to be drawn on the true ratio.
- The study was for UK roads, which tend to be more congested than those in the USA in general, although, if anything, Manhattan is even more congested.

When we applied our overall ratio to the value of UK utility construction as a whole, we arrived at an overall traffic delay cost of $2.1 billion.

We also observed two other important facts:

First, we concluded from our research that the major problems of conflict with traffic occur at a relatively low percentage of works. This conclusion was borne out by work from other sources and the observations of the utility authorities. Roads which are strategic in terms of traffic or because of other special circumstances may, in terms of length, only account for 10-20% of the utility work, but can account for around 80% of the disruption cost to traffic.

Our second observation was that the social costs rise in direct relation to the time of utility occupation of the road. This point may appear to be blindingly obvious. However, running up additional social costs by the extended time of the works was neither obvious or of concern to some of the utilities and their contractors.

There is no doubt that utility operations in highways are extremely disruptive to the economic and social fabric of a country. For a city like New York these costs could be several hundreds of millions of dollars a year. Depending on the value put on some of the impacts this figure could be substantially higher.

2. Installation Alternatives

In the last 20 years, a number of methods and technologies have emerged which allow us to install and rehabilitate our pipe and cable infrastructure without digging a trench. Set out below is a brief summary of the main techniques used for new installation, on-line replacement and rehabilitation of existing pies.

New installation

The following trenchless construction techniques can be used for the below ground installation of new pipes and cables which might previously have been installed by open-cut trenching:

- Impact Moling and Rod Pushing
- Directional Drilling
- Pipejacking and Microtunnelling

On-line replacement

Where there is a need to replace an existing pipe we can simultaneously remove the old pipe and install a new one by techniques such as:

- Pipe Bursting
- Pipe Splitting

Rehabilitation of existing pipeline

The rehabilitation of existing pipelines by repairing or renovating the existing pipeline has seen major developments both for gas and water as well as for sewer pipes. Rehabilitation is carried out from inside the pipe without digging a trench.

Methods include:

- Slip lining
- Close-fit liners
- Cured-in-place liners
- Spray-on linings

3. Best Practice in the Use of Trenchless Technology

Trenchless technology techniques are valuable in reducing disruption and social costs. Their considerable increase in use is in many cases due to their being directly competitive with traditional methods. However great benefits could accrue to the community and the environment if these non-disruptive methods were applied to a greater range of work.

Trenchless technology by itself is not a universal panacea. It is an engineering approach, which needs to be taken into account during the conceptual stage. We will never obtain the full benefits if we try to superimpose trenchless methods on a trenched design or make it an alternative form of construction.

A commonly expressed concern throughout the world is that trenchless methods are not appropriate because of lack of accuracy, underground congestion and soil conditions. I have to admit some sympathy with this view in that we have seen many examples of excess sales zeal and misuse of methods by consultants and contractors resulting in failures.

However today it is possible to install any type of pipe, of any diameter, in any soil conditions to a line and level accuracy of plus or minus 2-in. Like any other engineering concept the technology and its limitations has to be fully understood and matched to the specific site needs.

Concept

In an ideal world, it is the first stage during the initial planning and concept where a decision should be taken as to the relative impacts of alternative construction approaches.

As an engineer I have a fundamental belief that you can't design anything unless you know how it is to be constructed.

Engineering solutions based on trenched or trenchless methods will lead to quite different solutions. For example, in a sewer design the engineer must consider entirely different alignments for trenchless as opposed to a trenching solution. With trenchless methods, there is the possibility of going much deeper and working in more difficult soil conditions at very little additional cost. This may also allow the elimination of expensive pumping stations.

At this stage, environmental concerns will weigh heavily with the planners, who will be anxious to avoid problems with legislation and active pressure groups. Strangely, at present the same concerns do not seem apply to the human species and its habitat.

Design

Once we get to the design stage, the benefits that can be gained for the client and the community by the use of non-disruptive methods are diminished. Once the design concept has been established and the basic plans drawn up, the options are more limited. However, as the scheme is developed, we are able to draw up better evaluations and cost estimates for the alternatives.

Some engineers, in order to cover themselves and give the client a comparison, offer the bid option of a trenchless alternative on a traditional trenched design. Unfortunately this rarely produces a satisfactory answer in that the constraints of an open trench have greatly determined the rationale of the design. It is a different game. Rather like trying to get ice hockey players to play on a football pitch. Where adding such an option does have value is in locating specific sections, which will benefit from trenchless methods for example where a pipeline crosses a busy road.

Contract documents

A number of authorities have tried to factor into the penalties or charges in contract documents to reflect their evaluation of the disadvantages of trenched methods. This overcomes the contractual problem of taking away from the contractor his responsibility for temporary works, which includes the method for installing the pipe or cable.

Some of the methods used include:

- Lane rental—a fee for the space occupied on the highway during the works
- Liquidated damages for causing traffic delays greater than a given level
- Restricted working times
- Requirement to return all traffic lanes to use each day for peak hours
- Severe restriction on site occupation time

Implementation

Operating and laying out the work in a manner that minimizes the impacts on the community is a key area of best practice. This applies equally to trenched or trenchless methods. Individual works may be technically mundane and of relatively low value but their impact on the community may be great, generating costs many times the value of the construction. We need to undertake these works with the community in mind not just to meet the utility requirements.

4. International Experience and Practice

This section provides an overview of the attitudes of a number of countries to controlling utility disruption, evaluating utility disruption and the use of trenchless methods.

When looking at the experience of other countries it is apparent that authorities have very different approaches to the rights of the utilities in public roads. In many countries there is an increasing understanding that the underground space beneath public rights-of-way is a valuable resource. The tradition of using this space for installing utilities on a first-come / first-served basis or as a utility corridor can be harmful in terms of future needs. It also reduces the value of this resource.

The loss of public and private amenity and environmental aspects are difficult to evaluate, although nobody doubts that this is a real issue. Valuations and the level of environmental awareness will vary greatly from one country to another. It is not uncommon to find that utilities are required to spend substantial sums in mitigation measures to avoid disturbing flora and fauna. The disturbance to the human population often does not attract the same investment or attention.

We will take some examples from the experience of the UK, Scandinavia, France, Germany, Japan, Hong Kong, Singapore and Thailand.

United Kingdom

In the eyes of many international commentators, the UK is a world leader in legislation for mitigating disruption arising from utility works in roads. The watershed was the New Roads and Street Works Act 1991. (NRSWA). It is believed that this Act provides a framework that limits the power of the utilities and requires them to undertake work in a manner or by means that minimizes disruption to the public.

The perception is not matched by the reality. Many street authorities and interested transport bodies perceive the Act to have failed in this objective. This is borne out by responses of a survey of clients and contractors undertaking utility work in streets. The majority of respondents stated that social and indirect costs were not taken into account in economic assessments of works.

It also has to be recognized that between drafting the Act and its implementation there had been a change in the status of the utilities, who had moved from being state owned to being private companies with a prime responsibility to their shareholders.

Scandinavia

Unlike the situation in most countries, Scandinavian utility companies do not have rights of entry to the road. Before they can install new equipment, they must obtain permission from the owner, the highway or road authority. The utility must meet all costs associated with the work but it is not thought that any of the social costs are charged. Roads are inspected before and after the work.

France

In France the regulations controlling pipelaying vary between one Department and another. It is generally forbidden to cut newly laid road surfacing for utility installation. The embargo extends to 2, 3 or 5 years

Each municipality can also establish its own regulations for the roads under its control. For example, in Prefecture des Hautes-de-Seine, transverse crossings of roads by open trench are forbidden. In the Prefecture de l'Isere, open cut is forbidden if there are more than 2000 vehicles per day on the route.

Paris has a policy of coordinating utility works to minimize disruption. The municipality holds quarterly meetings with the utilities.

Toulouse has investigated the impacts of utility cuts on their roads and considers that road life is reduced from 30 years to 10 years when a road is subject to a number of trenched installations. They now levy a road reinstatement charge based on the trench width plus a strip 500 mm each side. Typically a charge for a 12-inch trench will be $75 per foot.

Germany

As a Federal Republic, considerable autonomy is delegated to the 16 Lander, who can create their own regulations in areas like environmental protection and highway operations. Concern about protecting the environment and not disturbing the community appears to be much higher than in many other countries. Many Lander have environmental regulations for trees and vegetation which limit open-cut working and encourage alternative trenchless solutions. . For example, it is forbidden in some Lander to carry out open cut trenching work below the canopy of a tree. Hamburg and other regions have restrictions on the lowering of the ground water table to limit ecological damage. In practice, this eliminates the use of deep trenching with de-watering.

Crossings of even moderately trafficked roads are installed by trenchless techniques.

Germany leads Europe in the use of trenchless methods. It has led the world in the development of sewer installation using microtunneling and pipejacking. Germany has a number of leading manufacturers of equipment and many experienced contractors.

Berlin has pioneered solutions to utility installation that do not create environmental damage or disruption to the community. The authorities have planned and designed constructions, like sewer installations, that exploit the advantages of microtunneling in minimizing impacts on the community. An example is the "Berlin Method" of installing sewer laterals radially from a manhole position, rather than directly onto the sewer. The authorities have found that not only does this reduce disruption but also provides easy access for maintenance and repairs, thereby eliminating future excavations.

Hamburg authorities have long been at the forefront in developing pressure-balance jacking methods to match the granular soils and high water tables.

There seems to be real concern by clients about the total costs of work including those to the community.

Japan

By dint of its congested cities and historical lack of sewer systems in most towns, Japan has turned to trenchless methods of installation. More than 700 miles of sewers are installed annually by microtunnelling and jacking methods. This is perhaps 20 times more than the length installed in USA.

A prime reason for this extensive use of trenchless methods is the Road Act, which is dealt with by street authorities, and the Road Traffic Act that is the responsibility of the police. These statutes clearly establish that roads are for the transportation of people and vehicles; to use them for other purposes is restricted, and sometimes prohibited. Construction in roads must comply with these Acts.

An annual charge is made to utilities that install their equipment in or on the road. Tokyo Gas pays something like $20 million a year for the right to have the gas network below the roads.

Empowered by the Road Traffic Act, the police also give permission with conditions. Detailed proposals have to be submitted well in advance with measures to mitigate the disruption and nuisance. In addition, detailed proposals for signing, barriers and protection of the public have to be provided.

On heavily trafficked roads, daytime construction is not permitted. Night working is required with the road returned to traffic use for next day. In the suburbs, construction may be permitted in the period between the morning and evening rush hour, but, again, construction has to be arranged to return the road to traffic each day.

It is "accepted wisdom" by clients and utilities that it makes no sense to damage the Japanese economy by using installation methods that create additional costs to the community.

Hong Kong

Hong Kong is one of the most congested regions in the world. The highway authority issues construction permits with severe restrictions on times and methods of working. Night working is frequently required with the road fully open to traffic by next morning. Plating is widely used to achieve this. This adds substantially to open-cut costs.
Pressure balance tunneling and microtunneling are extensively used despite the unfavorable soil conditions. Some large Horizontal Directional Drilling (HDD) crossings have been driven under navigation channels. Extensive sewer rehabilitation programs have been undertaken.

Singapore

The Singapore Government has gone further. It has completely banned trench work in busy streets.

Although a small country, Singapore leads the world in the percentage of utility work undertaken by trenchless methods. Singapore has particularly been a pioneer in the use of microtunneling for sewer installation, often in difficult soil conditions.

Thailand

Bangkok is a good example of effective use of trenchless technology design. When it was necessary to install a comprehensive sewer system throughout the city, the level of congestion and the lack of road space and with difficult soil conditions made traditional trenching totally unacceptable. The designers turned to microtunneling, not only to avoid disruption, but also to work in the very soft deltaic clays and a high water table.

Some hundreds of miles of new sewers ranging in size from 12” to 90” have been and are being installed by microtunnelling and pipejacking.

Comment on International Practice

The common thread running through this section is that the technologies for non-disruptive installation of utilities are readily available and are common to all countries. The wide variations in the use made of these technologies relate to a number of factors, including:

- The specific needs of each country in terms of utility installation or rehabilitation
- Characteristics in terms of population density and age of infrastructure
- Geological characteristics
- Relative prosperity

The Way Forward

My belief is that we cannot expect the utilities to do anything else but operate under prevailing legislation. Their primary concerns are to operate safe and reliable systems for their customers while obtaining a sufficient margin on their operations to provide a return on capital invested to ensure their continuity.

I am well aware that all utilities are striving to reduce costs and operational people are under pressure from management. This can result in them choosing a method of installation, which may be cheapest for the utility but can be very costly for the community.

Therefore the most important factor of all is the attitude of government and authorities towards the rights of the utilities and developing legislation that protects the community from the impacts of utility work in roads. This may add to the costs of the utilities’ operations and, in turn, result in higher utility charges to the customer but this is likely to be more acceptable than the present arrangement.

Various contractual approaches have tried or proposed. Many are flawed and don’t achieve the desired objectives.

I believe the key objectives in any scheme to reduce disruption should be:

- Be effective in reducing the disruption to the community
- Be simple to administer
- Not create unnecessary cost or administrative burdens on utilities
- Cover all works that can create disruption to the community

Lane Rental has been put forward as a possible means of encouraging less disruptive utility installation. Certainly Lane Rental has proved a useful tool on major highway schemes and resulted in early completions. I doubt very much if it is appropriate for utility work in streets for a number of reasons.

1. A great deal of utility works in streets does not significantly impact the community. There are many minor and suburban streets where if work is properly planned and implemented can be carried out using open cut methods with minor impacts.
2. Many works are of relatively small construction value and short duration.
3. Any scheme involving charging for occupation requires a significant administrative effort and cost to monitor, run and collect dues. It is also likely to create disputes between the utility and local administrative authority. This situation needs to be avoided.
4. In most cases the charges go into the pocket of the administration not to the community who suffered. It just becomes another tax.
5. Utilities will pass on the costs to the community through higher bills.

I would offer the following approach as a means of greatly improving the situation and without creating an administrative nightmare.

1. The highway administration should designate those roads and streets, which carry large volumes of traffic or are sensitive for some other reason. At a guess maybe 25% of streets would be designated as "Sensitive".
2. The utilities would be aware of the designated streets. Whenever they propose a scheme that involves working in these streets they would submit in advance to the highway administration an "impact statement". This would set out in detail the construction methods proposed and the alternatives considered, the period and dates of occupation and the predicted social cost. This cost would be calculated by a formula, similar to those models developed by FHA to calculate road delays.
3. The administration would have the power to ask the utility to think again and come back with a better solution where they considered impact was excessive and could be mitigated by alternative methods of working.

This approach has a number of advantages:

- It recognizes that only a small percentage of utility work creates the major disruption problems
- It covers all work in sensitive streets– large and small.
- It requires the utility to properly investigate, engineer and plan their works before submission. It also requires them to consider "Social Costs" and calculate this cost. It is my experience that utilities have responsible managers. If they become aware of a high impact and social cost they will, of there own volition, look for alternatives. Apart from anything else they will recognize the public relationship downside of trying to push through a high "social cost" solution.
- No money has to be charged or collected. The utilities will pay an additional cost in a small percentage of cases by having to adopt a more costly but less disruptive working method.
- As the utilities have to submit in advance to obtain approval this will provide an opportunity for the street authority to coordinate works of the various utilities to minimize impact.
- It encourages co-operation between utilities and the street authority in solving the problem

PART THREE: SURVEYS & SITE INVESTIGATIONS

- ***Overview***

Thorough surveys and site investigations are essential to all civil engineering projects, and especially to below-ground activities where the risk of encountering something unforeseen is at its highest. The various techniques now available should greatly reduce the chances of encountering major surprises in the course of trenchless installation, renewal or repair.

All trenchless systems are designed to cope with a specific range of conditions, and none is universally suitable. Knowledge of what exists below ground therefore influences not only the cost of the project, but also the choice of system to be used. The investigations required clearly vary from project to project, but three main groupings can be identified. For repair and renovation the main need is for accurate information about the size, shape, route and condition of the existing main or service, including data on any fittings or chambers. For new installations the principal requirement is for data on soil and groundwater conditions, and the location of existing mains, services and other obstructions. On-line replacement demands information on the material and dimensions of the line to be replaced, the nature of the pipe surround and the position of the line relative to adjacent pipes and cables.

For rehabilitation projects, one of the longest established investigative tools is closed-circuit television (CCTV) which first appeared in the 1950s and came of age in the eighties when modern electronics produced higher reliability, improved performance and lower cost. Other inspection techniques such as sonar and radar can, in the right circumstances, complement or replace information obtained from conventional CCTV surveys. Sonar is used mainly for underwater surveys (for example, in surcharged pipes), and, in addition to identifying defects, can produce quantitative data on pipe dimensions and silt levels. Systems are available for inspecting a part-full pipe by using a CCTV camera above the water line and a sonar transponder below. There is also potential for in-pipe radar, particularly if external voiding is suspected, since it allows the inspection to penetrate outside the pipe wall.

Partial collapse of a clayware sewer, revealed by CCTV inspection

Concern about leakage from sewers and the pollution of groundwater and aquifers has, in some countries, focused attention on systems which test the integrity of pipe joints. Whilst joint test and seal equipment has been available for some time, interest has increase in systems which test for leaks in the course of a conventional CCTV survey, using equipment integral with or towed behind the camera.

For new installations, information about soil conditions can be obtained by conventional trial-holes and borings.

In developed areas, one of the, most important survey tools is the pipe and cable locator which can detect existing metallic pipes, current-carrying electrical cables and telecommunications cables. Many types are available, most allowing the use of a transmitter to induce a signal in conductive pipes, which can then be traced from the surface with the receiver. Some pipe and cable detectors can also be used as bore-tracking devices in conjunction with directional drilling and guided boring machines. Ground-penetrating radar (GPR) systems have become more user-friendly in recent times, an can often detect non-metallic pipes, cables, zones of leakage and sub-surface discontinuities such as road construction layers or rock strata.

- ***CCTV***

The rehabilitation section of the trenchless technology industry owes its existence largely to the advent of reliable and affordable CCTV inspection systems in the 1970s and 80s. Not only was it thereafter impossible to pretend that underground infrastructure was in good condition simply because defects were out of sight, but also the means of classifying and prioritizing its rehabilitation became available.

One of the first recorded uses of a TV camera to survey a pipeline was in the 1950s, when a very large camera was pushed through a sewer in a wheelbarrow to convince the drainage committee of a London Borough that the brick sewer needed urgent repairs. In 1958 a usable, though cumbersome, CCTV pipeline inspection system was developed in Germany. Early cameras used cathode-ray tubes which were poorly suited to rough handling and aggressive environments, and the equipment tended to be fragile and temperamental. This changed in the 1980s with advances in electronics and the introduction of sol Id-state CCD (charge-coupled device) camera modules. Today's cameras are much smaller, lighter and more reliable than their predecessors, and high resolution color has become a standard feature in al I but the least expensive units.

Today, it is common in some countries for regular inspections of main sewers to be carried out as a matter of routine, so that sewerage authorities can compile comprehensive information on the condition of the underground infrastructure, an formulate a planned maintenance program. CCTV is also used for ad hoc inspections to identify the cause of specific problems. In addition to gravity pipelines, CCTV is finding increasing favor for the live inspection of pressure pipes.

Cameras may have fixed, forward-view heads, or heads which can pan and rotate to look directly at the pipe wall or up lateral connections. Zoom lenses are also available to give a close-up view of the pipe wall in large diameter pipelines.

Crawler-mounted zoom, pan & rotate CCTV camera

The camera may be mounted on skids and pulled through the pipeline by a winch, or, more commonly nowadays, it can be fitted to a self-powered tractor or crawler which is controlled from the operator's console. Tractor mounting allows singleended access to the pipeline, subject to normal safety regulations relating to the venting and gas monitoring of sewers.

Most CCTV equipment manufacturers can supply tractors to suit pipes from 150 mm diameter upwards. Some have elevating gantries to allow quick adjustment of camera height, whilst others are steerable to give directional control in large diameter or flat-bottomed conduits. There are also special tractors for non-circular pipes, with stabilizing wheels or skids which run on the side wall of the pipe.

The tractors are electrically powered, the power supply coming to the camera and tractor from the main control unit through an armored, multi-conductor cable which also carries the video and control signals. Some systems employ multiplexing which allows all tractor and camera control signals to be carried by a smaller number of conductors, thereby allowing the use of a smaller and lighter cable.

One of the main growth markets has been for portable systems, often supplied with a semi-rigid cable to allow the camera to be rodded up the pipe from a single access point. The camera is often fitted with a circular "brush" skid to centralize it within the pipe, although various forms of molded plastic and metal skids are also used. The relatively low cost of some of this equipment has broadened its appeal beyond the established specialist survey companies, and it is increasingly common for local plumbing and drainage contractors to use CCTV systems to detect and ascertain the nature of pipe defects.


Photo courtesy of Peapoint Inc

Modern, compact CCTV system with semi-rigid rod/cable and integral monitor

Many manufacturers of CCTV equipment who initially provided equipment designed mainly for use in sewers and drains have now turned their attention to other utilities such as gas and potable water, producing camera systems and ancillaries designed for live inspections. The compact dimensions of modern cameras allow their use in pipelines down to 50 mm diameter. At the other end of the scale, with adequate lighting CCTV can be used in pipes of over 2000 mm diameter.

Cameras designed for small diameter pipes often have an integral light head fitted around the lens. This consists of a ring of halogen bulbs providing enough illumination for pipes up to about 200 mm diameter, depending on the sensitivity of the camera. Additional lighting can be attached to the camera for larger diameters, the only limitation being the capacity of the power supply and cable. Cameras with pan and rotate heads usually have lights built into the head itself, which point wherever the head is facing, together with more powerful lights aligned along the axis of the pipe.

Specialized systems are available to survey lateral connections from within the main pipe. They comprise a tractor-driven pan-and-rotate camera with a second satellite camera mounted on top. The satellite camera can be pointed towards a lateral and launched up the branch on its own semi-rigid cable which is fed out from the main unit. All functions are controlled remotely from a vehicle-mounted console, and the systems can operate in pipes from 200 to over 1000 mm diameter.

Cameras can also be adapted to the inspection of vertical shafts, wells, boreholes and hollow piles, some having a rotating mirror which allows the wall of the shaft to be examined in detail at any cross-section. The weight of the camera and cable is critical for deep vertical inspections, since the full load has to be lowered and lifted by the winching equipment on the surface. It may also be difficult to prevent the camera from rotating.

CCTV camera with angled mirror for inspecting wells and boreholes

Photo courtesy of Telespec Ltd

Explosion protected (or "explosion proof") devices are designed and constructed so as to prevent any operation or malfunction of the equipment from igniting a flammable or explosive atmosphere. They may be particularly desirable for the inspection of sewers which can contain methane. Perhaps surprisingly at first consideration, the inspection of live gas mains, whilst entailing stringent safety precautions, does not necessarily require explosion-protected equipment. The gas within a pipeline cannot ignite in the absence of oxygen and may be regarded, therefore, as a non-explosive environment.

Unfortunately, the standards governing what is deemed to be "explosion protected" or "explosion proof" vary from one country to another, so a product that meets, for example, European requirements will not necessarily comply with those in the United States, and vice versa.

Proponents of explosion-protected equipment maintain that it represents a sensible safety precaution, whilst others claim that normal gas monitoring and sewer venting measures are adequate. The disincentives towards explosion protected equipment are its additional cost, greater size and more demanding maintenance requirements, and it remains to)e seen whether these are outweighed by customer demand for the highest levels of safety. If explosion protection becomes a general requirement for all equipment used in sewers, this will have implications not only for the CCTV industry but also for other systems such as in-pipe cutters and robotic repair techniques.

1) *CCTV Data Recording and Interrogation*

Another area which has seen major improvements over the years is the design of control and recording equipment, an indeed of the vehicles into which mainline equipment is normally fitted. In addition to recording the survey on video tape, it is possible to obtain a hard copy of a screen image using an on-line video printer, and to input survey information directly into a computerized database. All but the simplest systems include on-screen distance readings, together with other information which can be input from a keyboard.

Integrated keyboard and camera control console

Although the tapes recorded during a CCTV inspection may be viewed again if rehabilitation is proposed, the majority is never subsequently replayed. The information from them is used only to generate coded data on pipe features and defects for entry into the database which can be examined at a later stage by interrogation software. Many different database and software formats have been devised over the years, some allowing embedded graphics (e.g. video frame capture of major features and defects) and the facility to link into geographical information systems (GIS).

2) *Sonar*

Sonar survey techniques use reflected high frequency sound waves to locate and map discontinuities such as the wall of a pipe, in much the same way as nautical sonar systems locate undersea objects. Although operation in air is theoretically possible, sonar systems are almost always designed to work underwater. The sonar transponder is pulled through the pipe on skids or floats, and sends back an image of the pipe cross-section at predetermined intervals depending on the rate of forward movement and the rotational speed of the transponder.

The image is not a photographic picture of the kind obtained by a CCTV camera, but rather a diagram showing the shape of the pipe at each cross-section. The signal received by the device is influenced by the reflectivity of the surface off which the transmitted sound rebounds, and the image can show different levels of reflectivity. For example, soft silt in the invert of a pipe may be displayed in a different color to the hard pipe surface below it. Sonar does not, however, penetrate hard surfaces, so no information can be obtained about the thickness of the pipe wall or the nature of the surrounding ground.

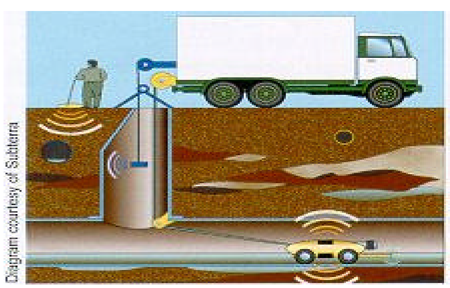
The other distinction from CCTV surveys is that sonar equipment can be calibrated to produce quantitative data on the pipe's dimensions. In other words, a sonar survey can indicate with reasonable accuracy the size and shape of the pipe at each cross-section, and the extent of any deformation. Fractures and other defects can also be revealed, although small cracks may not show up.

Sonar equipment is used to survey pipes which run full or part full, and where emptying the pipe or diverting the flow would be impracticable. It can also operate within part-full pipes In conjunction with a CCTV camera, so that the camera views the pipe above the water level while the sonar equipment simultaneously surveys below the water. A common problem with CCTV surveys is that the invert of the pipe is often underwater or obscured by silt, so its condition cannot be established by visual inspection. The combination of CCTV and sonar offers a possible solution.

3) *Ground Penetrating Radar*

In addition to its normal use for locating objects in air, radar can also detect discontinuities below ground. The extent of ground penetration is limited by attenuation of the signal: it increases at longer wavelengths, but resolution is higher at shorter wavelengths, so the choice of the best frequency is usually a compromise between the two. Ground penetrating radar (GPR) works best in dry, granular soils, and may not be able to see far through waterlogged ground or dense clays. It can reveal changes in soil strata, highway construction layers, buried pipes and cables, voids, leakage and hard inclusions.

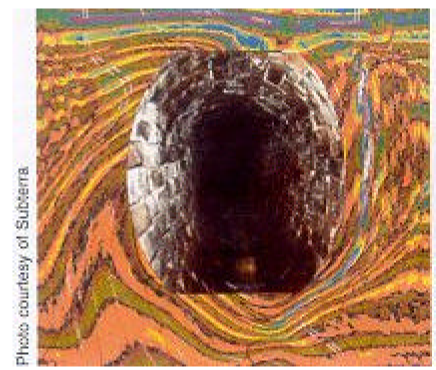
The equipment is normally packaged in the form of a box or sledge which is pulled slowly over the surface of the ground, rather like a lawn-mower without wheels. There is usually an integral liquid crystal display (LCD), together with some method of storing data for downloading to a computer. Systems have also been built to operate within a pipe, with the aim of finding voids in the surrounding ground or zones of leakage.



Ground-penetrating radar may be used from the surface, or from within a chamber or pipe

The major difficulty with GPR has always been the interpretation of the output, although in recent years some manufacturers have made considerable progress in demystifying it. To the uninitiated, the raw graphical output from a GPR survey often appears complex and unfathomable. Even an expert may rely on a high degree of deduction based on experience, rather than conclusive evidence.

The output can be "cleaned up" by filtering the data and optimizing sensitivity levels, and computer enhancement may then be applied to produce a graphical display which is much less daunting than the original. Some systems now claim to be user-friendly, even with more inexperienced operators. However, whilst GPR may indicate that a discontinuity exists below ground, there is often uncertainty about what the discontinuity actually is, and about its depth, due to variations in the radar velocity.



GPR output around an existing sewer, with a photograph of the sewer superimposed

When trying to locate something which is believed to exist but whose plan position is unknown, GPR can be of considerable assistance in the right ground conditions. Further progress on

GPR technology is likely in the future, and the technique will almost certainly become more widely used.

4) *Utility Detection Equipment*

Pipe and cable locators will be familiar to most people in the civil engineering industry, and are regarded as standard equipment for site investigations prior to trenching or underground construction projects. Their use has become even more essential with the advent of specialized, modern underground utilities such as fibre-optic cables, where the consequence of disruption can be severe and the cost of repairs extremely high.

Most cable locators work by detecting the electromagnetic signals generated around live cables, and can operate at various frequencies to suit electricity an telecommunications lines. Metallic pipe locators can be used as simple metal detectors, or more commonly in conjunction with a transmitter which induces in the pipe a signal that can be picked up by the receiver. Systems are available which can trace the path of cast iron and other metallic pipes at depths of up to 10 meters.

Receiver and transmitter for uti detection and tra

The location of non-metallic pipes is more difficult, and usually entails rodding or pulling a small transmitter through the pipeline, and following the signal with the receiver on the surface. Live gas or water pipes can be traced using a length of semi-rigid nylon-coated wire with a nose cone on the leading end and a connector block on the tail. A length of tracer wire is pushed directly into the pipe, through a glanding system or a service tee. A standard transmitter is attached to the connector block on the tail en of the wire, and a utility locator is then used to trace the line.

5) *Leak Detection*

Leak detection in pressure pipes, particularly water mains, has achieve prominence in some countries during the last few years, as water resources have become scarcer and there has been increased public and political pressure for wastage to be reduced.

Many, but not all, leakage detection systems for pressure pipes use a process known as "leak noise correlation". This involves identifying the sound of water escaping from a pipe by means of hydrophones in contact with the pipe at two locations a distance apart. Sophisticated computer software is then used to compare the data and pinpoint the location of the sound.

There are also modern equivalents of the traditional "listening sticks", using ground microphones which assist an experienced operator to locate the source of water leakage. Ground penetrating radar (GPR) may also be use to detect areas of leakage, operating either from the surface or from within a pipe.

6) *Summary*

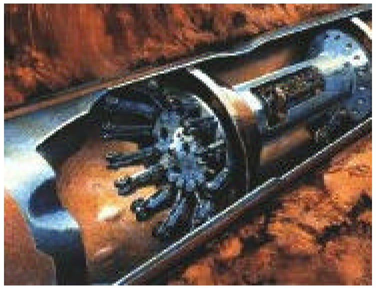
Thorough surveys and site investigations are essential to the success and efficiency of trenchless installation and repair techniques. The survey results also help to determine the most appropriate system. Any conventional site investigation method can be used in conjunction with trenchless technology.

- CCTV is the most common technique for inspecting gravity pipelines, and its use in pressure pipes is increasing. Many types of CCTV system are available for pipes of all sizes and shapes, including compact systems that are easily transportable
- The input of CCTV survey data into computerized interrogation and analysis systems facilitates planned maintenance and asset management procedures
- Sonar can be used either on its own or in conjunction with CCTV to obtain a profile of a pipe below the water level it can also provide quantitative information on pipe dimensions and silt levels
- Ground penetrating radar (GPR) can detect buried objects, discontinuities and leakage, depending on the nature of the ground. The output from some systems requires expert interpretation
- Utility detection equipment is in common use to plan an installation route and avoid expensive damage. Some locators can also be used for tracking guided bores
- Leak detection techniques are available for both gravity and pressure pipes, and can obviate the need for expensive excavations and reinstatements to trace the source of a problem

7) *Pipe Pigging*

The Need

Smart Pigs are inspection vehicles that move inside a pipeline pushed along by the flowing material. They have been in commercial use since 1965, primarily for the detection of wall thinning caused by ordinary corrosion. Until recently other types of defects - cracks, coating disbondment, dents and gouges were not detectable with pigs (Willke; 1998). The industry is demanding smart pigs that could pass along multidiameter pipelines and bends, that could detect the precise location of any problem, and that does not interfere with or need the flowing material to still be operational.



CalScan Smart Pig - Pipetronix Inc.

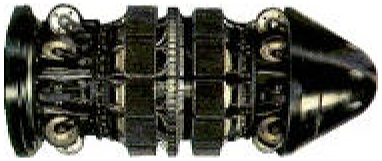
The Technology

Smart Pigs use different technologies to locate problems along the pipelines. Magnets have been used to detect corrosion where the most common technology is the Magnetic Flux Leakage (MFL) that detects corrosion on thinning walls. Another detection technology uses ultrasonic sensors to detect coating disbondment, cracks, dents and gouges. The Global

Positioning System (GPS) technology is being adapted to smart pigs to obtain the exact location of any problem in the pipe or to map the pipe itself. Some of these new Smart Pigs have a collapsing characteristic that allows them to get into multidiameter pipes and gate valves (Willke; 1998).

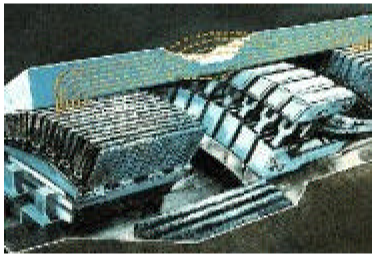
CalScan: Detecting dents - Pipetronix Inc.

The CalScan pig that can locate and measure geometric deviations. It works during the running operation of the pipelines, producing only an insignificant throughput loss. The CalScan pig can detect deformations from 0.6% up to 25%.



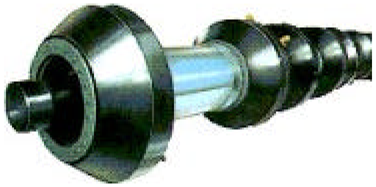
MagneScanHR Smart Pig - Pipetronix Inc.

For detecting pipeline corrosion Pipetronix designed the MagneScan HR system, which is based on the principle of magnetic flux leakage. This Smart Pig can differentiate between internal and external corrosion and detect changes in nominal wall thickness. A magnetic field is induced in the pipeline steel. If a flaw is present, part of this magnetic field escapes the wall. Extremely sensitive sensors detect and measure the resultant leakage field and allow the detection and sizing of metal loss and corrosion.



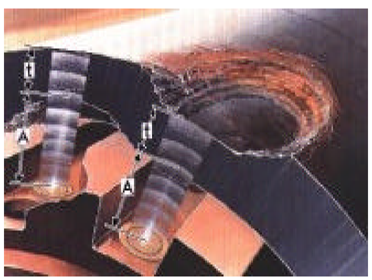
MagneScanHR: MFL technology - Pipetronix Inc.

An alternative to the MFL technology is the UltraScan Pig, which also monitors pipelines for corrosion. It uses ultrasonics to determine the pipe wall thickness. The UltraScan pig analyses the whole surface and length of the pipeline for traces of corrosion. This technique can be applied while normal operation of the pipeline is maintained without any significant reduction in pipeline flow. The UltraScan system allow the determination of the extent, location, depth, and internal/external position of the corrosion.



UltraScan Smart Pig - Pipetronix Inc.

Pipeline Integrity International Ltd. has developed special crawler pigs capable of propelling themselves through a pipeline when the product itself is unable to force the device through the line, or when there is no flowing material (Puyear; 1998).
Nowsco Well Service Ltd. offers the Geopig tool which measures pipewall deformations using differential GPS surveying equipment. This provides pipeline anomaly location (dents, buckles, wrinkles, and bending strain) within an accuracy of 1:2000 from any known reference point. It also allows the assessment of the dynamics associated with slope instability, subsidence, overburden, frost heave, river crossings, free spanning, overburden, and temperature and pressure changes. Comparison of repeat Geopig survey data will determine pipeline movements as small as one inch and differential bend curvature strain to +/- 0.02%. (P&GJ; 1997 and Nowsco web site)



UltraScan: Ultrasonic technology

The Benefits

High resolution intelligent pigs (smart pigs) can accurately detect, size, and locate corrosion or any other anomalies in pipelines. Once the problem is detected the information can be used to develop a pipeline de-rating schedule, implement a repair or replacement program, determine if re-inspection is necessary, and evaluate effectiveness of a corrosion inhibitor program. (Jones, Dawson, and Brown; 1995)
Transcontinental Gas Pipe Line Corporation (Transco) used a collapsible pig and realized an estimated savings of about $2 million by avoiding the cost of replacing valves in a pipeline section. "Transco believes a conservative estimate of its own savings over the next 10 years from use of this device could be $50 million." (GRI; 1997)

Status

"The Gas Research Institute (GRI), PRC International, the Canadian Energy Pipeline Association and British Gas are sponsoring the improvement of a collapsiple pig called "Elastic Wave Vehicle", for a 24-inch diameter pipe that could be resized for pipe diameters of 20 to 30 inches. Currently, the device exists only in sizes for 30 to 36 inches.
T.D. Williamson Inc. and C.W.Pope & Associates are developing smart pigs using electromagnetic acoustic transducers to detect stress corrosion cracking along pipes. This technology uses ultrasonics to detect cracks but employs a different method for generating energy into the pipe wall and interpreting information.

The U.S. Department of Transportation is working with the GRI and Tuboscope Vetco Pipeline Services to design an in-line inspection device to detect and quantify mechanical damage to pipelines." (GRI; 1997)

PART FOUR: HDPE and Water Systems

The U.S. Environmental Protection Agency has estimated that more than $138 billion needs to be spent on America's water infrastructure through 2014, just to make it comply with current regulations. More than half this amount, the EPA study says, is needed for new transmission and distribution systems. The report is based on figures accumulated in the mid-'90s, so the amount of money needed to achieve the same goal today is even higher.

Since the 1950s, most water distribution systems have been constructed with ductile iron and PVC (polyvinyl chloride) pipe.

Polyethylene pipe, widely used for a many varied applications, is not routinely used as potable water pipe. But proponents of high-density polyethylene pipe (HDPE) say this versatile product has many features that make it superior to ductile iron and PVC for rebuilding and the expansion of our water infrastructure, and the American Water Works Association (AWWA) has adopted standards that apply to polyethylene pipe for potable water.

"HDPE pipe is strong, extremely tough, and very durable," says Dave Allison, P.E., applications engineering manager at the Plastics Pipe Institute (PPI). "And HDPE is proven to be reliable and cost effective for a wide range of industrial, mining, and agricultural applications."

Natural gas utilities use HDPE pipe for both distribution and service lines; the ducts protecting much of the world's fiber optic telecommunications networks are made of HDPE.

Many of the characteristics that have made HDPE popular for these applications also make it suitable for water systems, says Allison.

"Polyethylene does not rust, rot, or corrode," Allison says. "Leak-tight, heat-fused joints create a homogeneous, monolithic system. Fusion joints are stronger than the pipe. HDPE maintains optimum flow rates, is not subject to tuberculation and has a high resistance to scale and biological build up. It is designed to withstand surges, and its high strain allowance virtually eliminates breakage due to freezing."

Polyethylene water pipe can be installed by a variety of methods which, depending on the project, may result in lower installation costs. HDPE pipe can be fused on the surface and placed in open trench, or it can be installed by any of several trenchless construction methods, including pipe bursting, sliplining, and horizontal directional drilling. Coiled lengths of smaller diameter HDPE also can be buried with vibratory or static plows.

"HDPE is better for water distribution piping than either PVC or ductile iron," says Mike Hawkins, sales manager for Central Plastics, the large Shawnee, OK manufacturer of fittings.

HDPE, says Hawkins, eliminates many of the problems inherent in ductile iron PVC systems.

Joints are the weak links in ductile iron and PVC water systems, Hawkins continues. During installation, ductile iron and PVC pipe sections pipe must be joined together, and each joint is a future problem area. Improperly installed, they can leak immediately. Or they can fail later. Such trouble spots allow treated water to leak out and be wasted, and also they permit infiltration of contaminants.

A run of HDPE pipe is fused into a single piece, requiring joints and gaskets only at transition points. A fused HDPE system significantly reduces the number of joints, reducing the potential for water loss and infiltration.

With all of these pluses, why hasn't polyethylene taken over the water market?
There are several answers:

- Ductile iron and PVC are firmly established as industry standards
- Water utility managers and engineers who design water systems are not aware of HDPE's benefits
- Fittings to connect HDPE to ductile iron and PVC have not been widely available
- Reluctance to change

Even though polyethylene pipe has gained AWWA acceptance, U.S. water utilities and the engineers who design water systems have been slow to consider it as an alternative to the products they know and have used for years. Why risk trying something that, to the potable water industry, is new?

"Resistance to change is typical with any new product or technology," observes Richard Kloxin, senior vice president for Kinsel Industries in Houston, a firm that has installed HDPE water pipe on a limited number of projects. "Internationally, HDPE has been used for water mains for years. It is a matter of education."

Some believe that suppliers have not effectively promoted HDPE pipe to water facility owners and engineers.

"HDPE manufacturers have taken a 'commodities' approach to marketing their products," comments another water and sewer contractor. "Their attitude has been: 'We make it, and we'll sell it to you. How you use it is up to you.' There has been little effort to educate a potentially huge market about the advantages of HDPE or to make HDPE user friendly to water people."

For example, pressure ratings for PVC and HDPE are not calculated the same way, making comparisons difficult, but the industry as a whole, the contractor says, has done little to help those who might consider using HDPE make meaningful comparisons between HDPE and PVC.

Most water line construction involves extensions to existing mains or replacing segments which are a part of established water systems, and many engineers do not consider HDPE, because they are reluctant to introduce a new type of pipe into a system.

Until recently, connecting HDPE to PVC or ductile iron could be a problem; there had not been a full selection of fittings to make transitions between HDPE and PVC or ductile iron.

"Development of a full compliment of transition fittings and service branches has been our company's focus," says Central Sales' Hawkins. "Today it isn't difficult to make the transition from HDPE to PVC or ductile iron, to extend or branch off a HDPE service main, to tap HDPE for service lines, and to restrain HDPE when it is necessary."

Hawkins says his company is actively promoting the benefits of HDPE water systems by providing speakers for educational sessions at trade shows, training distributors, and making individual presentations to engineers.

Proponents of HDPE for potable water systems believe a change is coming.

PPI's Allison says that HDPE pipe can save time and money through reduced installation costs and lower costs over the life of the system.

"A HDPE water system is ultimately the least expensive," says Hawkins. "And with the volume of work to be done, HDPE simply has to be a serious consideration for future water systems."

HDPE's suitability for several trenchless procedures should increase its appeal for future projects.

1) *The Facts on Polyethylene Vs Other Pipe Materials*

♦ **Corrosion -** Corrosion has been identified by some authorities as the greatest single cause of infrastructure deterioration. Estimates of the annual cost of corrosion of all things metal have been estimated to run into the billions of dollars.

Corrosion is an electrolytic process which requires the presence of electrically conductive materials, which for piping materials would be primarily iron, steel and copper. Metal pipe manufacturers strive to prevent corrosion by either coating their base materials with electrically insulating materials, or providing some sacrificial material which will corrode before the base metal. Insulating or dielectric materials used include coal tar derivatives, various epoxy coatings and most recently polymer coatings. Coatings have the disadvantages of being easily damaged during handling and possible discontinuities in the coating as a result of poor factory coating procedure. Any exposure of the base metal will allow electrolytic action to commence. In the sacrificial arena, coatings are typically zinc or in the case of corrugated steel, aluminum is used as well as zinc. While on the subject of sacrificial materials, another method of used to reduce corrosion in metal pipes is cathodic protection which relies on sacrificial anodes, usually of zinc or magnesium. Cathodic protection requires that the metal pipe be electrically continuous, which is no problem for welded steel pipe or soldered copper pipe, but becomes problematic with iron pipe. Iron pipe is installed in electrically discrete lengths insulated from each other by the elastomeric gasket used to seal the couplings. In order to use cathodic protection with iron pipe, the pipe sections must be electrically bonded at the time of installation.

Polyethylene is a dielectric material, so good in fact that it is used frequently as an insulating material for electrical conductors. Because it is a non-conductor, polyethylene is simply not subject to corrosion.

♦ **Chemical Resistance -** Polyethylene piping resists the effects of the chemicals encountered in water and sewer applications. Polyethylene's chemical inertness also means that it contributes no nutrients to further the growth of bacteria on pipe walls. Potable water is frequently produced with pH values either above or below the neutral value of 7. These ranges of pH have no effect on polyethylene, while other materials may be dramatically affected. Concrete and metals are extremely sensitive to water pH in the acid range, i.e. lower than seven. Many municipal water systems control the pH to maintain it slightly basic, just to reduce corrosion within metal pipe. The environment existing within sewers frequently leads to the presence of hydrogen sulfide gas, which combines with the water present in the humid atmosphere to produce sulfuric acid. Acids directly attack concrete and can quickly etch away the interior surface of a pipe, exposing the reinforcing cage.

Since the reinforcing is an essential component of the structure of the concrete pipe, once it's exposed the pipe quickly becomes unserviceable. Concrete is also subject to deterioration from high concentrations of sulfates, which often occur in ground water. In the ground water situation, the deterioration occurs from the outside in.

♦ **Abrasion Resistance -** Polyethylene's unique molecular structure gives it outstanding abrasion resistance. The very long molecule of polyethylene reacts in a manner analogous to a trampoline when abrasive particles impinge on it. The particles simply bounce off, whereas with the more rigid, short molecules of either steel or concrete the abrasive particles knock loose molecules of the pipe material. In many applications, polyethylene pipe outlasts steel pipe by a factor of three or more when transporting abrasive slurries or water with a significant sediment load. Polyethylene pipe has become the pipe of choice in many slurry transport applications. It is especially useful in temporary hydraulic dredging discharge lines. Not only does it resist the abrasion from suspended particles, it is fused into a strong leak tight, low head loss system that can be easily cut up into transportable lengths when the job is finished.

♦ **Flexibility -** Polyethylene is the only commonly used pipe material that is truly flexible. Most of the polyethylene pipe manufacturers give a "rule of thumb" that their products can be curved to a radius approximately 25 times the diameter of the pipe. As an example, 12-inch (one foot) diameter polyethylene pipe can be flexed to accommodate a curve with a radius of 25 feet. This can be a real advantage when installing water pipe, especially in residential subdivisions. Several water companies have reported savings by simply curving polyethylene pipe to serve short radius cul-de-sac's. While other pipe materials can accommodate some deflection at each gasketed joint, they are limited by the fact that the pipe is rigid between joints. Those materials accommodate long radius curves with a series of tangents, whereas polyethylene follows the curve. For smaller radius curves, the rigid pipe materials require fittings to make the required angular changes.

The flexibility of polyethylene pipe makes it the pipe of choice for installation in areas subject to seismic activity. The performance of polyethylene gas pipe in several of the more note worthy earthquakes such as Loma Prieta, October 17, 1989, San Francisco, CA area; North Ridge, January 17, 1994, Los Angeles, CA area; and South Hyogo, Kobe/Osaka area of Japan, was reportedly better than other pipe materials. One report from Kobe, Japan noted that metal pipe was particularly prone to failure at threaded connections. From that it is surmised that steel pipe, welded together, performed reasonably well, however because it lacks the flexibility of polyethylene, there were fewer failures in polyethylene. In the United States similar quake performance was observed for polyethylene gas pipe. It should be noted that polyethylene pipe used in water service has the same characteristic flexibility and is thus better able to resist the effects of ground movement and liquefaction. Authorities in the field of seismic protection of critical underground utilities consider polyethylene pipe to be the ideal material.

The flexibility of polyethylene pipe allows the smaller sizes, six inch diameter and smaller, to be coiled or placed on reels. Because the extrusion process by which polyethylene pipe is manufactured is a continuous process, there is theoretically no limit to the length of a single pipe. Coiling allows shipment of long continuous lengths, which greatly reduces the need for field joining with the associated risk of introducing a potential source of leakage. In the conduit field, it is not unusual to find reels holding a mile of conduit. This greatly increases the speed of installation as well as eliminating many potentially troublesome connections.

♦ **Smooth Surface -** Polyethylene pipe is manufactured by extrusion which produces a very smooth surface. This smooth surface on the interior gives polyethylene pipe its exceptional hydraulic characteristics. The smooth surface prevents any sort of biological or chemical constituent of the fluid being carried from adhering to the pipe surface, hence polyethylene pipe maintains its excellent flow characteristics through out its long life. Other types of pipe materials are subject to deterioration of their inner surfaces once put into service. While hydraulically, they may begin service with interior walls nearly as smooth as polyethylene, both corrosion and tuberculation cause degradation of their flow capacity. Polyethylene water pipe has a Hazen Williams "C" value of 155. New ductile iron pipe with a centrifugal cast mortar lining has nearly that value. With the passage of time, the polyethylene "C" values remain essentially unchanged, whereas the ductile iron pipe "C" value drops. It is not unusual to find old iron pipes with "C" values below 100. The constant "C" value for polyethylene means that flows remain the same with the same pumping effort over the life of the system. In other words, with reduced head losses, energy costs for pumping are reduced over the life of the system.

♦ **Heat Fusion Joining -** Polyethylene pipe is normally joined by heat fusion which produces strong, totally sealed connections. When using this process to join two lengths of pipe, the ends are "faced" to remove any contaminants and to bring the ends into perpendicularity with the axis of the pipe. The ends are then heated to a temperature adequate to melt the polyethylene and pressed together until cool. The procedure is very straightforward and is enhanced by machines which clamp the pipe, face it, heat the two ends, and force them together. A properly made fusion joint has the same or greater strength than the pipe itself and is liquid tight. Fusion fittings are manufactured for use with polyethylene pipe in a wide variety of sizes and types.. A variation on the fusion process, called "electrofusion" uses fittings and couplings that have a heating element built into them. To fuse these into a pipe system, the pipe-bonding surface is cleaned, and then the electrofusion fitting or coupling is secured in place. A "control box" is then connected to the fitting and the proper electric current is sent through the fitting to cause melting and subsequent fusion of the polyethylene of the pipe and fitting. These devices also produce full strength, leak tight joints. It is the ability to produce leak fee joints and connections with a simple, straightforward process that has helped insure wide acceptance of polyethylene pipe by the gas industry.

The same leak free concept has the potential for greatly reducing waste in the water industry. There are many water systems in the United States that are losing over 30% of the water treated and pumped into the distribution system. The leakage is occurring through the gaskets in "bell and spigot" joints and through leaks in deteriorated pipe. Not all leaks in water systems are the dramatic ruptures occasionally reported in the media, where streets are cratered and cars cast asunder. Many of the leaks are insidious, as in the case of leaking gaskets. Every gasketed joint leaks, although when the gasket is brand new the leakage may be very small, that leakage will increase as the years pass. Leakage at gaskets is also a serious health issue. In the event the water system piping pressure becomes negative due to fire pumping or some other cause, contaminants may be drawn into the pipe at each gasket. Gaskets are designed to increase their seal as the internal pipe pressure increases. In most cases the converse is also true, i.e., the ability to seal decreases as the pressure decreases and essentially ceases to exist as the pressure drops to zero. If the pressure should then become negative, most gaskets will not prevent the entry of contaminants.

Yet another advantage of the fusion joining procedure is the elimination of the need for restraining devices on joints and fittings. As mentioned above, the fusion process produces joints that are as strong as the pipe itself. With other piping materials that use bell and spigot joining, the joints are designed to push together rather easily during installation. While they will not pull apart as easily as they slide together, they are incapable of resisting tensile forces of anywhere near those required to fail the pipe. Hence, in order to prevent separation of bell and spigot joints in those locations subject to tensile forces, restraining devices are used. These are simply another costly hardware item, subject to corrosion effects, that must be installed to produce a complete system.

Polyethylene pipe's leak tight feature is of great value for wastewater sewers. Not only does it prevent any leakage from the pipe, with resultant ground water contamination, it also completely prevents infiltration. Infiltration is frequently the cause of overloaded wastewater treatment plants. Costly reconstruction or expansion of wastewater treatment plants can often be avoided by simply eliminating infiltration of ground water into the collection system.

♦ **Light Weight -** Polyethylene pipe's relatively lightweight reduces the requirement for heavy duty lifting equipment on the job site. Polyethylene's density is less than one, which means that pipe made from it is lighter than iron, steel or concrete pipe. Polyethylene pipe, when filled with water will actually float, which can ease installation in marine locations.

♦ **Economic Advantages -** Polyethylene pipe delivers a number of economic advantages to the pipe user. The major one is that of reduced maintenance. In addition leakage is eliminated, so water treatment costs are reduced. This is the primary reason the "for profit, privatized" water companies are moving towards polyethylene pipe. In waste water systems, elimination of infiltration reduces treatment costs and may even eliminate the need for expanded treatment facilities.

2) *Polyethylene Pipe for Water Application*

Use of polyethylene (PE) pipe for water mains has been steadily increasing in recent years. The pipe is manufactured by continuous extrusion, so is available in any length that can be conveniently handled. The material is very flexible, so it is ideal for use in hilly terrain, for installation around curves, and in areas with potential seismic activity. The pipe can generally be curved in a radius 25 times the diameter of the pipe. This flexibility allows pipe that is 6" (150 mm) or smaller in diameter to be coiled or placed on reels.

PE pipe is protected against degradation by addition of stabilizers and carbon black (which gives the pipe a black color). It is suggested that the pipe, other than black, not be stored exposed to the sun for over two years.

The industry standard for joining sections of PE pipe is by heat fusion. The principle of heat fusion is to heat the surface of the two cleaned and squared pipe ends to a designated temperature, then fuse them together by application of a sufficient force. The force causes the melted materials to flow and mix. As soon as the joint cools to ambient temperature, it is ready for handling. Tests have shown that these joints are stronger than the pipe wall itself. The most widely used method of joining individual lengths of large-diameter PE pipe is by butt heat fusion. Butt fusions are made in the field by a trained operator using a butt fusion machine that secures, precisely aligns, heats the pipe ends, and applies the necessary force to complete the fusion process.

Abrupt changes in pipeline direction can be made using PE fittings, which are also installed by fusion. Side connections can be made to pipe using a fusion saddle connection. Electrofusion fittings, which have internal heating coils, are also available in common pipe sizes. Electrofusion fittings do not require the use of a fusion machine. Mechanical joint fittings may also be used on the pipe, but the pipe is so slick, that restrained fittings must be used so they will stay in place. When restrained fittings are used, a stainless steel stiffener is placed inside the pipe to strengthen the walls against the restraining setscrews.

Table 1 – Advantages and Disadvantages of PE Pipes

Advantages	Disadvantages
Corrosion, abrasion and chemical resistant	Cannot be easily located with an electronic locator
Exceptionally smooth interior (C value of at least 150)	Cannot be electrically thawed
Easy to handle, ship and install because of light weight	Susceptibility to permeation
Great flexibility available in colors e.g., blue (water) or violet (recycled water)	Susceptible to buckling under a vacuum
Leak free fusion joints	Special equipment and a trained operator is required for making fusion joints

3) *HDPE Case Histories*

Case History 1: ***Pipe bursting project saves time and money***

As part of its sewer rehab project, the city of Baytown, Texas, elected to use 36-inch HDPE pipe to replace 36-inch Reinforced Concrete Pipe (RCP) sewer lines. To burst more than 3,700 feet of pipe in residential areas, the contractor used both static and pneumatic bursting systems. The pipe bursting method was recommended over three other procedures to avoid the major impact of bypass pumping and reduced flow capacity involved.

Case History 2: ***Sliplining polyethylene pipe rescues Colorado highway***

When a section of corrugated metal pipe culvert rusted and washed out, a busy Colorado highway was partially closed down to traffic. The Colorado Department of Transportation acted quickly to line the culvert with polyethylene pipe. Its light weight and durability were perfect for the project’s high elevation and isolated location. The line pipe was inserted from the uphill side of the culvert and pulled into position, then the joints were assembled. Filling the annular void space between the existing Corrugated Metal Pipe (CMP) and the liner pipe with grout was challenging, but successful. The liner and direct bury portions are in place, with flow restored and traffic running normally on the highway above it.

Case History 3: ***HDPE restores city drinking water***

A deteriorating cast iron water main in Henryetta, Oklahoma was leaking 300,000 gallons of water per day and threatening to shut off the city's water supply. Complicating factors included water temperature that changed 30 degrees in short time periods and steep slopes in the location of the leak. Reducing the number of pipe joints along the slope and accommodating the temperature differential, along with elevation problems, convinced city officials to select HDPE pipe. Fourteen-inch Iron Pipe Size (IPS) DR-11 water pipe was installed along the 1,400-foot section of line extending over the steep slope to the flatland below. The HDPE pipe solved the elevation and water temperature problems, and allowed for rapid installation that avoided shutting off the city's main water supply for an extended period of time.

Case History 4: ***Taking safe water to a rural community***

The cost of constructing long lengths of distribution piping deprives many rural residents of safe drinking water. Carlsbad Springs in Ontario, Canada studied a steadyflow water supply technology and chain trencher installations method, discovering they could save 66% over conventional water supply installations. Although high-density polyethylene pipe was not in the standards for watermain materials, an assessment of the material and appropriate jointing methods determined HDPE pipe was flexible, resistant to corrosion and smooth-walled. Carlsbad Springs installed approximately 33.5km (20.8mi.) of HDPE watermain ranging from 75mm to 200mm (3 inch to 8 inch) diameter. Using HDPE and chain trenching excavation, watermain installation costs were as low as $15 per foot for 6-inch diameter pipe.

PART FIVE: SLIPLINING

1) *Introduction*

Perhaps the oldest form of trenchless construction is the practice of inserting a smaller diameter pipe into a larger one, often called sliplining. It is difficult to say how old this technique is but Con Edison in New York used this method to insert miles of high-pressure steel gas mains into old cast iron mains in the early 1950's. In the 1970's Con Edison began a major 10 years project to replace leaking 36 and 42 inches cast iron mains by insertion with coated steel mains. When plastic pipe was accepted by the gas industry in the 1970's, they found that it could easily be inserted and had several advantages over steel pipe. Plastic pipe did not require the use of skids or casing insulators to prevent damage as did coated steel pipe, it slid easily into the host pipe because of a lower coefficient of friction and its flexibility allowed it to traverse some bends and reduced the size of the required insertion pits.

Since the sliplining of coated steel pipe has been successfully used for more than 50 years and plastic pipe for more than 30 years, sliplining remains a low cost option for replacement of old mains whenever the capacity of the old main can be reduced or where the operating pressure of the inserted main can be increased to compensate for the reduced cross-section.

In the case of potable water mains it is possible that the older host mains are so tuberculated that the flow after cleaning and insertion can temporarily be improved rather than reduced. However after many years of service it is probable that the capacity of the new smaller main will deteriorate and may not be adequate.

The choice of whether to slipline with coated steel pipe or plastic is open to serious discussion. In the gas industry for main operating at pressures up to 100 psig, PE is nearly always selected (SDR-11 HDPE has a gas rating of 100 psig and water rating of 160 psig). Because of PE's maintenance free reputation the gas industry is now installing some plastic mains at pressures up to 200 psig. Con Edison sliplined with steel mains in the 1970's because PE was not available in the larger sizes at that time. Today HDPE and fittings are available in larger sizes but may not always be in stock so lead time is a consideration.

2) *Sliplining with PE*

In 1984 NYC successfully sliplined a 36 inch diameter main on Central Park West with 32 inch HDPE SDR-17. The water main sliplined is shown in figure 1. The existing 1,900 feet of water main included three straight sections of 36-inch pipe connected by two short sections of 30-inch. Each long straight section was used as a sleeve for the 32-inch OD polyethylene liner pipe. The short section of 30-inch pipe was replaced by new conventional 30-inch pipe. Table 1 shows the work performed.

Central Park West

Location	**Length (ft)**	**Size (in.)**	**Description**
W 86th Street	125	36	Remove and replace 36-in. valve and 36-in. water main
W 86th St. to W 88th St.	525	32	Slip-line 36-in water main
W 88th St.	30	30	Conventional construction of reduce section
W 88th St. to W 90th St.	425	32	Slip-line 36-in water main
W 90th St.	65	30	Conventional construction of reduce section
W 90th St. to W93rd St.	725	32	Slip-line 36-in water main
W 93rd St.	95	36	Remove and replace 36-in. valve and water main

Figure 1: **Central Park West between W 86th & W 93rd Street**

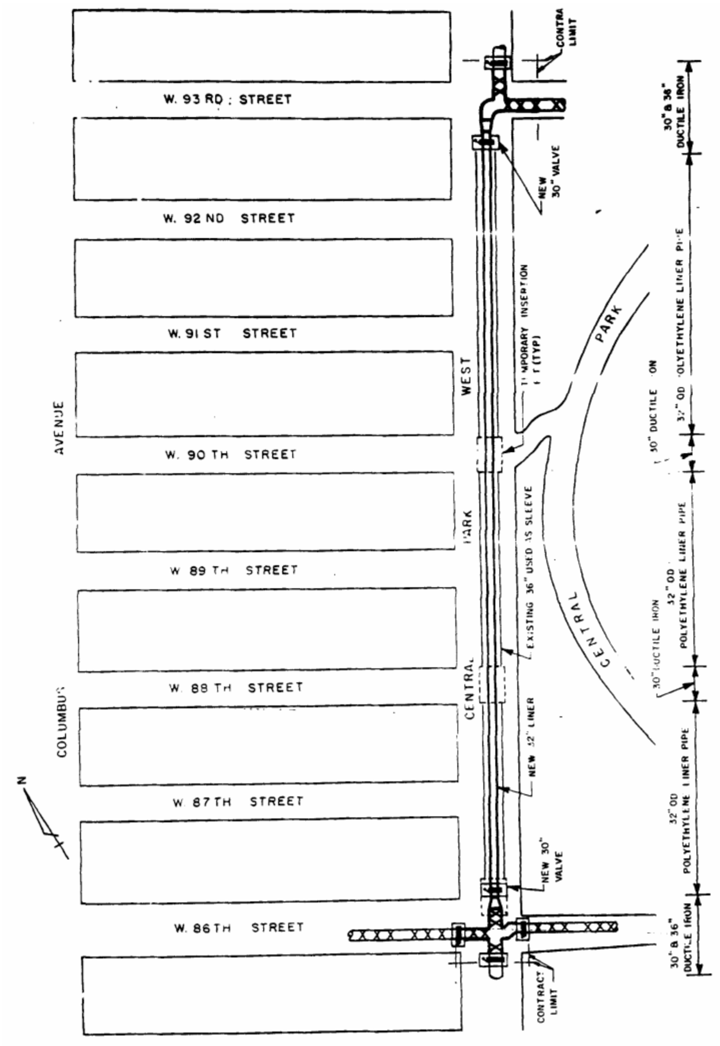


FIG. 4-6 CENTRAL PARK WEST BETWEEN 86TH & 93RD STREET

If PE pipe is sliplined into a larger host pipe, the PE is not supported by the host pipe and must be designed for the full structural loading. This requires SDR-17 pipe for 100 psig rating or SDR-11 for 160 psig rating. These heavy wall pipes and fittings are generally more expensive than coated steel pipe but the installation cost should be considerably less so total installed cost may not be much different. Only contractors familiar with PE pipe installation should be hired and adequate precautions taken to protect the pipe during installation. When sliplining PE the installer has the option to remove the external weld bead. Generally gas utilities do not remove the bead but where the clearance is very small it may be desirable.

3) *Sliplining with Steel Pipe*

Coated Steel pipe has also performed well in NYC for the gas industry. If steel pipe is selected it is important to:

a) Select the best external coating available to prevent corrosion
b) Select the best casing insulators or skids to protect the pipe coating and reduce the friction during insertion
c) Design an appropriate means of cathodically protecting the pipe
d) Decide whether the annular space between the host pipe and carrier pipe should be grouted or left open for future inspection and perhaps maintenance
e) Decide whether the welds are to be x-rayed and design the insertion pits accordingly

In selecting external coatings, verify that the coating performs well at the temperatures expected during installations and while in service. Coatings for field welds must be compatible with factory coatings and tolerant of field installation conditions. The choice of the wrong coating will severely affect the future maintenance of the facility. Consideration should be given to pre-testing program to assure the correct selection is made for both external and internal coating systems.

Casing insulators are subject to wear and impact damage during installations. Con Edison for example tested several different kinds of insulators to assure that they would not fail during installation or after years of service. One problem with casing insulators is their tendency to slide along the pipe, which could cause the coated pipe to drag on the host pipe, leading to coating damage and shorted cathodic protection. It is important that they are securely fastened and prevented from sliding.

Con Edison chose not to grout the annular space between the host and carrier gas pipe. This has allowed the company to periodically inspect the pipe and casing insulators and to make repairs when cathodic protection was found to be inadequate. In some situations it is common practice to grout this space with various types of grout or occasionally petroleum products to exclude the build up of water. If a grout is used it must be compatible with the external pipe coating systems and the environment. Whether the pipe is grouted or not, considerable care should be given to design or purchase suitable casing end seals. They should be rugged and designed to prevent ingress of ground water and soil.

If welds are to be x-rayed, additional pits may be desirable to allow the x-ray of welds while the next weld is being made. This allows the welders to continue without interruption and speeds up the installation.

Sliplining

Advantages	Disadvantages
Uses standard steel or PE pipe	Loss of capacity
Efficient and economical where connections are infrequent	Only for straight pipe-cut out bends and offsets
May be suitable for emergency rehabilitation	Excavate at all connections. Future connections are possible but more expensive

4) ***Technical Reference***

"Pipeline Rehabilitation by Sliplining with Polyethylene Pipe"

Foreword

Pipeline Rehabilitation by Sliplining with Polyethylene Pipe is one of the chapters being prepared for inclusion in the Plastics Pipe Institute's PPI Handbook of Polyethylene Piping, which will be issued as a complete volume in the future. This handbook will cover other uses of polyethylene piping systems including municipal, mining and industrial applications. Other topics to be addressed in the handbook will include engineering principles, design and installation of polyethylene piping systems and relevant codes and standards.

PPI is a division of The Society of the Plastics Industry, Inc. (SPI), and the major US
trade association representing all segments of the plastics industry.

The Municipal and Industrial (M&l) subgroup of PPI are producing the PPI Handbook of
Polyethylene Piping, M&I membership consists of major North American manufacturers
of polyethylene (PE) pipe and the fittings, PE piping materials, machinery, and equipment used for joining and installing PE piping, related test laboratories and professional organizations.

PPI maintains additional subgroups, which address other applications such as gas distribution. PPI and its subgroups provide technical and promotional support for the effective use and continued application of thermoplastics pipe and related products, consistent with the best public interest. PPI membership also include producers of polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polybutylene (PB}, and cross-linked PE (PEX) piping materials.

For a list of other publications available from PPI and/or further information, please contact:

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Introduction

An integral part of the infrastructure in the United States is its vast network of pipeline conduits and culverts. These are among the assets we take for granted, since most are buried and we never see them. We do not see them deteriorate either, but we know that they do. Television inspection of the interiors of these structures often reveals misaligned pipe segments, leaking pipe joints, or other failing pipe integrity,

The effects of continued deterioration of a pipeline could be a quite drastic and costly. A dilapidated gravity sewer system permits substantial infiltration of groundwater which increases the volume of flow and reduces the available hydraulic capacity of the existing line. So the old pipeline often increases treatment and transportation costs for the intended flow stream. Continued infiltration may also erode the soil envelope surrounding the pipe structure and cause eventual subsidence of the soil.

The case for positive-pressure pipelines is somewhat different, but the results are equally unacceptable. In this situation, continued leakage through the existing structure allows exfiltration of the contents of the flow stream that eventually leads to extensive property are valuable enough that their loss through exfiltration becomes another economic factor.

When the harmful results of pipeline deterioration become apparent, we must either find the most economical method that will restore the original function or abandon the function. Excavation and replacement of the deteriorating structure can prove prohibitively expensive and will also disrupt the service for which the original line is intended. An alternate method for restoration is "sliplining" or "insertion renewal" with polyethylene pipe. Over 30 years of filed experience shows that this is a proven cost-effective means that provides a new pipe structure with minimum disruption of service, surface traffic, or property damage that would be caused by extensive excavation.

The sliplining method involves accessing the deteriorated line at strategic points within the system and subsequently inserting polyethylene pipe lengths, joined into a continuous
tube, through the existing pipe structure. This technique has been used to rehabilitate gravity sewers sanitary force mains, water mains, outfall lines, gas mains, highway and drainage culverts, and other piping structures with extremely satisfactory results. It is equally appropriate for rehabilitating a drain culvert 40 feet long under a road or straight sewer line with manhole access as far as Vz mile apart. The technique has been used to restore pipe as small as 1-inch, and there are no apparent maximum pipe diameters.

Design Considerations

The engineering design required a sliplining project consists of five straightforward steps:

1. Select a pipe liner diameter
2. Determine a liner wall thickness
3. Analyze the flow capacity
4. Design necessary accesses such as terminal manholes, headwall service, and transition connections
5. Develop the contract documents

Select a Pipe Liner Diameter

To attain a maximum flow capacity, select the largest feasible diameter for the pipe liner. This is limited by the size and condition of the original pipe through which it will be inserted.

Sufficient clearance will be required during the sliplining process to insure trouble-free insertion, considering the grade and direction, the severity of any offset joints, and the structural integrity of the existing pipe system.

The selection of a polyethylene liner that has an outside diameter 10 less than the inside diameter of the pipe to be rehabilitated will generally serve the purposes. First, this size differential usually provides adequate clearance to accommodate the insertion process. And second, 75 to 100 or more of the original flow capacity .may be maintained. A differential of less than 10 may provide adequate clearance in larger diameter piping structures. It is quite common to select a 5 to 10 differential for piping systems with greater than 24-inch diameters, assuming that the conditions of the existing pipe structure will permit insertion of the liner.

Determine a Liner Wall Thickness

Pressure Pipe

A liner, which will be exposed to a constant internal pressure or to a combination of internal and external stresses, must be analyzed in a more detailed manner. The guidelines for a detailed loading analysis such as this are available from a variety of resources that discuss in detail the design principles concerned with underground installation of flexible piping materials.

In those installations were the liner will be subjected to direct earth loading, the pipe/soil system must be capable of withstanding all anticipated loads. These include earth loading, hydrostatic loading, and superimposed loads. The structural stability of a polyethylene liner under these conditions is determined largely by the quality of the external support. For these situations, refer to any of the above referenced information sources that concern direct burial of thermoplastic pipe. A polyethylene liner that has been selected to resist hydrostatic loading will generally accommodate typical external loading conditions if it is installed properly.

Other Loading Considerations

Filling of the entire annual space is rarely required. If it is properly positioned and sealed off at the termination points, a polyethylene liner will eliminate the sluice path that could contribute to the continued deterioration of most existing pipe structures. With a liner, a gradual accumulation of silt of sediment occurs within the annual space and this acts to eliminate the potential sluice path.

On occasion, deterioration of the original pipe may continue to occur even after the liner has been installed. This unusual situation may be result of excessive groundwater movement combined with a soil quality that precludes sedimentation within the annular space. As a result, uneven or concentrated point loading upon the pipe liner or even subsidence of the soil above the pipe system may occur. This can be avoided by filling the annular space with a cement-sand mixture, a low-density grout material, or fly ash.

Analyze the flow Capacity

The third step in the sliplining process is to assess the impact of sliplining of the hydraulic capacity of the existing pipe system. This is accomplished by using commonly accepted How equations to compare the How capacity of the original line against that of the smaller, newly installed polyethylene liner. Two equations widely used for this calculation are the

Manning Equation (Eq. 1) and the Hazen - Williams Approximation for other than gravity flow systems (Eq. 2).

Manning Equation for Gravity Flow

$$Q = \frac{1.486 * A * R^{.0687} * S^{0.5}}{N} \qquad \text{(Eq. 1)}$$

Where Q = Flow in cu ft/sec
A = Cross sectional area in square feet = 3.1416 * (Di / 2)^2
R = Hydraulic Radius in feet == Di / 4 for full How
S= Slope, ft/ft.
N = Manning Flow Factor for piping material = 0.009 for smooth wall polyethylene
D/ = Inside Diameter in feet

Hazen-Williams Approximation for Other Than Gravity Flow

$$H = \frac{1044 * G^{1.85}}{C_h^{1.85} * D_i^{4.865}} \qquad \text{(Eq. 2)}$$

Where H = Friction loss in ft H20/100 ft

G = Volumetric Flow Rate in gallons / minute == 2.449 * V * Di^2

Where V = Flow velocity in ft/sec

Di = inside diameter in inches

Ch = Hazen-Williams Flow Factor == 150 for polyethylene

The insertion of a smaller pipe within the existing system may appear to reduce the original flow capacity. In the majority of sliplining applications, however, this is not the case, The polyethylene liner is extremely smooth in comparison to most piping material. The improved flow characteristic for clear water is evidenced by a comparatively low Manning Flow Coefficient, N of 0.009, and a Hazen-Williams factor, *Ch*. of 150. While a reduction in pipe diameter does occur as a consequence of sliplining, it is largely compensated by the significant reduction in the Manning Flow Coefficient. As a result, flow capacity is maintained at or near the original flow condition. Manning Flow Coefficients for a variety of piping materials are listed in Table 1. These factors may be used to approximate the relative flow capacities of various piping materials

Table 1

Typical Manning Flow Coefficient for Water Through Common piping materials

Concrete	0.015
Clay Tile	0.012
Asbestos Cement	0.011
PVC	0.009
Polyethylene	0.009

Quite often the hydraulic capacity of a gravity How pipe can actually be improved by an insertion renewal. For example, consider the following illustrations of calculations using the Manning Equation.

Calculation for Flow Rate, Q, through 24-inch ID Concrete Pipe at 1% Slope (1 ft/l00ft)

$$Q = \frac{1.486*3.1414*(1)^2*0.5^{0.667}*(0.1)^{0.5}}{0.015}$$
$$= 19.6\ cu\ \ ft/\sec = 8800\ GPM$$

Calculation of Flow Rate, Q Through 22-inch OD Polyethylene Pipe with a 20.65-Inch
ID at 1% Slope (1ft/l00ft)

$$Q = \frac{1.486*3.1414*(0.8604)^2*0.0429^{0.667}*(0.1)^{0.5}}{0.009}$$
$$= 21.85\ cu\ \ ft/\sec = 9800\ GPM$$

Comparison of the two calculated flow rates shows that sliplining this 24-inch concrete pipe with the smaller polyethylene pipe actually improves the capacity by 1000 gallons per minute. This will often be the situation. Occasionally, however, the theoretical flow capacity of the liner may appear to be equivalent to or slightly less than that of the original system. In many such cases, the presence of the liner eliminates the infiltration associated with the deterioration of the original pipe and the corresponding burden this place on the existing flow capacity. So an apparently small reduction in theoretical flow capacity may, in reality, prove to be quite acceptable since it eliminates the infiltration and the effect this produces on available hydraulic capacity.

Develop the Contract Documents

When the rehabilitation design has been completed, attention will be focused on writing the specifications and contract documents that will ensure a successful installation. Reference documents for this purpose include: ASTM D3350(3), ASTM F585(4), ASTM F714(5), and ASTM F894(6). To assist further in the development of these documents, a model specification is being prepared by the Plastics. Pipe Institute.

The Sliplining Procedure

The standard sliplining procedure is normally a seven-step process. While the actual number of steps may vary to some degree in the field, the procedure remains the same for all practical purposes. The procedures for rehabilitation of gravity and positive pressure pipelines are essentially the same. Some subtle differences become apparent in the manner by which some of the basic steps are implemented.

The seven basic steps are:

1. Inspect the existing pipe
2. Clean and clear the line.
3. Join length of polyethylene pipe.
4. Access the original line.
5. Position the liner.
6. Make service and lateral corrections.
7. Make terminal connections and stabilize annual space.

Inspect the Existing Pipe

The first step for all sliplining projects is the inspection of the existing pipe. This will determine the condition of the line and the feasibility of insertion renewal. During this step, identify the number and the locations of offset pipe segments and other potential obstructions.

Use a remote-controlled closed-circuit television camera to inspect the pipe interior. As the unit is pulled or floated through the original pipe, the pictures can be viewed and recorded with on-site television recording equipment.

Clean and Clear the Line

The existing pipeline needs to be relatively clean to facilitate placement of the polyethylene liner. This second will ensure ease of installation. It may be accomplished by using cleaning buckets, kites or plugs, or by pulling a test section of polyethylene through the existing pipe structure.

Obviously, to attempt a liner insertion through a pipeline obstructed with excess sand, slime, tree roots, or deteriorated piping components would be uneconomical or even impossible. Step 2 is often undertaken in conjunction with the inspection process of Step 1.

Join Length of Polyethylene Pipe

Polyethylene pipe may be joined by either butt fusion technology or by gasketed bell and spigot joining methods. The specific method to be used will be determined by the type of polyethylene pipe being inserted into the existing pipe structure. Solid wall polyethylene pipe is usually joined during butt fusion techniques. Polyethylene profile pipe, on the other hand, is typically joined by integral gasketed bell and spigot joining methods.

Butt Fusion

Individual length of solid wall polyethylene pipe are joined by using butt fusion techniques. The integrity of this joining procedure is such that, when IMS performed properly, the strength of the resulting joint equals or exceeds the structural stability of the pipe itself. This facilititates the placement of a leak-free liner throughout the section of the existing system under rehabilitation.

The external fusion bead, fanned during the butt fusion process, can be removed following the completion of joint quality assurance procedures, by using a special tool prior to insertion into the existing system. The removal of the bead may be necessary in cases of minimal clearance between the liner and the existing pipeline.

Individual pulling are usually determined by naturally occurring changes in grade or direction of the existing pipe system. Severe changes in direction that exceed the maximum bending radius of the polyethylene liner may be used as access points. Likewise, severe offset joints, as revealed during the television survey, are also used commonly as access points. By judicious planning, potential obstructions to the lining procedure may be used to advantage.

There is a frequent question regarding the maximum pulling length for a given system. The answer, quite simply, is that ideally each pull should be as long as economically possible without exceeding the tensile strength of the polyethylene material. It is rare that a pull of this magnitude is ever attempted. As a matter of practicality, pulling lengths are more often restricted by physical considerations at the job site or by equipment limitations.

To ensure a satisfactory installation, however, the designer may want to analyze what is considered the maximum pulling length for a given situation. Maximum pulling length is a function of the tensile strength and weight of the polyethylene liner, the temperature at which the liner will be manipulated, the physical dimensions of the liner, and the frictional drag along the pipe length to be attempted.

Equations 3 and 4 are generally accepted for determination of the maximum feasible pulling length. One of the important factors in these calculations is the tensile strength of the particular polyethylene pipe product, which must be obtained from the manufacturer's
literature.

Maximum Pulling Force, MPF (Ib-force)

$$MPF = \frac{TS}{FS} \times \Pi \times \frac{OD^2 - ID^2}{4} \qquad \text{(Eq. 3)}$$

where:

MPF == Maximum Pulling Force
TS = Tensile strength of polyethylene; 2,800 psi at 73.4°F (23°C)
P-3.1416
OD = Outside diameter in inches
ID = Inside diameter in inches
FS = An acceptable Factor of Safety; usually equal to or greater than 1.50

Maximum Pulling Length, MPL (feet):

$$MPL = \frac{MPF}{W * 0.70} \qquad \text{(Eq. 4)}$$

where:

MPL = Maximum straight pulling length of relatively flat surface
MPF = Maximum pulling force (Eq. 3)
W = Pipe Weight, Ibs/ft
0.70 = Coefficient of friction for polyethylene on smooth sandy soils (static)

Gasketed Bell and Spigot Joining

Polyethylene profile pipe is typically jointed using gasketed bell and spigot techniques The integral bell and spigot method does not require fusion joining. Instead, the pipe segments are joined by pushing or "jacking" the spigot on the leading end of each pipe structure. In this case, the major design consideration is the maximum push length, which
can be calculated by using Eq. 5 and Eq. 6.

Maximum Pushing Force, MPHF (Ib-force)

$$MPL = S \times ID \times \Pi \times PHS \qquad \text{(Eq. 5)}$$

where:

S = Wall thickness of pipe waterway, inches
ID = Inside Diameter, inches
Π =3.1416
PHS = Allowable Pushing Stress, psi (typically 400 psi for profile wall pipe)

Maximum Pushing Length, MPHL (feet)

$$MPHL = \frac{MPHF}{W * CF} \qquad \text{(Eq.6)}$$

where:

MPHF = Maximum Pushing Force (Eq. 5)
W = Weight per foot, lb/ft
CF = Coefficient of friction

A coefficient of friction, CF in Eq. 6, is a measure of the relative difficulty encountered as the liner is pushed through the deteriorated pipe. Typically, pushing is accomplished while a flow is present through the old pipe; for this condition, CF = 0.10 Where there is no flow present, a typical value is CF = 0.30.

Access the Original Line

Excavation of the access pits is the next step in the insertion renewal procedure. Access pits will vary considerably in size and configuration, depending on a number of project related factors such as:

- Depth of the existing pipe
- Diameters of the liner and the existing pipe
- Prevailing soil conditions
- Equipment availability
- Traffic and service requirements
- Job site geography

For example, a fairly large access pit may be required when attempting to slipline a large diameter system that is buried deep in relatively unstable soil. In contrast, the access pit for a smaller diameter pipeline that is buried reasonably shallow (5 to 8 feet) may be only slightly wider than the liner itself. In actual practice, the simpler situation is more prevalent. An experienced contractor will recognize the limiting factors at a particular job site and utilize them to the best economic advantage, thus assuring a cost effective installation.

Position the Liner

Insertion of the polyethylene liner may be accomplished by one of several techniques. Prefused lengths of solid wall polyethylene pipe may be "pulled" or "pushed" into place. Gasket-jointed profile pipe, on the other hand, must be installed by the push method to maintain a watertight seal.

The "Pull" Technique

Prefused lengths of solid wall polyethylene liner may be pulled into place by using a cable and winch arrangement. The cable from the winch is fed through the section of pipe that is to be sliplined. Then the cable is fastened securely to the liner segment, thus permitting the liner to be pulled through the existing pipe and into place.

During the installation the liner is being pulled through the existing pipe from the left side toward a manhole at the right. This procedure requires some means, such as a pulling head. to attach the cable to the leading edge of the liner. The pulling head may be as simple or as sophisticated as the particular project demands or as economics may allow.

The pulling head may be fabricated of steel and fastened to the liner with bolts. They are spaced evenly around the circumference of the profile so that a uniform pulling force is distributed around the pipe wall. This type of fabricated pulling head will usually have a conical shape, aiding the liner as it glides over minor irregularities or through slightly offset joints in the old pipe system. The mechanical pulling head does not normally extend beyond the profile of the polyethylene liner and is usually perforated to accommodate flow as quickly as possible, once the liner is inserted inside the old system.

A less sophisticated but cost-effective approach is to fabricate a pulling head out of a few extra feet of liner that has been fused onto a single pipe pull. Cut evenly spaced wedges into the leading edge of the extra liner footage, making it look like the end of a banana being peeled. Collapse the ends toward the center and fasten them together with bolts or all-thread rods. Then attach the cable to secondary bolts that extend across the collapsed cross section.

As the polyethylene liner is pulled into the pipeline, a slight elongation of the liner may occur. A 24-hour relaxation period will allow the liner to return to its original dimensions. After the relaxation period, the field fabricated pulling head may be cut off.

The pull technique permits a smooth and relatively quick placement of the liner within an old pipe system. However, this method may not be entirely satisfactory when attempting to install a large-diameter heavy-walled polyethylene pipe. This is especially true when the load requires an unusually large downstream winch. A similar problem may exist as longer and larger pulls are attempted so that a heavier pulling cable is required. When the pull technique is not practical, consider the advantages that may be offered by the push technique.

The "Push" Technique

The push method of insertion renewal has become increasingly popular as larger and longer pipeline rehabilitations are attempted. This procedure circumvents the equipment limitations often encountered when trying to pull a large diameter polyethylene liner into place. When used for gasketed pipe, the push method allows insertion without disruption of flow.

This procedure uses a choker strap | placed around the liner at a workable distance from the access point. A track-hoe, back-hoe, or other piece of mechanical equipment pulls the choker to push the liner through the existing pipe. With each stroke of the back-hoe, the choker grips the pipe and pushes the leading edge of the liner further into the deteriorated pipe. At the end of each stroke, the choker must be moved back on the liner, usually by hand. Having a front-end loader or bulldozer simultaneously push on the trailing end of the liner segment may assist the whole process.

Gasketed polyethylene pipe typically uses the push technique to affect the pipe seal as well as the position the liner. This process inserts the liner without the necessity for having a high capacity winch and cable arrangement.

The Combination Technique

The push and pull techniques can sometimes be combined to provide the most efficient installation method. Typically, this arrangement can be used when attempting the placement of unusually heavy walled or long lengths of polyethylene liner.

Flow Control

For most insertion renewal projects it is not necessary to eliminate the entire flow stream within the existing pipe structure. Actually, some amount of flow can assist positioning of the liner by providing a lubricant along the liner length as it moves through the deteriorated pipe structure. However, an excessive flow can inhibit the insertion process. Likewise, the disruption of a How stream in excess of 50 of pipe capacity should be avoided.

The insertion procedure should be timed to take advantage of cyclic periods of low flow that occur during the operation of most gravity piping systems. During the insertion of the liner often a period of 30 minutes or less the annular space will probably carry sufficient flow to maintain a safe level in the operating sections of the system being rehabilitated. Flow can then be diverted into the liner upon final positioning of the liner. During periods of extensive flow blockage, the upstream piping system can be monitored to avoid unexpected flooding of drainage areas.

Consider establishing a flow control procedure for those gravity applications in which the depth of flow/ exceeds 50. The flow may be controlled by judicious operation of pump stations, plugging or blocking the flow, or bypass pumping of the flow stream.

Pressurized piping systems will require judicious operation of pump stations during the liner installation.

Make Service and Lateral Connections

After the recommended 24-hour relaxation period following the insertion of the polyethylene liner, each Individual service connection and lateral can be added to the new system. One common method of making these connections involves the use of a wraparound service saddle. The saddle is placed over a hole that has been cut through the liner and the entire saddle and gasket assembly is then fastened into place with stainless steel bands. Additional joint integrity can be obtained by extrusion welding of the lap joint created between the saddle base and the liner. The service lateral can then be connected into the saddle, using a readily available flexible coupling. Once the lateral has been connected, following standard direct burial procedures can stabilize the entire area.

For pressure applications, lateral connections can be made using sidewall fusion, ot branch saddles onto the liner. As an alternate, a molded or fabricated tee may be fused or flanged into the liner at the point where the lateral connection is required.

Make Terminal Connections and Stabilize the Annular Space Where Required

Making the terminal connections of the liner is the final step in the insertion renewal procedure. Pressurized pipe systems will require connection of the liner to the various system appurtenances. These terminal connections can be made readily through the use of pressure-rated polyethylene fittings and flanges with fusion technology. All of these require stabilization of the transition region to prevent point loading of the liner.

Gravity lines do not typically require pressure-capable connections to the other system appurtenances. In these situations, the annular space will be sealed to prevent migration of ground water along the annulus and, ultimately infiltration through the manhole or headwall connection. Sealing materials should be placed by gravity flow methods so that the liner's buckling resistance is not exceeded during installation. Consideration should be given to the specific load bearing characteristics of the fill material in light of the anticipated loading of the liner.

Summary

This chapter has provided an introductory discussion on the rehabilitation of a deteriotated pipe stature by insertion renewal with continuous lengths of polyethylene pipe. It also includes a brief description of other rehabilitation methods that utilize polyethylene and PVG piping. The sliplining or insertion renewal procedure is a cost- effective means by which a new pipeline is obtained with a minimum interference with Surface traffic. An inherent benefit of the technology is the installation of a new, structurally sound, leak-free piping system with improved flow characteristics. The resulting pipe structure allows for a flow capacity at or near that of the deteriorating pipe system while eliminating the potential for infiltration or exfiltration. And the best feature of all is the vastly improved longevity of the plastic pipe, especially compared to the decay normally associated with piping materials of the past.

The continuing deterioration of this country's infrastructure necessitates innovative solutions to persistent and costly problem. Insertions renewal, or sliplining is a cost-effective means by which one aspect of the infrastructure dilemma may be corrected without the expense and long-term service disruption associated with pipeline replacement.

5) Sliplining Case Study: *Gloucester Street Feedermain Sliplining*

Introduction

In 1997, the Region of Ottawa-Carleton identified the existing 914 mm watermain in Gloucester Street as a candidate for rehabilitation. The 1.3-kilometer watermain had failed twice in recent years; once in 1981 and again in 1992, both resulting in significant damage. The existing watermain was constructed of cast iron in 1916- 1917 and was considered to be in poor structural condition.

The watermain is located in downtown Ottawa and crosses every major north south arterial road into the city core. Moreover, the roadway was in good condition. A method of rehabilitating the watermain had to be developed that would ensure reliable service over a reasonable design life and the solution had to minimize the disruption to the road surface and traffic movement.

Adding to the challenge of undertaking such a significant project in the urban core was the fact that a series of other large construction projects were also taking place in the same area. The concentration of construction in the downtown area was due to a program called "Restore the Core." The purpose of this program was to renew infrastructure in the downtown core including major roadways used as ceremonial routes and the major piping residing beneath them. Millennium celebrations planned for the nation's capital made the schedule critical. Solutions had to be formulated quickly and with minimal added disruption to traffic movement.

The project proceeded to construction in the April 1999 and was completed by July 1999. A number of benefits were derived from the project: improved water system reliability, significant capital and social cost savings and recognition for selecting an innovative approach to the problem.

Background

The Region of Ottawa-Carleton is responsible for all components of the central water supply system in the Ottawa-Carleton area of 11 municipalities. The system currently services approximately 750,000 customers through a vast network of treatment, pumping, piping and storage facilities. The source of the water for most of the system is the Ottawa River. The Region is committed to providing a sufficient quantity and quality of water at all times including the summer peaks and during fire flow conditions.

The existing central water system includes two purification plants, 12 pumping stations, 9 storage facilities, and 2,500 kilometers of watermains conservatively valued at 2.5 billion dollars. Sizes of the watermains range from 102 mm to 1525 mm in diameter with approximately 14,000 hydrants and 24,000 valves. Federal, provincial and municipal legislation has guided the development of the water system first started in 1874. The overall condition of the system is very good and has been maintained through a variety of operational and capital program including rehabilitation and replacement. The Gloucester Street Feedermain is a critical link in the water distribution system. It serves a pressure district that encompasses the downtown core of Ottawa-Carleton. Water customers in this pressure district include many major corporations as well as Parliament Hill, National Defense Headquarters and many other federal and municipal offices.

Constructed during the First World War, this cast iron main had performed well over its service life however, the two recent failures led to an investigation that concluded that areas of the effective pipe wall thickness had been reduced by corrosion to approximately 37% of the original thickness. Further, the studies indicated that the pipe contained casting flaws. Knowledge of this information and the potential damages due to a failure led to the identification of the Gloucester Street feedermain as a candidate for rehabilitation.

Planning Phase

Robinson Consultants Inc. and Trenchless Design Engineering Ltd. complete were retained by the Region to complete a study to determine the most appropriate trenchless rehabilitation method for the Gloucester Street Feedermain. The initial phase of the investigation reviewed all available trenchless rehabilitation options for pressure pipes. The options were divided into three categories:

In the Group I Options (tight fit to host pipe, thermoplastic material) ROLLDOWN, Swagelining, U-Liner and Duraliner were evaluated. The 914 mm Gloucester Street Feedermain was outside the typical diameter for these techniques. For this reason as well as the significant host pipe cleaning and preparation costs or equipment availability in the area, these techniques were not considered appropriate for the Gloucester Street Feedermain project.

In the Group II Options (tight fit to host pipe, thermoset plastic material) Insituform was evaluated. Although a relatively new technique for pressure applications, this option was available in the size range required for the Gloucester Street feedermain.

The Group III Options (loose fit to host pipe, thermoplastic material) included an evaluation of available sliplining methods. This method was proven and applicable to the diameter of the Gloucester Street project.

Pipe bursting was also considered as an alternative to rehabilitation by lining. This option was not selected due to the potential impact to adjacent utilities and the road structure as well as an assumed high cost.

A further comparison between the sliplining technique and cured-in-place pipe technique was completed. Factors considered were hydraulics, life expectancy, reliability, operations and maintenance, social impact and construction cost.

A goal of the Gloucester Street watermain rehabilitation process was to maintain the current system capacity. Although each of the lining methods would reduce the interior diameter of the pipe, the liners would have significantly improved hydraulic characteristics over the existing watermain due to the smooth interior of the liners.

Discussions with Regional staff that completed the break repairs indicated that the interior of the pipe was irregular due to tuberculation. Based on the observations of the operations staff, the Hazen Williams roughness coefficient was estimated to be in the range of 70 to 90. Depending on the uniformity of the host pipe after cleaning, a cured-in-place pipe could have a roughness coefficient in the range of 120 to 140. Similarly, the roughness coefficient of a High Density Polyethylene (HDPE) pipe is in the range of 130 to 150. Therefore, the reduction in diameter that would occur for both options would not reduce the capacity of the rehabilitated pipe below that of the host pipe.

Interior of Gloucester Street Watermain Prior to Rehabilitation

Sliplining of a watermain of this diameter in a downtown urban setting is uncommon to North America, if not elsewhere. However, by selecting this process, the Region of Ottawa-Carleton ensured that the rehabilitated Gloucester Street watermain will have a long service life with the least social and economic impact to meet the demands of the water customers. The success of this project will undoubtedly lead the way to the rehabilitation of other watermains in the Region of Ottawa-Carleton using trenchless techniques.

Other factors considered in the choice between sliplining and CIPP were life expectancy, reliability, operations and maintenance, social costs, and capital costs. The disturbance to the road surface would have been significantly reduced if the CIPP technique was selected however, the use of thermoset plastics in potable water supply mains has a relatively short history. This led to many unanswered questions and legitimate concerns. For these reasons, the higher capital cost sliplining was recommended as the preferred rehabilitation technique.

Design and Construction Phase

After selecting the rehabilitation method, the Region of Ottawa-Carleton awarded the design and construction administration of the project to Robinson Consultants Inc. in association with Trenchless Design Engineering Ltd.

Closed Circuit Television Inspection

Early in the design process, a closed circuit television contract (CCTV) was tendered. The purpose of this contract was to confirm that the pipe alignment and elevation was consistent with the original 1916 and 1917 record drawings and to determine that the piping note been altered in anyway. In addition, it would supply some information regarding the extent of cleaning required for the rehabilitation contract. To minimize the disruption to the road surface access pits for insertion of the CCTV equipment were located where excavations would be necessary for the upcoming rehabilitation contract. Three access pits were selected and temporary water services were put in place to maintain water supply to the few properties that were connected to the feedermain.

Sections of the cast iron main were cut and removed to insert the CCTV camera. The inspection confirmed that the pipe's vertical and horizontal alignment were generally straight without any defined bends except for one shift in the alignment. Two 15' (approx.) bends were located at Bay Street, approximately 270 meters from the west end of the project. The inspection also confirmed that interior of the pipe was covered with a 25 mm to 40 mm thick layer of tuberculation.

Inserting the CCTV Camera Into the Watermain

Temporary bulkheads were constructed and the excavations were backfilled. The CCTV inspection was completed in November in the low water demand period and was not put back into service except for the section with building services. The rehabilitation was planned for early spring prior to the high water demand period. With the feedermain main now out of service rehabilitation was a priority.

National Research Council Studies

The Institute for Research in Construction at the National Research Council conducted two studies to determine firstly, the performance of the pipe with a grouted annular space versus an ungrouted annular space and secondly, the interaction between the various connections and the relined pipe.

A few of the key conclusions of the ungrouted vs. grouted study are:

- When failure of the host cast iron pipe occurs, the broken pieces are likely to cause large stress concentrations and local deformations on an ungrouted HDPE pipe.
- A grouted pipe has a higher resistance to buckling failure or collapse under the combined external loading and internal vacuum loading condition.

The final conclusion of the study was that a grouted pipe is expected to perform better with a longer service life.

The key conclusions from the second study are:

- Grouting the annulus with a cement-based grout can improve the structural capacity of the rehabilitated pipe.
- The bonding strength between an HDPE pipe and grout ring is small and cannot be relied upon for providing longitudinal circumferential restraint.

- External Load has a more significant impact on the stress in the pipe wall than internal load.
- The HDPE pipe in the grouted pipe has a total factor of safety of 3.4 against collapse under the worst internal and external buckling loading. For an ungrouted pipe, a total factor of safety of 1.7 can be expected. Buckling of OR 17 HDPE pipe in the proposed application is not a concern whether it is grouted or ungrouted.

As a result of these studies, the Gloucester Street Feedermain rehabilitation design was completed on the basis of a grouted annular space.

An on-going monitoring program has also been established with the Institute for Research in Construction. The performance of the pipe will be monitored under actual operating conditions for a minimum of 3 years to support the results of the studies.

Watermain Material Selection

An 840 mm (OD) DR 17 High Density Polyethylene Pipe was selected as the liner pipe. This diameter was considered appropriate to provide sufficient annular space between the liner pipe and the host pipe to ensure successful liner pulls and grouting.

HDPE is not a standard water supply main material in the Ottawa-Carleton area, particularly in this large diameter. This coupled with the fact that sidewall fusion services in this diameter are relatively uncommon, AWWA C-301 fittings were specified at valves and branches. C-301 pipe is a familiar material for the Regional Operations staff and has a well-proven track record for reliability.

It was decided that the length of feedermain in the Bay Street area where the two bends were located would be constructed by open cut methods. Slip lining around the bends was not possible. Concrete pressure pipe was selected as the pipe material.

HDPE flanged stub ends were fused onto the trailing end of the liner pipe prior to insertion. The stub ends were then flanged to the concrete pressure pipe fittings.

The stub ends were too large to be fused on the leading end of the insertion string and pulled through the pipe. An alternate method of flanging the HDPE pipe to the concrete pressure pipe fittings had to be determined. Aqua Grip fittings were specified. The use of these fittings allowed flanged connections to be made to the concrete pressure pipe fittings in areas where the fusion welding machine could not be inserted into the excavations. This significantly reduced the size of excavations at the connection points, a significant factor in high traffic areas.

Aqua Grip and Concrete Pressure Pipe Fittings

Existing Utilities

The Gloucester Street corridor is heavily occupied with many utilities. Large power duct banks, communications duct banks, gas mains, local watermains and sewers passed over, under and adjacent to the feedermain. Determining the accurate location of these utilities was essential to the success of the project. In areas where branches and services were to be reconnected and at the proposed pull pit and insertion pits, the utilities were field located and a Total Station survey was completed to update the base mapping. With this information, the insertion/pull pits and service/branch connections were designed so that no utility relocations were required.

Existing Utilities in Open Cut Section

Public Consultation

As with any major construction in high-density urban areas, public consultation is essential to the success of the project. Two Open Houses were held and regular newsletters were delivered to residents and area business. Radio and television was also a factor in public awareness. A communications plan developed prior to construction identified roles and ensured a quick response to public inquiries and complaints. For the most part, the low dig rehabilitation approach was well received by the public, the media and the area's political representatives.

Traffic Control Plan

Gloucester Street is a one-way street stretching across the downtown core from Bronson Avenue approximately 1.3 kilometers to Elgin Street. It crosses every major north south collector into downtown Ottawa servicing many key federal buildings. In addition to these traffic challenges, the downtown core of Ottawa is undergoing major reconstruction in preparation for the millennium and planned celebrations. These "Restore the Core" projects had already placed many constraints on traffic movement in the downtown area. A traffic control plan was developed in consultation with Regional and City of Ottawa staff. The plan gave consideration to the fact that storage would be required for the 15 m lengths of HDPE pipe that would be delivered to the site. Depending on the contractors methodology, the pipe could also be fused together along the roadway in much longer lengths prior to insertion. The final plan called for the roadway to be converted to a two way street to allow for full traffic movement along the street except for the immediate area surrounding the insertion and pull pits. These areas would be reduced to one controlled lane or completely closed for short periods of time. The construction was also planned in two stages in order to reduce impact on the street and the north south corridors. The staging was also required to ensure that the construction on Gloucester Street did not occur in the same area and at the same time as other construction projects that were occurring in the core. This plan coupled with the contractors technique of fusing and pulling one length into the host pipe at a time rather than fusing long lengths in advance of pulling, ensured effective traffic movement was maintained through out the project.

Construction Sequencing

A sliplining procedure plan was provided in the tender documents as a suggested approach to the project. Contractors were permitted to submit alternative methodology plans for approval after the tenders were submitted. The suggested plan proposed eight pulls ranging in length from 100 meters to 200 meters. The plan was prepared on the basis that the contractor would fuse long lengths of HDPE together and insert them into the cast iron main with one continuous pull. The long strings of pipe would span across intersections while being inserted obviously blocking traffic. Under this scenario, the contract called for pipe insertions to be completed at night to minimize the disruption on the major arterial roads in and out of the downtown core. This plan minimized the surface disruption by proposing that the insertion and pull pits be located at required excavation points such as valves, services and branch reconnections.

Contrary to the conceptional plan, the method agreed to with the contractor did not require the closure of the north south arterial roads. The number of insertion pits and pull pits was reduced and they were moved to mid-block locations. The plan also called for the insertion of short lengths of liner pipe that when placed in position for insertion would not block the north south arterial roads. This required excavations at locations where they would not otherwise be required however, not having to close the arterial roads, combined with the longer pull lengths proposed by the contractor, was considered sufficient reason to accept this alternative plan. Under this plan, the contract was completed in 6 pulls ranging in length from 130 to 270meters.

Pipe Cleaning

Prior to sliplining, the pipe was cleaned to remove any protrusions that would interfere with the liner insertion or damage the liner pipe. A metal cage was manufactured to approximately the same diameter as the inside of the cast iron pipe. The cage was connected to a cable and pulled through the pipe scraping the tuberculations off the pipe as it proceed along the pipe. A concrete vibrator was added to the cage to improve the effectiveness of the cleaning. The debris was then flushed from the pipe and the solids were disposed of at a landfill site and the water was disposed of at the Region's waste water treatment plant. After flushing, a CCTV inspection was completed to inspect the pipe interior. Remaining debris or protrusions would be identified and removed.

Cleaning Cage Inserted Into the Cast Iron Main

Sliplining

Prior to inserting the fused liner pipes, a short test section was pulled through the pipe. The test section would be inspected to determine if any protrusion remained in the pipe that would cause damage to the pipe exceeding the allowable limit. The test section would also reveal any ovality in the pipe that would prevent the liner pipe from being inserted completely into the cast iron main.

Test Section Ready for Insertion

The sliplining was completed by constructing a concentric cone on the lead end of the liner pipe. A series of short cables were then threaded through the cone and attached to the winch cable. The winch was located immediately above an opening in the cast iron main. A pulley was placed in the opening of the cast iron main to center the winch cable in the pipe. With the cable in place and attached to the leading end of the liner pipe, the HDPE pipe was pulled into the cast iron main.

The lengths of HDPE pipe were butt fused together with a McElroy welding machine. The fusion welder was located at the insertion pit in line with the cast iron main. As one length of pipe was advanced towards the insertion pit another length of pipe was welded onto the liner string. This process was repeated until the full length of liner was in place.

HDPE Pipe Insertion

Grouting

Prior to cleaning the cast iron main, holes were augered from the road surface to the top of the existing pipe approximately every 30 meters. A 50 mm hole was then cored through the cast iron. These holes were used as air holes and grout insertion points. The annular space was filled with a low strength, highly flowable grout.

Commissioning

The liner was tested at 1035 Kpa, prior to grouting. The testing was completed in accordance with the pipe manufactures recommendations. No leaks were detected.

Despite wrapping the ends of the HDPE pipe while being stored on site, debris and dust entered the pipe. Consequently, prior to installing the valves, the pipe was flushed with a solution of chlorinated water. This was completed to ensure a successful sterilization test. The feedermain was sterilized following the pressure test and put into service without delays.

Safety

Prior to starting construction, a procedure was enacted to protect the safety of the workers and the public while work working on the de-pressurized feedermain. The plan included the installation of new redundant side valves, capping of mains, valve tagging, removal of operating nuts on valves and chaining and padlocking operating wheels. Once the procedure was enacted, the Operations staff completed an Operations Log form and submitted the form to the Regional Project Manager and the Contractor. No changes to the plan were permitted without the prior approval of the Region's Project Manager.

Conclusions

The Gloucester Street Feedermain Rehabilitation project was completed with far less disruption to traffic and local residents and business than an open cut replacement project. The estimated capital cost savings are estimated to be $1,000,000 as compared to an open cut project. These savings are due in large part to the utility relocations and support that would be required to replace the watermain by conventional techniques.

Open cut replacement of the watermain would have severely disrupted the movement of traffic in and around the downtown core. The sliplining process allowed a plan to be developed that would ensure that key roads were not significantly impacted during traffic periods. The process was also flexible and could be changed to adjust to changes in traffic conditions. This was essential to the success of the project particularly with the concurrent “Restore the Core” projects under way in the downtown area.

PART SIX: ROLLDOWN TECHNOLOGY

1) Evaluation & Investigation of the existing Materials & Installation Methods for Lining Technology

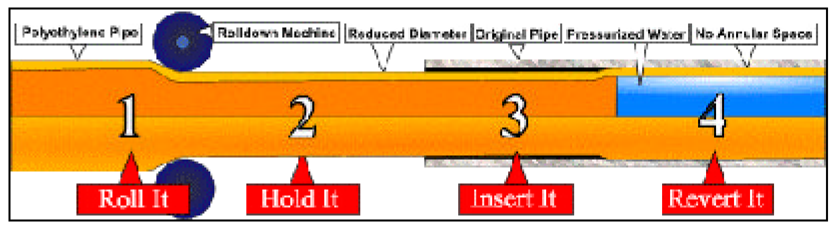
a) Introduction

The *Rolldown* process is used for the on-site cold reduction of close fit polyethylene (PE) liner for insertion into existing pressure pipelines. The *Rolldown* process can be used to install a fully structural liner where the liner pressure rating is equal to or greater than that of the host pipe. It can equally well be used to install semi-structural liner into higher pressure pipelines which are essentially in structurally sound condition, but which are suffering from localized corrosion perforation and/or leaking joints and/or deterioration of conveyed fluid quality arising from internal pipeline corrosion and/or deposition.
Individual pipe lengths are butt fused on site into appropriate lengths to suit particular site conditions and installation lengths. The fused lengths are then pushed through a set of specially designed rollers at ambient temperature, to concentrically reduce the liner diameter. The diameter is typically reduced by about 10%. A corresponding increase in wall thickness is observed at this stage. The reduced diameter is normally retained without the need for any external mechanical restraint. The pipe must be reduced in diameter as a separate operation prior to installation into the host pipe. Long continuous lengths can then be inserted in a single operation. Once processed, a rolled-down PE liner will retain its reduced size indefinitely without the need for any external mechanical restraint until it is reverted by internal pressurization.
The Rolldown process uses PE pipe made from standard grade PE resins (e.g. PE-80, PE-100).

Typically, the Rolldown process uses PE pipe with Standard Dimension Ratios (SDR = outside diameter/wall thickness) in the range 11 to 33, subject to certain practical limitations (See the following table).
Depending on site conditions section lengths up to 5000ft (1500m) can be inserted in a single pull. *Rolldown* is available over a range of diameters from 4” (100mm) to 20” (500mm).
After the Rolled PE has been inserted into the existing host pipe, the ends of the liner is filled with water and pressurized for the reversion process. During the reversion process, the liner expands to form a close fit with the host pipe. No subsequent grouting is required. A variety of end terminations can be fitted to complete the system.

b) Description of the process

Four steps to are necessary to rehabilitate pressure pipes with the Rolldown *process:*



- Step 1

Using the *Rolldown* process we are able to reduce the outside diameter of polyethylene pipe significantly without affecting the long-term characteristics of the pipe. Unlike other diameter reducing processes, *Rolldown* does not stretch the polyethylene nor weaken the pipeline material.

- Step 2

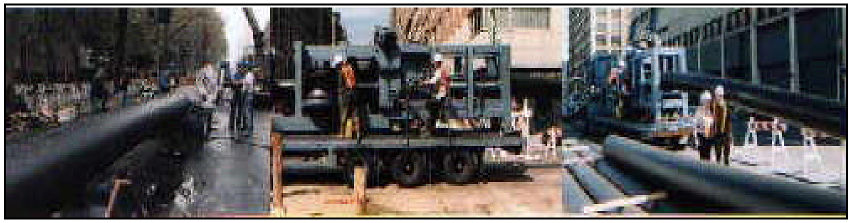
A polyethylene pipe, which has been reduced by the Rolldown process, will hold its new diameter for several days unless deliberate steps are taken to revert it to its original size. This allows much more control over the installation schedule than is possible with other processes.

- Step 3

As a result of the reduced diameter of the new pipe, conventional sliplining techniques are used to insert it into the original pipeline. Since winching loads are very low, neither pipe is subjected to harmful stress, even when large diameters or long lengths are installed.

- Step 4

After the insertion into the old pipe, hydrostatic pressure is used to trigger the molecular memory of the polyethylene. This causes the new pipe to attempt to return to its original diameter. As a result, it presses tightly against the inside of the old pipe, virtually eliminating all annular space.



Main characteristics of the Rolldown process

- Rehabilitate 4-inch through 20-inch diameter pipe
- SDR 42 through SDR 11 thin- or thick-wall, MDPE or HDPE pipe may be used
- Single installations greater than 3,000 feet have been achieved
- Normal Rolldown rate is 6 to 8 feet per minute
- Installation speed of 18 to 20 feet per minute is common
- Pipe may be butt-fused before or after Rolldown
- Tests prove Rolldown has no negative effect on polyethylene
- Rolldown reduces diameter without elongating pipe
- Pipe is reverted with pressurized water at ambient temperatures
- Over 200 miles of pipeline have been rehabilitated with the Rolldown process

Problems Solved by Rolldown

- **Pipeline structural deterioration problems**
  Rolldown can be used to process and install PE pipe liners, which have a full structural capability for gas, water and other suitable pressure pipeline applications
- **Pipeline internal corrosion problems**
  Rolldown PE pipe linings provide a highly effective, corrosion-resistant barrier between the bore of the existing pipe and the conveyed product
- **Water quality problems associated with pipeline internal corrosion and deposits**
  Rolldown PE pipe linings arrest the pipe bore tuberculation and corrosion, which contribute to

conveyed water quality problems in water supply and distribution pipelines. In addition, the smooth surface of Rolldown PE linings helps resist the formation of other pipe bore deposits in operation

- **Flow capacity problems arising from pipe bore tuberculation and deposits**

Rolldown PE linings present a smooth surface to the conveyed fluid, which helps maximize the flow capacity of the lined pipe. Thanks to the extremely low friction coefficient of the PE liner, in many cases it is possible to increase the hydraulic capacity of previously heavily tuberculated mains and deposit-fouled pipelines

- **Leakage from corrosion holes and failed pipeline joints**
  Rolldown PE linings provide a continuous pressure-tight envelope inside the existing pipeline which can be designed effectively to span corrosion holes and joint gaps

c) Specifications for pipeline renewal

Rolldown Process
Design considerations
• Available for 4 - 20 inches diameter pipes • Uses SDR 42-11 thin or thick wall, MDPE or HDPE • Site location/access facilities • Host pipe type and wall thickness design • Pipeline internal operating pressure • Pipeline length • Type of joint and flange rating of host pipe • Conveyed fluid composition • Operating temperature • Internal Condition of Host pipe (scale build up, internal lining/coating etc) • Site drawings (showing vertical and horizontal offsets)

Materials and fittings	
Host pipe material	• Identification and indication of its structural integrity required • Existing pipeline inside diameter must be quantified to allow for optimum sizing of liner pipe
Liner material	• Polyethylene resin compound must be specified as either medium or high density in accordance with ASTM Standard D3350 • Physical and mechanical performance properties of the polyethylene pipe material to be deformed must be available to optimize the performance and installation of the liner
End terminations	• *Fully structural capacity:* Standard PE fusion and/or mechanical jointing technology can be used. The liner can be mechanically expanded to suit the size of standard couplers, provided the final outside diameter does not exceed 5% of the liner's *original* (i.e. as-manufactured) outside diameter. In order to ensure adequate sealing the following information must be supplied: • Host pipe inside diameter • Host pipe outer diameter • Flange rating • Host pipe and flange specification
Bends and fittings	• Rolled pipe is typically capable of negotiating bends up to 11.25^o subject to appropriate pipe dimension and site conditions. • All other fittings and tees must be removed. Such excavations may however, conveniently be used as insertion and receiving pits for the *Rolldown* installation

System Installation	
Accessibility	The line of the existing pipeline must be located, noting any potential problems, such as bends, hydrants and valves.
Excavations	Insertion and receiving pits should be excavated at appropriate locations along the length of the existing main. The positioning of the machine and space required for liner pipe "stringing out" should be considered when selecting launch site
Cleaning	The host pipe should be cleaned prior to lining. Adequate cleaning processes include the use of scraper pigs followed by a "rubber pull-through", wire brush, pressure jetting or pressure pigging. Other cleaning processes may be used which can be shown to remove excess debris from the inside of the pipeline
CCTV Inspection	CCTV inspection should be carried out before and after cleaning. Any significant protrusions, which will inhibit cleaning, should be removed. The post cleaning inspections should confirm the cleanliness of the main, and identify any remaining protrusions into the main; if significant they should be removed prior to lining. A proving pig may also be used to check for protrusions into the main.

Section lengths	Installation segment lengths are normally determined jointly by the owner/engineer and the installer. These are governed primarily by site and pipeline factors such as terrain, accessibility, bends and fittings
Bends/Fittings	Bends greater than 11.25^0 must be removed prior to lining. The minimum allowable bend radii for the *Rolldown* liners is typically 25 times the liner outer diameter for DR 11-17 and 37.5 times the liner outer diameter for DR 26-33. These must be taken into consideration when excavating the bend sections
Size Verification	The outside diameter of the PE liner pipe is typically chosen to be slightly larger (approximately 5%) than the minimum clear bore of the host pipe. The *Rolldown* process will then produce a liner that is smaller than the minimum clear inside diameter of the host pipe, to ensure ease of insertion. The liner outer diameter is limited during reversion to a maximum of 5% greater than the original outer diameter, ensuring a tight fit with the host pipe when reverted. An accurate measurement of the host pipe internal diameter must be available.
Liner Installation	The liner is deformed prior to installation and stored alongside the pipeline. The liner deformation is held without the need for mechanical restraints. An approved lubricant (e.g. bentonite) is used to aid the installation process

Semi-Structural: Liner design guarantees long-term hole/gap spanning capability under design operating conditions. Structural support is necessary from the host pipe to withstand general

Temperature	The diameter reduction, and subsequent retention of this deformation is dependent on temperature as well as specific PE resin and DR values. The *Rolldown* process can be successfully carried out in the temperature range 42°F (5°C) to 86°F (30°C).
Jointing	• Pipe strings must be jointed prior to being pushed through the *Rolldown* machine. Conventional butt fusion is the required method and the external weld beads must be removed. • Adjacent sections of rolled PE liner can also be butt fused and satisfactory reverted.
Winch loads	**The deformation process involves *pushing* the liner pipe through the *Rolldown* rollers, and therefore the liner elongation is kept to below 3%.**
Machine Capacities	Subterra currently has 3 types of machine, which are applicable for the following liner outside diameter ranges. Need to contact *Rolldown* installer for sizes outside this range.

Type of Machine	PE liner Outer Diameter	
	Inches	mm
1	4-8	100-200
2	8-14	200-350
3	16-20	400-500

End Fittings/Reversion	• A swabbing pig should be inserted into the liner pipe and suitable end fittings attached to the end of each section of *Rolldown* liner pipe for reversion. The pipeline should then be carefully filled with clean water. All air should be expelled from the system to enable adequate expansion control. The reversion pressures are determined by the temperature, DR of the liner and the PE resin type. • If the *Rolldown* liner pipe is such that it is not fully structurally rated, all points where the PE leaves the constraints of the host pipe should be carefully monitored and suitable measures taken to ensure over expansion does not occur. • During the reversion process, the liner and fittings are inspected for leaks. The reversion pressure should be maintained for a minimum of 12 hours to ensure complete reversion and a close fit between the liner and the host pipe. • Before draining the liner both ends of the reverted section should be vented to prevent the occurrence of vacuum collapse.

operating pressures/external loads.
Fully structural: No structural support required from host pipe against internal/external pressures/loads.
Non-structural: Anti-corrosion barrier only. No gap bridging capability. (e.g. Epoxy resin lining).

d) System Features and Benefits

Rolldown Process	
Potable Water Applications	The *Rolldown* processes use PE liner pipe manufactured from standard pipe-grade resins. Where the PE pipe to be processed by *Rolldown* already has a National approval for use in contact with public potable water supplies, the resultant liner will retain this approval. In particular, the internal surface of the PE pipe liner is not contacted by the *Rolldown* process. Furthermore, the reversion of the liner to a close fit with the host pipe can subsequently be carried out by pressurization using cold water taken from the public supply (where available). The pipeline fittings must also be water quality approved.
Continuous Barrier Liner	• Arrest internal corrosion of host pipe. • Prevents leakage from holes, joints
Liner Pipe Made from Standard Pipe Grade Resins	• Uses materials already approved in country for potable water/gas application. • Standard PE resin liner pipe materials generally already well characterized: usually manufactured under a formal QA scheme
Thin-walled PE Liner	Structural/Semi-structural PE liner • Structural liner is effectively a new pipeline installation. • Semi-Structural applications minimize liner materials usage/costs, maximize free bore of relined pipeline

Close-fit liner	• Maximizes flow capacity. • Grouting not required.
Smooth liner bore	Maximizes flow capacity
Simple Process Equipment	Available for all diameters of PE pipe 100mm to 500mm
Shape of the liner	Diametral reductions of about 10% (dependent on process details): • Easy insertion into host pipe • May negotiate bends of up to 11 ¼ °
Process Specification	Reduced Diameter held indefinitely until reversion carried out: • No external mechanical restraint needed to maintain reduced size. • Insertion is effectively a slip-lining operation. • Insertion winching loads required only overcoming friction between liner and host pipe. • Process can be stopped/restarted without detriment.

Install Liner Direct from Machine or as Separate Operation	On-site operational flexibility and convenience
Low Installation Winching Loads	• Maximizes insertion lengths (single pulls > 1500 meters have already been achieved) • **Minimizes liner elongations/residual tensile stresses after installation**
Process Stop/Start Capability	On-site operational flexibility and convenience
Reversion to Close-fit with Host Pipe using Water at Ambient Temperature	• Simple reversion procedure • No process heating/specialist pipe shape reforming requirements
Well-characterized PE Liner ability to span Corrosion Holes/Joints Gaps	***Validated 50-year liner design procedures available***
Pipe Rehabilitation Process	Utilizes existing pipeline asset as a conduit
Minimum Dig Process	• Minimum disturbance of adjacent services and structures. • Minimizes the requirement for imported natural fill materials for re-instating excavations. • Reduces disposal of excavated material to landfill. • Small site footprint. • Less environmental/social disruption compared with open-cut laying.

e) Material Qualifications

The Rolldown process uses custom-made MDPE or HDPE pipe manufactured from standard pipe-grade resins, which is purchased to fit the exact internal diameter of the host pipe to be lined. The user should verify by documentation from the pipe manufacturer or by pre-installation testing that the pipe to be supplied meets all required standards for the intended use and that it is suitable for installation with the Rolldown method of installation. Where the PE pipe to be processed by Rolldown already has a national approval for use in contact with public potable water supplies, the resultant liner will retain this approval.

In addition the pipe should exhibit excellent slow-crack growth resistance and should not be subject to Rapid Crack Growth (RCP) for the conditions of pressure, temperature and diameter required for the intended application. Large diameter pipes operating at low temperatures and at higher pressures may be more prone to RCP failure.

Effect on Strength Characteristic

Tests have shown that correctly processed and reverted Rolldown PE liners meet the key mechanical strength requirements for virgin PE pipe of the same grade.

Test	Material	Size/SDR	Hoop Stress (Mpa)	Target
Unnotched hydrostatic pressure test @ 20°C	PE-100	315/11	145 hrs	>100 hrs
Notched hydrostatic pressure test @ 80°C	PE-80 PE-80 PE-80 PE-80 PE-100	162/26 213/26 268/26 315/26 315/11	>1507 hrs >1507 hrs >1608 hrs >2099 hrs 260 hrs	>170 hrs >170 hrs >170 hrs >170 hrs >165 hrs
Rapid crack propagation resistance (14 bar at 0°C)	PE-100	315/11	Arrested within 6 meters	Arrest within 18 meters

2) Evaluation of Rolldown Current State of Practice

The Rolldown technology has been extensively and successfully used in the USA and Europe. In the USA the first installation was completed in September 1994, while in Europe the same technique has been used for the first time in 1986 in the United Kingdom.

USA Subline Work Completed Between 1994 and 2000

Installation Date	Length (feet)	Diameter (inches)	Service	Location	Client	Years in Service
Dec-00	125	12	W	Queens Blvd, Queens, NY	NYCDEP	1
Dec-00	125	12	W	60th St, Queens, NY	NYCDEP	1
Dec-99	252	12	W	Liberty Av, Queens, NY	NYCDEP	2
Nov-98	183	12	W	Hillside Av, Queens, NY	NYCDEP	3
Oct-98	1,828	16	G	35th Ave, Queens, NY	Con Edison	3
Dec-97	317	4	G	Manderson, WY	Keyspan Energy	4
Dec-97	1,230	3	G	Manderson, WY	Keyspan Energy	4
Nov-97	1,000	4	G	Manderson, WY	Keyspan Energy	4
Nov-97	3,000	3	G	Manderson, WY	Keyspan Energy	4
Jun-97	800	36	G	Ave A, Manhattan, NY	Con Edison	4
May-97	1,200	30	G	Tinton Ave, BX, NY	Con Edison	4
Subline Total = 10,060 ft						

International Subline Installations

Installation Date	Length (feet)	Diameter (inches)	Service	Location	Client	Years in Service
2001	5,000	16	W/S	Stockholm, Sweden	NCC	0
2001	175	12	S	New Jersey, USA	Middlesex County Water	0
2001	400	12	W	New York, USA	NYCDEP	0
2000	3,400	38	W	Amsterdam, Holland	Amsterdam Water	1
2000	1,140	24	S	Los Angeles, USA	Thousand Oaks	1
2000	1,250	16	W	Padova, Italy	AMAG	1
2000	1,000	24	W	Stokholm, Sweden	Stockholm Water	1
2000	42,000	20	W	Lincoln, UK	Anglian Water	1
1999	4,520	16	S	Sodertalje, Sweden	NCC	2
1999	24,800	20	W	Rufford, UK	Severn Trent Water	2
1999	8,680	48	W	Utrecht, Holland	WRK Water Co.	2
1999	558	18	S	Haarlem, Holland	Amsterdam Water	2
1999	2,310	12	S	Nice, France	SMCE	2
1999	4,712	24	G	Padova, Italy	AMAG	2
1999	2,728	36	S	Beckton, UK	Thames Water	2
1988	930	12	W	New York, USA	NYCDEP	3
1988	1,860	16	G	New York, USA	Con Edison	3
1988	465	9	I	North Sea, UK	Mobil/AMEC	3
1988	26,660	30	W	Camps, UK	West of Scotland Water	3
1997	620	36	G	New York, USA	Con Edison	4
1997	1,085	30	G	New York, USA	Con Edison	4
1997	22,940	6	W	Thimbleby, UK	Yorkshire Water	4
1997	7,440	30	W	Burnhope, UK	Northumbrian Water	4
1997	9920	18	W	Wakefield, UK	Yorkshire Water	4
1996	930	5	I	North Sea, UK	Mobil/AMEC	5
1994	7,750	24	W	Southampton	Southern Water	7
1993	5,980	20/24	W	Oakwood, UK	Essex Water	8
1992	9,300	18	W	Fontburn, UK	Northumbrian Water	9

Key:

- W = Water Distribution
- G = Gas Distribution
- S = Pumping Sewer (Force Main)
- I = Industrial (Water Injection)

3) Evaluation of Current Design Procedures

The Subline process is typically used to install thin-walled PE liners into existing pipelines. Thus, in general, the liners installed have sufficient structural strength in their own right to withstand the full operating pressure of the pipeline throughout the whole of the planed asset life following lining (typically 50 years minimum). This is particularly true for liners to be installed in high-pressure water supply mains or similar. In these instances, the liner relies on the residual structural strength of the host pipe to act as the primary pressure containment envelope over the remaining life of the asset. It is therefore important that the host pipe is generally in a structurally sound condition, and can be expected to remain so throughout the rest of the design life for the relined main.
Under such circumstances, thin-walled PE liner pipe is capable of spanning

- Corrosion holes
- Former ferrule tapping holes
- Circumferential gaps (e.g. pulled joints, circumferential fractures)

and other similar features, subject to certain design limits. However, such thin-walled, non-pressure rated liners are generally not suitable for lining pipelines with, or likely to be subject to, longitudinal splits. Clearly this is not always the case, as some thin-wall PE liners may have sufficient long-term strength to withstand low service pressures, such as those in low pressure water mains and gas pipelines, where the internal pressure does not exceed the 50-year strength of the liner.

The Subline process involves the folding of PE pipe at ambient temperature, holding it in this reduced form temporarily, inserting it into the existing main to be lined, and reverting to a close fit with the existing main by pressurization with water at ambient temperature.

The Subline process uses PE pipe made from standard, pipe grade PE resins (PE-80, PE-100). Typically, the Subline process uses PE pipe with Standard Dimension Ratios (SDR = outside diameter/wall thickness) of 26 or greater, subject to certain practical limitations. It is ideally suited for dealing with pipelines, which are essentially in a structurally sound condition, but which are suffering from localized corrosion perforation and/or leaking joints and/or deterioration of conveyed product quality arising from internal pipeline corrosion and/or deposition, and for preventing corrosion in new pipelines.

Major benefits usually associated with conventional PE pipe lining processes, such as the reduction or elimination of internal corrosion, the improvement in flow capacity created by the smoothness of the new PE pipe, etc., are further enhanced with the thin-wall liner approach. The thinner wall increases cross-sectional area, when compared with the conventional sliplining, while reducing the amount (and consequently the cost) of the PE liner material. The following table shows examples of the benefits for 48 inches diameter pipe.

Potential Flow Improvements and Reductions in Material Usage (48 inches)

Pipe	Liner SDR	Actual Bore Diameter [inches]	Liner Wall Thickness [inches]	Actual Flow [US gal/sec]	Relative Flow vs. host [%]	Relative Flow vs. SDR 11 [%]	Liner Weight Saving vs. SDR 11 [%]
Host	-	48.03	-	569	100	-	-
Liner	11	38.82	4.32	609	107	-	0
Liner	17	41.90	2.80	744	131	122	33
Liner	26	43.86	1.83	840	148	138	55
Liner	33	44.64	1.44	879	155	144	64
Liner	42	45.26	1.13	912	160	150	72
Liner	50	45.63	0.95	932	164	153	76
Liner	61	45.98	0.78	950	167	156	80
Steel	36"/0.375"	35.25	-	466	82	-	-
Epoxy*		48.0	0.04	1,062			
Cement*		46.6	0.71	788			

Assumptions:

Hazen-Williams "C"-values:

Cast iron host = 80 (100 years old; moderate/appreciable corrosion)
PE liner = 150
New coated steel pipe = 150
Epoxy = 150
Cement = 120

Hydraulic gradient = 0.005
Class of liner fit = 1%

*** Thin Film: No Structural Benefit**

From the previous Table we see that using Subterra PE liners we gain an immediate increase in flow capacity, up to 67%. Based on the fact that the maximum design pressure must be 150 psig, we can observe that even using the SDR 11 Liner, which is a very heavy liner with a wall thickness of 4.32 inches, we still gain an increase of 7% of the relative flow if compared with the host pipe.

The use of thin-walled PE liners depends primarily on the ability of the host pipe to provide the primary pressure retention capability, while the PE liner provides the sealing membrane. While the use of a thin-wall liner to seal leaks in pressure pipelines is not a new concept, it is not as well understood as a pipeline rehabilitation methods. For this reason a number of technical questions have to be resolved in relation to the ability of the liner to withstand the range of operational conditions to which it is likely to be exposed:

a) The ability of the liner to withstand positive external pressures without buckling collapse, either during pipe empty situations (e.g., pre-commissioning, maintenance, etc.) or under partial or full vacuum arising from pipeline surge events.
b) The ability of the pipe to span localized corrosion holes and/or pipeline joint gaps in the main without failure under service pressure throughout the asset design life.

The PE liner pipes installed by the Subline process which have design service ratings greater than the actual operating pressure of the host pipe require no structural support from the host main to withstand the internal pressure.

Those PE liner pipes which have design service pressure ratings less than the operating pressure of the host pipeline can also be installed using the Subline process, provided that the host pipe remains generally intact, and has sufficient residual strength to contain the expected service pressures.

Validated design procedures have been developed for selecting the correct PE liner thickness for such situations to ensure that the liner will be capable of bridging design corrosion holes and joint gaps without failure over a minimum 50-year design life.

Subline PE liners may therefore fall into the categories of semi-structural or fully-structural linings, depending on the design operating pressure of the lined host pipeline.

a) Step 1: Check the Availability of Subline

The first step to do in order to design the Subline PE liner is to check the availability of the product. Even the PE pipe is available in the range of 75 to 1,600 mm we have to consider if the pipe itself is suitable for the specific application of interest.

Subline Range of Application

PE pipe Outside Diameter (mm)	Wall Thickness (mm)							
	SDR 11	SDR 17	SDR 26	SDR 33	SDR 42	SDR 50	SDR 61	SDR 80
75	6.8	4.4	2.9	2.3	1.8	1.5	1.2	0.9
100	9.1	5.9	3.8	3.0	2.4	2.0	1.6	1.3
110	10.0	6.5	4.2	3.3	2.6	2.2	1.8	1.4
125	11.4	7.4	4.8	3.8	3.0	2.5	2.0	1.6
150	13.6	8.8	5.8	4.5	3.6	3.0	2.5	1.9
160	14.5	9.4	6.2	4.8	3.8	3.2	2.6	2.0
180	16.4	10.6	6.9	5.5	4.3	3.6	3.0	2.3
200	18.2	11.8	7.7	6.1	4.8	4.0	3.3	2.5
213	19.4	12.5	8.2	6.5	5.1	4.3	3.5	2.7
225	20.5	13.2	8.7	6.8	5.4	4.5	3.7	2.8
250	22.7	14.7	9.6	7.6	6.0	5.0	4.1	3.1
280	25.5	16.5	10.8	8.5	6.7	5.6	4.6	3.5
300	27.3	17.6	11.5	9.1	7.1	6.0	4.9	3.8
315	28.6	18.5	12.1	9.5	7.5	6.3	5.2	3.9
355	32.3	20.9	13.7	10.8	8.5	7.1	5.8	4.4
400	36.4	23.5	15.4	12.1	9.5	8.0	6.6	5.0
450	40.9	26.5	17.3	13.6	10.7	9.0	7.4	5.6
500	45.5	29.4	19.2	15.2	11.9	10.0	8.2	6.3
560	50.9	32.9	21.5	17.0	13.3	11.2	9.2	7.0
600	54.5	35.3	23.1	18.2	14.3	12.0	9.8	7.5
630	57.3	37.1	24.2	19.1	15.0	12.6	10.3	7.9
710	64.5	41.8	27.3	21.5	16.9	14.2	11.6	8.9
750	68.2	44.1	28.8	22.7	17.9	15.0	12.3	9.4
800	72.7	47.1	30.8	24.2	19.0	16.0	13.1	10.0
900	81.8	52.9	34.6	27.3	21.4	18.0	14.8	11.3
1000	90.9	58.8	38.5	30.3	23.8	20.0	16.4	12.5
1200	109.1	70.6	46.2	36.4	28.6	24.0	19.7	15.0
1400	127.3	82.4	53.8	42.4	33.3	28.0	23.0	17.5
1600	145.5	94.1	61.5	48.5	38.1	32.0	26.2	20.0

- Suitable for Subline
- Suitability depends on PE resin specification
- Wall thickness < 3mm
- Not recommended for Subline

b) Step 2: Survey the Existing Main to be Lined

In this phase there is the need to identify line, level, and position of manufactured bends, tees and other similar fittings.

c) Step 3: Determine the Size of the PE Liner

The outside diameter of the liner is typically chosen to be approximately 5 mm smaller than the actual minimum clear bore of the host pipeline. This is to ensure that the liner will form a wrinkle-free, close fit when reverted under pressure inside the host pipeline.

d) Step 4: Buckling Stability Check – "Pipe Empty" Condition

It is necessary to ensure that the liner does not collapse in the "pipe empty" condition after installation and reversion when (and if) the lined main is subsequently drained down (either before or after commissioning).

If the groundwater level is above the invert level of the host pipe, the groundwater may enter the annulus between the host pipe and liner through any leaking joints/corrosion holes etc. in the host pipeline. The resulting external hydrostatic pressure of water on the liner has the potential to cause the liner to collapse (buckle).

This could allow more groundwater (and soil) to enter the annular space, which could then prevent a full reversion of the liner to a close fit with the host pipe when re-pressurized.

Design of liners against buckling collapse inside a rigid host pipe can be done using constrained buckling formulae of the form here shown:

P_{crit} = KE(D/t)^m/SF(1-?^{2})

Where:

Pcrit = Critical external pressure to cause buckling collapse.
E = Flexural modulus of the liner material
D = Outside diameter of the liner
t = Wall thickness of the liner
SF = Design safety factor against buckling
? = Poisson's ratio (0.48 for PE)
K,m = Factors which depend on the class of liner fit (CoF) in the host pipe
CoF = (host pipe bore diameter – liner outside diameter) / (liner outside diameter)

Class of Liner (CoF %)	K	m
0.0	1.00	-2.20
1.0	5.17	-2.74
1.5	5.23	-2.77
2.0	5.27	-2.80
2.5	5.36	-2.83
3.0	5.42	-2.86
3.5	5.49	-2.88
4.0	5.55	-2.91
4.5	5.62	-2.94
5.0	5.69	-2.97

The following table is to determine the maximum permissible liner SDR (i.e. minimum liner thickness) required to avoid the risk of liner collapse in the "pipe empty" condition; this is given as a function of depth of groundwater (H_{crit}) above the mid-height of the host pipe for two specific classes of liner fit (i.e. 1% and 4%):

Depth of Ground Water Above Mid Height of the Host Pipe (H_{crit}) (Meters of H_2O)	Maximum Permissible Liner SDR to avoid buckling in the "Pipe Empty" Condition			
	PE-80 /MDPE		PE-100 /HPPE	
	CoF = 1%	CoF = 4%	CoF = 1%	CoF = 4%
0.5	78	62	83	66
1.0	61	49	64	52
1.5	52	43	55	45
2.0	47	39	50	41
2.5	43	36	46	38
3.0	41	34	43	35
3.5	38	32	41	34
4.0	37	30	39	32
4.5	35	29	37	31
5.0	34	28	36	30
5.5	33	27	35	29
6.0	32	26	33	28
6.5	31	26	33	27
7.0	30	25	32	27
7.5	29	24	31	26
8.0	28	24	30	25
8.5	28	23	29	25
9.0	27	23	29	24
9.5	27	23	28	24
10.0	26	22	28	23
SF = 1.5				

Note: Step d) can be omitted if there is no risk of the groundwater level rising above the invert level of the host.

e) Buckling Stability Check – "Vacuum Collapse"

It is necessary to ensure that the liner will not collapse if the lined pipe is subject to an internal vacuum during service, for example as a result of a surge event.

The following table is helpful to determine the maximum permissible liner SDR (i.e. minimum liner thickness) required to avoid the risk of vacuum collapse of liner due to surge in service.

Depth of Ground Water Above Mid Height of the Host Pipe (H_{crit}) (Meters of H_2O)	Critical Pressure Differential to Cause Vacuum Collapse (P_{crit})	Maximum Permissible Liner SDR to avoid Vacuum Collapse during Surge Events			
		PE-80/MDPE		PE-100/HPPE	
	bar	CoF = 1%	CoF = 4%	CoF = 1%	CoF = 4%
0.0	1.00	44	36	48	30
0.5	1.05	43	35	47	38
1.0	1.10	42	35	46	38
1.5	1.15	41	34	45	37
2.0	1.20	41	34	45	37
2.5	1.25	40	33	44	36
3.0	1.29	40	33	43	36
3.5	1.34	39	32	43	35
4.0	1.39	39	32	42	35
4.5	1.44	38	32	42	34
5.0	1.49	38	31	41	34
5.5	1.54	37	31	41	34
6.0	1.59	37	31	40	33
6.5	1.64	36	30	40	33
7.0	1.69	36	30	39	33
7.5	1.74	36	30	39	32
8.0	1.78	35	29	39	32
8.5	1.83	35	29	38	32
9.0	1.88	35	29	38	31
9.5	1.93	34	29	38	31
10.0	1.98	34	28	37	31
SDRs given are for full vacuum events. Higher SDRs may be acceptable for partial vacuum events. SF = 1.5					

Note: Step e) can be omitted if there is no risk of vacuum in the lined pipe during service.

These numbers represent the worst-case design scenarios, so that higher SDR's may be acceptable where smaller liner fit deficits are achieved and/or reduced design safety factors are appropriate. The table also illustrates as relatively thin PE wall sections can be safely used at normal depths of cover, in particular in situations where the risk of surge in service is negligible. In this case the pipe-empty condition would be the only criterion for determining liner-buckling resistance.

f) Determine the Hole Spanning Ability of the Liner

The capability of a thin-walled PE liner to span corrosion holes and joint gaps under pressure in the host main has been the subject of extensive research at the University of Bradford, UK (Boot et al, 1995). It has been demonstrated that in the vast majority of pressure pipeline applications the host pipe will only suffer localized corrosion damage during the design life (50 years) of the rehabilitation method. In addition, relevant short and long-term mechanical properties of the PE liner pipe materials were determined and values for both short-term and 50-years exposure were derived. The research team made use of the finite element method to determine materials properties. Results were then extrapolated to give the predicted liner failure pressure after 50 years. These predicted values are shown in the following Figure.

Hole Spanning Chart

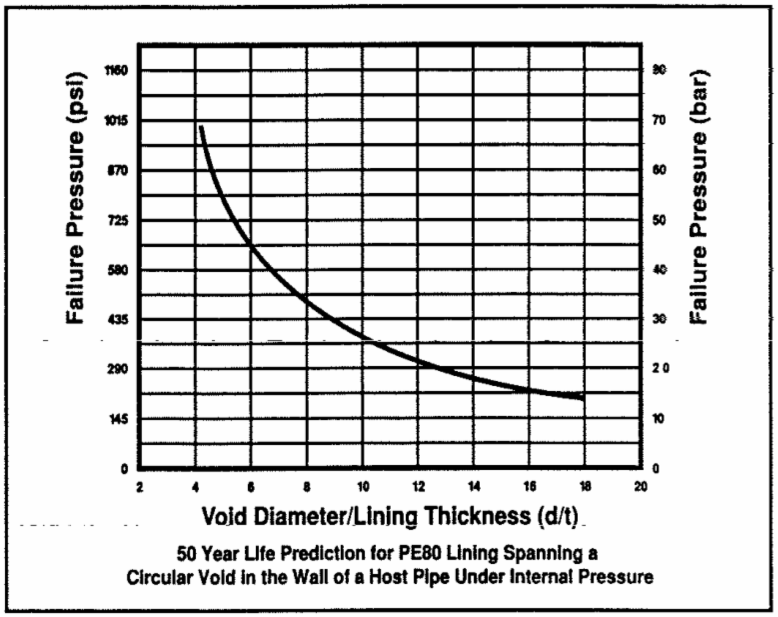


Figure 1 - 50-year life prediction for PE80 lining spanning a circular void in the wall of a host pipe under internal pressure.

Example concerning the Hole Spanning Capability

Using the Hole Spanning Chart we are now able to predict the maximum size of corrosion (etc.) hole that the liner is capable of spanning reliably over a 50-year design life. Assuming that the working pressure is 150 psig (as mentioned above) we see that the curve intersect this value at d/t = 20. In other words this means that if the liner thickness is 1 inch (we are assuming to rehabilitate the pipe using the Subline system), then the maximum size of hole that the liner will safely span over the design life will be 20 x 1 = 20 inches. On the other hand we can say (just to take another example) that if the maximum projected diameter of corrosion (etc.) hole in the host pipe is 30 inches, then the minimum required liner thickness will be 30 / 20 = 1.5 inches.

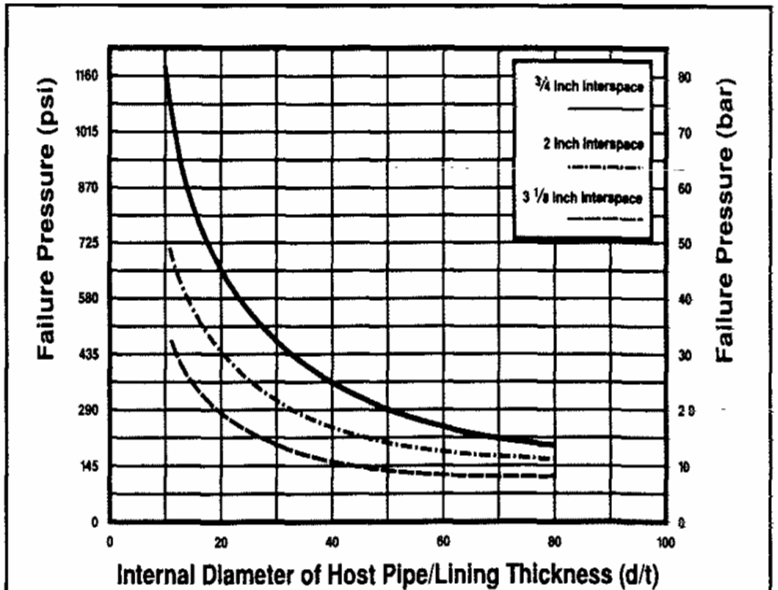
Note 1
For an irregularly shaped hole, design for an equivalent circular hole which has the same surface area as the actual hole.
Note 2
The Hole Spanning Chart is for PE-80 (MDPE) liners. For PE-100 (HPPE) liners, 50-year design failure pressures can be assumed to be approximately 15% higher.
Note 3
The Hole Spanning Chart is valid for operating temperatures of up to 20°C, and for conveyed products, which do not impair the mechanical properties of PE liner pipe.

g) Determine the Circumferential Gap Spanning Ability of the Liner

Use the Gap Spanning Chart below to determine the maximum width of fully circumferential gap (i.e. “interspace” in the pipeline axial direction) that a semi-structural liner is capable of spanning reliably over a 50-year design life, as follows:

6. Define the maximum continuous operating pressure of the pipeline.
7. Define the desired gap spanning design safety factor.
8. Calculate the minimum required 50-year liner failure pressure (product of the maximum continuous pipeline operating pressure and the chosen design safety factor).
9. If the lines SDR have previously been defined in Steps 4 and/or 5, use this value and the calculated 50-year liner failure pressure to read off/interpolate the maximum gap width that can be safely spanned by the liner over the 50-year design life from the Gap Spanning Chart below.

10. If Steps 4 and 5 have not been required, and the maximum gap width is known or has been defined, use this and the calculated 50-year liner failure pressure to read off the minimum required liner SDR from the Gap Spanning Chart below.



50 Year Life Prediction for PE80 Lining Spanning a Longitudinal gap (interspace) in the Host Pipe Under Internal Pressure

Figure 2 - 50-year life prediction for PE80 lining spanning a longitudinal gap (interspace) in the host pipe under internal pressure.

Example on the Gap Spanning Capability

Let suppose that we are engaged to design a pressure pipe with a design maximum continuous operating pressure equal to 12 bars and a design safety factor equal to 2. Therefore the minimum required 50-year liner failure pressure is equal to 24 bars.

Case 1: The SDR Liner is known

Let assume that the liner SDR is given from steps d and/or e and it is equal to 42. Then from the Gap Spanning Chart, Failure Pressure of 24 bars and Host Pipe Internal Diameter/Lining Thickness (i.e. liner SDR) intersect at a maximum permissible interspace (fully circumferential gap) width is equal to 20 mm.

Case 2: There is no risk of Liner Buckling/Vacuum Collapse/Gap Width Known

Let assume that the maximum gap width is equal to 50 mm. Then from the Gap Spanning Chart we read across from Failure Pressure of 24 bars to the 50 mm interspace line, and we read down to obtain the maximum permissible liner SDR (i.e. minimum liner wall thickness) to ensure safe spanning of the gap over the 50-year design life, i.e. the maximum SDR is equal to 27.

Note 1

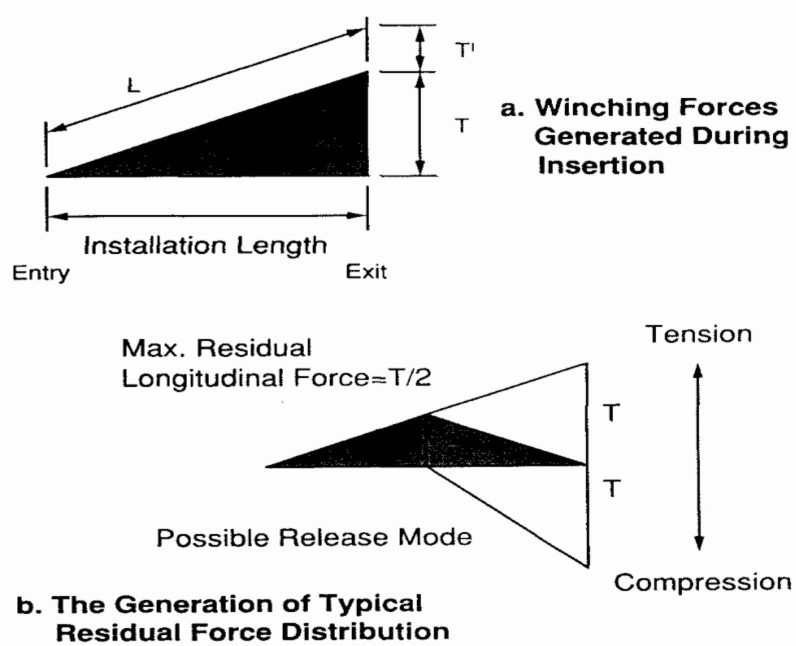
The Gap Spanning Chart is for PE-80 (MDPE) liners. For PE-100 (HDPE) liners, 50-year design failure pressures can be assumed to be approximately 15% higher.

Note 2

The Gap Spanning Chart is valid for an operating temperature up to 20°C, and for conveyed products which do not impair the mechanical properties of PE liner pipe.

h) Winching Forces

Another design aspect that has to be mentioned is the problem of the winching forces generated during insertion. When the deformed pipe is pulled into the main with a winch, it necessarily induces longitudinal stresses in the PE liner pipe. Assuming that friction is evenly distributed, the following Figure shows the variation in tensile force induced along the installation length.



Longitudinal residual stress effects induced in the lining by the wiching process

Thus T' is the force at entry and T is the maximum force required to overcome frictional effects. Upon release of the winch force, equilibrium requires the tension at both ends of the installation to be zero (Figure 4b). However, friction between lining and host pipe will now ensure that T is only partially released. The residual force system due to winching is therefore illustrated in Figure 4b. Typically the maximum tensile stress is of the order of 0.25N/mm^2 per 100-meter installation lengths. This will be increased due to bends, but can be reduced or eliminated by lubrication or flotation of the lining. Creep relaxation will also ensure these stresses reduce with time. Consequently, a well-designed installation induces only minimal long-term stresses in the lining due to this effect.

Maximum Permissible Winching Loads for MDPE/PE-80 (@20°C)

Pipe Size	Maximum Pulling Load (Tonnes)				
	SDR-26	SDR-33	SDR-42	SDR-61	SDR-80
75	0.47	0.38	0.30	0.21	0.16
100	0.84	0.67	0.53	0.37	0.28
110	1.02	0.81	0.64	0.44	0.34
125	1.31	1.04	0.83	0.57	0.44
150	1.89	1.50	1.19	0.82	0.63
160	2.15	1.71	1.35	0.94	0.72
180	2.72	2.16	1.71	1.19	0.91
200	3.36	2.67	2.11	1.47	1.12
213	3.81	3.03	2.40	1.66	1.27
225	4.26	3.38	2.68	1.86	1.42
250	5.26	4.18	3.30	2.29	1.75
280	6.59	5.24	4.14	2.87	2.20
300	7.57	6.01	4.76	3.30	2.53
315	8.34	6.63	5.24	3.64	2.78
355	10.60	8.42	6.66	4.62	3.54
400	13.45	10.69	8.46	5.87	4.49
450	17.03	13.43	10.70	7.42	5.68
500	21.02	16.70	13.21	9.17	7.02
560	26.37	20.95	16.57	11.50	8.80
600	30.27	24.05	19.03	13.20	10.10
630	33.37	26.52	20.98	14.55	11.14
710	42.39	33.68	26.64	18.48	14.15
750	47.30	37.58	29.73	20.62	15.79
800	53.82	42.76	33.82	23.46	17.96
900	68.11	54.12	42.81	29.70	22.73
1000	84.09	66.81	52.85	36.66	28.07
1200	121.09	96.21	76.10	52.80	40.42
1400	164.81	130.95	103.58	71.86	55.01
1600	215.27	171.04	135.29	93.86	71.85
MDPE Maximum Permitted Pulling Stress @ 20°C = 7.1 MPa					

Maximum Permissible Winching Loads for HDPE/PE-100 (@20°C)

Pipe Size	Maximum Pulling Load (Tonnes)				
	SDR-26	SDR-33	SDR-42	SDR-61	SDR-80
75	0.63	0.50	0.40	0.28	0.21
100	1.13	0.89	0.71	0.49	0.38
110	1.36	1.08	0.86	0.59	0.45
125	1.76	1.40	1.10	0.77	0.59
150	2.53	2.01	1.59	1.10	0.84
160	2.88	2.29	1.81	1.26	0.96
180	3.65	2.90	2.29	1.59	1.22
200	4.50	3.58	2.83	1.96	1.50
213	5.10	4.06	3.21	2.23	1.70
225	5.70	4.53	3.58	2.48	1.90
250	7.03	5.59	4.42	3.07	2.35
280	8.82	7.01	5.54	3.85	2.94
300	10.13	8.05	6.36	4.42	3.38
315	11.16	8.87	7.02	4.87	3.73
355	14.18	11.27	8.91	6.18	4.73
400	18.00	14.30	11.31	7.85	6.01
450	22.78	18.10	14.32	9.93	7.60
500	28.13	22.35	17.68	12.26	9.39
560	35.28	28.04	22.18	15.38	11.78
600	40.50	32.18	25.46	17.66	13.52
630	44.66	35.48	28.07	19.47	14.91
710	56.72	45.07	35.65	24.73	18.93
750	63.29	50.29	39.78	27.59	21.12
800	72.01	57.21	45.26	31.40	24.03
900	91.13	72.41	57.28	39.74	30.42
1000	112.51	89.40	70.71	49.06	37.55
1200	162.02	128.73	101.82	70.64	54.08
1400	220.52	175.22	138.59	96.15	73.61
1600	288.03	228.86	181.02	125.58	96.14
MDPE Maximum Permitted Pulling Stress @ 20°C = 9.5 MPa					

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Winch Capacity Requirements

PE Liner Pipe Size (mm)	Winch Capacity (Tonnes)
75 – 300	5
300 – 500	10
Greater than 500	20

i) Insertion Pits

The Subline process reduces the cross-section area of the PE liner to some 40% of its original. This reduction greatly facilitates the insertion and winching of the formed liner through the existing host pipe. The reduced cross-section of the liner minimizes the frictional drag of the liner in the host pipe during installation. This, together with the fact that the Subline shape is produced by pushing the liner pipe through the process, means that very substantial lengths can potentially be installed in a single pull in straight host pipeline runs.

Experience has shown that lengths of pipeline of 1,000+ meters may be lined in a single pull using the Subline process, subject to the line, level and size of main. Anyway the length of the Subline insertion pit depends on the diameter and depth of the existing pipeline.

The following table indicates the minimum pit length requirements:

Cover Depth (m)	≤ 1	1 -2	2 -3
Liner Diameter (m)	Minimum Length of Insertion Pit (Meters)		
100	2	3	3
150	4	5	6
200	5	6	7
250	6	8	9
300	7	9	11
400	8	10	11
500	9	11	13
600	9	11	13
800	10	12	14
1000	10	12	15

j) Typical Processing Temperature Range

Typically, minus 5°C to + 30°C (actual range depends on material type and wall thickness).

4) Quality Control & Construction Inspections Procedures

Thin-walled PE liners installed in high-pressure water supply mains rely on the residual structural strength of the host pipe to act as the primary pressure containment envelope over the remaining life of the asset. It is therefore important to determine whether the host pipe is generally in structurally sound condition and can be expected to remain so for the rest of the design life of the relined main. A pre-CCTV inspection should be conducted to:

a) Verify that the main is free of significant cracks, holes, gouges or other indications of structural damage.
b) To locate any protruding service connections or other obstructions that could damage the liner during installation
c) Locate any bends or offsets in the line and grade of the pipe
d) Locate main line fittings and branch connections

The CCTV inspection should be supplemented with appropriate non-destructive testing methods if there is evidence of structural impairment. If host pipe coupons are to be taken, consider using pipe sections to be removed at the planned installation openings.

PE pipes can be damaged by improper shipping or handling during unloading. The installer should inspect the pipe during the unloading operation to verify that the pipe was not damaged in shipping or during unloading. Photos should be taken to document any damages and support claims. PE pipes should be stored at the job site in a manner that is consistent with the manufacturers recommendations and periodically inspected to detect accidental construction damage or damage by vandalism.

The fused lengths of PE pipe shall be properly supported during installation to assure that it is not damaged by dragging on the ground or by contact with sharp edges of traffic plates.

The open end of the host pipe should be appropriately covered to prevent any sharp edges that could damage the PE liner during insertion.

The host pipe should be kept sealed during any interruptions and overnight to prevent entry of animals or by rainwater or vandalism. It is critical that the host pipe remain clean during the entire lining effort.

After the liner has been installed and re-rounded, it should be subjected to a hydrostatic pressure test at a pressure equal to or greater than the desired pressure rating of the rehabilitated main. Generally this test is conducted at pressures and for durations equal to the owner's or code requirements for a new facility with the same pressure rating. The pipe to be tested should be adequately braced to withstand the expected end thrust forces and assure safety of the workers and the public.

After the lined main is drained, it should be re-inspected with CCTV to assure that the liner is properly expanded and free of any significant imperfections.

The final tie-in fittings should be visually inspected at operating pressure to assure that there is no leakage.

3) *Rolldown Case Study*

Abstract

New York City in general and the borough of Manhattan in particular has one of the most congested infrastructures in the world, rivaling some cities in Japan. Conventional replacement in this environment often involves hand excavation and combined with street opening restrictions and permits, makes the cost of replacement amongst the highest in the country. NO-DIG methods, which eliminate much of the excavation and restoration costs, have the potential to reduce costs by 50 percent or more.

This paper describes the first Rolldown project in the United States performed during the fall of 1994 on a section of the Broadway/Van Cortland Park main in the Bronx, NY. Consolidated Edison of New York used the Rolldown method to rehabilitate approximately 4,300 feet of 12-inch cast iron gas main.

Con Edison Rolldown Case Study

Con Edison's Bronx Customers Service department selected a site on Broadway just south of the New York City/Yonkers border adjacent to Van Cortland Park where a 12-inch cast iron main required frequent joint leak repairs. This site was particularly appealing because it was long enough to evaluate several methods in the same environment and had relatively few services. The main was installed in 1905 and was expected to contain some accumulation of coal tars from the day of manufactured gas, typical of other mains we could line in the future. One known disadvantage was that the main was buried in the middle of the road with over eight feet of cover and located directly beneath an abandoned trolley system with steel rails and wood ties. The roadway consisted of asphalt over a concrete base on top of the original cobblestone pavement. Any required excavation would be slow and expensive and planning to reduce digging was more important than usual.

The project was performed by PIM Corporation under a subcontract agreement with Subterra of the United Kingdom. The criteria was to tight fit line the existing 12-inch low pressure main with high density SDR-11 polyethylene pipe so that system could be upgraded to 100 psig in the future. The custom ordered pipe was supplied by Phillips Driscopipe and sized slightly larger than the inside diameter of the cast iron main. The total length of the first project was approximately 1,800 feet and was to be installed in three sections because of large branch connections and the desire not to block street intersections.

To begin the project suitable sized launch and receiving excavations had to be made to access the main for inspection and cleaning and for the pipe insertion to follow. After the main was decommissioned and purged of gas, a CCTV camera inspection was undertaken to establish the number and location of protruding fittings. The camera survey also revealed the internal condition of the main and determined the correct level of pre-cleaning required prior to new pipe insertion.

The polyethylene pipe was hydraulically pushed through a set of calibrated rollers rather than pulled through rollers or dies. Because the pipe was under compression rather than tension there was little change in pipe length and the diameter reduction of approximately 6-8% occurred with a corresponding increase in pipe wall thickness. When the pipe emerged from the set of rollers, it stayed in its reduced diameter state for several days (depending on ambient temperature). This interesting feature enables the polyethylene pipe to be rolled down on one day and inserted the next. For this project it was possible to roll down and insert on the same day.

The polyethylene pipe, now reduced in diameter, was then slip-lined in the conventional manner. In order to keep the frictional forces to a minimum, a water-based lubricant was used. The longest installation length for this project was 800 feet and a pulling force of 5,000 lbs was all that was necessary to install the pipe.

The newly installed polyethylene pipe had to be reverted to ensure a tight fit against the inside of the old cast iron pipe wall. This was accomplished by fitting special purpose flange adapters to the ends of the rolled down pipe after resizing the pipe ends. With the pipe ends sealed the pipeline was filled with water and pressurized to about 350 psig and allowed to revert overnight.

With reversion complete the special end fittings were removed and the pipe was drained and swabbed dry. The new custom sized pipe was reconnected to standard size 12-inch polyethylene pipe using special reducing electrofusion couplings.

Although this first project did not require the attachment of new existing services onto the rolled down pipe, Con Edison confirmed that this could be accomplished with equipment already in use. A laboratory test was also conducted to assure that standard size polyethylene service tees could be properly fused to the slightly smaller rolled down pipe. If a new service were to be attached to the lined section of pipe in the future, a window cutter would be used. Experience with this tool assured that it is possible to cut out a window without damaging the new plastic main.

Conclusion

Bronx Gas Construction reactivated the line on October 14, ten days after taking the main out of service. Richard V. Lawson, Manager of Bronx Gas Construction, was so pleased with the project that he immediately planned two additional projects bringing the total footage lined to approximately 4,300 feet. Mr. Lawson said that “Rolldown proved to be ideally suited for the installations of high density, heavy wall SDR-11 pipe and this project demonstrated that the vendor’s equipment and crews were capable of working in a busy city environment”. As Mr. Frank Ayers, Principal Research Engineer, observed, “The Rolldown technique avoided the high pulling forces associated with most other modified liners and that the controlled reversion feature allowed more flexibility for routine insertion”.

The success of the project was made possible by the team of Bronx Gas Construction and Research and Development, working closely with PIM Corporation and experienced Subterra technicians. The first usage of this technique in the United States demonstrated that the Rolldown technique could be effective polyethylene lining system for gas mains operating at pressures up to 100 psig.

PART SEVEN: SUBLINE TECHNOLOGY

1) *Evaluation & Investigation of the existing Materials & Installation Methods for Lining Technology*

a) Introduction

The *Subline* process, which has been developed and patented by Subterra, is used for the cold site folding and insertion of polyethylene (PE) liner pipes into existing pressure pipelines. The *Subline* liner provides a continuous lining which prevents further internal pipeline corrosion, seals leaking joints and corrosion perforations, and provides a hydraulically smooth surface which, together with the thin-wall sections used, generally results in enhanced flow characteristic after lining. *Subline* generally uses thin wall PE pipe and may be considered a semi-structural liner. Full structural integrity depends upon the matrix of the original pipe and liner combination. Individual pipe lengths are butt fused on site into appropriate string lengths to suit particular site conditions and installation lengths. The strings are then processed through the *Subline* hydraulically – operated gripping machine and forming device which produces the characteristic "heart" – from *Subline* cross section. The cross-section of the sublined pipe is typically 40% less than the cross-section of the original PE pipe. As the pipe leaves the *Subline* forming equipment, it is held in its temporary new configuration by restraining bands.

The deformed pipe may be either inserted directly into the existing pipeline or held above the ground temporarily for later insertion. The insertion operation may be stopped as required, and long continuous lengths can be inserted in a single operation.

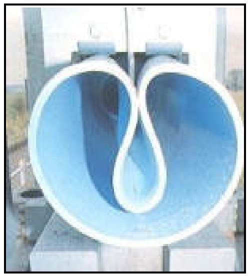
Depending on site conditions section lengths up to 3300ft (1000m) can be inserted in a single pull over a range of diameters from 3" (75mm) to 64" (1600mm). After the sublined PE pipe has been inserted into the existing main, the ends of the liner are sealed off. The liner is then filled with water and pressurized for the reversion process.

During the reversion process, the restraining bands burst under the internal pressure, allowing the liner pipe to return to its original round shape and size, forming a tight fit within the host pipe. No subsequent grouting is required.

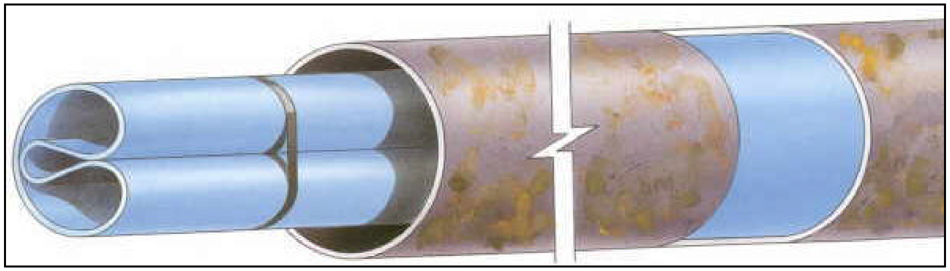
A variety of end terminations can be fitted to complete the system.

b) Description of the process

Close-fit it Thin-Wall Liners for Pipes from 3inches to 60 inches Diameter



The **Subline** system uses standard polyethylene (PE) pipe to create a close-fit liner within an existing pipe. It is specifically designed for thin-wall applications in diameters up to 60 inches. In the **Subline** system PE pipe is pushed through formers which fold it into a 'C' shape which is temporarily held by strappings. This creates a clearance for the installation of the PE pipe into the original pipe to be renovated. The folded pipe is then pressurised which snaps the strappings allowing it to revert back to its original shape, to form a close fit within the host pipe, sealing leakage and preventing corrosion.

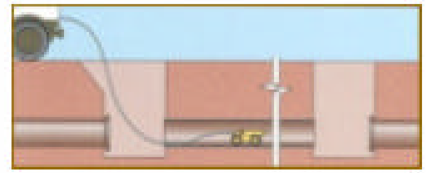


Features

Cold Process: No heating equipment required, the process is carried out at ambient temperature.
Minimal Elongation: Low winching forces, minimises residual stresses after installation.
Process Stop-Start Capability: Flexibility of insertion procedures.

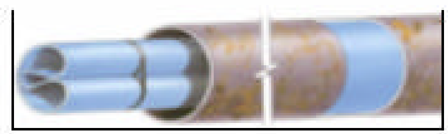
- **Available from 3 to 60 inches diameter**
- **Cures leakage**
- **Stops internal corrosion**
- **Quick installation**
- **Thin wall and smooth bore maximises flow capacity**
- **Close-fit lining**
- **Uses standard PE material**
- **Does not disturb adjacent services**
- **Wall thicknesses from 1/4" inches to 1"**
- **Can negotiate bends up to 11-1/4° to 22-1/2°**
- **Long length installation possible (>3000 feet)**

How to Install Subline



- **Stage 1:**
Cleaning: The internal corrosion and any deposits are cleaned off and the pipe surveyed with CCTV. If there are any problem areas such as intruding services these are dealt with at this stage.
Pre-installation: The polyethylene (PE) pipe string is created by butt fusion welding individual lengths of pipes, which can be supplied as coils or sticks.

- **Stage 2:**
Processing: The pipe string is then passed through the Subline machine, folded into the 'C' shape and held by strapping. This folded pipe is then pulled into the existing line.



- **Stage 3:**
Reversion: When the PE pipe is in position within the host pipe it is filled with water and pressurised, breaking the strappings and reverting the PE to its circular shape, forming a close-fit thin wall liner.

- **Stage 4:**
Reconnection: The lined main is reconnected to the system using proprietary couplings designed specifically for use with lined mains.

- **Stage 5:**
Service reconnection: Service pipes can be reconnected by the use of proprietary fittings designed specifically for use with lined mains.

Problems Solved by Subline

- **Pipeline internal corrosion problems**
  Subline PE pipe linings provide a highly effective, corrosion-resistant barrier between the bore of the existing pipe and the conveyed product.
- **Water quality problems associated with pipeline internal corrosion**
  Subline PE pipe linings arrest the pipe bore tuberculation and corrosion which contribute to conveyed water quality problems in water supply and distribution pipelines. In addition, the smooth surface of Subline PE linings helps resist the formation of other pipe bore deposits in operation.
- **Leakage from corrosion holes and failed pipeline joints**
  Subline PE pipe linings provide a continuous pressure-tight envelope inside the existing pipeline which can be designed effectively to span corrosion holes and joint gaps.
- **Flow capacity problems arising from pipe bore tuberculation and deposits**
  Subline PE pipe linings present a smooth surface to the conveyed product, which helps maximize the flow capacity of the lined pipe. Thanks to the extremely low friction coefficient of the PE liner, and the thin-walled PE linings which can be installed by the Subline process, in many cases it is possible to increase the hydraulic capacity of previously heavily tuberculated mains and deposit-fouled pipelines.

c) Specifications for pipeline renewal

Subline Process	
Design considerations	
• Available for 3 – 60 inches diameter pipes • Uses SDR 30-60 thin wall, MDPE or HDPE • Site location/access facilities • Host pipe type and wall thickness design • Pipeline internal operating pressure • Pipeline length • Type of joint and flange rating of host pipe • Conveyed fluid composition • Operating temperature • Internal Condition of Host pipe (scale build up, internal lining/coating etc) • Site drawings (showing vertical and horizontal offsets)	
Materials and fittings	
Host Pipe Material	• Identification and indication of its structural integrity required • Existing pipeline inside diameter must be quantified to allow for optimum sizing of liner pipe
Liner Material	• Polyethylene resin compound must be specified as either medium or high density in accordance with ASTM Standard D3350 • Physical and mechanical performance properties of the polyethylene pipe material to be deformed must be available to optimize the performance and installation of the liner
End Terminations	• *Semi-structura1 capacity:* Proprietary liner end terminations are to be used. These are typically end load resistant up to the strength of the liner only. Anchorage at fittings and/or flanged ends should be designed for thrust restraint.
Bends and fittings	*Subline* is capable of negotiating bends depending on the liner pipe dimension and site condition. • *Semi-structural application*: bends up to 22.5° • *Structural applications*: 11.25° are typical. All other fittings and tees must be removed. Such excavations may however, conveniently be used as insertion and receiving pits for the *Subline* installation.

System Installation	
Accessibility	The line of the existing pipeline must be located, noting any potential problems, such as bends, hydrants and valves.
Excavations	Insertion and receiving pits should be excavated at appropria te locations along the length of the existing main. The positioning of the machine and space required for liner pipe "stringing out" should be considered when selecting launch site
Cleaning	Good host pipe internal diameter surface preparation is required as a basis for the *Subline* lining process. Adequate cleaning processes include the use of scraper pigs followed by a "rubber pull-through", wire brush, pressure jetting, pressure pigging. Other cleaning processes may be used which can be shown to remove excess debris from the inside of the pipeline.
CCTV Inspection	CCTV inspection should be carried out before and after cleaning. Any significant protrusions, which will inhibit cleaning, should be removed. The post cleaning inspections should confirm the cleanliness of the main, and identify any remaining protrusions into the main; if significant they should be removed prior to lining.
Section lengths	Installation segment lengths are normally determined jointly by the owner/engineer and the installer. These are governed primarily by site and pipeline factors such as terrain, accessibility, bends and fittings
Bends/Fittings	The ability of Subline formed PE liner pipe to flex easily about its mirror plane, and its greatly reduced cross-section area makes it possible for Subline to negotiate small angle bends. In some semi-structural applications up to and including 45° bends can be satisfactory lined with minimum bend radii of 8 times the nominal diameter of the liner, depending on the liner wall thicknes s and host pipe diameter.
Size Verification	The outside diameter of the PE liner pipe is typically chosen to be approximately 0.2" (5mm) smaller than the actual minimum inside diameter of the host pipe. This is to ensure that the liner (which expands on reversion) will form a wrinkle -free close fit when reverted under pressure inside the host pipe. An accurate measurement of the host pipe internal diameter must be available.
Liner Installation	Folding and insertion of the liner can be carried out as a single operation (as the deformation can be a stop/start process). Alternatively the liner may be folded prior to installation and stored alongside the pipeline. Retraining bands hold the liner in its deformed profile during the installation procedure. An approved lubricant (e.g. bentonite) is used to aid the installation process.
Temperature	• The PE liner pipe should not be deformed at temperature less than 42°F (5°C). • Care should be taken and advice sought for installation temperature in excess of 86°F (30°C)
Jointing	Pipe strings must be jointed prior to being pushed through the *Subline* machine. Conventional butt fusion is the required method and the external weld beads should be removed.
Winch loads	The deformation process involves *pushing* the liner pipe through the *Subline* machine, as such the winch loads required are low. This enables long lengths to be inserted in one pull.
Machine Capacities	Subterra currently has 4 types of machine, which cater for the following liner outside diameter ranges.

Type of Machine	PE liner Outer Diameter Inches	mm
1	3-8	100-200
2	8-14	200-350
3	16-40	400-1000
4	40-64	1000-1600

End Fittings/Reversion

- The ends of each section of the *Subline* liner pipe should be re-rounded to accept a suitable end fitting for reversion. Hydraulic squeeze-off tools may also be used for reversion of PE. The operating pressure of the system dictates the choice of the connection.
- When the *Subline* liner pipe is such that it is not fully structurally rated, all points where the PE leaves the constraints of the host pipe should be supported against the pipeline design internal pressure.
- Reversion pressures are dependent on temperature, liner pipe material and DR. The pressure should be maintained for at least 12 hours. During this time, the line and fittings are inspected for leaks. Chlorination (if required) can be carried out at this time.
- Before draining the liner both ends of the reverted section should be vented to prevent the occurrence of vacuum collapse.
- The end terminations enable standard fittings to be attached.

Semi-Structural: Liner design guarantees long-term hole/gap spanning capability under design operating conditions. Structural support is necessary from the host pipe to withstand general operating pressures/external loads.
Fully structural: No structural support required from host pipe against internal/external pressures/loads.
Non-structural: Anti-corrosion barrier only. No gap bridging capability. (e.g. Epoxy resin lining).

Subline Process	
Potable Water Applications	The *Subline* processes use PE liner pipe manufactured from standard pipe-grade resins. Where the PE pipe to be processed by *Subline* already has a National approval for use in contact with public potable water supplies, the resultant liner will retain this approval. In particular, the internal surface of the PE pipe liner is not contacted by the *Subline* process. Furthermore, the reversion of the liner to a close fit with the host pipe can subsequently be carried out by pressurization using cold water taken from the public supply (where available). The pipeline fittings must also be water quality approved.
Continuous Barrier Liner	• Arrest internal corrosion of host pipe. • Prevents leakage from holes, joints
Liner Pipe Made from Standard Pipe Grade Resins	• Uses materials already approved in country for potable water/gas application. • Standard PE resin liner pipe materials generally already well characterized: usually manufactured under a formal QA scheme
Thin-walled PE Liner	Structural/Semi-structural PE liner • Structural liner is effectively a new pipeline installation. • Semi-Structural applications minimize liner materials usage/costs, maximize free bore of relined pipeline
Close-fit liner	• Maximizes flow capacity. • Grouting not required.
Smooth liner bore	Maximizes flow capacity
Simple Process Equipment	Available for all diameters of PE pipe (75-1600mm)
Ambient Temperature Process	No process heating requirements
Shape of the liner	*Subline* shape is 40% of the original liner cross-sectional area: • Very easy insertion into host pipe. • Minimizes friction. • Minimizes winching loads. • Permits negotiation of bends up to 45^o.
Process Specification	Pipe folded by pushing through former (no tension required): • Insertion winching loads required only overcoming friction between liner and host pipe. • Process can be stopped/restarted without detriment.
Install Liner Direct from Machine or as Separate Operation	On-site operational flexibility and convenience
Low Installation Winching Loads	Maximizes insertion lengths (single pulls > 750 meters already achieves)
Process Stop/Start Capability	On-site operational flexibility and convenience
Reversion to Close-fit with Host Pipe using Water at Ambient Temperature	• Simple reversion procedure • No process heating/specialist pipe shape reforming requirements
Well-characterized PE Liner ability to span Corrosion Holes/Joints Gaps	Validated 50-year liner design procedures available
Pipe Rehabilitation Process	Utilizes existing pipeline asset as a conduit
Minimum Dig Process	• Minimum disturbance of adjacent services and structures. • Minimizes the requirement for imported natural fill materials for re-instating excavations. • Reduces disposal of excavated material to landfill. • Small site footprint. • Less environmental/social disruption compared with open-cut laying.

e) Material qualifications

Using the *Subline* system, thin-walled polyethylene pipes are fused into strings of the required length. These are then folded on site at ambient temperature using a special forming machine. In the folded conditions, the PE string is pulled into the existing concrete main and then filled with water at ambient temperature and re-rounded under pressure. This means that during the *Subline* process, the PE-liner is subjected to significant deformations. In fact the pressurization phase first burst the temporary restraining bands and than, with the increase of the reversion pressure, re-round the liner. The durability of the installed liner will thus depend on the effects of the cold deformation process and on the capacity of the material to withstand the installation stresses and subsequent operating conditions, such as span gaps in leaking joints, corrosion holes, etc. Polyethylene is a typical thermoplastic material. In this respect, the short-term properties differ significantly from those for the long term. In the short term, PE behaves somewhat like a hard rubber, but in the long term the material resembles pitch. It collapses slowly under the influence of its own weight. This is the reason why in utilizing PE pipes for relining we want to make sure of both the short term and the long-term properties of the material.
WRK Amsterdam Utrecht, a water transport company, set up a project (WRK Amsterdam Utrecht → WAU) in order to make sure that the concrete mains renovated with the PE-liner would last for at least 50 years. KIWA (Netherlands Institute for examination of water supply pipes and fittings) took the following examination standards as a starting point for the test to be performed:

- BRL-K 533/03 Pipes of PE for the transport of drinking water
- BRL-K 558/01 Pipes of PE, folded at the factory site, for the renovation of mains for the transport of drinking water

Based on the results of long-term tests at various temperatures, indication have been obtained that the chosen material will not fail in a brittle manner at the temperature of the water to be transported over the required design life of 50 years. Of course this life expectancy is determined by the complete design of the liner, i.e. taking into account such design criteria as implosion, potential angular deflection of the joints and settlement of the pipeline in the low bearing capacity of the soil. All these aspect of the pipeline renovation design have been examined by KIWA and as a result there was no evidence that the renovated mains would not satisfy the client's requirement of 50 years life expectancy.
In addition to this tests Subterra submitted a trial section of liner to Pipeline Developments (PDL) for testing in order to determine the effect on the impact and slow crack growth resistance of the PE liner as a result of the folding process and subsequent reversion. The trial section of the liner had been folded to the same degree required for the insertion into the host pipe. A section of the liner that had not been folded was also supplied to allow comparison with the folded trial liner.
The sections of 1200 mm (48 inches) SDR 41 PE liner that were supplied were produced by the American manufacturer Plexco, using a black PE 3408 pipe resin.
Some results were:

- Examination of the fracture surfaces from both the original and Sublined pipes indicated that failure had proceeded in an exclusively ductile manner.

- The slight differences in the impact toughness of the original and Sublined pipes were not considered to be due to the folding process.

And finally:

- On the basis of testing that were conducted, the Sublining process carried out on a section of 1200 mm (48 inches) SDR 41 (Plexco) liner, appears to have caused no dentrimental effect to the notched impact toughness or slow crack growth resistance.

Product Approvals

a) Potable Water Applications

The Subline process uses PE liner pipe manufactured from standard pipe-grade resins. Where the PE pipe to be processes by Subline already has a National approval for use in contact with public water supplies, the resultant liner will retain this approval. In particular, the internal surface of the PE pipe liner is not contacted by the Subline process. Furthermore, the reversion of the liner to a close fit with the host pipe can subsequently be carried out by pressurization using cold water taken from the public supply (where available). The pipeline fittings used must also be water quality approved.

b) Effect on Strength Characteristics

Tests carried out to date have shown that correctly-processed and reverted Subline PE liners meet the Key mechanical strength requirements for virgin PE pipe of the same grade.

Test	Material	Size/SDR	Unformed Material	Processed Material	Target
Tensile Strength (Mpa)	PE-100 PE-100 PE-80 PE-80	225/17.6 560/26 450/42 469/21	23 25 18.7 19.1	25 26 18.2 18.9	19 19 15 15
Unnotched Hydrostatic Pressure Test @ 80°C (Hours)	PE-100 PE-80	225/17.6 469/21	- -	> 1,100 @ 4.6 MPa > 1,400 @ 5.0 MPa	> 1,000 @ 4.6 MPa > 1,000 @ 4.6 MPa

2) Evaluation of the current state of practice

The Subline technology has been extensively and successfully used in the USA and Europe. In the USA the first installation was completed in May 1997, while in Europe the same technique has been used for the first time in 1992 in Fontburn (UK).

USA Subline Work Completed Between 1994 and 2000

Installation Date	Length (feet)	Diameter (inches)	Service	Location	Client	Years in Service
Dec-00	125	12	W	Queens Blvd, Queens, NY	NYCDEP	1
Dec-00	125	12	W	60th St, Queens, NY	NYCDEP	1
Dec-99	252	12	W	Liberty Av, Queens, NY	NYCDEP	2
Nov-98	183	12	W	Hillside Av, Queens, NY	NYCDEP	3
Oct-98	1,828	16	G	35th Ave, Queens, NY	Con Edison	3
Dec-97	317	4	G	Manderson, WY	Keyspan Energy	4
Dec-97	1,230	3	G	Manderson, WY	Keyspan Energy	4
Nov-97	1,000	4	G	Manderson, WY	Keyspan Energy	4
Nov-97	3,000	3	G	Manderson, WY	Keyspan Energy	4
Jun-97	800	36	G	Ave A, Manhattan, NY	Con Edison	4
May-97	1,200	30	G	Tinton Ave, BX, NY	Con Edison	4
Subline Total = 10,060 ft						

International Subline Installations

Installation Date	Length (feet)	Diameter (inches)	Service	Location	Client	Years in Service
2001	5,000	16	W/S	Stockholm, Sweden	NCC	0
2001	175	12	S	New Jersey, USA	Middlesex County Water	0
2001	400	12	W	New York, USA	NYCDEP	0
2000	3,400	38	W	Amsterdam, Holland	Amsterdam Water	1
2000	1,140	24	S	Los Angeles, USA	Thousand Oaks	1
2000	1,250	16	W	Padova, Italy	AMAG	1
2000	1,000	24	W	Stokholm, Sweden	Stockholm Water	1
2000	42,000	20	W	Lincoln, UK	Anglian Water	1
1999	4,520	16	S	Sodertalje, Sweden	NCC	2
1999	24,800	20	W	Rufford, UK	Severn Trent Water	2
1999	8,680	48	W	Utrecht, Holland	WRK Water Co.	2
1999	558	18	S	Haarlem, Holland	Amsterdam Water	2
1999	2,310	12	S	Nice, France	SMCE	2
1999	4,712	24	G	Padova, Italy	AMAG	2
1999	2,728	36	S	Beckton, UK	Thames Water	2

1998*	930	12	W	New York, USA	NYCDEP	3
1998*	1,860	16	G	New York, USA	Con Edison	3
1998*	465	9	I	North Sea, UK	Mobil/AMEC	3
1998*	26,66 0	30	W	Camps, UK	West of Scotland Water	3
1997	620	36	G	New York, USA	Con Edison	4
1997	1,085	30	G	New York, USA	Con Edison	4
1997	22,94 0	6	W	Thimbleby, UK	Yorkshire Water	4
1997	7,440	30	W	Burnhope, UK	Northumbrian Water	4
1997	9920	18	W	Wakefield, UK	Yorkshire Water	4
1996	930	5	I	North Sea, UK	Mobil/AMEC	5
1994	7,750	24	W	Southampton	Southern Water	7
1993	5,980	20/24	W	Oakwood, UK	Essex Water	8
1992	9,300	18	W	Fontburn, UK	Northumbrian Water	9

Key:

- W = Water Distribution
- G = Gas Distribution
- S = Pumping Sewer (Force Main)
- I = Industrial (Water Injection)

3) Evaluation of Current Design Procedures

The Subline process is typically used to install thin-walled PE liners into existing pipelines. Thus, in general, the liners installed have sufficient structural strength in their own right to withstand the full operating pressure of the pipeline throughout the whole of the planed asset life following lining (typically 50 years minimum). This is particularly true for liners to be installed in high-pressure water supply mains or similar. In these instances, the liner relies on the residual structural strength of the host pipe to act as the primary pressure containment envelope over the remaining life of the asset. It is therefore important that the host pipe is generally in a structurally sound condition, and can be expected to remain so throughout the rest of the design life for the relined main.
Under such circumstances, thin-walled PE liner pipe is capable of spanning

- Corrosion holes
- Former ferrule tapping holes
- Circumferential gaps (e.g. pulled joints, circumferential fractures)

and other similar features, subject to certain design limits. However, such thin-walled, non-pressure rated liners are generally not suitable for lining pipelines with, or likely to be subject to, longitudinal splits. Clearly this is not always the case, as some thin-wall PE liners may have sufficient long-term strength to withstand low service pressures, such as those in low pressure water mains and gas pipelines, where the internal pressure does not exceed the 50-year strength of the liner.
The Subline process involves the folding of PE pipe at ambient temperature, holding it in this reduced form temporarily, inserting it into the existing main to be lined, and reverting to a

close fit with the existing main by pressurization with water at ambient temperature.

The Subline process uses PE pipe made from standard, pipe grade PE resins (PE-80, PE-100). Typically, the Subline process uses PE pipe with Standard Dimension Ratios (SDR = outside diameter/wall thickness) of 26 or greater, subject to certain practical limitations. It is ideally suited for dealing with pipelines, which are essentially in a structurally sound condition, but which are suffering from localized corrosion perforation and/or leaking joints and/or deterioration of conveyed product quality arising from internal pipeline corrosion and/or deposition, and for preventing corrosion in new pipelines.

Major benefits usually associated with conventional PE pipe lining processes, such as the reduction or elimination of internal corrosion, the improvement in flow capacity created by the smoothness of the new PE pipe, etc., are further enhanced with the thin-wall liner approach. The thinner wall increases cross-sectional area, when compared with the conventional sliplining, while reducing the amount (and consequently the cost) of the PE liner material. The following table shows examples of the benefits for 48 inches diameter pipe.

Potential Flow Improvements and Reductions in Material Usage (48 inches)

Pipe	Liner SDR	Actual Bore Diameter	Liner Wall Thickness	Actual Flow	Relative Flow		Liner Weight Saving
		[inches]	[inches]	[US gal/sec]	vs. host [%]	vs. SDR 11 [%]	vs. SDR 11 [%]
Host	-	48.03	-	569	100	-	-
Liner	11	38.82	4.32	609	107	-	0
Liner	17	41.90	2.80	744	131	122	33
Liner	26	43.86	1.83	840	148	138	55
Liner	33	44.64	1.44	879	155	144	64
Liner	42	45.26	1.13	912	160	150	72
Liner	50	45.63	0.95	932	164	153	76
Liner	61	45.98	0.78	950	167	156	80
Steel	36”/0.375”	35.25	-	466	82	-	-
Epoxy*		48.0	0.04	1,062			
Cement*		46.6	0.71	788			

Assumptions:

Hazen-Williams “C”-values:

Cast iron host = 80 (100 years old; moderate/appreciable corrosion)
PE liner = 150
New coated steel pipe = 150
Epoxy = 150
Cement = 120

Hydraulic gradient = 0.005
Class of liner fit = 1%

*** Thin Film: No Structural Benefit**

From the previous Table we see that using Subterra PE liners we gain an immediate increase in flow capacity, up to 67%. Based on the fact that the maximum design pressure must be 150 psig, we can observe that even using the SDR 11 Liner, which is a very heavy liner with a wall thickness of 4.32 inches, we still gain an increase of 7% of the relative flow if compared with the host pipe.

The use of thin-walled PE liners depends primarily on the ability of the host pipe to provide the primary pressure retention capability, while the PE liner provides the sealing membrane. While the use of a thin-wall liner to seal leaks in pressure pipelines is not a new concept, it is not as well understood as a pipeline rehabilitation methods. For this reason a number of technical questions have to be resolved in relation to the ability of the liner to withstand the range of operational conditions to which it is likely to be exposed:

c) The ability of the liner to withstand positive external pressures without buckling collapse, either during pipe empty situations (e.g., pre-commissioning, maintenance, etc.) or under partial or full vacuum arising from pipeline surge events.
d) The ability of the pipe to span localized corrosion holes and/or pipeline joint gaps in the main without failure under service pressure throughout the asset design life.

The PE liner pipes installed by the Subline process which have design service ratings greater than the actual operating pressure of the host pipe require no structural support from the host main to withstand the internal pressure.

Those PE liner pipes which have design service pressure ratings less than the operating pressure of the host pipeline can also be installed using the Subline process, provided that the host pipe remains generally intact, and has sufficient residual strength to contain the expected service pressures.

Validated design procedures have been developed for selecting the correct PE liner thickness for such situations to ensure that the liner will be capable of bridging design corrosion holes and joint gaps without failure over a minimum 50-year design life. Subline PE liners may therefore fall into the categories of semi-structural or fully-structural linings, depending on the design operating pressure of the lined host pipeline.

a) Step 1: Check the Availability of Subline

The first step to do in order to design the Subline PE liner is to check the availability of the product. Even the PE pipe is available in the range of 75 to 1,600 mm we have to consider if the pipe itself is suitable for the specific application of interest.

PE pipe Outside Diameter (mm)	Wall Thickness (mm)							
	SDR 11	SDR 17	SDR 26	SDR 33	SDR 42	SDR 50	SDR 61	SDR 80
75	6.8	4.4	2.9	2.3	1.8	1.5	1.2	0.9
100	9.1	5.9	3.8	3.0	2.4	2.0	1.6	1.3
110	10.0	6.5	4.2	3.3	2.6	2.2	1.8	1.4
125	11.4	7.4	4.8	3.8	3.0	2.5	2.0	1.6
150	13.6	8.8	5.8	4.5	3.6	3.0	2.5	1.9
160	14.5	9.4	6.2	4.8	3.8	3.2	2.6	2.0
180	16.4	10.6	6.9	5.5	4.3	3.6	3.0	2.3
200	18.2	11.8	7.7	6.1	4.8	4.0	3.3	2.5
213	19.4	12.5	8.2	6.5	5.1	4.3	3.5	2.7
225	20.5	13.2	8.7	6.8	5.4	4.5	3.7	2.8
250	22.7	14.7	9.6	7.6	6.0	5.0	4.1	3.1
280	25.5	16.5	10.8	8.5	6.7	5.6	4.6	3.5
300	27.3	17.6	11.5	9.1	7.1	6.0	4.9	3.8
315	28.6	18.5	12.1	9.5	7.5	6.3	5.2	3.9
355	32.3	20.9	13.7	10.8	8.5	7.1	5.8	4.4
400	36.4	23.5	15.4	12.1	9.5	8.0	6.6	5.0
450	40.9	26.5	17.3	13.6	10.7	9.0	7.4	5.6
500	45.5	29.4	19.2	15.2	11.9	10.0	8.2	6.3
560	50.9	32.9	21.5	17.0	13.3	11.2	9.2	7.0
600	54.5	35.3	23.1	18.2	14.3	12.0	9.8	7.5
630	57.3	37.1	24.2	19.1	15.0	12.6	10.3	7.9
710	64.5	41.8	27.3	21.5	16.9	14.2	11.6	8.9
750	68.2	44.1	28.8	22.7	17.9	15.0	12.3	9.4
800	72.7	47.1	30.8	24.2	19.0	16.0	13.1	10.0
900	81.8	52.9	34.6	27.3	21.4	18.0	14.8	11.3
1000	90.9	58.8	38.5	30.3	23.8	20.0	16.4	12.5
1200	109.1	70.6	46.2	36.4	28.6	24.0	19.7	15.0
1400	127.3	82.4	53.8	42.4	33.3	28.0	23.0	17.5
1600	145.5	94.1	61.5	48.5	38.1	32.0	26.2	20.0

Suitable for Subline

Suitability depends on PE resin specification

Wall thickness < 3mm

Not recommended for Subline

b) Step 2: Survey the Existing Main to be Lined

In this phase there is the need to identify line, level, and position of manufactured bends, tees and other similar fittings.

c) Step 3: Determine the Size of the PE Liner

The outside diameter of the liner is typically chosen to be approximately 5 mm smaller than the actual minimum clear bore of the host pipeline. This is to ensure that the liner will form a wrinkle-free, close fit when reverted under pressure inside the host pipeline.

d) Step 4: Buckling Stability Check – "Pipe Empty" Condition

It is necessary to ensure that the liner does not collapse in the "pipe empty" condition after installation and reversion when (and if) the lined main is subsequently drained down (either before or after commissioning).
If the groundwater level is above the invert level of the host pipe, the groundwater may enter the annulus between the host pipe and liner through any leaking joints/corrosion holes etc. in the host pipeline. The resulting external hydrostatic pressure of water on the liner has the potential to cause the liner to collapse (buckle).
This could allow more groundwater (and soil) to enter the annular space, which could then prevent a full reversion of the liner to a close fit with the host pipe when re-pressurized.
Design of liners against buckling collapse inside a rigid host pipe can be done using constrained buckling formulae of the form here shown:

$P_{crit} = KE(D/t)^m/SF(1-?^2)$

Where:

Pcrit = Critical external pressure to cause buckling collapse.
E = Flexural modulus of the liner material
D = Outside diameter of the liner
t = Wall thickness of the liner
SF = Design safety factor against buckling
? = Poisson's ratio (0.48 for PE)
K,m = Factors which depend on the class of liner fit (CoF) in the host pipe
CoF = (host pipe bore diameter – liner outside diameter) / (liner outside diameter)

Class of Liner (CoF %)	K	m
0.0	1.00	-2.20
1.0	5.17	-2.74
1.5	5.23	-2.77
2.0	5.27	-2.80
2.5	5.36	-2.83
3.0	5.42	-2.86
3.5	5.49	-2.88
4.0	5.55	-2.91
4.5	5.62	-2.94
5.0	5.69	-2.97

The following table is to determine the maximum permissible liner SDR (i.e. minimum liner thickness) required to avoid the risk of liner collapse in the "pipe empty" condition; this is given as a function of depth of groundwater (H_{crit}) above the mid-height of the host pipe for two specific classes of liner fit (i.e. 1% and 4%):

Depth of Ground Water Above Mid Height of the Host Pipe (H_{crit}) (Meters of H_2O)	Maximum Permissible Liner SDR to avoid buckling in the "Pipe Empty" Condition			
	PE-80/MDPE		PE-100/HPPE	
	CoF = 1%	CoF = 4%	CoF = 1%	CoF = 4%
0.5	78	62	83	66
1.0	61	49	64	52
1.5	52	43	55	45
2.0	47	39	50	41
2.5	43	36	46	38
3.0	41	34	43	35
3.5	38	32	41	34
4.0	37	30	39	32
4.5	35	29	37	31
5.0	34	28	36	30
5.5	33	27	35	29
6.0	32	26	33	28
6.5	31	26	33	27
7.0	30	25	32	27
7.5	29	24	31	26
8.0	28	24	30	25
8.5	28	23	29	25
9.0	27	23	29	24
9.5	27	23	28	24
10.0	26	22	28	23
SF = 1.5				

Note: Step d) can be omitted if there is no risk of the groundwater level rising above the invert level of the host.

e) Buckling Stability Check – "Vacuum Collapse"

It is necessary to ensure that the liner will not collapse if the lined pipe is subject to an internal vacuum during service, for example as a result of a surge event.
The following table is helpful to determine the maximum permissible liner SDR (i.e. minimum liner thickness) required to avoid the risk of vacuum collapse of liner due to surge in service.

Depth of Ground Water Above Mid Height of the Host Pipe (H_{crit}) (Meters of H_2O)	Critical Pressure Differential to Cause Vacuum Collapse (P_{crit})	Maximum Permissible Liner SDR to avoid Vacuum Collapse during Surge Events			
		PE-80/MDPE		PE-100/HPPE	
	bar	CoF = 1%	CoF = 4%	CoF = 1%	CoF = 4%
0.0	1.00	44	36	48	30
0.5	1.05	43	35	47	38
1.0	1.10	42	35	46	38
1.5	1.15	41	34	45	37
2.0	1.20	41	34	45	37
2.5	1.25	40	33	44	36
3.0	1.29	40	33	43	36
3.5	1.34	39	32	43	35
4.0	1.39	39	32	42	35
4.5	1.44	38	32	42	34
5.0	1.49	38	31	41	34
5.5	1.54	37	31	41	34
6.0	1.59	37	31	40	33
6.5	1.64	36	30	40	33
7.0	1.69	36	30	39	33
7.5	1.74	36	30	39	32
8.0	1.78	35	29	39	32
8.5	1.83	35	29	38	32
9.0	1.88	35	29	38	31
9.5	1.93	34	29	38	31
10.0	1.98	34	28	37	31
SDRs given are for full vacuum events. Higher SDRs may be acceptable for partial vacuum events. SF = 1.5					

Note: Step e) can be omitted if there is no risk of vacuum in the lined pipe during service.
These numbers represent the worst-case design scenarios, so that higher SDR's may be acceptable where smaller liner fit deficits are achieved and/or reduced design safety factors are appropriate. The table also illustrates as relatively thin PE wall sections can be safely used at normal depths of cover, in particular in situations where the risk of surge in service is negligible. In this case the pipe-empty condition would be the only criterion for determining liner-buckling resistance.

f) Determine the Hole Spanning Ability of the Liner

The capability of a thin-walled PE liner to span corrosion holes and joint gaps under pressure in the host main has been the subject of extensive research at the University of Bradford, UK (Boot et al, 1995). It has been demonstrated that in the vast majority of pressure pipeline applications the host pipe will only suffer localized corrosion damage during the design life (50 years) of the rehabilitation method. In addition, relevant short and long-term mechanical properties of the PE liner pipe materials were determined and values for both short-term and 50-years exposure were derived. The research team made use of the finite element method to determine materials properties. Results were then extrapolated to give the predicted liner failure pressure after 50 years. These predicted values are shown in the following Figure.

Hole Spanning Chart

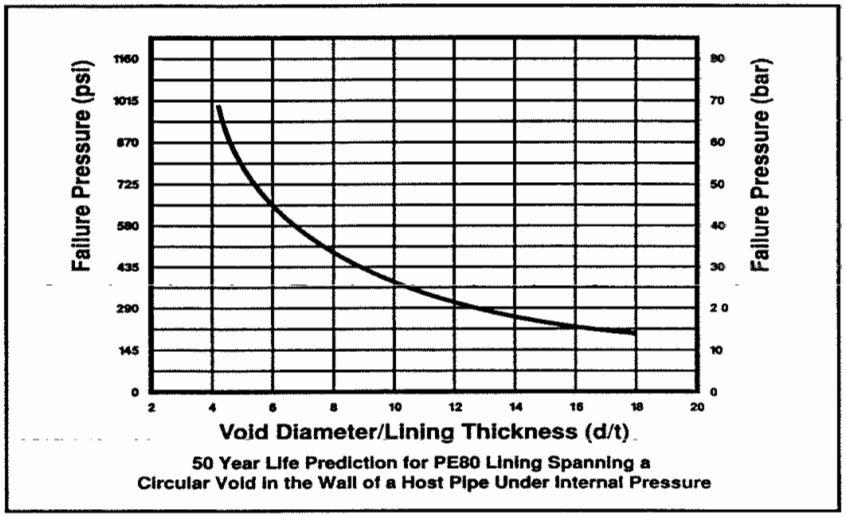


Figure 1 - 50-year life prediction for PE80 lining spanning a circular void in the wall of a host pipe under internal pressure.

Example concerning the Hole Spanning Capability

Using the Hole Spanning Chart we are now able to predict the maximum size of corrosion (etc.) hole that the liner is capable of spanning reliably over a 50-year design life. Assuming that the working pressure is 150 psig (as mentioned above) we see that the curve intersect this value at d/t = 20. In other words this means that if the liner thickness is 1 inch (we are assuming to rehabilitate the pipe using the Subline system), then the maximum size of hole that the liner will safely span over the design life will be 20 x 1 = 20 inches. On the other hand we can say (just to take another example) that if the maximum projected diameter of corrosion (etc.) hole in the host pipe is 30 inches, then the minimum required liner thickness will be 30 / 20 = 1.5 inches.

Note 1
For an irregularly shaped hole, design for an equivalent circular hole which has the same surface area as the actual hole.

Note 2
The Hole Spanning Chart is for PE-80 (MDPE) liners. For PE-100 (HPPE) liners, 50-year design failure pressures can be assumed to be approximately 15% higher.

Note 3
The Hole Spanning Chart is valid for operating temperatures of up to 20°C, and for conveyed products, which do not impair the mechanical properties of PE liner pipe.

g) Determine the Circumferential Gap Spanning Ability of the Liner

Use the Gap Spanning Chart below to determine the maximum width of fully circumferential gap (i.e. "interspace" in the pipeline axial direction) that a semi-structural liner is capable of spanning reliably over a 50-year design life, as follows:

1. Define the maximum continuous operating pressure of the pipeline.
2. Define the desired gap spanning design safety factor.
3. Calculate the minimum required 50-year liner failure pressure (product of the maximum continuous pipeline operating pressure and the chosen design safety factor).
4. If the lines SDR have previously been defined in Steps 4 and/or 5, use this value and the calculated 50-year liner failure pressure to read off/interpolate the maximum gap width that can be safely spanned by the liner over the 50-year design life from the Gap Spanning Chart below.
5. If Steps 4 and 5 have not been required, and the maximum gap width is known or has been defined, use this and the calculated 50-year liner failure pressure to read off the

minimum required liner SDR from the Gap Spanning Chart below.

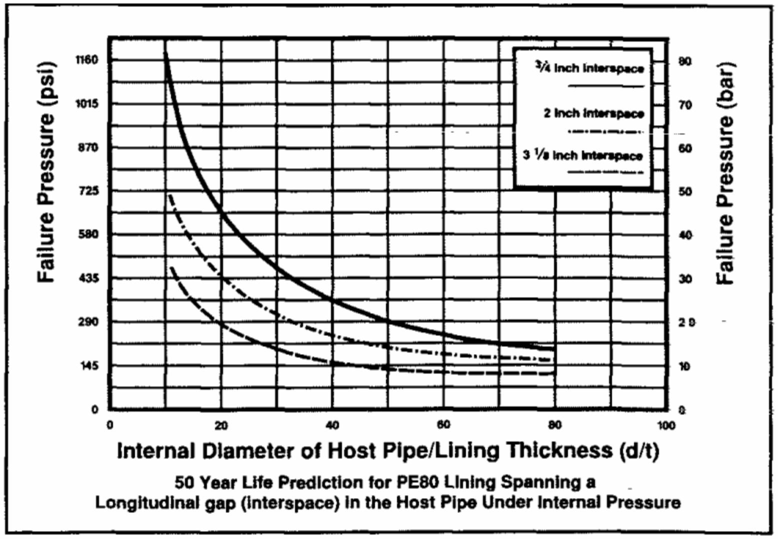


Figure 2 - 50-year life prediction for PE80 lining spanning a longitudinal gap (interspace) in the host pipe under internal pressure.

Example on the Gap Spanning Capability

Let suppose that we are engaged to design a pressure pipe with a design maximum continuous operating pressure equal to 12 bars and a design safety factor equal to 2. Therefore the minimum required 50-year liner failure pressure is equal to 24 bars.

Case 1: The SDR Liner is known

Let assume that the liner SDR is given from steps d and/or e and it is equal to 42. Then from the Gap Spanning Chart, Failure Pressure of 24 bars and Host Pipe Internal Diameter/Lining Thickness (i.e. liner SDR) intersect at a maximum permissible interspace (fully circumferential gap) width is equal to 20 mm.

Case 2: There is no risk of Liner Buckling/Vacuum Collapse/Gap Width Known

Let assume that the maximum gap width is equal to 50 mm. Then from the Gap Spanning Chart we read across from Failure Pressure of 24 bars to the 50 mm interspace line, and we read down to obtain the maximum permissible liner SDR (i.e. minimum liner wall thickness) to ensure safe spanning of the gap over the 50-year design life, i.e. the maximum SDR is equal to 27.

Note 1

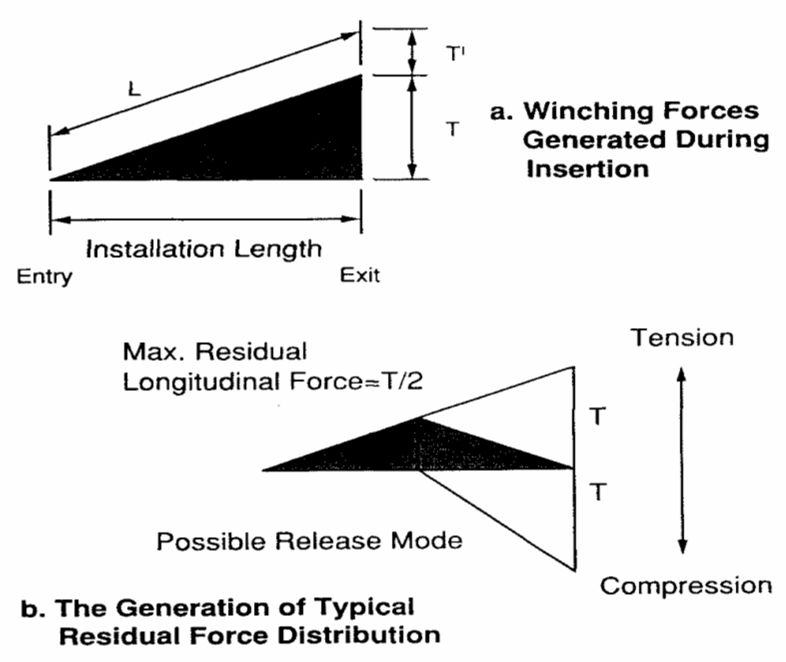
The Gap Spanning Chart is for PE-80 (MDPE) liners. For PE-100 (HDPE) liners, 50-year design failure pressures can be assumed to be approximately 15% higher.

Note 2

The Gap Spanning Chart is valid for an operating temperature up to 20°C, and for conveyed products which do not impair the mechanical properties of PE liner pipe.

h) Winching Forces

Another design aspect that has to be mentioned is the problem of the winching forces generated during insertion. When the deformed pipe is pulled into the main with a winch, it necessarily induces longitudinal stresses in the PE liner pipe. Assuming that friction is evenly distributed, the following Figure shows the variation in tensile force induced along the installation length.



Longitudinal residual stress effects induced in the lining by the wiching process

Thus T' is the force at entry and T is the maximum force required to overcome frictional effects. Upon release of the winch force, equilibrium requires the tension at both ends of the installation to be zero (Figure 4b). However, friction between lining and host pipe will now ensure that T is only partially released. The residual force system due to winching is therefore illustrated in Figure 4b. Typically the maximum tensile stress is of the order of 0.25N/mm^2 per 100-meter installation lengths. This will be increased due to bends, but can be reduced or eliminated by lubrication or flotation of the lining. Creep relaxation will also ensure these stresses reduce with time. Consequently, a well-designed installation induces only minimal long-term stresses in the lining due to this effect.

Maximum Permissible Winching Loads for MDPE/PE-80 (@20° C)

Pipe Size	Maximum Pulling Load (Tonnes)				
	SDR-26	SDR-33	SDR-42	SDR-61	SDR-80
75	0.47	0.38	0.30	0.21	0.16
100	0.84	0.67	0.53	0.37	0.28
110	1.02	0.81	0.64	0.44	0.34
125	1.31	1.04	0.83	0.57	0.44
150	1.89	1.50	1.19	0.82	0.63
160	2.15	1.71	1.35	0.94	0.72
180	2.72	2.16	1.71	1.19	0.91
200	3.36	2.67	2.11	1.47	1.12
213	3.81	3.03	2.40	1.66	1.27
225	4.26	3.38	2.68	1.86	1.42
250	5.26	4.18	3.30	2.29	1.75
280	6.59	5.24	4.14	2.87	2.20
300	7.57	6.01	4.76	3.30	2.53
315	8.34	6.63	5.24	3.64	2.78
355	10.60	8.42	6.66	4.62	3.54
400	13.45	10.69	8.46	5.87	4.49
450	17.03	13.43	10.70	7.42	5.68
500	21.02	16.70	13.21	9.17	7.02
560	26.37	20.95	16.57	11.50	8.80
600	30.27	24.05	19.03	13.20	10.10
630	33.37	26.52	20.98	14.55	11.14
710	42.39	33.68	26.64	18.48	14.15
750	47.30	37.58	29.73	20.62	15.79
800	53.82	42.76	33.82	23.46	17.96
900	68.11	54.12	42.81	29.70	22.73
1000	84.09	66.81	52.85	36.66	28.07
1200	121.09	96.21	76.10	52.80	40.42
1400	164.81	130.95	103.58	71.86	55.01
1600	215.27	171.04	135.29	93.86	71.85
MDPE Maximum Permitted Pulling Stress @ 20°C = 7.1 MPa					

Maximum Permissible Winching Loads for HDPE/PE-100 (@20°C)

Pipe Size	Maximum Pulling Load (Tonnes)				
	SDR-26	SDR-33	SDR-42	SDR-61	SDR-80
75	0.63	0.50	0.40	0.28	0.21
100	1.13	0.89	0.71	0.49	0.38
110	1.36	1.08	0.86	0.59	0.45
125	1.76	1.40	1.10	0.77	0.59
150	2.53	2.01	1.59	1.10	0.84
160	2.88	2.29	1.81	1.26	0.96
180	3.65	2.90	2.29	1.59	1.22
200	4.50	3.58	2.83	1.96	1.50
213	5.10	4.06	3.21	2.23	1.70
225	5.70	4.53	3.58	2.48	1.90
250	7.03	5.59	4.42	3.07	2.35
280	8.82	7.01	5.54	3.85	2.94
300	10.13	8.05	6.36	4.42	3.38
315	11.16	8.87	7.02	4.87	3.73
355	14.18	11.27	8.91	6.18	4.73
400	18.00	14.30	11.31	7.85	6.01
450	22.78	18.10	14.32	9.93	7.60
500	28.13	22.35	17.68	12.26	9.39
560	35.28	28.04	22.18	15.38	11.78
600	40.50	32.18	25.46	17.66	13.52
630	44.66	35.48	28.07	19.47	14.91
710	56.72	45.07	35.65	24.73	18.93
750	63.29	50.29	39.78	27.59	21.12
800	72.01	57.21	45.26	31.40	24.03
900	91.13	72.41	57.28	39.74	30.42
1000	112.51	89.40	70.71	49.06	37.55
1200	162.02	128.73	101.82	70.64	54.08
1400	220.52	175.22	138.59	96.15	73.61
1600	288.03	228.86	181.02	125.58	96.14
MDPE Maximum Permitted Pulling Stress @ 20°C = 9.5 MPa					

Winch Capacity Requirements

PE Liner Pipe Size (mm)	Winch Capacity (Tonnes)
75 – 300	5
300 – 500	10
Greater than 500	20

i) Insertion Pits

The Subline process reduces the cross-section area of the PE liner to some 40% of its original. This reduction greatly facilitates the insertion and winching of the formed liner through the existing host pipe. The reduced cross-section of the liner minimizes the frictional drag of the liner in the host pipe during installation. This, together with the fact that the Subline shape is produced by pushing the liner pipe through the process, means that very substantial lengths can potentially be installed in a single pull in straight host pipeline runs.
Experience has shown that lengths of pipeline of 1,000+ meters may be lined in a single pull using the Subline process, subject to the line, level and size of main. Anyway the length of the Subline insertion pit depends on the diameter and depth of the existing pipeline.
The following table indicates the minimum pit length requirements:

Cover Depth (m)	**£ 1**	**1 -2**	**2 -3**
Liner Diameter (m)	**Minimum Length of Insertion Pit (Meters)**		
100	2	3	3
150	4	5	6
200	5	6	7
250	6	8	9
300	7	9	11
400	8	10	11
500	9	11	13
600	9	11	13
800	10	12	14
1000	10	12	15

j) Typical Processing Temperature Range

Typically, minus 5°C to + 30°C (actual range depends on material type and wall thickness).

4) Quality Control & Construction Inspections Procedures

Thin-walled PE liners installed in high-pressure water supply mains rely on the residual structural strength of the host pipe to act as the primary pressure containment envelope over the remaining life of the asset. It is therefore important to determine whether the host pipe is generally in structurally sound condition and can be expected to remain so for the rest of the design life of the relined main. A pre-CCTV inspection should be conducted to:

a) Verify that the main is free of significant cracks, holes, gouges or other indications of structural damage.

b) To locate any protruding service connections or other obstructions that could damage the liner during installation
c) Locate any bends or offsets in the line and grade of the pipe
d) Locate main line fittings and branch connections

The CCTV inspection should be supplemented with appropriate non-destructive testing methods if there is evidence of structural impairment. If host pipe coupons are to be taken, consider using pipe sections to be removed at the planned installation openings.
PE pipes can be damaged by improper shipping or handling during unloading. The installer should inspect the pipe during the unloading operation to verify that the pipe was not damaged in shipping or during unloading. Photos should be taken to document any damages and support claims. PE pipes should be stored at the job site in a manner that is consistent with the manufacturers recommendations and periodically inspected to detect accidental construction damage or damage by vandalism.
The fused lengths of PE pipe shall be properly supported during installation to assure that it is not damaged by dragging on the ground or by contact with sharp edges of traffic plates. The open end of the host pipe should be appropriately covered to prevent any sharp edges that could damage the PE liner during insertion.
The host pipe should be kept sealed during any interruptions and overnight to prevent entry of animals or by rainwater or vandalism. It is critical that the host pipe remain clean during the entire lining effort.
After the liner has been installed and re-rounded, it should be subjected to a hydrostatic pressure test at a pressure equal to or greater than the desired pressure rating of the rehabilitated main. Generally this test is conducted at pressures and for durations equal to the owner's or code requirements for a new facility with the same pressure rating. The pipe to be tested

should be adequately braced to withstand the expected end thrust forces and assure safety of the workers and the public.

After the lined main is drained, it should be re-inspected with CCTV to assure that the liner is properly expanded and free of any significant imperfections.

The final tie-in fittings should be visually inspected at operating pressure to assure that there is no leakage.

5) Subline Case Studies

Subline Case Study 1: *World's largest diameter close-fit PE lining*

Subterra's patented Subline close-fit lining system was recently used to line two 4,600 ft. lengths of twin DN 1200 (48 in) pipelines with PE near Amsterdam.

Subterra, through its Benelux licensee Etersol, recently completed the world's largest diameter close-fit PE lining project: the rehabilitation of a strategic bulk water transfer pipeline near Amsterdam, Holland.

The Problem

WRK, the Utrecht-based Dutch water company transports pretreated surface water taken from a canal intake at its works in Nieuwegein to the dunes near Zandvoort on the coast to the west of Amsterdam by means of three pre-stressed concrete (PSC) pipelines of diameter DN 1200 (48 in.) and DN 1500 (60 in.).

The twin DN 1200 (48 in.) PSC pipelines were originally laid 30 to 40 years ago. While they remain in an excellent structural condition, progressive movement in areas with very poor soil has, in the past, led to joint displacement (longitudinal and angular) and consequent leakage.

In the past, the affected joints had been repaired by means of internal joint seals. For part of its length, these pipelines run parallel with, and in close proximity to, the main railway line running from Amsterdam to the Southern Netherlands and Germany, and to the E9 motorway.

The planned upgrading of the railway line to TGV status, and the associated widening of the motorway, stimulated the search for a more comprehensive and permanent solution to safeguard future water supplies.

The principal concern was that future ground movement, exacerbated by the increase in ground vibration associated with the augmented rail and road links, could lead to further joint displacement and leakage, eventually undermining rail/road foundations.

The Solution

Working closely with IWACO (consulting engineers) and KIWA (the Netherlands institute for the examination of water supply pipes and fittings), and based on technical and economic considerations, the decision was taken to line two 1,4km lengths of the twin DN 1200 (48 in.) pipelines with PE using Subterra's patented Subline close- fit lining system.

In the Subline process thin-walled PE pipes are fused into string lengths to suit site conditions (in this case approximately 1,150 ft.) and are then folded at ambient temperature on site into a heart shape using the specialist Subline forming equipment.

The folded pipe is held in shape by use of temporary restraining bands and then inserted into the existing main to be lined using conventional slip-lining technology.

Winching loads are low - as a result of the greatly reduced cross sectional area - and well below 50% of the yield strength of the PE pipe. Once inserted, the PE liner is reverted to form a close-fit with the existing main by pressurizing with water at ambient temperature.

For this project, standard PE-80 grade PE pipe was used. The diameter was 48 in. with an SDR (Standard Dimensional Ratio) of 61 giving a wail thickness of approximately 0.8 in.

The pipe was produced by Höhn in Germany and supplied by Polva NL in lengths of 80 ft. in order to minimize on-site welding.

The lining was installed in 8 sections by Subterra's Belgium-based Benelux licensee, Etersol. On-site technical support was provided by the Subterra team.

Each lined section was between 920 ft. and 1180 ft. from insertion to reception pit. The lining work was carried out over an eight-week period finishing in July 1999, and included lining through a siphon in which the line of the pipe deviated some 3 ft. over an 80 ft. length.

Subline Case Study 2

Introduction

Installations were performed in two sites (Bronx and Manhattan) in May and June 1997. In the Bronx a 30 inches diameter SDR 32.5 HDPE pipe was installed in 1,200 ft of cast iron main. In Manhattan a 36 inches diameter SDR 60 HDPE pipe was installed in 600 ft of cast iron main. All installations were successful. The deformed pipe reverted back to its original round shape and expanded tightly against the cast iron main.

Many of the features of the Subline process were exhibited during the installations, including:

- The ability to stop and restart the installation
- The ability to add lengths of pipe during the installation process
- The ability to install long lengths
- The ability to make repairs to the pipe during the installation
- The ability to attach saddles after the installation was complete

The Subline process proved to be adaptable to difficult or changing conditions at the jobsite. In Manhattan, additional lengths of pipe had to be fused on during the installation process, due to the limited space available to string out pipe on the jobsite. In the Bronx, the installation was stopped overnight after the pipe was damaged by vandalism. The damaged section was cut out and the installation was completed the following day.

Three side wall branch saddles were fused onto the 30-inches main in the Bronx after it was re-rounded. Two were installed in pre-cut windows. The third was installed, as a new service would be, by cutting a window in the cast iron main using standard tools and procedures. This was accomplished without damaging the PE pipe.

Viking Johnson Liner Grips were installed at both ends of each installation. They are designed for use with thin-wall polyethylene liners, to support the ends and to seal the annular space between the PE pipe and the main to prevent gas tracking (See the following Figure). All four segments passed hydrostatic pressure tests, conducted for two hours at 90 psig.

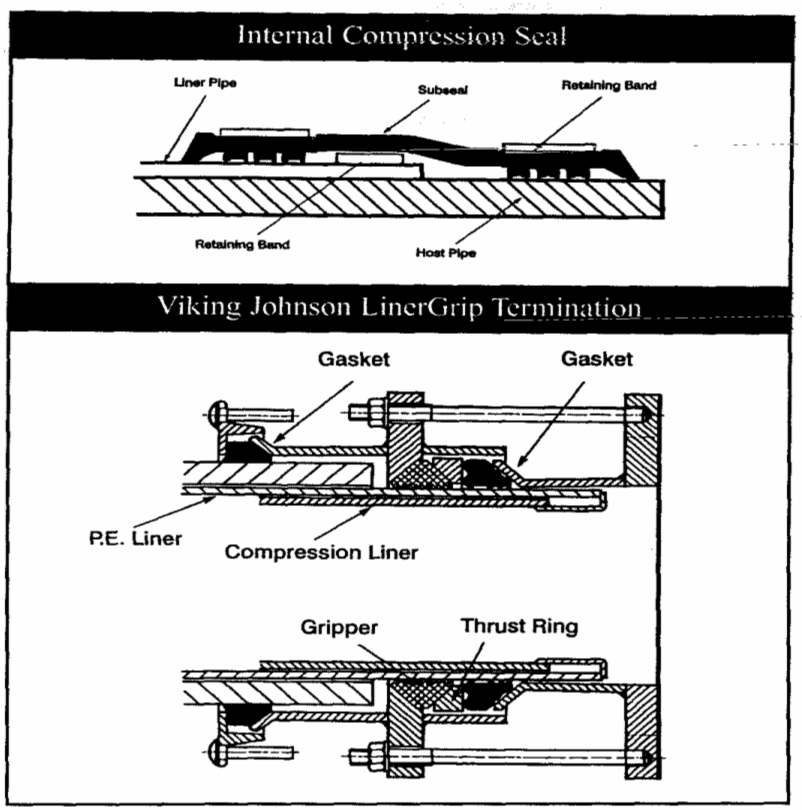


Figure 5 - Termination fittings for thin-wall PE liners

The two 36-in. installations in Manhattan were less than 300 ft, but were not limited by the process. In fact:

- There was no visual evidence of any change in the PE pipe, during or after deforming and reversion. No longitudinal shrinkage was observed. Both installations on the 30-inch Tinton Avenue project were more than 600 ft long. Unlike other deform/reform PE processes, the deforming and reversion were done at ambient temperatures; no thermal stresses were placed on the PE pipe. The pipe reverted to its round shape, as observed at the exposed ends. The post-installation video inspection revealed a smooth interior wall throughout the installations.
- Precautions were taken to prevent damage to the PE pipe. Skids were used when the pipe was moved on the street. The ends of the cast iron main were beveled, and temporary protective strips were installed to prevent damage during installation. Minor damage, which occurred during the installation, was repaired on the site. An inspection of the PE entering and exiting the cast iron main revealed no indication of any damage to the pipe.
- Winch loadings were very low (2-3 tons) for the majority of the project. Loads were increased to about 14 tons when the installation passed through the drip pot and accompanying bend on Tinton Avenue in the Bronx. Plexco PE 3408 high-density material has nominal yield strength of 3,200 psig. The Plexco literature recommends limiting stresses to 40% of nominal yield, or 1,280 psig. The maximum pulling 1oads reached 14 tons in the Bronx. This corresponds to a stress of about 340 psig, or about 25% of the allowable stress. In Manhattan, the maximum pulling load was 3 tons, corresponding to a stress of 92 psig, or about 7% of the allowable stress.
- The installation was stopped and started several times at the two sites. Fusion was carried on during the installation process, both to repair damage and add additional lengths. The ability to adapt to changes in ambient temperature was also demonstrated when the installation was stopped for extended periods and resumed at different times of day.

PART EIGHT: SWAGELINING TECHNOLOGY

1) Evaluation & Investigation of the existing Materials & Installation Methods for Lining Technology

a) Introduction

The Swagelining system was developed by the British gas industry as a trenchless method of rehabilitating its own aging cast iron distribution system, and is now licensed by *Advantica*. The patented process is used to renew both low and higher-pressure gas lines all over the world.

In fact, the Swagelining system has been used to renew cast iron, ductile iron, and steel pipes in diameters ranging from 3" (75mm) to 36" (900mm), and in a wide range of pressures in lengths up to 3,000' (1,000m). The Swage-lining process allows a new, tight-fitting polyethylene (PE) pipe to be placed inside an existing gas line. PE pipe has been used in direct-burial applications for many years in the gas industry. Now, a wide variety of PE pipes and a full compliment of tapping, branching, and connection methods have been developed to provide a total renewal system.

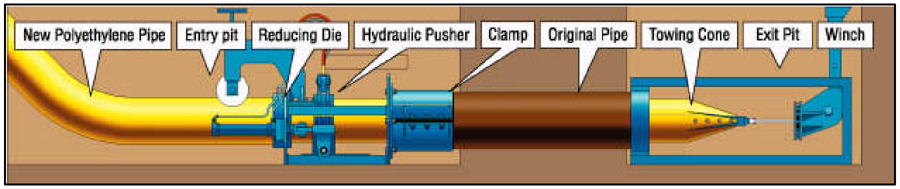
PE pipes used in the Swagelining process are manufactured to ISO, AGA, ASTM, and API standards, so lines renewed by this process have known physical properties and an established service life. There is no shrinkage or curing, and no field chemistry is required. Polyethylene is flexible, leaktight, and highly resistant to chemical attack.

Since there is very little difference between gas and potable water distribution mains, the *Swagelining* process has been used extensively to rehabilitate both types of systems. PE pipe is approved for potable water service in most countries, and can be specified to withstand a wide range of internal pressures and burial depths. As a result, it is not necessary for the PE liner to depend upon the original pipe for strength.

Finally, when the host pipe is structurally sound, the wall thickness of the liner may be reduced. Since sections of PE pipe are butt fused together, there are no joints where leaks could develop in the future. However, standard fittings are available to allow sections of PE-lined pipe to be easily and securely reconnected to the rest of your water transmission or distribution system.

b) Description of the process

Four steps to are necessary to rehabilitate pressure pipes with the Swagelining process:



- **Step 1**

Using the *Swagelining* process we are able to reduce the outside diameter of polyethylene pipe significantly without affecting the long-term characteristics of the pipe. Unlike other diameter reducing processes, *Swagelining* does not stretch so much the polyethylene nor weaken the pipeline material.

- **Step 2**

A polyethylene pipe, which has been reduced by the *Swagelining* process, is pulled through a reduction die to temporarily reduce its diameter and so, due to the high tension, becomes longer. The pipe will hold its new diameter on condition that the tension is maintained.

This does not allow as much control over the installation schedule as it is possible with other processes like *Rolldown* (where the lined pipe is pushed).

- **Step 3**

As a result of the reduced diameter of the new pipe, conventional sliplining techniques are used to insert it into the original pipeline. Since winching loads are very high, pipe is subjected to harmful stress, when large diameters or long lengths are installed**.**

- **Step 4**

After the PE liner has been pulled completely through the host pipe, the pulling force is removed. *This allows the PE pipe to return toward its original diameter until it presses tightly against the inside wall of the host pipe*. As a result, no hydrostatic pressure is needed to trigger the molecular memory of the polyethylene.

Main characteristics of the *Swagelining* process are shown below:

- ***The towing cone emerging from the swaging machine.***

- ***At the job site, sections of PE pipe are butt fused together to form a single, joint-less pipe.***

- ***The PE liner disappears into the old pipe.***

- ***Workers lubricate the PE pipes with vegetable oil as it leaves the swagelining machine.***

Main characteristics of the *Swagelining* process

- Rehabilitate 3-inch through 36-inch diameter pipe
- SDR 42 through SDR 17 thin- or thick-wall, MDPE or HDPE pipe may be used
- Normal *Swagelining* rate is 6-10 ft per minute and in lengths between 300-3000 ft
- Pipe may be butt-fused before *Swagelining*
- *Swagelining* reduces diameter in elongating pipe
- Pipe is reverted as soon as the pulling force is removed
- Over 600 miles of pipeline have been rehabilitated with the *Swagelining* process

Problems Solved by *Swagelining*

- **Pipeline structural deterioration problems**
  Swagelining can be used to process and install PE pipe liners, which have a full structural capability for gas, water and other suitable pressure pipeline applications
- **Pipeline internal corrosion problems**
  Swagelining PE pipe linings provide a highly effective, corrosion-resistant barrier between the bore of the existing pipe and the conveyed product
- **Water quality problems associated with pipeline internal corrosion and deposits**
  Swagelining PE pipe linings arrest the pipe bore tuberculation and corrosion, which contribute to conveyed water quality problems in water supply and distribution pipelines. In addition, the smooth surface of *Swagelining* PE linings helps resist the formation of other pipe bore deposits in operation
- **Flow capacity problems arising from pipe bore tuberculation and deposits**
  Swagelining PE linings present a smooth surface to the conveyed fluid, which helps maximize the flow capacity of the lined pipe. Thanks to the extremely low friction coefficient of the PE liner, in many cases it is possible to increase the hydraulic capacity of previously heavily tuberculated mains and deposit-fouled pipelines
- **Leakage from corrosion holes and failed pipeline joints**
  Swagelining PE linings provide a continuous pressure-tight envelope inside the existing pipeline which can be designed effectively to span corrosion holes and joint gaps

c) Specifications for pipeline renewal

Swagelining Process	
Design considerations	
• Available for 3 - 36 inches diameter pipes • Uses SDR 42-17 thin or thick wall, MDPE or HDPE • Site location/access facilities • Host pipe type and wall thickness design • Pipeline internal operating pressure • Pipeline length • Type of joint and flange rating of host pipe • Conveyed fluid composition • Operating temperature • Internal Condition of Host pipe (scale build up, internal lining/coating etc) • Site drawings (showing vertical and horizontal offsets)	
Materials and fittings	
Host pipe material	• Identification and indication of its structural integrity required • Existing pipeline inside diameter must be quantified to allow for optimum sizing of liner pipe
Liner material	• Polyethylene resin compound must be specified as either medium or high density in accordance with ASTM Standard D3350 • Physical and mechanical performance properties of the polyethylene pipe material to be deformed must be available to optimize the performance and installation of the liner
End terminations	• *Fully structural capacity:* Standard PE fusion and/or mechanical jointing technology can be used. In order to ensure adequate sealing the following information must be supplied: • Host pipe inside diameter • Host pipe outer diameter • Flange rating • Host pipe and flange specification
Bends and fittings	• Swage lined pipe is typically capable of negotiating bends up to 15° subject to appropriate pipe dimension and site conditions. • All other fittings and tees must be removed. Such excavations may however, conveniently be used as insertion and receiving pits for the *Swagelining* installation

System Installation	
Accessibility	The line of the existing pipeline must be located, noting any potential problems, such as bends, hydrants and valves.
Excavations	Insertion and receiving pits should be excavated at appropriate locations along the length of the existing main. The positioning of the machine and space required for liner pipe "stringing out" should be considered when selecting launch site
Cleaning	The host pipe should be cleaned prior to lining. Adequate cleaning processes include the use of scraper pigs followed by a "rubber pull-through", wire brush, pressure jetting or pressure pigging. Other cleaning processes may be used which can be shown to remove excess debris from the inside of the pipeline
CCTV Inspection	CCTV inspection should be carried out before and after cleaning. Any significant protrusions, which will inhibit cleaning, should be removed. The post cleaning inspections should confirm the cleanliness of the main, and identify any remaining protrusions into the main; if significant they should be removed prior to lining. A proving pig may also be used to check for protrusions into the main.
Section lengths	Installation segment lengths are normally determined jointly by the owner/engineer and the installer. These are governed primarily by site and pipeline factors such as terrain, accessibility, bends and fittings.
Size Verification	The outside diameter of the PE liner pipe is typically chosen to be slightly larger than the minimum clear bore of the host pipe. The *Swagelining* process will then produce a liner that is smaller than the minimum clear inside diameter of the host pipe, to ensure ease of insertion.
Liner Installation	The liner is deformed prior to installation but cannot be stored alongside the pipeline. The liner deformation is held thanks to the pulling load. An approved lubricant (e.g. vegetable oil) is used to aid the installation process

Temperature	The diameter reduction, and subsequent retention of this deformation is dependent on temperature as well as specific PE resin and DR values.
Jointing	• Pipe strings must be jointed prior to being pushed through the *Swagelining* machine. Conventional butt fusion is the required method and the external weld beads must be removed.
End Fittings/Reversion	• As soon as the pulling force is removed the pipe begins to revert • PE liner length should exceed the host pipe length, so that after the contraction process, all the host pipe will be properly lined • During the reversion process, the liner and fittings are inspecte d for leaks • Before draining the liner both ends of the reverted section should be vented to prevent the occurrence of vacuum collapse.

Semi-Structural: Liner design guarantees long-term hole/gap spanning capability under design operating conditions. Structural support is necessary from the host pipe to withstand general operating pressures/external loads.

Fully structural: No structural support required from host pipe against internal/external pressures/loads.

Non-structural: Anti-corrosion barrier only. No gap bridging capability. (e.g. Epoxy resin lining*)*.

d) System Features and Benefits

	<u>Swagelining Process</u>
Potable Water Applications	The *Swagelining* processes use PE liner pipe manufactured from standard pipe-grade resins. Where the PE pipe to be processed by *Swagelining* already has a National approval for use in contact with public potable water supplies, the resultant liner will retain this approval. In particular, the internal surface of the PE pipe liner is not contacted by the *Swagelining* process. The pipeline fittings must also be water quality approved.
Continuous Barrier Liner	• Arrest internal corrosion of host pipe. • Prevents leakage from holes, joints
Liner Pipe Made from Standard Pipe Grade Resins	• Uses materials already approved in country for potable water/gas application. • Standard PE resin liner pipe materials generally already well characterized: usually manufactured under a formal QA scheme
Close-fit liner	• Maximizes flow capacity. • Grouting not required.
Smooth liner bore	Maximizes flow capacity
Simple Process Equipment	Available for all diameters of PE pipe 3-36 inches
Process Specification	Reduced Diameter held indefinitely while pulling load is maintained: • External mechanical restraint needed to maintain reduced size. • Insertion is effectively a slip-lining operation. • Insertion winching loads required overcoming friction between liner and host pipe and maintaining the reduction in diameter.

Install Liner Direct from Machine or as Separate Operation	No on-site flexibility and convenience since any reduction in liner diameter requires a maintained pulling load
High Installation Winching Loads	Maximizes insertion lengths (single pulls > 1,500 feet have already been achieved)
Process Stop/Start Capability	No on-site operational flexibility and convenience
Reversion to Close-fit	Simple reversion procedure
Well-characterized PE Liner ability to span Corrosion Holes/Joints Gaps	Validated 50-year liner design procedures available
Pipe Rehabilitation Process	Utilizes existing pipeline asset as a conduit
Minimum Dig Process	• Minimum disturbance of adjacent services and structures. • Minimizes the requirement for imported natural fill materials for re-instating excavations. • Reduces disposal of excavated material to landfill. • Small site footprint. • Less environmental/social disruption compared with open-cut laying.

e) Material Qualifications

The Swagelining process uses custom-made MDPE or HDPE pipe manufactured from standard pipe-grade resins, which is purchased to fit the exact internal diameter of the host pipe to be lined. The user should verify by documentation from the pipe manufacturer or by pre-installation testing that the pipe to be supplied meets all required standards for the intended use and that it is suitable for installation with the Swagelining method of installation. Where the PE pipe to be processed by Swagelining already has a national approval for use in contact with public potable water supplies, the resultant liner will retain this approval.

In addition the pipe should exhibit excellent slow-crack growth resistance and should not be subject to Rapid Crack Growth (RCP) for the conditions of pressure, temperature and diameter required for the intended application. Large diameter pipes operating at low temperatures and at higher pressures may be more prone to RCP failure.

2) Evaluation of Swagelining Current State of Practice

The Swagelining technology has been extensively and successfully used in the USA and Europe. The following tables show the Swagelining ability to line a wide range of pipes in challenging environments.

Country	City	Pipe Diameter	Pipe Length	Pressure [psi]
FRANCE	Caen	20” dia. HDPE	2.5 miles long	95
Colorado, USA	Greeley	27" dia. HDPE	1.5 miles long	225
California, USA	Pasadena *Bridge Crossing*	8“ dia. HDPE	0.19 miles long	80
FRANCE	Pierrefitte *Generale Compagnie des Eaux*	32” dia. HDPE	395’	25
Scotland, UK	Tayside *North of Scotland Water Authority*	28” dia. MDPE	0.9 miles long	235
ARGENTINA	Vaguales *Pluspetrol Ey PSA*	2-7/8" dia. MDPE	1.5 miles long	1,395
Texas, USA	Laporte *Union Carbide*	12"-18“ dia. HDPE	1.2 miles long	110
ENGLAND, UK	Doncaster *Yorkshire Water plc*	20" dia. MDPE	0.47 miles long	150
ARGENTINA	Medanito *Perez Companc SA*	6“ dia. MDPE	0.22miles long	River Crossing

Swagelining Gas Works

Country	City	Pipe Diameter	Pipe Length	Pressure [psi]
United Kingdom	Throughout UK *BG plc (formerly British Gas plc)*	6” - 18“ dia. MDPE	Hundreds of miles	30-60
New York, USA	Hicksville *Long Island Lighting Co*	8" diameter	0.19 miles	60
New Jersey, USA	**Union** ***Elizabethtown Gas***	20" dia. MDPE	0.68 miles	30
Canada	**Toronto** ***Enbridge (formerly Consumers Gas)***	8" dia. HDPE	0.1 miles	60
California, USA	**Paso Robles** ***Unocal***	4" dia. MDPE	1.25 miles	100

Swagelining Sewer Works

Country	City	Pipe Diameter	Pipe Length	Pressure [psi]
GERMANY	Heidenau	20" dia. HDPE	0.27 miles long	River crossing
Virginia, USA	Ft. Monroe	*US Military*	8” - 16" dia. MDPE	2.3 miles long

3) Evaluation of Swagelining Current Design Procedures

The Swagelining process may be used to install relatively heavy-section PE liners into existing pipelines. Thus, for utility pressure pipeline applications, the heavy wall PE liners which are installed by the Swagelining process generally have sufficient structural strength in their own right to withstand the full pipeline operating pressure throughout the whole of the planned asset life – typically 50 years minimum (i.e. fully-structural liner design application). The host pipe in such instances acts simply as a conduit for the installation of the liner. Whilst the host pipeline is thus not required to provide any structural support to the liner and could effectively be discounted in any structural analysis of the liner's future performance, any residual host pipe structural strength will clearly enhance the structural capability of the installed liner where it receives such support.

For other applications where the pipeline operating pressure exceeds the normal pressure rating of the PE liner, the liner would rely on the residual structural strength of the host pipe to act as the primary pressure containment envelope over the remaining life of the asset. In these instances (i.e. semi-structural lining design applications) it is therefore important that the host pipe is generally in a structurally-sound condition, and can be expected to remain so throughout the rest of the design life of the relined main. Most of the recent Swagelining work on water mains utilizes thin wall PE liners, especially for large diameter mains.

Mains Cleaning

Good host pipe bore surface preparation is recommended as a basis for the Swagelining process. The main should be cleaned as necessary by vacuum, wire brush, pull-through, pressure jetting, pressure pigging or scraper pig pulled through by a wire winch cable, followed by a rubber "pull-through" to remove residual loose material. In extreme cases, rack feed boring may be required, particularly for removing tuberculation in water mains up to 150 mm diameter.

Configuration of the Main: Maximum Section Lengths

The Swagelining process reduces the original external diameter of the PE liner. This reduction enables the Swaged liner to be inserted into the existing host pipeline as for a normal sliplining operation, directly from the machine.

Even if Swagelining involves pulling the liner pipe through the process, very substantial lengths can potentially be installed in a single pull in straight host pipeline runs.

The load, which is used to winch the pipe into place, is needed to affect the pipe diameter reduction process; the maximum permissible tensile load on the pipe can therefore be used to overcome any friction between the liner pipe and the host pipe wall during insertion. To date, lengths of pipeline of up to 3,000 feet have been lined. The actual length achieved depends on the line, level and size of the main, liner size, the annular clearance and other practical site factors such as numbers of bends, branches, fittings and customer service connections.

Bends, Tees and other Fittings

Some bends and all other fittings will normally need to be removed prior to lining with Swagelining process. Many of these excavations may conveniently be adapted for use as liner entry pits and winching pits.

4) Quality Control & Construction Inspections Procedures

PE pipes can be damaged by improper shipping or handling during unloading. The installer should inspect the pipe during the unloading operation to verify that the pipe was not damaged in shipping or during unloading. Photos should be taken to document any damages and support claims. PE pipes should be stored at the job site in a manner that is consistent with the manufacturers recommendations and periodically inspected to detect accidental construction damage or damage by vandalism.

The fused lengths of PE pipe shall be properly supported during installation to assure that it is not damaged by dragging on the ground or by contact with sharp edges of traffic plates. The open end of the host pipe should be appropriately covered to prevent any sharp edges that could damage the PE liner during insertion.

The host pipe should be kept sealed during any interruptions and overnight to prevent entry of animals or by rainwater or vandalism. It is critical that the host pipe remain clean during the entire lining effort.

After the liner has been installed and reverted, it should be subjected to a hydrostatic pressure test at a pressure equal to or greater than the desired pressure rating of the rehabilitated main. Generally this test is conducted at pressures and for durations equal to the owner's or code requirements for a new facility with the same pressure rating. The pipe to be tested should be adequately braced to withstand the expected end thrust forces and assure safety of the workers and the public.

After the lined main is drained, it should be re-inspected with CCTV to assure that the liner is properly expanded and free of any significant imperfections.

The final tie-in fittings should be visually inspected at operating pressure to assure that there is no leakage.

5) Swagelining Case Studies

Swagelining Case Study 1: *Swagelining Renews Potable Water Transmission Lines*

By Daniel F. Moore, P.E., Water Systems Engineer, Water and Sewer Department
City of Greeley, CO

The city of Greeley, CO, depends upon two parallel 27” steel transmission lines to supply it with potable water from a source 33 miles away. The pipelines are about 50 years old and a significant corrosion problem had developed in an 8,000” section of each pipe. To make matters worse, rapid development around and over these water mains severely limited access to them.

A sacrificial anode cathodic protection system was installed when the pipelines were new, but it had been neglected for the next 40 years. During that time, corrosion found its way through damaged and misapplied coatings and weakened the pipes. In 1988 a new cathodic protection system was installed to replace the old one and the incidence of new leaks dropped dramatically, but serious damage had already been done. Prior to installing the new cathodic protection system, as many as ten leaks per year developed in the most seriously damaged section. Since these leaks developed under normal working pressures, planned pressure increases would create even more leaks.

The Water and Sewer Department wanted to be proactive and replace the pipelines, but found the lines were now covered with residential and commercial development. Homes had been built within a few feet of the pipelines, and a trailer park, state highway, railroad, other utilities, and even a cemetery had been built over them. It would be extremely difficult, costly, and disruptive to dig the pipelines up and replace them.

The severity of the problem became apparent in the middle of July 1995, one of the hottest day of the year. A leak was reported near a railroad track in the troublesome area. This was very serious because the pipe was not in a casing and the owner of the railroad would not allow an excavation through the tracks to find the leak.

Leaks are normally easy to find from the exterior of an exposed, pressurized pipe and can be repaired quickly, with the pipe in service, by inserting a gasketed tapping screw in the hole. However, without access to the exterior of the pipe, the line would have to be taken out of service, and an attempt made to find the leak from the inside without benefit of water pressure.

Opening the pipe would deprive the city of a much-needed 10 million gallons of water every day the line was out of service, and the odds of a quick repair were not very good. As it turned out, the leak was found to be accessible and was repaired without any major incident. However, the leak did motivate the city to find a long-term solution for this high-risk section of pipeline. It was decided that one pipe could be taken out of service and replaced or repaired during the winter months. The other pipe would remain in service to supply Greeley with potable water. That pipe could be replaced or repaired the following winter.

Solution Criteria

In order to find the best solution to the problem, a performance specification outlining the desired result was given to interested contractors. The criteria specified the solution should:

- Be NSF approved for potable water
- Remain leakproof for at least 50 years
- Minimize excavations and couplings
- Maintain existing flow capacity as much as possible
- Be installed during the winter months when demand is lowest
- Withstand 200 pounds pressure while spanning a 2.5” hole
- Be economical and maintenance-free
- Install in compliance with OSHA’s safe construction practices

Several proposals were made and each was evaluated on how well it met the specified criteria. The first proposal was for an open-cut, total replacement. This proposal was attractive because the pipe could be up-sized, but the total cost, in terms of money, time, and social disruption, was considered to be too high. The estimated monetary cost was at least $200 per linear foot.

The second proposal was for sliplining a polyethylene (PE) pipe capable of withstanding 80 psi without any dependence upon the host pipe. In order to withstand that 80-psi, the wall of the liner would have to be 1.5” thick. The installation method required annular space between the host pipe and liner so the liner would not bind when it was pulled through the host pipe. It was decided that the combination of liner thicknesses and annular space would result in too great a reduction in flow capacity. This method would have cost about $75 per linear foot.

Two proposals were received for inserting a tight-fitting, high-density polyethylene (HDPE) liner into the old pipeline. Both methods would take advantage of the remaining structural strength of the host pipe. This would allow a relatively thin-walled SDR-40 liner to be used. The smoothness of the HDPE appeared to offset the small reduction in inside diameter, resulting in very little, if any, reduction in flow capacity. The decision was made to award the rehabilitation contract to ARB Inc., Lake Forest, CA, a license of the Swagelining process, at approximately $85 per linear foot.

The Swagelining process was developed by BG plc, formerly British Gas plc, as a rehabilitation process for its own gas lines. However, because of Swagelining's uniqueness, the process has been used successfully to protect over 500 miles of pipe ranging from 3 to 36 inches in diameter. This protection includes water, forced sewer, gas, oil, and a wide range of industrial production lines all over the world.

The Swagelining process uses PE pipe which has an outside diameter slightly larger than the inside diameter of the pipe to be lined. During the installation process, the PE pipe is pulled through a die to temporarily reduce its outside diameter. This reduction allows the PE to be easily pulled through the outer pipe. When the pulling force has been disconnected, the PE pipe begins to return to its original diameter. However, just before the PE pipe relaxes completely it presses tightly against the inside of the host pipe, eliminating the annular space.

Planning the installation

Dave Arthurs, Manager, Pipe Rehabilitation Division, ARB, explained that it is not unusual to install PE liners in single pulls of up to 1,500 ft with the Swagelining process. However, the process does not handle bends well if they are over 15° in the 8,000 ft. Greeley rehabilitation project, the contractor decided to place an entry/exit pit at each bend. The locations of other entry/exit pits were based on balancing the length of the pulls with convenience of locations. This resulted in eight pulls which averaged 1,000 ft each.

The polyethylene pipe was delivered in 50 ft lengths and was joined together using the butt-fusion method. This process heats two touching ends of PE pipe until their molecules are homogenetically intertwined. The fusion actually creates a new pipe without a joint. Only a small bead is left where the fusing occurred, and it is removed from the exterior surface.

Since the wind chill factor at the job site often resulted in temperatures well below zero, plywood tents were made to house the fusing operation. A special heater was also used to warm the PE pipe to approximately room temperature before it was pulled through the reducing die. Since the heater was only 18 feet long and the outside temperature was so low, the insertion process was much slower than normal. Between 3 and 4 hours were required for a 1,000 pull. A 20 to 25 ft of the spool section of the original steel pipe was removed from the line in each entry/exit pit. This would allow sufficient room for the liner to be pulled into the relatively straight sections of the host pipe. When straight sections of pipe were removed, they were lined with the PE pipe above ground and reinserted to close the pipeline after the rest of the host pipe had been lined. When curved sections which could not be lined were removed, they were exposed coated on the inside before they were used again.

After two adjacent pipeline sections and the spool pieces had been lined, the pieces were joined with special connectors designed and manufactured by ARB and Greeley's Water and Sewer Department. Epoxy-coated steel sleeves were inserted into the ends of the PE liners to reinforce them enough to withstand the exterior pressure of 4-piece shell clamps. Dresser couplings were also used to finish the connections.

After the pipe was completely connected, the line was pressure tested at 150 psi. when no leaks were found, the line was chlorinated and flushed before it was put back in service. The line was pigged a year later to be sure there were no leaks due to liner shrinkage or loose reinforcement rings.

The first 8,000 ft of one of the two parallel pipes was lined in the 1996-97 winter and the same section of the other pipe was lined in the winter of '97-'98. There have been no leaks on either of these two pipes since the PE liner was installed. The standard design life of the PE liner is 50 years, but it may last longer. As long as the outside pipe holds up, there is no known reason for the PE liner to fail. The remainder of the pipeline is in good enough shape that no rehabilitation is pending.

Swagelining Case Study 2: *Pipes Successfully Relined*

By Mike Grahek

Mr. Grahek is Contract Administrator for Pipeline Rehabilitation

Los Angeles Department of Water and Power

Abstract

During routine testing, the Los Angeles Department of Water Power's (LAWP) Trunk Line Testing Program identified leaks in two trunk lines. The identification of weak points in LADWP's large-diameter pipelines is designed to reduce emergency repairs, collateral damage, and prolonged service interruptions.

The pipelines were between 60 and 70 years old, and the weak sections of both were about 4000 feel long. One line was 24''-diameter and the other was 36". Both were under moderately busy, multilane streets. The 24" pipe had welded joints and was pressurized to 211 psi. The installation crew had apparently improvised bells and spigots on the square-end pipe joints. It appeared that a tool such as crescent wrench had been used to bend one end of the pipeline out, and the joining end of the next pipe in, before the two pieces were pushed together and welded. The joints in the 36" pipeline were riveted and the water was pressurized to 50 psi.

Repair or Replace?

Because of their locations, both pipelines could have been replaced, but they were also in good enough condition to be rehabilitated. Both pipelines were structurally sound, even though the inside of the 24" line was severely pitted, and the exterior of the 36" line was badly corroded. The 24" pipe had originally been coated, inside and out, with coal-tar enamel, but most of the coating on the inside had been worn away of lost to corrosion. The interior of the 36" pipeline had been lined with cement during the 1960's and was still in good condition.

When the cost and results of total replacement were compared to various rehabilitation technologies, rehabilitation proved to be the best choice. Rehabilitation would extend the life of the pipelines another 50 to 100 years, and could be accomplished much faster than total replacement, and would cost significantly less. Several rehabilitation options were considered, including built-up cement mortar lining (CML), cured-in-place pipe, and tight fitting polyethylene (PE) pipe.

The PE liner is pulled through a die, which temporarily reduced its diameter and allows it to pass through the host pipe without damaging either the pipe or the liner.

CML has reserved LADWP well in the past, but it is possible to get seepage though the material and that would exacerbate the existing external corrosion problem. A pressure-rated, cured-in-place technology is available, but in this case, it was prohibitively expensive. It would have cost almost as much as total replacement. After considering ling-term serviceability, cost, and ease of application, a tight-fitting, high-density PE (HDPE) liner was specified for the rehabilitation projects.

Once the specifications were written, bids were taken and the contract was awarded to ARB of Lake Forest, CA. The contract amount for lining the pipes using the Swagelining process was about one-third the estimated cost of total replacement.

The Technology

Because of its' versatility, the Swagelinig process has been used successfully to line over 600 miles of pipe, ranging from 3 to 36 inches in diameter. These pipes include water gas, oil, forced sewer, and a wide range of industrial production lines all over the world, both onshore and off. The process allows an existing pipe to be lined with an extremely tight-fitting PE pipe. Because the PE pipe has an outside diameter slightly larger than the inside diameter of the pipe to be lined, it is pulled through a die during the installation process to temporarily reduce its outside diameter. This reduction allows the PE pipe to be easily pulled through the post pipe.

Since PE pipes retain a memory of their original size and shape, they begin to return to their original diameter soon after the pulling force has been disconnected. Within hours, the PE pipe presses tightly against the inside of the host pipe, eliminating the annular space. The PE pipes used in the Swagelining process are manufactured to ISO, AGA, ASTM, and API standards, so the linings have known physical properties and an established service life.

Installation

Both pipes were lined with SDR-32.5 HDPE, which is rated for 50 psi. So, the liner could stand alone in the 36" diameter pipeline, even though it is not necessary in this case. Single pulls up to 1500' ling have been made with the Swagelining Process, but the longest pull in these installations was 822'.

Pits were excavated at 500' to 800' intervals along the pipelines to create entry and exit points for the liner. Before each insertion, individual 40' lengths of PE pipe were butt fused together to form a monolithic pipe long enough to extend from one entry pit to the next exit pit.

Just before the fused pipe entered the host pipe, it passed through a simple metal ring, or die, which temporarily reduced the outside diameter of the PE pipe. The reduced diameter was slightly less than the inside diameter of the host pipe, so the PE pipe could be pulled into place without exceeding 50% of the yield strength of the material. As long as the yield-strength of the PE is not exceeded, no permanent deformation will occur.

Lubricants such as vegetable oil were used to reduce the pulling forces even more. Pulling forces averaged about 22 tons for the 24" pipe, and about 27 tons for the 36" pipe. The average insertion speed was between 5 and 8 feet per minute.

After the PE liner is pulled through the host pipe, it is allowed to relax until it presses tightly against the inner surface of the host pipe, and it's length is stable. In this state, the PE liner extends several feet beyond the end of the host pipe.

Reconnecting the Lined Pipe

The lined sections of the pipelines were fitted with special flanges sold by SPF, a fittings company in the UK. The flange assembly is similar to external mechanical couplings, which slip over the end of the host pipe, and are bolted into place. The inner surface of the flange's collar contains several parallel groves, which are designed to grip the PE pipe when a compression ring is pressed into the open end of the PE pipe. When the flange is in place, the end of the PE pipe is cut off and dressed flush with the face of the flange.

After the flanges were in place, blind flanges were attached and each section was pressure tested to the operation pressure of the line. The spaces between lined sections of pipe are bridged with flanged steel nipples. These nipples contain air release assembles, gate valves, blowoffs, or any other required fittings.

Potable Water Rehabilitation

The use of trenchless rehabilitation technologies has been much more widely accepted in other areas that in potable water. That may be partly due to the fact that more stringent approvals are required for use of new materials with portable water. At a minimum, utilities require all products to have NSF approval, and some require an AWWA specification. Other utilities may be looking at the Green Book of minimum specifications for technologies. All of these approvals take time, but several technologies, such as Swagelining, Already have them.
The Cleaning, Lining, and Rehabilitation of Water Mains Committee of AWWA is in the process of publishing a new manual, M28, which will address many of the trenchless rehabilitation processes for potable water which are available today. This publication could help designers, engineers, and contractors research the products, which are available to them now.

Based on the EPA Need Assessment for Potable Water, the industry will need between $200 Billion and $300 Billion worth of rehabilitation work over the next 20 years. Faced with such needs, the cost savings offered by potable water rehabilitation processes such as Swagelining are tremendous.

Swagelining Case Study 3: *Making Savings on French Rehabilitation*

Abstract

Swagelining has quickly proven itself in France as a cost-effective method to rehabilitate pressure pipes. Recent pipeline renovations in Caen, Dijon, and Peirrefitte demonstrate the features and benefits of this technology.

Swagelining

The Swagelining process was developed by BG plc, formerly British Gas plc, as a rehabilitation process for their own gas lines. However, because of its unique-ness, the process has been used successfully to line 1000km (600 miles) of pipe ranging from 75mm to 900mm (3 to 36 inches) in diameter. These pipes include gas, oil, water, forced sewer, and a wide range of industrial production lines all over the world, both onshore and off.

The Swagelining process allows an existing pipe to be lined with an extremely tight-fitting polyethylene (PE) pipe. Because the PE pipe has an outside diameter of the pipe to be lined, it is bulled through a die during the installation process to temporarily reduce its outside diameter. This reduction allows the PE to be easily pulled through the outer pope. Since PE pipes retain a memory of their original size and shape, they begin to return to their original diameter as soon as the pulling force has been disconnected. Within hours, the PE pipe presses tightly against the inside of the outer pipe, eliminating the annular space. The PE pipes used in the Swagelining Process are manufactured to ISO, AGA, ASTM, and API standards, so the linings have known physical properties and an established service life.

Advantages

BG claims a variety of advantages for its Swagelining process including Minimum Disruption – Very long sections of pope can be replaced from relatively short entry and exit pits, eliminating the danger and disruption of long, open trenches: Fast Installation – Typically, the new PE pipe is pulled into an existing pipeline at a rate of 2-3 meters per minute and in length between 100 and 1000 m. Strong New Pipe – While thin-walled PE pipe is used as internal protection for pipelines, some installations are made with PE pipe which is designed for direct burial. As a result, the new PE pipe does not rely upon the old pipe in any way.

From the PE lining itself there are advantages including: Jointless Construction – Individual sections of PE pipe are welded together by butt fusion to form a continuous, composite pipe with no difference between the pipe and the weld. Proven fittings are available to join the PE to any other pipes in the system: Improved Flow – The inner surface of PE pipe is so smooth that overall flow is often increased, even though the inside diameter is slightly smaller than the original pipe.

In terms of the contract operation, there are also factors of: Reduced Risk – Because there is so little excavation and installation times are so short, inconvenience to people, traffic, and other utilities is much less than with open-trench pipeline replacement: Coast Savings – Swagelining often results in significant savings over other pipeline renovation and replacement technologies due to its fast, trenchless installation, standard materials and the fact there is no annular space to grout.

French Installations

SADE C.G.T.H., established in 1918, was the first subsidiary company of the Comnagnie Generale des Eeaux which was founded in 1853. SADE, a contracting company, is primarily involved in water pipeline construction and rehabilitation. SADE has been at the forefront of the development of the Swagelining system, and has used the patented process to replace pressure pipes in France for the past four years. During that time, SADE has rehabilitated water mains in places such as Caen, Dijon, and Pierrefitte, in the Seine-Saint Denis district near Paris.

"We have compared Swagelining with other pipeline rehabilitation techniques in Before and After tests many times," said Eric Albert, Manager of Rehabilitation, SADE. "The material properties of the PE pipe installed with the Swagelining process are always exactly the same before and after the tests. That's not the case with other techniques," he said. "That is why we use the Swagelining process. It does not harm the liner. It is completely safe."

After over a century of service, the 27km long, 508mm diameter water main that transported potable water from 26 sources to the reservoir of Gueriniere had become unreliable. The grey cast iron was relatively fragile and the joints were no longer watertight.

The Ville de Caen, in its obligation to assure a quality water supply, decided to rehabilitate the water main. Following an examination of different pipeline rehabilitation techniques, the Ville de Caen chose SADE and the Swagelining process for the pipeline renovation to avoid and open-trench installation for environmental reasons.

"We chose the Swagelining Process for several reasons," explained monsieur Robbe, Director of the Technical Service Department for Water & Sewerage, at 2 rue du Villon, Les Buissions, Caen. "The small reduction in pipe diameter was offset by the smoothness of the new pipe, so there was no loss of hydraulic capacity. Structurally, the liner is self-supporting, so it does not rely on the host pipe for strength. Swagelining is environmentally friendly because it allows for the rehabilitation of length up to 400 m without excavation. That allowed us to cross difficult sections such as cemetery, a school, and personal properties with minimum disruption."

The first phase of the project involved 4 km of pipeline within the urban area of Caen. That portion was completed in 5 months. The three following phases were on the outskirts of Caen and totaled 3 km of pipeline.

Dijon

When a burst occurred in 600mm cast iron potable water main under the Boulevard Joffre in Dijon, Lyonaise des Eaux-Dumes decided the pipeline had to be replaced. Even though it was only about 35 years old, the cast iron had become very brittle and it was subjected to vibration caused by heavy traffic on the street above. Bursts could only become more frequent and severe.

Several alternative rehabilitation techniques were carefully studied. Clearly, the new pipeline could not rely on the old pipe for structural strength, and it needed to preserve as much flow capacity as possible. Cured-in-place processes were rejected because they were not considered a good pressure pipe, and too much flow capacity would be lost if standard sliplining was used. It soon became clear that the Swagelining process would retain the most flow capacity, and it was strong enough for direct burial yet flexible enough to withstand heavy vibration.

"Swagelining was our best option," said monsieur Chantre, Chief Engineer, Lyonnaise Dijon. "It only cost about 20% more than the least expensive option, but it left no annular space. In fact, I think we did not lose any flow capacity because of the extreme smoothness of the new PE liner. However, at that time Swagelining had not been used in any 600mm pipelines in France."

As it turned out, the 600mm size did not present a problem, it just became another national record. SADE installed 1300 meter of PE pipe in the old pipeline in six separate pulls for an average of 217m per pull. “We set a record with that installation,” monsieur Chantre said. “But, it was not the last time we used the Swagelinig process.

“Recently, we had a problem with two 800mm water mains which are laid beneath a major commercial area,” he continued. “We knew that if the pipes burst, it could be very dangerous and destructive, so w began to plan for their replacement of rehabilitation.”

When the options and their costs were compared, Sliplining with smooth-walled pipe was the least expensive, but the pipe size would be reduced from 800mm to 710mm. Swagelining would cost about 13% more, but since the liner would be smooth walled and tight fitting, there would be little or no reduction in flow capacity. Sliplining a pipe with reinforced ribs would cost about 10% more than Swagelining, and the pipe diameter would be reduced form 800mm to 710mm.

“Naturally, we chose Swagelining process again, and the project wag very successful. We are very happy with the technology. It’s a very good solution, and so far we have no problems. I think we will continue to use it in the future,” monsieur Chantre said.

Pierrefitte

Following the record-breaking installation of a 600mm pipeline in Dijon, but before the installation of the 800mm liners, the Swagelining process was used in Pierrefitte in the Seine-Saint Denis district on the outskirts of Paris to install an 800mm liner in a potable water main owned by the Syndicat des Eaux d’Ile de France.

In May, a steel-core concrete water distribution main, which was a critical outlet pipe from a standby reservoir, fractured. This presented an emergency because of the approaching holiday period and because of the extra demands for water the summer would bring.

Ordinarily, the repair would have been very simple, but in this case, part of the damaged pipe ran through the cellars of a service building. In addition, the pipe was five meters deep, and no alternative outlets from the reservoir were available to bypass the damaged section.

SADE had previously solved difficult problems for the Syndicat des Eaux d’Ile de France, so they were called upon again to propose a solution to this problem. After they suggested using the Swagelining process to insert a structural PE lining in the damaged section of the pipe, the order was given for SADE to proceed with the work.

The section of pipe to be lined was about 120 meters long. Work was started by making an entry pit where the PE pipe could pass through a heating unit before being reduced and pulled through the line by a 50-ton winch placed at an exit pit at the other end of the line. Each pit was about 2meters wide and 15 meters long. After the PE pipe had been pilled into place, it was connected to the old pipe via flanged fittings, and the pipeline was put back into service.

“Over 2500 m of water main in the Paris area have already been renovated with the Swagelining process,” monsieur Albaret explained. “Given the underground congestion, Swagelining is especially valuable because open trenches are avoided and the existing pipeline is neither abandoned or destroyed. I expect Swagelining to be much more popular in the future because it is such a good solution and is so cost-effective.”

PART NINE: PIPE BURSTING
"Fracturable Pipeline"

Applications include: Cast Iron, Clay, Concrete, and other fracturable Gas, Water, Sewer, and Production Pipelines.

1) *Introduction*

Pipe bursting is a form of trenchless pipe replacement in which an existing underground pipe is replaced with a completely new pipe but without the disturbance and cost of excavating a trench from the surface. The process typically involves the insertion of a tool into the existing pipe that has a maximum diameter that is slightly larger than the existing pipe. This tool is used to break the existing pipe into pieces and to displace the pieces and neighboring soil outward into the surrounding ground while a new pipe is installed behind the tool.

There are several variations of the process with different approaches to various aspects of the breakage and replacement. Pipe bursting was first developed in the United Kingdom where it was patented in 1981. It was patented in the United States in 1986, but it has only become a common technique in the past few years. The technique was developed for replacement of cast-iron gas pipes, but its major application in the United States is for sewer pipe replacement. The total footage of pipe replaced using pipe bursting in the United States is growing at approximately 20 percent per year (Hopwood 1998).

Thus, *Pipe Bursting* can replace existing piping without expensive excavation and restoration costs. This system saves money for all parties' municipality, contractor and customer. Designed with versatility and simplicity in mind, this system is ideal for replacing or upsizing existing water main, sewer or storm water piping. *Pipe bursting* is fast becoming the preferred method, and can handle projects up to 36 inches diameter and pull in pipe lengths up to 1,000 l.f. All the equipment required for a job can be easily and quickly transported. Pipe Bursting involves minimal excavation, which is extremely important when other utilities are close or when landscape restoration is an issue.

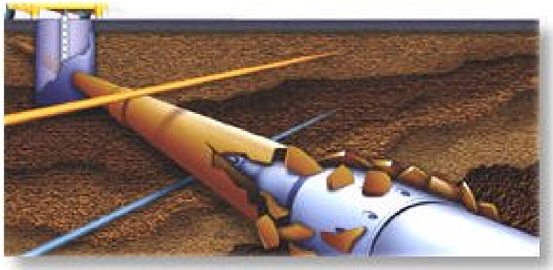


Figure 1: **Typical Pipe Bursting behavior**

History

In the late 70's British Gas was faced with a problem of deteriorating gas lines in severely congested and developed areas. Open cutting to replace these lines was cost prohibitive and sometimes not an option. So in conjunction with a utility contractor, British Gas developed the patented process of Pipe Bursting to replace fracturable pipes including water, sewer, gas, and telephone. During the Pipe Bursting process, excavation and the disturbance to the surrounding community is greatly reduced.
Pipe Bursting, used to replace old lines, is:

- Used extensively in Europe.
- Actively used in the United States since 1988.

- British Gas (BG plc) developed and patented the process.
- 37 million feet of Pipe Bursting footage worldwide.
- 80% of Pipe Bursting is done with pneumatic systems.
- Over 6,000 Miles in use (both main lines and service lateral)**:** Cities all across North America are using Pipe bursting to maintain or improve their pipeline systems.

The cost of upsizing over 6,000 feet of 15-inch and 18-inch pipe to 24-inch polyethylene in Colorado was one million dollars less than dig-and-replace.

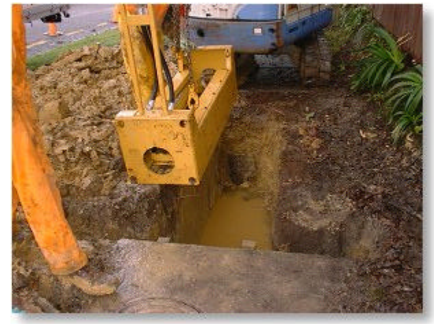
A wide choice of replacement materials

With Pipe-bursting, you have a wide choice of replacement materials, Polyethylene, PVC, glass fiber, and many types of metal pipe have been used successfully. Regardless of the material you choose, you will have the assurances that it has been manufactured to strict national standards such as AGA, API, ASTM, and AWWA. Your new pipeline will have known physical properties, and an established service life. With Pipe bursting, you do not have to worry about field chemistry or the stress of reducing or reshaping pipe. You get the material that suits you best, not the limitations of the technology.

Pipe Bursting involves expanding and breaking an existing utility and simultaneously pulling in the new carrier line, which is usually Polyethylene pipe (HDPE). Pipe Bursting, historically, is done on pipes that can fracture cast iron, clay, PVC, asbestos & concrete, reinforced concrete.

Component Functions

Typically, pipe bursting requires the following tools:



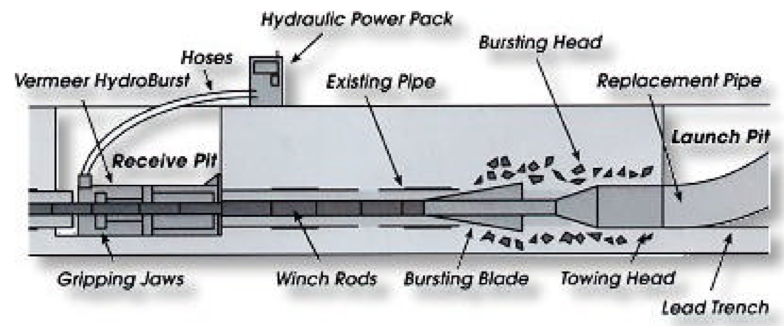


Figure 2: **Pipe Bursting Components**

- *Winch* - Winch helps guide the tool, burst head, and new pipe into the old pipe.
- *Pneumatic Tool* - The impact force of the tool cracks the old pipe.
- *Burst Head* - The burst head pushes the old pipe fragments, called shards, into the surrounding soils.

- *New Pipe* - The new pipe is attached to the burst head and is pulled in as the burst is done.

2) *The Pipe Bursting Process*

The pneumatic bursting tool is inserted inside the new polyethylene pipe. A proper sized bursting head is then attached to the new PE pipe. A winch cable is then hooked to the tool that will help keep it on line as it progresses through the existing line. As the pneumatic tool moves forward the assembly is simultaneously winched. The action bursts the existing pipe and pushes the pieces of old pipe into the surrounding soil no further than the outside edge of the bursting head, as the new PE pipe is pulled into place. The pneumatic tool is protected inside the new pipe and the steel burst head is the leading edge used to fracture the old pipe. When the bursting head has reached its destination, the stake down unit and winch cable are removed, then the tool is placed into reverse. The reverse action of the tool helps to back it out of the new line all the way to the launch pit. The bursting head is cut off and removed. The installation of the new pipe is now complete and ready for connection.

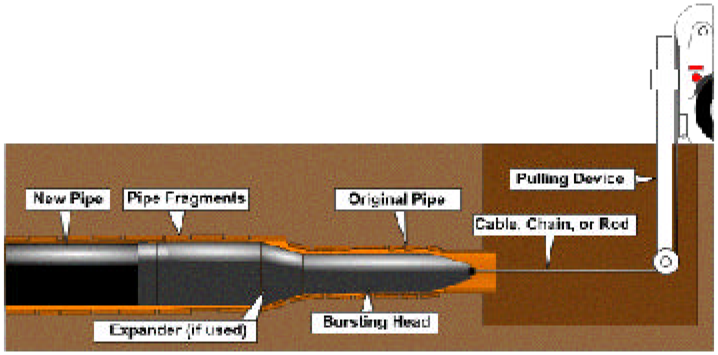


Figure 3: **Pipe Bursting Process**

Overview of the Technology

Pipe bursting is an on-line replacement technique that offers a means for replacing existing deteriorated pipelines. Pipe bursting, also referred to as 'pipe cracking," is a method where the host pipe is broken up and pushed aside, while a new pipe of equal or larger diameter is pulled or jacked in place. Pipe bursting can be utilized for a “size-to-size" replacement or for 'upsizing” of the existing pipe. While greatly influenced by site conditions, upsizing of 25 percent to 100 percent of the original pipe diameter is fairly common. Because of the outward expansion of the old pipe fragments, it is necessary to disconnect laterals and service pipes prior to using pipe bursting. While remote disconnection is made possible through recent developments, the most common method is by means of excavation pits at the lateral/service pipe location.

The number and frequency of lateral or service connections is a determining factor when assessing the economic viability of Pipe Bursting.

Although "pipe bursting" is a generic term, there are actually three commonly used methods for achieving this: pneumatic or percussive pipe bursting; hydraulic pipe bursting, and static pipe bursting.

Pipe bursting is a method for replacing pipe by bursting from within while simultaneously pulling in a new pipe. The method involves the use of a static, pneumatic or hydraulic pipe bursting tool drawn through the inside of the pipe by a winched cable with the new pipe attached behind the tool. The bursting tool breaks the old pipe by applying radial force against the pipe and then pushes pipe fragments into the surrounding soil. Similar methods include pipe rodding and pipe splitting.

Pipe bursting can be used to replace clay, concrete, cast iron and PVC pipe with PE, PVC or fiberglass pipe. Gas, power, sewer, telecom and water lines from 4" - 36" in diameter have been replaced using pipe bursting.

Pipe bursting works well in areas with compactable soil and where surrounding utilities or roadbeds won't be disturbed by the vibration and compaction. Pipe bursting does not work with sharp bends.

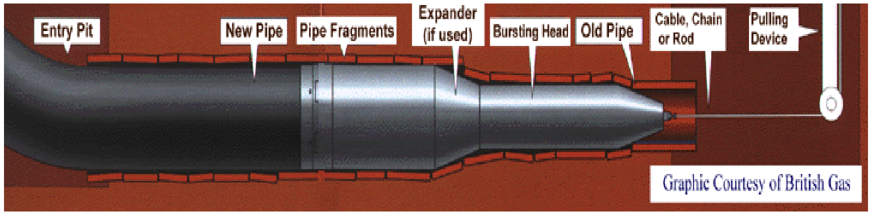


Figure 4: Components of Head for Pipe Bursting

Different heads are available:

A. Static Head

Static heads have no moving internal parts. The head is simply pulled through the old pipe by a heavy-duty pulling device.

Of the entire pipe bursting methods this is the fastest.

Pipe Bursting Using a Static Head

The contractor T-C Inc., Indianapolis, Ind., utilized the static pipe bursting method for pipe replacement. Machine pits used in static pipe bursting can range in size from 13ft, 8ft or to the size of a manhole. Some types of bursting equipment only require the insertion of a mechanical arm or leg with a pulley into a manhole to direct and pull a cable or chain. Depending on ground conditions and depth of the host pipe, shoring may be required, though sloped walls are also an option.

Generally, vertical walls are used to keep the footprint of the excavation to a minimum; this assists in minimizing surface disruption and the cost of restoration. Insertion pits are generally smaller than the machine pits. As a rule of thumb, for static bursting methods using continuous pipe, the length of the insertion pit should be 12 times the diameter of the new product pipe. Additionally, a length to account for the slope depending on the depth of the excavation at a ratio of 1.5 to 2.5 run to 1 depth should be added. The slope ratio largely depends on the bend radius of the product pipe.

The width of the pit depends on the amount of space required for crews to maneuver around the pipe in the pit to connect the bursting head. Generally, insertion pits need only be approximately 4 ft in width. Service pits may be excavated with a minimal surface footprint. The size of the pit depends on the depth of excavation and the maneuverability of the excavation equipment in the confined space of the pit. Generally, a service pit may only be 4 ft in diameter to provide enough space for a worker to disconnect and reconnect the lateral. These pits may be shored using large diameter steel pipe sections, depending on the pit depth.

After excavation of the pits is complete, the bursting machine can be lowered and secured into the machine pit. The bursting machine is secured to the sharing in the pit to minimize lateral movement of the machine during pipe bursting. Additionally, the face of the excavation, to which the bursting machine pushes against during the installation, is reinforced with timber or steel plates to evenly distribute the bearing area. Once secure, the bursting machine pushes or “shunts” rods through the line to be replaced to the insertion pit. As each section of rod is pushed into the host pipe, another section is connected until a continuous string of rods is in the host line.

To assist the progression of the drill pipe string, a blunt nosed bullet head is attached to the first section of rod in the string. This head prevents the string from catching on pipe joints, as well as allows the pipe to push or bore through debris or sediment that may be in the original pipe. Once the drive rod string reaches the insertion pit, the product pipe is attached as illustrated in *Figure 5*.

Static heads have no moving internal parts.

The head is simply pulled through the old

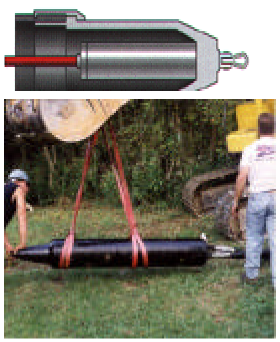
Figure 5: **Static Head Representation**

Adequate measures have to be taken to insure that the product line is not damaged as it enters the insertion pit. This can be accomplished with the addition of rollers or supports under the product pipe at intervals that keep the bend radius of the pipe within the manufactures recommended limits. The bursting machine pulls the drive string and disconnects sections from the string as the burst progresses. As the bursting head advances, the host pipe is burst while the product line is simultaneously installed. The head advances to the machine pit where it is disconnected from the product string. At this time, the product is inspected for damage. If no damage is found, the new line is ready to be reestablished to the existing network.

Generally, the new line is given time for any residual stresses from the installation to dissipate before any service connections are made or pit restoration performed. Once the product line is determined to have relaxed, generally within a 24-hour period, lateral services are reconnected and the site restored. In this project a “chain pull” method was utilized.

B. Pneumatic Head

Pipe bursting using a pneumatic bursting head (*Fig. 6*) relies on the percussive fracture mechanism to break out the old pipe in which the tool travels. The new pipe, usually polyethylene, is pre-welded, fused to the required length, and is simultaneously drawn in behind the bursting head. Cable or rods are attached to the nose of the bursting head to enhance the percussive force, and also to maintain the head on correct line and grade. This technique is primarily aimed at replacement of pressure pipes, and has been used in diameter *ranges from 4 in. to over 20 in.*



Pneumatic heads use pulsating air pressure to drive them forward and burst old pipe. A small pulling device guides the head.

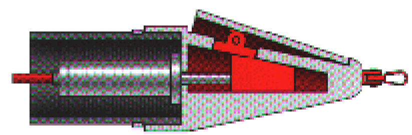
Figure 6: **Pneumatic Head Representation**

C. Hydraulic Head

One of the factors to consider with a pneumatic pipe bursting system is the effect of percussion on adjoining utility services, foundations and paved surfaces. An alternative is Hydraulic pipe bursting (*Fig. 7*). In the hydraulic pipe bursting systems, a compact bursting head is equipped with 'petals" which open and close under hydraulic pressure. The bursting head is first expanded to crack the host pipe, and then retracted.

Hydraulic jacks push the pipe string forward, while tension is applied to the nose of the head using a chain or rod to maintain directional stability.

The process is repeated until the entire host pipe is replaced. Fused polyethylene (PE) pipes or short segments of polyethylene pipes with 'snap-lock" joints are commonly utilized for the new pipe. Recently vitrified clay pipes with stainless steel joint collars, to enhance shear strength, have been used, thereby allowing sewers to be replaced using traditional inert materials. Hydraulic bursting is primarily used for on-line replacement of sewers and gravity pipelines. *To date, pipes in the diameter range of 6-in. through 40-in. have been replaced using the hydraulic method.*



Designed for cast iron pipe, the hydraulic head expands at it is pulled through, bursting both the old pipe and heavy joints.

Figure 7: **Hydraulic Head Representation**

The solutions

- Often, Pipe Bursting is more cost effective than open cut excavation.
- Pipe Bursting is a replacement method, not a rehabilitation method.
- Pipe Bursting can increase capacity up to 100% or more over the existing system.

- Pipe Bursting reduces the risk of contacting existing utilities during pipeline replacement.
- Pipe Bursting can be accomplished despite unstable ground, partially collapsed lines, or a high water table.
- Pipe Bursting uses the existing pipeline, maintaining line and grade.
- Pipe Bursting keeps the laterals in the same place and on the same grade.

Advantages

1. Pipe Bursting is the only trenchless method that can be used to increase the capacity of the system by upsizing the line. Other methods like cured in-place or sliplining do not allow this. With Pipe Bursting, capacity can be increased up to 100% or more.

2. Pipe Bursting for replacement of the line is the preferred method if:

    - The pipe is not structurally sound.
    - Capacity is an issue.
    - There are dips, sags or offset joints.
    - There are missing pipe sections or partially collapsed lines.
    - All debris, rocks, silt and roots cannot be completely cleaned prior to lining.

    All types of lining procedures will conform the lining to whatever the structure of the line is. Laterals often require "hard taps". No grouting accepted.

3. New, Leak proof Fittings at Every Service Connection. The pipeline materials used in the Pipe bursting process have a wide variety of proven, standard fittings. These fittings may be used to reconnect your new pipe to the existing system or to lateral service lines. Either way, every connection will be made with proven, leak proof, off-the-shelf fittings.

Figure 8: **typical fittings**

4. Safe Operation
    Pipe bursting has been used successfully in both municipal and industrial applications to replace many different types of pipelines. Gas, water, sewer, and production lines, as well as communication ducts have all been replaced with Pipe bursting, even in crowded underground situations. Experience has shown that the operation of pipe bursting heads does not damage other buried utilities, even when they are only a few feet away. The surrounding soil serves to adsorb the vibrations created by the pneumatic heads, and pipe fragments are pushed far enough away to prevent damage to the new pipe. And, since most pipelines are

below the frost line, Pipe bursting operations can be carried out safely at any time of the year.

5. Environmentally Friendly
   Since digging is limited to relatively small access pits, Pipebursting is much less traumatic than traditional pipeline replacement. Long sections of pipe can be replaced without introducing open trenches and heavy equipment. And, since the old pipe is left undisturbed underground, it does not present a disposal problem.

Cutting Costs/Significant Cost Savings

Without doubt, Pipe-bursting is one of the most economical ways to replace a buried pipeline. The direct costs are generally lower than the traditional dig-and-replace method, but when time, disruption, and restoration costs are added in, Pipe-bursting is far less expensive.
Typically Pipe Bursting reduces up to 85% of excavation and related costs:

- Excavation: 1 backhole 2 Dump trucks
- Removal of Old Pipe and Spoil: Dump/disposal costs of old pipe and dirt
- Backfill to Bed New Pipe: delivered to site (material, labor and compaction)
- Asphalt: Delivered and compacted

Figure 9: **Typical Excavation for Pipe Bursting**

3) *Pipe Bursting Case Studies*

Pipe Bursting Case Study 1: *Demonstration of Innovative Water Main Renewal techniques*

Source: AWWA Research Foundation

Part of the AWWA report is the evaluation of pipe bursting technologies. The hydraulic and pneumatic pipe bursting technologies were demonstrated in Houston during the week of October 21, 1996 and in Chicago during the weeks of June 3 and June 10, 1996.

The demonstration projects provided an opportunity to collect various types of data related to pipe bursting operations. The type of data collected during this demonstration included noise levels during installations, surface heave and settlement along the axis of the installation, vibrations and productivity. The capability of the pipe bursting machines to deal with repair clamps was also of interest.

The following observations were made:

- *Noise Levels:* For hydraulic pipe bursting, the highest noise level was 94 dB, which was recorded immediately adjacent to a vacuum truck that was used to remove water and debris from the pits. For pneumatic pipe bursting the highest noise level was about 86 dB. In Chicago the background noise level was in the range of 70 to 105 dB, and the highest recorded noise was 102 dB at the machine pit. In summary, the noise levels experienced during any of the demonstrations were not more than those due to normal open-cut construction methods, and they were of shorter duration.

- *Surface Displacement:* In Houston, no measurable surface heave or disruption was found. In Chicago, except for the significant amount of heave seen at the machine pit due to the failing of the pit wall, no significant heave was observed.
- *Vibrations:* Vibration data collected at the demonstrations did not indicate that pipe bursting would damage existing surface structures or nearby underground utilities. In general, vibrations seem to have little impact if the utility located nearby is at least two diameters of the burst pipe away. In Houston, out of the 500 data points collected from the two demonstrations, all the recorded points were within the safe portions of the USBM and OSM envelopes. In Chicago, the highest monitored peak particle velocities (PPVs) were 0.018 in./sec, well below the allowable level of 2 in./sec.
- *Productivity:* The tasks that look considerable time were setting up the bypass lines to provide service for customers, fusion of HDPE pipes, and tying back the services. The actual pipe bursting took less than a day for the successful demonstrations.
- *Hydraulic Capacity:* Because of increased internal smoothness of the pipes, the hydraulic capacity of the pipes greatly improved as measured by their Hazen-Williams C-values.
- *Pipe Bursting Costs:* The construction cost for all three October demonstrations (i.e. hydraulic pipe bursting, pneumatic pipe bursting and Rolldown rehabilitation) was approximately $100/ft. per one of the contractors, the long-term cost for replacement by pipe bursting should go down to $45/ft. this price would include all site activities including temporary bypass and site restoration. For the Chicago project, the cost of installation of the 8-in. MT-push pipe by the static pull pipe bursting method was approximately $150/ft. Based on adjustments made due to the experimental nature of the project, the cost could be reduced to about $136/ft. it should be noted, however, that these cost estimates did not include disconnecting and reconnecting service lines.

Pipe Bursting Case Study 2: *Static Pipe Bursting for the North American Gas & Water Markets*

By Jim Schill, Technical Author
NO-Dig Magazine, April 2001

After being field tested and developed in Europe by Tracto Technik, the Groundburst was recently launched in North America at the UCT 2001 event in Houston, Texas by TT Technologies, U.S.A. The hydraulic pipe bursting system, which has the ability to split ductile iron and steel lines, has already been involved in several high profile jobs in the United States and the potential for more work is great.

Comparison

While pneumatic bursting works well with a wide variety of fracturable host pipe materials and diameters, ductile iron and steel pipes have been a limitation of the pneumatic method. In the United States the demand for pipe bursting grew in the sanitary sewer market, but did not establish itself so well in the water and gas markets because of the abundance of ductile iron and steel pipes.

That is beginning to change with the recent introduction of the hydraulically powered Groundburst static pipe bursting system which gives contractors the ability to split and replace ductile iron, steel and lined pipes.

During the static bursting process, specially designed bladed rollers are pulled through an existing line by a hydraulically powered bursting unit. As the bladed rollers are pulled through, they split the host pipe. An expander attached to the rollers forces the split pipe into the surrounding soil while simultaneously pulling in the new pipe.
Patented Quicklock bursting rods are easily and securely linked together not screwed together like traditional drill stems or other static bursting systems. This system speeds the installation process as well as the breakdown procedure. The rods can be quickly removed one at a time at the exit pit as bursting occur.
For longer lengths of pipe or runs with slight bends, the project can be divided. A 1,000 ft long run for example, can be divided into two 500 ft sections with the Groundburst operating from a position in the middle. While one section is being burst, the Quicklock bursting rods are pulled from the first section through the Groundburst and fed into the next section.
That way, as the first section is completed, the next bursting run can begin almost immediately.
According to TT Technologies Pipe Bursting Specialist Collins Orton, bursting steel as well as ductile iron is a significant advancement in trenchless pipe replacement. He said, "I see this technology having a great impact on the gas and water industries. There are miles of steel and ductile iron lines throughout North America that are undersized and/or deteriorating, which need to be replaced. Some of this work is even required by legislation. Being able to replace and upsize these lines without digging them up is a benefit to everyone."

California

Recently, pipe rehabilitation contractor ARB, Inc, Lake Forest, California, was able to do something few contractors in North America have, replace a 6 in diameter, 10 gauge steel water main with 8 in diameter HDPE using pipe bursting. The project was completed for the South Tahoe Public Utility District (STPUD), South Lake Tahoe, California.
The existing 330 ft long steel water main was being replaced as part of a water tank rehabilitation project. Because the line ran through a section of national forest, open cutting was not an option. Pipe bursting was the method of choice for this particular project. Because traditional pneumatic pipe bursting has been largely unsuccessful in bursting ductile and steel pipe, ARB Rehabilitation Manager Dave Arthurs turned to the hydraulically powered Groundburst 1000G rig, the largest of three Groundburst models.
For the STPUD project the ARB crew dug a 5 ft by 15 ft launch pit at the beginning of the run and a 5 ft by 20 ft exit pit 330 ft away. The bursting unit was positioned in the exit pit and connected to a hydraulic power pack. The crew then began inserting the Quicklock bursting rods through the host pipe and into the launch pit. A flexible guide rod attached to the front of the first rod was used to help ensure the smooth installation of these rods.
On arrival at the launch pit, the ARB crew removed the guide rod and attached the bladed cutting wheels, bursting head, expander and new HDPE. The entire configuration was then pulled back through the host pipe by the hydraulic bursting unit. The 8 in diameter HDPE was installed without incident in approximately 45 minutes.
After the HDPE was in place, the ARB crew removed the bursting equipment. The new main was then chlorinated, tested and put into service.
Arthurs said, "Our crew was very impressed by how easy the machine was to operate. They were even more impressed that we were able to split steel pipe. We have done an extensive amount of pneumatic pipe bursting but have never previously used a static system. This was our first attempt bursting steel

pipe. Overall, we were very pleased with the results of the project."

Washington State

Pilchuck Contractors of Kent, Washington has also been bursting steel lines. The company's project, however, have been for the gas industry. The utility contractor utilizes several types of trenchless technology, but has limited pipe-bursting experience. Using the static bursting system, they recently replaced a substantial amount of steel gas mains for Puget Sound Energy (PSE) of Bellevue, Washington.

According to TT Technologies Pipe Bursting Specialist Jim Moore, there are major gas line rehabilitation and replacement projects underway in that part of the country. Moore said, "Hundreds of thousands of feet a year are being replaced through a major remediation program that is regulated by the Washington State Utility Commission. Much of that work is bare steel and wrought iron pipe."

For its first project with the Groundburst, Pilchuck Contractors burst a 4 in diameter, 0.188 wall (3/16 in) steel gas main and replaced it with 4 in diameter HDPE pipe. The 120 ft main ran under the highly traveled Des Moines Memorial Drive. The Pilchuck crew used the smallest Groundburst model, the 400G, for the job. According to Pilchuck Vice President Bob Gray, working with the static system was very easy. He said, "The machine is pretty straight forward. Our crew caught on quickly."

The Pilchuck crew dug both the launch pit at the beginning of the run and an exit pit at the end. After the bursting rods were inserted through the host pipe, the bladed cutting wheels, bursting head and expander were attached, along with the 120 ft of new 4 in diameter polyethylene pipe. A weak link was used to help ensure pipe integrity.

According to Gray, the new line was also pressurized during pullback. He said, "We pressurized the new HDPE pipe to 100 lb/in^2 during pullback for two reasons. First, if there were a loss of pressure, we would know something happened to the pipe. Second, pressure testing of the new pipe was required. That testing lasts for four hours.

In order to limit the amount of time residents were without service, we began pressure testing right away."

The Pilchuck crew was able to complete the burst in less than two hours. The new 5/8 in diameter services were tied into the main using standard sidewall fusion couplings.

Night Moves

Even before the Des Moines Memorial Drive project was finished, PSE approached Gray with another project. The new project, in Bellevue, Washington, called for the replacement of 800 ft of 4 in diameter steel gas main with 6 in diameter HDPE pipe.

Gray explained, "The Bellevue project was done in conjunction with another project our telephone/communications division was performing in the same location. PSE wanted a gas main upsized in downtown Bellevue. Getting both projects done at the same time, during the night, ment less downtown disruption. Utilizing trenchless pipe splitting meant a tremendous saving in restoration and paving costs."

The Pilchuck crew divided the 800 ft long run into four smaller runs so commercial service could be restored in a timely fashion. In addition, the city wanted to limit the amount of disruption downtown and imposed a 200 ft construction zone limitation.

According to Gray the existing backfill proved to be the most difficult part of the Bellevue project. He said, "We ran into a lot of Controlled Density Fill (CDF). CDF is basically really weak cement. It's a flowable material that is able to fill gaps and voids. It's becoming very popular in the Washington State area, especially for road restorations. We see it used a lot instead of standard crushed rock backfill. You can dig through it with a back-hoe, but not with a hand shovel."

Despite the difficult backfill, the Pilchuck crew was able to burst and replace the 800 ft long steel main over four nights. As a result of pipe bursting the main, 65 ft of asphalt restoration was required as opposed to 800 ft if the project had been open cut.

Future Projects

Both Gray and Arthurs agree that the ductile iron and steel rehabilitation market is sizeable. Arthurs said, "I expect to do a lot of this work in the future. There is great potential on both sides, gas and water."

Gray said, "We already have sizeable replacement contract that allows us to choose the method of installation. Splitting pipe is a great option to have. We can save a tremendous amount money in paving and restoration costs."

4) *Pipe Bursting Project Consideration*

Host Pipe Materials	Most techniques are limited to brittle pipe materials such as cast iron, clay and un-reinforced concrete.
Host Pipe Condition	In all cases, the success of the operation is dependent on accurate assessment of the condition of the existing pipe. Repairs noted during video inspections, such as joint repairs with stainless steel sleeves or injection of epoxy and concrete around the host pipe, may not be suitable for bursting. Excavating the points of repairs may become necessary and will affect the cost of the project. If the host pipe has accumulation of sediments, this can cause the bursting tool to lift up and go off course. Hence the host pipe may require cleaning prior to bursting. If the bursting tool encounters a collapsed section of a pipe, the tool can go off track and snap the winch line attached to the nose, thereby halting progress.
Host Pipe Size	Currently, the majority of the pipe bursting in the world is achieved for pipe diameters in the range of 6-in. through 40-in. Typical upsizing is in the 25 percent through 100 percent range. Equipment selection is dependent on host pipe diameter and required upsizing.
Host Pipe Depth and Profile	Expansion of the surrounding soil, especially during upsizing, is affected by depth, as is water table consideration. As the depth increases the start and exit pits required for the operation become larger and more complex. If there are bends in the existing pipe, bursting tools are often unable to navigate sharp bend.
Surrounding Soil Conditions and Types	In most instances the original host pipe was installed by 'trenching" and hence the top of the pipe is most likely in 'fill material." Pipe bursting is best suited where the surrounding soil is "compressible," such as clay. It is necessary that after the tool has burst the old pipe, the cavity remain open and stable until the new pipe is in place. If the surrounding soil is clean sand for instance, this will not happen, requiring the use of bentonite slurry and other considerations. Another important consideration is that the base soil

	be able to support the weight of the tool, expander and the new pipe. A sewer line that has been leaking for some time may have cavities and pockets around it and may not be able to support this weight.
Burst Length	In sewer rehabilitation application, burst lengths are typically from manhole to manhole. Longer lengths can be achieved by passing through an intermediate manhole with proper care and preparation: Longer lengths generally require application of bentonite slurry to reduce skin friction between the pipe and surrounding soil. Burst length is a function of pipe size. The larger the pipe diameter, the heavier the pipe that has to be pushed/pulled into place.
Product Pipe Materials	Pre-fused High-Density Polyethylene (HDPE) pipes or segmental polyethylene pipes with "nap-lock" joints are the most commonly utilized product pipe materials.
Adjoining Utilities and Services	Historically, the rule of thumb has been that utilities farther than three times the diameter of the product (new) pipe are generally unaffected by pipe bursting. All interfering and crossing utilities must be located and exposed prior to bursting. Gas services are normally excavated so as to provide temporary service.
Start and Exit Pits	For sewer applications, start and exit pits are usually at manhole locations. Manhole inverts often require modifications to allow for passage of the bursting tool. All pits must be prepared and shored per regulations. For manhole entry, all confined space safety procedures must be followed.

5) *Studies related to this technology*

"Design and Application Issues for Pipe Bursting", Louisiana Tech University

Ray Sterling, Alan Atalah, Paul Hadala

During 1996 and 1997, the Trenchless Technology Center was involved in a research project involving pipe bursting. This project involved field and analytical studies of ground movements, ground vibrations and -other design issues associated with trenchless pipe replacement. The firms participating in and supporting the project were British Gas, CSR Pipeline Systems, Earth Tool Corp., Kinsel Industries, Mid-South Trenchless, Miller Pipeline *Co.,* Roy F. Weston Inc., TRS Ltd., and TT Technologies Inc.

Major funding for the project was received from the Louisiana Board of Regents' Support Fund. This research and demonstration work supplemented previous studies in Europe on the dynamic and static ground movements resulting from pipe bursting and the implications on replacement pipe design of the pipe fragments remaining from the existing pipe. The research has helped to develop an understanding of the effects of the process on the surrounding ground and to refine the safe limits for pipe bursting in terms of proximity to existing services and other structures.

1. **Ground Vibrations**

Extensive measurements of the velocity of vibrational ground movement associated with pipe bursting were made. These measurements were made at seven job sites located in various regions of the United States and at the TTC test site in Ruston, La. The jobs involved various degrees of upsizing (0 percent to 50 percent) and difficulty associated with the bursting. The sizes of existing pipe burst ranged from 6 in. to 15 in. diameter and the largest replacement pipe size used was 18 in. diameter.

Ground velocity data were recorded using geophones and a portable data recorder in two principal ways -- as a displacement-time record over a selected time interval and as a peak ground velocity in any direction over a time interval. The first method allowed the calculation of the frequency of the ground vibration as well as the maximum ground velocity but allowed fewer measurements due to field data storage limitations. The second method recorded only the peak ground velocity but allowed many more readings to be taken during a pipe bursting operation.

The measurements were taken at various locations along a pipe bursting job segment and at various off- sets from the centerline of the pipe being burst. In measurements at the TTC field test site, measurements also were taken at the bottom of holes excavated to various depths above the pipe being burst. In this manner, data were obtained for vibration levels at various distances from a bursting head under a variety of job site conditions using three pipe bursting techniques - pneumatic, hydraulic expansion and static pull.

The maximum ground velocity data recorded using the first method (i.e. with associated frequency information) was compared with standard criteria for damage to buildings caused by blasting vibrations. All the data recorded using both methods was used to study the relationship of ground velocity levels to the distance of the measurement point from the calculated position of the bursting head at the time of the measurement.

The main conclusions associated with the monitored vibrations and their analyses are:

- Only four readings out of the 832 measurements recorded with associated frequency data exceeded either of the threshold criteria for cosmetic cracks in buildings developed by the U.S. Bureau of Mines and the Office of Surface Mining. Three of these four readings were unreliable (one reading for external factors and two for having a frequency below the manufacturer's specified minimum frequency of 2 Hz). The fourth reading was just above the threshold criteria.
- The higher levels of observed vibration tended to be in a frequency range of30 to 100 Hz that is well above the natural frequency of buildings (typical range from 5 to 11 Hz).
- Buried pipes and structures are able to withstand much higher levels of vibration than surface structures of similar integrity. None of the vibration levels recorded would be expected to cause distress to buried structures.

- Only the data from the pneumatic pipe bursting system provided reasonable correlation for the peak particle velocities recorded against distance from the bursting head. This is thought to be a result of a large number of vibration measurements associated with non-burst-related vibrations that are recorded during the non-burst portion of the slower burst cycles involved with the other methods. This resulted from the way the data were recorded and it was impossible, after the fact, to correlate vibration data only during the active part of the bursting cycle.
- For the range of bursting projects monitored, the regression equations (95 percent prediction interval upper limit) and the field measurements made in test holes close to the bursting head indicate that damaging levels of ground vibration to underground structures (velocities of 5 in./second) are unlikely to be reached at a distance greater than 2.5 ft from the bursting head. Damaging levels for sensitive surface structures (velocities of 2 in./second with a frequency in the range from 30 to 100 Hz) may be reached within distances of 8 ft from the bursting head, but this will rarely be an issue when replacing pipes in a public right-of-way. Eighty-three percent of the recorded vibration frequencies were within the 30 to 100Hz range.
- The vibration levels present during bursting will be dependent on the power/impact applied to the bursting process and hence on the size and material of the pipe being replaced and on the degree of upsizing. The reported results and their analysis reflect the equipment used at the sites monitored.
- Overall, it can be summarized that while ground vibrations may be quite noticeable to a person standing on the surface close to a bursting operation, the levels of vibrations recorded are very unlikely to be damaging except at very close distances to the bursting operation.

2. Noise

The main source of noise during a trenchless pipe replacement operation is typically the air compressor used. Since air compressors are present on most construction sites, the noise associated with pipe replacement presents no special concerns. In the pneumatic system, noise is also released from the open end of the replacement pipe due to the cyclical release of pressure associated with the pneumatic action, but this effect is localized and unlikely to be of special concern.

3. Stress in Replacement Pipe

The stresses in the replacement pipe were measured during two bursts at the TTC test site. The actual axial pipe stress in a 12-in was first measured, HDPE pipe being used to replace an 8-in. clay pipe using pneumatic pipe bursting. The second burst consisted in an actual axial pipe stress measured in a 10-in, HDPE pipe being used to replace an 8-in. clay pipe using the hydraulic expansion system.

The actual stresses measured during each burst were quite different but both fell approximately within the range of stresses calculated by the above assumptions. Both the site conditions and the bursting method varied between the two monitored bursts and hence the two tests cannot be directly com-pared with each other. The limited number of conditions represented and the variance of the results allow only limited conclusions. These are:

- Existing methods of estimating friction loads on pipes for trenchless technology appear to match the range of stresses measured.
- Measures to retard the collapse of soil around the replacement pipe will lower stresses in the replacement pipe.
- None of the stresses measured exceeded about two-thirds of the yield stress of the HDPE pipe, but the bursting run was not long about 90 ft.
- The level of stress in the replacement pipe was actually less for the pipe with larger upsizing percentage, so there is not a direct relationship between upsizing percentage and replacement pipe stress.
- The magnitude of the stress cycling in the replacement pipe during installation is small compared with the mean stress level, i.e. pneumatic impact effects or longitudinal stress variations during hydraulic expansion are not significant in the systems tested
- More attention to estimating the potential stress in the replacement pipe and/or monitoring the pulling force applied to the pipe behind the burst head is recommended when site conditions and length of burst may cause high pipe stresses.
- The use of lubrication muds will reduce axial pipe stresses by resisting hole collapse during bursting and by reducing the pipe-soil friction coefficient.

4. Ground Displacements

The ground movements measured in the research project varied from ground displacements with a symmetrical pattern of heave displacements that would be expected from theoretical considerations and from the previous laboratory and field studies reported in the literature to significantly asymmetrical displacements and significant settlements.

The ground displacements are principally dependent on the degree of upsizing, the type and compaction level of the existing soil around the pipe, and nature of confinement of the soil around the pipe (e.g. near surface vs. deeply buried). Cohesive soils tend to give more predictable soil displacement profiles whereas in sands localized collapse is possible within the tail void of the expansion head.

In the job sites monitored, the ground surface movements were mostly heaving movements. The maximum ground surface movement monitored on a pavement surface was 1.26 in. for a 33 percent upsizing of a 6-in. pipe at 6 ft below the surface. The maximum ground surface movement monitored on anon-paved surface was 3 in. for replacing 10 inches VCP with a 10 inches HDPE pipe at 10 ft below the surface in stiff clay soil.

These values were exceptional singular movements, and the majority of the surface movements were within the range of minus 0.25 to plus 0.75 in.

At the TTC test site, the ground displacements involved significant settlement away from the immediate vicinity of the pipe. This is due to the relatively low level of compaction of the backfill soils at the reconstructed test site and the newness of the backfill. Under such conditions the pipe bursting process acts to consolidate the existing soils, allowing the diameter increase to be absorbed by soil compactiol1 within a short distance of the pipe. At greater distances from the pipe continued soil compaction caused by the bursting vibrations and ground disturbance may result in ground settlement.

The most critical conditions for consideration of ground displacement due to pipe bursting are when:

- The pipe to be burst is shallow and ground displacements will tend to be primarily directed upward.
- Significant upsizing percentages for large diameter pipes are used.
- Deteriorated existing utilities are present within two to three diameters of the pipe being replaced.

The replacement or upsizing of deep utilities away from other utility lines will have no or little impact on these lines or surface structures unless the surrounding soil is a collapsible soil.

It should be noted that significant ground movements are also usually associated with open trench replacement of pipes

(Rogers 1995).

5. Position of Replacement Pipe

The replacement pipe naturally follows closely the line and grade of the original pipe. However, the centerline of the replacement pipe will only rarely coincide with the centerline of the original pipe because the position of the new pipe will depend on variations in the resistance to the expansion movements in the soil caused by the bursting operations. These movements will occur even in size-for-size replacement because the bursting head is of a larger diameter than the replacement pipe. Figure 10 illustrates the qualitative types of movements that are probable under various site and soil conditions.

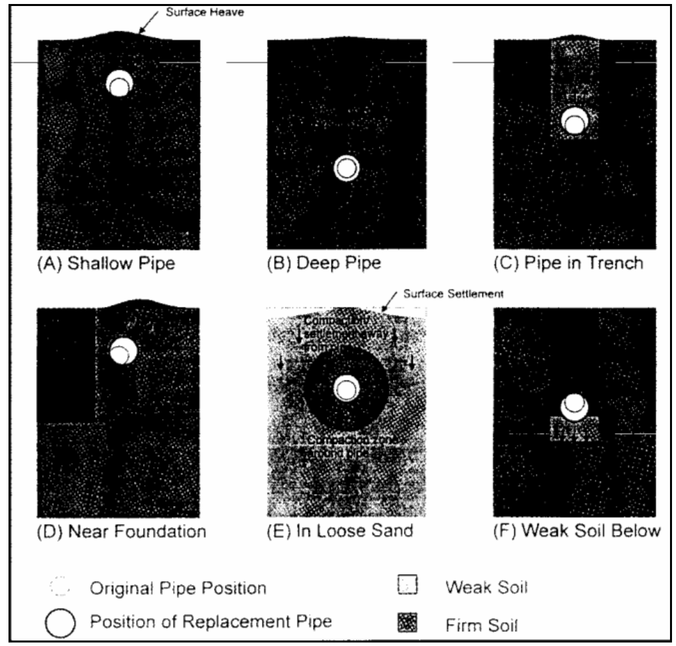


Figure 10

The major factors that affect the relative position of the replacement pipe are:

- Soil displacements will occur in the direction of the least soil resistance - usually toward the surface. This tends to cause the centerline of an upsized pipe to be higher than the original pipe but the invert elevations to match closely (*Figure 10.A*). If, the existing pipe is deep, the expansion tends to occur more equally in all directions. Under this condition, the centerline of the replacement pipe will closely match that of the existing pipe, but the invert elevation of an upsized pipe will be lower than that for the existing pipe (*Figure 10.B*). It follows from this that, if the depth of the pipe varies significantly along a pipe segment to be burst, and then the grade of the new pipe may be slightly different to that of the old pipe. This may be an issue in sewer pipes laid on very flat grades.

- Soil displacement is affected by the installation conditions for the existing pipe and the presence of surrounding structures. Ground movements may be mostly confined within the original trench for the existing pipe or may be strongly asymmetrical if a rigid structure is close to one side of the pipe (*Figures 10.C and 10.D*).

- The size of the expansion head is typically larger than the replacement pipe. This allows the replacement pipe to take different positions within the soil cavity depending on longitudinal bending of the pipe and/or localized ground movements.

- When a stiff replacement pipe (large diameter, thick wall) is given insufficient room in the insertion pit to be lined up with the original pipe, the pipe may deviate downward from the original grade near the insertion pit.
- Sags in the existing pipe will tend to be reduced by the replacement process if the soil conditions around the pipe are uniform. If an existing sag in a pipe has been caused by a soft zone beneath the pipe, however, the pipe may be forced by the bursting operation toward the soft zone, thus accentuating the sag (*Figure 10.F*). Longer than normal bursting heads can be used to enhance straightening effects.

- Significant sediment in the invert of the existing pipe will tend to cause the bursting head to move upward relative to the existing pipe.

- It is rare but possible for a bursting head to break out only one side of a pipe and to move substantially outside the envelope of the existing pipe. In one case in Albuquerque, N.M., a hard soil or rock base beneath the existing pipe inhibited breakage of the underside of the pipe and caused the bursting head to break out at the top of the pipe. This problem was solved by adapting the bursting head to promote splitting of the base of the existing pipe.

- The bursting head may be forced up or down as it enters the receiving manhole if the exit point has not been enlarged to accommodate the larger diameter of the bursting head relative to both the existing pipe and the replacement pipe. If the hole is too small, the bursting head will tend to split the manhole, either pushing the base of the manhole downward or the upper portion of the manhole upward depending on their relative resistance to the imposed forces.

- There is little reported data on the line and grade of replacement pipes in the literature but several municipal engineers have reported grade problems with the replacement pipe. These were rarely serious but care should be taken to anticipate ground movements and replacement pipe position when sewer pipes are laid on minimum grades.

6. Effect on Crossing Utilities

As a physical demonstration of the impact on crossing utilities, 2-in. diameter PVC pipes were laid at 1 ft and 2 ft above the top of the clay pipes to be burst at the TTC test sites. Each pipe crossed perpendicularly two of the clay pipes to be burst during the tests. The clay pipes were 5 ft apart and were burst at different times. There were a total of six PVC crossing pipes and each was pressurized to approximately 50 psig prior to the bursting and checked to see whether they held pressure as the bursting and upsizing was carried out. None of the crossing pipes lost pressure because of the 25 percent upsizing. The crossing pipe at 1 ft above the clay pipe for the 50 percent upsizing survived the first upsizing but failed when the adjacent pipe was similarly upsized. The crossing pipe at 2 ft above the clay pipe survived both 50 percent upsizing. Given the oversized expansion head, the upsizing and the relative upward displacement of the upsized pipe, it is calculated that the expansion head would have passed within 6 in. of the original position of the closest crossing pipe. Older, more brittle pipes clearly would not survive as well as a new PVC pipe, but it had been expected that all the pipes at 1 ft from the top of the burst pipe would be unlikely to survive the replacement.

In practice, pipes within two pipe diameters of a pipe to be burst and especially of a pipe to be upsized would be locally excavated to provide stress relief to the existing pipe. The worst case for adjacent utilities is when they are not known about and not discovered prior to the replacement operation. This situation resulted in a burst water pipe on one of the sites monitored for research project.

7. Disposition of Fragments of Existing Pipe

The pattern of VCP pipe fragments was studied at the TTC test site by excavation of inspection pits at selected locations along the bursts. The inspection pits were located in sand, silt and clay backfill materials.

In the sand backfill, the fragments of the existing 8 in. diameter VCP pipe tended to be located at the sides and bottom of the replacement pipe. In the silt and clay backfills, the pipe fragments were located more fully around the perimeter of the replacement pipe. The sizes of visible pipe fragments were mostly in the 0.75 by 1 in. to 4 by 6 in. range. The largest fragment recovered was approximately 7 by 11 in. Scratches in the replacement HDPE pipe were numerous but not deep. The deeper scratches were approximately 0.04 in. deep. The pipe fragments tended not to be immediately adjacent to the replacement pipe - they were mostly at a separation of 0.13 to 0.25 in. from the replacement pipe. This indicates that the soil flowed at least partly around the pipe fragments to fill the annular space created by the larger diameter of the bursting head. The pipe fragments tended to be aligned in conformance with the circumference of the replacement pipe, but insufficient area of pipe was exposed to undertake an estimate of the statistical distribution of the orientation of pipe fragments as was done by Wayman (1995).

For applications with no or low internal pressure, the scratching or gouging of the replacement pipe from VCP pipe fragments appears to be minor and can be easily offset by choosing a higher than minimum pipe wall thickness (SDR).

For pressure pipe applications, a sleeve pipe is typically installed during the bursting operation with the product pipe installed later within the sleeve. Larger gouges in the replacement pipe were observed during the job site visits due to poor procedures in pipe handling on the surface (e.g. dragging the assembled replacement pipe to the job site behind a truck).

8. Non-completion of Bursting Operations

Pipe bursting of existing lines is not always successful. This is usually because the bursting head gets stuck at an unexpected obstruction in or around the pipe. Typical examples are:

- Steel repair clamps on water pipes
- Concrete encasement of pipes
- Root balls of trees that encircle pipes

It is possible to use more powerful equipment and specially designed bursting heads to offset these difficulties, but, if the difficulties are not anticipated ahead of time, an unscheduled dig may be needed to retrieve the bursting head. Also, obstructions and unusual conditions surrounding the pipe may increase ground vibrations and accentuate ground movements in particular directions.

Pipe bursting represents an effective method for trenchless replacement of existing pipes. The research results discussed have supplemented the experience gained by contractors, manufacturers and public works engineers and have resulted in:

- A greatly improved understanding of the level of vibration and ground movement associated with pipe replacement operations and how these diminish with distance from the burst location
- Greater confidence in the technical data underpinning the effect of pipe bursting on surrounding utilities and on the pipe drawn in as a replacement.
- Identification of some potential problem areas to avoid under particular job site conditions.

PART TEN: PIPE SPLITTING
"Ductile and Fracurable Pipeline"

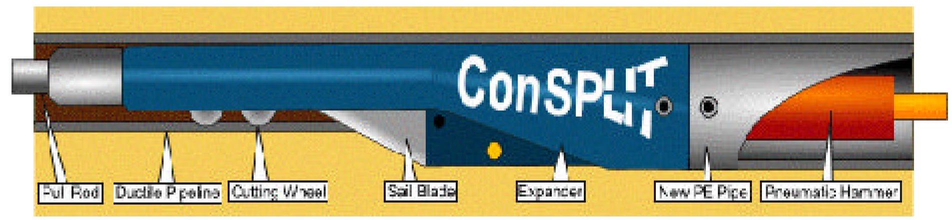
Applications include: Steel, Ductile Iron, Plastic and Cast Iron Gas, Water and Production Pipelines

1) *Introduction*

While pipe bursting of fracturable pipelines has been practiced in the U.S. since 1988, there was no equipment available to split ductile materials such as steel or ductile iron until the early 90's. Conventional pipe bursting was also limited in its ability to defeat heavy repair clamps on joints and band clamps. In 1992 Con Edison won the award for the Best New Tenchless Technology issued by the International Institute for Trenchless Technology for their development of Con Split. Con Split easily handled steel and ductile pipelines and also broke different clamps and couplings on cast iron mains. As Con Split continued to develop it replaced conventional pipe bursting equipment used by the PIM Corporation. More recently British Gas acquired the rights to Con Split and its use throughout the United States is expected to increase significantly.

Con Split is similar to pipe bursting but offers several advantages. It does not cause the type of ground vibrations common to pneumatic bursting and generally can be used much closer to other utilities. The splitting blade can also be positioned away from nearby facilities to further reduce the risk of damage. The history of Con Splits usage supports the claim that damage to other nearby facilities is much less than that caused by conventional trenching.

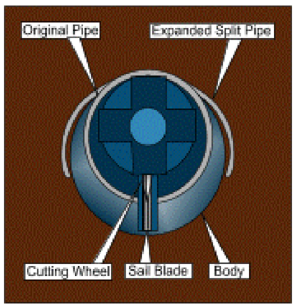
Con Split can be obtained from area contractors on relatively short notice and can be effectively used for emergency replacements of gas and water mains up to 10 inches in diameter. The economies of its use depend on the spacing of service connections but Con Edison uses it effectively with service spacing as close as 30 feet. Longer spacing result in greater savings.

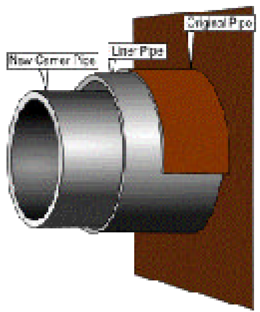


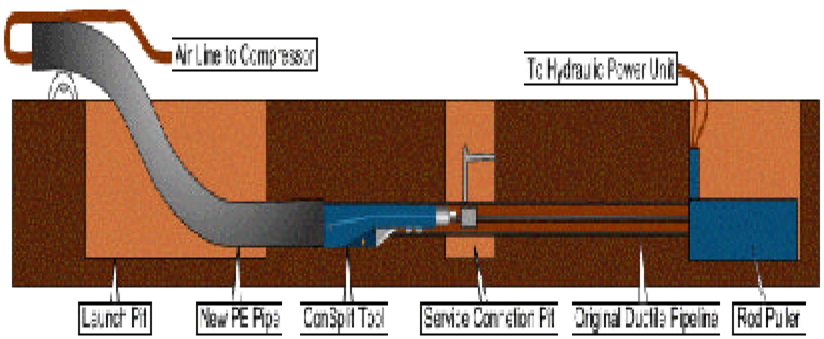
The patented Con Split tool is launched into an existing pipe at an entry pit and pulled through the pipeline to an exit pit. The old pipe is split open and expanded out into the soil, allowing a polyethylene pipe to be pulled into the enlarged hole immediately behind the Con Split tool. As the Con Split tool moves through the old pipe, two cutting wheels press a deep cut into the interior pipe wall. The eccentric body of the Con Split expander concentrates stress at the cut. This tears the pipe along the cut and opens it smoothly without high pulling forces. A sail blade located between the cutting wheels and eccentric body cuts through repair clamps. When especially strong fittings such as steel barrel compression couplings are encountered, a pneumatic hammer inside the Con Split tool supplies the added force needed to drive the blade through the coupling. When the splitting operation is complete, a new polyethylene carrier pipe is pulled into the protective liner pipe.

- Costs 50% less than excavation
- Replaces 2-inch through 8-inch pipe
- Virtually eliminates risk to other utilities
- Installation rate of 5 to 6 feet per minute
- Eliminates open trenches
- Typical installation lengths of 400 feet
- Splits steel barrel compression couplings
- Up-size or size-for-size replacements

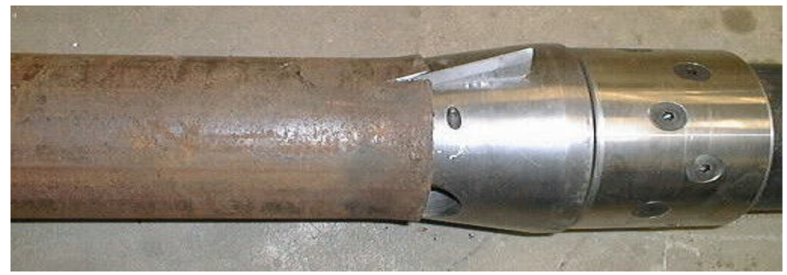
Developed and proven by Consolidated Edison Company of New York, Inc.







2) *The Con Split Process*



PART ELEVEN: CURED-IN-PLACE LINING

1) *Overview*

The main alternative to sliplining and its variants is cured-in-place lining, sometimes referred to as "in-situ lining", "soft lining" or "cured-in-place-pipe" (CIPP), which has dominated the non-man-entry sewer renovation market in many countries for over twenty years. For brevity, these Guidelines refer to all cured-in-place lining techniques as CIPP systems, although it should be noted that not all providers of such systems use this term.

Although several competitive systems are now available, the common feature is the use of a fabric tube impregnated with polyester or epoxy resin. The tube is inserted into the existing pipeline and inflated against the pipe wall, then cured either at ambient temperature or, more commonly in all but the smallest diameters, by re-circulating hot water or steam. Some variations use ultra-violet light to cure the resin.

CIPP systems create a close-fit "pipe-within-a-pipe" which has quantifiable structural strength and can be designed to suit various loading conditions. The ring-stiffness of the liner is enhanced by the restraint provided by the host pipe and the surrounding ground, but systems designed for gravity pipelines do not rely on a bond between the liner and the substrate. Systems which rely on the host pipe for some measure of structural support are sometimes known as 'interactive lining' techniques

Multiple fractures in a clayware pipe – this is representative of the most severe damage that can be renovated using cured-in-place lining techniques

As well as minimizing bore reduction, an inherent advantage of cured-in-place liners is their ability to conform to almost any shape of pipe, making them suitable for relining non-circular cross-sections. Provided that the liner perimeter has been correctly measured and that the material does not shrink significantly during cure, a close-fit liner should result. Their main limitation is the wall thickness, and hence the quantity, weight and cost of material, which may be required for larger sizes or for severe loading conditions, particularly in non-circular pipes.

Laterals can be re-opened remotely after lining, but care must be taken during installation to ensure that surplus resin does not enter branches. CIPP systems are also available for lining laterals from within the main pipe.

The major disadvantage of CIPP lining systems is the need to take the host pipe out of service during installation and cure. In gravity pipes, where flows are very low, it may be possible to plug any incoming pipes and to rely on the storage within the system. In other cases flow diversion or over-pumping will generally be required.

Some CIPP systems are suitable for use in large diameter (man-entry) pipes.

2) ***Applications***

Sewers	Yes	
Gas pipelines	Yes	(See note A)
Potable water pipelines	Yes	(See note B)
Chemical/ industrial pipelines	Yes	(See note C)
Straight pipelines	Yes	
Pipelines with bends	Yes	(See note D)
Circular pipes	Yes	
Non-circular pipes	Yes	
Pipelines with varying cross-section	?	(See note E)
Pipelines with lateral connections	Yes	
Pipelines with deformation	?	(See note F)
On-line replacement (size for size)	No	
Pressure pipelines	?	(See note G)
Man-entry pipelines	Yes	(See note H)

A. Certain types of CIPP system have been designed specifically for use in gas pipelines rather than gravity sewers.
B. Approval of the relevant regulatory body is needed for all materials in contact with potable water. Most CIPP systems are not intended for the renovation of potable water mains, but there are some which have been designed or adapted and approved for this purpose.
C. The correct resin formulation must be chosen to resist unusually aggressive effluents and/or high temperatures.
D. Wrinkling of the fabric may occur on the inner face of the bend, depending on the bend radius, the type of fabric used and the liner thickness.
E. Some CIPP systems allow the fabric tube to be tailor-made to match changes in the circumference or perimeter of the pipeline within a manhole-to-manhole section. Other systems use a fabric which can stretch to accommodate small variations in cross-section. It should be noted that, since CIPP liners are flexible prior to cure and can conform to almost any shape of host pipe, the critical measurement is that of the pipe's circumference or perimeter.

F. A widely accepted rule is that sewers with less than 10% deformation can be lined without any prior re-rounding. Ovality reduces the ability of the liner to withstand external loading such as hydrostatic pressure, and should be taken into account in the design.
G. Most CIPP systems were originally intended for gravity pipelines, but certain proprietary techniques are available for pressure pipes. See also notes A and B above.
H. Although used mainly in non-man-entry pipelines, some systems are also suitable for the renovation of large diameter sewers and culverts. The liner wall-thickness, weight and cost are the main limitations.

3) *Design & Specification*

Because liner specifications and design procedures vary from country to country and are subject to periodic amendment, it is outside the scope of these Guidelines to include reference to all national standards.

In countries where established local criteria do not exist, a widely-used standard is the *Specification for Renovation of Gravity Sewers by Lining with Cured-in-Place Pipes* contained in WIS 4-34-04, March 1995: Issue 2, published by WRc in the UK. Design procedures for determining the required wall thickness of circular and non-circular sections under different loading conditions are given in the WRc *Sewerage Rehabilitation Manual.*

Specifications for pressure (gas and water) applications are laid down by the relevant utility companies and approvals bodies. Most countries have strict requirements and accreditation procedures for all materials likely to come into contact with potable water.

4) *Installation – General*

As with all renovation systems, thorough cleaning and preparation are essential prerequisites. In non-man-entry sewers and other pipelines, inspection should be carried out by CCTV immediately prior to relining - old surveys can be misleading. Man-entry sewers may be surveyed by CCTV or manually.

All silt and debris must be removed completely, and a further inspection is recommended after cleaning to verify this. Care should be taken to avoid excessive pressures when using jetting equipment in damaged sewers, since this can exacerbate the defects. intruding connections, encrustation and other hard deposits should be removed by mechanical or high-pressure water cutting equipment, followed by cleaning to remove the debris that this generates.

It is important to remove any loose fragments of pipe which may fall in as the liner is being inserted. This is particularly critical with 'towed-in' liners where a broken piece of pipe may fall onto the liner as it is being winched in, and then be trapped between the liner and the pipe wall when the liner is inflated. Inverted liners tend to cause less disturbance to the pipe fabric, but problems may still occur.

Most CIPP systems require flow diversion during installation and cure. This period may be from a few hours to over a day, depending on the system and the characteristics of the pipeline. Lateral connections will be blocked by the liner until reopened, and provision should be made for removing surcharged effluent if there is insufficient capacity in the branch system. The build-up of effluent in a blocked lateral creates an external pressure on the liner, which may be significant if the sewer is deep. Measures may be required to limit the surcharge head.

Although CIPP systems are trenchless and designed to minimize disruption, vehicles and plant are needed on the surface throughout the installation procedure, especially at the entry manhole. Traffic regulation may therefore be required.

There may be short-term environmental implications with CIPP systems based on polyester resins, since the styrene solvent present in the uncured resin gives off a heavy vapor with a strong odor. However, although the vapor can be a health risk in high concentrations, such levels are not typically found around CIPP installations. Indeed, styrene vapor is detectable to humans at concentrations of less than one part per million, and the odor becomes unbearably strong at levels below those at which it represents a hazard. However, to avoid any nuisance, adequate ventilation around the work site is essential. This problem applies only until the resin has cured.

Polyester resins may be adversely affected by water until they have cured, which may be of relevance in a pipeline with infiltration or backed-up connections. In some cases, the use of a "pre-liner" (see below) can overcome problems of contamination.

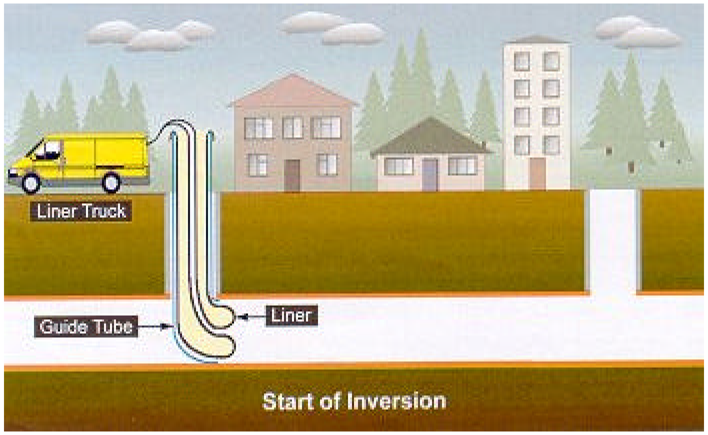
5) *Installation in Sewers - Thermal Cure*

The following describes a typical process for installing thermal-cured CIPP liners in sewers. Each proprietary system has its own methodology, and the description below is intended as a guide rather than as a statement of best practice.

The majority of thermal-cure liners for gravity pipelines comprise a non-woven fabric usually polyester needle-felt-impregnated with polyester resin. Some systems use a composite material such as felt and glass-fiber. The formulation of the resin can be adapted to suit different cure regimes and effluent characteristics.

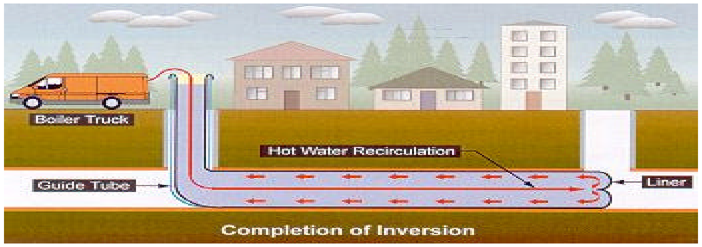
The liner fabric is usually coated on the outer face of the tube - which becomes the inner surface of an inverted liner - with a membrane of polyester, polyethylene, surlyn or polyurethane, depending on the application. The membrane serves several functions - it retains the resin during impregnation and transportation, it retains the water (or air) during inversion, and it provides a low-friction, hydraulically efficient inner surface to the finished liner. Some systems use a separate membrane rather than an applied coating, and this may be removed after installation.

Impregnation is normally carried out in the factory under a vacuum to exclude air and ensure the uniform distribution of resin. This is known as the *wetting-out* process. Depending on the characteristics of the resin, the liner may be delivered to site in a refrigerated vehicle, to prevent the curing reaction from starting prematurely.



Insertion into the existing pipe is usually carried out either by winching into place or by an inversion process wherein water (or sometimes air) pressure is used to turn the liner inside out as it travels along the pipe. The following procedure is typical:

a. A scaffold tower is constructed over the insertion manhole to provide the head of water necessary to invert the liner. In deep sewers, the tower may be unnecessary.
b. A guide tube (which may be made from dry liner material) is installed between the inlet of the sewer and the top of the scaffold tower, with a rigid collar at the upper end to which the liner will be attached.
c. The leading end of the liner is turned inside out manually for a predetermined length, usually a few meters, and is then clamped to the collar of the guide tube. Attached to the trailing end is a hose which will run within the full length of the liner after inversion.
d. Water is introduced into the turned-back section, which causes the liner to continue inverting through the guide tube and the host pipe. The pressure of water forces the liner against the existing pipe wall.
e. When inversion is complete, the water inside the liner is circulated through a boiler unit, using the hose attached to the trailing end to ensure that hot water passes through the whole length of the liner. The rate of heat input is controlled according to the required cure regime of the resin.



f. Temperatures at various points on the surface of the liner are monitored with thermocouples.
g. Once cure has been achieved, the water is gradually cooled down before being release.
h. The ends of the liner are trimmed. Sometimes a few centimeters of liner may be left protruding from the manhole wall, which provides a better seal and also mechanically locks the liner in place.
i. If necessary, lateral connections are reopened with a robotic cutter.

Some systems use a pre-liner which is installed within the host pipe before inverting the impregnated liner tube. The pre-liner is intended to stop surplus resin from entering lateral connections, and it also prevents contamination of the uncured resin by water infiltrating into the sewer or from surcharged connections.

Some systems involve winching in the liner rather than using an inversion technique. Inversion may be difficult in certain locations because of the need to create an adequate head of water (although devices are available to generate the head by a combination of air and water pressure), and towing in the liner avoids the need for scaffold towers and overhead working. However, there are limitations to the size and weight of liner which can be winched in without stretching or tearing it, and winching a heavy liner through a damaged pipe can disturb the fabric still further.

6) *UV-Cured Liners*

As an alternative to curing with hot water, there are systems using resins which cure under ultra-violet light. The amount of plant required is generally less than for thermal cure systems.

UV-cured liners are often made from glass-fiber or a combination of glass-fiber and polyester needle-felt, with an outer membrane and a temporary inner sleeve to protect the liner during storage, shipping and installation.

It is possible to use resins with a storage time of several weeks at ambient temperature, so refrigeration is not required. Various resin formulations are available to suit the nature of the effluent.

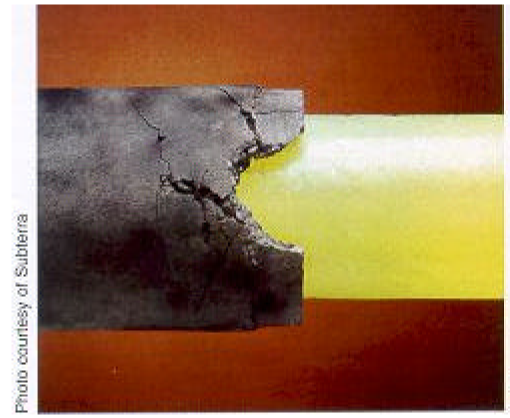
Installation generally follows the following procedure:

a. After the usual pre-survey an cleaning, the pre-impregnated liner is winched or inverted into position.
b. The UV light source is inserted into the liner, and the sealing packers are inflated in each manhole.
c. The liner is pressurized, typically to about 0.6 bar. The inner sleeve transfers the internal pressure to the liner material which is pressed against the pipe wall. The outer membrane prevents any escape of resin.

The UV light source is pulled through the liner at a controlled rate, while internal pressure is maintained

d. While pressure is maintained, curing is effected by moving the UV light source through the liner at an electronically monitored speed dependent on the temperature of the liner during the chemical reaction.
e. When the curing process is complete, pressure is released and the inner sleeve is removed

Typical curing times are between 0.5 and 0.9 meters per minute, and lengths of up to 200 meters can be lined continuously. UV-cured systems are available for pipes from 100 to 1000 mm diameter, with liner wall thicknesses from 3 to 15 mm. Variations are under development to line lateral connections.



Completed UV-cured liner

7) *Installation in Sewers - Ambient Cure*

Ambient-cure lining systems are used mainly for the renovation of small diameter sewers drains and other pipe work, including vertical rainwater and soil pipes. They use similar fabrics to thermal-cure systems - normally a coated felt - and most use polyester resins which are formulated to cure without the application of heat.

Ambient-cure systems avoid the need for boilers or other heat sources, and therefore tend to be less expensive than their thermal-cure counterparts. The properties of the finished product may not, however, be equal to those of a thermal-cured liner, and the lack of external control over the curing cycle means that these systems are not usually suitable for pipes above 150 mm diameter, or for long lengths of pipeline.

The installation procedure is generally as follows:

a. Unlike thermal-cure systems, mixing of the resin and impregnation of the liner are often carried out on site. A measured quantity of the resin is mixed, with different amounts of catalyst and accelerator being added according to the temperature and the speed of reaction required.
b. The liner, with the coating on the outside of the tube, is laid out along the road or on firm ground, and the resin is poured in at one end. The resin is worked along the tube using a heavy roller, until the whole liner is saturated. Since a vacuum cannot be applied as with factory-impregnated liners, it is essential to ensure complete impregnation of the fabric and the removal of all air pockets.
c. The impregnated tube is pulled or winched into the host pipe, and a temporary inner sleeve is either pulled or inverted through it. This sleeve will contain the air or water used for inflation.
d. Water or compressed air is introduced into the temporary sleeve, which pressurizes the liner against the existing pipe wall.
e. When sufficient time is judged to have elapsed for the resin to cure, the pressure is removed and the temporary sleeve is withdrawn.
f. The ends of the liner are trimmed, and laterals reopened if necessary.

Installation of an ambient-cure liner in a site with difficult access

There are numerous variations on the above theme, including portable pressure-vessels for inverting the inner sleeve under air pressure.

Because of the low capital cost of equipment, ambient-cure relining systems have become popular with many small contractors as an alternative to carrying out drainage repairs by excavation.

8) *Cured-in-Place Liners for Water and Gas Main Renovation*

The structural characteristics required of a pressure pipe liner are quite different from those required of sewer liners. The primary loading on sewer pipes is external, and the most important structural parameters are elastic modulus and wall thickness which together provide the ring stiffness to resist buckling.

Pressure pipes, except in small diameters, fail less frequently through external loading. The most significant forces on the pipe are generally caused by the internal pressure which creates tensile stresses in the pipe or liner, and the most common pipe defects are corrosion and leakage from joints. Pressure pipe liners do not generally require as much ring stiffness as sewer liners, but they do need to withstand the bursting forces generated by internal pressure.

For this reason, the fabric used for CIPP pressure pipe liners tends to have a higher tensile strength than that for sewer liners, and, because flexural stresses are not so critical, the wall thickness of the liner is usually much less. Glass-fiber or a glass-fiber composite is commonly used, except in woven hoselinings which generally use polyester fibers.

The fabric of woven hoselinings is normally impregnated with epoxy resin, rather than polyester, which may produce an adhesive bond with the substrate and eliminates water paths which could allow internal corrosion to continue. Epoxies may also be more acceptable in contact with potable water.

Most of the techniques aimed at pressure-pipe renovation were initially developed for the gas market, mainly in Japan, but several CIPP systems are now available to renovate potable water mains.

The installation process is similar in concept to the inversion method used for gravity pipe liners. However, because pressure pipe liners are less bulky, it is possible to contain the impregnated liner within a pressure vessel and to invert the liner through the host pipe with compressed air. Curing is achieved by introducing steam into the liner.

In addition to the thin-walled liners described above, there are also CIPP techniques using epoxy resins which do not rely on a bond to the existing pipe wall. These systems develop their strength from the composite action of the resin and fibers rather than a woven jacket, and are designed to resist both internal.

9) ***Summary***

- Most cured-in-place lining systems are intended for the renovation of gravity pipelines, though pressure pipe systems are also available.
- They are versatile, being able to accommodate non-circular sections, bends, changes of cross section, all pipe materials and various loading conditions.
- They produce a close-fit liner with a smooth internal surface, and the low hydraulic roughness often compensates for the reduction in bore.
- The liners generally used are resistant to all chemicals normally found in sewers.
- Special resin formulations are available for particularly aggressive effluents.
- Pipes from less than I 00 mm to over 2500 mm diameter can be relined, although the economics may become less favorable in the largest sizes as the weight and cost of materials increases.
- Lateral connections can be opened remotely from within the main pipeline.
- Lateral relining systems are available for installation either from within the main or from the upstream end of the lateral. These can provide an integral, sealed lining system for gravity sewers.
- The host pipe is blocked during insertion and cure of the CIPP liner, and flow diversion will often be

required unless there is adequate storage in the upstream pipes.

- Cured-in-place techniques have a track record going back over 25 years, and their durability is well established.

10) *Reconstruction of Pressure Pipelines by Lining with Woven-fabric Flexible Tubing Using the Starline® Technique*

Introduction

In the Starline® technique, seamless circular-woven-fabric flexible tubing made of polyester fabric with a plastic coating is inserted into the pipe with compressed air by the reversion (flanging) method and glued to the interior wall of the pipe with a solvent-free mixed adhesive agent. This gluing operation requires that the interior wall of the pipe be clean. The entire course of the reconstruction operation can be described briefly as follows:

a) Excavation of starting and ending openings
b) Taking the section being reconstructed out of operation
c) Pipe cleaning with subsequent TV inspection
d) Reconstruction operation with setting period and compression trial
e) Connecting service lines with TV cutter system and inspection
f) Putting the reconstructed section back into operation

The major advantage of the Starline® technique compared to trenched replacement is that it is a much faster method of construction. At the current state of the art, relining with woven-fabric flexible tubing offers additional benefits due to the fact that the woven-fabric flexible tubing should not leak if the pipe should break. Since the reconstructed pipeline can be expected to have a service life which is at least as long as that of new piping, assuming the static conditions of the old piping do not weaken, this technique exhibits a very high level of economic efficiency. Since 1991, the Starline® technique, developed and patented by the Karl Weiss Group of Companies, has been successfully used in regional gas distribution networks to reconstruct more than 330 Km of grey cast iron pipelines with a nominal width of up to DN 600 (24in). Especially in densely populated urban areas, Starline®'s method of construction offers substantial benefits.
Starline® 1000 tubing for the reconstruction of drinking water pipes conforms to the German guidelines for drinking water compatibility (KTW recommendations), and resistance to microbes (DVGW Work Sheet W 270).
As opposed to the conventional method of pipeline renewal, reconstruction with the Starline® technique offers the following distinct advantages:

Speed

Reconstruction can be accomplished in much less time than it takes to renew pipelines. Apart from the fact that preliminary and follow-up work, which consist in large part of underground construction, are reduced to more than 90%, it normally takes only two days at most to disconnect, clean, reconstruct and reconnect a section of pipeline approximately 200 meters long. The Starline® technique uses a mobile reconstruction unit independent of the reconstruction vehicle to enable reconstruction in areas which are not accessible to trucks.

Cost benefit

In urban areas, the Starline® technique is particularly efficient in comparison to simultaneously renewing pipelines and disposing of the old pipes. The reconstruction unit itself can be uncoupled from the reconstructed pipeline after the reconstruction operations. Thus several lengths of pipelines can be reconstructed in one day using only one set of equipment. As a result of the cold-setting adhesive system, no high-energy steam is required.

Environmentally compatible

This is essentially due to the fact that less underground construction work must be carried out, which also reduces annoyance to residents and obstruction of traffic, as well as preventing damage to roots of plants growing above the pipelines. Another advantage is the fact that the old piping can continue to be used, since it must not be disposed of, or that the dead-ended pipelines must not remain in the already overcrowded ground.

Using the patented Starline® 1000 technique, grey cast iron and steel pipelines of the regional water supply companies of up to a nominal diameter of DN 1200 (48in) can be successfully rehabilitated. The fabric reinforced tube and adhesive material comply with the KTW guidelines for drinking water compatibility and the requirements of the DVGW recommendations W 270.

The trenchless construction method of the technique, which is described in the following, presents a significant advantage, especially in inner –city areas.

11) *The Starline*â *1000 technique*

Description of the procedure for the Starline â 1000 technique

In the Starline®1000 technique, a joint-less, endless woven, fabric reinforced tube made of polyester fabric with PE coating is inserted into the pipe to be rehabilitated using the inversion method and is glued onto the inner wall of the pipe using a solvent-free, thermosetting two-component EP adhesive. A clean inner wall is the precondition for the gluing process.
The whole of the rehabilitation process can be summarized by the following key points:

- Preparing of the start and finishing pits
- Taking the section to be rehabilitated out of service
- Pipe cleaning with subsequent CCTV inspection
- Rehabilitation process with hardening period (approx. 2 – 3 hours and tested for leaks)
- Connection of lateral connections using the TV cutter system and inspection
- Reconnection of the rehabilitated section
- Back-filling of the pits and reinstatement of the surfaces

In practice, cleaning using high pressure water jetting (800 – 1500 bar) and if necessary, subsequent sand blasting of the inside of the pipe whilst simultaneously sucking out the granulate have proven to be the most successful method.
After cleaning a CCTV inspection is made and the results are documented. Hindrances, such as line valves or too large changes in direction (bends>45°), which endanger the qualitative rehabilitation, must be eliminated for the pipe length prior to the rehabilitation.

The actual rehabilitation process can be carried out after the pipes have been successfully cleaned. To this end, fabric tubing prepared to fit the length of the rehabilitation run is filled with a defined quantity of adhesive and is driven into a pressure drum.

The pressure drum is then connected to the rehabilitation section with the aid of a transport tube and the inversion process is then commenced by the introduction of drinking water and the application of an overpressure of nitrogen. The fabric-reinforced tube is turned inside out on being driven into the rehabilitation length and the adhesive is thus applied between the inner wall of the pipe and the rehabilitation tube. The level of the pressure within the pressure drum for the inversion of the fabric-reinforced tube depends upon the nominal diameter and the length of the rehabilitation stretch. The speed of the rehabilitation during this process is lies between 4 to 8 m/min.

At the end of the rehabilitation stretch, the fabric-reinforced tube is driven into a trap cage and the warm water hardening period begins. During the whole of the hardening period, (approx. 2-3 hours) a pressure, dependent upon the nominal diameter, is maintained within the pipe reach. For this, the pressure drum is released/separated from the rehabilitation route by a collapsible tubing unit and the free end of the pipe section is closed off with a pressure proof cap. Thus, the rehabilitation drum is once more available for the next rehabilitation. During the inversion and hardening period, the internal pressure within the pipeline is recorded.

After the hardening time has passed (approx. 2-3 hours later) and a successful hydraulic pressure test has been carried out, the rehabilitation length is relieved of the pressure and the lateral connections are connected to the rehabilitated reach. The existing lateral pipes can either be connected by conventional means, or can be opened with the help of a TV supported robot from the inside. At the same time, the success of the rehabilitation is controlled by a CCTV inspection and is documented.

The most important functional process during the insertion of the rehabilitation tube is the inversion process of the fabric-reinforced tube filled with adhesive. Therefore, this process is briefly explained in the following. The turning inside out of the fabric-reinforced tube is achieved by means of a reversing head, which is attached to the pipe opening of the rehabilitation stretch. A pressure proof tubing unit is flange-mounted to the reversing head, which achieves the connection to the pressure drum. The open end of the fabric-reinforced tube filled with adhesive is fastened to the sealing surface between the reversing head and the tubing unit and closed so that it is pressure sealed. By increasing the pressure within the pressure drum and the tubing unit, the rehabilitation tube inverts itself in the opening of the reversing head. In this way, the side of the rehabilitation tube covered with the adhesive reaches the inner wall of the pipe and the plastic coated side of the fabric-reinforced tube now forms the inner wall of the pipe. During this process, the whole of the rehabilitation process is controlled by the pressure and number of revolutions of the pressure drum.

Prerequisites for the Starline® 1000 technique

The technique requires specific machines and devices, which include:

- The pressure drum for the up-take of the rehabilitation material- fabric reinforced tube/adhesive
- The transport tubing, i.e. the connecting element between the pressure drum and the collapsible unit
- Centring socket and collapsible tubing (connecting element between the grey cast pipe to be rehabilitated and the transport tubing)
- Trap cage (end piece on the grey cast iron pipe to be rehabilitated, where the reversed fabric-reinforced tube, coated with the adhesive, is held fast within the target pit)

Quality assurance and training in the Starline® 1000 technique

The basis of the quality assurance for the Starline®-1000 technique are the same as those stated in the DIN 30658 "Means for the subsequent sealing of gas pipelines"; Part 1 "Non-reinforced plastic and fabric-reinforced tube linings, requirements and tests" as well as the working recommendations G 478 "Rehabilitation of gas pipelines using Fabric-reinforced tube lining – requirements, quality assurance and testing" of the DVGW standards.

The production of a consistently high level of quality requires well-trained personnel, in addition to certain technical prerequisites, which are described in the following paragraphs.

The bases of the training of the workforce are procedural and working instructions. They are an integral component of a quality assured execution of the techniques as, apart from the description of the procedure, they also include all of the regulations with respect to the documentation of the quality relevant work stages and parameters. The procedures and working instructions have been, and will be, up-dated in accordance with the latest knowledge and requirements.

Training events are held at least twice a year, at which the employees are familiarized with the new developments and changes to the working instructions, the content of which is also documented.

The materials used for the fabric-reinforced tube lining are the fabric-reinforced tube and adhesive. The combination of both of these materials must ensure that through the gluing of the fabric-reinforced tube within a pipe, an age-resistant, fully covering and, in straight pipes, fold and bubble free lining can be produced, as well as being compliant with respect to its KTW and W-270-permits.

Here it must be taken into consideration that the old grey cast iron pipes have internal pipe diameter tolerances determined by the production process, which must be compensated by the malleability of the fabric-reinforced tube in the direction of its circumference. In order to be able to fulfill these requirements, the fabric-reinforced tube and the adhesive must be tested for their suitability in a testing procedure, which is analogue and in accordance with DIN 30658-1.
Among other things, the following tests are carried out:

- Thickness of the fabric reinforced tube
- Tensile resistance of the fabric-reinforced tube in a longitudinal and transverse direction
- Resistance to ageing of both materials
- Impermeability properties
- Resistance to migration
- Peeling resistance
- Internal pressure creep resistance
- Reaction to tapping

- Impermeability after a pipe breakage

The achievement of the tested parameters is ensured for the Starline® 1000 technique by means of the following admission controls:

Adhesive

The thermosetting or cold setting, solvent free two-component EP adhesive Starline® 1000 is produced for a summer and a winter setting. In an in-house goods acceptance laboratory, the binding viscosity process for each adhesive batch is measured and compared with the respective appropriate, defined calibration curve. If the curve lies within the tolerance range, the material is released. In this way, it is ensured that the adhesive is workable for an hour and after a hardening period of 2 to 3 hours, has hardened to such an extent, that the rehabilitated pipeline can be reconnected to the existing supply network.

In addition to this, the following tests are also carried out and the results recorded:

- Viscosity of the adhesive components in their delivered condition under certain defined conditions.

- 180° peeling resistance on steel platelets under the application of the same adhesive sample material as is used to determine the viscosity progress. The test is carried out analogue to section 5.5.2.9 of the DIN 30658-1. In the case of cold-setting and thermosetting systems, this sample must be stored at 20°C before determining the value of the loss in adhesion.

Fabric-reinforced tube

1. Testing of the whole delivery for transport damage.

2. Random sample testing of each incoming batch of fabric-reinforced tube of a single nominal diameter for the followings parameters:

   a. *Tube thickness*

The compliance with the tolerance range given by the manufacturer for the wall thickness of the tube us carried out in three locations using a suitable measuring device, which lie evenly spaced along the length of the tube.

   b. *Flat tube width (Tube diameter)*

A 1m long piece of fabric-reinforced tube selected randomly is measured using a suitable measuring instrument at 3 measuring locations for the width of the tube when lying flat and the results are compared with the tolerances given by the manufacturer.

   c. *Impermeability*

A 1m long piece of fabric reinforced tube selected randomly, is filled with compressed air, whereby the fabric-side faces outwards. The test pressure must equate to at least 1.3 times the maximum possible inversion pressure during the rehabilitation and must be maintained for 20 minutes. The impermeability is to be tested by means of a substance, which is brushed on and which forms foam.

d. *Strain characteristics*

A 1m long piece of fabric-reinforced tube selected randomly, is to be stretched with the fabric side facing outwards and in 0.2 bar steps from the inside, is to be loaded by means of compressed air up to 1.3 times the maximum inversion pressure required for the technique. The circumference of the tube is to be measured for each pressure step set (0.2 bar steps) after 15-second setting time. The measured values must be the same as the specific desidered values for the technique with respect to its reaction to lateral strain.

e. *Bursting pressure*

A 1m long piece of fabric-reinforced tube selected randomly, is to be stretched with the fabric side facing outwards and filled with water. Every 15 second, the internal tube pressure is to be increased by 0.2 bar until the tube bursts. The bursting pressure must be greater than 1.3 times the maximum possible tube inversion pressure and the maximum permissible operating pressure of the rehabilitated pipeline.

Equipment

Precondition for an environmentally compatible execution of the pipe rehabilitation which achieves the quality standards set is equipment, which are in line with the latest technological developments as well as the valid regulations with respect to:

- Safety
- Noise protection
- Pollution abatement of the air, soil and water

The required proofs must cover an extent which is set down by legislation, continuously be tested for their validity and be safely kept for at least the whole duration of the service life.

All parts of the Starline® 1000 equipment, which are subjected to pressure, are to be manufactured, tested and handed over in accordance with the regulations of the pressurized container legislation. These parts of the equipment are subjected to an in-house pressure test annually. Ever 5 years an external repeat test on the pressure drum is carried out by a technical control association.

The operation of the equipment may only be carried out by trained personnel who have been familiarized with the operating instructions of the equipment's machinery and in accordance with the working instructions. These requirements are fulfilled by the respective training sessions.

The rehabilitation devices and plant must be so designed, that during the rehabilitation and hardening process. All of the process relevant data can be controlled, monitored and recorded by suitable testing, measuring and control installations.
For this reason, a control unit equipped with a manometer recorder (DSR) was developed for the Starline® 1000 technique.

Measuring and control installations must be calibrated at predetermined intervals, however at least once a year.

This is usually carried out in the company Starline® pipe service during the winter months. All of the appropriate testing techniques and the record files of the test lists are all located here for all of the equipment to be tested. All testing devices, which serve to provide the documented proof of the quality of the rehabilitated pipelines, must also be subjected to a regular testing with normal calibration or certified reference measurement devices. This particularly concerns the measuring devices for the incoming goods tests, the pressure and temperature monitoring.

Execution (type and extent) and results of the test are documented. Here, it is necessary that the measuring equipment are fitted with devices or rather inventory numbers and labels, from which, the due date for the next inspection can be deducted. Only tested measuring devices with a valid test label may be used. The measuring device number is recorded on the appropriate protocols.

In order to ensure that the aforementioned quality assurance requirements are also complied with. It is necessary to carry out unannounced controls on the construction sites.

The controls are carried out by the QM representative within the framework of the internal auditing and include the following main items:

- Compliance with the respective working and operating instructions
- Random sample controls of the measuring devices, if necessary, also the calibration of the measuring devices
- Taking sample from the rehabilitated pipe stretches
- Checking the condition of the technology used
- Elimination of defects determined by setting down appropriate measures

The following tests are carried out on the samples taken within the framework of the internal controls:

a) *Simulation of a pipe failure for cast iron pipes*

In order that in the case of a pipe failure, the impermeability of the fabric-reinforced tube remains free of local loosening of the tube/adhesive material system from the pipe wall, apart from the achievement of the minimum peeling resistance, it must also be proven that the resistance to ripping of the tube material lies above the bonding durability of the fabric reinforced tube adhesive pipe system in the case of a pipe breakage. This test is carried out on a 1m long piece of rehabilitated pipe. The 1m long test piece is broken in the middle with a pipe-cracking device and is brought out of alignment by 4°. At the pipe ends, the fabric-reinforced tube is cut back to 100mm pipe lengths and removed. Using a secured force plate, the piece of pipe is closed in both sides and subjected to an internal pipe pressure of 1.3 bar using compressed air. After 20 minutes storage, no bubbles may appear under water from the broken part of the pipe. This pipe breakage simulation is to be carried out up to DN 300 (12in) in the way described. For greater nominal diameters, the investigations can be carried out on test pieces, which have a pipe socket in the middle. The misalignment is also set at 4°, after the bell and spigot joint material has been removed.

b) *Determination of the peeling resistance*

The peeling test is preferably carried out as a destructive testing method preferred for the monitoring and assessment of the glued area pre treatment. Here, the fabric-reinforced tube is tensioned locally by means of a linear introduction of vertical force, i.e. at 90° to the adhesive layer. The lining is pulled off of the pipe wall along the pipe circumference of the prepared half shell with a constant speed of 10mm/min. The test can either be carried out on an in-house test stand or by a recognized testing institution analogue with that which is laid down in DIN 30658-1.

The peeling resistance in N/cm results from the average value of the force measured above the peeling path related to the width of the sample of 5-cm. The evaluation of the average peeling resistance gained, by means of a subsequent number value comparison with reference values, is not conclusive in most cases. Decisive for a quality assured rehabilitation is much more a glue layer which covers the whole area and which is attached to the cleaned inner pipe surface, which is characterized by a constant gradient of the curve. As further assessment criteria for the surface preliminary treatment serves to provide subsequent separated areas analysis, apart from the analysis of the force-path progress, by means of which, the separating behavior (cohesive in the adhesive layer/ adhesive on the pipe or the residual dirt layer) as well as the thickness of the adhesive layer can be determined. The results of the peeling test are recorded in a protocol.

A characteristic value of the peeling resistance is obtained in accordance with the computer-supported evaluation of the measure data:

$$\textit{average peeling resistance: } p_s = \frac{Fm}{b}$$

with Fm: average peeling force
b: *strip width*

c) *Tapping test*

On one of the test pieces for which the peeling resistance has been determined in accordance with the method described above, the tube is drilled from the outside inwards in the area, which is still covered with fabric-reinforced tube. The diameter of the drill is 1" and it is to be produced using a saw tooth cutter. The fabric-reinforced tube in the area of the pipe wall piece loosened pipe wall must be able to be removed completely from this pipe in connection with this.

Consideration of the service life of rehabilitated pipes

The basis of an estimation of the life expectancy of a pipe which has been rehabilitated by using the Starline® 1000 technique the tests are to be carried out in accordance with the tests and requirements laid down in DIN 30658-1 (non-reinforced fabric tubes and fabric reinforced tube for the subsequent sealing off of gas pipelines, safety requirements and tests). Here, the tests are carried out on the tube and the adhesive as well as on the rehabilitated samples (steel and cast iron pipes). The following tables shows the requirements of lines test pieces by means of examples (item. 6.5 DIN 30658-1).

Properties of lined test bodies	*Desidered Value*
Handling	**Free of bubbles & folds**
Impermeability at 10 bars	**Impermeable**
Ageing resistance	**Resistant**
Migration resistance	
• **After tapping**	**Resistant**
• **After the welding on of branches**	**Resistant**
Resistance to temperature change	
• **Grey cast iron pipes**	**Resistant**
• **Steel pipes**	**Resistant**
Resistance against mi salignments (a°=4° for more than 1.0 bar of internal pressure)	**Resistant**
Peeling resistance	
• **After hardening**	**N/cm ^{3} 10**
• **After ageing**	**N/cm ^{3} 10**
Internal pressure – creep resistance for 10 bars	**Std. ^{3} 1000**
Impermeability after pipe breakage	
• **Bending failure**	**Impermeable**
• **Shear failure**	**Impermeable**

The Starline® 1000 technique fulfills all of the requirements in accordance with KTW, W 270 and those analogue to the DIN 30658-1 for all of the tests. In the estimation of the service life expectancy it is assumed that a pressure pipe rehabilitated by means of the Starline® 1000-technique has the same service life expectancy as a newly laid pipeline

12) *Insituform*

Introduction

Insituform's experience in the trenchless pipe rehabilitation business is unequalled. In nearly 30 years, they have successfully rehabilitated more than 7,500 miles of pipe using our proven trenchless technologies**.**

Insituforms' processes are designed for rehabilitating a wide range of pipes:

- Diameters - from 2 to in excess of 100 inches (51mm to in excess of 2.4m)
- Pressures - from gravity sewers to pressure pipes with operating pressures in excess of 200 psi (14 bar)
- Shapes - circular and non-circular
- Temperatures - from 32° to 140° F (0°- 60° C)
- Pipe Materials - all types

Indeed, aging water mains often suffer from corrosion, tuberculation (that is to say sediment, encrustation and corrosion by-products on the inside of pipes that, in time, effectively block the free passage of water) or excessive leakage. These problems can affect water quality, decrease hydraulic capacity of the main or contribute to water loss. In some cases, the main may be structurally weak and prone to breakage.

The Thermopipe™ System

In July 2000 Insituform Technologies, Inc. has acquired the Thermopipe business from Angus Flexible Pipelines, a division of Angus Fire Armour Limited (Angus) including the worldwide intellectual property rights, know-how, and related assets. The Thermopipe system is a polyester reinforced polyethylene tube which is reinforced with woven polyester fiber and is factory folded into a “C” shape. It is used primarily to structurally rehabilitate small diameter drinking water pipes. Under the terms of parallel license and supply agreements, Angus will continue to manufacture the Thermopipe product and accessories for Insituform.

Since 1997, Insituform has had an exclusive license from Angus to market and install the Thermopipe system in North America. The company intends to continue using the process in its own pipe rehabilitation operations in North America and Europe and to license the process in other countries. The process has gained acceptance in drinking water applications in the United Kingdom where the system is installed by a number of accredited contractors who now will receive technical and marketing support from Insituform.

The Thermopipe™ System solves internal corrosion problems and improves water quality by providing a continuous, impermeable barrier between the host pipe and the water.

Insituform offers the Thermopipe™ System in limited geographical areas. To determine if it can be used for your water main rehabilitation needs, contact Insituform Technical Representative (U.S. or Canada inquiries only).

Thermopipe ™ System

With a long-term independent pressure rating of up to 230 psi, the Thermopipe System is ideally suited for rehabilitating distribution mains of up to eight inches in diameter. It can be used to rehabilitate pipes of all common types of materials and can navigate 45°, and in some cases 90°, bends in the main. The process is very rapid, enabling pipe segments up to 750 feet to be rehabilitated in just a few hours. The Thermopipe™ System meets the requirements of ANSI/NSF Standard 61.

Insituform PPL® (Pressure Pipe Liner)

Insituform PPL is a lining system for structurally sound pipelines. It has been developed from the same basic materials and technologies as the Insituform process, which has been used to rehabilitate thousands of miles of gravity flow pipe since 1971. It is available in a range of thicknesses to meet specific design requirements, icluding vacuum loading and resistance to external loads when the pipe is depressurized. Insituform PPL can be installed in pipes of all common types of material, in diameters up to 48 inches and through bends of up to 90 degrees.

Insituform PPL utilizes a reinforced felt tube, which is impregnated with a specially modified epoxy resin system. Water pressure is then used to invert (turn inside out) and propel the tube through the pipe from an access pit to a receiving pit.

After the Insituform PPL reaches the receiving pit, a curing process is initialed, where heat is used to cure the epoxy resin and form a tight fitting, jointless pipe lining. After cure, the ends of the liner are cut off and end seals are installed before the line is placed back in service.

Paltem (CIP Liner)

Insituform Technologies, Inc. Paltem pipe lining system is used to rehabilitate pressure pipelines that have been damaged by corrosion or are experiencing leakage through joints, pinholes or other pipe defects.

This system can be installed in pipes ranging from 4 to 40 inches (102-1016 mm) in diameter, with operating pressures in excess of 200 psig (14 bar), and temperatures ranging from 32°-100°F (0°-38°C). It can be installed through 90° bends and maintains or enhances flow capacity.

Pipe lined with Paltem process

The PALTEM process

Insituform was the pioneer of the CIP lining processes, with patents dating back to 1971. The Insituform process uses non-woven, coated polyester felt as the carrier for the thermoset resin. When the resin is cured, the composite forms a rigid plastic pipe with sufficient wall thickness to withstand external hydrostatic buckling loads while restrained in the existing pipeline. The largest market for CIP products has been the municipal sewer market, both in the US and throughout the world. Insituform is the world leader in the CIP sewer rehabilitation market, with about a 70% share of the market New York Times, November 3, 1996.

Insituform is the North American licensee for the PALTEM process. PALTEM was developed in the late 1970's in a joint venture by Tokyo Gas and Ashimori Industry Co., Ltd., of Osaka, Japan. This process was developed for the Japanese gas industry, primarily to prevent failures in aged pipelines caused by earthquakes and ground movement. For this process, a woven, seamless polyester hose coated with a polyester elastomer skin is impregnated with an epoxy resin. The composite is inverted into the pipeline with air pressure. Curing the epoxy resin adheres the liner to the inner wall of the pipeline. Either heated or ambient curing can be used with the epoxy resin.

According to product literature, PALTEM has been installed in more than 1200 miles of natural gas mains and services worldwide. PALTEM has been installed in gas distribution systems by British Gas, Gaz de France, Ruhrgas (Germany), Gas Madrid, Denmark Gas Company, Swedish Gas Company, and at least nine US gas companies. The process has also been adapted for potable water and sewer applications.

Products similar to PALTEM

Phoenix Lining process

The Phoenix Lining process was jointly developed by Osaka Gas and Osaka Bousui Construction Company in 1981. The process is similar to PALTEM, using a seamless woven polyester hose with an epoxy resin. In fact, Ashimori supplies a large percentage of the hose for the Phoenix process. More than 300 miles of Phoenix liner has been installed in gas mains worldwide including:

- Osaka Gas
- Toho Gas
- British Gas
- Gaz de France
- GASAG (Berlin)
- and other European gas companies.

Amex process

The Amex process was first introduced in Germany in 1975. Miller Pipeline Corporation is the US licensee for the Amex process. Miller Pipeline indicates that over 1,200 miles of gas mains and in excess of 10,000 services have been lined in Germany, France, Hungary, Spain, and Switzerland. The process varies from PALTEM and Phoenix in that a knitted hose is pulled into the pipeline; a polyurethane membrane, carrying a polyurethane resin, is then inverted into the hose. The composite is then cured at ambient temperature.

Miller Pipeline Corp. has the AMEX 2000 and AMEX 32-400 pipe lining systems. They use three components: a textile reinforcement hose, a polyurethane membrane, and a two-part polyurethane adhesive. The textile hose is first pulled through the host pipe. The membrane is filled with adhesive and passed through rollers, which distribute the adhesive. It is then inverted into the textile reinforcement where the adhesive binds the membrane, textile and host pipe wall together.

These systems are also easy to install, but like all cured-in-place systems, extensive host-pipe cleaning is required prior to installation. The AMEX 2000 is designed of use on pipelines operating from low pressure up to *60 psig*, while the AMEX 32-400 is designed for use on mains operating under *15 psig*.

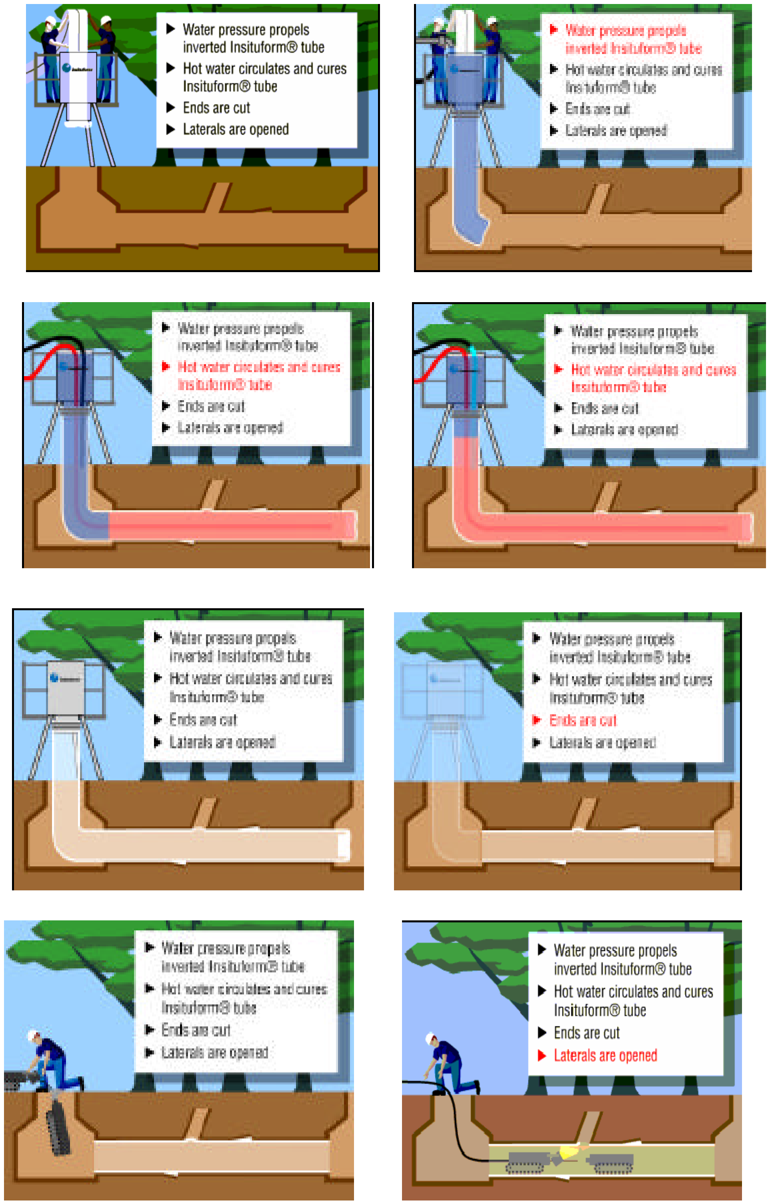
The AMEX 2000 polyurethane liner is pulled through adjustable squeeze rollers and placed into a pressure box in a layered manner.

After polymerization of the adhesive, the pipeline is ready for pressure testing or service installations.

The city of Houston, with a reputation for trying new and innovative solutions, has renovated over one million feet of pipeline using cured-in-place methods. Their system of choice involves a resin-impregnated felt line that is pulled in and filled with hot water until the resin has set.

In other words, the process can be described as follows:

Installation techniques may vary based on job site requirements



- **Benefits**

Cured-in-place repair of underground utilities in many cases provides an alternative to open trench replacement. This method refurbishes the existing pipe and provides for many additional years of service. This is accomplished without the disruption and complications of open trench methods.

- **Status**

Cured-in-place repair methods are gaining popularity, especially with gas utility companies.

- **Barriers**

Current codes and standards and insufficient knowledge are two barriers to cured-in-place pipe repair. However, Insituform Technologies has obtained official French approval for Thermopipe, the flexible polyester-reinforced polyethylene system for the structural renovation of water mains.

The achievement follows a detailed evaluation of the complete lining system by the Institute Pasteur in Lille, allowing the issue of an “Attestation de Conformite Sanitaire” (ACS). This means that Thermopipe is cleared for use in the structural relining of potable water mains throughout France.

The first French Thermopipe installation has already been carried out in St. Brieuc, Brittany, where Insituform France relined 900 ft of an old 8-in. diameter cast-iron water pipe in two days. The French approval is a timely success for Insituform, which is aiming to expand the use of Thermopipe throughout the European water industry. In addition to the

United States and Australia, the system has already been approved in the United Kingdom and Germany, and the company expects to make approval submissions to authorities in a number of other European countries.

Close-Fit Polythylene Lining

Insituform also offers its Titeliner® and Insituform CF™ close-fit polyethylene lining technologies for rehabilitating water mains. These "modified" sliplining systems use high density polyethylene pipe which is either temporarily reduced in diameter or folded before being pulled into the host pipe.

After insertion, the polyethylene pipe expands to fit against the inner wall of the host pipe. These close-fit polyethylene lining systems are designed for pipes which are reasonably straight and readily accessible. These systems offer the cost benefit of polyethylene piping while eliminating the significant reduction in flow capacity found in traditional sliplining processes.

Case Study: *Insituform Rehabilitates Distribution and Transmission Mains Without Disrupting the Community*

Water utilities in North America must continually confront the problems of aging transmission and distribution mains. Leaks due to corrosion present a serious problem - and when breaks occur, a high cost in dollars and public relations. With this in mind, St. Louis County Water Company (SLCWC) has begun researching and using trenchless pipe rehabilitation technologies to renovate these water mains.

Transmission Main Rehabilitation

During the drought year of 1953, the city of Glendale, Missouri, a suburb of St. Louis, laid a 20-inch cast-iron main beneath Sappington Road to supply water to South County and to augment the water supply flowing through the existing six-inch main installed in 1912. Today, this water main still serves as a major north-south transmission line between St. Louis' populous central and south county areas.

In 1994, the City of Glendale complained to SLCWC of the cost of street repairs every time this 20-inch main broke - which by then was twice in a four-month period - and requested that the water company do something about it. At the time, SLCWC's main replacement program was the best means to solve leak and break problems: this ongoing program monitors the 3,900 miles of transmission and distribution mains in the SLCWC system and budgets a certain number of mains every year for repair or replacement. But other mains took precedence for earlier replacement because of their break rates, number of customers affected and cost. The most SLCWC could do, for the time being, was repair the leak once again.

But the water company's commitment to work closely with their cities' public works departments - and to continually investigate new technology for cost-effective solutions - stimulated research into trenchless methods of pipe rehabilitation.

In 1996, SLCWC's research took them to a company headquartered in their own service area. Insituform Technologies, Inc., a world leader in trenchless pipeline renewal processes, offers a number of lining methods that not only repair leaks and breaks, but also restore host pipes' functionality at their original operating pressures, even through bends.

Ground-breaking but still trenchless

In 1996, SLCWC decided to test Insituform's Paltem process on a 325-foot long, six-inch diameter, 1950s vintage service main (at Collingwood Ave.). This was to be the first use of Paltem by the potable-water industry in the United States. The Paltem liner, a woven polyester jacket with a polyethylene coating, adheres to host pipes with epoxy resin and, except for the access pits at either end of a job, does not normally require any digging.

The two companies worked together on this ground-breaking project, which consultant Roy F. Weston monitored for an AWWARF research program, and its success led SLCWC to lining the Sappington transmission main with Paltem as well. The technology was perfect for this stretch of pipe, which, in 1997, became the first transmission main in North America to be rehabilitated this way.

On March 3, 1997, the 20" transmission main experienced its next serious break, and patching it that day closed off a well traveled city block from traffic, damaged a sizable portion of the street and left a large number of residents - as well as North Glendale Elementary School - without water. But a few months later, rehabilitating 780 feet of the main with Paltem took Insituform only two days and saved SLCWC 20% of the money that conventional replacement would have cost them. Glendale residents endured only about two hours without water service, and this was at off-peak times of day when the impact on their water habits was minimal.

Prior to the installation, SLCWC worked to prepare the main for Insituform's Paltem liner. This included transferring seven services to the original - and still used - six-inch main alongside the 20-inch one; cutting in a six-inch valve between fire and domestic services of Glendale Elementary School to ensure reliability; and securing blind flanges at the now-severed pipe connections.

The Paltem hose was "wet-out" at one of Insituform's facilities and then driven in a refrigerated truck to the Sappington Road site. Two small access pits had previously been dug at each end of the pipe. The wet-out hose was then installed by inversion into the transmission main. During the inversion process, water is used to push the hose from the insertion point to the completion point. The resin-saturated side of the hose adheres to the existing pipe wall and the coated side becomes the inside of the rehabilitated pipe. The liner navigated four 45-degree bends in the pipe. Paltem can be used to line bends up to 90 degrees in pipes from six inches to 39 inches in diameter.

That night, the water used to invert the liner was heated to cure the resin. The crew used a heat-exchanger, where the water in the boiler passed the heat (through the exchanger wall) to the sterilized water in the pipe. This prevented contamination of the new pipe wall with the water that ran through the boiler. After the new Paltem liner cured and cooled, the water was drained from the pipe so that the ends could be cut back to fit the sections with internal end-seals. SLCWC then attached the lined pipe to the unlined pipe with spool pieces and performed the sterilization and test procedures.

The rehabilitated pipe was once again restored to reliable service. Paltem's structural integrity allows for the cured liner to span large gaps in the host pipe caused by internal corrosion and joint leaks and, in fact, was developed in Japan for earthquake-prone areas.

Distribution Main Rehabilitation

During the preparations for the Paltem project, the two companies were in contact about another potable-water pipe product recently licensed to Insituform by Angus Fire, a company in the United Kingdom. Thermopipe™, suitable for three to eight inch mains, is another woven polyester tube impregnated with polyethylene that arrives sterile on-site, folded into a "C" shape and wound on a reel.

In the spirit of finding cost-effective, non-disruptive methods of doing business, SLCWC decided to renovate three six-inch distribution mains with Thermopipe, which was designed specifically for that purpose. The three mains run beneath high-traffic railroad tracks, making them a higher risk than other mains.

In the case of these three distribution mains, no customers were affected because the approximately 200-foot sections that were lined within railroad tracks' right-of-ways do not have services running from them. The time it takes Insituform to install Thermopipe is a fraction of other lining methods, and it took them only a few hours to line each of the three locations.

After the folded Thermopipe liner is pulled into the host pipe, it is inflated with a combination of air and low-pressure steam, which softens the polyethylene so it can expand to fit the pipe. As Thermopipe cools, it hardens again to the point of being structurally independent. The low-pressure steam also sterilizes it a second time; this sterilization process passes drinking-water tests and eventually could be approved protocol in the U.S. It is already approved in the U.K. and considered a great benefit to save time in the installation process.

Donovan Larson, Manager of System Engineering at SLCWC, said that the end result is a fully renovated, NSF-approved drinking-water pipe whose renovation does not upset his customers. "Thermopipe does the same thing as replacing," he said. "We're interested in making our pipes problem-free, and this accomplishes that same goal."

Because the pipes were situated beneath railroad crossings SLCWC decided to try Thermopipe in those three spots, Larson explained. A leak beneath a railroad track can soften the ground and endanger the integrity of the track. The three sites chosen to renovate first run under tracks which carry passenger trains: the trains that they would least want to see derailed in the unlikely event of a severe break condition. And the fact that the pipes were installed in the 1920's made the tracks more vulnerable - because in later years, the water company only installed pipes with steel casings beneath railroad tracks.

Thermopipe and Paltem are part of the portfolio of renovation products which Insituform is developing to meet the needs of the potable - water market. The aim is to give customers, such as SLCWC, a wider range of options as they continue to evaluate non-disruptive ways to improve their pipe systems.

The social impact of trenchless pipe rehabilitation

North Glendale Elementary School, which is just a block from the jobsite at Sappington and Brownell, daily contains hundreds of active children racing for the cafeteria, the drinking fountains and the bathrooms. Having their water shut down for even an hour was not a situation this SLCWC customer wanted to face again. By using the Paltem method for rehabilitating water mains, the need for future repairs is minimized and the process involves minimal downtime.

Dan Gummersheimer, System Engineer for SLCWC and project coordinator on this rehabilitation, said that digging holes and shutting off customers' water is getting to be less of a problem as trenchless technology penetrates the water market. "The water company did the necessary transfers [for this project]. For that, we shut off water for one hour - at most - and when Insituform came to do the inversion, they didn't shut off anyone's water," he said.

SLCWC, in trying to employ cost-effective, non-disruptive technologies, considered Insituform's services and products not only due to price but the value to its customers as well. Had they used the open-cut method, said Gummersheimer, the project "would have been really expensive and disruptive. We would've taken out the entire southbound lane; and replacing it with eight inches of concrete and four inches of asphalt would have cost about $130,000, and that's just for the pavement." The final estimate for open-cut replacement turned out to be $246,000. In contrast, the Paltem lining method cost a little over $195,000 for the entire project.

The projects where Thermopipe was used, according to Larson of SLCWC, saved the water company from having to bore horizontally under the railroad tracks and slide new casing pipes through, which costs between $150 and $200 per foot - not to mention the safety concerns of aged cast-iron pipes beneath passenger-train tracks.

"Our system isn't perfect, and every year it's less perfect," said Larson, so "water facilities have to look at new methods to overcome traditional problems, while considering the high expense of replacing and customer dissatisfaction with the inconvenience of their properties being torn up. It's important our customers realize we're trying to squeeze pennies; we're looking for solutions. We're an intelligent, investigating utility with some sense of economy."

PART TWELVE: CURED-IN-PLACE LINING

1) *Evaluation & Investigation of the existing Materials & Installation Methods for the Epoxy Technology*

a) Introduction

Cementitious products have been used in underground rehabilitation for centuries. However, only in the past 15 years, has there been a significant increase in the specification and use of those products exhibiting greater chemical resistance and longer life expectancy, so that nowadays the process is firmly established as a cost effective method for the internal corrosion protection of a wide range of pipeline materials, which are used for the conveyance of potable and raw waters. The processes and equipment used for this purpose will all be familiar to practitioners in the field of coating application. However, strict regulations and controls have been developed for the on-site application of epoxy resin materials where these will subsequently come into direct contact with water supplies intended from human consumption. Foremost among these controls are the regulations, which have been developed in the UK by the Department of the Environment's Drinking Water Inspectorate (DWI).

The Epoxy technology is classified as a non-structural renovation technique. It does not solve leakage problems, neither does it deal with structural problems that may be experienced on iron pipelines as a result of major external corrosion.

Increasing use of the epoxy resin lining process has largely been at the expense of cement mortar lining, which it has almost completely replaced as the preferred relining process in the UK. The reasons for this change are associated with increasing awareness of water quality problems and concern about the long-term durability of cement mortar linings in certain waters. Investigations have also shown that lining the cleaned main with epoxy resin can significantly reduce levels of polycyclic aromatic hydrocarbons (PAH) emanating from coal tar linings applied as a factory coating for internal protection of iron pipes. In addition to this the epoxy lining process has demonstrated others practical benefits over cement mortar lining.

ELC 257/91 is a second-generation, two part epoxy resin material which has been specifically formulated for the in-situ lining of public drinking water pipelines. It has received full approval for use in contact with public drinking water supplies from the UK Department of the Environment's Drinking Water Inspectorate, as well as numerous other National regulatory and advisory agencies around the world. A particular feature of the formulation is that it contains no solvents or benzyl alcohol.

a) Description of the process

The Process - Stage by Stage

1) Excavation: pipe section isolation
- Main entered and section isolated
- Up to 650 feet per application
- Suitable for 3 inch pipes and larger
- No extended trench work required

2) Preparation
- Removal of tuberculation
- Choice of cleaning method based on the pipe diameter and internal condition

- Pigging, boring, scrapping
- Swabbing of residual loose debris

3) Application

- Epoxy prepared in an application rig
- Pre-lining checks undertaken
- Lining machine launched into pipe and drawn towards rig
- Winch rate and pumping pressures monitored to achieve minimum 40 mil. (1mm) lining
- Ends of pipe capped on completion

Preparation and cleaning

Generally speaking bends greater than 221/2 degrees and tees will need to be removed where these will obstruct the free passage of the lining application head during the lining operation. It is also recommended that valves, hydrants and washouts are removed during the lining process and either refurbished or replaced according to their size and condition.
It is essential that the main prepared ready for lining is free of any standing water, and that all customer service connections are properly closed to prevent any back-flow of water into the main, as both of these can have a serious adverse effect on lining quality.

Proper surface preparation of a host structure requires that the contractor removes all contaminants including oils, greases, laitance, existing coatings, etc. from the surfaces to be coated. A sound, clean substrate with adequate profile and porosity to promote adhesion between the host structure and the coating or lining system being installed must be produced. Generally, this can be accomplished with proper decontamination and cleaning of the surfaces using environmentally friendly degreasers, detergents, steam, acid etching, low-high pressure water cleaning, wet abrasive blast and/or dry abrasive blast.

Techniques that could be considered include power boring, drag scraping, pressure scraping, abrasive pigging and jetting techniques (See the following Table).

Cleaning Techniques – Summary

Cleaning Technique	**Applicable Size Range (inches)**	**Maximum Section Length Treated (feet)**
Power Boring	>3	600
Drag Scraping	3 to 18+	650
Abrasive Pigging	3 to 100	6,000
Pressure Scraping	>18	6,000
Pressure Jetting	>3	750

With the exception of drag scraping, which is normally carried out dry, there is a requirement to dispose of large volumes of water and debris as part of the cleaning operation.

It is important to prove the main to ensure free passage of the lining application head and nowadays the use of polypropylene proving pigs has been superseded by color close circuit TV inspection (CCTV) of the entire section of main to be lined. As well as inspecting the efficiency of cleaning the color CCTV survey can also be used to precisely identify passing valves, leaking customer connections, dropped joints, 'lead fish', and protruding customer connections. Quality assurance record documentation should include sections for recording the results of this survey.

Reconnection

The normal reconnection procedures are as follows:

- Reconnect lined section to main using pre-chlorinated, pre-lined make-up pipe lengths and couplings
- Disinfect lined section in accordance with the utility’s specified procedure (e.g. maintain minimum free chlorine residual of 50mg/l for at least 30 minutes contact time)
- Flush main to waste with potable water
- Return main to service
- Open customer's connections
- Water sample to be taken by client for bacteriological examination