INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	**TRENCHLESS TECHNOLOGIES RESOURCE CENTRE**	
	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	CURED-IN-PLACE (CIPP) LINING SYSTEMS	LAST UPDATED MARCH 2009

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), This technology and its variants have dominated the non-man-entry sewer renovation market in many countries for almost thirty 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 many 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.

Insertion is achieved in one of two ways. One is to invert the hose into the pipe using compressed air or water, which automatically pushes the liner material against the host pipe wall. The other is to winch the un-inflated liner through the pipe, inflating it once it is in the correct position. The difference between the two techniques is that in the first option there is usually no relative movement between the liner material and the pipe wall during installation, whilst with the second there is the potential for friction/contact damage between the liner and the host pipe surface unless a protective sheet or pre-liner is used.

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.

The wide variety of CIPP systems now commercially available can be classified in terms of:

a) The structure and composition of the lining tube
b) The method of installation
c) The method of cure
d) The type of resin used

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CURED IN PLACE LINING SYSTEM VARIETIES

Liner Tube Material	Installation type	Cure Type	Resin	Main Application	Comment
Plain Polyester Felt	Water Inversion	Hot Water	Polyester (PE) Vinyl Ester (VE) Epoxy (EP)	Gravity	The original system still most widely used for sewers
		Ambient	PE,VE,EP	Gravity	Used for small diameter/short length pipes and service laterals
	Air inversion	Steam	PE,VE,EP	gravity	Small/medium Dia. – rapid cure and high productivity
	Pull in and inflate (PIF)	Steam, hot water or ambient	PE,VE,,EP	Gravity	Alternative installation method
Fibre Reinforced Polyester Felt- 2d random chopped strands distributed throughout thickness	Water inversion	Hot water	VE, EP	Pressure (water mains if Approved resins used)	Semi and fully structural variants
Fibre Reinforced polyester Felt – structured glass fabric	Water /air Inversion or PIF	Steam or hot water	PE,VE,EP	Pressure and Gravity	Allows reduced wall thickness for gravity applications
	Air Inversion or PIF	UV Light	Special	Gravity	Reduced thickness plus rapid cure
Carbon fibre reinforced polyester felt (Carbon Fibres placed at inner and outer tube surfaces	Air Inversion	Steam	PE or VE	Deep/Large diameter gravity pipes	Sandwich structure gives max ring stiffness at min thickness
Circular Woven Polyester Fibre Hose	Water/air inversion or PIF	Hot water/steam or ambient	EP	Pressure	Semi structural Class C depends on adhesion
Woven Hose Plus Felt		Heat	Epoxy	Pressure	Semi structural Class B does not require adhesion
Woven Hose Plus Felt Plus Structured Glass Fibre Fabric		Heat	Epoxy	Pressure	Semi or Fully structural Class A

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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 minimising 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. The use of fibre reinforcement either glass or carbon can significantly reduce the design wall thickness required for large diameter/deep buried pipes and enable use of air inversion/steam cure.

In Gravity pipelines, laterals can be re-opened remotely after lining using a robotic cutter, but care must be taken during installation to ensure that surplus resin does not enter branches. The annulus between the liner and pipe inner wall at the connection location provides a path for water leakage. This is overcome by one of the following methods:

a) Use of low shrink resin systems which do not create an annulus
b) Installation of a resin felt seal (Top Hat) at the lateral/ main pipe junction
c) Sealing the annulus with injected grout at the lateral location

CIPP Systems can also be used to line all or part of lateral pipes using one of the following systems:

a) Inversion of the liner into the lateral from within the main lined pipe (Bottom up Technique) via a top hat seal
b) Inversion of the liner from the top of the lateral into the main pipe and subsequent installation of a top hat or injected grout seal
c) Pulling the liner through the main lined pipe and then up the lateral followed by inflation and cure. A top hat seal is pre-attached to the bottom of the lateral liner and pulled into the connection

Laterals are generally 75 mm to 150 mm diameter and frequently contain sharp bends >45 degrees. Use of conventional felt liners creates folds at the bends which may partly block the lined pipe. To solve this problem a special thin flexible fabric liner has been developed.

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One of the disadvantages of CIPP lining systems is the need to take the host pipe out of service during liner 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 - see elsewhere.

2. CIPP APPLICATIONS

Sewers	Yes	
Gas pipelines	Yes	Certain types of CIPP system have been designed specifically for use in gas pipelines rather than gravity sewers.
Potable water pipelines	Yes	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
Chemical/Industrial pipelines	Yes	The correct resin formulation must be chosen to resist unusually aggressive effluents and/or high temperatures
Straight pipelines	Yes	
Pipelines with bends	Yes	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.
Circular pipes	Yes	
Non-circular pipes	Yes	
Pipelines with varying cross-section	Possible (See comment)	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 that 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.
Pipelines with lateral connections	Yes	
Pipelines with deformation	Possible (See comment)	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.
On-line replacement (size for size)	No	However the improvement in surface roughness (C value after lining may compensate for the reduction in flow cross section
Pressure pipelines	Possible (See comment)	Most CIPP systems were originally intended for gravity pipelines, but certain proprietary techniques are available for pressure pipes. See also notes A and B.
Man-entry pipelines	Yes	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. Specific design methods for CIPP liners in sewer applications have been developed in the UK, the USA, France and Germany. A wide range of CEN standards covering all the members of the European community are under development.

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. A North American Standard with wide applicability is ASTM F-1216 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' or 'winched-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 minimise 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 vapour with a strong odour. However, although the vapour can be a health risk

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in high concentrations, such levels are not typically found around CIPP installations. Indeed, styrene vapour is detectable to humans at concentrations of less than 1 ppm, and the odour 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. A further environmental hazard can be the discharge of large quantities of hot inversion water after cure and some environmental authorities impose restrictions on this aspect of the process. Use of air inversion and steam or UV light curing systems are potential solutions to this problem.

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 later) can overcome problems of contamination.

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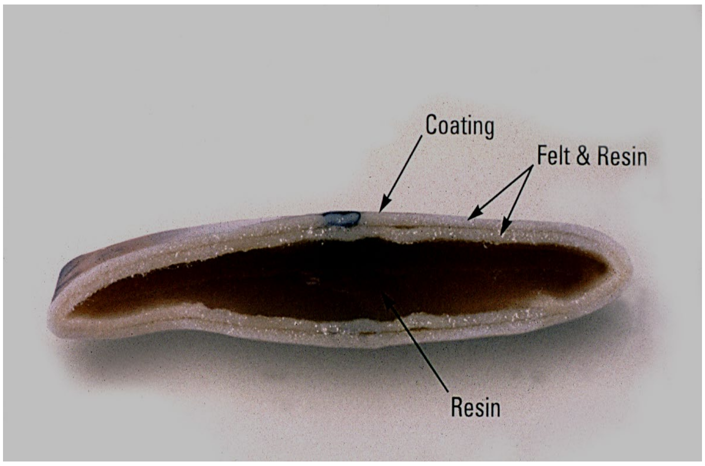
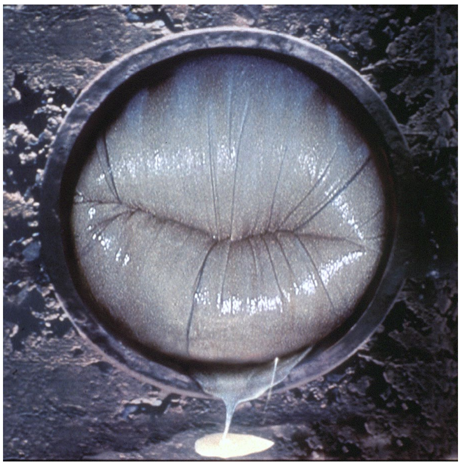
5. INSTALLATION IN SEWERS - THERMAL CURE

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-fibre. The formulation of the resin can be adapted to suit different cure regimes and effluent characteristics.



A POLYESTER FELT LNING TUBE (Above) and (below) The INVERSION FACE



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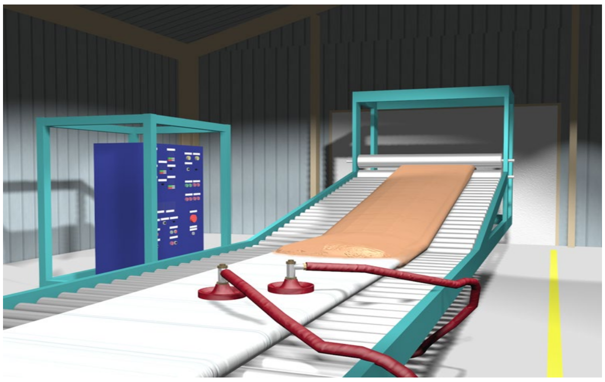
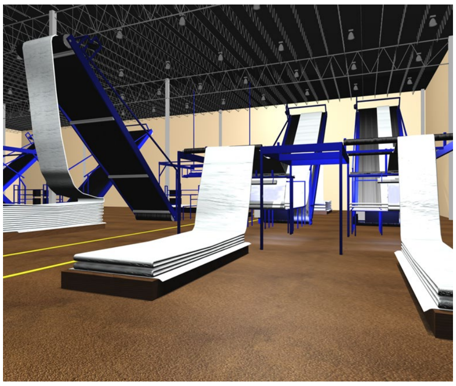
The liner fabric is usually coated on the outer face of the tube - which becomes the inner surface of an inverted liner - with a membrane of polyester, polyethylene, surlyn or polyurethane, depending on the application. The membrane serves several functions - it retains the resin during impregnation and transportation, it retains the water (or air) during inversion, and it provides a low-friction, hydraulically efficient inner surface to the finished liner.

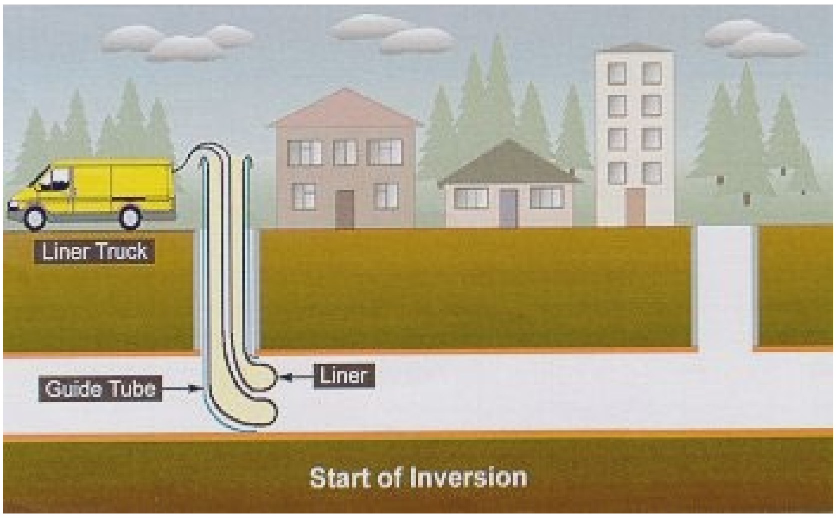
Some systems use a separate membrane rather than an applied coating, and this may be removed after installation. Impregnation is normally carried out in the factory under a vacuum to exclude air and ensure the uniform distribution of resin. This is known as the 'wetting-out' process. Depending on the characteristics of the resin, the liner may be delivered to site in a refrigerated vehicle, to prevent the curing reaction from starting prematurely.





Schematics of the resin impregnation process for CIPP liners

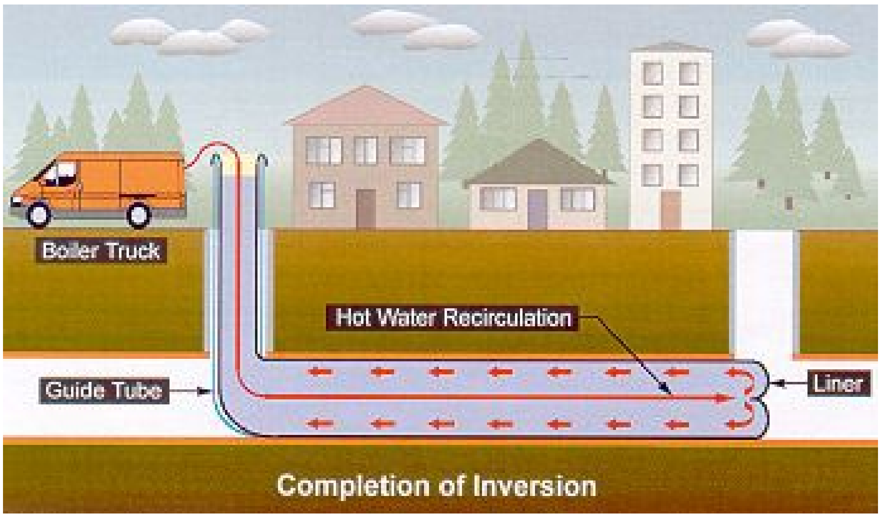
Insertion into the existing sewer is usually carried out either by winching into place or by an inversion process wherein water (or sometimes air) pressure is used to turn the liner inside out as it travels along the pipe.



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. In some instances a pressure vessel is used to provide the water pressure required to invert the liner eliminating the need for a tower. The latter is also becoming increasingly common as safety regulations pertaining to 'working at height' become more stringent worldwide. Working with pressure vessels removes this requirement for CIPP installations.

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 manually turned inside out for a predetermined length, usually a few metres, and is then clamped to the collar of the guide tube. Attached to the trailing end is a hose that 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 into 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 using 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 centimetres 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 (Pull in and Inflate – PIF) 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 also avoids the need for scaffold towers and overhead working. However, there are limitations to the size and weight of liner that can be winched in without stretching or tearing it, and winching a heavy liner through a damaged pipe can damage the fabric still further.

Whilst historically most thermal cure lining operations have utilised hot water to provide the temperature change required to set the resin in a liner material, during the course of 2006, some companies, largely in the UK, introduced a compressed air inversion/steam cure system for use in sewer pipelines. Generally using an inversion drum, the liner material is inverted through the damaged pipe using compressed air applied to the liner which is installed on a self-contained reel within the drum. The same principle can also be applied to larger diameter pipes with the impregnated liner transported to site stacked conventionally in a refrigerated truck. The liner is then passed through a system of rollers positioned above the manhole which allow air pressure to be applied to the section of inverting liner below the rollers The liner is then heated, throughout its length, with steam generated by a boiler in the lining unit truck. For large diameters use of this technique eliminates the need to supply, heat and dispose of large quantities of inversion water and offers faster installation and cure and hence improved productivity. A variant of this technique aimed at small diameter sewers uses a lining tube with a polymer film on both faces which is pressure impregnated in the factory, pulled into the pipe, inflated with air and steam cured. The system is claimed to offer minimum energy use, shorter installation times and consistently high quality

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6. UV-CURED LINERS

As an alternative to curing with hot water or steam, 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-fibre or a combination of glass-fibre and polyester needle-felt, with an outer membrane and a temporary inner sleeve to protect the liner during storage, shipping and installation.

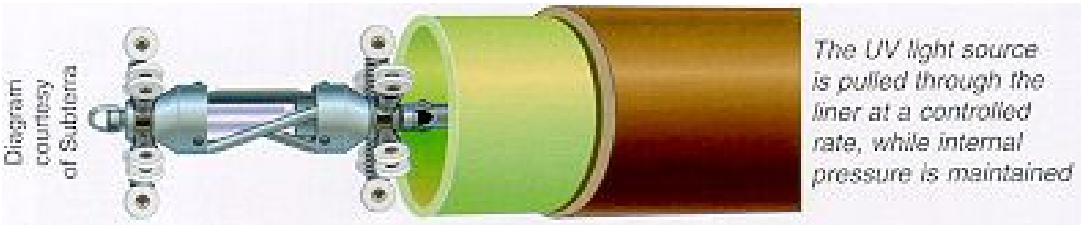
It is possible to use resins with a storage time of several weeks at ambient temperature, so refrigeration is not required. Various resin formulations are available to suit the nature of the effluent.

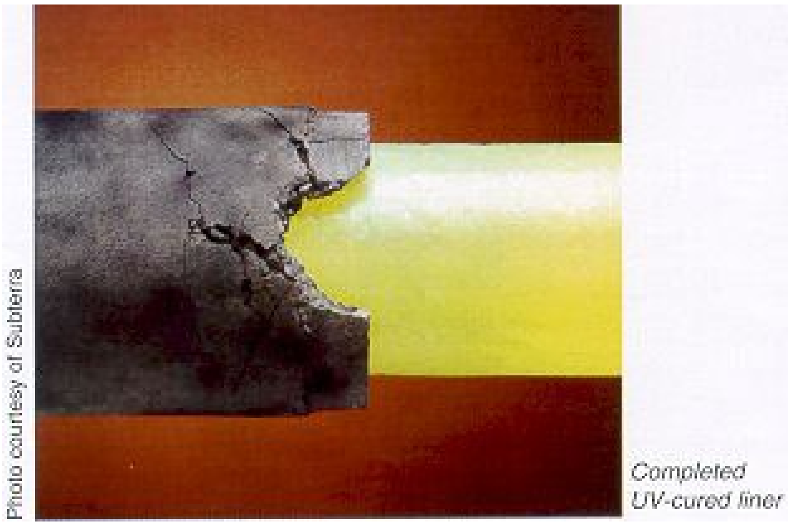
Installation generally follows the following procedure:-

a. After the usual pre-survey and cleaning, the pre-impregnated liner is winched or inverted into position in the host pipe.
b. The UV light source is inserted into the liner, and the sealing packers are inflated in each manhole.
c. The liner is pressurised, 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.

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 m/min, and lengths of up to 200 m can be lined continuously. UV-cured systems are available for pipes from 100 to 1,000 mm diameter, with liner wall thicknesses from 3 to 15 mm. Variations are under development to line lateral connections.

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7. INSTALLATION IN SEWERS - AMBIENT CURE

Ambient-cure lining systems are used mainly for the renovation of small diameter sewers and laterals, 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 ambient nature of the resin does mean that, more often than not, impregnation of the liner is done at site or close to the work site just prior to installation, in order to eliminate the potential for the resin curing before insertion is completed.

The installation procedure is generally as follows:-

a. Unlike thermal-cure systems, as mixing of the resin and impregnation of the liner are generally 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.


Installation of an ambient-cure liner in a site with difficult access

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 pressurises 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.

There are numerous variations on the above theme, including increasingly the use of 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.

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8. CURED-IN-PLACE LINERS FOR PRESSURE PIPE APPLICATIONS (WATER AND GAS MAIN, RENOVATION)

The structural characteristics required of a pressure pipe liner are quite different from those for a sewer liner. 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, seldom fail through external loading. The most significant forces on the pipe are generally caused by the internal pressure, which creates circumferential tensile stresses in the pipe or liner. 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.

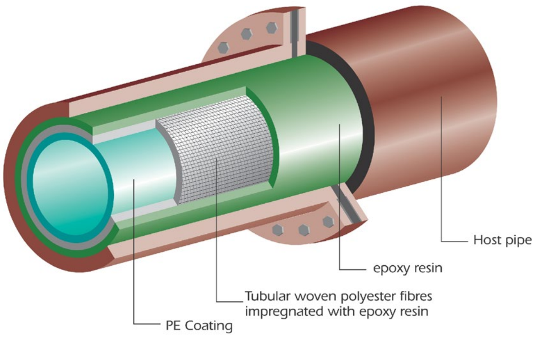
For this reason, the fabric used for CIPP pressure pipe liners incorporates various types of fibre reinforcement which significantly increase the tensile strength of the cured composite. In addition, because flexural stresses are not so critical, the wall thickness of the liner is usually much less than for sewer pipe relining. Glass-fibre or a glass-fibre composite is commonly used, except in woven hose linings which generally use polyester fibres.

The fabric of woven hose linings 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 essential if approval for potable water contact is required.

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.

Woven Hose Liner Circular Weaving system



Section through a Woven Hose Lining System

In addition to the thin-walled hose lining methods 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 fibres rather than a woven jacket, and are designed to resist both internal and external forces.

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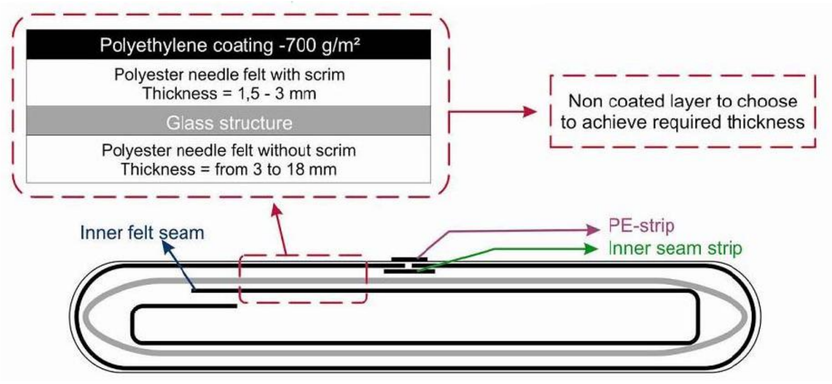

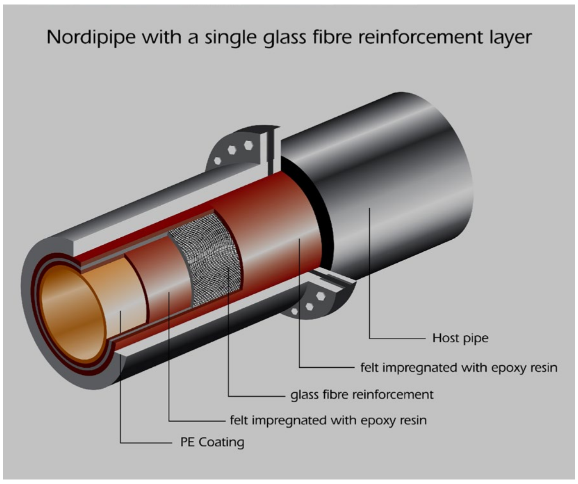

Multi layer Composite Lining System

Such systems may be classified as either semi or fully structural pipe as described in the Design Section of these Guidelines.

9. SUMMARY

1. Most cured-in-place lining systems are intended for the renovation of gravity pipelines, though pressure pipe systems are also available.
2. They are versatile, being able to accommodate non-circular sections, bends, and change of cross-section, all pipe materials and various loading conditions.
3. They produce a close-fit liner with a smooth internal surface, and the low hydraulic roughness often compensates for any reduction in bore.
4. The liners, generally used, are resistant to all chemicals normally found in sewers.
5. Special resin formulations are available for particularly aggressive effluents.
6. Pipes from less than 100 mm to over 2,500 mm diameter can be relined, although the economics may become less favourable in the largest sizes as the weight and cost of materials increases.
7. Lateral connections can be opened remotely from within the main pipeline.
8. 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.
9. 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.
10. Cured-in-place techniques have a track record going back over 25 years, and their durability is well established.

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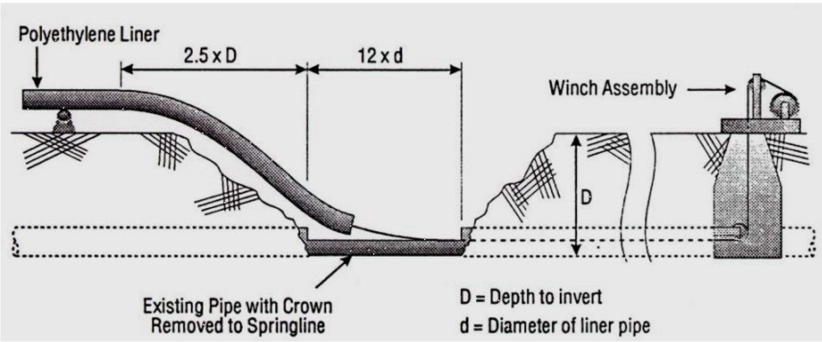
	SLIPLINING	LAST UPDATED MARCH 2009

1. OVERVIEW

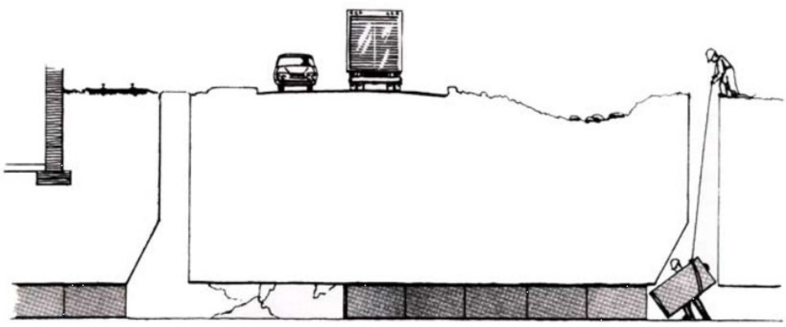
Possibly the simplest technique for renovating non-man-entry pipelines is sliplining, which basically entails pushing or pulling a new pipeline into the old one. The concept of using the 'hole in the ground' created by the old pipe as a route to install a replacement pipe within the old is long established, and there are reports of clayware pipes being winched into old sewers and culverts many decades ago.

The availability of polymeric pipes, particularly fusion-jointed polyethylene, increased the popularity of sliplining techniques. Short section polymeric pipes may be formed into 'slip' liners by fusion welding or with mechanical, collarless joints. They are also used extensively with on-line replacement techniques such as pipe bursting (*see Section 4*).

Although, in theory, any material can be used for the new pipe, in practice polyethylene (PE) is the most common choice. 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 very long continuous lengths prior to being winched into the host pipe. More recently a heat fusible form of PVC has been introduced which allows this product to be slip lined in a similar manner to PE.



CONTINUOUS SLIPLINING



SEGMENTAL SLIPLINING

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Annulus grouting may be necessary after the insertion of the liner, so that the structure of the existing pipe provides some restraint and increases ring stiffness and hence resistance to external hydrostatic loads. In practice, the grouting operation can be the most difficult part of the job. The loss of cross-sectional area may also be significant, particularly if the liner size is governed by the diameters of commercially available extruded pipes, or where the size must be further reduced to negotiate deformation or displaced joints in the host pipe. As a result of these limitations, conventional sliplining has become less common than close-fit lining (covered later), but may still be the best choice in certain cases.

2. APPLICATIONS

Sewers	?	(see note A)
Gas Pipelines	Yes	
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	?	(see note E)
Pipelines with varying cross section	?	(see note F)
Pipelines with lateral connections	?	(see note G)
Pipelines with deformations	?	(see note F)
Pressure pipelines	Yes	
Man-entry pipelines	?	(see note H)

A. *Sliplining can be used to renovate sewers, but is not usually the first choice system for gravity pipelines because of the reduction in bore.*
B. *Approval of the relevant regulatory body is needed for all materials in contact with potable water.*
C. *Severe bends cannot usually be negotiated, especially at larger diameters. All bends add to the friction between the old and new pipes during installation, and so reduce the length of liner that can be pulled in without overstressing the pipe.*
D. *PE pipes are available for non-circular sections, although they are relatively uncommon.*
E. *The liner must be sized to the minimum dimensions of the host pipe, unless tapers are incorporated.*
F. *It is usually necessary to excavate to connections and disconnect them prior to liner installation, and certainly prior to grouting. Internal reconnection may be possible, although the process is more complicated than with close-fit lining.*
G. *Because of the weight of material, it is unusual to pull a new pipeline into a man-entry pipe as a continuous string. Man-entry renovation techniques are covered elsewhere.*

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3. DESIGN REQUIREMENTS

Pipes used for sliplining are generally, but not always, stand-alone pipes of similar type and specification to those used for new installations. PE pipes are usually aimed at applications where internal pressure is the main criterion, and the design of PE slip liners in pressure pipes should follow the same principles as for new pipes.

Annulus grouting may not be required when lining pressure pipes, but is usually necessary for gravity pipelines in order to increase the ring stiffness of the liner. Slip liners in sewers are usually designed to be restrained by the host pipe and the annulus grout, but do not form a bond with the existing pipe wall. In such cases, the grout acts only as a filler and does not require high structural strength. Systems which rely on the host pipe for some measure of structural support are sometimes known as ‘interactive lining’ techniques.

Because of the relatively low flexural modulus of PE, thick-walled pipes may be needed to withstand high external loading. This may be a significant factor with gravity pipes, which are laid at considerable depths or are subjected to high vehicle loading. In such cases it may be more economical to design the PE liner as a permanent formwork for high strength grout, rather than to increase the wall thickness of the liner itself. In this type of lining system the grout is the main structural element.

In all cases, the liner must be designed to withstand not only the internal and external forces in service, but also the loads during installation - particularly winching forces and grout pressure.

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4. LINER PIPES

As indicated above, sliplining pipes are most commonly made from polyethylene, but may be of any material that can be inserted into the host pipe. The main criterion is that, in order to minimise the bore reduction, joints or sockets should not protrude beyond the pipe barrel.

Clearly, if a pipe string is to be winched in, the joints must not pull apart. Butt-fused PE is often used, the fusion taking place either on the surface or within the insertion pit.

Subject to constraints of space, fusion on the surface allows the preparation of long pipe strings, which can be pulled in quickly to minimise the interruption to service. However, due to the curvature limitations of the pipe, this method of installation can require long starter trenches, especially with pipes that are deep or of large diameter. In-trench fusion allows a shorter excavation, but installation can proceed only as quickly as the joints can be welded and cooled.

The normal procedures and precautions for butt-fused joints in new installations apply equally to sliplining pipes, and the recommendations of the pipe and fusion equipment manufacturers should be followed closely.

Butt-fusion jointing of a PE slipliner

A more recent development, in the USA, is the butt fusion welding of uPVC pipes. This enables standard uPVC pressure pipe to be used in a similar manner to polyethylene, in applications which involve insertion by pulling. The butt fusion welding process requires careful control of resin formulation and fusion conditions.

There are two common alternatives to fused joints - screw joints and snap-fit joints. The former may be used in pipe materials such as polypropylene, and can give a reliable and quickly assembled joint at the expense of higher manufacturing cost. Pipe joints which snap together may be unable to withstand high tensile forces, and are often pushed in from the insertion pit by hydraulic rams. This is a similar technique to that used in some forms of on-line replacement described elsewhere.

Mechanically jointed pipes are available in lengths to suit the space available for insertion, and can be installed from existing chambers. The machining of the joints may, however, represent a large proportion of manufacturing cost, so short-length pipes often have a relatively high unit cost.

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5. INSERTION

As discussed above, liners may be pulled or pushed in (or spirally wound see later). If pulled in, an important component is the towing head, which grips the new pipe and transmits the force from the winch cable. The towing head should provide a secure connection without imposing high, localised stresses. Some designs also seal the end of the pipe to prevent soil or debris from entering, this being particularly desirable for potable water applications.

Small diameter slip liners are often pulled in using ‘towing socks’. These are tubes made from diamond-shaped mesh, which tend to reduce in diameter and grip the liner as a pull is exerted.

To avoid over stressing the liner, a breakaway connector may be fitted between the winch cable and the towing head. These connectors have a series of interchangeable pins that determine the load at which the two halves of the unit will part company. Although undesirable, breakage of the connector is usually preferable to pipe damage and subsequent failure, and the presence of a breakaway connector also concentrates the minds of the operatives on avoiding excessive winch forces.

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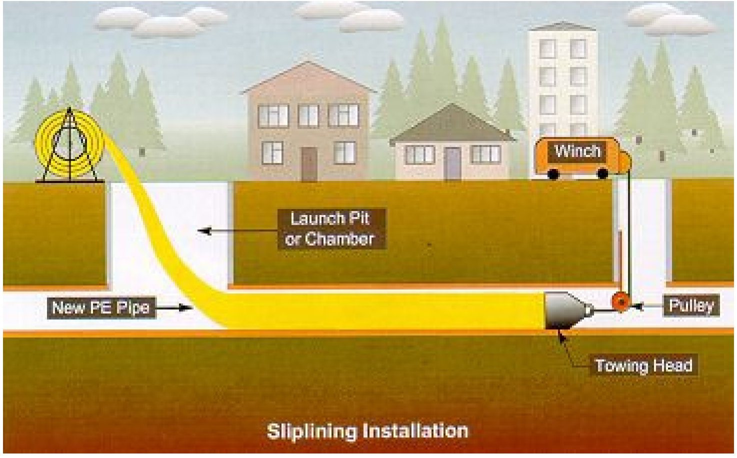

Small liners may be pulled in manually, but most need a winch. The winch should apply a steady, progressive pull, without snatching or uncontrolled variations in force. Careful consideration should be given to the positioning of the winch and the routing of the cable, and it is often necessary to fit additional pulleys within the manhole or reception pit, to ensure that the cable has an unobstructed path and does not abrade on any part of the chamber.

Preparing to pull in a 500 mm diameter PE slipliner

There are numerous designs of pipe pushing machines, either manually or hydraulically powered. Some types are designed to operate from within the insertion pit, whilst others are located on the surface just behind the insertion pit. The pushing machine grips the liner pipe and pushes it forward into the host pipe. The gripping mechanism is then released and returns to the starting position, and the process is repeated.

Sliplining by Pushing
Large Diameter Reinforced
Plastic Matrix pipes

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6. SPIRALLY WOUND LINERS

In the original ISTT Guidelines the earliest form of spirally wound liners, which involved an annulus between the host pipe and liner, were described in this section. In the revised ISTT Guidelines all of the aspects of the spiral winding process are considered together in a dedicated Section (see later).

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7. GROUTING

Lining systems in which the liner bonds to, and acts in composite with, the existing pipe, and systems in which the liner tube acts simply as a permanent former for the annulus grout, require structural grouts with a compressive strength generally between 10 and 20 kPa.

Liners which are restrained by the host pipe, but do not need to bond to it, require only a filler which can transmit loads between the two elements. Some of the grouts used for this purpose have a similar strength to that of stiff clay - around 1kPa - although there is no harm in using higher strength materials.

General purpose Ordinary Portland Cement and Pulverised Fuel Ash (OPC/PFA) grouts are commonly used although a variety of special formulations are available. One of these is a very low viscosity grout that flows through the annulus under gravity or minimal pressure, but sets in about 20 minutes. An advantage of quick-gelling grouts is that they allow stage grouting to proceed more quickly than with conventional materials.

The forces on a liner during grouting are sometimes higher than anything encountered during normal service, and failures due to grout pressure and flotation forces must be avoided. Flotation forces are sometimes underestimated, especially in larger liners, and it should be remembered that the force is related to the weight of grout displaced by the liner (i.e. the volume of the liner multiplied by the grout density) rather than the weight of grout in the annulus.

It is common practice to fill the liner with water during grouting, which helps to counteract the flotation force and to resist external pressure. Even so, since most grouts have a specific gravity greater than 1.0, it may still be necessary to grout in stages, especially with larger gravity pipelines where the gradient is critical and flotation could not be accepted.

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8. LIVE INSERTION AND SERVICE PIPE RENOVATION

Several techniques have been developed to allow the insertion of a new polyethylene pipeline into an existing gas main or service without interrupting the supply. These methods generally rely on gas flowing through the annular space between the old and new pipelines during installation, and so entail a reduction in pipe bore. This may be acceptable in the case of old mains originally designed for gas of lower calorific value, or distributed at pressures lower than those currently available.

It is outside the scope of this document to describe the many proprietary systems for live insertion. For obvious safety reasons, strict and detailed procedures are laid down for installation, and the following is intended only as a general guide to the basic principles. Systems are available for low and medium pressure mains.

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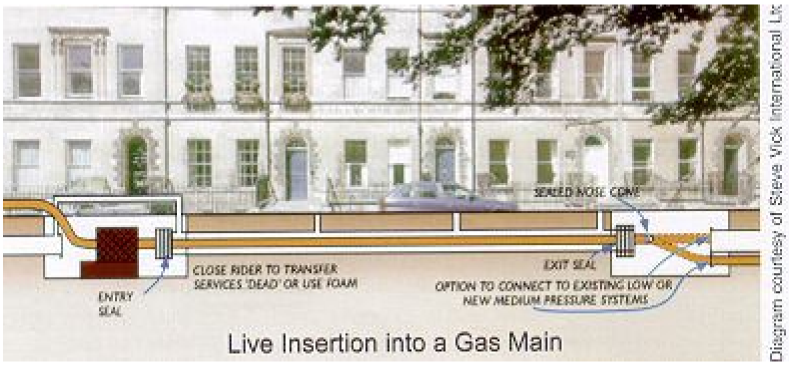
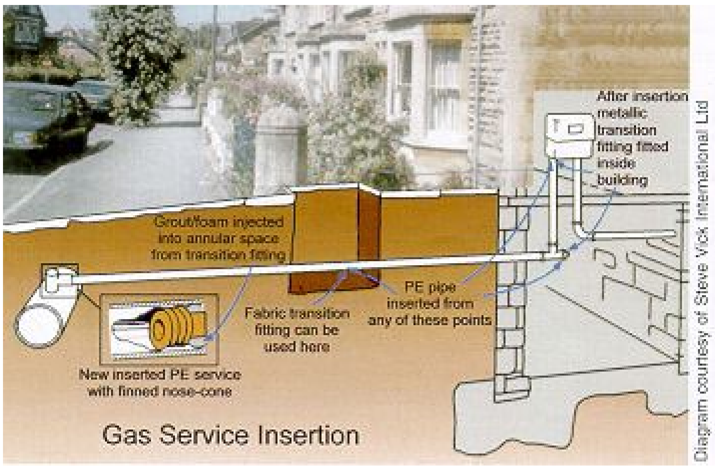
The first stage is to isolate the section of main to be renovated, keeping it supplied with gas via a bypass at one or both ends of the isolated section. The new polyethylene pipe is then fed through gland seals attached to the old main at the entry excavation, and is pushed using pneumatic or hydraulic machines through the entire length of main to be renovated. Typical insertion lengths are between 100 and 500 metres.



Live Insertion into a Gas Main

There are different variations on the technique, but in the simplest version the new PE pipe is passed through gland seals in the exit excavation, and can then be connected either to the existing pipe or to a new, generally higher pressure, network. In all variations, the annular space between the old and new pipes is used to maintain supplies to consumers during installation. To facilitate the transfer of services to the new PE pipe, polyurethane foam is injected into the annular space to stop the flow of gas, allowing the old main to be cut away and the new connection made. Gas mains from 75 mm to 450 mm diameter can be relined using this method.

For the renovation of gas service pipes, a technique is available that allows the existing gas meter position to be maintained by enabling the insertion of PE pipe through a 90° elbow, around a tee, or through a number of long-radius bends. After removal of the meter and the main stopcock, the line-blowing assembly is fitted to the service connection at the meter position. Air is blown through the old service pipe to remove any loose rust. The pipe receiver, bend and standpipe are fitted to the service, and air is allowed quickly into the pipe to blow a line through to the far end. This is then used to pull back the winch cable, and the winch is fitted to the top of the pipe receiver. A short length of PE pipe is winched through to remove any further rust or encrustation. The full length pipe is installed by using the winch in combination with a pushing force applied manually from the other end, and a test is applied after a brief period to allow the pipe to recover from any stretching. The technique can be adapted for the renewal of water services.



Gas Service Insertion

A method of live insertion for gas service pipes has been developed in which a new PE pipe is pushed into an old steel service through a gland sealing system attached to the old pipe, either inside the consumer's premises or by means of a small excavation outside the building. No excavation is necessary at the service connection with the gas main in the highway. The annular space between the old and new pipes is filled with a permanent sealant, which is prevented from entering the mains system by a type of nosecone fitted to the leading end of the PE pipe. The system is available for steel services from 20 to 50 mm diameter, operating at pressures up to 50 millibar. Adaptations to enable the use of the technique at higher pressures and in water networks are under development.

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9. LATERALS AND BRANCH CONNECTIONS

The reconnection of laterals and branches in conjunction with sliplining of gravity pipelines usually necessitates excavation. It may be possible to cut an opening in the liner prior to grouting, and to insert an inflatable bag up the lateral to seal between the branch and the liner and prevent grout from entering either. However, the complexity of this operation is justified only if external access is very difficult or impossible, and the procedure can be used only in larger pipes.

Excavation must take place, and the branch must be disconnected, before grouting is carried out. Electrofusion is commonly used to fit branches to PE liners, in the same way as for new installations. Special couplings are available to reconnect the new junction to the existing branch.

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10. SUMMARY

1. Sliplining is a conceptually simple technique, which can be applied to either pressure or gravity pipelines.
2. Virtually any type of durable liner material can be used, although polyethylene is the most common.
3. Standard pipes and fittings, as used for new installations, can also be used for sliplining, except that joints should not protrude beyond the pipe barrel.
4. Liners may be pulled in or pushed in, depending on the liner material and the joint design.
5. A pipeline as good as new may result, but the bore reduction may be significant.
6. Grouting is generally required, at least in gravity pipelines, to increase resistance to external loads.
7. Techniques are available for the insertion of liners into live gas mains.
8. Laterals must usually be reconnected by excavation.

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INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	CLOSE FIT THERMOPLASTIC LINING	LAST UPDATED MARCH 2009

1. OVERVIEW

The use of Thermoplastic liners that are deliberately deformed prior to insertion, and then reverted to their original shape/size once in position so that they fit closely inside the host pipe, is known as 'Close Fit lining' or 'modified sliplining'. Such techniques are a logical development of basic sliplining, and can be applied to both gravity and pressure pipes. The key advantages over conventional sliplining are:

a. better retention of flow capacity of host pipe after lining

b. ability to use thinner wall liners in a semi-structural manner

It should be noted that Cured-In-Place lining is also a close fit system which is covered separately elsewhere in this Guideline.

2. PRINCIPLES AND CLASSIFICATION OF METHODS

The principle of the Close Fit Lining methods is to use a polyethylene or PVC liner pipe with original outside diameter from 5% less to 3% more than the inside diameter of the host pipe. The liner pipe is then temporarily reduced in diameter to give sufficient clearance for insertion into the host pipe. Once inserted, the liner is 'reverted' to its original shape/size to form a Close Fit lining. The various close fit lining methods can be classified in terms of:

a. The method used for Diameter Reduction (Symmetrical or Fold and Form)

b. The method used for reversion (natural, heat, pressure)

c. The type of liner material (PE, Fibre reinforced PE, uPVC, PVC alloys)

The available methods are summarised on this basis in the Table below: [Each method imposes limitations on the liner thickness and diameter range that can be processed and this determines the structural capability of the installed liner. This also depends on the mechanical properties of the liner material i.e. PE80, PE100, uPVC etc, and is discussed in more detail in the design section.

Reduction Method		Material	Min Diam (Mm)	Max Diam (Mm)	Max Sdr (Min T)	Min Sdr (Max T)	Strength Class	Max Pressure (Class A) Bar	Main Application
Symmetrical	Tension (static die)	PE 80/100	75	1000	80	11	A,B	16	Pressure Pipes
	Tension (Roller die)	PE80/100	150	1000	80	11	A,B	16	Pressure Pipes
	Compression	PE 80/100	100	500	33	11	A,B	16 up to 400 mm then 10	Pressure Pipes
	No reduction	uPVC/moPVC	100	900	42	18	A	10	Pressure Pipes
Fold and form	Site folded	PE 80/100	75	1600	80	26	A,B	6 @ 400 mm to 2.5 @ 1600 mm	Pressure Pipes
	Factory folded (Hot)	PE 80/100	100	500	33	17	A,B	10	Pressure and Gravity Pipes
		uPVC and uPVC/PE alloys	150	500	33	33	A,B	8	Gravity
			100	600	25	14	A,B	16	Pressure pipes
	Factory Folded (cold)	PE 80/100	100	300	50	33	A,B	4	Pressure Pipes
	Factory Folded (hot)	Polyester Fibre Reinforced PE (PRP)	70	300	50	30	A	16 to 150 mm 10 to 300 mm	Pressure Pipes
Expanded flat hose	Flat hose re-rounded by the service Pressure	Aramid Fibre Reinforced PE	150	500	50	25	A	Up to 40 bar	Pressure Pipes

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3. SYMMETRICAL REDUCTION SYSTEMS

These involve reducing the diameter of a PE liner pipe by pulling or pushing it through a die, consisting of either a hole in a plate or a circular aperture formed from a series of grooved rollers. The circular cross section of the liner is retained during diameter reduction and subsequent reversion. The methods can be further subdivided into TENSION and COMPRESSION based systems depending on the source of the energy used to deform the liner.

3.1 TENSION BASED SYSTEMS

In TENSION based systems the liner is winched through a die directly into the pipe to be renovated. The diameter reduction produced by the die is maintained by the tension in the winch wire. Once the winch tension is released, the liner begins to return fairly rapidly toward its original OD until it hits the pipe wall to form a tightly fitting liner. The die can be a circular hole in a metal plate or a circular orifice formed by a series of grooved rollers which may be driven and/or braked.

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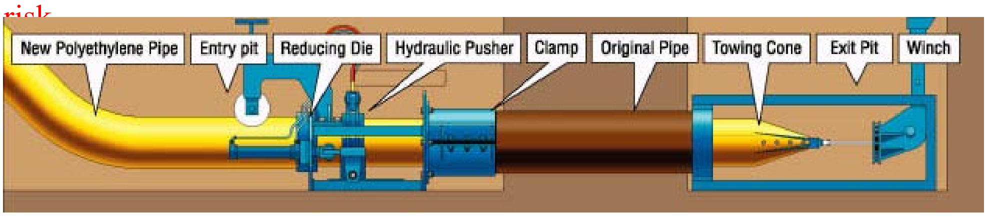

Tension based symmetrical reduction lining systems

After winching the reduced diameter liner into the host pipe and sealing both ends, pressure is applied to revert the liner to its original size. The technique can be applied to fully pressure-rated pipe, or to thin-walled non-structural liners for corrosion protection and leak sealing, and liners can be installed around gradual bends. Systems are commonly available in diameters from 100 to 600 mm, but the technique has been used in diameters up to 1,100 mm.

In COMPRESSION based systems the liner is pushed through a series of circular apertures formed by an array of grooved rollers which may be driven. The reduction in diameter is associated with an increase in wall thickness, and is substantially retained until subsequent reversion, achieved using internal water pressure. This characteristic allows diameter reduction to be separated in terms of time and/or location from insertion and reversion. It also allows the reduction process to be paused to allow attachment of additional liner lengths before the reduction equipment. Hybrid tension/compression based technologies are now available combining the simplicity, speed and capital cost advantages of the tension method with the delayed reversion benefits of the compression system.

These techniques were originally developed for the gas industry, but are also suitable for most types of pressure pipes including potable water mains. Because the maximum diameter reduction and hence insertion clearance is limited by the properties of the material, these processes are not commonly used in sewers, which may have displaced joints or other dimensional irregularities. A material with a higher flexural modulus than polyethylene liners is also preferable for gravity pipes with high external loading.

An alternative technique utilises a fusible form of uPVC pressure pipe with a standard OD some 10 to 20% smaller than the host pipe ID. After fusion welding into long strings and insertion the liner is expanded by heat and pressure to a Close Fit. During the expansion process molecular orientation occurs which increases the hoop tensile strength and hence pressure capability of the liner. In principle the system offers a Class A lining at significantly lower wall thickness than PE based systems.

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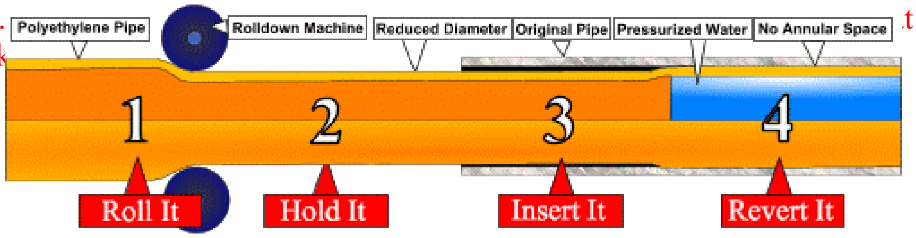
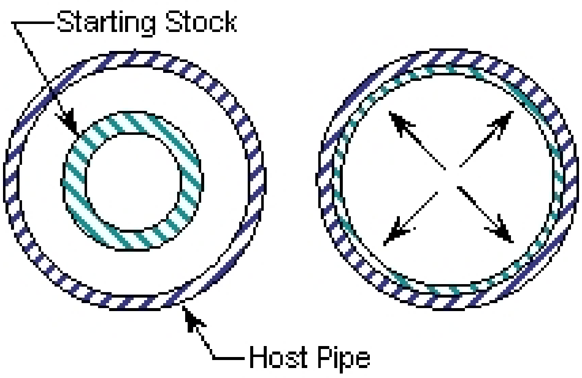


Photo courtesy of Subterra

Machine for simultaneously reducing the diameter of a PE pipe and inserting it into the host pipeline



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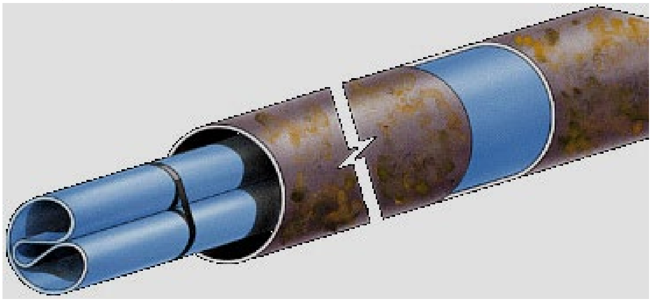
4. FOLD AND FORM PROCESSES

Folded liners are sometimes known as 'Fold and Formed pipe' liners (FFP), and most involve forming the liner pipe into a 'U' or 'C' shape prior to installation. As with symmetrical reduction systems the principle of fold and form liners is to reduce the effective size of the liner during insertion, and then to revert it to its original shape to produce a Close Fit within the host pipe. Folded liners are available for both pressure and gravity pipelines. Polyethylene is generally used for pressure applications, whilst uPVC and PVC alloy folded liners are available for gravity pipes.

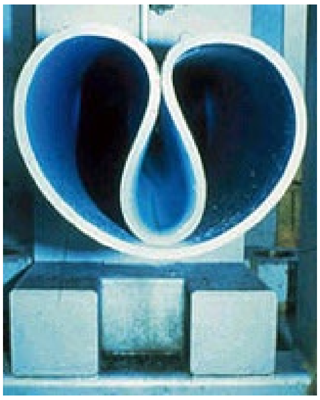
In some systems, the liner is folded in the factory and delivered to site in coils. It is then winched into the host pipe. PE liners, especially thin-walled ones, may be reverted by pressure alone, but PVC liners require heating.



Factory folded Polyethylene Lining System

In other systems, PE liners are folded on site as part of the insertion process using a forming machine. The technique uses standard PE pipe, which is folded into a ‘U’ or ‘C’ shape for insertion into the host pipe.

The shape is retained by temporary straps that break when the installed liner is pressurised during the reversion stage. The liner can be installed in long lengths (over 1,000 m), and around bends subject to pipe diameter and other factors.



PVC based liners are often pre-heated before insertion to increase flexibility, and, once in place, are heated internally to create a uniform temperature throughout the material. Reversion can be achieved progressively by inserting a rounding device into the upstream end of the liner, which is propelled by steam pressure to the downstream end. As the device progresses it expands the liner against the wall of the host pipe, and also forces out any liquids between the liner and the pipe. When flexible, the liner moulds to the shape of the host pipe, and usually forms dimples at lateral connections. Pressure is maintained while the liner cools to a rigid state, after which the ends are trimmed and laterals reopened. A typical installation takes approximately five hours. It should be noted that the cooling effects of groundwater infiltration may adversely affect the ability of the liner to reform to the shape of the host pipe, and the use of an alternative technique may be desirable under such circumstances.

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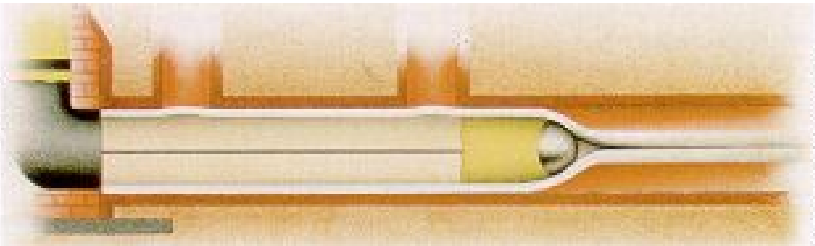
Photo courtesy of Insituform Technologies

Folded PVC liner for sewer renovation, showing close fit after reversion

Factory folded PVC liners are available in diameters from 100 to 350 mm, and are made from a type of PVC alloy that is modified to accommodate the folding and reforming process. The degree of modification varies greatly between different products - some have a relatively high flexural modulus of between 2,000 and 2,500 MPa, whilst other highly modified compounds attain values of only 900 to 1,100 MPa, a figure similar to polyethylene. This must be taken into account in the structural design of the liner.



The folded PVC liner is expanded using a rounding device propelled through the pipe

Diagram courtesy of Insituform Technologies

Close-fit renovation of small diameter pipelines with a pressure-rated polyethylene replacement can be achieved using cross-linked polyethylene (PE-X) whose properties include shape memory. This allows pipes to be extruded at a given diameter and subsequently reduced in size by about 25%, the product then being coiled into long lengths for delivery to site. The size reduction allows the negotiation of constrictions and offset joints. Once inserted, the pipe is heated using a hot air tool, which activates the shape memory of the material and causes it to revert to the size at which it was extruded. The liner pipe expands to achieve a close fit, moulding itself to any intrusions and joints. If, prior to reversion, the host pipe is broken out at the position of branch connections, the new pipe expands to the correct dimensions for the use of standard Electrofusion fittings.

A water main relining system is available which comprises a circular woven polyester jacket encapsulated in polyethylene. This flexible hose is hot folded in the factory into a tight 'C' shape and wound onto a drum. On site the liner is pulled into the host pipe and inflated using low pressure steam. The process produces a thin walled liner which can have an unsupported fifty-year burst strength of up to 23 bar depending on diameter. The system is currently available in the size range 70 to 200 mm, and lengths of up to 200 m can be installed in one operation. The system can be used to line through bends.

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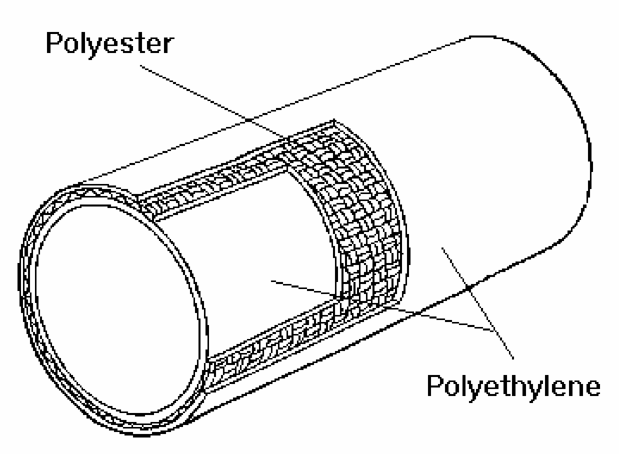

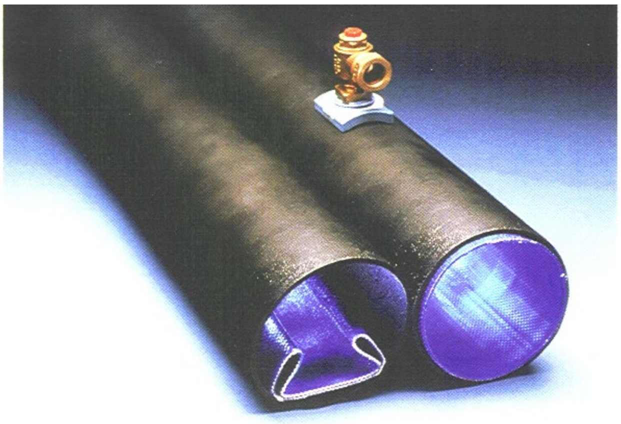

Polyester reinforced polyethylene

A similar process uses circular woven Aramid fibre as a reinforcement for polyethylene. The product is brought to site as a flattened hose on a drum containing up to 4,500 m of liner depending on diameter. The hose is pulled into the host pipe at up to 400m/min and special end fittings attached. When the service pressure is applied the liner expands until it contacts the pipe wall. The system is fully structural up to 40 bar in the diameter range 150 mm to 500 mm.

Aramid Fibre Reinforced Polyethylene Lining System

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Two techniques for relining small diameter (12 to 18 mm) water service pipes are aimed at leakage control and the avoidance of contamination from lead pipes. In the first, a folded polyethylene film liner is wound on a reel contained within a pressure vessel. The motive force is created by air pressure acting on a small flexible 'bullet' fastened to the end of the liner. Air from an oil-free compressor is released into the pressure vessel, driving the bullet into the pipe and carrying the liner behind it. The liner is then inflated with compressed air and held in place with standard plumbing fittings, allowing the water supply to be reinstated quickly. The second involves the insertion of an undersized, extruded polyester (PET) tube, which is expanded with steam pressure and secured in place with standard plumbing fittings.

Formed in Place Thermoplastic Liners

Currently undergoing tests at the time of writing (March 2009) this technique seeks to combine the installation benefits of CIPP technology with the performance advantages of Thermoplastic lining. The lining material arrives on site as a mixture of glass fibres (for stiffness and strength) and thermoplastic fibres that during processing becomes the matrix that surrounds the reinforcing fibres.

During installation hot pressurised air applied via a PIG device melts the matrix polymer and then an inversion bag is used to create a thin tube of the combined reinforcing fibre/polymer composite forming a close fit lining to the host pipe. Variants suited to both gravity and pressure pipes in diameters up to 250 mm are under commercial development.

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5. APPLICATIONS

Sewers	Yes	(see note A)
Gas pipelines	Yes	
Potable water pipelines	Yes	(see note B)
Chemical/ industrial pipelines	Yes	(see note H)
Straight pipelines	Yes	
Pipelines with bends	Yes	(see note C)
Circular pipes	Yes	
Non-circular pipes	?	(see note D)
Pipelines with varying cross-section	?	(see note E)
Pipelines with lateral connections	?	(see note F)
Pipelines with deformation	?	(see note E)
Pressure pipelines	Yes	
Man-entry pipelines	Yes	(see note G)

Notes:

A. There are proprietary systems aimed specifically at the renovation of sewers, using folded liners which are then reverted (or spirally wound liners whose diameter is increased after insertion – see later). Swage lining techniques are not, however, generally suitable for sewers.

B. Approval of the relevant regulatory body is needed for all materials in contact with potable water.

C. All bends add to the friction between the old and new pipes during installation, and so reduce the length of liner that can be pulled in without overstressing the pipe.

D. Folded liners may be able to conform to some non-circular profiles when reverted. Swaged liners are intended for circular pipes.

E. Swaged and folded liners are not able to accommodate significant variations in host pipe perimeter, but expanded, spirally wound liners may be suitable. Folded liners can sometimes be used in pipes that have become deformed.

F. Subject to pipe diameter, internal reconnection may be possible using robotic equipment, although for pressure pipes it is more common to excavate.

G. Some close-fit lining systems are intended for use in large diameter pipelines (including man-entry pipes), whilst others are aimed principally at the smaller sizes.

H. Subject to the liner material being compatible with the chemicals.

6. SUMMARY

1. Reduced diameter (swaged) liners are suitable for the structural relining of gas and water mains, producing a close-fit liner within the host pipe. They may not be suitable for pipes with severe joint displacements or dimensional irregularities.

2. Folded PE liners offer an effective means of installing close-fit structural or non-structural liner within a pressure or gravity pipe. The properties of thin-walled polyethylene are not ideal for structurally unsound pipelines with high external loads.

3. Folded PVC liners are suitable for gravity pipelines up to 350 mm diameter, and offer good chemical resistance and relatively short installation times. High groundwater tables and infiltration can impair the installation process.

4. Folded polyester and Aramid fibre-reinforced PE liners are for use in water main renovation, and are sufficiently flexible during installation to negotiate bends.

5. Small-bore folded PE membrane liners or expendable polyester liners can be used for leakage control in water services and to prevent contamination from lead pipes.

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1. OVERVIEW

Spirally wound lining processes include methods whereby a pipe or liner is formed in-situ by helically winding a uPVC strip into a pipe form within a host pipe, normally from an existing access or manhole, This reduces or eliminates the need for a lead-in trench. To increase its stiffness, the strip 'joint' is ribbed with 'T-beams' on what becomes the outer surface of the new lining. In some systems the edges of the strip lock together to form a watertight seal, whilst in others a separate sealing strip is used to join together the adjacent turns of the helix. To strengthen the liner further some systems offer a steel banding addition to the jointing for additional ring stiffness.

Spiral wound lining can be viewed from two different viewpoints within the renovation technology sector. First it can be viewed as a SLIPLINING technique where the spiral liner is installed into a pipe and the annulus between it and the host pipe is grouted to complete the lining. An alternative installation system allows the liner to be expanded once inserted to form a Close Fit Lining.

There are also two methods of installation that can be employed. One utilises a winding machine to form the liner shape within the host pipe, the other is to form the liner manually using a man-entry operation within the host pipe. The former is generally used for 'smaller' diameter pipelines, although the winding rigs can operate up to what might be considered man-entry sizes. The mechanically wound systems offer diameter ranges from 150 mm up to 1,800 mm. The manually constructed liners tend to be applicable to generally larger diameter pipe sizes from 1,200 mm to 3,600 mm diameter.

Another recent development uses a profiled HDPE strip instead of uPVC. After winding, the junction between adjacent strips is heat fusion welded to ensure a high strength water tight joint. The profile incorporates a steel reinforcing strip as an inclusive part of the PE extrusion process.

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2. MECHANICALLY WOUND SLIPLINING

Often known as spirally wound lining, the tube is formed by a hydraulically driven winding machine which is normally positioned in a manhole or small access excavation. The lead end of the tube travels down the host pipe as further turns of the helix are added. Since the whole tube is rotating during installation, a limiting factor can be the friction and weight of liner that the winding machine is capable of turning. Flotation may be used to reduce the load.

Photo courtesy of Subterra

Production of a spirally wound liner, showing the tube emerging from the winding machine

An alternative spirally wound technique uses a winding machine that travels through the host pipe as it creates the tube, thereby removing the need to rotate the liner itself. By using a winding cage shaped to suit the host pipe, non-circular sections can be lined, including ovoid, egg-shaped and rectangular.

After installation of the tube, annulus grouting is carried out in the same way as for sliplining with other pipe materials, and the outer ribs provide a mechanical key between the liner and the grout.

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3. MANUALLY WOUND LINING

Manually wound liners comprise a similar material to that used in mechanically wound systems but are designed for easier construction at larger diameters from within the host pipe.

Manually wound spiral lining.
Picture courtesy of Danby International Ltd

The PVC strip is fed into the man-entry sized pipeline from the surface along with the required joint sealing strip. Operators in the pipe form the liner to the diameter and shape required by hand, inserting the spiral jointing strip as they progress. The advantage of this system is that many abnormalities in the host pipe shape can be allowed for during construction, minimising the grouting necessary to lock the new liner into the host pipe.

Normally, the lengths of host pipe can be lined and grouted in a single shift. Alternatively, a section of pipeline may be partially completed to the stage before grouting. This then allows several sections of to be grouted in a single operation.

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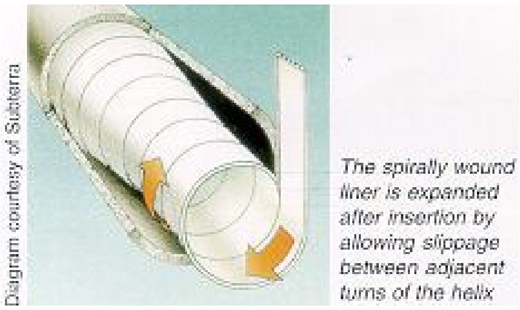
4. MECHANICALLY WOUND CLOSE FIT LINING

Some versions of the spirally wound lining technique, used for gravity pipelines, offer the facility to expand the installed liner to provide a close fit within the host pipe. During installation, the joint between adjacent turns of the helix is prevented from slipping by a locking wire. Once the liner is in position over the whole host pipe length, the winding machine continues to operate, and the locking wire is pulled back progressively to allow the joint to slip and the helix to increase in diameter.



As with the standard form of spiral liners, low flows in the pipeline can be accommodated during installation without the use of over pumping or diversion. Since there is no grouting, groundwater may enter manholes by following the path between the outer T-beams. It is therefore essential to provide a good seal between the liner and the host pipe at chambers. Sealing must also be carried out at any lateral connections.

The structural properties of the liner are governed by the need to wind the PVC strip into a helix, and spirally wound liners may not be able to resist high external loads.

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5. SUMMARY

1. Three varieties of spiral lining are available: Machine wound Sliplined, Machine wound Close Fit and manually fitted.
2. Mechanically wound diameter ranges available from 150 mm up to 1,800 mm, using a shaft based or in-pipe winding machine.
3. Manually wound/installed diameter ranges available from 1,200 mm to 3,600 mm diameter.

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4. Some systems are capable of being used in low flow situations without over pumping of existing flows.
5. Spiral wound lining comprises a method whereby a pipe or liner is formed in-situ by helically winding a uPVC strip into a pipe form within a host pipe normally from an existing access or manhole. A new PE version has recently become available.

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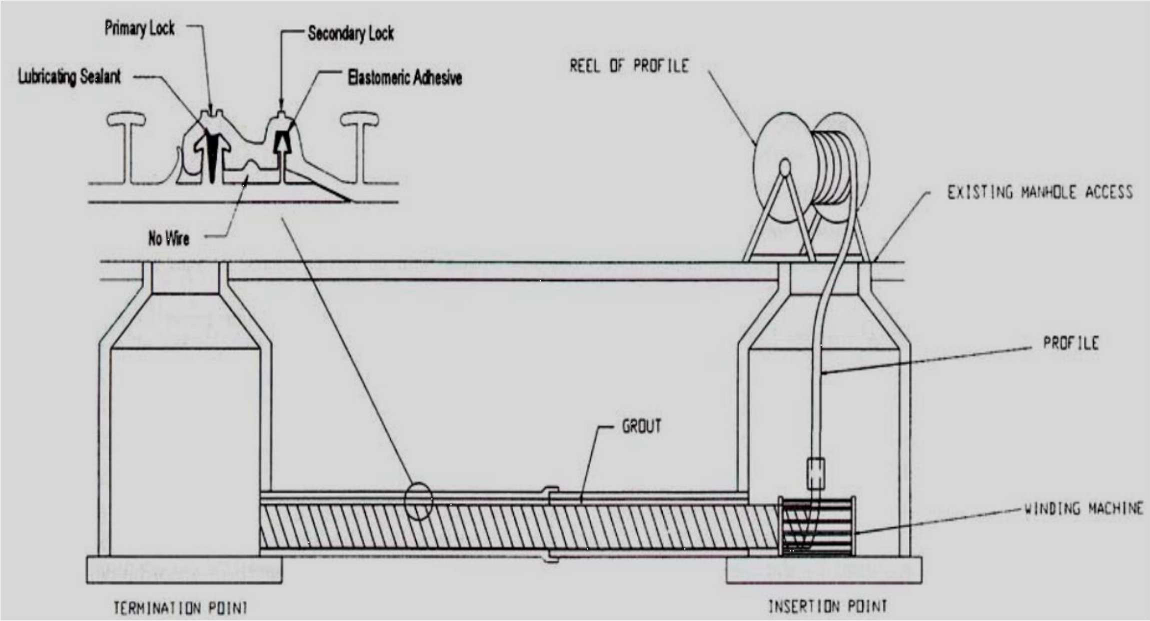
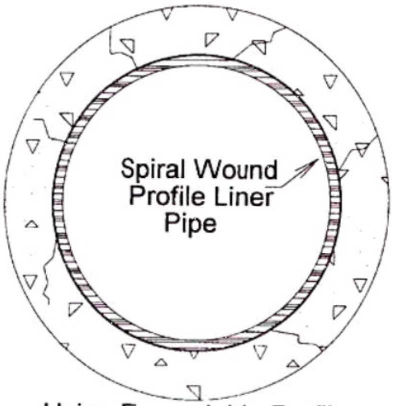
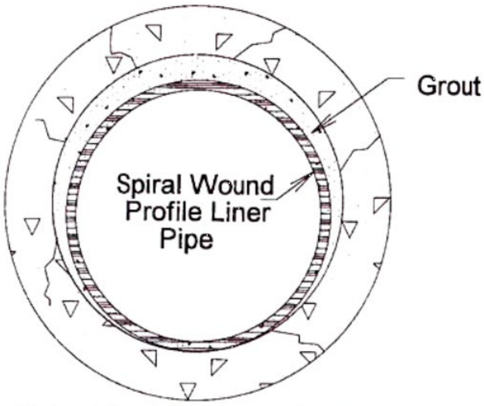




Using Expandable Profile Liner Pipe Pressed Against Existing Pipe Wall



Using Fixed Diameter Profile Annular Space Filled With Grout

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<tr><td>SECTIONAL LINERS</td><td>LAST UPDATED MARCH 2009</td></tr>
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1. OVERVIEW

Sectional Lining involves the lining of man-entry sized pipes by the insertion of pre-formed liners, either whole or in sections for assembly in-situ.

2. APPLICATION ENVELOPE

Usually applied in gravity sewer situations, liner sections are available from minimum man-entry sizes, the size of which depends largely on the country in which the liner is to be applied and its local regulations. However generally sizes between 825 and 6,400 mm have been available with liner section thicknesses from 10 to 30 mm. Section lengths are nominally between 0.5 and 1.5 m for installation in all shapes of pipe and may be WRc Type I or II Liners.

These dimensions are, in many cases, simply examples of what is available as some manufacturers manufacture to client order to whatever diameter, shape, length and joint arrangement required, including length and shape variations to accommodate pipeline bends and anomalies. Sectional liners can also be designed for lining pumping mains.

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3. INSTALLED LINER MATERIAL

Sectional liners are generally constructed of GRC (glass-reinforced concrete), GRP (glass-reinforced plastic) or RPM (reinforced polymer matrix). Sectional liners are generally installed and connected along the length of a pipeline. They are then grouted in-situ, filling the annulus between liner and host pipe to complete the lining process. The option also exists to utilise a combination of in-situ applied Gunite or Shotcrete and prefabricated invert units under the right circumstances.

The sections themselves may also be sub-divided, depending on the liners ultimate sizes and pipeline access circumstances with a liner being divided horizontally or vertically in further sections for ease of transport. Sections may be invert and/or left/right side sections or combinations thereof.

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4. EQUIPMENT

A significant amount of equipment is required to complete a sectional lining operation including segment lifting and delivery equipment (both surface and in-pipe requirements), grout mixing and injection equipment or gunite/shotcrete spraying equipment, pipeline plugs and confined spaces/safety apparatus. This also means that operators in the pipe will need to be fully trained not only in the construction of the liner but also to confined space working certification according to local regulations.

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5. ACCESS REQUIREMENTS
A sectional lining operation will also need good logistical management for site storage for materials, working space for delivery apparatus and mixing stations, well managed site access in many instances all requiring a generally small footprint.

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6. LINER PERFORMANCE
Liners can be designed to withstand external and internal water pressures, chemical attack, soil and traffic loads. However, overall performance and durability have a significant dependency on the level of workmanship of the installation of the liner both of the liner itself and its grouting. The fact that the liner is a form of sliplining will lead to some loss of hydraulic capacity.

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7. CONNECTIONS & FITTINGS
As with all lining technologies, lateral connections will have to be remade once the main lining is completed. This may be achieved using prefabricated or in-situ fabricated joint connections and seals. They can also usually be installed without the need for open cut working from inside the now lined pipe.

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8. BENDS
As previously mentioned bends can be accommodated during the section fabrication process by most manufacturers using prefabricated bend designs. This does however rely on a very accurate pipeline survey work in the planning stage to ensure the bend characteristics are well established. Large radius bends may also utilise some form of flexibility in the section jointing mechanism to accommodate the directional change.

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9. TIMESCALES
Construction can be slow depending on the size of the liner sections, the ease of placement and the grouting system requirements. Normally work rates are viewed in m/day rather then 10s or hundreds of m/day.

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10. STANDARDS & SPECIFICATIONS

WRc has issued a range of WIS and Information and Guidance Notes for Sectional Liners.

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11. SOCIAL & ENVIRONMENTAL IMPACT

There is nominally some impact on the local environment associated with the duration of these projects, but properly managed this can be minimised.

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12. HEALTH & SAFETY ISSUES

Confined spaces considerations and security of pipe plugs sealing off working sections from on-line sections are critical issues with manpower being in the sewer under rehabilitation for long periods of time. Pipe segment storage and lifting, use of chemicals and traffic management are also important.

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13. LIMITATIONS

Sectional lining is only practical for man entry pipe sizes. As mentioned there is always some loss of hydraulic capability, which needs to be accounted for by planners against projected future capacity requirements. The level of workmanship required for a successful installation of sectional liners would also require relatively high levels of supervision.

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14. COST CATEGORY

>CIPP in man entry sizes.

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15. SELECTION INDICATORS

The Sectional lining option would generally be chosen for large diameter sewers rehabilitation. Flow through construction is possible using the technique so minimising over pumping requirements in the right circumstances in terms of Health and Safety.

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16. SUMMARY

1. Generally applied to gravity operations in man-entry sizes only.
2. Generally constructed of GRC (glass-reinforced concrete), GRP (glass-reinforced plastic) or RPM (reinforced polymer matrix) materials.
3. Can be equipment and time intensive due to the multi-stage installation process.
4. Liners can be designed to withstand external and internal water pressures, chemical attack, soil and traffic loads.
5. Loss of hydraulic capacity due to the nature of the construction process.
6. Cost greater than for CIPP lining in man-entry sizes.

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<tr><td>TRENCHLESS TECHNOLOGY OVERVIEWS</td><td>THIRD EDITION</td></tr>
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DEFINITION

Current European Standards (e.g. EN 13689:2002) define “RENOVATION” as work incorporating all or part of the original fabric of the pipeline by means of which its current performance is improved. This section on Pipeline Renovation technologies includes all processes used to renovate a pipeline over manhole-to-manhole lengths or greater, by installation of a lining in the existing pipe. For convenience this section includes conventional sliplining although, unless grouted, the liner acts independently and does not incorporate any of the original pipeline fabric. On this basis it could be included in the “On Line” replacement technologies discussed in section 4 of these guidelines.

The full ISTT TRENCHLESS Resource Centre Guidelines for each of the techniques featured below can be accessed by clicking the More> links in this summary.

This group of processes includes the following technologies:

a. Introduction – Liner Design; Service Connections & Laterals and Liner termination, bends, valves and other obstructions More>
b. In-situ Applied Coatings More>
c. CIPP Lining More>
d. Sliplining More>
e. Close Fit Thermoplastic Linings More>
f. Spiral Wound linings More>
g. Sectional Liners More>

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1. **INTRODUCTION**

Before considering the individual technologies in detail it is useful to discuss some issues common to all the processes. These include:

a) Liner Design, Material Properties and Design strengths
b) Service Connections and Laterals
c) Liner termination, bends, valves, and other obstructions

A) LINER DESIGN, MATERIAL PROPERTIES, AND DESIGN STRENGTHS

In general the design of a lining system for any given application involves the following three distinct steps:

a) Assessment of the deficiencies of current performance of the existing pipeline;
b) Selection of a lining technique and material capable of rectifying these deficiencies;
c) Determination of the amount of lining material (expressed as wall thickness or SDR) needed to secure acceptable performance of the renovated pipeline for a specified extended design life. The earliest design concepts for liner pipes tended to take the suitability of a chosen renovation technique as read, and focussed exclusively on steps a) and c). Thus for example in ASTM F1216 (originally published in 1989) different formulae for liner wall thickness to resist both external and internal loading are associated simply with defined states of deterioration of the host pipe.

Typical loads on buried pipelines include a selection of the following:

Load Type	Cause	Mode Of Failure	Stress In Liner	Key Liner Design Parameters
External	Vertical Loads Due To Backfill	Longitudinal Fracture At Crown And Springings	Load Carried By Host Pipe	None
	Vertical Loads Due Traffic	Longitudinal Fracture At Crown And Springings	Load Carried By Host Pipe	None
	Hydrostatic Loads Due To Ground Water Pressure	Ring Buckling	Load Carried By Liner	Flexural Strength And Modulus
	Shear Loads	Circumferential Fracture	Load Carried By Host Until It Fails Then Transferred To Liner	Shear Strength
	Longitudinal Flexure Due To Uneven Bedding	Beam Failure Circumferential Fracture	Load Carried By Host Until Failure Then By Liner At Fracture Location	Longitudinal Flexural Strength And Modulus
	Longitudinal Tension/ Compression	Circumferential Fracture	Minimal	Longitudinal Tensile And Compressive Strengths And Modulii
	Thermal Loads	Circumferential Fracture	Loads Due To Differences In Cofficients Of Thermal Expansion Between Host And Liner	Expansion Coefficient
Internal	Pressure Of Gas Or Liquid Conveyed	Longitudinal (Burst) Failure	Radial Circumferential Tension	Circumferential Tensile Strength And Modulus
	Vacuum Loads Cyclic Loads	Equivalent To External Hydrostatic Loads	Loads Carried By Liner	Flexural Strength And Modulus

Most of the liner systems used are a close fit to the host pipe and loads are shared between the liner and the host pipe in proportion to their relative elastic stiffness. The

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liners are therefore termed interactive and form a structural composite with the host. However due to the lower thickness and elastic modulus of plastic based liners relative to the host pipe the majority of the loads are carried by the host pipe

GRAVITY PIPE LINER DESIGN

Lined gravity pipes are subject to the external loads listed in the table above. In current USA design practice (e.g. ASTM F-1216) the host pipe is classified as either "Fully Deteriorated" or "Partially Deteriorated". In the fully deteriorated case the host pipe is assumed to be incapable of carrying any of the external imposed loads and hence the liner is designed to support all of these without assistance from the host pipe. In the partially deteriorated case the host pipe is assumed to be capable of carrying earth and traffic loads while the liner carries external hydrostatic loads due to groundwater. It is now widely accepted that the fully deteriorated condition hardly ever occurs in practice and most international standards now design in accordance with the partially deteriorated assumptions.

When subject to external hydrostatic loads the liner eventually fails by elastic buckling. The load to cause failure is a function of liner thickness, flexural modulus, and the degree of side support offered by the host pipe. Well established design formulae are available to incorporate these parameters together with variables such as ovality and annular gaps between liner and host pipe. The flexural modulus value used should be appropriate to long term (50 year) loading.

2. CLASSIFICATION AND DESIGN OF PRESSURE PIPE LINERS

The key to demystifying the subject is a clear understanding of the primary interaction between a flexible liner and its relatively rigid host when subject to internal pressure. The authors have contributed over the years to two simple classification concepts that provide the basis for detailed, technique family specific, analysis.

The first is the simple "independent" vs. "interactive" classification adopted in current European renovation product standards and illustrated in Figure 1.

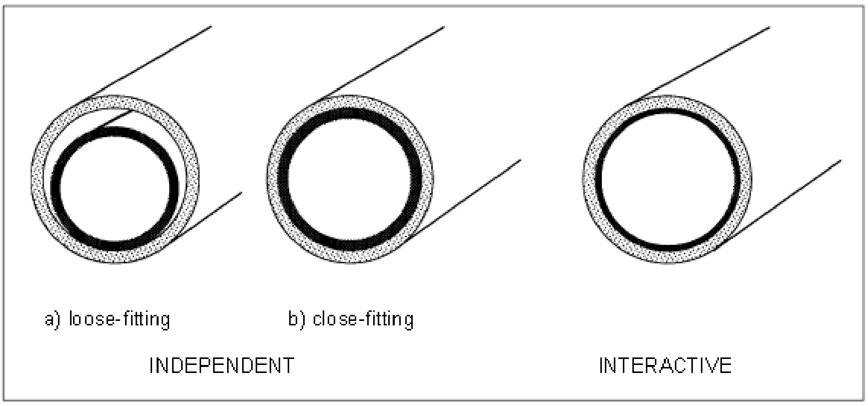

Figure 1. Structural classification of pressure pipe liners according to EN 13689:2002

It is important to note that in EN 13689 these adjectives are not defined in isolation but incorporated in the following compound terms:

1. Independent pressure pipe liner: Liner capable on its own of resisting without failure all applicable internal loads throughout its design life.

2. Interactive pressure pipe liner: Liner which relies on the existing pipeline for some measure of radial support in order to resist without failure all applicable internal loads throughout its design life.

These terms define two basic levels of structural capability of pressure pipe liners. While requiring radial support to withstand the full internal pressure long-term, *interactive* liner pipes can nevertheless bridge holes and joint gaps and are well established as a solution for sealing or preventing development of leaks in pipelines that are otherwise structurally sound.

Independent pressure pipe liners, on the other hand, while capable of resisting the long-term internal pressure on their own, in practice do so only where the liner is *loose-fitting* (a). In the case of a *close-fitting* liner (b), there will generally be significant interaction with the host pipe, resulting in transfer of most or all of the internal pressure stress to the host pipe until the latter fails. This is because plastics liner pipe materials (e.g. polyethylene) are very much less stiff than typical host pipe materials (e.g. cast iron, steel or concrete).

In the second system of classification, adopted by the American Water Works Association in the 2nd edition of its Manual M28 (2001), the primary distinction is between liners defined as “Non-Structural”, “Semi-Structural” and “Fully Structural”. In fact four classes in total are defined, because the “Semi-Structural” category, broadly corresponding to the “interactive” classification of CEN, is subdivided according to whether the liner has inherent ring stiffness or relies on adhesion to the host to prevent collapse when the pipeline is depressurised.

These two existing published systems of structural classification are summarised and combined into a new universal system proposed by the authors in Figure 2.

<table>
<tr><td rowspan="2">CEN</td><td colspan="2">INDEPENDENT</td><td colspan="2">INTERACTIVE</td><td>-</td></tr>
<tr><td>Loose-fitting</td><td colspan="3">Close-fitting</td><td>-</td></tr>
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<tr><td colspan="2">Class IV</td><td>Class III</td><td>Class II</td><td>Class I</td></tr>
<tr><td>Universal</td><td colspan="2">Class A</td><td>Class B</td><td>Class C</td><td>Class D</td></tr>
</table>

Figure 2. Proposed "universal" pressure pipe liner classification system compared with existing

The defining characteristics of each individual liner class are given in Figure 3.

Liner characteristics	Class A	Class B	Class C	Class D
Can survive internally or externally induced (burst, bending or shear) failure of host pipe	✓	-	-	-
Long-term pressure rating ≥ maximum allowable operating pressure (MAOP)	✓	-	-	-
Inherent ring stiffness 1)	✓	✓	- 2)	- 2)
Long-term hole and gap spanning at MAOP	✓	✓ 3)	✓	-
Provides internal barrier layer 4)	✓	✓	✓	✓

NOTES: 1) minimum requirement is for liner to be self-supporting when pipe is depressurized

2) relies on adhesion to the host pipe to be self-supporting when depressurized

3) becomes sufficiently close-fit for radial transfer of internal pressure stress to host pipe, either during installation or within a short period from initial application of operating pressure

4) serves as barrier to corrosion, abrasion and/or tuberculation/scaling of host pipe, and to contamination of pipe contents by host pipe; also generally reduces surface roughness for improved flowcapacity

Figure 3 Liner characteristics associated with each universal class

The liner characteristics defined by Figure 3 for the universal classes A – D extend the definitions of AWWA classes IV – I in the following important respects:

a) Explicit recognition of longitudinal bending and shear failure modes, induced by external ground movements and/or traffic loads, which a Class A liner is expected to survive in addition to possible burst of the host under transferred internal pressure. Such externally induced failure modes apply especially to small diameter host pipes of brittle materials, such as cast iron of less than 200 mm diameter.

b) Clarification by Note 3 of the implicit requirement that a class B liner not already in close contact with the host pipe after installation must expand sufficiently under the short-term operating pressure to close any residual annular gap. Where this is not the case, as for example may occur when a nominally close-fitting thin-wall/high SDR liner is subject to relatively low service pressures, the liner pipe will be effectively loose-fitting and must be designed as Class A to have adequate independent long-term internal pressure resistance.

It should be re-emphasised that the above classification refers only to the response of the liner pipe to internal pressure in the hoop direction. In pressure liner design it is also generally necessary to consider longitudinal forces, as caused directly by pressurisation and/or due to the residual effects of installation (e.g. unrelieved winching and/or thermal stresses). Furthermore, where pipelines operate at pressures less than the external head of groundwater (as may occur, for example, in low pressure distribution systems), or are subject to periods of depressurisation, negative pressure transients and/or amplitude cycles of pressure (for example sewer force mains), external loads can prove to be the critical determinant of liner wall thickness.

These further liner design aspects are treated in detail elsewhere, and are all characterised by strong interaction between the host pipe and ground.

However the relatively simple matrix depicted by Figs 2 and 3 nevertheless provides a good basis for selection of suitable renovation technologies for most practical pressure lining applications.

In trying to apply the design principles summarised in the first part of this paper the potential user of a renovation solution will need to consider the following issues.

For fully structural lining systems (Class A):

a) the extent to which a host pipe containing a fully structural liner can be considered equivalent to a replacement pipe
b) the extent to which the structural capability of the liner has been independently verified including consideration of the effects of the installation procedures
c) the behaviour of the liner under different types of future host pipe failure

For semi-structural lining systems (Classes B and C):

a) the relevance of calculated hole and gap spanning capabilities to the known condition of the host pipe and likely changes in that condition when lined
b) the probable service life of the renovated line
c) the cost savings from using a semi-structural liner balanced against the higher risk when compared to a fully structural liner or a full replacement

The replacement pipe issue is becoming increasingly important to utilities wishing to account for the value of their buried assets and expenditure on rehabilitation in accordance with the protocols of funding providers and regulators. There is no universally accepted understanding of the term “equivalent to a replacement pipe”. To the most conservative users it implies that the installed liner can meet all the design requirements of a direct buried pipe without support from the host. For the reasons discussed above however, this concept does not reflect the reality of liner behaviour and if applied in practice tends to be unnecessarily restrictive.

The purpose of rehabilitation by structural renovation is to restore and preserve the functionality of an existing pipe line over an acceptable design life based on reasonable assumptions related to the future degradation and structural failure mode of the original pipe.

By definition a fully structural (Class A) liner shall be capable of surviving any dynamic stresses associated with future structural failure of the host pipe and should then continue to carry the internal pressure loads over the remaining design life. The latter capability is verified by third party long term testing appropriate to the liner material. The former could be demonstrated by tests but at present it is a matter of engineering judgment. Most users readily accept that liners which are not bonded to the host, such as close-fit polyethylene, will survive the failure event, but liners which are or could be bonded may not and tests may be required.

The other key considerations are external loads and vacuum and an additional criterion for “replacement pipe” status may be the ability to support defined soil, traffic and hydrostatic loads before and after host pipe failure. In practice external loading will only be a significant factor when the pipe is depressurised and in view of the strong dependence of the flexural properties and hence liner thickness on the assumed loading time it is important to make realistic assumptions on the maximum depressurisation time. Use of an overly conservative view will result in excessive liner design thickness leading to higher cost, flow reduction and installation problems.

For semi-structural renovation systems the design process involves calculation of the maximum dimensions of holes and gaps which can be spanned by the liner on a long term basis at the operating pressure. Such phenomena should however be adequately covered by testing – for any given lining system.

MATERIAL PROPERTIES AND DESIGN STRENGTHS

The design process described above is based on the determination of design values for the key material properties such as Flexural Strength and Modulus and Tensile Strength and Modulus. These Design Values can be related to the Measured Mechanical Properties by a series of Reduction/Safety Factors. These Factors include the following:

F= Long Term Creep Factor to allow for Time Dependence of Mechanical Properties, typically 0.3 to 0.4

Fv= Material Variability Factor to allow for Inherent Material Variability

Fs= Scale Factor to allow for the Reduction in Strength Associated with the difference in Loaded Volume between Small Laboratory Test Samples and the Installed Liner

Fm= Fabrication Factor to allow for Increase in Variability Associated with Site Fabrication compared to laboratory or factory fabrication

Fd= Design Factor to allow for Uncertainty in Applied Loads

The Long Term Creep Factor is normally determined by measuring the Time to Failure of samples loaded at different proportions of the Short Term Failure Load. It is normal to conduct Tests to 10,000 hours, and then extrapolate results to 50 Years.

The product of these factors can range from 3 to 8 or more and since this total factor has a major impact on liner thickness and hence costs potential users of the system should seek evidence from third party tests to verify the validity of the stated design values.

B) SERVICE CONNECTIONS AND LATERALS

All close fit lining systems except the thinnest class D in-situ coating systems will cover and block service connections and laterals associated with the pipe to be lined. These must be reinstated after lining before the pipe can be returned to service and this process can significantly affect the final performance of the lined pipe and the productivity, level of disruption and cost effectiveness of the lining technology.

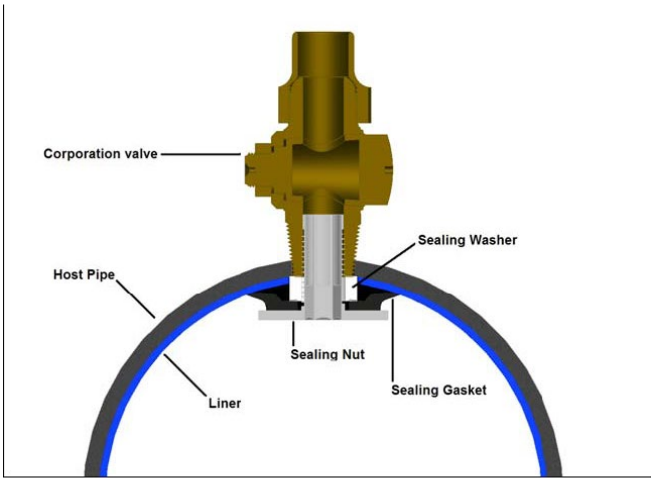
In the case of gravity pipes such as sanitary and storm sewers the most common connections involve lateral pipes in the diameter range 75 mm to 200 mm entering collector lines in the range 150 mm to 600 mm. The longitudinal and radial location of such connections can be observed and recorded during a pre lining CCTV survey. After lining the covered connections are reopened with a robotic cutter operated by a skilled technician using a CCTV image to position the cutter. In the case of CIPP and some types of thermoplastic lining this procedure is aided by visible depressions in the liner surface which are formed at the connection during liner installation. It is important to fully open the connection to avoid any residual liner protrusions which could subsequently block the lateral and most users have specific performance standards for this process. Users are also becoming increasingly concerned over the possibility of leakage of water into any annulus between liner and pipe at the cut edge of the liner. This is further discussed in detail in the CIPP and Close Fit Thermoplastic Guidelines.

An additional concern with some types of thermoplastic liner is thermally induced longitudinal movement of the liner after installation. If laterals are reinstated before this occurs the liner may move to fully or partially cover the connection. This is normally accommodated by postponing lateral reinstatement for 12 to 24 hours to allow all movements to occur.

In the case of Pressure Pipes such as water and gas mains the most common connections involve supply pipes in the size range 12 mm to 50 mm diameter exiting from distribution pipes in the diameter range 100 mm to 300 mm. Such connections are normally made via a mechanical fitting which is screwed into the distribution pipe and frequently protrudes into the body of the pipe. Although these can be located via CCTV in a similar manner to sewer laterals they are much more difficult to reinstate from within the lined pipe. Cutting a hole in the liner at the connection location will allow water or gas under pressure to enter the annulus between the liner and the pipe wall and hence cause leakage. Until recently the only available solution was to excavate a hole at the connection location prior to lining and remove the existing fitting. After lining a hole is drilled in the liner from the outside and a special fitting used to reinstate the connection and seal the annulus. In water and gas mains such service connections may occur every 10 metres and the need for local excavations at this frequency greatly increases the cost and disruption associated with the lining technology. Although these costs can be reduced by using technologies such as vacuum excavation the lack of a remote reinstatement method has inhibited the more widespread use of the lining technologies for such pipes.

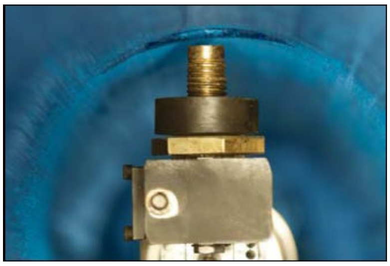
More recently two solutions to this problem have been developed. One is suitable for CIPP lining systems and involves lining over the connection and ensuring there is sufficient excess resin between the liner and the pipe wall to seal the annulus The connection is then re-opened by cutting a hole from the inside with a remote cutter. This technique has been used for the renovation of deeply buried water mains in Canada and the Northern USA.

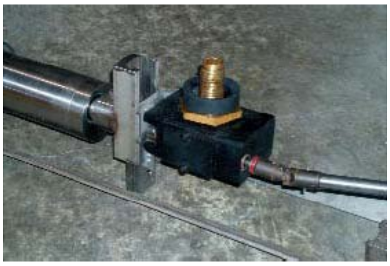
Another and more widely applicable solution utilises a mechanical sealing apparatus, referred to as a sealing nut and sealing gasket, which is screwed into the internal bore of a typical corporation valve (see Fig. 3). The rubber gasket on the sealing apparatus provides a water tight seal between the gasket and the liner. The sealing apparatus consists of brass or stainless sealing nut and an EPDM sealing gasket, all acceptable for drinking water contact. A secondary sealing washer is provided within the rubber sealing gasket to provide a seal between the sealing nut and the corporation valve. A secondary gasket is needed as the sealing nut is commonly installed with a self-tapping thread. An alternative method of installation involves pre-tapping the corporation valve, allowing for a standard tapered threaded sealing nut which may be screwed into the corporation valve.



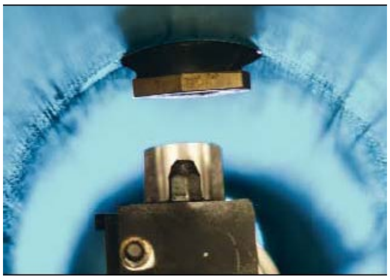
Left – Diagram of service connection reinstatement system.
Below – Milling of corporation valve protrusion in a water main.

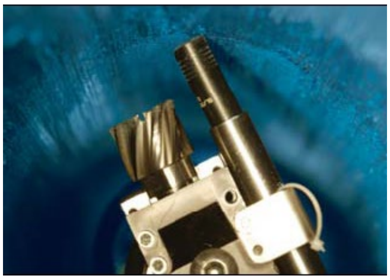
The process of installing a 'Corporation Valve' into a pressure main





A Sealing installer device





Far Left – Installation of sealing nut and gasket

Left – Connection locator and cutter

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Prior to lining the pipe is inspected using CCTV to identify the locations of the service connections. At the same time, a robotic cutter enters with the CCTV camera and is used to mill off any protruding service connections. This ensures proper location of the service after lining, and avoids interference with the installation process when a close fit PE lining solution is being used. During the entire process of CCTV inspection and milling, a data log of the location of each connection. In addition, indicator marks are placed on the CCTV coaxial cable to provide a second indicator mark for future reference.

After installation of the liner a robot equipped with a camera, cutter, and eddy current Location system is used to reopen all the connections. A second robot is then used to Insert and screw the sealing nut device into the exposed fittings and thereby complete the Reinstatement of the connections.

C) LINER TERMINATIONS, BENDS, VALVES AND OTHER IN LINE OBSTRUCTIONS

It is necessary to terminate liners in the following situations:

a) At manholes and liner entry and exit pits
b) On either side of major branches, valves etc
c) On either side of vertical or horizontal bends which the lining system is unable to negotiate

The termination must seal the annulus between the liner and the host pipe and sustain any Longitudinal loads caused by internal pressure or thermal movement.

There are two main types of termination:

a) Internal – The liner is terminated before the end of the pipe and sealed and secured with an internal expanding Clamp ring. In some cases an internal protruding circumferential ridge acts as a mould for the Inserted liner and anchors it against longitudinal movement. The end of the pipe is then fitted with a standard mechanical flange which can be used to attach the lined pipe to an adjacent lined pipe or unlined section or a flanged valve.

Internal connection seal and backing ring (left) and (right) Seal fitted and expanded.

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b) External – The liner is extended beyond the end of the pipe and if necessary expanded and the exposed length incorporated in a mechanical flange adaptor which clamps the liner, seals the annulus and can be used to connect other flanged items as described above. If the liner material is a Thermoplastic, a plastic flange adaptor can be fusion welded to the liner.

External Flange Fittings

Bends

Liner systems differ substantially in their capability to negotiate vertical and horizontal manufactured bends. CIPP systems generally offer the greatest capability although care must be taken to ensure that installation through a bend does not adversely affect the liner strength. Thermoplastic pipes are less capable and the capability decreases with increasing liner thickness. If the bend is severe the liner will be subject to wrinkling on the inside face of the liner.

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	TRENCHLESS TECHNOLOGIES INFORMATION CENTRE	
INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGY GUIDELINES	THIRD EDITION
	INSITU APPLIED COATINGS	LAST UPDATED MARCH 2009

1. OVERVIEW

This Section covers spray lining systems for small diameter (non man-entry) pressure pipelines. Spray lining techniques for man-entry pipes and chambers are covered elsewhere. The technologies involve the application of a generally thin cementitious or thermoset resin coating, either epoxy or Polyurethane (PU), to the inner surface of metallic or asbestos cement pipelines. The function of the coating is to separate the flow stream from the pipe wall and hence eliminate or significantly reduce corrosion and/or flow stream contamination. The cement-based systems create a highly alkaline environment at the coating/pipe interface which passivates the pipe wall and inhibits corrosion. The polymer-based systems create a thin, impermeable protection barrier.

When used on installed pipelines all of these technologies depend on prior thorough cleaning to restore the original bore by removing accumulated corrosion products (Tuberculation). This also creates a surface to which the lining material can bond, a key factor in the future performance of the lining.

When applied as a thin layer (Cement Mortar 3 to 6 mm, Epoxy and PU 1 mm) all three systems are presumed to have minimal effect on the structural integrity of the host pipe or leakage. More recently the developers of the PU based systems have introduced a much thicker lining (3 mm plus) which can be classed as semi-structural and is capable of bridging joint gaps and holes to prevent leakage. The cement-based systems were first used in the 1920's as a factory applied protective coating for new cast and ductile iron and steel pipes. According to W Walsh, a cement-lining contractor in the USA, the extension of this technique to the in-situ lining of buried pipes was accomplished in 1933 by one Carl Perkins, a founder of the company. However there are other claimants to this accolade.

CML (Cement Mortar Lining) has been widely used to rehabilitate water mains in the UK, North America, and parts of Europe. However in the UK, concerns over the performance of CML in soft water and the reduction in flow capacity in pipes of 4 in (100 mm) diameter, and less, prompted the search for an alternative and epoxy lining was born. The end result was the complete replacement of cement mortar lining by epoxy in the UK, but not in the USA and other countries where CML still thrives, particularly for larger pipes, in spite of the availability of epoxy. In the UK, Epoxy lining is now being replaced by Polyurethane, on the basis of its rapid cure capability, which allows the possibility of returning a water main to service within 12 hours. Supporters of this process also claim it offers easier application in larger diameter pipes and the possibility of thicker coatings.

Development work has been carried out on spray lining techniques for non-man-entry sewers, but so far no such method has achieved commercial prominence. This may be partly because of the different requirements of sewer renovation, where the aim is usually to increase the pipe's resistance to external loading rather than to prevent corrosion, and partly because of the practical difficulties of ensuring that inflow to the sewer is completely stopped while the material is being applied and cured. A practical spray-lining system for sewers would avoid the problem of lateral reconnection inherent with most other renovation techniques.

Spray lining is seldom used in gas mains, although in some countries it is used extensively in gas service pipes. This Section concentrates on the application of spray lining to potable water mains, which is the most common worldwide use of the technique.

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2. PREPARATION

Since spray lining is usually intended as a protective coating which may rely on a bond with the existing substrate, thorough preparation of the host pipe is important. Old water mains, particularly those made of cast iron, often have heavy internal deposits of corrosion and scale, which in some cases may reduce the effective bore to a fraction of the original size.

Cleaning techniques include high-pressure water jetting, scraping, pigging, rack-feed borers and mechanically-driven devices such as cutters and chain flails. There is often a balance to be drawn between removing all traces of corrosion and avoiding damage to the pipe wall, and some of the more aggressive techniques should be used with caution.

Pipe scrapers are designed to remove hard deposits and nodules when winched through a pipe, and consist of a number of spring steel blades mounted on a central shaft. A towing eye is fitted to each end of the shaft, allowing the tool to be pulled back if necessary.

Wire brush pigs comprise two circular wire brushes on a central shaft with a towing eye at each end, and are used to remove loose deposits and dust prior to lining. They may also be used to remove debris loosened by a pipe scraper.

Cleaning pigs are available in a wide range of types, and are usually moulded from hard resin with an abrasive outer layer. Some have carbide studs around the barrel to remove hard deposits. They are normally driven through the main by water pressure, and can travel distances of several kilometres in continuous pipelines. In a heavily encrusted pipe, pigging is carried out in stages using pigs of increasing size.

Foam pigs are generally pushed through a pipeline by air or water pressure, but versions are available that can be pulled through with a towing rope. They are generally used to remove dust or fluids from pipes of any material, and are also suitable for line drying.

Some models have transmitter housings for pipeline location and tracing. Foam pigs are often bi-directional and sufficiently flexible to pass through fittings such as bends, valves and branch connections. They may also negotiate reduced pipe diameters and partial obstructions.

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'Pull-throughs' (also known as 'squeegees') remove fine material and fluids from pipes. They consist of two thick rubber discs fitted to a central shaft, which has a towing eye at each end. Foam pigs or pull-throughs are often used as the final stage of the preparation process, to produce a clean, dry surface to which the spray lining material can be applied.

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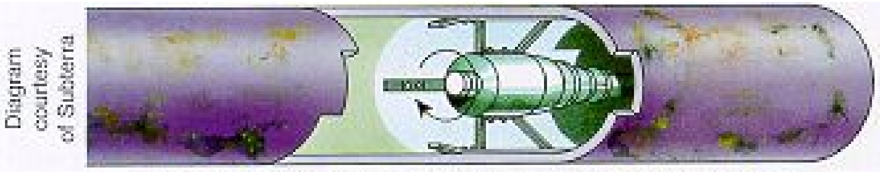
3. CEMENT MORTAR LINING

The application of a cement mortar lining is a common and relatively inexpensive method of water main renovation. The cement mortar serves two main functions - the alkalinity of the cement inhibits corrosion of iron pipe, and the relatively smooth internal surface reduces hydraulic roughness and improves flow characteristics. It should be noted that cement mortar lining is also applied to many new cast iron and ductile iron pipes, also to inhibit corrosion.

The lining does not fulfil a structural function other than to reduce the rate at which the host pipe will deteriorate, so the technique is not appropriate for pipes which leak, or where corrosion has reduced the wall thickness significantly.

As stated above, thorough preparation of the existing pipe is essential. It is also important to apply sufficient thickness of mortar in order to create the alkaline environment at the mortar/iron interface. As with steel reinforcement in concrete structures, inadequate cover to the metal will allow the onset of corrosion, which will cause the mortar to crack and spall.



Application of cement mortar by a rotating-head spray machine

Application is generally carried out by a spraying machine which is either fed through hoses from the surface, or, particularly in larger pipes, may have its own hopper containing pre-mixed mortar. Forward speed control of the machine is important to produce a consistent thickness of mortar. Spray application is followed by trowelling. This may be carried out by rotating spatulas fitted to the spraying machine, or sometimes by a simple tubular shield of the required internal diameter, which is pulled through behind the machine. Whatever system is used, it is essential to centralise the equipment within the host pipe so that the coating is of constant thickness around the whole perimeter.

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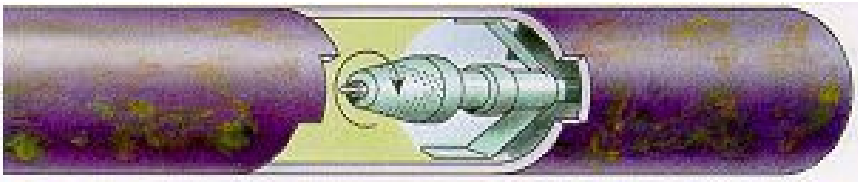
4. EPOXY AND POLYURETHANE LINING

Epoxy and Polyurethane lining may be seen as alternatives to cement mortar lining, with similar function - to provide corrosion protection and a smooth bore. The objective is for the resin to bond with the prepared internal surface of the pipe, forming a coating which prevents water penetration and corrosion. The coatings are generally much thinner than cement mortar linings, and therefore do not cause significant bore reduction. They also cure more quickly than cement-based materials. However, any defect in the coating may allow corrosion to start and, unlike cement mortar, there is no alkalinity to inhibit deterioration chemically. The resins are also relatively expensive compared with cementitious materials.

Resins, which have been approved for the lining of water mains by the relevant National Authority, do not impair the quality of the conveyed water, provided they are mixed properly in the correct ratio and cured correctly. Resin should not be used for lining water pipes unless the particular formulation has been officially accredited for this purpose. National approval bodies are those such as DWI in the UK and NSF in the USA. In the UK these technologies can only be used by approved contractors operating in accordance with published guidelines.



Application of epoxy resin

The resin is applied by a spraying machine, which usually has a high speed rotating nozzle. The thickness of the coating is controlled by the flow rate and the forward speed of the machine. In most systems, the resin base and hardener are fed through separate hoses and are combined by a static mixer just behind the spray nozzle. Ideally, the cure time should be as short as possible to minimise the period during which the main is out of service, and also to reduce the risk of contamination of the resin prior to cure. However, too rapid a cure carries the risk of blocking the static mixer or the nozzle. Unlike with cement mortar lining, the resin is not smoothed or trowelled after spraying, and the surface quality depends on the application technique and the properties of the material.

Various resin formulations are available, including high-build, thixotropic materials that resist sagging. Some water utilities have a preferred material or an approved list of materials for particular applications, and details will be included in the contract specification.

Epoxy lining spray-head

5. SUMMARY

The following table summarises the main features of each technology:

	Cement Mortar Lining	Epoxy Spray Lining	Polyurethane Spray Lining
Principle	Thin layer of cement mortar passivates ferrous pipes and prevents corrosion	A 1 mm barrier layer of two part solvent free epoxy resin mixed at spray head	Similar to epoxy but uses polyurethane resin
Types Of Pipe	CI,DI,STEEL, A/C		
Dia. Range (mm)	100-2000	75-600	75-1600
Access	Entry/Exit Pits Every 200 m And At Valves		
Preparation	Aggressive cleaning using drag scrape ,water jet ,borer		
Max Length	200 m	200m	200m
Connections	May cause blockage which must be cleared	No effect	No Effect
Fittings	Remove all	Remove all	Remove all
Out Of Service	48 hr minimum	16 hr minimum	2 hr minimum
Track Record	Extensive	Extensive	Extensive
Current Usage	Mainly USA	Mainly UK and Europe Some in USA	
Advantages	Low cost and easy to use	No bore restriction reduced outage time	No bore restriction Easier to apply in Large pipes. Same day return to service
Disadvantages	Bore restriction in small pipes. Not for soft water	Higher Material costs Rigorous QA procedures	

1. Thorough preparation of the existing pipe is important, particularly with spray lining systems, and a variety of techniques is available for descaling, cleaning and swabbing.
2. Spray lining techniques for small to medium diameter pipelines are aimed principally at the renovation of potable water mains. All materials must be approved for contact with drinking water by the relevant regulatory bodies.
3. Cement mortar lining is relatively inexpensive, offers chemical protection against corrosion of the host pipe, and provides a smooth bore. However, the required thickness of material may produce a significant reduction in bore, and the life expectancy of the lining may be less than for many other renovation techniques.
4. The application and curing of epoxy and polyurethane lining is generally quicker than cement mortar lining and causes minimal bore reduction, but careful quality control during application and curing is essential to avoid any defects in the lining that would allow corrosion to restart.
5. Neither cement mortar lining nor epoxy spray lining are suitable for pipelines that have structural defects or leaks. Polyurethane linings can be applied at greater thicknesses which have some semi structural and leakage prevention capability

The cost of spray lining compared with other renovation techniques should be weighed against the relative durability, structural capability and longevity of the alternative systems.

IN SITU APLIED COATINGS – THICK SEMI OR FULLY STRUCTURAL

POLYMER BASED

Epoxy and polyurethane based coatings are widely used for the rehabilitation and corrosion protection of man entry pipes, tunnels, manholes and other water and wastewater structures. The materials in two-part, 100% solids, solvent free formulations are hand or spray applied in thicknesses up to 5 mm. Careful surface preparation is needed to ensure good adhesion between the coating and the substrate.

Some manufacturers of polyurethane based coatings are claiming that they can now apply thicker coatings inside small diameter pipes, saying that these behave in a semi or even fully structural manner. More recently tests have been successfully completed where thick coat PU resins have been applied to eliminate leakage in pipes.

By the end of 2006, one UK manufacturer of polyurethane had launched a semi structural lining system, involving resin layers of 3 mm thickness, or more. The company claims that, when used in water mains, such a system offers:

- Rapid cure, hence same-day return to service
- The ability to span joint gaps and small holes, thus preventing leakage
- The ability to survive and bridge circumferential failures, the most common problem found in small diameter cast iron pipes
- A system that does not block service connections, therefore does not require local excavation to reinstate them

The system has been quite widely used and tested by a number of water companies across the UK.

CEMENT BASED

Concrete can be applied by spraying in man entry tunnels and pipes using techniques such as Shotcrete and Gunite.

Reinforcement can be incorporated in the sprayed layer either by use of polymer or steel fibres incorporated in the mix, or by positioning layers of reinforcing fabric on the pipe wall prior to application of the concrete. This allows the layer to act as a semi or fully structural lining.

Ferro cement is a variant of these technologies, in which a very fine steel mesh is incorporated in the sprayed layer giving excellent crack control. This material has been widely used in developing countries, to manufacturer a wide range of objects. The material has also been used as a structural lining in pipes and tunnels used for both gravity and pressure applications.

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Additional Information may be obtained using the following:

1) ISTT conference papers
2) Other conference papers
3) Standards/guidelines
4) List of ISTT member contractors
5) Other contractors

Details may be obtained directly from ISTT: info@istt.com