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DEFINITION

This section on Pipeline Renovation technologies includes all processes used to rehabilitate a pipeline over manhole-to-manhole lengths or greater, by whatever means, from within the confines of that existing pipeline.

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

This group of processes includes the following technologies:

a. Insitu Applied Coatings More>
b. CIPP Lining More>
c. Sliplining More>
d. Close fit linings More>
e. Spiral Winding linings More>
f. Sectional Liners More>

Whilst every effort has been made to ensure that the Guidelines given here are as complete and accurate as possible, if there is any information that you consider to be missing from this Guideline or have seen any information that you feel is incorrect please contact ISTT directly stating the omission or incorrect item. ISTT will endeavour to correct any such omission or error subject to further investigation to validate any such claim. Email: info@istt.com

ISTT — INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	**TRENCHLESS TECHNOLOGIES INFORMATION CENTRE**	
	TRENCHLESS TECHNOLOGY GUIDELINES	SECOND EDITION
	INSITU APPLIED COATINGS	LAST UPDATED DECEMBER 2006

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 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.

All three systems are presumed to have minimal effect on the structural integrity of the host pipe or leakage, although more recently the developers of the PU based systems claim the potential for thicker more structural coatings, and have successfully completed installation where thicker coatings have been used to eliminate leakage in pressure pipes. 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, 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.

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.

‘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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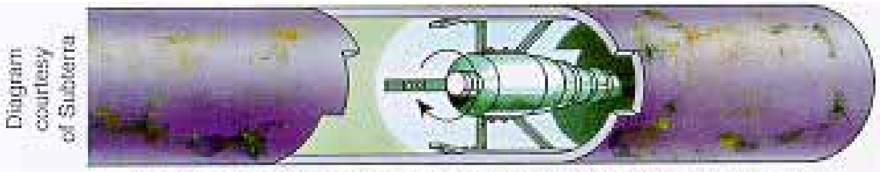
3. CEMENT MOTAR LINING

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 fulfill 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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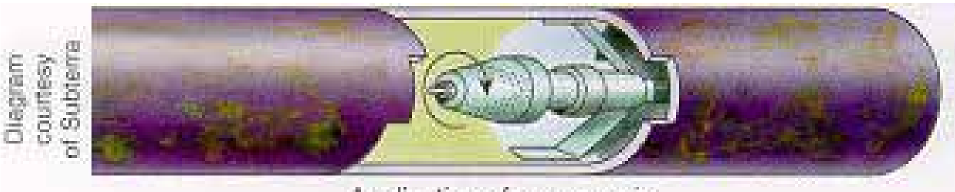
4. EPOXY AND POLYURETHANE LINING

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.

Epoxy lining spray-head

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.

5. SUMMARY

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 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.
6. 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.

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APPENDIX 1

INSITU APPLIED COATINGS – THIN NON STRUCTURAL

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

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		
Diam 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		
Connections	No effect		
Fittings	Remove all		
Out Of Service	48 hr min	16 hr min	2 hr min
Track Record	Extensive		
Current Usage	Mainly USA		
Advantages			
Disadvs			
Selection Indicators	Pipes >300 mm		

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APPENDIX 2

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 spray applied 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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1. OVERVIEW

The main alternative to sliplining and its variants is cured-in-place lining, sometimes referred to as ‘insitu lining’, ‘soft lining’ or ‘cured-in-place-pipe’ (CIPP), which has dominated the non-man-entry sewer renovation market in many countries for almost thrity 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. The main types are listed below.

CURED IN PLACE LINING SYSTEM VARIETIES

Liner Tube Material	Cure Type	Resin	Main Application	Comment
Polyester Felt	Heat or Amibent	Pe,Ve,Ep	Gravity Pipes	The original system still most widely used for sewers
Glass Reinforced Polyester Felt	Heat	Ve, Ep	Pressure Pipes	Semi and fully structural variants
Glass Fibre Structured Fabric	Heat	Pe.Ve.Ep/	Gravity and Pressure	Allows reduced thickness for gravity applications
	Light	Special	Gravity	Reduced thickness plus rapid cure
Circular Woven Polyester Fibre Hose	Heat or Ambient	Ep	Pressure	Semi structural depends on adhesion
Woven Hose Plus Felt	Heat	Ep	Pressure	Semi structural – does not require adhesion
Woven Hose Plus Felt Plus Structured Glass Fibre Fabric	Heat	Ep	Pressure	Fully structural

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

Insertion is achieved in one of two ways. One is to invert the hose into the pipe using compressed 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 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. Systems which rely on the host pipe for some measure of structural support are sometimes known as ‘interactive lining’ techniques.

Multiple fractures in a clayware pipe – this is representative of the most severe damage that can be renovated using cured-in-place lining techniques

As well as 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.

In Gravity pipelines, laterals can be re-opened remotely after lining, but care must be taken during installation to ensure that surplus resin does not enter branches. CIPP systems are also available for lining laterals from within the main pipe.

The major disadvantage of CIPP lining systems is the need to take the host pipe out of service during installation and cure. In gravity pipes, where flows are very low, it may be possible to plug any incoming pipes and to rely on the storage within the system. In other cases flow diversion or over-pumping will generally be required.

Some CIPP systems are suitable for use in large diameter (man-entry) pipes - see elsewhere.

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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	
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.

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3. DESIGN & SPECIFICATION

Because liner specifications and design procedures vary from country to country and are subject to periodic amendment, it is outside the scope of these Guidelines to include reference to all National standards.

In countries where established local criteria do not exist, a widely-used standard is the Specification for Renovation of Gravity Sewers by Lining with Cured-in-Place Pipes contained in WIS 4-34-04, March 1995: Issue 2, published by WRc in the UK. Design procedures for determining the required wall thickness of circular and non-circular sections under different loading conditions are given in the WRc Sewerage Rehabilitation Manual.

Specifications for pressure (gas and water) applications are laid down by the relevant utility companies and approvals bodies. Most countries have strict requirements and accreditation procedures for all materials likely to come into contact with potable water.

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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 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.

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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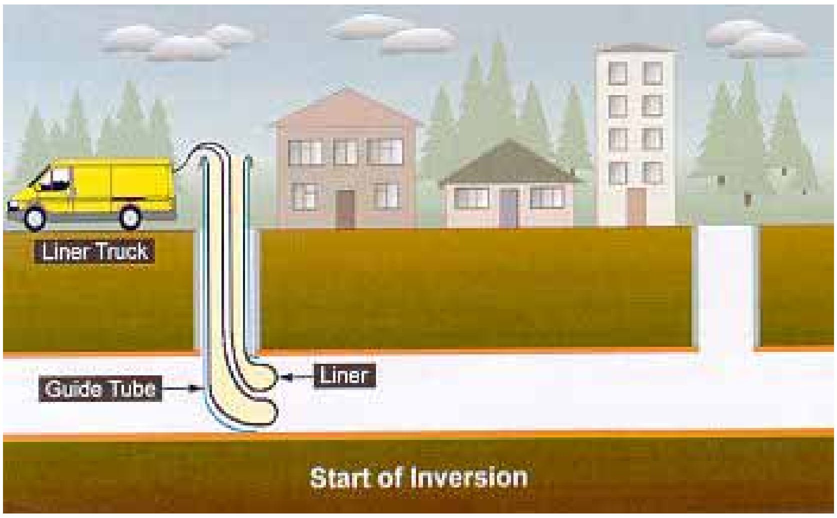
5. INSTALLATION IN SEWERS - THERMAL CURE

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.

The liner fabric is usually coated on the outer face of the tube - which becomes the inner surface of an inverted liner - with a membrane of polyester, polyethylene, surlyn or polyurethane, depending on the application. The membrane serves several functions - it retains the resin during impregnation and transportation, it retains the water (or air) during inversion, and it provides a low-friction, hydraulically efficient inner surface to the finished liner. Some systems use a separate membrane rather than an applied coating, and this may be removed after installation.

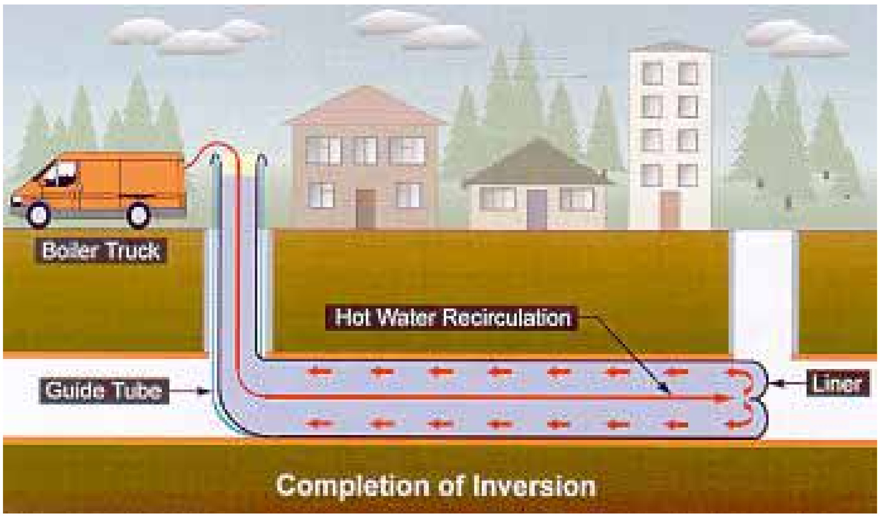
Impregnation is normally carried out in the factory under a vacuum to exclude air and ensure the uniform distribution of resin. This is known as the 'wetting-out' process. Depending on the characteristics of the resin, the liner may be delivered to site in a refrigerated vehicle, to prevent the curing reaction from starting prematurely.



Insertion into the existing 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.
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 involve winching in the liner rather than using an inversion technique. Inversion may be difficult in certain locations because of the need to create an adequate head of water (although devices are available to generate the head by a combination of air and water pressure), and towing in the liner avoids the need for scaffold towers and overhead working. However, there are limitations to the size and weight of liner 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 have 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 liner is then heated, throughout its length, with steam generated by a boiler in the lining unit truck.

A major advantage claimed for the most recent lining systems using this technique is that they produce a liner which does not shrink on curing. This eliminates the potential for infiltration leakage along the interface between the host pipe wall and the liner's outer skin, in turn reducing the need for remedial sealing of lateral connections. This facility also ensure that any infiltration problem is not simply passed further down the problematic pipeline.

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6. UV-CURED LINERS

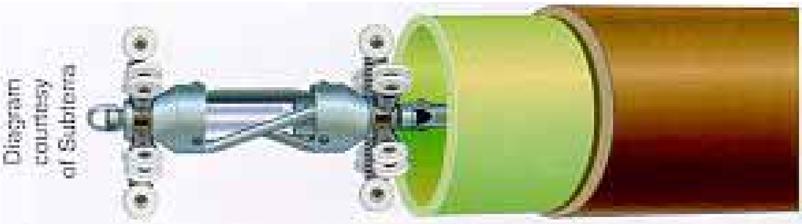
As an alternative to curing with hot water, there are systems using resins which cure under ultra-violet light. The amount of plant required is generally less than for thermal cure systems.

UV-cured liners are often made from glass-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.

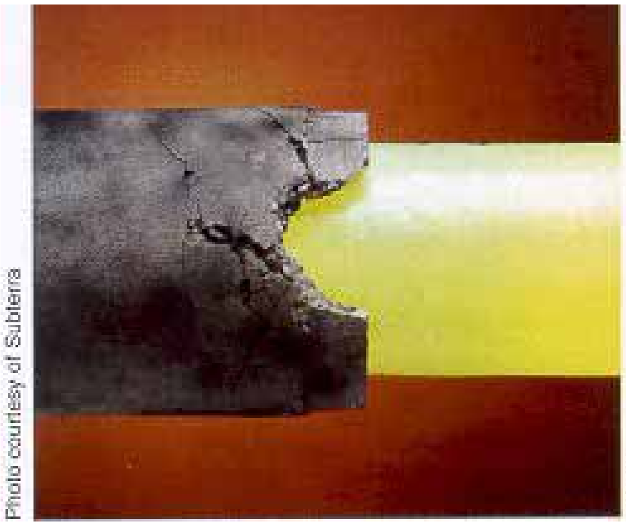
It is possible to use resins with a storage time of several weeks at ambient temperature, so refrigeration is not required. Various resin formulations are available to suit the nature of the effluent.

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.



The UV light source is pulled through the liner at a controlled rate, while internal pressure is maintained



Completed UV-cured liner

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, drains and other pipework, 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.

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.

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

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 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, fail less frequently through external loading. The most significant forces on the pipe are generally caused by the internal pressure, which creates tensile stresses in the pipe or liner. The most common pipe defects are corrosion and leakage from joints. Pressure pipe liners do not generally require as much ring stiffness as sewer liners, but they do need to withstand the bursting forces generated by internal pressure.

For this reason, the fabric used for CIPP pressure pipe liners tends to have a higher tensile strength than that for sewer liners and, because flexural stresses are not so critical, the wall thickness of the liner is usually much less. Glass-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 more acceptable in contact with potable water.

Most of the techniques aimed at pressure-pipe renovation were initially developed for the gas market, mainly in Japan, but several CIPP systems are now available to renovate potable water mains.

The installation process is similar in concept to the inversion method used for gravity pipe liners. However, because pressure pipe liners are less bulky, it is possible to contain the impregnated liner within a pressure vessel, and to invert the liner through the host pipe with compressed air. Curing is achieved by introducing steam into the liner.

In addition to the thin-walled liners described above, there are also CIPP techniques using epoxy resins, which do not rely on a bond to the existing pipe wall. These systems develop their strength from the composite action of the resin and fibres rather than a woven jacket, and are designed to resist both internal and external forces.

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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, 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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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' by installing a new 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 slipliners by fusion welding or with mechanical, collarless joints. They are also used extensively with on-line replacement techniques such as pipe bursting (*see Section 5*).

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 a very long continuous length prior to being winched into the host pipe.

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. 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, plain sliplining has become less common than close-fit lining (covered later), but may still be the best choice in certain cases.

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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 slipliners in pressure pipes should follow the same principles as for new pipes. Thin-walled (nonstructural) liners may occasionally be used, provided that the existing pipe is known to offer sufficient restraint, and that complete grout filling of the annulus can be achieved so that no part of the liner is unsupported. This is often difficult to guarantee, and thin-walled liners are therefore not favoured for basic sliplining, although they are frequently used in modified (close-fit) sliplining.

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. Slipliners 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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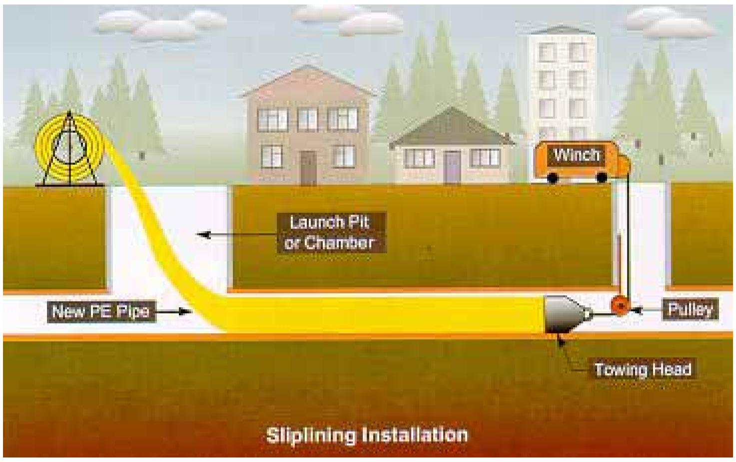
5. INSERTION

As discussed above, slipliners may be pulled in, 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 slipliners 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.



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.

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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 strength similar 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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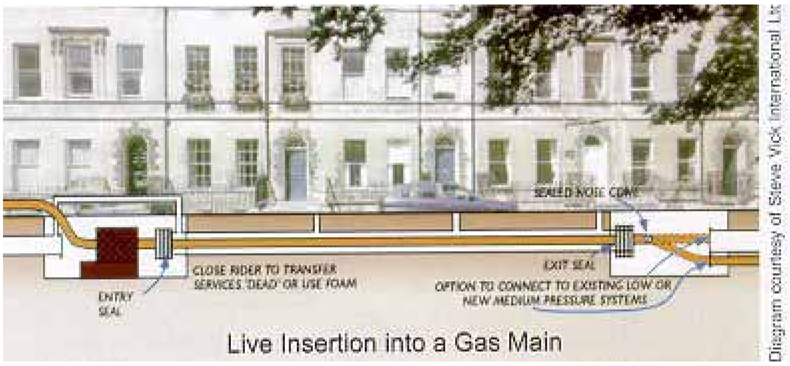
8. LIVE INSERTION AND SERVICE PIPE RENOVATION

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.

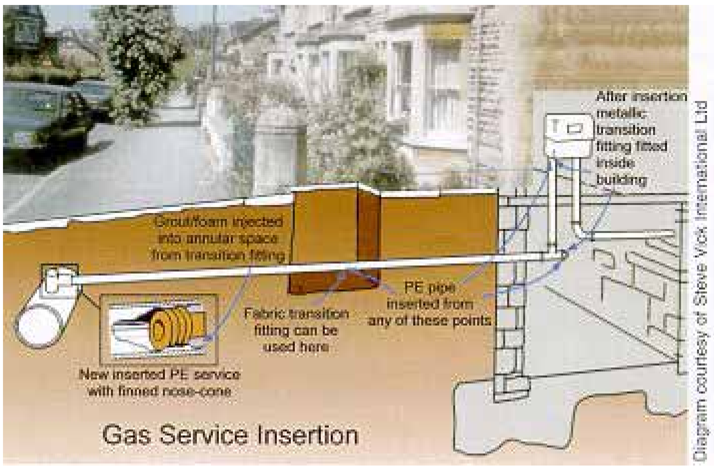
It is outside the scope of this document to describe the many proprietary systems for live insertion. For obvious safety reasons, strict and detailed procedures are laid down for installation, and the following is intended only as a general guide to the basic principles. Systems are available for low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

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.



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^{o} 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.



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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iSTT INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
	TRENCHLESS TECHNOLOGY GUIDELINES	SECOND EDITION
	CLOSE FIT THERMOPLASTIC LINING	LAST UPDATED OCTOBER 2006

1. OVERVIEW

The use of liners that are deliberately deformed prior to insertion, and then reverted to their original shape once in position so that they fit closely inside the host pipe, 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. Cured-in-place lining may also be referred to as ‘Close Fit’, but 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 and then temporarily reduce its diameter to give sufficient clearance for insertion. Once inserted the liner is ‘reverted’ to its original shape/size to form a Close Fit lining. 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, 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 liner material i.e PE80, PE100, uPVC etc, and is discussed in more detail in the design section.]

REDUCTION METHOD		Material	Min Dia (mm)	Max Dia (mm)	Max SDR min (t)	Min SDR Max (t)	Strength class	Max Pressure Class IV (bar)	Main Application
symmetrical	Tension	PE 80/100	75	1000	80	11	2/3 or 4	16	Pressure
	Compression	PE 80/100	100	500	33	11	2/3 or 4	16 up to 400 then 10	Pressure
	No reduction	uPVC/moPVC	100	900	42	18	4	10	Pressure
Fold and form	Site folded	PE 80/100	75	1600	80	26	2/3 or 4	6 @ 400 to 2.5 @ 1600	Pressure
	Factory folded (Hot)	PE 80/100	100	500	33	17	2/3or 4	10	Pressure and Gravity
		uPVC and alloys	150	500	33	33	N/A	N/A	Gravity
			100	600	25	14	4	16	Pressure
	Factory Folded (cold)	PE	100	300	50	33	2/3	N/A	Pressure
	Factory Folded (hot)	Polyester reinforced PE	70	200	50	30	4	16 to 150 10 to 250	Pressure

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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.

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.

A development of this technique utilises standard uPVC pressure pipe with an OD some 10 to 20% smaller than the host pipe ID. After 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 pressure capability.

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. The reduction in diameter is associated with an increase in wall thickness, and is substantially retained until subsequent reversion 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.

Photo courtesy of Subterra

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

The techniques were developed for the gas industry, although they are suitable for most types of pressure pipes including potable water mains. Because the diameter reduction 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 most swaged liners is also preferable for gravity pipes with high external loading.

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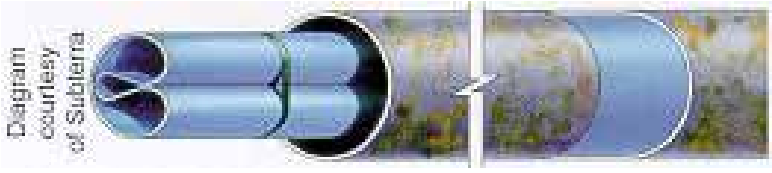
4. FOLD AND FORM PROCESSES

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 reduced-diameter liners, the principle of folded 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 PVC folded liners are available for gravity pipes.

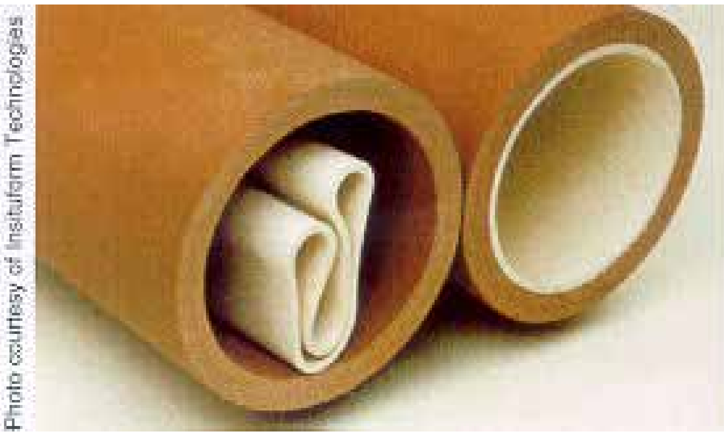
In some systems, the liner is folded in the factory and delivered to site in coils. It is then winched into the host pipe. PE liners, especially thin-walled ones, may be reverted by pressure alone, but PVC liners require heating. In other systems, PE liners are folded on site as part of the insertion process. Factory folded PE liners for pressure pipes are available in diameters up to 450 mm, whilst liners folded on site can extend to 1,600 mm diameter.



The folded liner is inserted into the host pipe, and then reverted to its original shape

As an alternative to folding the pipe prior to delivery, there is a close-fit lining technique for thin-walled liners in which a circular PE pipe is pushed through a forming machine on site. The technique uses standard PE pipe, which is folded into a 'U' or 'C' shape for insertion into the existing 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.

Thermoplastic PVC 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 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.



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

Folded PVC liners are available in diameters from 100 to 350 mm, and are made from a type of PVC 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.

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 folded in a tight 'C' shape before being inserted 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.

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.

Factory folded liners are supplied to site on a coil or drum while site folded systems use strings.

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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.

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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-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, which 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 addition 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. Second it can be viewed as a close fit liner, but only with the products that have been produced that, once installed through the host pipe, can be expanded in diameter to fit against the inner surface of the host pipe. 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 diameters 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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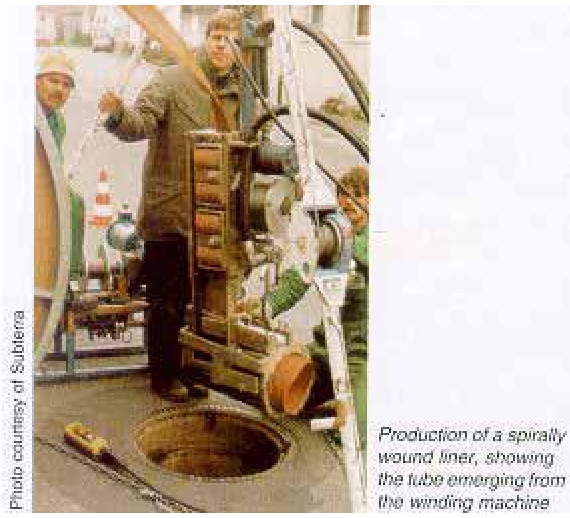
2. MECHANICALLY WOUND SLIPLINING

Often known as spirally wound lining, the tube is formed by an 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.



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 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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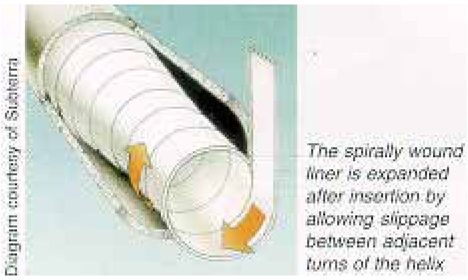
4. MECHANICALLY WOUND CLOSE FIT LINING
Some versions of the spirally wound lining technique, used for gravity pipelines, offer the facility to expand the installed liner to provide a close fit within the host pipe. During installation, the joint between adjacent turns of the helix is prevented from slipping 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 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.
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 i.d. 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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INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	**TRENCHLESS TECHNOLOGIES INFORMATION CENTRE**	
	TRENCHLESS TECHNOLOGY GUIDELINES	SECOND EDITION
	SECTIONAL LINERS	LAST UPDATED OCTOBER 2006

1. OVERVIEW

Sectional Lining is generally taken to be the sliplining of man-entry sized pipes by the introduction 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 soffet 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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