INTERNATIONAL SOCIETY FOR TRENCHLESS TECHNOLOGY	TRENCHLESS TECHNOLOGIES RESOURCE CENTRE	
	TRENCHLESS TECHNOLOGY GUIDELINES	SECOND EDITION
	CLOSE FIT THERMOPLASTIC LINING	NEW VERSION AUGUST 2005

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 often 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 these Guidelines.

2. PRINCIPLES AND CLASSIFICATION OF METHODS

The principal of the close fit lining methods is to use a polyethylene or PVC liner pipe with original OD from 5% less to 3% more than the ID 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 following Table

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.

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.

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

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.

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

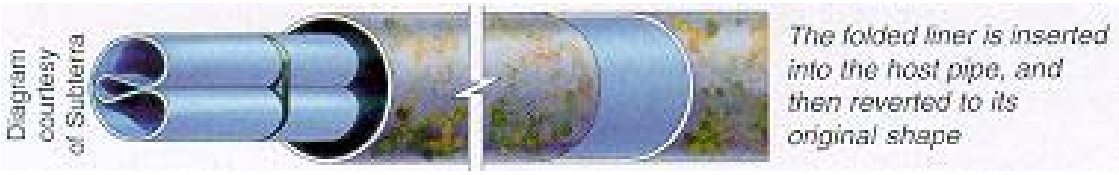
The techniques were developed for the gas industry, although they are suitable for most types of pressure pipes including potable water mains. Because the diameter reduction is limited by the properties of the material, these processes are not commonly used in sewers, which may have displaced joints 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.

4. FOLD AND FORM PROCESSES

Folded liners are sometimes known as ‘fold and formed pipeliners’ (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

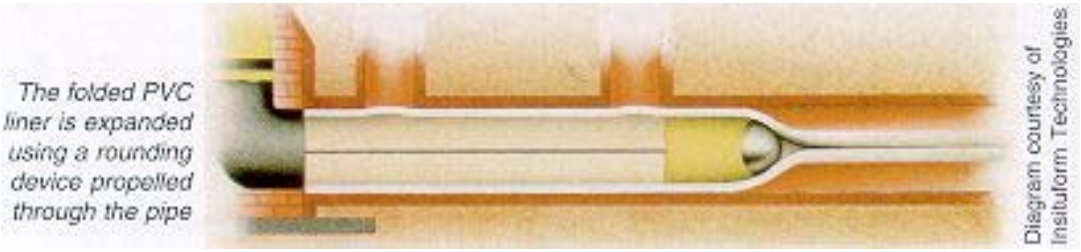
As an alternative to folding the pipe prior to delivery, there is a close-fit lining technique for thin-walled liners in which a circular PE pipe is pushed through a forming machine on site. The technique uses standard PE pipe, which is folded into a 'U' or 'C' shape for insertion into the existing pipe.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



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

Diagram courtesy of Insituform Technologies

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

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. 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.

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

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.