Sydney Mechanical Chapter

IMechE – Engineers Australia - ASME

Trenchless Technology for the Rehabilitation of Deteriorated Pipelines

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Interflow™

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Trenchless Technology for the Rehabilitation of Deteriorated Pipelines

This section deals with techniques for the rehabilitation or renewal of deteriorated underground pipelines without the need for excavation.

This is a fast growing industry.

In every city in the world there are underground pipelines that are reaching the end of their useful lives. As well as the risk of pipeline collapse, this can lead to unacceptable problems such as wastage of water, or pollution through exfiltration from sewer mains.

Usually the oldest infrastructure lies within valuable, high density urban areas. The cost of digging to replace these pipelines is prohibitive, and the ensuing community disruption would not be tolerated.

Thus the Trenchless Technology industry has developed, offering techniques for restoring these pipelines with minimal excavation.

This section will deal principally with rehabilitation of deteriorated sewers and stormwater pipelines. There seems to be in Australia and New Zealand a greater requirement for renewal of these types of pipelines than for water mains.

A possible reason for this is that water mains, which operate under pressure, are typically shallower than sewers and in urban areas are often located in footpaths. Thus they are more economically replaced than gravity sewers which are often deeper and more remotely located.

OVERVIEW OF SEWER REHABILITATION

Techniques for renewal of deteriorated sewers can be divided into 2 classifications:

1. *Non-Structural:* This form of rehabilitation aims to repair deteriorated pipelines by means that prevent further deterioration. Typical examples are epoxy lining of water mains, or grout sealing of cracked or leaking sewers.
2. *Structural*: This typically involves installing a liner that renews the deteriorated pipe's structural and hydraulic capacity.

Over the past decade major advances have been made in providing liners that offer higher standards of performance while being more economical and convenient to install.

Latest advances have included pipelines at both ends of the size scale.

New techniques are now available for providing structural liners for large sized pipelines. These have in the past presented particular difficulties for water authorities, who have often resorted to short term repairs until the danger of collapse became too acute.

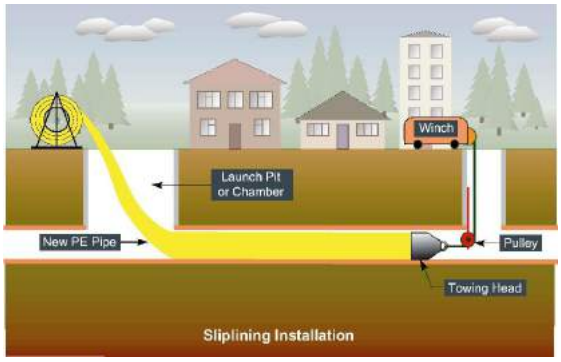
At the other end, there are now efficient and economical systems for lining of house service lines with minimal excavation.

SLIP LINING

Slip lining is the simplest technique for renovating man-entry and non-man-entry pipelines. It 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. Over the years many different types of pipes have been used, including clay, concrete FRC and Hobas.

Although, in theory, any material can be used for the new pipe, today polyethylene is the most common choice in smaller sizes. The material is well established in the potable water and gas industries, and is abrasion resistant and sufficiently flexible to negotiate minor bends during installation. It can be butt-fused into a long lengths prior to being winched into the host pipe.



In most cases it will be necessary to grout the annulus between the host pipe and the inserted pipe in order to hold it firmly in position

The loss of cross-sectional area may 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 slip lining has become less common than close-fit lining, but may still be the best choice in certain cases.

Advantages:

- Suitable for a wide range of pipe types and diameters
- Relatively cheap simple process

Disadvantages:

- Considerable loss of internal diameter
- Launch and reception pits must be dug
- Lateral connections must be excavated and re-built

CURED-IN-PLACE LINING

Cured-in-place lining is a "close fit" alternative to slip lining that has been used around the world for over 20 years. It is sometimes referred to as `soft lining' or `cast-in-place-pipe' (CIPP).

Although several competitive systems are 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 most commonly by re-circulating hot water or steam. Some variations cure using ultra-violet light.

CIPP systems create a close-fit 'pipe-within-a-pipe' which has quantifiable structural strength and can be designed to suit various loading conditions.

Cured-in-place liners can be manufactured to conform to almost any shape of pipe, making them suitable for lining of non-circular e.g. ovoid cross-sections.

Some systems use a fabric which can stretch to accommodate small variations in cross-section. Since CIPP liners are flexible prior to cure and conform under pressure to the shape of host pipe, correct measurement of the pipe's internal circumference is critical.

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 lining systems typically require the host pipe to be 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.

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.

CIPP systems were originally developed for gravity pipelines, but certain proprietary techniques are available for pressure pipes.

Installation

Thorough preparation is important to the success of a CIPP installation. The following are among the factors to be considered:

- Intruding connections, encrustation and other hard deposits should be removed
- Thorough cleaning of the pipeline, including removal of fat, grease and debris
- Pre-lining repairs to missing inverts etc may be needed if the liner is to have a circular cross section
- Flow diversion or bypass pumping during installation and cure. As laterals will also be blocked, consideration needs to be given to maintaining services to householders
- Traffic regulation may be needed because of the size of the support vehicles, particularly at the originating manhole.
- Polyester resins give off styrene fumes with a strong odour during cure. This can be an irritant and ventilation around the site may be needed.
- Infiltration may adversely affect the curing of the resin. A "pre-liner" or pre-sealing may need to be installed.

Each proprietary system has its own methodology, and the description below is intended as a guide rather than as a statement of best practice.

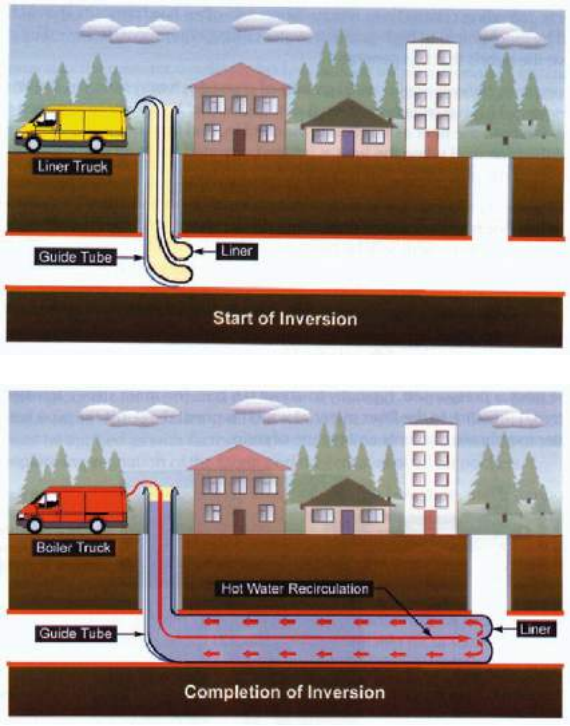
The majority of thermal-cure liners for gravity pipelines comprise a non-woven fabric – usually polyester needle-felt – impregnated with polyester resin. Some systems use a composite material such as felt and glass-fibre. The formulation of the resin can be adapted to suit different cure regimes and 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, PVC 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.

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.



Installation of CIPP by Inversion

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:-

1. 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.
2. 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.
3. The leading end of the liner is turned inside-out manually for a predetermined length, usually a few metres, and is then clamped to the collar of the guide tube. A hose is attached to the trailing end which will run within the full length of the liner after inversion.
4. Water is introduced into the turned-back section, which causes the liner to continue inverting through the guide tube and the host pipe. The pressure of water forces the liner against the existing pipe wall.
5. 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.
6. Temperatures at various points on the surface of the liner are monitored with thermocouples.
7. Once cure has been achieved, the water is gradually cooled down before being released.
8. 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.
9. 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.

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.

Advantages:

- Close fit liner minimises loss of pipe bore
- Typically installed without digging
- Suitable for non-circular shapes
- Longest international track record for close fit liners
- Handles most pipeline curves

Disadvantages:

- Material properties depend on successful underground curing
- Susceptible to wrinkling and cross sectional irregularity if pre-lining repairs insufficient
- Bypass pumping usually needed
- Limited ability to accommodate pipe diameter variations

FOLD-AND-FORM LINERS

These are "close fit" 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.

Techniques commonly available involve folding the liner into a `U' or `C' shape prior to insertion, and then using heat and/or pressure to restore circularity.

The process is typically limited to liners less than 450mm in diameter. Variations are available in polyethylene and PVC for both pressure pipes and gravity sewers.

Fold-and-Form liner before and after expansion

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.

The liner is folded in the factory and delivered to site in coils. It is then winched into the host pipe. The liner can be installed in long lengths and around bends subject to pipe diameter and other factors.

Once in place, the liner is 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, and propelling it 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.

Groundwater infiltration may adversely affect the ability of the liner to reform to the shape of the host pipe.

Folded PVC liners may be made from a type of PVC which is modified to allow the folding and reforming process. The degree of modification varies greatly between different products.

Advantages:

- Close fit liner minimises loss of pipe bore
- Typically installed without digging
- Can handle pipeline curves
- Installation may be possible without bypass pumping

Disadvantages:

- Groundwater and infiltration can affect success of liner reversion
- Shrinkage can be a problem after installation (particularly for polyethylene liners)
- Susceptible to cross-sectional irregularities if pre-lining repairs not sufficient

EXPANDED SPIRAL WOUND LINERS

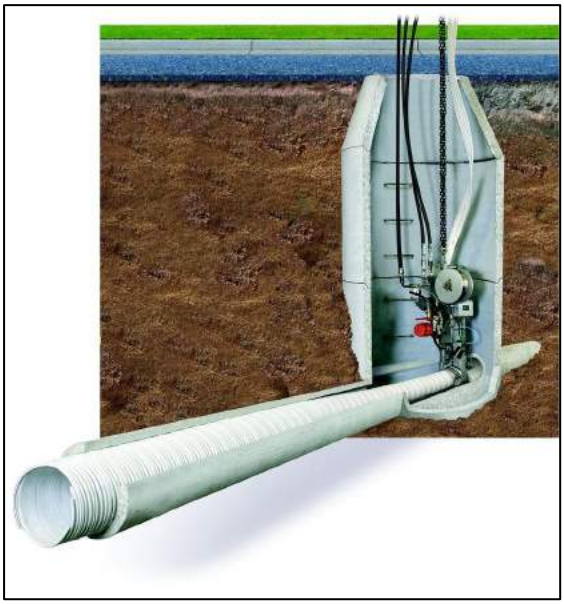
The most installed "close fit" liner in Australia is the Australian developed Rib Loc Expanda Pipe spiral wound liner.

The system consists of a single strip of PVC, which is spirally wound into the existing pipeline via a patented winding machine positioned in the base of an existing access chamber. The edges of the strip interlock as it is spirally wound to form a continuous liner inside the host pipe. Once a section of Expanda Pipe is installed, a mechanical process is used to radially expand it to fit tightly against the wall of the deteriorated host pipe.

Expanda Pipe is suitable for pipes with internal diameters from 150mm to 750mm. A range of plastic profiles with varying stiffnesses is available to provide a liner that meets structural design Specifications.

It differs from the other types of close fit liners in that Expanda Pipe:

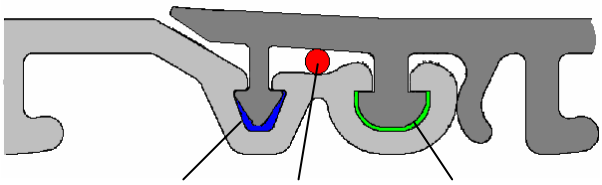
- Is formed inside the deteriorated pipe
- Does not require heating at any stage of the on-site installation process



Expanda Pipes liner installed from a machine in the base of a manhole

Installation

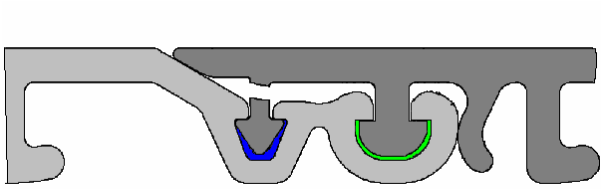
- The deteriorated pipeline is first cleared of debris, cleaned and CCTV inspected. Locations of lateral connections are logged.
- The Rib Loc winding machine is lowered to the base of the manhole. The PVC profile is fed through the top of the manhole and into the winding machine.
- The Expanda Pipe profile is wound in at a diameter smaller than the host pipe. The profile edges interlock to maintain the desired wind-in diameter.



Hot melt adhesive *Wire* *Sealant*

Expanda Pipe Lock During Installation

- Winding is stopped when the wound pipe reaches the upstream manhole. The end of the Expanda Pipe is then torsionally restrained. Expansion of the liner commences by pulling the cutting wire, severing the secondary (sacrificial) lock.
- As the cutting wire is progressively removed, more profile is wound into the line. The lubricating sealant in the primary lock allows adjacent profile wraps to slide relative to each other. In response to the additional profile, the liner expands in diameter to fit tightly against the inside wall of the deteriorated pipe.



Expanda Pipe Lock After Expansion

- The process continues until the liner has been expanded for the full length of the deteriorated pipeline between manholes. Then the lining is complete
- The ends of the liner at both manholes are sealed with an epoxy resin material and rendered to make them smooth with the host pipe.
- Laterals can be immediately reinstated by robotic cutting, with the joint being sealed in compliance with the customer's Specification.

Advantages:

- Assured material properties – not dependent on successful curing or heat treatment
- Diameter can vary according to the actual diameter of the host pipe
- Circular cross section with uniform wall thickness. No softening during installation, so does not take shape of deteriorated host pipe
- Faster installation as no heating or curing
- Bypass pumping rarely needed
- CCTV monitored during installation
- No shrinkage after installation as no heating is applied

Disadvantages

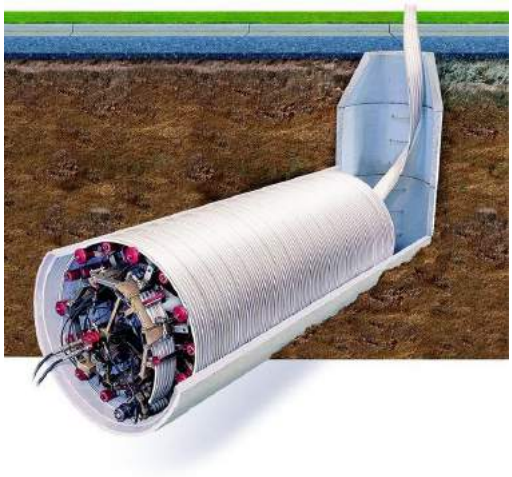
- Not suitable for oviform pipes
- Limited ability to line around bends

SPIRAL WOUND LINERS FOR LARGE DIAMETER PIPELINES

Rotaloc, a variation on the spiral winding process, has been developed by Rib Loc Australia Pty Ltd for installing structural liners in larger diameter pipelines.

Rotaloc is different from other spiral wound technologies in that:

- the winding machine travels along the deteriorated pipeline as it winds the liner
- the winding machine has the capacity to alter the diameter of the liner as it traverses the pipeline.



Rotaloc spiral winding machine

Rotaloc is a one-step process that provides a structural liner in contact with the pipe wall, even if the diameter changes along the pipeline length.

It has the capacity to handle deteriorated pipelines from 800mm to 1,800mm diameter with offset joints and deflections.

The Rotaloc lock is simpler that the Expanda Pipe joint, as installation is a one-step process that does not require the whole of the liner to rotate.

Rib Loc received the International Society for Trenchless Technology's "No Dig 2001" Award for Rotaloc, meaning it was considered to be the most important advance in the industry that year.

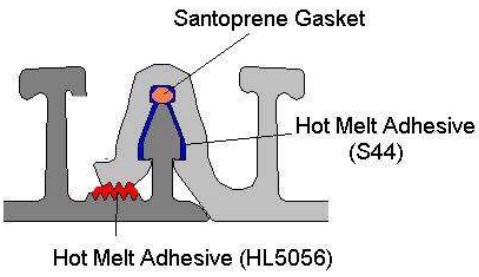


Diagram of the Rotaloc lock

REPAIR OF LATERAL CONNECTIONS

All of the liner types listed above are capable of providing a water tight, root tight structural liner inside a deteriorated sewer.

Problems arise when the liner must be cut to re-connect a house service line.

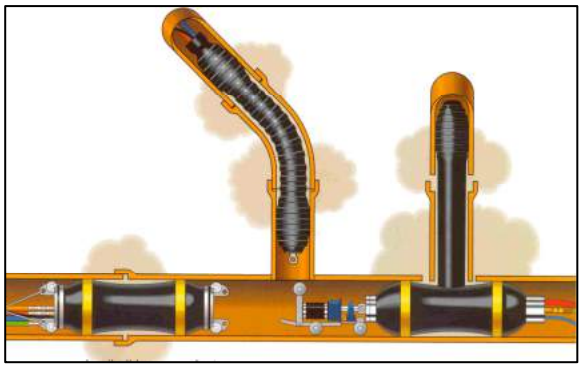
All close fit liners leave a gap between the liner and the host pipe which can provide a water path. This can lead to points of infiltration and exfiltration at house service line connections and access chambers.

Gaps can exist because of a number of possible factors including:

- Shrinkage in liners that use heat during the installation process
- Tolerances in manufacture of both liner and original host pipe
- Irregularities in the cross sectional shape of the deteriorated pipe

These gaps can be an entry point for root growth into the sewer. Water Authority experience has also shown that these gaps must be sealed if inflow and infiltration reduction targets are to be met.

In the mid 1990's hydrophilic polyurethane applied with a packer was adopted as the preferred grout sealing method. A lateral sleeve grouting packer was used to seal gaps at lateral connections. Use of this type of packer meant that the grout was applied under pressure to the defect and held at that pressure for its recommended curing time. The effectiveness of the seal could be immediately and economically hydrostatically tested using the same packer.



Packers for applying polyurethane grout to seal gaps in pipelines, laterals and junctions

Evaluation by Sydney Water showed that generally this grout could be considered to remain effective for a period of only 5 years. However below the level of the water table indications are that the grout may have a considerably longer effective life - though not for the 50+ years expected of sewer liners.

The polyurethane is susceptible to deterioration in the wetting and drying cycles typically found in Sydney's climatic conditions. Also, to be effective, any roots have to be totally removed before the polyurethane liquid is injected. If not, the polyurethane simply formed around the roots, which kept on growing.

Since 2001 better options have been developed based on cured-in-place technology that installs a tee shaped piece at the connection. The tee bonds to the liner and the lateral pipeline providing a physical barrier, rather than a seal, against leakage and root ingress. These options fall into two types:

- Lateral Connection Repair (LCR) comprising a short tee that bonds to the full circumference of the main sewer liner
- "Top Hats" named after the shape of the fitting, which is a tube that seals to the lateral pipeline and a "brim" that seals to the liner or host pipe around the lateral opening.

↑ *LCR type fitting*

← *"Top Hat" type fitting.*

Both prior to resin impregnation

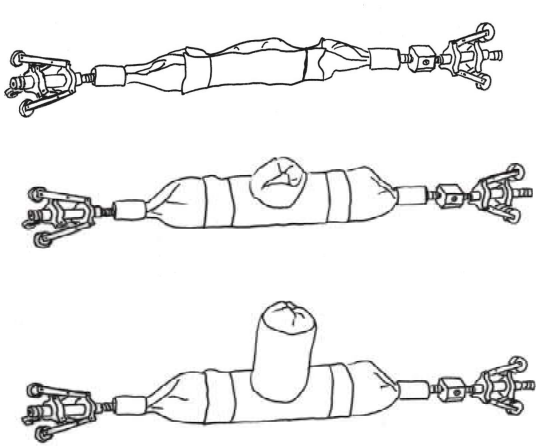
Each of these types of seals are installed using inflatable packers.

In the case of the LCR type, the fitting is mounted on a packer with an inflatable bulb that goes up the house service line.

In contrast, the tube of the top hat is contained within the body of the packer, and inverted into the house service line.

The installation procedure is typically as follows:

- After installation of the liner in the deteriorated sewer, the household service (lateral) connection is opened by a robotic cutter. Where necessary, roots and debris are cleaned from the junction.
- The tee piece is impregnated with resin
- The tee piece is mounted on the deflated packer. The lateral sealing bulb is positioned inside the body of the packer.
- The packer is passed down the sewer manhole then winched in position in the pipeline and orientated so that the lateral sealing bulb is adjacent to the opening for the householder service pipeline. The position of the packer is monitored by a CCTV camera in the pipeline



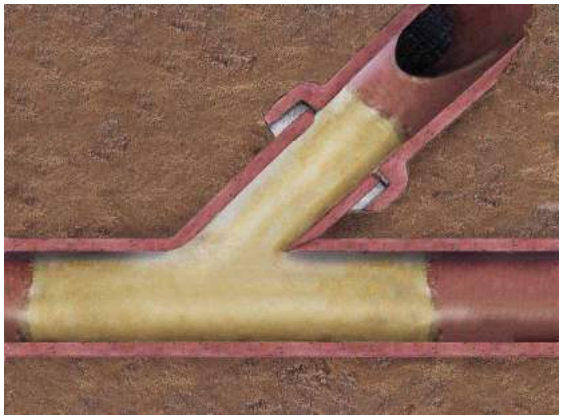
Stages of installation of a "Top Hat" showing reversion as inflation proceeds

- Inflation of the packer commences, sealing the circumference of the body of the packer against the sewer main, and forcing the lateral sealing bulb up the house service pipeline
- When fully inflated, the packer holds the tee piece tightly against the pipelines. Typically the tee will extend past the first joint in the household service pipeline.
- The pressure from the packer squeezes the excess resin from the felt into any gaps in the connection, thus providing mechanical as well as adhesive bond. The tee is held under a pressure for its curing time – typically about 2 hours.
- After curing is complete, the packer is deflated and removed, leaving the tee firmly bonded to the liner and household service pipeline.

Features of this solution include:

- Provides a strong physical barrier to roots, groundwater etc (rather than merely a seal)

- Bonds to both the liner in the sewer main and the householder's service pipeline.
- Made from materials known to be unaffected in sewerage conditions, so having an expected service life in excess of 50 years
- Can be installed using existing manholes, without the need for excavation
- Can be installed economically



Installed LCR

Installed "Top Hat" from inside the main

In Australia LCR's have become the preferred solution with over 4,000 having been installed over the past 3 years.

Silicate resins are preferred because of their strength, adhesion and curing properties.

Testing has included abrasion resistance testing in accordance with the "Hamburg Model." This is a test developed by the City of Hamburg, Germany, that involves jetting a quantity of grit through a length of pipeline with 4 LCRs installed at junctions along its length.

The LCRs are CCTV inspected after various numbers of jetting cycles have been completed, then pressure tested at the conclusion of 30 cycles.

The LCR passed this testing, which was independently witnessed.

SPECIFICATIONS FOR SEWER LINERS

Contractors tendering for sewer lining projects will base their offers on the Contract Specification.

As the Trenchless Technology industry is rapidly advancing, it is essential that Water Authorities regularly review their Specifications to ensure they are able to take advantage of the latest developments that Contractors are able to offer.

Specifications should be performance based, specifying the outcome that is required, rather than attempting to precisely specify how it should be achieved.

Issues that should be addressed in a Specification for sewer liners include:

Purpose:

- Is the purpose of the lining to restore the structural integrity of the deteriorated pipeline, or is it merely a coating to prevent further deterioration or improve the flow characteristics?
- What is the expected life of the liner?
- What materials are considered suitable?

Design:

Many types of lining systems are imported, typically from Europe or North America. These countries have different design Specifications for installed liners. A liner designed to these Specifications could be expected to have a different wall thickness compared to a liner designed to Specifications accepted by New Zealand and Australian Water Authorities.

It is important that the same design Specification is applied to all liners offered to allow them to be properly compared.

Therefore the precise liner design method should be specified, together with the values of the variables that should be applied, e.g. liner modulus, pipeline depth, water table height etc.

Installation:

The installation section of the Specification should define the responsibilities of the Contractor, without being proscriptive about the processes to be used.

Examples include:

- Cleaning and preparation of the sewer to enable successful installation of the liner should be the responsibility of the Contractor

- Different types of lining systems have different flow control requirements. The Contractor should determine what flow control is necessary. They should be responsible for its implementation subject to the requirement that no spillage is acceptable.

Junction Reinstatement

No type of liner on its own can reliably provide a water-tight seal when cut to make a junction connection. Therefore a decision needs to be made as to the type of junction reinstatement that would be acceptable to the Authority.

The required junction reinstatement should then be clearly specified.

Inspection and Testing

This section of a Specification would typically include:

- CCTV inspection to confirm the quality of installation and check for the presence of defects that may affect long term strength, hydraulic performance or may cause accumulation of solids:
  - lining does not provide a circular bore
  - lining not hydraulically smooth
  - inadequate material properties
  - variation in lining thickness
  - poor quality cut outs
- Pressure testing of a sample of lines. The test method is usually the same as for new plastic sewer pipelines.
- Monitoring of longitudinal shortening. This is advisable to ensure that shrinkage has not obstructed junctions with house service lines

Schedule of Technical Information

Examples of the type of information that tenderers should be expected to supply to allow their offer to be properly evaluated include:

1. Liner Details

- Full details of liner material including physical and chemical properties, durability, abrasion and chemical resistance, methods of manufacture and Standards governing material and manufacture
- Thickness of lining for each length of sewer to be lined, with calculations to confirm that this thickness complies with the design method given in this Specification.
- Moment of inertia of the liner wall, long term flexural modulus, allowable long term strain

2. Installation Details

- Details on methods of cleaning and repairing the host pipe prior to installation, including bridging over major holes and missing inverts. (Are these pre-lining repairs included in the tendered bid price?)
- Details on methods of liner installation including methods of flow control as required
- Details of liner finishing and effective sealing at access chambers