REHABILITATION OF LARGE DIAMETER PIPELINES – THE POSSIBILITIES CONTINUE TO EXPAND

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ABSTRACT

As machine spiral wound liners continue to gain acceptance for the structural rehabilitation of large diameter gravity pipelines, innovative ways are being found to use their features to overcome some of the difficulties inherent in such projects.

The continuing development in Australia of spiral wound lining systems has meant that methods of addressing these difficulties have changed. They have increased the possibilities of providing structural liners for deteriorated pipelines with diameters in excess of 1,800mm. Fixed or expanded diameter liners continue to be developed, with steel reinforcement used to provide greater stiffness in the larger diameters.

These liners have won prestigious international awards, and are now being installed world-wide.

This Paper details the different types of spiral wound liners available for structural lining of gravity pipelines with diameters from 600mm to over 1,800mm. While Rib Loc Expanda Pipe and Rib Loc Rotaloc are now well established, the latest development is Ribline – a high stiffness, fixed diameter steel reinforced polyethylene liner, used when a high stiffness large diameter liner is required.

The Paper will also provide detailed analysis of projects where these liners were installed, including how the inherent difficulties listed above were overcome. This includes the world's first major Ribline project, currently being undertaken for Sydney Water, involving the structural lining of some 1.3 kilometres of deteriorated 1800mm diameter reinforced concrete sewer up to seven metres below surface level.

KEYWORDS

Pipeline rehabilitation, spiral wound, structural liners, Rotaloc, Ribline

1. INTRODUCTION

Spiral wound liners have been used over the past decade to restore the structural integrity of deteriorated sewer and stormwater pipelines around the world in diameters from 150mm to 1,800mm.

Liners are typically installed without excavation, using a winding machine placed in the base of an existing manhole or access chamber. The liner is formed from a single, continuous strip of plastic with edges that lock together as it is wound by the winding machine. The plastic strip is profiled, with tees on the outer side, to provide a liner with a high stiffness to weight ratio. The side of the plastic strip that forms the inside of the liner is smooth, so minimising flow resistance.

In smaller diameters, up to 750mm, Rib Loc Expanda Pipe liner is expanded by a mechanical process that includes cutting of part of the double lock that holds adjacent strips of wound profile together.

Two relatively new spiral wound lining systems are currently being used in Australia for lining of larger diameter deteriorated pipelines:

- Rib Loc Rotaloc: for pipelines with diameters from 825mm to about 1,800mm
- Rib Loc Ribline: for pipelines with diameters up to 1,800mm and greater

Both of these types of liners are "structural" meaning they can be designed to take loads from soil, groundwater and traffic as if the deteriorated host pipe has no remaining strength. In effect, they renew the pipeline rather than repair or rehabilitate it.

Typically, Rotaloc and Ribline can be installed from existing access chambers without the need for excavation.

Each of these types of liners has a different method of providing a high stiffness liner in a large diameter pipeline.

2. THE LINERS
3.
2.1 ROTALOC

A Rotaloc liner is formed as a profiled plastic strip is fed into a winding machine that rotates as it locks the edges together. The rotating winding machine, in effect, "crawls" forward down the line along the profile strip, locking the edges together.

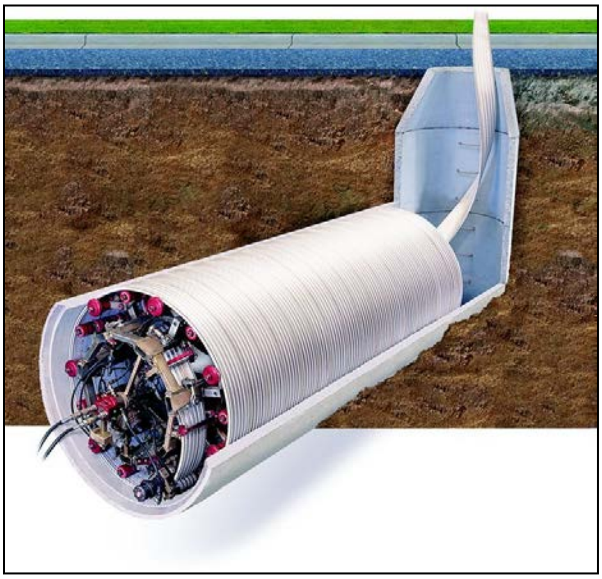

Fig 1: Rotaloc winding machine

The "arms" of the winding machine that hold the profile and lock its edges together are attached to hydraulic rams. These can move to alter the diameter at which the profile is wound to form a liner. By this method, it is possible to maximise the liner's diameter by adjusting it so it contacts the internal wall of the host pipe, while still remaining circular. When point deflections, stepped joints etc are encountered, the hydraulic arms reduce the liner diameter until the obstruction is passed. The liner then returns to the maximum diameter.

These arms also offer the ability to reduce liner diameter to facilitate the negotiation of changes of direction in the pipeline.

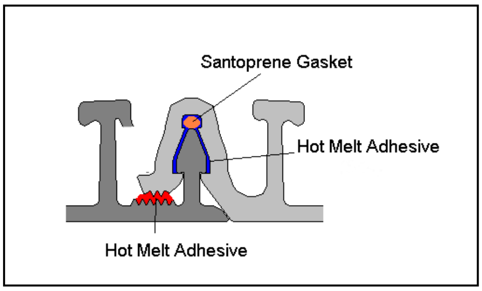

Figure 2: Rotaloc lock configuration

As with other Rib Loc lining systems, little or no excavation is necessary and, because no heating or curing is used during installation, the lined pipeline can be put back into service immediately.

As the whole length of the liner does not rotate, the forces on the lock are much less than with other types of machine spiral wound liners. Thus the lock used to form the liner can be much simpler.

The spiral lock of the Rotaloc PVC profile contains adhesives as well as an EPDM rubber seal. All sealants and adhesives are pre-applied as part of the plastic strip extrusion process. No sealants or additional sealing components need to be applied on site. This removes one of the more complicated site processes associated with pipe installation. Greater precision can be achieved in a controlled factory environment.

Two profiles are currently available to suit liner design requirements. These profiles vary the thickness of the plastic and the height of the tee ribs.

All components used to form a Rotaloc liner have been extensively tested for suitability for use in a sewer environment. Tests have been conducted on lining components and manufactured liners.

In particular, tests on wound liners were performed to satisfy the chemical resistance requirements of contracts in the Middle East, where high temperatures, high acidity and highly saline groundwater preclude the use of many pipeline materials.

Rotaloc was awarded the International Society for Trenchless Technology's "No Dig 2001" award as the most important worldwide advance in the industry in 2001/2002.

2.2 RIBLINE

Rib Loc Ribline is a fixed diameter liner comprising steel ribs encased in polyethylene profile. The general arrangement is as shown in Figure 3.

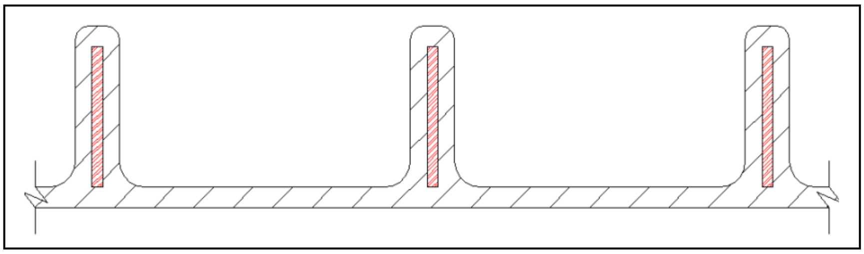

Figure 3: General arrangement of Ribline cross section showing steel encased in the polyethylene

Ribline is installed by a winding machine placed in the base of an access chamber. The polyethylene / steel profile is fed from an above ground spool to the machine, which helically winds it, welding the edges together, to form a "pipe within a pipe."

The winding machine can be set to manufacture the largest fixed diameter that will fit into the deteriorated host pipe. The annulus between the liner and the host pipe is filled with cementitious grout.

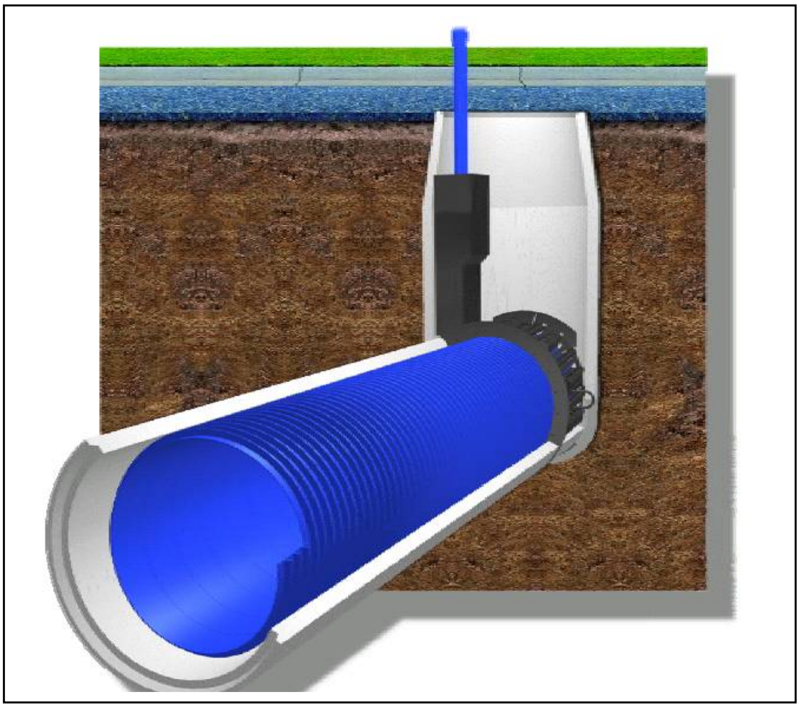

Figure 4: Illustration of Ribline installation

Ribline is a further development of 2 existing Rib Loc pipe and liner technologies:

- Ribsteel: steel reinforced PVC fixed diameter liner, made in diameters from 800mm to 1,800mm. This is the product that won the International Society for Trenchless Technology's "No Dig '97 Award." Ribline offers the advantages of being much lighter in weight and cheaper to produce than Ribsteel.

- Rib Loc "Plastream" Pipe: Plastream is steel reinforced polyethylene drainage pipe. It is being installed Australia wide for stormwater applications with diameters from 225mm to 2,250mm. It is also suitable for fabrication into detention tanks.

3. DESIGN OF ROTALOC AND RIBLINE LINERS

Rotaloc and Ribline can be designed as "structural" liners. In accordance with most pipeline rehabilitation Specifications. This means they can be designed in the same manner as flexible pipe capable of carrying all loads from soil, groundwater, traffic etc. Most design Specifications assume that the deteriorated host pipe has no remaining strength and is merely part of the soil system supporting the liner. Typically the design method given in Australian / New Zealand Standard AS/NZS2566.1 "Buried Flexible Pipelines, Part 1: Structural Design" is applied.

Both of these types of liners can be classified as WRc Type 2, meaning their strength does not rely on forming a composite section by bonding to the deteriorated host pipe. This provides greater confidence that the design assumptions will be achieved, as, for example, cleaning and preparation of the deteriorated host pipe is not as critical to the strength of the restored pipeline.

In accordance with the principles of flexible pipeline design, the support the pipe receives from the embedment surrounding it must be taken into account when determining its load carrying capacity. Grouting of a liner, filling gaps between the liner and host pipe as well as voids inside and outside the pipe obviously enhances this embedment support. Typically, Australian and New Zealand Specifications require conservative values of soil modulus to be used in liner design. Typically these values are:

- 2 MPa for ungrouted liners
- 4 MPa or 5 MPa for grouted liners

Stiffness of a liner (or pipe) varies with the cube of diameter. The formula used is $S = \frac{EI}{D^3}$. For smaller diameter pipelines, Rib Loc Expanda Pipe typically has sufficient stiffness to satisfy design requirements without enhancement of the embedment and so grouting is rarely required.

Grouting is typically required in larger diameter pipelines where Rotaloc is used, to enable the liner to most efficiently meet the design Specification. Its stiffness comes from the moment of inertia of the PVC profile.

As pipe diameter increases, so the strength of the pipe wall must increase to provide sufficient stiffness to meet design requirements. For large diameter pipes, over 1,500mm in diameter, the steel reinforcement in Ribline achieves this in a light weight and economically efficient manner. As Ribline is a fixed diameter liner, there is always an annulus between the liner and the host pipe. Thus grouting is needed to firmly hold the liner in position, irrespective of the structural design requirements.

4. CASE STUDIES

4.1 CONCORD ROTALOC PROJECT

Projects using Rotaloc have been completed in Australia, The United Arab Emirates, Germany, France, Italy, Hong Kong and India. Liners have been installed in pipelines from 800mm diameter to 1800mm diameter.

Experience on these projects shows that Rotaloc offers new options for overcoming serious project difficulties.

On the Concord project, in inner western Sydney, difficulties to be overcome included limited working hours, bypass pumping, tight bends and working in a residential area.

This Contract, awarded to Interflow Pty Limited, called for the rehabilitation of part of Sydney Water's Concord sewer sub-main, originally constructed in 1935. A 560m long section of 915mm diameter reinforced concrete pipeline required a structural liner and 6 manholes required rehabilitation. The pipeline and manholes had all suffered deterioration due to hydrogen sulphide gas attack.

The section of sub-main to be lined contained 4 tight radius bends. According to information provided, these bends had the following dimensions:

Bend No.	Angle	Radius (m)	Arc Length (m)
AC1	89°	7.62	12
AC2a	108°	7.62	10
AC4	92°	7.62	12
AC5a	89°	7.62	12

The rehabilitated section of sub-main receives flows from 3 sewage pumping stations (SPSs):

- SPS 90: This pumped directly into the manhole at the upstream end of the deteriorated section. Sydney Water allocated a *six-hour* period from 9am to 3pm during which flow would be stored. Interflow was only permitted to enter the pipeline during this 6-hour period, although work external to the pipeline could extend before and after.

- SPS 91 – This pumping station discharged into a manhole approximately 100metres from the start of the project through a 600mm rising main. These flows could not be shut off or diverted as they drained from all local systems. The only option was to bypass pump from SPS 91 to a sewer that discharges into downstream pumping station SPS 41.

  Setting up of the bypass system involved two x 200mm pumps (one active and one standby) complete with 1,100 metres of 200mm diameter polyethylene delivery pipe with Victaulic couplings in 6 and 12 metre lengths. The temporary pipeline crossed environmentally sensitive parklands and a concrete stormwater channel. A temporary bridge was constructed across the channel to support the pipe. A pump technician was constantly on site to monitor the pumps and also walk the delivery line on a regular basis to check for leaks or vandalism.

- SPS 41 – This pumping station discharged into the manhole at the downstream end of the project. Sydney Water diverted it permanently for the duration of the works, with the stipulation that it should be capable of being restored to full operational use in storm conditions.

The location in Concord West is an established residential area with quiet, wide, tree-lined roads. To avoid disruption to residents, noise and traffic control issues needed to be addressed.

Typically, Interflow was able to install up to 80 metres of Rotaloc liner during the 6 hour time frame allowed for pipeline access. Typically, this lining could be completed in 3 hours of winding time. After setting up of the machine, winding was by remote control from above ground, where the machine operator monitored installation via CCTV cameras mounted on the Rotaloc machine. Man-entry to the deteriorated pipeline during liner installation was not necessary – an important consideration. The remainder of the time was taken up with setting up of the machine in the pipeline, removing it at completion of the day's lining work, then making the site safe prior to finishing work for the day.

Despite the bypass pumping and co-ordination with the pumping stations, there was always flow in the deteriorated pipeline during liner installation from local sewer reticulation systems.

Innovation was needed to provide effective rehabilitation at the bends, as they were too acute to allow straightforward lining.

Two of the bends were renovated with structural epoxy mortar, and two were lined with a combination of Rotaloc profile and epoxy. It was found that despite the advice that all bends had the same radius, two were definitely tighter than the others.

On previous projects it had been found possible to simply "drive" the Rotaloc machine around bends, with the strain capabilities of the uPVC profile allowing the liner to conform to the angle and radius of the bend without wrinkling or undue deformation. Previously in pipes of approximately 900mm diameter, bends of 15 metre radius had been lined in this manner.

This type of installation was not possible in the configuration of bends on the Concord project. The technique adopted was to wind the liner as far as possible into the bend. With the lock on the inside of the bend remaining secure, the winding machine was then angled slightly and winding resumed. Winding continued until the liner came out of lock on the outside of the bend. It was found that, using this procedure, the bend could be lined in segments of between 0.5m and 1.5m. The gaps on the outside of the bend were filled with structural epoxy.

As the deteriorated pipeline was gas attacked, the cross section of the pipe was an irregular shape. The Contract required Interflow to fill voids in the pipe external to the liner with cement grout. Prior to lining, 100mm diameter grout injection holes were drilled down from road level through the top of the pipe at 20 metre centres. Grout was then introduced through these injection holes after lining.

The project was completed on budget within 8 working weeks, more than 5 weeks ahead of schedule.

4.2 COOGEE RIBLINE PROJECT

The Coogee Diversion Sewer is a major trunk main that carries flow from south eastern Sydney to Sydney Water's largest coastal treatment plant at Malabar. As well as carrying flow from the city, it also collects gravity inflow from the beach-side suburbs of Coogee, Lurline Bay and Maroubra.

A 1.28 kilometre section of 1,800mm diameter main was found to be suffering from gas attack, which could be expected to escalate in coming years. A 50 metre section was in particularly bad condition, with exposed reinforcement badly corroded. The pipeline contained considerable quantities of silt, and all 10 manholes required rehabilitation.

The maximum depth of the pipeline on this section was 20 metres. The water table was considered to be as high as 6 metres above the invert. In all, the project comprised 10 lengths, with distances between manholes ranging from 35 metres to 225 metres.

The Sydney Water Specification required a structural, high stiffness liner.

An advantage of the Ribline system is that a high stiffness liner can be configured by varying the cross-section of the steel reinforcement encased within the high density polyethylene. Design showed that adequate stiffness could be provided by a liner with an internal diameter of 1,700mm and wall height of 31mm. Survey showed that the actual internal diameter of the deteriorated host pipe was 1,830mm. Therefore if the liner was centralised in the pipeline, the annulus between the outside of the liner would be 34mm.

The configuration of the manholes, with the access shaft offset from the pipeline, meant excavation above the manholes was inevitable. Excavation was minimised to a shaft with an area approximately equal to the base of the manhole. A total of 5 access shafts were constructed for liner installation to allow an upstream and downstream installation from each shaft.

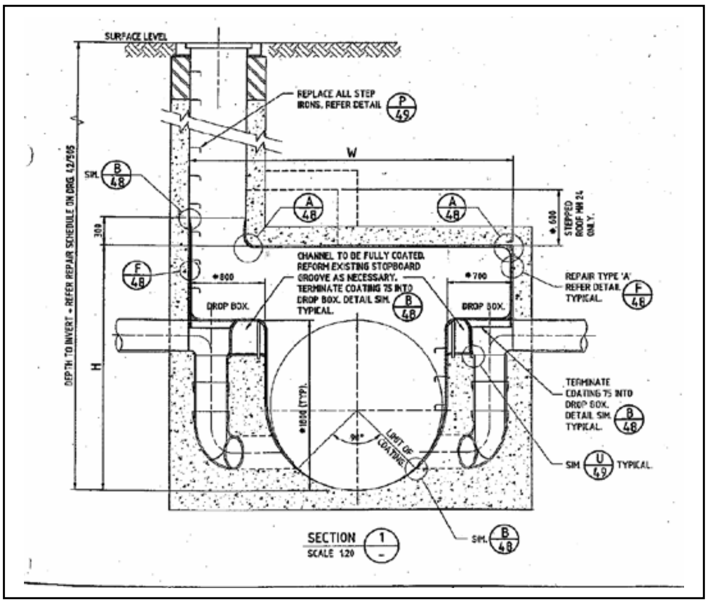

Figure 5: Access chamber detail at Coogee

Flow control, vital to the success and safety of the project, comprised two components:

- Bypass over-pumping
- Controlled flow release.

An over-pumping arrangement was installed to take flow around the worksite in a single stage. Double stop-boards (1.5 metres apart) were installed in a shaft upstream of the works. Flow stored behind the stop-boards was pumped through dual 315mm diameter PN8 PE100 polyethylene piping some 1,300m to a manhole downstream of the works. The pipes were joined by butt or electrofusion welding to maximise flow security. The pipes were buried in trenches for road crossings and at driveway accesses. A total 3,400m of PE pipe were set up for the bypass via two (2) 300mm Godwin pumps.

The stop-boards could be raised to enable some flow into the pipe section being lined. This aided installation as it allowed the liner to float as winding continued, so reducing friction at the winding head. An advantage of the Ribline process is that installation does not block the pipeline. In the event of rainfall upstream of the site, equipment could be rapidly removed and the liner secured. The flow management plan meant that the risk of surcharging was virtually non existent.

Figure 7: Temporary propping of liner for grouting

One of the issues associated with this project was that approximately 300m of pipeline runs under a deep depression or gully which is some 17m – 20m below normal ground level within an operating rifle range. Therefore, a large temporary scaffold stairway had to be installed to provide safe access to the access chamber within the gully, as shown in Figure 6.

Grouting works were completed immediately following the completion of each liner in order to secure each liner and close out each part of the works.

Grouting of a liner of this diameter requires careful planning and execution to ensure that the grout forces and flotation forces do not deform or damage the liner. A further complication was added in that the Client wanted the liner to sit on the original pipe invert rather than being allowed to float the to the top of the pipe as is normal practice.
Therefore, Interflow chose to secure each liner with 4m long 200mm x 200mm universal column (UC) sections laid end to end across the invert of each liner. The UCs were used to brace the liner to the pipe invert with acro props installed every 4m bracing the UC's from the host pipe invert as shown in Figure 7.

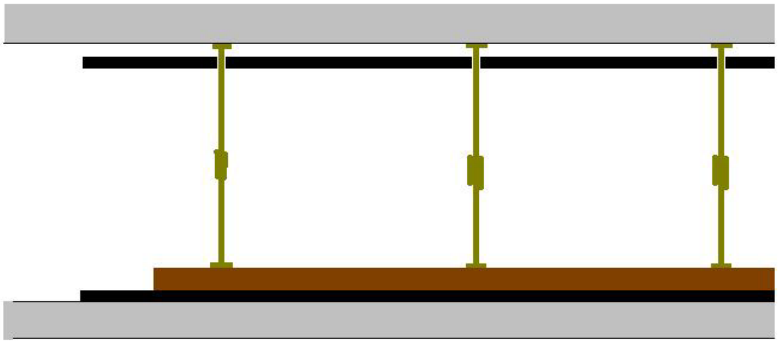

Figure 6: Temporary scaffold access to lining chamber in gully

In order to stop the liner from deforming due to the grout flotation forces, grouting was carried out using a 3 stage approach to completely fill the annulus between the liner and host pipe. A further innovation incorporated to the grouting process was the development of an in-line grout foaming unit by Interflow and one of its suppliers. The grout foaming unit is capable of reducing the specific gravity of standard cement grout from 1.7 to 1.2 as was the case on the Coogee project.

The use of the grout foaming unit reduces the volume of grout delivered to site by 30% and also reduces the hydrostatic loads on the liner during grouting. The density of the grout could be further reduced below 1 with the use of this unit, however, it was decided to maintain a density of 1.2 in order to displace groundwater trapped behind the liner more effectively.

This project is approaching completion in October 2005 and is the largest Ribline project carried out in the world to date.

5. SUMMARY

It can be seen from the above case studies that a number of machine spiral wound lining technologies have been proven to provide;

- Fully structural liners for gravity pipelines suffering from various degrees of structural deterioration.
- Cost effective alternatives to more traditional “dig and relay” methods or total replacement techniques.
- Community and environment friendly solutions which reduce the amount of excavation required as well as total time on site.
- Long term rehabilitation alternatives to isolated “patch” repairs on high risk assets.
- Safety benefits due to a reduction in major civil works required for rehabilitation.