STRUCTURAL RENEWAL OF DETERIORATED UNDER-ROAD CULVERTS

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ABSTRACT (500 WORDS MAXIMUM)

For Councils and Road Authorities, "out of sight and out of mind" is an increasingly unsatisfactory position to take when considering the condition of under-road stormwater culverts.

Deterioration in culverts can lead ultimately to road collapse, sometimes with tragic consequences. Sinking of the road surface above a culvert is often an indication that urgent action is required beyond merely filling the subsidence in the carriageway.

Repetitive loading can cause cracking and joint separation in concrete pipes, while corrosion and abrasion can leave corrugated metal culverts in a dangerous condition.

But roads and highways can't always be closed while they are dug up and replaced.

The situation is the same for sewer and stormwater pipelines in built up city areas. Under every city and town in the world clay, concrete, steel and cast-iron pipelines, many over 50 years old, that are leaking, cracking and corroding. But digging up these pipelines in built up areas and installing new ones would be prohibitively expensive and unreasonably disruptive to the community.

Authorities realise that ignoring the situation is not an acceptable option, so the Trenchless Technology industry has come into being, developing methods to restore the structural condition and flow capacities of deteriorated underground pipelines using techniques that minimise the need for excavation.

Trenchless Technology is an area where the New Zealand and Australian industry is well up with the world leaders, both in terms of developing innovative construction techniques and carrying out demanding rehabilitation projects.

Some of these techniques can be applied to road culverts. Liners can be installed that restore the structural condition of culverts without needing road excavation or causing disruption.

Design of these liners typically assumes that the existing deteriorated culvert has no remaining strength and so all loads are taken by the liner.

This Paper details three lining systems available in New Zealand for deteriorated sewers that have also been used to structurally line stormwater drains and culverts with diameters from 150mm to 3,000mm. It includes examples of projects where these technologies were used, the design issues addressed, and the challenges overcome.

KEYWORDS

Culverts, trenchless, structural renewal, structural design,

PRESENTER PROFILE

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1 INTRODUCTION

Under every city in the world are water and wastewater pipelines reaching the end of their useful lives. Clay, concrete, steel and cast iron pipelines, many over 50 years old, are leaking, cracking and corroding. But digging up these pipelines in inner city areas and installing new ones would be prohibitively expensive and unacceptably disruptive to the community.

The same situation applies to under-road culverts.

Deterioration in culverts can lead ultimately to road collapse, sometimes with tragic consequences. Sinking of the road surface above a culvert is often an indication that urgent action is required beyond merely filling the subsidence in the carriageway.

Abrasion and corrosion are issues that can cause rapid deterioration in corrugated steel and aluminium culverts. FRC culverts also seem to be particularly vulnerable.

Abrasion of the pipe wall occurs through the action of materials carried in flow impacting on the pipe wall.

Debris carried in high flow storm events, such as tree branches, boulders or any other substantial debris can impact on the pipe walls causing serious damage. The situation can be made worse if the flow is acidic. The problem is greater on the upstream side of the corrugations.

Concrete culverts are not immune from deterioration. Their life can also be shortened by corrosion and abrasion, but being rigid, they are more susceptible to cracking caused by repetitive loading or ground movement.

Joint dislocation can occur as a result of errors in the installation process, including improper alignment, or improperly installed bedding or backfill. Settlement or other forms of pipe movement (ground movement or landslides) can produce differential movement of pipes, leading to openings in the joints of the pipe.

Apart from not being readily visible, implementing a program of renewal of deteriorated culverts presents some obvious challenges for Road Authorities.

- Excavating and replacing a culvert would mean road closure for an extended period of time. This would probably be unacceptable to the community, as well as unrealistically expensive.
- Culverts beneath embankments are often difficult to access.

The problems facing Road Authorities parallel those facing Water Authorities with their aging underground infrastructure.

Beneath every city in the world are sewer and stormwater pipelines reaching the end of their useful lives. But, as with road culverts, excavation and replacement is not feasible in built up city areas. But doing nothing is not an acceptable option.

Fig 1: Perforations in the rusted invert of a corrugated metal culvert

Fig 2: Cracks in the top of a reinforced concrete culvert

Figures 3 and 4: Road collapses caused by embedment being washed into a deteriorated or defective culvert or pipeline, leading to the formation of voids beneath the surface.

In response to this need, the Trenchless Technology industry has come into being, offering solutions that restore the structural and flow capacity of deteriorated underground pipelines using methods that require minimal excavation and which cause minimal community disruption. The best of these solutions offers:

- Installation of liners designed to the same structural Standards as for new pipelines.
- Access that does not require excavation. Liners can be installed from manholes.
- Small worksites. Suitable for congested urban areas.
- No interruption to wastewater services to the community during the process.

Some of the technologies developed by the industry have been successfully adapted for the rehabilitation of culverts, offering the same benefits. Issues that need to be addressed when lining culverts, compared to lining sewers include:

- Culverts are naturally installed in low contour areas where groundwater gathers, such as in gullies, at the bottom of embankments, in creek beds etc often making access and site conditions difficult.
- There is usually environmental and/or community sensitivity associated with these locations.
- Culverts need to have sufficient stiffness and strength to be load bearing and to accommodate the loads of road or rail traffic above.
- Culverts are often larger in diameter but shorter in length compared to sewer pipes, so pipe stiffness becomes a critical factor.
- Culverts can deteriorate as a result of corrosion or abrasion, so the liner should be corrosion proof (ie non-metallic) and highly resistant to abrasion, as well as be resistant to chemical attack.
- The inside lining of culverts must be strong enough to withstand damage from impact by boulders, rubble, branches etc during periods of heavy rain or floods.

2 POSSIBLE SOLUTIONS

2.1 OPTION TYPES

Solutions to rehabilitate deteriorated culverts fall into two categories:

1. Short term partial repair
2. Renewal of the asset

Partial repair, involving fixing only the problem area – typically the invert - has the advantage of less initial cost, but is likely to only move the problem to a different area. Eventually renewal will be needed.

For corrugated metal culverts, the most common type of partial repair is to line the invert with concrete. While this can increase the resistance of the invert to corrosion and abrasion, it merely moves the problem further up the wall of the culvert.

Figure 5: Concreting the invert of a culvert can extend its life, but ultimately moves corrosion and abrasion problems further up the wall.

In these instances, partial repair may be a less cost-effective option in the long term than the renewal option. The other important consideration is that the concrete layer in the invert can hamper the works when it is decided to affect the permanent renewal option. Often the original bore size of the culvert is needed so as to avoid hydraulic loss, and when this is required the concrete may need to be removed prior to carrying out permanent renewal works. Removal of the concrete from a prior partial repair job, will increase the cost of a permanent renewal option.

The simplest method for renewal of culverts without excavation is to install a new pipe inside the deteriorated culvert. Called slip lining this involves pushing or pulling steel, concrete, fibreglass or polyethylene plastic pipes into the culvert.

Obvious issues include:

- Considerable loss of internal diameter, as only a set range of standard diameter pipes is available. They cannot be modified to meet the diameter requirements of a culvert.
- High pushing or pulling forces, particularly for heavy concrete pipes. Large jacks are required with considerable support structure to be transported and installed.
- Large worksite needed, including space to store the pipes.

These drawbacks need to be considered by Road Authorities when determining the optimum solution for permanent renewal.

2.2 WOUND IN PLACE (SPIRAL WOUND) LINERS

New Zealand has used two of the three available Australian developed wound-in-place lining technologies that have proven suitable for structural rehabilitation of deteriorated culverts, overcoming the above issues. The three technologies are:

- Expanda Pipe
- Rotaloc
- Ribline

Each of these technologies offers the advantages of:

- Structural lining. The liner can be designed to take all loads from soil and traffic as if the deteriorated culvert has no remaining strength.
- Optimal diameter. These technologies allow supply of custom diameters to best meet the requirements of the deteriorated pipe or culvert they are lining.
- Increased flow capacity. The liners have smooth interior walls, so the lined culvert can carry more flow than the original corrugated metal or concrete culvert, particularly as minimal diameter has been lost.
- Being designed for lining sewers in built up city areas, they only require a small site "footprint."

Each of these technologies uses a continuous strip of plastic, fed to a winding machine which winds it into a continuous helix, locking or welding the edges together to form a pipe inside the deteriorated culvert. The winding machine can be set to wind the diameter of liner required. Different configurations of plastic are available, so liners can be provided to meet the design requirements of the project.

The installation systems for these liners have been effectively designed as mobile pipe manufacturing plants capable of producing liners on site. The installation machinery is compact and portable, so the liners can be economically installed in remote regions.

The plastic strip is delivered to site on spools, so minimising transport costs and the area needed for on-site storage. A compact 2 metre diameter spool can contain sufficient plastic strip to manufacture tens of metres of large diameter liner.

While each of these types of liners has some fundamental features in common, they differ in aspects relating to installation and structural capacity. All the technology was developed in Australia.

2.2.1 EXPANDA PIPE

Expanda Pipe is a system used for providing structural liners for deteriorated pipelines with diameters from 150mm to 1,200mm.

A continuous strip of UPVC is fed to a winding machine placed at the base of a manhole or adjacent to the headwalls of a culvert. The winding machine takes the plastic strip and winds it into a continuous helix, locking the edges together. The liner "corkscrews" up inside the deteriorated culvert until it reaches the far end. Obviously the liner must be initially installed at a smaller diameter than the conduit it is lining.

A unique feature of Expanda Pipe is that a patented mechanical process is used to expand the liner tightly against the host conduit wall after initial installation. This means there is minimal loss of internal diameter.

The plastic strip is smooth on the inside with continuous stiffening ribs down the other side. This gives the liner a smooth inner bore, maximum structural stiffness and minimum weight. Different weights and heights of plastic strip are available to allow a liner to be provided that meets design requirements.

Expanda Pipe has been used in New Zealand for some 15 years. Since 1991 over 3,500 kilometres of deteriorated pipeline have been lined throughout New Zealand and Australia, mostly in deteriorated sewers.

Figure 6: Installing Expanda Pipe in under-road and rail culverts

2.2.2 ROTALOC

Rotaloc is also a UPVC liner but differs from Expanda Pipe in that the winding machine travels up the deteriorated conduit, rotating and winding the liner, locking the edges of the UPVC strip together. The winding machine can alter diameter as it moves, so providing a liner as close as possible to the conduit wall, even if the diameter changes along the conduit length. Loss of internal diameter is minimised.

Figure 7: Rotaloc liner being installed in a corrugated metal culvert

Rotaloc uses heavier, thicker plastic strip than Expanda Pipe, so can meet the structural stiffness requirements of larger diameter liners. It is typically used for lining pipelines and culverts with any diameter from 900mm to 1,500mm.

Cementitious grout is injected behind the liner after installation to fill any gaps between the liner and host culvert, as well as voids in the host pipe. By providing additional support to the liner, cementitious grout increases the liner's load carrying capacity allowing it to be applied to badly deteriorated culverts under high embankments.

The ends of the liner are sealed with structural epoxy.

2.2.3 RIBLINE

Ribline is a high-density polyethylene liner reinforced with steel. It is used for lining culverts with diameters up to and exceeding 3,000mm. The liner is smooth on the inside with ribs on the outside. Each rib encases a continuous strip of steel.

The liner is supplied as a continuous strip of steel reinforced polyethylene profile that is helically wound-in-place in the host culvert by a machine located at the headwall.

The edges of the profile strip are joined by extrusion welding, with the welding head located inside the winding machine. Ribline is thus a strong, joint-free liner.

The liner diameter is set by the winding head. By changing the size of the head, the diameter can be set to provide the largest liner that will fit into the conduit.

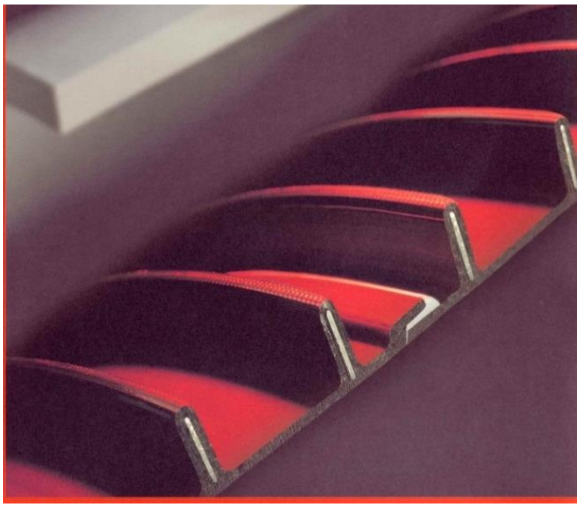

Figure 8: Cross section of Ribline polyethylene profile showing the steel reinforcement in each rib and the weld joining successive helically wound strips

After the liner has been installed the ends are sealed with structural epoxy.

Cementitious grout is pumped behind the liner to fill voids between the liner and the deteriorated host pipe and provide enhanced support to the liner.

2.3 DESIGN OF LINERS

These liners are "structural," meaning they are intended to be load bearing, rather than only providing a smooth coating to restore the surface.

Typically design requirements specify that the Expanda Pipe, Rotaloc or Ribline liner must be structurally designed in accordance with the method given in Australian/New Zealand Standard AS/NZS 2566.1 "Buried Flexible Pipelines, Part 1: Structural Design." This is the Standard that is used for the design of new pipelines, so would also be used if the deteriorated culvert was dug up and replaced with new pipes.

Liners are typically designed to take all loads, including full soil and traffic load, as if the host culvert had no remaining strength, merely forming part of the embankment around the liner. Importantly design does NOT rely on bonding of the liner to the wall nor does it rely on the structure of the deteriorated culvert.

In the majority of design cases Equation 5.4(5) from the Standard governs design:

$$q = \frac{(S_{DL} \times 10^{-6})^{\frac{1}{3}} (E')^{\frac{2}{3}} \times 10^3}{F_S} \quad \ldots \quad \ldots \quad \ldots \quad \textit{AS/NZS2566.1 Equation 5.4(5)}$$

Where: q = loads on the culvert from soil, traffic etc
S_{DL} = Stiffness of the liner (a measured property for flexible pipes)
E' = Combined Soil Modulus (design property based on the type of embedment surrounding the culvert)
F_S = Factor of Safety (typically specified as = 2.5)

Expanda Pipe, Rotaloc and Ribline liners have been configured to meet the requirements of this design method for typical culvert conditions for the range of diameters for which they are applicable. The stiffness of a liner (or a flexible pipe) depends on the liner material, the wall configuration and the diameter. The thicker the liner the greater the stiffness for the same diameter. The larger the diameter, the thicker or heavier the liner wall has to be to have the same stiffness. For Ribline, intended for use in large diameter applications, the liner is reinforced with steel as it is not practical to manufacture a purely plastic liner sufficiently thick to have the required stiffness.

The Combined Soil Modulus represents the support the liner (or a pipe) obtains from its surrounding embedment. By encasing a liner in cementitious grout, it is reasonable to assume it receives support at least equivalent to that from the fill in an embankment.

The stiffness of the liner combined with the support it receives from the embankment embedment is usually sufficient to meet the design Specification based on the above equation and the design method given in the Standard. This includes the design condition where full highway loading is applied.

An improvement in flow capacity is typically experienced after lining. The smoothness of the liner, particularly when compared with a corrugated metal conduit, more than compensates for the loss of internal diameter. The increased velocity of flow through the culvert means that protection measures may be necessary at the exit to protect against corrosion.

Figure 9: Installing a Ribline liner in an 1830mm diameter culvert. Note the culvert in the foreground has been completed, including grouting and epoxy end sealing.

2.4 EXPERIENCE WITH SPIRAL WOUND LINERS

Expanda Pipe, Rotaloc and Ribline have been used to structurally restore deteriorated under-road and under-rail culverts in New Zealand as well as each State of Australia. The capacity of these lining systems to be economically transported and set up on site has been put to the test with culverts being lined in some of the most remote regions.

Some examples have been:

Expanda Pipe: A recent unconventional New Zealand example was a project in Stevenage, Hamilton. This required lining of a non-circular culvert with vertical sides, a flat invert and an arched crown.

A circular liner was installed, expanded to the maximum circular diameter that would fit. The void around the outside of the liner was filled with cementitious grout. As well as providing structural renewal, with the grouted liner designed to take all loads, lining improved the flow characteristics as the smooth circular invert as it minimised the possibility of future silt build up.

Figure 10: Non-circular culvert subject to deterioration and heavy siltation

Figure 11: Expanda Pipe liner installed restores structural capacity. Curved invert reduces siltation

Rotaloc: Culverts up to 1,800mm in diameter have been lined in New Zealand with Rotaloc. The largest has been in Hastings some 2 years ago.

Ribline: To date this has not been used in culverts in New Zealand, although it has been used for rehabilitation of deteriorated large diameter sewers. The largest diameter culvert lined with a wound-in-place liner in Australia, and hence the world, was at Dural near Sydney A 2,750mm internal diameter liner was installed in the nominally 3,000mm diameter corrugated metal culvert. The liner was extended so that it could be encased in an extension of the embankment, allowing widening of the road.

3 CONCLUSIONS

Road Authorities and Councils are increasingly inspecting and (if required) rehabilitating their culvert assets. Events of the past whereby major road collapses have occurred has led to an increase in asset management procedures to consider the maintenance requirements of under-road culverts. Corrugated metal culverts are particularly vulnerable.

Technology is now available to keep the road open while structurally restoring these culverts using methods that overcome the inherent difficulties of remote location and difficult site access.

Lining by Australian developed wound-in-place technology can be provided without causing inconvenience to road users or the community. The liners can be safely installed with due consideration of environmental issues.

They can be designed to take all loads from soil and traffic, assuming no load carrying contribution from the deteriorated culvert. Having a smooth internal surface, rather than corrugated, means flow capacity is typically increased.

Wound-in-place liners, having been installed in New Zealand for some 15 years to restore deteriorated underground sewers, are now being proved by Road Authorities to be equally applicable to under-road culverts.

The technologies are suitable for conduits with diameters as small as 150mm. Most applications so far have been in larger diameters with culverts being relined in excess of 3 metres in diameter.