ORAKEI MAIN SEWER REHABILITATION MH1-MH3 UTILISING SPIRAL WOUND PVC LINING

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ABSTRACT

The Orakei Main Sewer MH1-MH3 section, constructed in 1959, currently provides local network storage and is utilised as an emergency overflow from Watercare Pump Station 64.

The concrete pipe had suffered mortar loss and corrosion, exposing the reinforcement bars and compromising the structural strength of the sewer. The pipeline is located in an upmarket Auckland waterfront district. Watercare decided that in order to satisfactorily rehabilitate the sewer with least disruption to the public, that an in-line rehabilitation process should be investigated.

Three rehabilitation options were presented at Tender Stage:

- Calcium aluminate cement mortar application
- Spiral wound PVC profile strip lining, grouted in place
- Cured-in-place pipe (CIPP) lining

The tender evaluation process determined that the most cost effective option was spiral wound PVC lining. Following tender award, the project was delivered within 3 months causing minimal disruption to the local community and least impact to Watercare operational requirements.

This rehabilitation process has cost-effectively extended the life of the sewer section by 50 years. Upon completion of the project, the strength of the liner was verified by a water pressure test, the first time in Australia and New Zealand that a pressure test had been undertaken on a liner of this size in the field.

KEYWORDS

Wastewater Transmission, Trenchless Technology, Project Delivery, Pressure Testing, Sewer Lining.

1 INTRODUCTION AND BACKGROUND INFORMATION

1.1 WATERCARE SERVICES LIMITED

Watercare Services Limited (Watercare) is New Zealand's largest company in the water and wastewater industry. Each day, Watercare supplies around 330 million litres of water and treats around 408 million litres of wastewater through a system of 16,000 kms of water and wastewater pipes across the Auckland Region. The company is a council-controlled organisation, wholly owned by Auckland Council. It does not operate to make a profit and benefits are returned to the people of Auckland in the company's pricing structure.

Over the next 30 years, Auckland is predicted to grow by one million people. Watercare is responding to this predicted grown by prudently planning and developing water and wastewater infrastructure in a way that will contribute to the future economic, social and environmental health and well-being of the region (Watercare Services Limited 2013 Annual Report).

As a minimum cost provider, Watercare strives to determine cost effective technologies for infrastructure renewal projects and are increasingly resorting to trenchless technologies to meet business objectives.

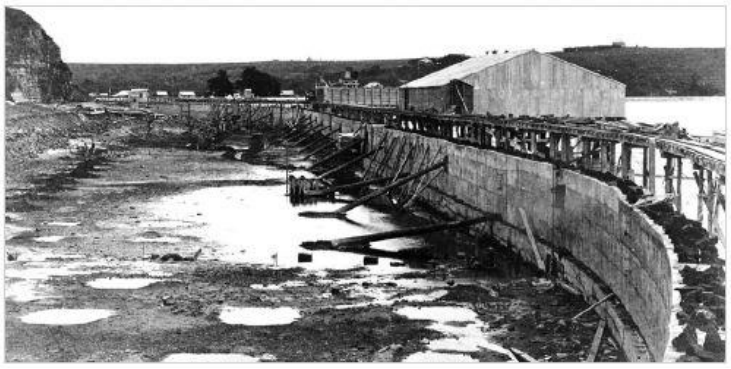
The Orakei Main Sewer Rehabilitation Manhole (MH)1-MH3 Project provides a specific example where Watercare utilised a cost effective trenchless rehabilitation technique to substantially extend an ageing asset life with minimum public disruption.

1.2 ORAKEI MAIN SEWER – AUCKLANDS WASTEWATER HISTORY

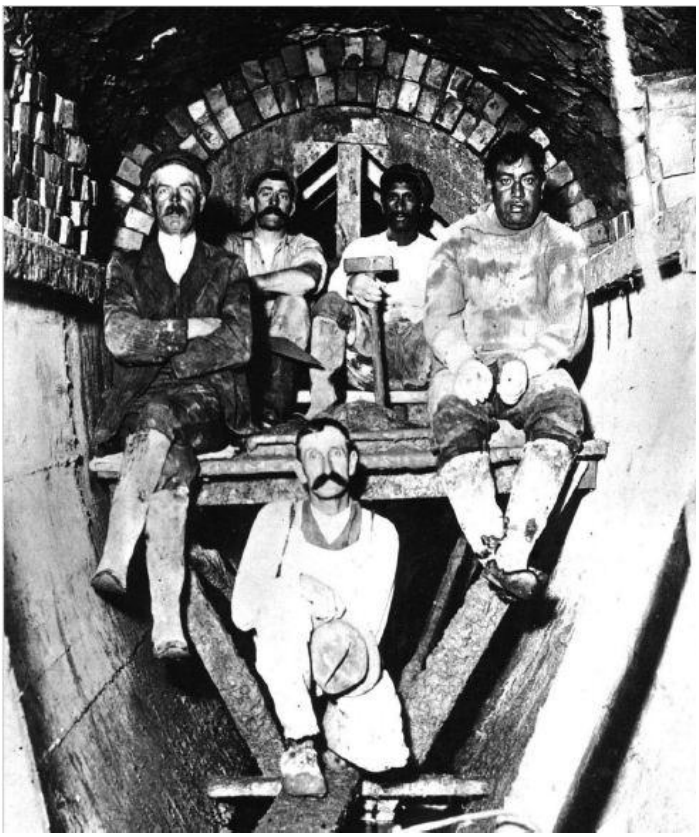
In the late 19th Century, the requirement for an Auckland city-wide reticulated wastewater disposal system was identified. At that time, the main form of wastewater disposal was 'nightsoil' collection. This involved the collection of wastes from individual dwellings at night by a horse drawn cart. As the city population increased, unsanitary conditions and odour generated from this practice was also increasing in the local streams and bays around the Waitemata Harbour. In addition, public outbreaks of Typhoid attributed to low levels of sanitation had been occurring in the crowded working class area of Ponsonby.

In 1903, as the city's population had reached 100,000, a recommendation for a reticulated scheme to handle both wastewater and stormwater was presented by a London engineer, Mr G. Midgley Taylor. Taylor's scheme involved the construction of the Orakei Main Sewer flowing eastward from Point Chevalier to Okahu Point where storage tanks would hold the flow of screened but untreated wastewater, which would then be discharged through a 300 metre outfall pipe to Okahu Bay. The Hobson Bay Sewer pipe was also constructed as part of this scheme and the project was completed in 1914. The majority of the sewer pipelines constructed under this scheme are still in use today, although most sections of the branch sewers have now been rehabilitated using a variety of trenchless techniques.

In subsequent decades, an expanding Auckland population and advancing technologies resulted in the construction of what is now known as Mangere Wastewater Treatment Plant (WwTP) in South Auckland in 1960. When this plant was commissioned, the flows which had previously been discharged via the Orakei outfall were diverted to the WWTP and the redundant storage tanks were converted into exhibition areas for Kelly Tarltons Aquarium, a popular Auckland tourist destination.



Photograph 1: Wastewater storage tanks under construction in Orakei in 1911



Photograph 2: Construction of the Hobson Bay Sewer

1.3 ORAKEI MAIN SEWER DIVERSION MH1-MH3

With the decision to discontinue the discharge of wastewater flows via the Orakei outfall, in the 1950's, it became necessary for Watercare (previously the Auckland Metropolitan Drainage Board) to construct the Orakei Main Sewer MH1-MH3 and associated pumping station No 16 to transfer the diverted flows into the newly commissioned Eastern Interceptor.

In its original form, the 590m diversion section functioned as a gravity sewer, using 61"/1.55m reinforced concrete rubber ring joint (RCRRJ) pipes, with a gradient of 0.25% (1 in 400) from MH1-MH3. It is worth noting that the contract drawings for the original construction of the diversion section show extensive field drainage and provision for additional bedding, to allow for the poor quality of the reclaimed swamp ground in which the pipeline was to be built.

In 2010, Watercare undertook a further significant upgrade in the area, which included the construction of Pump Station (PS) 64 and the Orakei Main Sewer Hobson Diversion. The Orakei Main Sewer MH1-MH3 was no longer required to operate as a trunk sewer, and is now utilised as storage, network reticulation and a pumped emergency overflow from PS 64. An overview of the network is illustrated on figure 1 overleaf.

During the period in which it operated as a transmission pipeline, the sewer suffered extensive mortar loss in the arc above the flow line. In November 2012, Watercare approved capital expenditure for the design and construction for the rehabilitation of the Orakei Main Sewer MH1-MH3.

Figure 1: Orakei Main Sewer Infrastructure

1.4 PROJECT OBJECTIVES

The Orakei Main Sewer Rehabilitation MH1-MH3 project objectives were:

- Rehabilitate 590m of 1550mm diameter wastewater sewer utilising trenchless techniques
- Prevention of wastewater overflows to sensitive environments as a result of pipe failure
- Avoidance of expensive and unpredictable emergency repairs
- Minimise unacceptable service disruptions to customers
- Minimise public disruption

1.5 STAKEHOLDER REQUIREMENTS

The Orakei Main Sewer MH1-MH3 is located in an upmarket Auckland waterfront location. The sewer intersects the Orakei Domain, Watene Reserve, Reihana Street and Watene Crescent. A key driver in the utilisation of trenchless technologies for this project was to ensure minimal public disruption in this sensitive area. Access to the sewer for construction was able to be through the existing manholes and a contractor set up area was established in the car park adjacent to the reserve and Watercare Pump Station 64. This resulted in minimal disruption to sports facilities in the reserve.

MH2 in the middle of the run, was deemed to be the most advantageous for gaining construction access and had been utilised by Watercare in the past for scheduled maintenance. This access was situated in a property driveway, as shown in photograph 3 overleaf, and continual liaison was required with the property owner throughout construction.

The use of trenchless technologies also significantly minimizes the impact on the road corridor and subsequent traffic management.

The benefits described above greatly enhance Watercares working relationships and reputation with key stakeholders including Auckland Transport, Auckland Council Parks, Local Sports Clubs and the general public.

Photograph 3: Manhole 2 located in Watene Crescent

2 DESIGN DEVELOPMENT AND TENDER PREPARATION

2.1 INTRODUCTION

In January 2013, Watercare appointed AECOM New Zealand to undertaken the design, tendering and contract supervision for the Orakei Main Sewer Rehabilitation MH1-MH3.

The design phase of this project had a number of objectives, including:

- Review of existing investigation reports and condition data
- Investigation & assessment of utility services & adjacent structures likely to be affected by the works
- Assessment of rehabilitation processes applicable to the project
- Flow diversions & management of the works
- Constructability, operation & maintenance strategy
- Consenting and landowner approvals, stakeholder consultation strategy
- Engineer's estimates
- Risk assessment

A primary requirement in selection of construction methodologies for this project was to minimise risk in the construction phase of the project, and adverse effects of the project on the public and affected stakeholders.

2.2 INVESTIGATION

The CCTV surveys and other preliminary investigations previously undertaken by Watercare had found significant evidence of corrosion damage in the pipe, including extensive loss of mortar cover to the aggregate, exposure of the reinforcing matrix, and profile deformation above the flow line. Multiple failed joints were also visible.

The as-built records did not provide much useful information about the quality of the bedding and backfill, but the ground in which the pipeline is laid is believed to be reclaimed. The CCTV showed many minor gradient changes, suggesting that it may have settled after it was laid.

The Auckland Metropolitan Drainage Board (AMDB) long section drawing showed that the reinforced concrete rubber ring joint pipes used to construct the diversion section were a mixture of '20ft head' and '50ft head' pipes, but no further details were available to provide any indication of the load capacity or reinforcing in the pipes. In any case, it was quite clear that the inner layer of reinforcement, where exposed, could no longer be providing the stiffness for which the pipes had been designed.

It had been determined that the reduced flow through the pipeline following commissioning of the Orakei Main Sewer Hobson Diversion Tunnel in 2010 had resulted in a marked reduction in the corrosion rate. Nevertheless, it was obvious from the CCTV surveys that the extent of structural damage was such that it could not be expected to last indefinitely without intervention, and that a fully structural lining process of some kind would have to be applied to achieve the life extension required.

2.3 DESIGN DEVELOPMENT

The greatest loading on the pipeline is the soil and hydrostatic load at the south western end, adjacent to PS64, but it also runs under local roading (Watene Crescent) and grass reserve areas as illustrated on Figure 2 below. Heavy vehicle traffic does use this road on occasions, and even the grass areas are subject to truck loads during community events.

Figure 2: Orakei Main Sewer MH1-MH3

This pipeline is also very unusual in that it must function as a pumped overflow when inflows to the PS64 Pumping Station exceed capacity of the downstream sections (approximately 4 times per year), as well as being a gravity sewer in normal service. This feature required that the rehabilitation process should also provide for the line to be able to serve as a pressure main when operating as the pumped overflow.

Although the pressure required to drive the pumped overflow is not great when compared to the pressures in rising mains, the requirement for internal pressure capacity is not a common one facing designers of rehabilitation projects in wastewater conduits of this size. Figure 3 overleaf shows an excerpt from the Watercare Hydraulic plan for the sewer section.

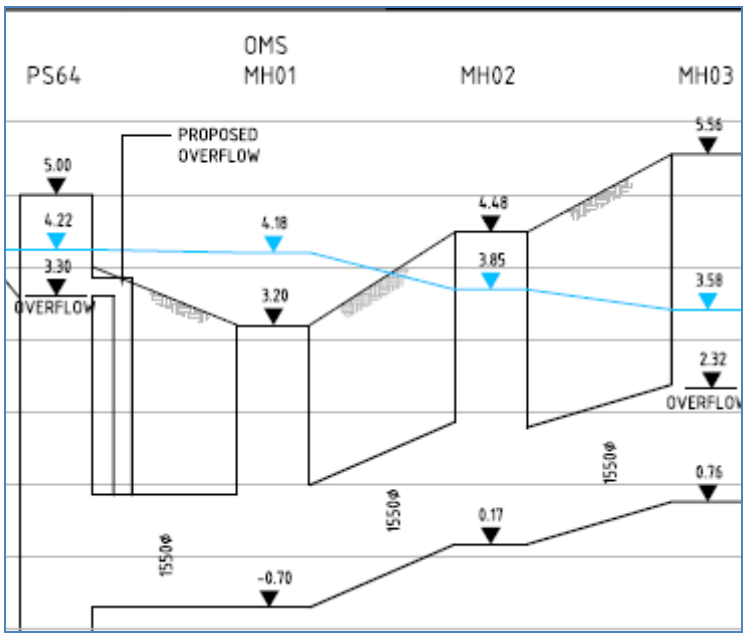


Figure 3: Orakei Main Sewer MH1-MH3 Hydraulic Grade Line

In normal service, following the commissioning of the Orakei Main Sewer Hobson Diversion, the section only carries local reticulation flows in the range of 20 to 50 l/s.

Prior to the Hobson Diversion being available, it previously carried the entire flow of the Orakei main sewer, and it would not have been practical to take this section out of service for a rehabilitation construction project. Even during prolonged dry weather, the minimum flows would have required management of flows up to 500 l/s, making any of these rehabilitation processes a challenging proposition.

In contrast, once the Hobson Diversion had been commissioned, and the Orakei main Sewer MH1-MH3 section was no longer required to carry more than the local reticulation flow, these issues became much less of an obstacle to a rehabilitation project, and permitted for the use of a much wider range of rehabilitation methodologies, including:

- Spiral wound PVC profile strip lining
- Cured-in place pipe lining
- Insitu reconstruction by reinforcement replacement and calcium aluminate cement (CAC) mortar spray

The option of replacing this pipeline section by conventional open excavation was not considered, as it would have involved extensive disruption and inconvenience to a sensitive part of Auckland's waterfront, and substantial disruption to the sports and community events which take place on the Reserve.

Sliplining with GRP segments was also briefly considered as an option, but it was discounted, for a number of reasons, including the following:

- The tight timescale for the project would not have allowed sufficient time for development of a new Watercare specification to cover the design and installation of suitable linings
- The extent of excavation would probably have been wider than for the other methodologies considered
- The cost of the structural slip lining segments would probably have been greater
- The time to manufacture the segments would have extended the project timescale

A particular factor affecting projects of this nature in New Zealand is that for each rehabilitation methodology, the number of specialist contractors capable of doing the work required is very small, and in some cases,

limited to only one. This often results in difficulty in getting a competitive tender from the small pool of prospective tenderers.

For this reason, it was decided to advance three rehabilitation construction techniques to Tender Stage:

- Cured-in-Place-Pipe (CIPP) lining
- Calcium Aluminate Cement (CAC) Mortar Lining
- Spiral Wound PVC Strip Lining

Unusually, in this project, the balance of technical factors made it possible to invite tenders from four different specialist contractors, who between them offered competitive pricing for two of the three selected rehabilitation methodologies.

2.4 SCOPE OF WORKS

2.4.1 SCOPE OF WORKS

The form of contract utilised for the project was the NZS 3910:2003 Conditions of Contract for Building and Civil Engineering Construction and the main scope of works was identified as:

- Compilation of detailed construction methodology for the works specified in the contract
- High pressure (140 MPa/20,000 psi) water blasting of the sewer to remove loose and corroded concrete
- Confined space health and safety management to include the supply and operation of ventilation, flow management, communications systems, safety apparatus and specialized equipment
- Supply and installation of materials to carry out structural lining or rehabilitation of the pipeline
- Enabling works, flow management and co-ordination with Watercare Operations and Projects Teams to gain access approval to work in the sewer
- Undertake a low pressure hydrostatic test
- Post-rehabilitation CCTV, walk through inspections and as-built data
- Reinstatement of all disturbed areas

2.4.2 PIPE DETAILS

The sewer pipeline rehabilitation lengths and manhole dimensions are illustrated on Table 1 below.

	chainage		Depth to invert		Length	Shape	Size (Ø or WxH)	
	ft	m	ft	m	m		inch	m
MH03	2010	612.8	13	3.95				
					239	Round	61"	1.549
MH02	1225	373.5	12.7	3.89				
					346	Round	61"	1.549
MH01	90.16	27.5	16	4.88				

Table 1: Manhole distances and dimensions

3 TENDER AND CONSTRUCTION

3.1 TENDER

The project was advanced to tender stage in March 2013. Three competitive tenders were received and included both the spiral wound PVC strip lining and cured in place pipe (CIPP) rehabilitation techniques.

Following a tender evaluation, Interflow Pty Limited were awarded the Orakei Main Sewer Rehabilitation MH1-MH3 contract, utilising their Rotaloc® PVC relining system.

In their tender submission Interflow presented the whole of life benefits of the system to be:

- The Rotaloc® liner proposed provides more than surface protection, it has independent structural strength. This provides long term renewal for the deteriorated pipelines and greater assurance of long term effectiveness.
- Designed to take all loads from soil, traffic and groundwater as if the deteriorated host pipe has no remaining strength. The Rotaloc® liner does not rely on bonding to the host pipe to be able to resist loads.
- Smooth internal surface for greater flow capacity. As the liner does not soften and attempt to mould to the irregular shape of the deteriorated host pipe, a Rotaloc® liner will not have wrinkles, folds or steps. Rotaloc will provide a circular liner with uniform wall configuration.
- Greater abrasion and corrosion resistance. uPVC is inert in sewer conditions and has abrasion resistance proven in some 40 years of continuous use in New Zealand sewage systems. It has superior properties in both of these areas compared to gunite.
- More assured quality as it is machine-installed. It does not rely entirely on workmanship
- No bypass required. The Rotaloc® liner will be installed without the need for construction and operation of a bypass pumping system and can be installed during normal working hours
- Rotaloc® is installed by a mechanical process which, as well as providing greater quality assurance also means greater safety as less man-entry is required.

3.2 COST

The tender submission proposed resulted in a 20% cost saving for Watercare in comparison to the capital expenditure estimate undertaken at business development stage.

This saving was significant as the capital cost of infrastructure works in Auckland had been rising steadily due to a number of factors, including:

- The limited number of contractors in the market with the know-how to install specialised rehabilitation products of the scale, complexity and risk inherent in this project
- The competition for specialised contractor and support resources arising from the demands of the Christchurch emergency rebuild programme
- Emerging technologies which increase the feasibility (and cost) of previously impracticable projects

Interflow commenced construction on site on 29 April 2013, and practical completion was achieved on 9 August 2013. The main project milestones consisted of:

- Submission and acceptance of construction management plan and methodology
- Submission and acceptance of Watercare's Access Activity Authority (AAA) for works affecting Watercare Assets and a Job Safety and Workplace Environmental plan (JSWEP) by Watercare Projects and Operations Teams
- Site establishment and implementation of flow controls
- Waterblast cleaning the sewer and high pressure waterblast scabbling at manhole entry / exit to prepare for epoxy mortar sealing
- Installation of Rotaloc Machine
- Lining of sewer from MH2 to MH3 – 239m and MH1 to MH2 – 346m
- Removal of Rotaloc Machine
- Grouting
- Final CCTV and walk over inspection
- Pressure Test

Key work milestones involved considerable enabling, testing and inspection works. The liner installation process in the live sewer started on 6 May 2013, and was completed by mid July, despite some weather delays, the addition of significant extra work, and pressure on the contractor's resources from other Watercare projects which were in progress at the same time.

A visual and physical inspection was carried out in July 2013, with satisfactory results, but the pressure test was postponed until the following dry season, to minimise risk, and because of constraints on the contractor's availability.

3.3 HEALTH AND SAFETY

Due to the high risk nature of construction in a live sewer system, a large number of health and safety factors required consideration to include:

- Confined Space Entry immediately upstream of pump station inlet
- Long distances to nearest available exit points for installation crews
- Flow management of major sewer flows with minimal freeboard at MH2
- Working in a live sewer system with potential contaminants
- Work in a live sewer subject to sudden increases in flow level due to rainfall in upstream catchments
- Requirement to work in areas accessible to the public, stakeholders, and traffic

3.4 OPERATIONAL CONSTRAINTS

Although the Orakei Main Sewer MH1-MH3 is not presently utilised as a trunk sewer, it does carry a constant local reticulation flow of 20-50 l/s and during periods of wet weather is utilised as emergency overflow from PS64 – approximately 4 times per year.

Auckland's subtropical climate, with high levels of rainfall occurring year-round with an average of 1240mm per year, provides a challenging environment for construction in a live sewer system.

The Watercare Wastewater Transmission Operational Team are responsible for the daily operation and maintenance of 58 wastewater pumping stations and 350km of wastewater transmission sewers throughout Auckland. In-line sewer rehabilitation has substantial advantages from a cost, time and stakeholder point of

view, but it requires extensive co-ordination of in-house resources to ensure that all works undertaken on the sewer system do not hinder their functionality. On a daily basis, Wastewater Transmission Operations could be coordinating up to 10 contractors working in their live sewers.

These constraints made it difficult to ensure that construction programme objectives were met. It involved daily (sometimes hourly) co-ordination with Wastewater Operations, Wastewater Projects Team, the Engineers Representative and the Contractor. Risks, Hazards and weather were assessed on a daily basis to determine if it is safe for the contractor to undertake their works.

The main operational hazard for the Orakei Main Sewer Rehabilitation MH1-MH3 was the fact that this sewer line is required to be available for use at short notice as emergency storage from PS64. This functionality had to remain fully available throughout the project, in addition to the requirement for Interflow to work during dry weather only, when flows through the diversion section were low enough for the Rotaloc installation process to be carried out without overpumping.

For the pressure test phase of work, Interflow installed a weir board in MH3 to divert flows via the Orakei Main Sewer pipeline section MH3 to MH6, so that they could be diverted to reach PS64 via an alternative gravity route whilst the section MH1 to MH3 was isolated for the duration of the pressure test.

Although the inflow at MH3 is normally around 20 l/s during dry weather and diversion of the flow by the alternative route was relatively simple, it required a forecast of at least three days of dry weather for this flow diversion to be installed, since it would prevent the use of the PS64 emergency storage until the pressure test was completed.

3.5 TECHNICAL CHALLENGES

3.5.1 ROTALOC DESIGN

The principal advantage of the Rotaloc system for this project was that it allowed for the lining to be installed without any major flow management, as well as meeting the requirement to provide a fully structural rehabilitation, capable of withstanding internal pressure, and maintaining hydraulic capacity in the diversion section. Figure 4 below illustrates the Rotaloc standard profile strip. Photograph 4 below shows the Rotaloc installation in the live sewer.

Figure 4: Rotaloc Standard Profile Strip

Photograph 4: Rotaloc installation in the Orakei Main Sewer MH1-MH3

3.5.2 END SEALS

Due to the poor quality of the surrounding soil, and the evidence of subsidence during the life of the pipeline, the contract specification also included a requirement for the liner ends to be fully sealed with epoxy mortar at the manhole terminations. In order to provide a sound surface for bonding of this seal, ultra high pressure water blasting was used to scabble the pipe entry and exit before placing the mortar. Visual inspection after the liner installation confirmed the effectiveness of this technique

3.5.3 GROUTING

Once the Rotaloc® lining strip had been fully installed, a cementititous grout was applied to fill the annular space between the lining strip and the host pipe. In the case of this project, the liner was designed to be fully structural, and to withstand internal pressure, which meant that the grouting process had to be 100% effective. This was verified by several visual and mechanical inspections in the course of the installation process.

3.5.4 FLAT TOP SEWER BEND AT MH3

Immediately downstream of MH3, there was a curved section, including a 10m length of rectangular culvert, which presented a further challenge for this project. The standard Rotaloc liner would not have been suitable for lining this curve, and the original intention was to rehabilitate this section by conventional reconstructive techniques, using reinforcement replacement and shotcreting with calcium aluminate cement mortar. However, Interflow proposed a newly developed variant of the Rotaloc® profile for this section, which allowed for the same rehabilitation process to be used throughout. For the flat top section, the lining was continued into the manhole, and the void space was filled with grout, so that the circular profile was installed continuously from MH03 to MH02. The bend profile strip utilized is illustrated on figure 5 below and shown in photographs 5 and 6 overleaf.

Figure 5: Rotaloc Bend Profile Strip

Photographs 5 & 6: Rotaloc installation in the Sewer Bend MH2-MH3

4 COMMISSIONING AND TESTING

4.1 PRESSURE TEST SPECIFICATION

Due to the fact that the Orakei Main Sewer MH1-MH3 operates as a pumped emergency storage from PS64, the contract specification included a requirement for a post construction low pressure hydrostatic test on the full length of the pipeline, as described in AS2566:2. This was in addition to the visual and mechanical testing also specified

The specification stated that the test head was to be 2 m above the highest point in the pipeline section, and the acceptance criterion would be that the water volume loss should be less than the volume calculated in accordance with section 6 of the standard.

The following test procedure was specified, and was used by the Contractor

- Plug the ends of the pipeline
- Brace / support the plugs adequately to safely withstand forces generated by the test pressure.
- Fill the pipeline with water and leave overnight before testing.
- Apply the test pressure and measure volume loss

If the volume loss was less than the allowable loss, the pipeline section would be considered to have passed the test.

4.2 OPERATIONAL LIAISON AND H&S REQUIREMENTS

Once the main lining installation works had been completed, the practical completion certificate was issued in August 2013. However, it had become clear that the weather had settled into the winter 'wet' pattern, making it difficult to plan a work activity requiring at least three days forecast of fine weather. It was therefore decided to postpone the pressure test until March 2014.

Due to the high risk nature of the works, Interflow's pressure test methodology and health, safety and hazard analysis had been substantially reviewed by all parties and accepted significantly in advance of the proposed works. Meetings were also held with the Contractor, Engineers Representative, Watercare Operations and Projects Teams to consider and assess the risks and discuss roles, responsibilities and communication protocols.

4.3 PRESSURE TEST RESULT

It was anticipated that the pressure test could be difficult to complete quickly because of the risk of delays due to:

- Time required to fill the pipeline (110m3)
- Time required to purge air from the test water
- Time required to soakage
- Risk of weather delays

Approximately 1 day was required to fill and purge the pipeline. Within a couple of hours, the volume had stabilised to less than the allowable rate, and the test was started. Within 30 minutes, it was clear that there was no significant loss of volume from the pipeline. The pressure test was deemed to be successful and it was the first time in Australia and New Zealand that a pressure test had been undertaken in the field on a Rotaloc lined pipe of this size.

5 CONCLUSIONS

Watercare as an Auckland Council Controlled Organisation, are obligated to be a minimum cost provider in its provision of water and wastewater services throughout the Auckland Region. Where feasible, Watercare strive to utilise trenchless technologies in their infrastructure projects due to their significant cost and programme benefits. In addition, the utilisation of trenchless technologies results in a reduced disruption to the general public and key stakeholders enabling works to be undertaken with minimum community and traffic disruption.

The Orakei Main Sewer Rehabilitation MH1-MH3 project was an example of a trenchless project that substantially exceeded its project deliverables. The project was delivered significantly ahead of programme and resulted in a 20% cost saving for Watercare.

There were a number of high risk elements to the project including working in a live sewerage system, Auckland's unpredictable climate and the hazards associated with pressure testing a 1550mm diameter sewer in the field. Significant collaboration was required from Watercare Operations and Projects Team, the Engineers Representative and the Contractor to mitigate the risks and the team successfully delivered a project ahead of time and under budget.

ACKNOWLEDGEMENTS

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