THE CHALLENGES OF RELINING A BRICK CULVERT IN AN URBAN ENVIRONMENT

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ABSTRACT

Pipeline rehabilitation in urban environments presents major challenges to asset owners. This paper focuses on how Auckland Council overcame these challenges to rehabilitate a 140m length of 1350mm diameter stormwater brick culvert which also carries wastewater overflow in rainfall events from the sewer system serving a portion of the Freemans Bay catchment. The culvert was built in the early 1920s and it was subsequently covered in stages as fill was brought in and placed on top of the culvert over the years. Recent condition assessments indicated that sections of this culvert had experienced severe deterioration, posing high risk for a structural failure. The critical section of the culvert runs under the Freemans Bay School grounds.

The site constraints included 10m deep non-engineered fill, contaminated soil, high water table, tidal inundation, and working in school grounds. Since replacement would have been a very costly solution and resulting in significant community disruption and environmental impacts, a decision was made to rehabilitate in place using a trenchless construction method. A cured-in-place-pipe (CIPP) structural lining was identified as a most appropriate method for rehabilitation. A 10m deep shaft had to be constructed to enable the lining installation. The physical works were successfully completed with minimal inconvenience and disruption to the school, residents, traffic, and community activities.

The paper explores the decision processes in selecting the most adequate rehabilitation method. It describes the investigation, design and construction challenges, the strategies used to manage the risks and the approach ultimately utilised for this unique project.

KEYWORDS

Stormwater brick culvert; condition assessment; pipe rehabilitation; CIPP lining.

PRESENTER PROFILE

Branko Veljanovski is a chartered civil engineer with significant design experience in water infrastructure, including stormwater, wastewater and roading associated precast concrete products, and various pipeline installation and rehabilitation methodologies. Branko has a specialist engineering knowledge in concrete durability and specification, condition assessment and service life predictive modelling of infrastructure assets.

INTRODUCTION

Culvert pipes play an integral part in stormwater infrastructure. The complexity and direct costs of their maintenance are increased with the increase in diameter. The indirect costs associated with maintenance, replacement, risk of failure, road closure, litigations and property damage due to flooding can be significant.

An existing stormwater brick culvert, which runs under the Freemans Bay School grounds (Fig. 1), was found to be in critical condition, posing high risk for a structural failure. AECOM was engaged to inspect the condition of the culvert and to develop concept options for pipe renewal. The walk through inspection carried out in early 2013 confirmed that the condition of this section of the pipeline had deteriorated significantly. The pipeline was evaluated using a recognised methodology, the WRc Sewerage Risk Management Condition Grading Criteria for brick sewers (Ref. 1).

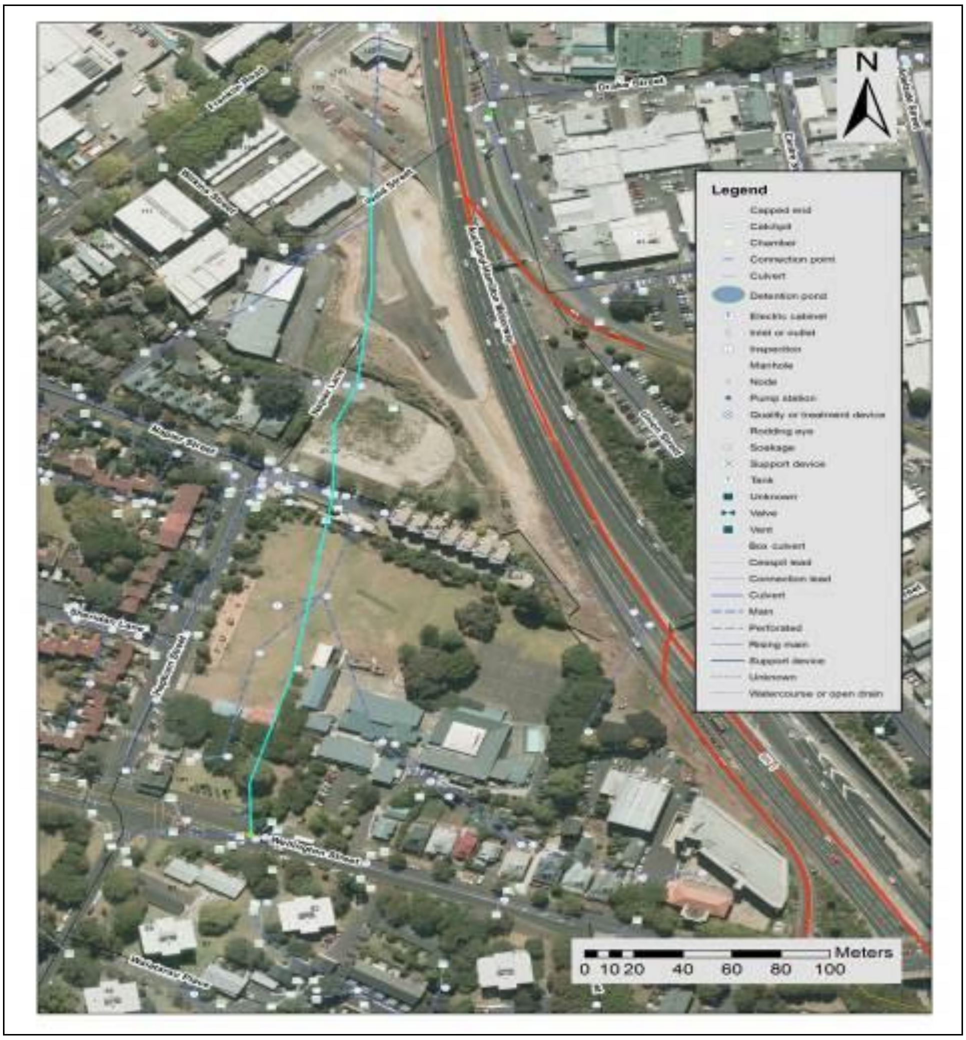

Fig. 1 Site Location (Freemans Bay) - Plan view of the stormwater brick culvert

The section of the stormwater culvert running from a manhole at Wellington Street to a manhole at Napier Lane is thought to have been installed in sections over an existing gully, and subsequently covered in stages as fill was brought in and placed on top of the culvert over the years. In parts of its alignment, the pipe runs under buildings, school playground and main road. It consists of eleven sections of culvert, varying in cross section and dimensions, ranging from a 1050 mm circular brick culvert to a 2250mm x 1900mm brick and masonry stormwater tunnel, made of basalt block walls and arched brick roofs (Fig. 10). The individual construction lengths vary from 5m to 72m. The culvert is estimated to be more than 80 years old.

1 HISTORICAL BACKGROUND

Freemans Bay, the name of a former bay, is now an inner city suburb of Auckland. The historical bay was filled in to a large extent, and lost its shoreline to reclamation works. Historically a poor and often disreputable quarter, it is now a wealthy neighborhood known for its mix of heritage homes and more recent single-dwelling houses, as well as for its two large parks.

Since the turn of the 20th century, extensive land reclamation (partly using stone quarried from nearby headlands) has seen Freemans Bay itself disappear (Fig. 2). The reclamation of the old bay began in 1870s and was finished in 1901, with Victoria Park created on most of the resulting flat area. It is still public land used mostly for sports purposes.

The coastline shifted more than one kilometre to the northwest of the city centre and is now composed of the concrete wharves of Viaduct Basin and the Tank Farm.

Fig. 2 Hickson's 1882 plan of Auckland, showing the area from Patterson Street to Wellington Street, and the line of the stream/culvert (Sir George Grey Special Collections, Auckland Libraries, Map 91)

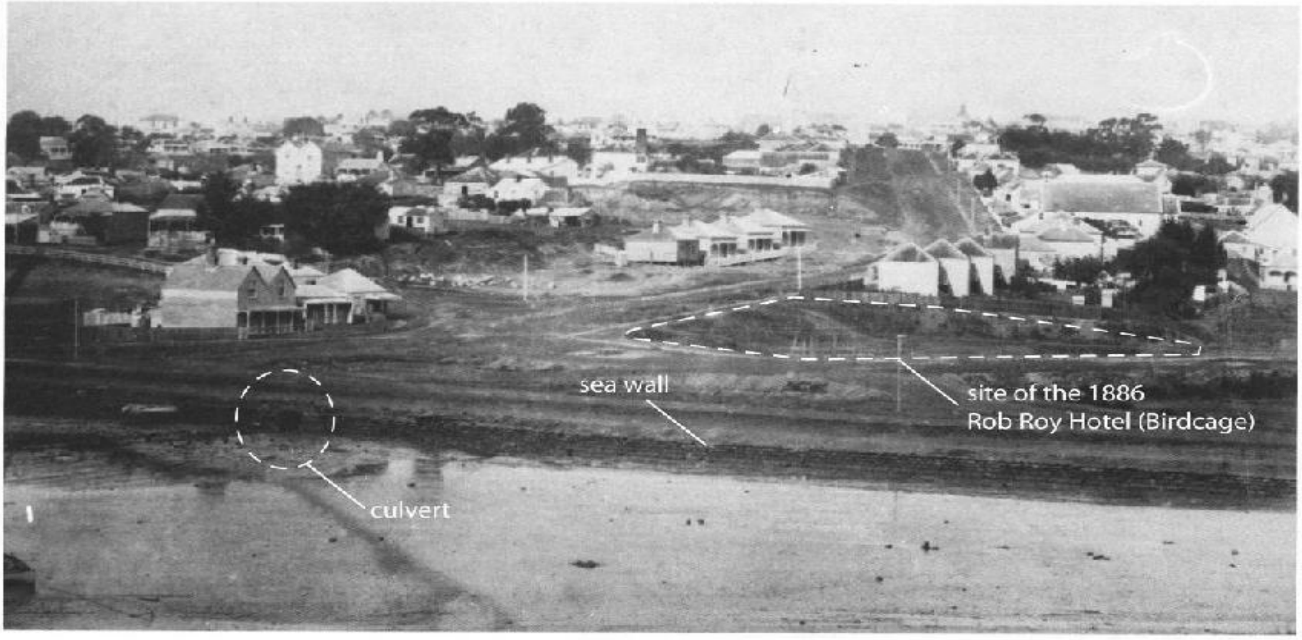

Fig. 3 Undated photograph of Freemans Bay illustrating the Patterson Street sea wall and the culvert draining into the bay. The photo was evidently taken after construction of the sea wall (between 1873 and 1880), but before construction of the Rob Roy Hotel (construction began in 1885 and finished in 1886). The site of the Rob Roy Hotel is indicated (photo: Broomhall, Auckland War Memorial Museum, C16406)

The existing culvert is part of the development history. The historical context enables and understanding of the type of the soil surrounding the culvert, and that it may be contaminated. It also confirms that the culvert was developed as a combined sewer (Fig. 4).

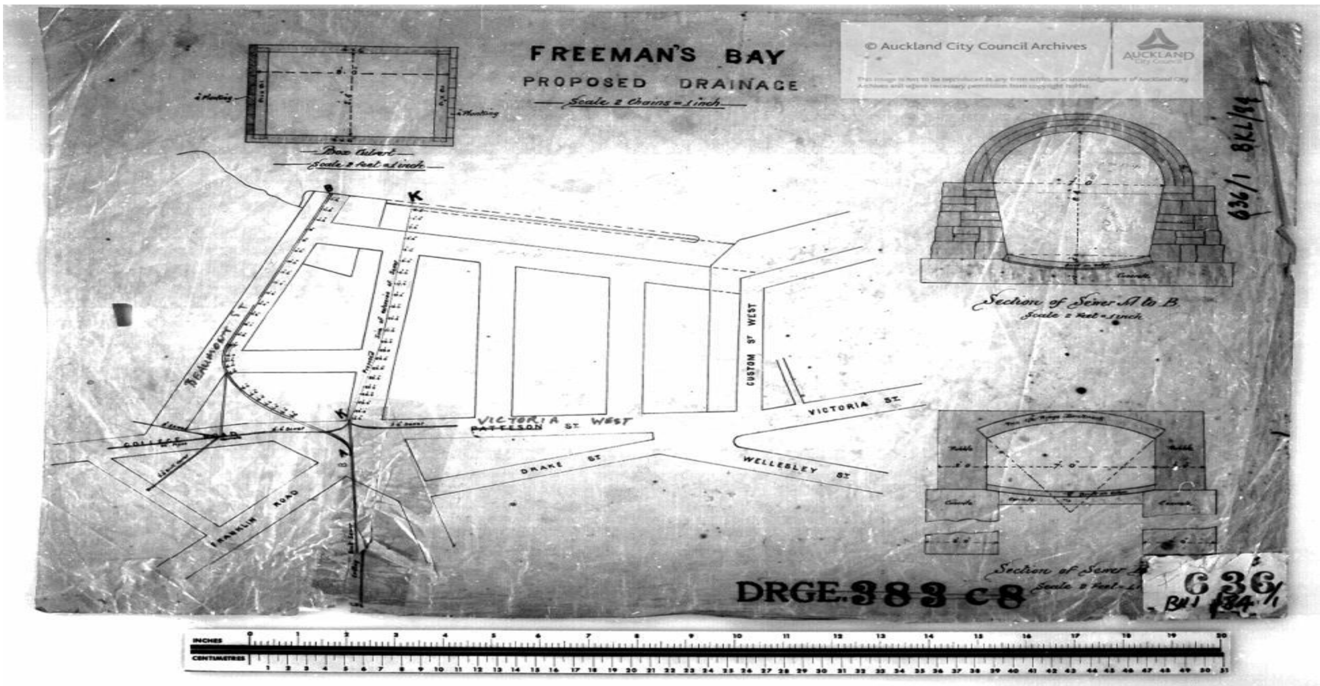

Fig. 4 Plan of proposed drainage at Freemans Bay. The plan is undated. However, it seems that some of the drainage (on Beaumont St, Victoria St, and Franklin Rd) may have been already present, with only one section from K-K stated as a 'proposed line of extension of sewer' (indicated by the arrow). This suggests that the plan post-dates the Drake Street to Patterson Street reclamation (between 1873 and 1880), and was probably drawn after the Beaumont St reclamation (1885-1888) and prior to or during the Victoria Park reclamation in 1886-1901 (Auckland Council Archives 033, DRGE 636)

2 DEFINING THE CULVERT'S CONDITION

The culvert was previously inspected in 2000 and some deterioration had been identified. The 2013 walk through inspection found that the condition had deteriorated significantly since then, however the rate of deterioration was difficult to establish without detailed information from the prior investigation of 2000. The actual inspection photographs were compared to those provided in the WRc Structural Assessment Poster for brick sewer published in 1994, as per below.

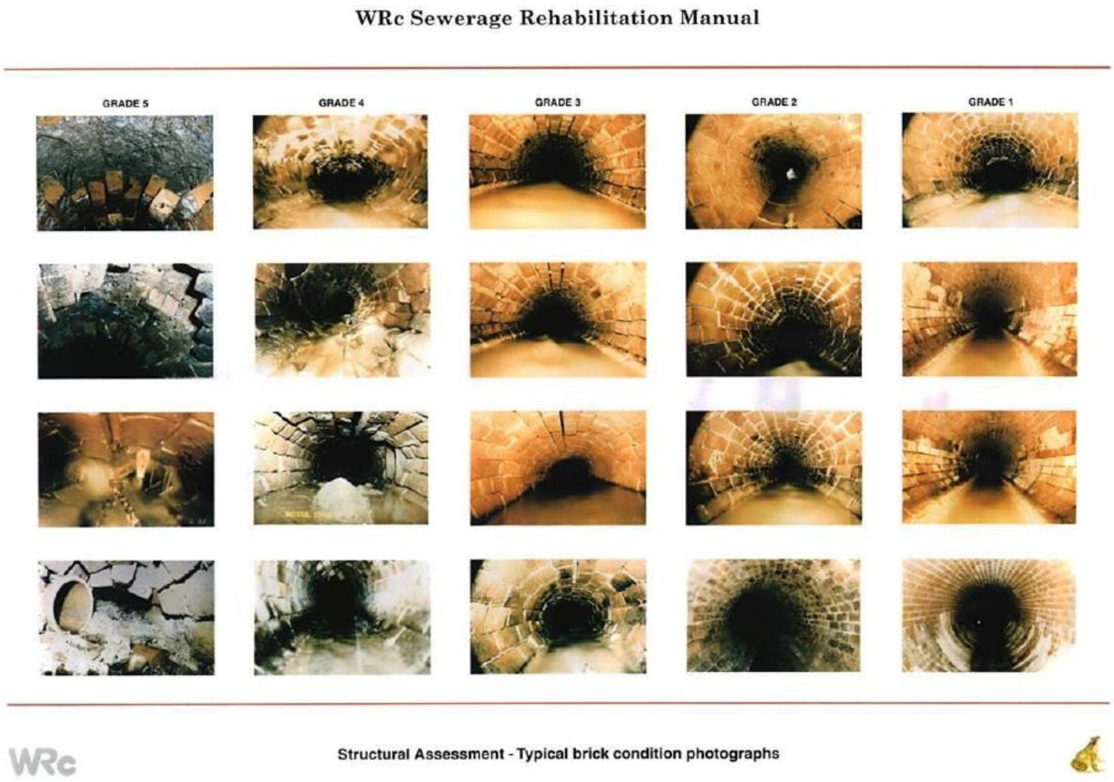

Fig. 5 WRc Structural Assessment Poster for Brick Culverts

Internal Condition Grade Descriptions

Grade	Grade Implication
5	Collapsed or collapse imminent
4	Collapse likely in foreseeable future
3	Collapse unlikely in near future but further deterioration likely
2	Minimal collapse likelihood in short term but potential for further deterioration
1	Acceptable structural condition

2.1 Condition Assessment

Following the preliminary walk through inspection and the subsequent investigation via laser profiling and CCTV inspection, condition assessment ranking was established using the WRc procedures as presented in the Sewerage Rehabilitation Manual, 4th Edition (Ref. 1).

Fig. 6 Displaced brick, longitudinal crack at crown

Fig. 7 Extended longitudinal crack, lime deposits

Fig. 8 Extended longitudinal crack, deformation

Fig. 9 Multiple cracking, old repointing

Some of the actual photographs (Figures 6-9) are indicative of a brick culvert in Internal Condition Grade 4 (see Table 1), which is deemed likely to collapse in the foreseeable future according to the WRc Sewer Rehabilitation Manual 4th edition.

Internal Condition Grade	Typical Defect Descriptions
5	Already collapsed Missing Invert Deformation >10% and fractured Displaced/hanging brickwork and deformation <10% Extensive areas of missing brickwork
4	Total mortar loss (depth missing> 50 mm) with deformation >10% Deformation up to 10% and fractured Displaced/hanging brickwork Small number of missing bricks Dropped invert (drop > 20 mm) Moderate loss of level Surface damage - spalling large (entire surface of brick is missing) Surface damage - wear large (entire surface of brick is missing)
3	Total mortar loss (depth missing > 50 mm) without other defects More than one longitudinal crack (at a single location) Multiple cracking Single bricks displaced Deformation <5%, no fracture and only moderate mortar loss Surface damage - spalling medium (large areas of chipped brick) Surface damage - wear medium (entire surface of brick is missing)
2	Circumferential cracking Single longitudinal crack Surface mortar loss (depth missing <15 mm) Surface damage - spalling slight (breaking away of small fragments from the surface) Surface damage - wear slight (increased roughness)
1	No structural defects
Note: Deformed sewers that have subsequently been relined with a structural lining can normally be considered to have no deformation.	

Table 1 - Condition grading extracted from the WRc Sewerage Rehabilitation Manual 4th Edition

The photographs show degraded mortar and mortar loss at least to a depth of one brick and there are signs of fracture and longitudinal cracks in the crown, and displaced and sheared brickwork at the crown. Some loose and missing bricks were evident, indicating continuing deterioration. Also, bricks missing from the inner ring demonstrate that the brickwork is no longer in compression and is potentially unstable. Changes from circular to oval shape and extensive lime deposits were also observed, particularly in section L. Lime deposits and encrustation are usually taken to be evidence of running infiltration through the damaged brickwork. Table 2 shows the walk through inspection data.

Deformation of the pipe is important to consider partly because it is an indicator of condition, and partly because the extent of deformation will influence repair options available.

From the photographs obtained with the walk through inspection, it was not possible to determine the extent of deformation. A spot measurement of deformation was difficult due to local surface roughness of the brickwork, hence Laser Profiling and CCTV inspection have been undertaken to provide an assessment of the deformation characteristics and to more accurately assess the Condition Grade of the culvert. The deformation was determined to be less than 10%; i.e. the max deformation measured as part of the laser profiling was 7.2% (Fig. 11), typical for Condition Grading of 4. Laser profiling is discussed in more detail in Section 2.2.

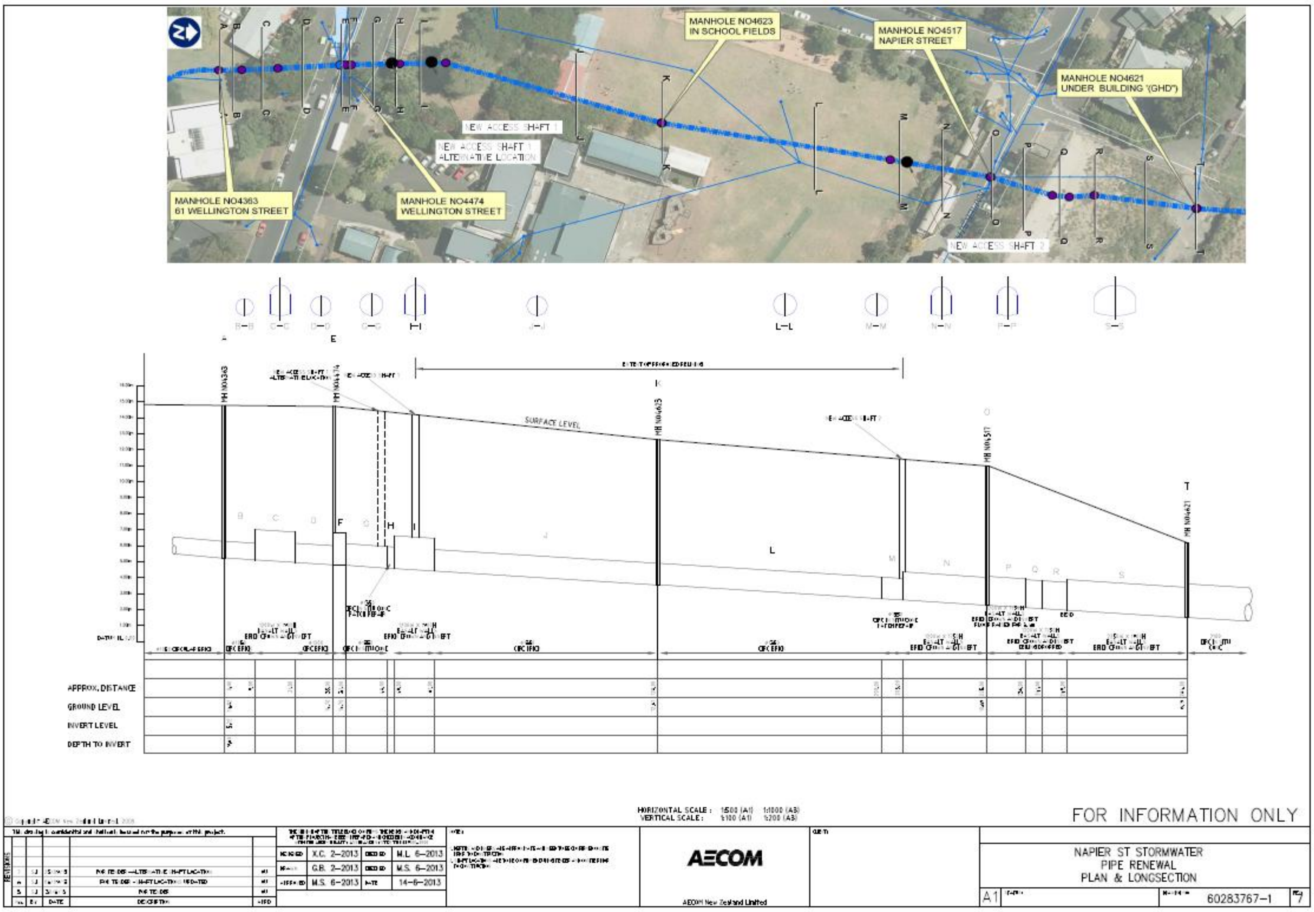

Fig. 10 Napier St Stormwater Culvert Rehabilitation – Plan and Long Section

The service life of a culvert may differ from its design life, and it depends largely on the supporting soil, local environment, and corrosive and abrasive properties of the transported fluid and solids. Recognising the effects of these factors on the deterioration of culverts and taking actions to maintain serviceability conditions can prolong its service life. This may reduce the need for premature replacement of culverts and may also prevent costly culvert failures. The historical context enabled an understanding of the type of supporting soil, and likely contaminants in the transported fluid (Figures 3 & 4).

The following process was followed as part of the initial condition assessment:

- Measure/Quantify the extent of deterioration.
- Determine the effect of that deterioration on the condition of the pipe.
- Set the scale of parameters that describe the condition of the pipe as a whole.
- Compare the existing deterioration with previous records of condition assessment.

Dist. u/s (m)	**Cont. (m)**	**Meas. from**	**Cond Code**	**Sev.**	**Pos. From**	**Pos. To**	**Photo**	**Remarks**
18		U	CL	M	12	12		Crack in Crown, profile deformation
18		U	ED	D			See above	Lime deposits
20		U	LO		9	9		150 dia EW
28		U	LO		10	10		150 dia EW
42		U	CC	M				
43		U	PB	S	6	6		Missing brick
45	F2, S3	U	DF	M	12	12		Multiple Cracks in crown , profile deformation

Table 2 - Napier St Stormwater brick culvert inspection log sheet

The WRc Sewer Risk Management (SRM) refers to consideration of supplementary information as part of a procedure to uprate an internal condition grade by one or two categories. This information may include unstable soil surrounding the culvert, fluctuating groundwater pressure, poor construction standard or continuing evidence of deterioration. From the background information, it seems reasonable to assume that the support for the culvert provided by the landfill is less than ideal. It is also known that the area where the culvert is situated is prone to flooding with groundwater close to ground surface and that the original construction standards were not high. Comparison with the 2000 inspection has been used to confirm continuing deterioration.

The risk has been considered as a combination of the probability of asset failure and a forecast of the severity of the consequences of asset failure on the level of service to customers and the environment.

2.2 Laser Profiling

Laser profiling proved to be a useful additional tool for assessment of both the issue and the remedial options. This section details the formats used and the usefulness of outputs.

Viewing and Reporting

There are a number of viewing and reporting formats available. The ones used for this project were:

Flat Profile report. This records the differences in measurements between the theoretical and actual as a flat strip representation of the inner wall of the pipe, with the soffit (12 o'clock) in the centre and invert (6 o'clock) at the top and bottom. The colour codes indicate the actual shape of the pipe as it relates to the defined base shape.

Flat profile reports do not necessarily indicate structural deformation. They show only that the actual inner circumference/wall of the pipe differs in dimensions from the user-defined base shape. Where differences are indicated they are assessed by checking the ovality (where relevant) and/or the CCTV video record.

Ovality report. This is a graphical representation of the ovality as previously defined. It is accurate for circular pipelines only but can be used on partly-circular sections, similarly to the Flat Profile report to indicate possible areas of concern. Ovality can also be shown at a selected distance along the pipeline, as a numerical value in a box.

Examples below show two typical cross sections (Figures 11 and 12). The reporting enables comparison of the various data.

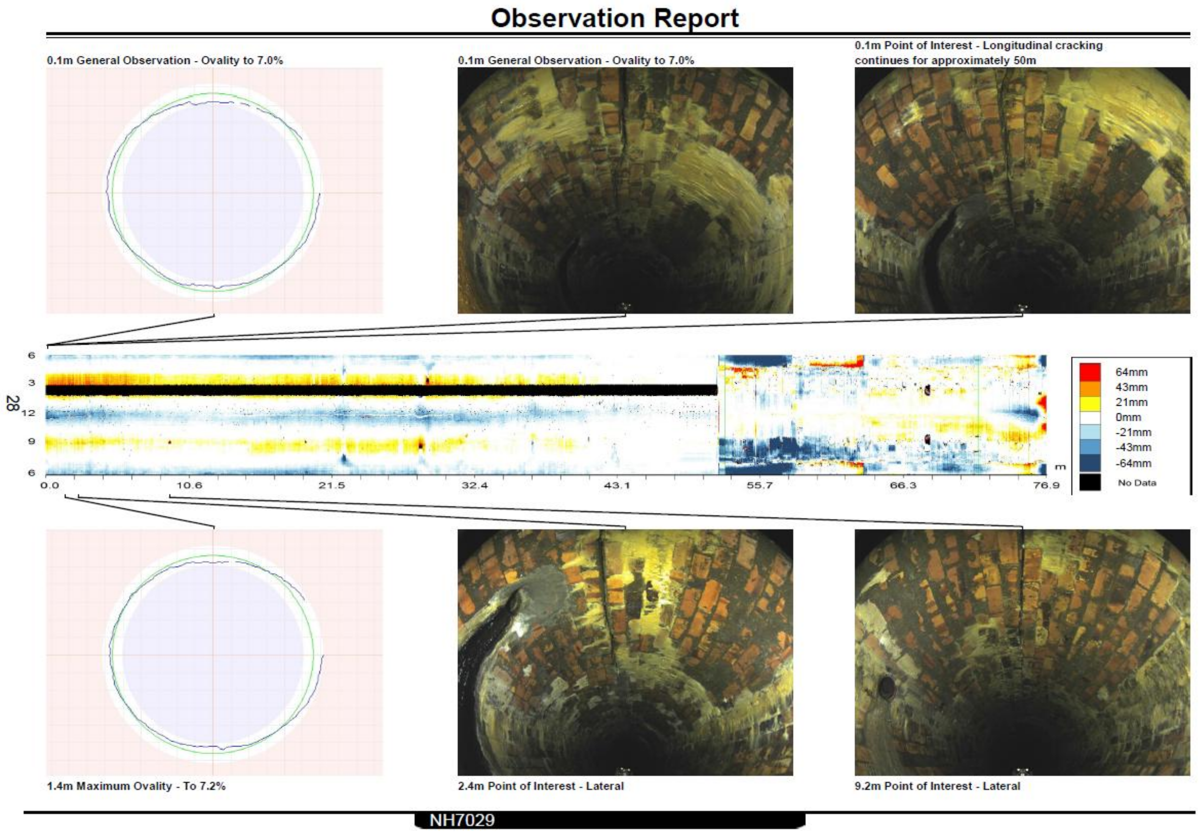

Fig. 11 Laser Profiling and Ovality Graph

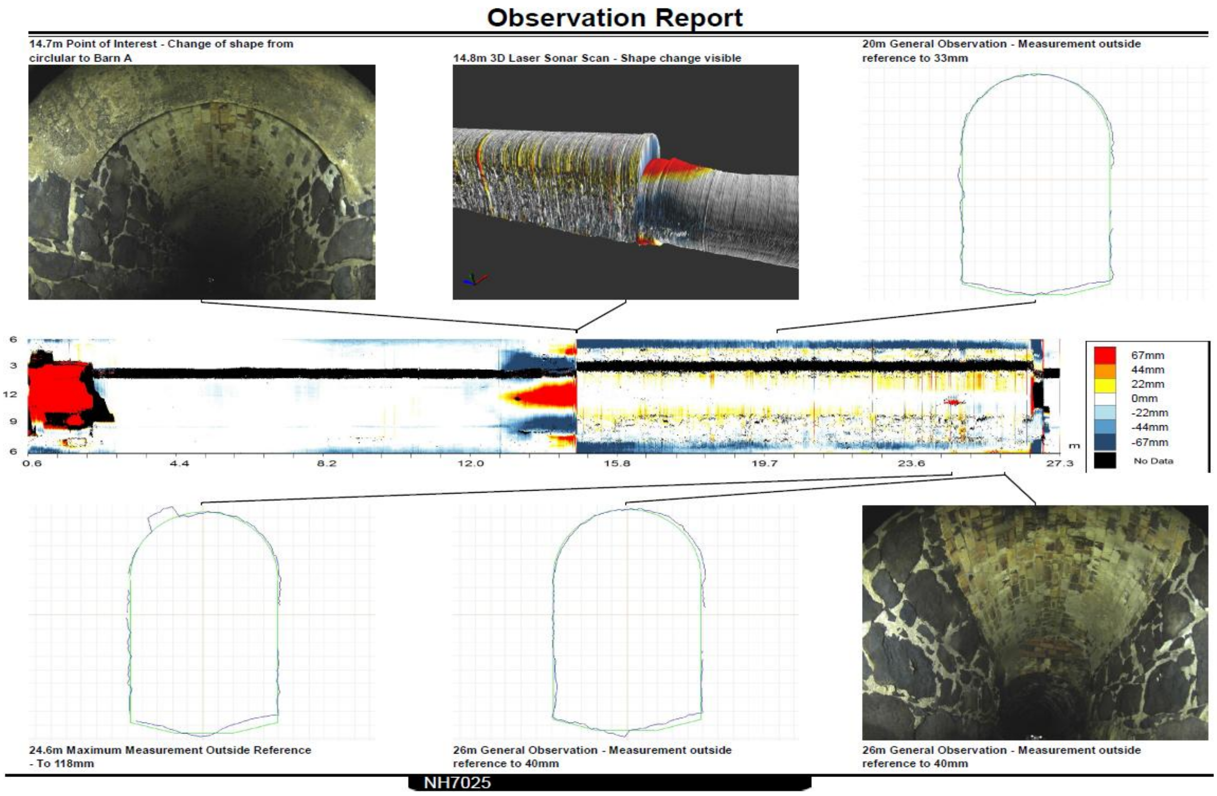

Fig. 12 Laser Profiling, Change of Culvert's Geometry

3 SELECTING A WORKABLE SOLUTION

As a result of the investigations, the stormwater brick culvert has been assessed to be in need of urgent renewal or rehabilitation. Options considered were: do nothing and monitor, open cut, pipe jacking, spiral wound liners, and cured in place pipe (CIPP) with some remedial work. There were multiple challenges in evaluating applicable rehabilitation methods. These included:

• Constructability issues such as worker entry and safety issues during construction, bypass requirements, maintaining services during construction, minimising school disruption, access site requirements, coordinating with multiple stakeholders, and minimising community impacts.
• How to establish the tender documents to provide an equitable bidding situation for multiple liner methods.
• How to establish design criteria that would maximise benefits to Auckland Council at the lowest possible whole-of-life cost.

In general, the rehabilitation approaches may include partial rehabilitations to extend performance life as well as full structural rehabilitations to reset the life cycle performance clock. Which one is most appropriate and cost effective depends on the deterioration rate of the asset, the ability of the rehabilitation method to extend performance life, and the cost and social/environmental impact of the method against competing approaches. There remain several issues that apply directly to the selection of rehabilitation methods that have a strong bearing on the cost effectiveness of rehabilitation programs and their impact on traffic and environment in the areas where the rehabilitation work is needed.

The key decision needs were to determine:

- Whether to renovate or replace (via trenchless or open-cut construction methods) the brick culvert
- Which of the commercially available rehabilitation methods were suitable for this particular application

Open-cut replacement has been the standard practice in the past, but its preferential use over trenchless techniques has been significantly diminished in the past two decades. Awareness of the indirect and social costs associated with utility work in congested urban areas (i.e. traffic congestion, business impacts, noise and dust) have encouraged the use of 'full' costing approaches in determining the choice between open-cut replacement and trenchless rehabilitation or replacement methods. Often, however, the choice of trenchless technologies is driven by acknowledged environmental constraints and expected public pressure rather than by a quantitative calculation of full direct, indirect and social costs. Also, differences in social and indirect impacts are often addressed in work requirements that reduce or eliminate any cost advantage to open cut in an urban environment.

The constraints for this project were likely to include restrictions on work hours, noise barriers, plating of excavations for traffic flow during peak periods, storage and treatment of excavated materials, potential impact on local business and risk of damage to adjacent utilities or their relocation. Selection of trenchless rehabilitation approaches involves a screening process followed by a more detailed evaluation of the technologies. It is generally easy to exclude some technologies as evidently not suitable for a particular application. The remaining technologies may be generally suitable, but have different cost, risk, setup area requirements, life cycle performance, compatible materials and environmental impacts.

A new element in these considerations is how 'green' a product or process is. For example, many trenchless methods have a much lower carbon footprint than open-cut repairs. Evaluation of technology differences in a rational and impartial manner is a persistent but important challenge.

The following options were considered:

Option 1. Do Nothing - a high risk strategy given the potential safety and economic consequences of failure.

Option 2. Replace by open cut construction. This was excluded for reasons of direct engineering cost, potentially massive community costs due to traffic and business disruption, environmental and safety hazards and geotechnical considerations.

Option 3. Replace by Pipe Jacking or Microtunnelling. In this case Microtunnelling would be preferred to Pipe Jacking at the depths of cover indicated from safety and operational considerations. These were considered to be high risk options due to the unknown geotechnical conditions along the alignment. Any geotechnical survey undertaken to facilitate equipment selection and to minimise risk would need to be comprehensive. Borehole data and geophysical testing would struggle to confirm the strata comprising landfill over decades. A comprehensive survey would be akin to excavating a pilot bore along the full length of the proposed pipeline and would be exceptionally expensive, over and above the already high costs implicit in the construction by microtunnelling for a relatively short length of very deep stormwater culvert. The mobilisation costs and the construction of access pits in landfill would likely push the project costs even higher than anticipated.

Option 4. Repair by CIPP or Spiral Wound Lining. This option would potentially minimise disruption because it would make full use of the existing manholes in the ground. However, lining with a spiral wound PVC or polyethylene reinforced liner involves some reduction in diameter and an annular gap in the order of 50mm. This would require grouting to develop full strength and lock the liner in position.

PROJECT LEVEL DECISIONS TO REPAIR, REHABILITATE, REPLACE OR DO NOTHING

The decision processes involved in evaluating project alternatives are summarised below (Fig. 13).

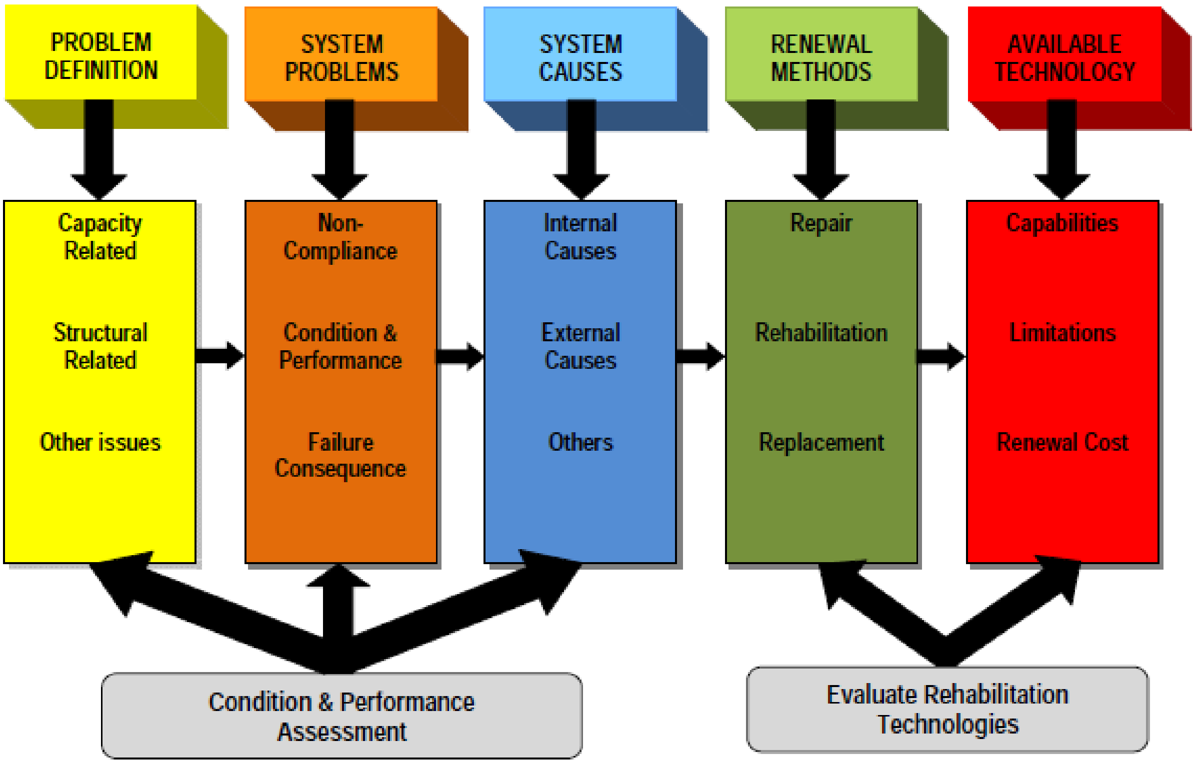

Fig. 13 Conceptual framework for selecting appropriate technology

An important part of the remedial selection procedure was to define the hydraulic loading anticipated for the stormwater culvert. The project specification required minimal reduction in flow capacity. This highlighted the criticality of the capacity in selection of the remedial options. Notwithstanding the above, selection of Option 4 – Cured in Place Pipe - appeared to provide hydraulic capacity equal to or better than the existing brick culvert even though there is inevitably some small loss of diameter. The effect of any reduction in cross-section due to the lining can be considered along with improved hydraulic roughness of the liner material to determine the probable impact. In general, it is considered that the CIPP lining improves the flow characteristics of the pipe being rehabilitated. Flow is improved because the inner surface of CIPP is extremely smooth and continuous, without any joints or discontinuities that create friction to flow (Ref 6-7).

4 PREFERRED OPTION

The project was let as a design and build contract for relining. The successful tenderer, The Fletcher Construction Company Ltd, trading as PipeWorks, proposed a CIPP rather than a Spiral Wound relining solution. It was considered that the CIPP liner would be a full length circular lining for the most critical section of the culvert. The uniformity of CIPP construction along the length of the Napier Street culvert is desirable to maximise installation lengths during construction, so that the lining task can be completed to a good standard for future maintenance and operating characteristics. The CIPP lining would provide a lining with greater flexibility than the existing culvert and would also be an appropriate solution for earthquake conditions; recent earthquake experiences in several countries show that the CIPP lined pipelines are able to accommodate a very high level of ground motion, thus providing substantial benefits for seismic strengthening in addition to rehabilitation of aging and deteriorated pipelines (Ref. 8, 9 & 10). In providing a strong, thin, and fully structural liner with additional flexibility, it was considered CIPP to be the most technically viable solution which, combined with the estimated cost, became one of the most attractive options.

This is a mature technology in one sense, as CIPP liners have been installed since 1971. However, changes in the technical and operational aspects of CIPP lining continue to evolve. These are driven partly by technical innovations and partly by the need to stay competitive both within the CIPP market and in terms of competition with other liner systems.

Considering all of the project requirements, the project team selected the iPlus Composite CIPP liner reinforced with glass fibres in order to increase the strength of the cured pipe to withstand the project specific set of loads, while decreasing the thickness of the finished product. This allowed for greater flow capacity and a reduction in the amount of resin that is typically used in large-diameter pipes, and also translated into a thinner product that weighs less for handling and transport. This composite-reinforced liner provided greater strength and stiffness with nearly half the wall thickness of the conventional CIPP products, and it proved to be the most practical solution to rehabilitate the 1350 mm diameter Napier St stormwater brick culvert.

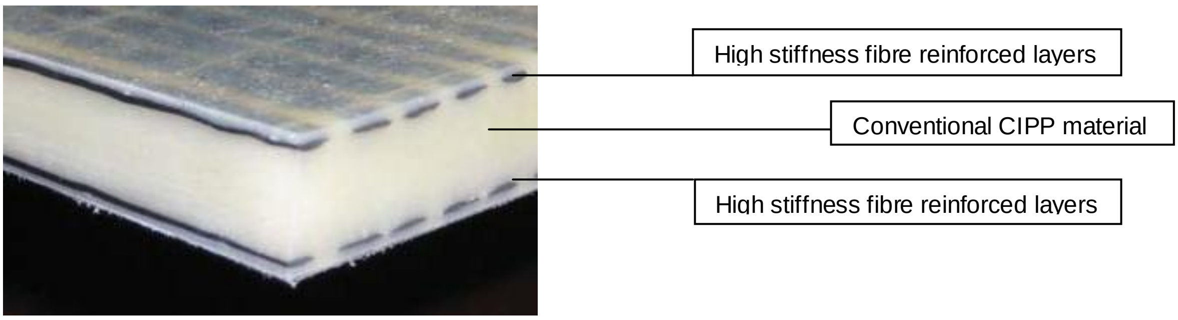

Fig. 14 iPlus Composite Sandwich Construction

5 DESIGN AND CONSTRUCTION PLANNING

In addition to the liner material and culvert's hydraulic capacity, there were a number of other constructability issues on the project which needed to be addressed. The identified construction area was known to be prone to flooding in wet weather, and this indicated that the water table in this area would be close to the surface throughout much of the year. This factor made it necessary to consider possible extensive shoring and support for any excavation, requiring well pointing to reduce infiltration of groundwater to the excavated location.

One new access shaft was required for installation of the liner. Shaft locations were analysed in detail to position it in an area which would minimise disruption of traffic flow, noise and community impacts, and provide maximum whole-of-life usefulness. This location required an approval from the Ministry of Education and Freemans Bay Primary School to excavate a 10m deep, 2m diameter access shaft and construct a new 10m deep 1.5m diameter manhole in the school grounds.

Community impacts were identified as a key challenge. In particular, the Freemans Bay School, as a main external stakeholder has been the project team's priority in terms of the Health & Safety and Environmental aspects, and minimisation of disruption of all school activities during normal school hours, as well as after hours.

An appropriate noise management plan was developed and successfully implemented so that the work activities during both day and night time were within the allowable limits. Unique field conditions at the project site included contaminants in soil and groundwater, which have been managed in accordance with the approved soil and groundwater contamination plan.

The project constraints highlighted the need for a collaborative effort from the Project Manager, Engineer, Consultants and the Contractor. This effort notwithstanding, the need for extensive experience within the cured-in-place pipe (CIPP) industry dealing with extraordinary installations was a pre-requisite. Ensuring that the project team has the competence, capability, availability and knowledge was an important factor for the successful project outcome.

Key project activities included:

- Planning and Investigations (Laser Profiling, Geotechnical, Soil Settlement, etc.)
- Risk identification and management
- Communication with the stakeholders, regulatory authorities, landowners
- Development of Design Criteria and Liner Specification
- Selection of a suitable Contractor
- Value added engineering
- Cost Management
- Innovation
- Verification that the proposed project outcomes met project objectives

6 PROJECT EXECUTION

The rehabilitation works included installation of a 36.5mm thick structural iPlus Composite CIPP liner (approx. length of 140m), a next-generation glass fibre reinforced cured-in-place-pipe (CIPP) solution with greater strength and stiffness than the traditional CIPP.

This type of liner required less resin and less energy to cure the liner. Also, the iPlus Composite CIPP liner was installed in less time than conventional CIPP, saving energy and reducing emissions released into the air from on-site equipment.

Figure 15 shows the liner inversion process employed in this project. It demonstrates how the liner was inserted into the brick culvert through a steel chute (also shown in Figures 23, 24 and 25) which turns the liner front through 90 degree angle so that the liner runs horizontally within the brick culvert.

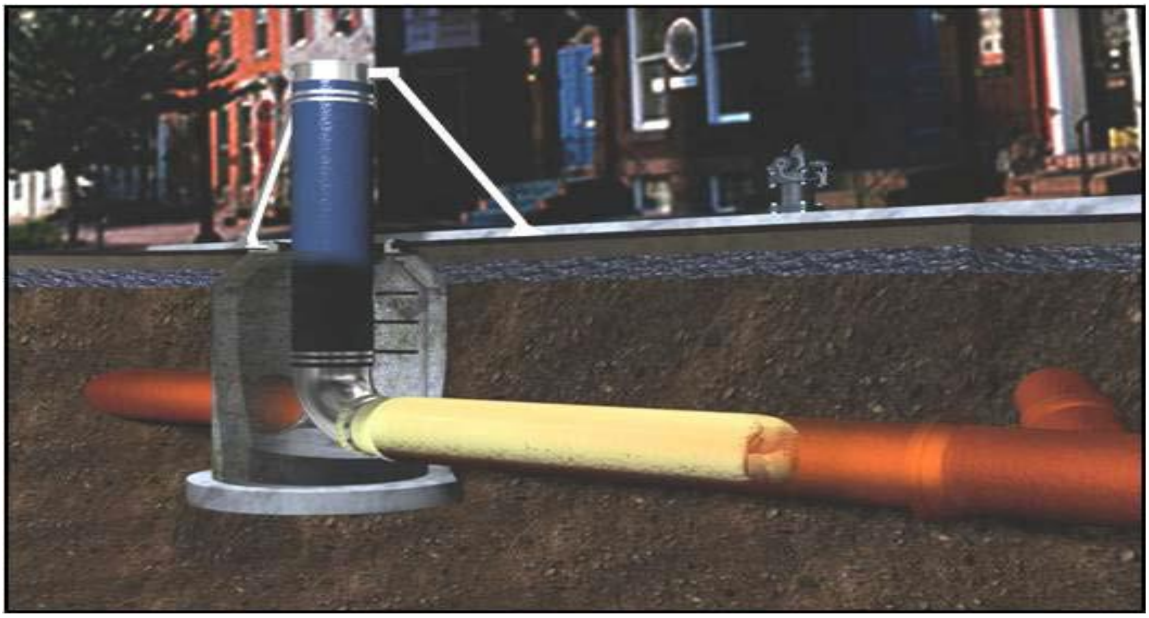

Fig. 15 CIPP Installation Liner Inversion - (Courtesy Insituform Technologies, Inc.)

The choice of liner influences the required site layout and the size of the work area. The new access shaft and the work site were positioned on the northern end of the school playground to optimise the use of the playground and minimise the disruption (Fig. 16).

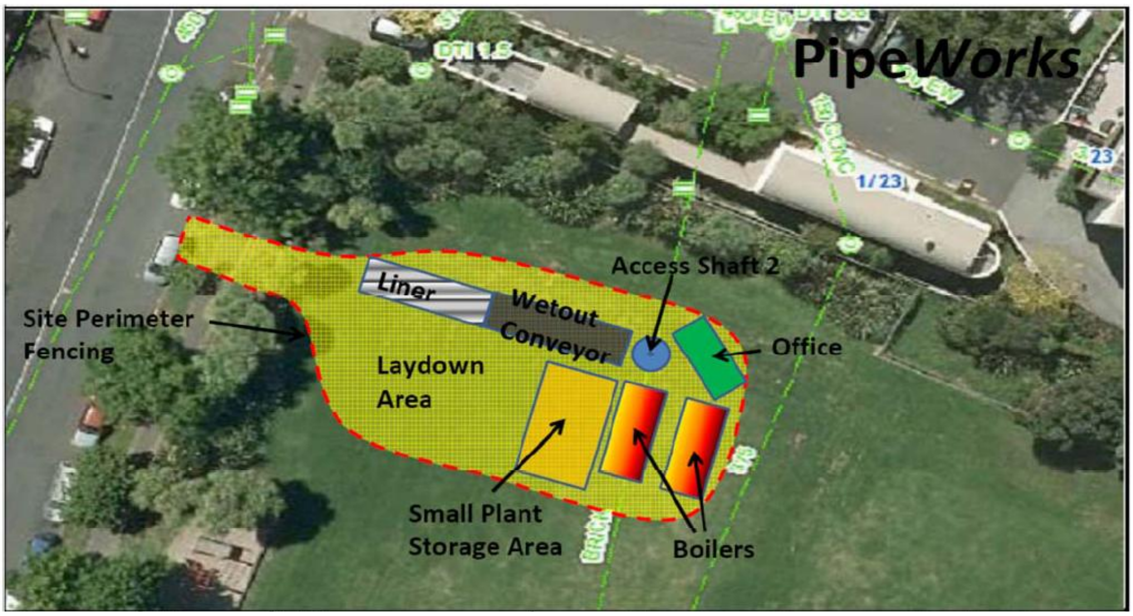

Fig. 16 Work Site – Layout

6.1 Shaft Construction

The position of the shaft above the brick culvert was determined by probing an 80mm core into the culvert to verify the centre and depth of the pipe, whilst this was monitored internally by CCTV camera from within the culvert. Once the centre of the culvert had been verified (Fig. 17), four additional bore holes were drilled to the soffit level of the culvert. These four holes ensured that the subsequent layers of fill material placed over time were free of large obstructions placed in the fill that could prevent the installation of the shaft.

Fig. 17 Establishing the centre of the culvert

Fig. 18 Installing the steel casing

The shaft site was initially excavated to a depth of 1.0m to remove topsoil. The excavation was approximately 3.0m x 3.0m in area and it formed the capping level for the primary shaft. An initial 1.5m diameter auger was used to bore a hole to a depth within 0.50m of the brick work of the pipe. The 2.0m diameter primary steel casing was installed simultaneously with the auger (Figures 18 and 21).

Figures 19 and 20 show the site preparation for management of the contaminated soil.

Fig. 19 Site Preparation for soil management

Fig. 20 Contaminated soil management

At the capping level, two waler beams were welded to the top of the primary shaft to support the shaft, and prevent any applicable loading being transferred onto the culvert beneath.

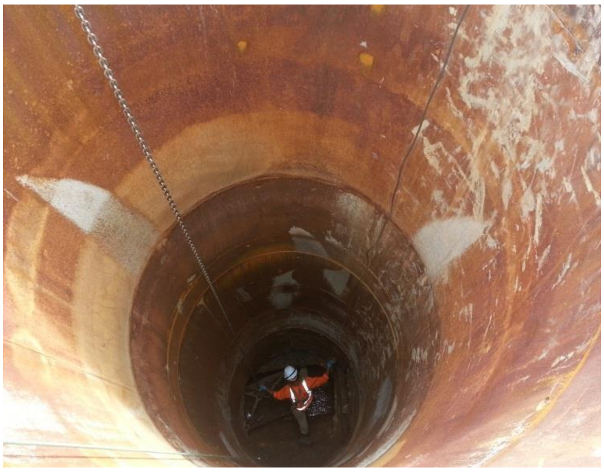

Fig. 21 Access shaft with steel casing

The shaft provided safe access to the culvert for the purpose of installing the CIPP liner. An additional 2.5m diameter top shaft section was fitted above the primary shaft. This also formed a safety barrier around the shaft while still allowing easy access to the shaft through the opening gate. A protective bead was welded around the top edge to prevent any damage or injuries from the exposed steel edge.

6.2 Liner preparation and set-out

6.2.1 Liner Preparation

The 1350mm diameter liner was laid out on the roller system approximately 48hrs before the over-the-hole wet-out process was commenced (Fig. 23). A 12 tonne excavator was used to facilitate this operation, with extra special care taken in order not to damage the liner whilst it was being laid out.

Vacuum 'cups' were placed at 3-4m intervals along the laid out liner to vacuum the line for at least 12 hours prior to the wet-out process to eliminate any air pockets that may inhibit uniform resin migration through the liner.

Fig. 22 Sealed Liner laid out on the roller system

Fig. 23 Liner impregnation conveyor

6.2.2 Liner Wet-out

The resin was batched in 2 x 5000 litre mixing vats off site and was then transported to site in 1000 litre pods.

The resin was transferred to the liner via air pump while vacuum controls on the liner continued for the duration of the wet-out operation. After the first batch had been added to the liner, the liner was sealed and then rolled through the roller system at the pre-set gap measurement, ensuring that the liner had the correct volume of resin per lin.m for the thickness required (Figures 22 and 25). The liner was inverted directly into the host pipe from the wet-out roller utilising the "Over-the-Hole Wet-Out" technique (Figures 25 and 27).

The liner was wet-out for the full length of the pipe, excluding the depth of the access shaft.

Fig. 24 Liner Insertion

Fig. 25 Liner running to inversion chute

Figure 24 shows the crane lowering the liner attached to the custom-made steel chute (90 degree return at bottom end) into the new access shaft before the insertion starts.

Fig. 26 Liner inversion setup, top of access shaft

Fig. 27 Impregnated liner fed into the culvert

6.3 Flow Management

The bypass system consisted of a series of small submersible pumps, placed within the culvert approximately 30m upstream from the extent of the CIPP line. This positioning coincided with the location of the discharge point to the Watercare overflow chamber located in the central medium of Wellington Street.

A total of four pumps were positioned within the culvert at this location; each pump was electrically driven by a generator positioned on the road in Wellington Street. Four delivery hoses provided independent discharges from each pump.

6.4 CIPP Installation and Curing

6.4.1 Liner inversion

The inversion frame was installed atop the access shaft, aligned to receive a direct feed of the liner from the wet conveyor (Fig. 22). The dry end of the liner was turned back and attached to the inversion ring. The resin impregnated liner was set to begin from 1.0m above the bottom of the access shaft.

The starting ropes were attached to the liner at a predetermined measurement to facilitate the liner going around the bend at the base of the access shaft. At this bend it was expected that there would be a bunching effect on the liner through the inside radius of the bend. The wrinkles formed there were cut off after the curing cycle was completed. Water was added to the 'column' at the rate of inversion required.

Displaced water at the upstream end-point was drawn off with pumps and discharged to a nearby sewer manhole. A pre-manufactured liner bag end was attached to the tail of the liner; a holdback rope was attached to this bag end which enabled an effective control of the inversion speed. The holdback rope was run through a suitable bollard. Figure 26 shows the liner inversion setup viewed from top of the access shaft.

6.4.2 Curing of the Liner

Once the liner was inverted, the curing/circulation hoses (2 x 100mm diameter) were attached to the bag end which delivered the hot water from the hot water boilers. The quantity of water that had been heated in this installation was 197m^3. The liner was cured as per the graph indicated below (Fig. 28).

Temperatures were monitored continuously from all access points; i.e. upstream, midstream and downstream by data logging thermocouples. Two boilers ran for the duration of the curing, however they were switched off periodically to control the curing period.

The Contractor successfully installed the glass-fibre composite CIPP liner, working diligently with the Principal and the Consultants to ensure that the challenges of this project were addressed and the Principal's expectations were met.

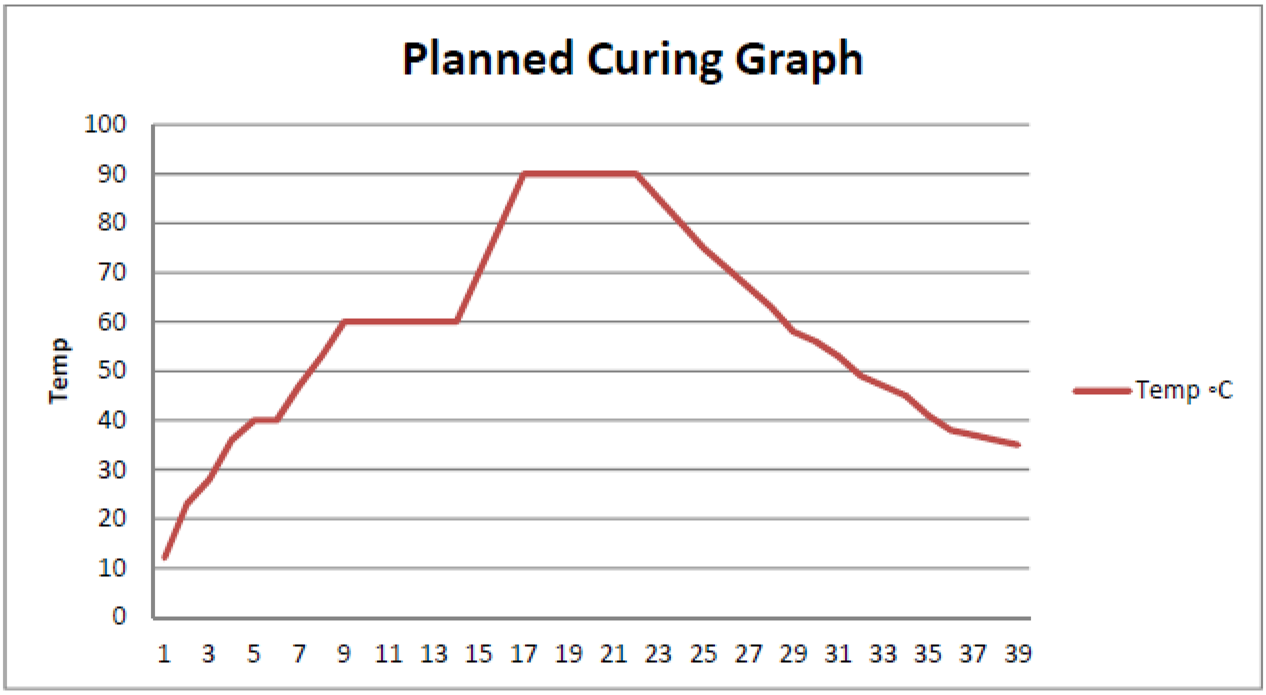

Fig. 28 Planned Curing Graph

6.5 New Manhole Construction

The new manhole built after the completion of the lining, provided an improved future access to the rehabilitated culvert for maintenance and inspection. The annulus between the manhole risers and the steel casing had been filled with flowable fill. A reinforced concrete 'ring' had been constructed on top of the primary shaft to prevent any possibility of the load from the manhole structure being transferred to the culvert.

Conclusions

1. Undertaking a formal condition survey provides justification for the work, and also identifies elements which are not as critical, potentially saving/postponing money that would otherwise be spent on remedial works.

2. Detailed geotechnical investigations during preliminary stages regardless of the likely soil conditions are useful to inform design, costing and risk management.

3. Identify possible constraints due to underground services early. This activity was performed during the preliminary phase of the project so conflicts in major utility corridors were known.

4. It is important to explore all options of remediation before committing to high-cost replacement or repair. Seemingly very difficult buried infrastructure can be dealt with by trenchless industry specialists who possess relevant in-depth knowledge and experience.

5. It is useful to know what other Council departments have planned. In this case, Auckland Transport and Watercare Services Ltd were contacted and kept abreast of the Napier St Stormwater Rehabilitation Project, ensuring no other works took place at the same time.

6. Adequate resources are a significant factor for project success. Having a project team with the required competency, capability, knowledge and motivation to successfully complete the project was a key factor for the successful project outcome. In these circumstances, the tender process and use of non-price attributes needs to reflect the project requirements.

7. Communication with stakeholders is fundamental from early stages to minimise delivery risks. Ministry of Education and Freemans Bay Primary School had been consulted and kept updated on the project progress and programme.

8. High risk elements of installation had been discussed openly between the project team to ensure the best value outcome for risk mitigation was chosen.

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DISCLAIMER

This document has been subjected to the Auckland Council's Engineering & Technical Services peer review and has been approved for publication. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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