Remuera branch 1 & 2 rehabilitation 2009

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ABSTRACT

Pipeline rehabilitation has presented major challenges to owners and contractors as cities have developed. This paper illustrates how Watercare overcame these challenges to carry out repairs to their Remuera Branch 1 & 2 sewers. These sewers were built in 1910s. A century later, they were approaching the ends of their lives. Although they had been built under farmland, the districts they run through are now occupied by some of the most expensive real estate in NZ, and St Kentigern's School. These site factors dictated that a trenchless rehabilitation method would have to be used for the rehabilitation of both sewers. CIPP (cured-in-place-pipe) lining was identified as the most appropriate method for rehabilitation of the egg shaped sewers. A 250 litre /sec flow diversion was required to allow the use of this rehabilitation method, and a 17m deep temporary shaft had to be drilled in the grounds of St Kentigern's school to enable the lining installation to proceed. The contract team completed the work successfully with minimal inconvenience to the residents and commuters of Auckland’s eastern suburbs. The Branch 1 &2 sewers are now be expected to give at least another 100 years service.

KEYWORDS

Cured in place pipe, CIPP, egg shape, brick sewer

Contents

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1 INTRODUCTION

According to Watercare's official history, Auckland, had the worst public health record of any New Zealand city in the early 1900s. This was due to such practices as dumping "night soil" into waterways, street drains, and on to gardens, to avoid paying for its disposal.

The resulting outbreaks of disease and health problems increased pressure for the construction of sewers in the city, and eventually, construction of the Remuera Branch 1 and 2 sewers took place in the early 1910s. The Remuera Branch 1 & 2 sewers provided nearly a century of service, but by the early 2000s, it had become apparent they were in need of rehabilitation, as they were showing signs of significant loss of structural integrity.

Watercare's board approved the rehabilitation works in the lower sections of Remuera Branch 1 (MH05 to MH01) in late 2007 following the planning and investigation phases of the project. The equivalent works in Branch 2 were approved in February 2009.

This rehabilitation project was the final project in a series, under which the entire length of the Remuera Branch 1 and 2 sewers had been repaired or rehabilitated. The upstream sections, which were generally laid at shallower depths and carried smaller flows, had been rehabilitated earlier under previous projects. This left only the sections which presented the most interesting and difficult challenges from a consenting and design perspective. These challenges included completing two of the largest individual CIPP installations undertaken in Australasia.

The construction on Branch 1 took place during the 2009 summer holiday period, and in Branch 2 during the 2010 summer holiday period. Both branches are now back in service, and may be expected to give at least another 100 years service. The project work was carried out with minimal disruption to the community and other stakeholders. This paper describes the background to the project, discusses the engineering and consenting challenges that had to be met in the course of its implementation, and presents the lessons learned.

REMUERA BRANCH 1 & 2 REHABILITATION

1.1 HISTORICAL BACKGROUND

As the population of Auckland grew in the late 19th century it became the unhealthiest city in New Zealand. This was largely due to widespread use of unsafe waste disposal practices in order to avoid paying for the disposal of waste. Such unsafe practices included tipping waste into waterways and onto gardens which were then used to produce food.

A typhoid outbreak occurred in 1878, adding pressure to the case of building a reticulation system, but construction was delayed by economic circumstances until the early years of the 20th century.

In 1903, Auckland's population passed 100,000, and in 1908, the City Council and the 19 individual borough councils approved a scheme to construct a sewer system. This system was to include the main interceptor, which ran from Point Chevalier to Orakei, and its tributary branches, including Branches 1 and 2.

Construction works on the interceptor were underway by 1911, and the works on Branches 1 and 2 were undertaken at the same time. Figure 1 shows the technique used to construct sections within a tunnel. For the interceptor sewer, the sewer structure was built up to the internal surface of the tunnel. Figure 2 shows the construction of a similar size sewer, in this case the London Northern Outfall, by cut-and-cover methods. This technique was also used both for the Orakei main and its branch sewers. Although Orakei main sewer was larger than Branches 1 and 2, the range of construction techniques used for these branches was very similar.

Figure 1 Orakei Main Sewer construction, 1910

Figure 2 Thames Water Outfall construction

The sections of Branch 1 and 2 discussed in this paper were built inside tunnels, running at considerable depths under headlands. The small size of the tunnels in which Branch 1 and 2 were built (approx 1.7m high by 1m wide) would have made working conditions very cramped and difficult, and it is very impressive to see the standards of workmanship these men achieved under such conditions.

The tunnels in which the branch sewers were constructed were cut to a larger height than the sewer, to allow working room for the construction crew. After the sewer construction was completed, there was a space above the sewers, which was often left unfilled, or only loosely filled. This presence of this space created problems in the design of the rehabilitation project, which will be discussed further on in this paper.

Figure 3 - Hobson Bay chart, 1913

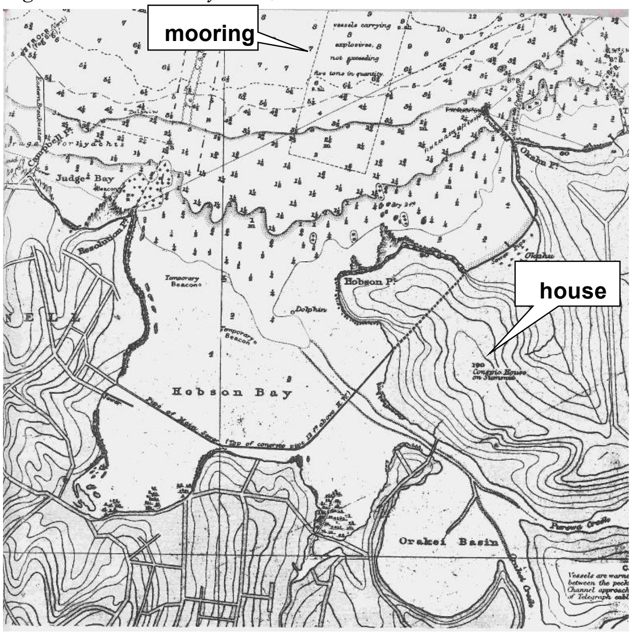


Figure 3 shows a 1913 Admiralty chart of the area in which the Orakei main and branch 1 & 2 sewers were built.

The districts in which the Orakei Main and the branch sewers were constructed were at the time completely open farmland. Photographs taken at the time show no buildings and this figure indicates that there is only one house visible from the sea at that time. This is probably just as well, since the chart also indicates the location of a mooring for vessels carrying not more than 5 tonnes of explosives at what is now the site of Tamaki Drive.

Figures 4 and 5 show that as late as 1921 the area was still entirely rural. Other references show that it was not until after second world war that this area acquired its present suburban character.

Figure 4 Hobson Bay 1921

Figure 5 Hobson Bay 1918

Figure 6 – Orakei main storage tanks

The interceptor sewer was connected to storage tanks at Orakei, which discharged into the Waitemata harbour on outgoing tides. However, in the 1950s, the interceptor was connected to the Mangere Treatment plant. The storage tanks now house Kelly Tarlton's Underwater World. Figure 6 shows the construction of the original storage tanks in 1911.

1.2 SITE DETAILS

The section of Remuera Branch 1 that required rehabilitation lies between MH05 and MH01, adjacent to the Orakei main sewer. This section runs from Sonia Avenue to the foot of a cliff facing Hobson bay. The extract from the original sewer long section in Figure 7 below shows the locations of the manholes and roads within this sewer section. The text in the original drawing is difficult to read, even at full size, but the difficult nature of the landscape in the area is obvious; the maximum depth to invert is over 20m in the grounds of St Kentigern's school.

Figure 7 Long section – Remuera Branch 1 sewer (Watercare Services Ltd)

The preceding investigation phase of the project had already determined that the most appropriate method for rehabilitation of this sewer section was cured-in-place pipe (CIPP) lining. This is a method in which a resin-impregnated tube is introduced into the sewer, and cured with hot water, to produce a new pipe within the existing sewer which conforms to the shape of the host pipe. The thickness of liner required in this case was 21mm.

None of the manholes within this part of the sewer could be used as entry manholes for trenchless pipeline repair techniques of a type which would be suitable for the project. There were also no suitable locations within the road reserve where temporary manholes could be constructed. This was because of the presence of other underground utilities, lack of working room, proximity of residential areas and other constraints. After extensive consideration and investigation, the sports field of St Kentigern's School was identified as the only practicable site at which a temporary shaft of the required diameter for lining this sewer could be created. The temporary access point had to be as near the halfway mark between MH05 and MH01 as possible to minimize the technical difficulties presented by the installation of a CIPP liner of the size required for this sewer. This point will be discussed further under the Liner Installation section of this paper.

The section of Branch 2 requiring rehabilitation runs from MH6 to MH01, adjacent to the Orakei main sewer. This section runs under residential areas between Victoria Avenue and Portland Rd and meets the Orakei main at the foot of a cliff facing Hobson bay. The extract from the long section in Figure 8 below shows the locations of the manholes and roads within this sewer section. Again, the text in these 1911 drawings is difficult to read, but the topographic challenges of the site are obvious.

Figure 8 Long section – Remuera Branch 2 sewer (Watercare Services Ltd)

CIPP lining had also been identified as the most appropriate rehabilitation method for this section. Once again, the problem with using this rehabilitation method was the selection of an entry point for liner insertion. With the exception of MH02, all the manholes were either completely inaccessible, or in locations which were totally unsuitable for CIPP liner insertion. MH02 also presented problems, because its location in the middle of the carriageway on Shore Rd meant that it could not be used for lining without closing the traffic lane. Auckland City Council was unwilling to approve a traffic management plan requiring lane closure on this main arterial traffic route.

It was therefore determined that it would be necessary to install another temporary access shaft in Shore Rd, closer to the kerb, so that the liner installation could be carried out without closing either lane of Shore Rd.

The aerial photograph in Figure 9 shows the project site from above, and gives a good perspective view of the site. It clearly shows how parts of the site are now occupied by residential housing, and where a large part of the final stretch of the Branch 1 sewer runs under the site of St Kentigern's School. Also visible in this view is the fact that the seaward side of the project site was occupied by Fletcher Construction, which was at the time of this project engaged in the construction of the Project Hobson Tunnel. One of the tunnel access shafts lay immediately adjacent to MH01 on the Branch 1 sewer. Therefore the access to MH01 on Branch 1 and 2 was closed off at the time because both of these manholes lay within the boundaries of the Project Hobson site. This also shows the locations of Baradene College and Victoria Ave Primary school.

The volumes of traffic generated in this area by the presence of three large schools was a major factor in the design phase of the project, as it meant that Auckland CC required all major phases of the project work to take place during school holidays. Shore Rd also serves as one of the main arteries by which commuter traffic enters the CBD from Auckland's Eastern suburbs. Auckland CC was understandably nervous about allowing any works on Shore Rd at the best of times.

Figure 9   Remuera Branch 1 & 2 site locations, aerial view

Figure 10   Remuera Branch 1 & 2 GIS Map

Figure 10 shows an aerial view of the same part of Remuera, taken from Watercare's GIS system. It gives a plan view of the extent of the site location, and illustrates the scale of the problem faced in designing the flow management for the Branch 1 stage of the works. It also shows clearly how Shore Rd runs right through the middle of the work sites for both branches.

This aerial view also clearly shows the location of Martin Wilson Field, an Auckland City Council reserve, on the right hand side of the photo. This reserve is used by St Kentigern's School for their sports activities during the school term and by others at weekends.

Auckland City were extremely helpful to this project by allowing Watercare to use the reserve as an assembly area for welding and preparing the 1km long flow diversion pipe which was required to transfer flows from the grit chamber in Manawa Rd to the Orakei main sewer. The pipe used was 355mm SDR11 PE100 pipe, and it was recycled after this project to another Watercare project with minimal loss.

The flow diversion pipe for Branch 1 ran along the bed of the stream which is visible at the western side of Martin Wilson Field. It then ran under Shore Rd via a culvert and out into Hobson Bay where it skirted the edge of the mangroves, before re-entering the Watercare system via a hatch on the Orakei main sewer.

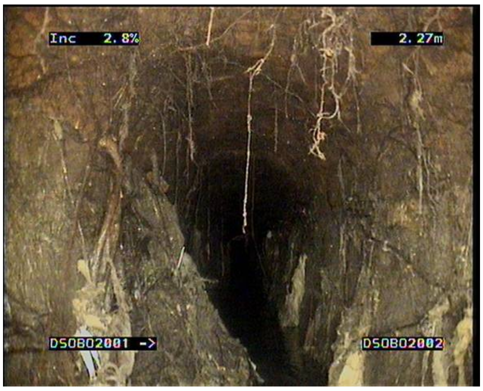
The main reason for the urgency to get these two branches lined was the detection of large root intrusions in both branches, as shown in figures 11 and 12, and the need to eliminate the risk of blockage or structural failure in the sewer that these defects implied.

A risk assessment was carried out for both branches, which determined that the level of risk in both branches had reached the point at which rehabilitation action was required. Factors considered included:-

- the probable serious consequences of any structural failure in sections of the sewers lying under inaccessible parts of the landscape, and
- Engineering judgments on the probability of a failure occurring due to the fragile nature of the brickwork in parts of the sewer.

Figure 11 Root intrusions Branch 1

Figure 12 Root intrusions Branch 2



In the investigation phase of this project, Watercare had discovered that the tunnel voids around these sewers had been left unfilled over large parts of their length after the construction of the sewers had been completed. This meant that the design of the rehabilitation process had to avoid creating any significant internal pressure, because it could not be assumed that the host pipe was fully supported externally along its length from manhole to manhole.

The existence of cavities between the sewer pipe and the tunnel also made it difficult to establish how far along the sewer the risk of root intrusion extended. It was clear in the case of the intrusion in Branch 1 that the particular tree whose roots were visible was at least 10m away from the point of the root intrusion. In Branch 2, the distance was less, but in both cases, the root intrusions were found in sections of the sewer where it would have been completely impracticable to carry out repairs by conventional excavation methods. Excavations at any of the root intrusion sites would also have created a possibility of exposure to liability risks in future.

Both the root intrusions visible in these photographs were removed by man entry. It was considered that the use of mechanical root removal devices such as chain flails or high pressure water blasting would create a risk of further damage to the brickwork of the sewer.

1.3 SELECTION OF REHABILITATION METHODS

During the investigation phase of this project, Watercare considered a range of possibilities for the replacement and rehabilitation of the Branch 1 and 2 sewers.

At the time of this investigation, CIPP lining was found to be the only practicable lining method that would provide structural reinforcement to the sewer without unacceptable loss of flow capacity. Whilst other lining methods might have been able to offer similar performance in a round host pipe, the egg shape profile of Branch 1 and 2 eliminated all other contenders in this case.

Watercare's construction contract cost database also indicated that replacement of the sewers by tunnelling would have been several times the cost of the CIPP lining, and in any case, replacement would have required a much longer consenting and planning phase than a trenchless rehabilitation project.

2 INSTALLATION PROJECT

2.1 PROJECT FEATURES

In common with many of Watercare's recent rehabilitation projects, this project exhibited the following particular features:-

- Flow capacity was not to be diminished significantly by the rehabilitation methodology;
- The host pipe had an irregular shape, with a profile that varied along its length;
- Reinforcement of the existing host pipe structure was required, to stabilise the sewer structure, and extend its lifetime by at least 50 years
- Pipe surcharges could occur, creating internal pressures;
- Erosion problems could occur as the result of water jet or bucket cleaning
- H_2S gas attack was a known problem within the sewer;
- Elimination or reduction of infiltration and inflow was required

The CIPP lining process was identified as the only practicable rehabilitation method for this particular project, mainly because of the egg shape profile of both branches. The process was invented in the UK in 1970 by an agricultural engineer, Eric Wood, and it has since become one of the major weapons in the armoury of the trenchless pipeline industry. It has been used to rehabilitate many thousands of kilometres of deteriorated pipelines in the last 40 years.

This project is one of the largest CIPP projects of ever undertaken in New Zealand, in terms of the length and diameter of linings installed in individual insertions, and in the scale of the flow diversion required to enable these insertions to take place.

2.2 PREPARATION FOR REHABILITATION OF BRANCH 1

The following figures show key locations along the route of the Branch 1 sewer. Figures 13 and14 show the location of the grit chamber at the upstream end of the pipeline. The chamber was to be used as the wet well for the temporary flow management setup whilst the CIPP linings were installed in the branch, and preparatory and finishing works were carried out.

The grit chamber lies within a few metres of residential housing, and when the chamber lids were lifted, odour would have been a problem for the neighbours if it had not been controlled. Similarly, any equipment used for work at this location outside working hours has to be fully silenced, as the neighbours would complain quickly about any noise arising from the site outside working hours.

Figure 13 Manawa Rd & grit chamber

Figure 14 Grit chamber

Both of these issues had to be covered very thoroughly in the design stage of the project because it was clear that the grit chamber was the only practicable location for the temporary pumping station. A lot of time and effort went into liaising with the neighbours at this site, and into the design of the noise and odour control measures. This liaison continued throughout the implementation phase of the works. The result was that not one complaint was received from this site.

Figure 15 shows the location of MH05 in the front garden of a private property at the end of Sonia Avenue. This road is a quiet residential cul-de-sac, and it is an unsuitable location for a CIPP lining manhole since working room around it is very restricted and it lies under overhead power lines. There is also very little freeboard at this manhole, and it lies next to a wetland and stream. Similarly, MH04 lies in the front porch of the house shown in Figure 16, so it is totally unsuitable for use as a CIPP installation manhole.

Figure 15 MH05, Sonia Ave

Figure 16 MH04, Sonia Avenue

Figure 17 shows the general location of MH03. It lies in the residential property in the middle of the photo, halfway down a right-of-way which gives access to several other properties. As a result of this inaccessible location, this manhole is totally unsuitable for use as a CIPP insertion manhole.

Figure 18 shows an aerial view of the location of MH01, within the boundaries of Fletcher Construction's site for Project Hobson. This manhole was also inaccessible to vehicles. This manhole could therefore not be used for CIPP liner insertion, and even the minor finishing works at this manhole required all the necessary equipment to be carried to the location by hand, over a considerable distance.

Figure 1 7 location of MH03, Shore Rd

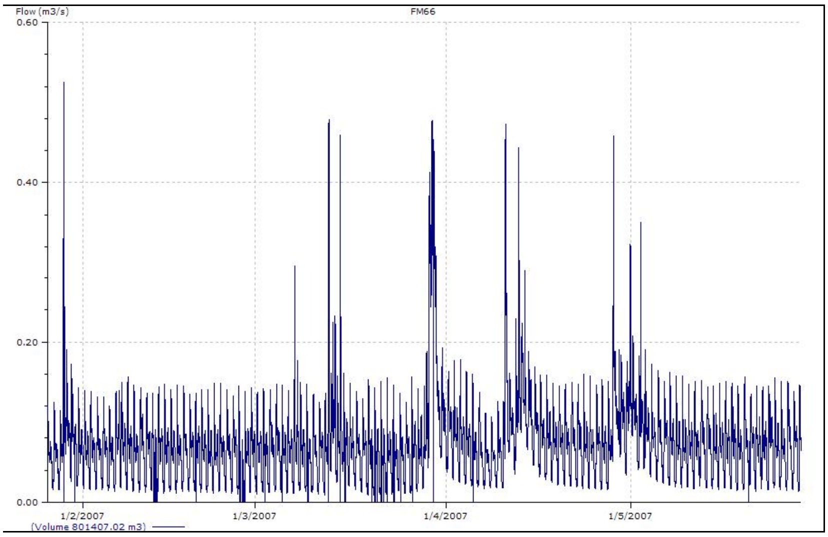
Figure 18 MH01 location- in Project Hobson site

2.3 FLOW MANAGEMENT

The flow management required on this project was a major exercise in its own right, and was the equivalent of setting up a 1km temporary rising main for several weeks. In order to minimise the risk of spills, the flow diversion pipework was designed to be constructed using fully welded polyethylene pipe. The cost of this pipework was minimised by using it again on another Watercare project when this project was completed.

Figure 19 below shows a snapshot of the data obtained at MH03 during February 2007. The peak dry weather flow at this location is about 160 litres per second (l/s), but the flow rises to about 500 l/s during rain events.

Figure 19 – MH03Branch 1 flow monitor data excerpt, February 2007



This meant that the lining work had to be scheduled to take place when at least three days fine weather could be reliably expected. In Auckland, this requirement can be a challenge at any time of year. In effect, this factor restricted the working period to the months of January – April, and even then, as the figure shows, care had to be taken to time the insertions to occur between rain events.

The flow diversion specification was written to require provision of pump capacity capable of diverting up to 250 l/s, to allow for peak dry weather flow (PDWF) plus minor rain events. There was about ½ hour storage available in the upstream section, from the grit chamber to MH08. The pump setup worked without a hitch throughout the project, and the upstream storage capacity was not called into play.

The diversion pipe welding was carried out by certified welders on Martin Wilson Field. Every weld joint was computer monitored and recorded, and full testing was carried out on test samples in accordance with Watercare's standard procedures for rising main pipeline welding. Figure 20 shows assembly of the pipe string in Martin Wilson field, using 15m lengths of pipe, to minimise wastage. Figure 21 shows the pump setup, which used a single 300mm pump plus two 200mm pumps. The largest pump alone was capable of approx 150 l/s. Working together, the three pumps could deliver a combined flow of about 240 l/s. Figure 22 shows the beginning of the pipe string running from the temporary pump station towards Martin Wilson field, via the wetland at the south end of this reserve.

One condition of the consent from Auckland City for the use of this park was that the contractors should avoid damaging the playing field surfaces and prevent others from entering the site with vehicles This condition was met in full, by the contractor's crew taking great care to keep the site barriers closed at all times when the site was unattended.

Figure 23 shows how little freeboard was available at the grit chamber, and therefore, how little the flow would have to rise before spilling. With only about ½ hour storage available at peak dry weather flow (PDWF) in the event of pump failure, it was imperative that the pumps should be manned and monitored whenever works were in progress.

Figure 20 Assembling the bypass pipe string

Figure 21 Pump setup at Manawa Rd grit chamber

Figure 22 bypass pipe setup at grit chamber

Figure 23 Flow entering grit chamber

The next set of photographs (figure 24 to 26) shows the bypass pipeline running out to sea from Shore Rd to enter the Orakei Main near to MH01. The pipeline was floated out to sea from Martin Wilson Field at high tide, and fixed to the Orakei Main. Before the closed circuit television (CTTV) and cleaning works started the bypass line and pump setup were tested at full power for 4 hours.

Figure 24 Bypass pipe route to Hobson Bay

Figure 25 Bypass pipe arriving at Orakei Main

Figure 26 Bypass Pipe entry at Orakei Main

Before the pipe string was dismantled, it was flushed with clean water, to prevent contamination of the environment by any remaining sewage in the pipe. The cut pipes were then shipped off to become part of a new rising main at Hobsonville. Very little wastage occurred, as the tough and resilient nature of the polyethylene pipe proved itself, and because the contract included financial incentives to minimise the damage to the pipe during the dismantling and transportation of the pipe to the next project site.

2.4 TEMPORARY SHAFT DRILLING AT ST KENTIGERN SCHOOL

Once the bypass pipe had been set up and tested the contractor was allowed to start drilling the temporary access shaft. In the first stage of this operation, an auger drill (figure 27) was used to start the shaft coring, followed by a reaming operation using the drill head shown in figure 28, which enlarged the hole to its final diameter of 3m. The coordinates for the shaft had been located and marked out by a registered surveyor. A specialist subcontractor was nominated in the contract schedule for the shaft drilling operation. The hole was drilled to the required level, 17m below the surface, within 1 day.

Figure 27 Auger drilling temporary shaft

Figure 28 "apple coring" head for drilling

A steel casing was then installed in the shaft and grouted into place. The entire shaft drilling operation went very smoothly and took less than two working days. Geotechnical investigation data for the site showed ideal conditions for this temporary shaft drilling operation to be used. As the shaft was opened to its final diameter, a steel casing was installed to stabilise the shaft, as shown in figure 29. This casing was 16m long by 3m diameter, and was assembled in situ as the shaft drilling progressed. The final 1m excavation and penetration into the Branch 1 sewer was made by hand, in order to minimize risk of collapse of the sewer. The flow diversion was kept running at this stage of the operation, with a TV camera monitoring the operation from inside the sewer. The shaft was found to be exactly on target when the sewer was exposed, as can be seen in Figure 29, where the flow in the sewer is visible through the aperture at the base of the shaft, after it was opened.

Figure 29 steel casing stabilisation *Figure 30 Sewer crown opened up*

2.5 LINER INSTALLATION

As soon as this project was awarded, the liners were ordered from the contractor's overseas supplier. In order to avoid causing delays to St Kentigern's School construction project, and to meet the deadline for the construction to take place during the school summer holidays, the liners had to be flown in from the USA. The flow diversion subcontractor also had to order and ship the 300mm pump used on this project when the contract was awarded.

Once the sewer had been opened, preparations commenced for the installation of the CIPP liners upstream and downstream from the sewer opening. The Figures 31 and 32 below show the first liner arriving on site on a flatbed truck.

Figure 31 Liner arrival at site *Figure 32 Liner unloading*

Approximately 35 tonnes of resin mixture was required to fill the two liners used in Branch 1. The contractor elected to set up a liner impregnation facility at the site, in order to eliminate the practical difficulties involved in chilling and shipping bulky and heavy liners to site. The liners were dry on arrival, but once the resin had been added to them, the weight was of the order of 30 + tonnes for each liner. A similar weight of ice was required when storing the liners to guard against premature curing of the resin. This is a significant risk with liners of this size and thickness.

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This decision to impregnate at site left the contractor with the challenge of inverting the line into the sewer at the same time as filling it with resin; this operation is known as "over the hole wetout". The duration of the complete impregnation, installation, and curing operation would therefore extend to over three or more days. During this time, the flow diversion system would be required to operate continuously, and it was essential that this operation should not commence until 3 days fine weather could be expected, with a high confidence level.

Figures 33 to 36 show the sequence of events involved in getting the resin into the liner tube. In figure 33, the crew are manhandling the liner off its delivery pallet, onto the impregnation conveyor. The liner is dry at this point, but vacuum has been applied to extract air from it, in preparation for resin addition. This makes the liner very stiff and unwieldy. Figure 34 shows the liner in position on the conveyor, with vacuum hoses in place. The vacuuming operation can take many hours, since all air must be removed from the liner before the resin is pumped into it. (air inclusions will reduce the strength of the finished liner)

Figure 35 shows the resin mixing taking place, and illustrates well the scale of this operation, in which approx 35 tonnes of resin were used to impregnate the liners on Branch 1. Many separate batches of resin had to be prepared to fill the liners used in these insertions, and a high degree of attention to detail is required to ensure effective coordination of the insertion and impregnation processes during on-site impregnation. Figure 36 shows the resin being pumped into the liner.

Figure 33 Liner preparation for impregnation

Figure 34 Liner vacuuming

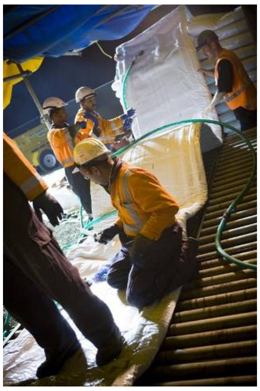

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Figure 35 Resin mixing

Figure 36 Liner impregnation

The liner coating must kept free of damage during handling since it forms the barrier which allows for vacuum impregnation of the liner. The coating also protects the resin from coming into direct contact with the water used to cure it during the installation process.

Once the liner has been filled with resin, it also becomes heavy (approx 40kg/m) and lifting gear is required to start the installation process. This is a critical stage of the installation, since the liner could easily be seriously damaged by an inexperienced crane operator. It is also important to protect the resin filled liner from exposure to sunlight, since the UV content can trigger a premature chemical reaction if the liner is exposed for too long.

Figures 37 to 40 show how the liner is introduced into the sewer. After the first part of the liner has been filled with resin, it is passed through rollers to control the quantity of resin per metre of liner to the correct amount for the thickness required. It is then taken through a steel chute, as shown in figure 37, which is used to turn the liner nose through 90º, so that it will run horizontally within the sewer. Note how the liner is turned inside out at this stage, so that the resin bearing side is now the outside surface, and the coated side is now the inside surface.

The steel chute, with the liner attached, is then lowered into the start manhole for the liner installation. This operation is shown in figure 38.

Figure 37 Liner attachment to steel chute

Figure 38 Liner insertion

The liner inversion continues until the liner nose is halfway to the end manhole; at this point, water circulation hoses and holdback ropes are attached to the liner tail, before continuing with the inversion. Figure 39 shows an intermediate stage in the liner insertion, with the liner entering the top of the inversion chute. (this is visible as the funnel at the base of the ladder).

Once the liner is fully inverted, the circulation hoses are connected to the water heater, and curing begins. The water temperature inside the liner must reach approximately 60º to initiate the chemical reaction which causes the resin to harden. It is essential to monitor the liner temperature at several points to ensure that resin curing is detected, before stopping the circulation of the hot water. In these liner installations, over 200 m^3 of water had to be heated to about 85ºC, requiring two large heater units to be used.

Figure 39 Liner running to inversion chute

Figure 40 Liner curing

The curing process was carried through to completion and then the process water was drained from the hardened liner.

The liner ends were cut off and then finishing work in the manholes was carried out. Figures 41 to 43 show the process of reconstructing the base of the shaft as it is taken from its initial state to the finished state. Figure 44 shows a view of MH04 after lining. In fig 42, the internal surface of the finished liner is visible. This surface is the same coated surface that started off on the outside of the liner before it was inverted during the insertion process.

Figure 41 Branch 1 sewer at shaft base, before lining

Figure 42 Shaft base reinstatement after lining

Figure 43 Shaft base, with resin lining

Figure 44 MH04 finishing

Once both liners had been installed, and the finishing work on the manholes completed, a final TV inspection was carried out to record the condition of the sewer. A reinforced concrete plug was set in the shaft base, with an air gap between the plug and the sewer. The shaft was then filled with flowable fill. Another reinforced concrete plug was set on top of the shaft at a depth of 0.5m below the finished surface level. This was done to eliminate the risk of subsidence at a later date.

From this point onwards, the construction work on Branch 1 was essentially complete, and only site reinstatement remained. The work on Branch 2 shared many of the same features as the work on Branch 1, except that the liner installations were carried out from a temporary manhole in Shore Rd. The sewer dimensions were smaller, but access to the manholes was even more of a challenge, as most of them were located within private properties on steeply sloping ground. Both sewers are now back in service, and may be expected to provide at least another 100 years of service.

St Kentigern's School were able to complete their project on time for the planned opening date late in 2009, without delays, due to the timely completion of the Watercare sewer works on the site. There is also no visible evidence of the project at any of the locations shown in this paper, and the work was carried out with minimal disruption to traffic or residents.

3 CONCLUSIONS & LESSONS LEARNED

As with any large CIPP lining project, the key factors which contribute to a successful outcome include:

- Thorough planning and investigation
- Effective liaison with regulatory authorities, landowners, and stakeholders
- Development of effective working relationships with all parties involved
- Detailed analysis of the technical issues
- Careful selection of contractors and subcontractors, with skills appropriate for the project

In designing and implementing this project, many of the individuals that I worked with were the same as on previous projects, but some were inevitably people with whom I had not worked before. In order to obtain consents and the active cooperation of many separate stakeholders for this project, it was necessary to put a lot of effort into building the relationships with these stakeholders, so that they would feel comfortable with the demands the project made on them and their organisations.

A particular feature of CIPP lining is that once the lining process has started, it cannot be interrupted without great risk of losing the liner. Although the CIPP installation process is quick to execute, it is a process which leaves little room for error. Many stages of the liner preparation and installation process can go wrong if the CIPP contractor's crew does observe rigorous quality assurance (QA) and safety procedures.

At the same time, when the unforeseen does happen, it is necessary to develop innovative and cost effective solutions to new problems at short notice. Experienced CIPP crews should be capable of dealing with these unexpected events, but it is always best to avoid them by thorough planning, risk analysis, and rehearsal in advance. The contractor's crew in this project met that challenge.

Fortunately, no significant technical departures from the anticipated project plan occurred on this project, but the work on Branch 2 was delayed by the discovery of a landslip at one of the manholes, necessitating a programme change at short notice.

Accurate and comprehensive quality assurance (QA) records must be kept, in order to ensure that the contractor can demonstrate that the installed liner achieves the performance intended by the designer. In a project of this type, the time window in which the raw data for QA records can be gathered is very limited. This objective of the project was also achieved with no significant omissions.

All these factors combined to put a lot of stress on the stakeholders in the project, and this highlights the need for effective teamwork between individuals working for many separate organisations.

Watercare is one of the few organisations in New Zealand with large numbers of brick egg shaped sewers that provide opportunities to carry out work of the type described in this paper. It is also one of the few organisations in New Zealand that do rehabilitation projects of this scale on a regular basis. Continuity and practice in projects involving work of a similar nature is important because it allows the designers, contractors, regulatory authorities, suppliers, and specialist subcontractors to maintain the levels of specialist skills required to carry out this sort of work effectively and safely.

4 ACKNOWLEDGEMENTS

I am enormously grateful to all the people and organisations who contributed to the success of this project in various forms. In particular, I would like to thank the following:

Watercare Services Ltd, Auckland City Council, Auckland Regional Council;

Utility Operators – Vector Ltd, Telecom Ltd, Metrowater Ltd

Pipeworks and Fletcher Construction Ltd

St Kentigern's School trust board, Gibson O'Connor Ltd, and Opus Consultants Ltd

All the subcontractors, including Pump Hire Ltd, Sykes Pumps NZ Ltd, Spiral Drillers Ltd

Tyco Flow Control Pacific Pty Ltd

The neighbours, residents, park users, bus operators and road users in and around the project site and its neighbourhood.