# CHRISTCHURCH BRICK BARRELS SEWER REHABILITATION

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## ABSTRACT

SCIRT (The Stronger Christchurch Infrastructure Rebuild Team) is responsible for rebuilding horizontal infrastructure in Christchurch following the earthquakes of 2010 and 2011. The head contractual agreement within SCIRT is an alliance between owner participants (Canterbury Earthquake Recovery Authority, Christchurch City Council and New Zealand Transport Agency) and non-owner participants City Care, Downer, Fletcher, Fulton Hogan and McConnell Dowell.  There are also many other Christchurch-based companies, who are part of SCIRT, playing a vital role in delivering the SCIRT programme of work.

The earthquakes have had an obvious effect on the visible environment in the city. Less obvious, but equally serious, is the destructive effect these earthquakes have had on the unseen underground utilities.

As one of NZ’s earliest established cities, Christchurch built many of its major sewers before the advent of reinforced precast concrete pipe, using unreinforced brick and concrete. Many of these sewers were also constructed as egg shapes, in accordance with the design philosophies of the time.

Unfortunately, these brick sewers are particularly vulnerable to the effects of earthquakes, and present unique challenges in the investigation, design and construction phases of reconstruction works. The pipelines continue to deteriorate more rapidly than usual, as the result of continuing aftershocks, in the same way as the above-ground heritage buildings, constructed using similar techniques.

SCIRT has therefore prioritised brick barrel wastewater and stormwater pipelines in the Central City for rehabilitation, in order to prepare for the next phase of work, in which the roading and above ground infrastructure will be reconstructed.

This paper reviews the technical issues that we have had to address in the following areas

- identifying pipelines needing priority for rehabilitation
- selecting appropriate and cost-effective rehabilitation methodologies
- selecting specialist contractors
- implementing the physical works programme

## KEYWORDS

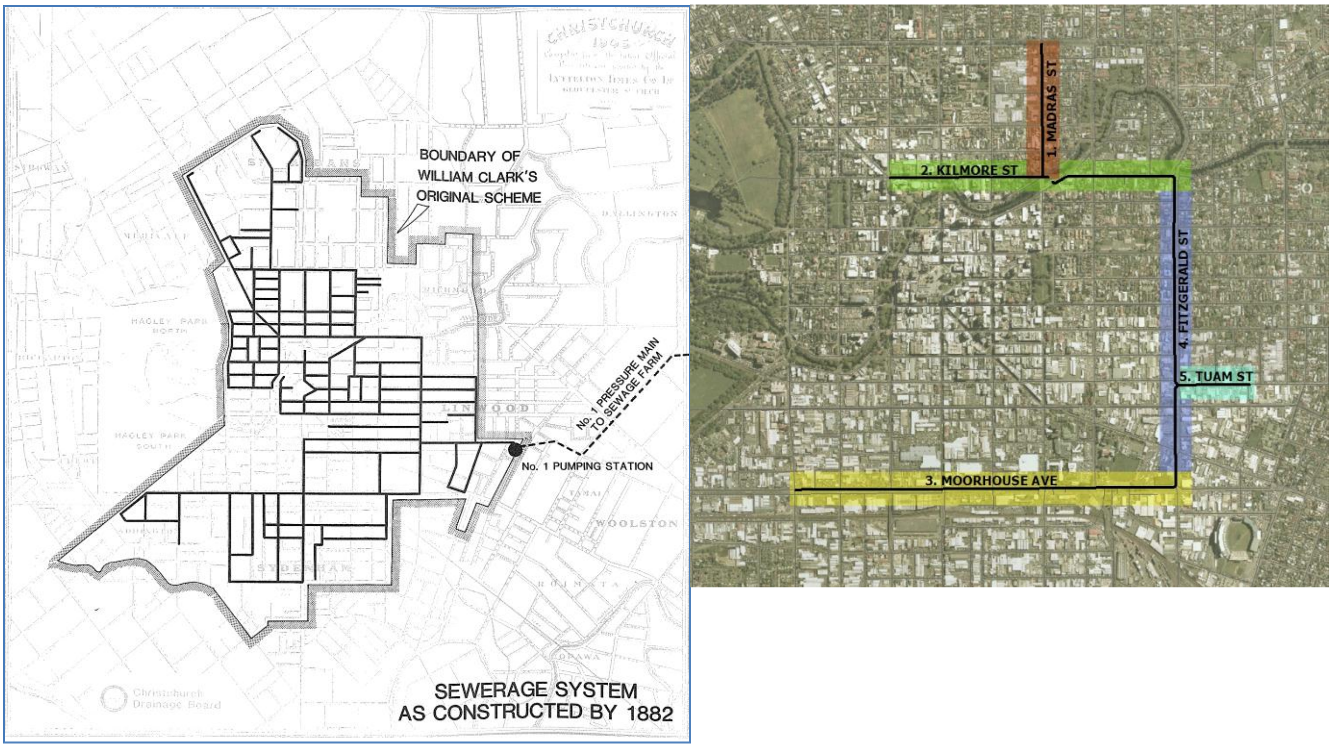
Christchurch, brick barrels, cured in place pipe, CIPP, egg shape, spiral wound lining, flow diversion

# 1 INTRODUCTION

Christchurch's wastewater network has suffered extensive damage from the series of earthquakes which started in September 2010. Since then, there have been over 10,000 quakes and aftershocks of varying magnitude, and these continue to the present day, approximately two years later.

The city's original network, as shown in Figure 1 below has suffered extensive structural damage. The sewers shown in this figure were built to a separated scheme proposed by an English engineer, William Clark, and were constructed in the late 19th Century, using brick construction techniques and shape profiles such as egg shapes, ovals, and ovoids, which were in common use at the time, as well as circular profiles. The map in Figure 1 roughly corresponds the area covered by the work describe in this paper, although the network configuration has expanded a long way beyond this area since 1882.

*Figure 1 – original Sewer network*




In some cases, the extent of earthquake damage is obvious, with large visible displacements of the sewer structure, but the majority of the sewer damage is in the form of multiple smaller defects.

These apparently minor defects cause the sewers to become unserviceable by allowing huge volumes of silt to enter directly into the damaged sections, and those downstream of them. In the sections containing significant numbers of laterals, these are also severely damaged in most cases, and they also provide an entry route for large silt volumes during seismic events.

Shortly after the first earthquake, CCTV surveys of the network started, and it continues at the time of writing this paper, since many of the earlier surveys have had to be repeated as the result of later deterioration in the networks.

Prior to the formation of SCIRT, Christchurch City Council engaged AECOM to review the CCTV surveys which had been carried out up to June 2011. About 40% of the network in the four avenues area had been surveyed by then. Of these, about 40% were found to be critically damaged, and a further 40% were found to be in severely damaged condition, defined as probably requiring rehabilitation within 5 years, to prevent premature failure. Only about 20% were assessed as having sufficient structural and watertight integrity to last beyond 10 years.

Following submission of the AECOM report, the newly formed SCIRT organisation decided to prioritise renewal of the stormwater and wastewater brick barrel pipes within the Central City area. Early completion of these pipes is critical to enable other services and roading to be rebuilt prior to the commencement of the vertical infrastructure rebuild.

The Central City area is nominally bounded by the “Four Avenues”, namely Bealey Ave, Fitzgerald Ave, Moorhouse St and Deans Avenues. The brick barrel pipes in this area are laid at depths to invert of between 2.5m and 4m.

*Table 1 - Brick Barrel Pipes*

| Service | Predominate Shape | Nominal Size (mm) | Length (km) |
|---|---|---|---|
| Wastewater | Egg shaped | 400 mm to 900 mm | Approx 5.2km |
| Stormwater | Round, with some oval | 300mm to 1,100 mm | Approx 6.9km |

The survey and condition assessment has now been completed. The project team has identified the most appropriate rehabilitation methodologies and design criteria for the construction programme. Specialist rehabilitation contractors have been engaged and construction works are now well underway. Once completed, the lining works scheduled in the rehabilitation programme will enable the brick barrel sewers to survive future smaller earthquakes intact, and to minimise the levels of damage resulting from larger seismic events.

This paper reviews the work carried out to date, and provides an overview of work remaining to be completed under the project.

# 2 ORIGINS OF THE SEWER NETWORK

Christchurch City was founded in the 1850's, and incorporated as New Zealand's first city, by Royal Charter, in 1856. By the 1870's it had become New Zealand's unhealthiest city, suffering outbreaks of water-borne diseases such as typhoid, and it became apparent that action was urgently required to provide effective drainage and to address the public health issues of the rapidly growing city.

Christchurch's location, in a swamp, and the conflicting interests of different suburbs, made the problem an expensive one to solve (some ratepayers strongly opposed the plans for a drainage system on the grounds of cost), and the debate on the solution was protracted. In 1875 the New Zealand Government created the Christchurch Drainage Board by an act of parliament, with overall authority to tackle the problem. The population at the time was 12,000 people.

The Board employed an English consulting engineer, William Clark, to design the system. After a month's work, he presented to the Board a comprehensive report, a plan (Figure 1), and explanatory diagrams. He considered that the greatest problem for the city was its water-logged site, particularly in winter. He also realised that the saturated soil in Christchurch would create major problems for the construction of the sewer network.

*Figure 2 Construction conditions in 1918 (Christchurch Drainage Board)*

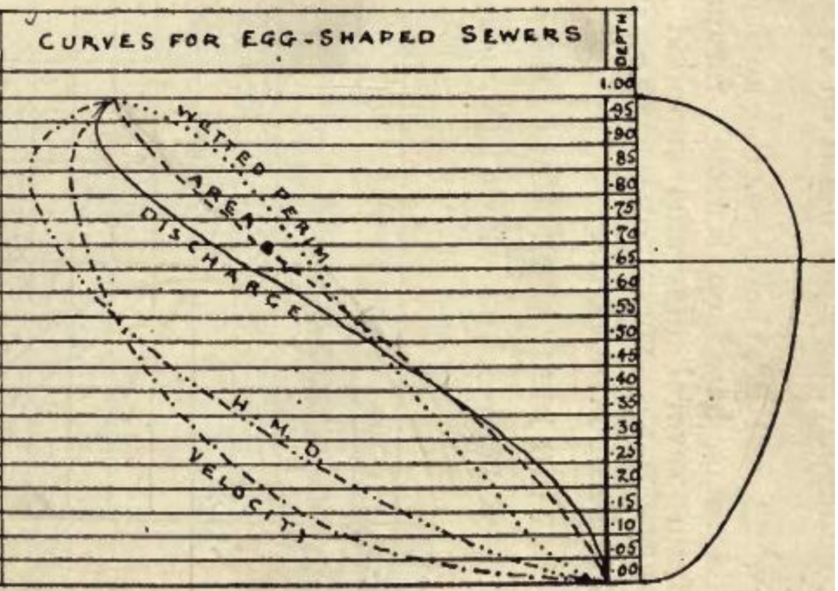
There were problems with quicksand and shingle when construction started, particularly in the area around the Tuam St pumping station. However, the work got easier as construction progressed, and the benefits of the earlier phase of construction were achieved. The main sewers in the inner city and a siphon under the Avon River were completed after two years work in 1882.

## 2.1 BRICK BARREL SEWERS

Clark's scheme made extensive use of brick barrel construction for the larger sewers, and in accordance with the design philosophies in use at the time, many of them were constructed as egg shapes, or variations on ovals. Bricks were readily available, and could be laid manually. In the days before powered construction plant, this was essential, and many Victorian cities used the same construction techniques to build their sewers, for the same reasons. Figure 3 below shows an excerpt from one of the design manuals in use at the time. Such manuals are often still the best references for information on the construction and design techniques used.

*Figure 3 Egg shape sewer design data (Sewerage Engineer's Note-book, 2nd edition, Albert Wollheim 1896)*

| AREA | WETTED PERIM. | H.M.D. | VELOCITY | DISCH. | DEPTH |
|---|---|---|---|---|---|
| 1 00 | 1.00 | 1.00 | 1.00 | 1.00 | 100 |
| ·978 | ·862 | 1.109 | 1.053 | 1.027 | ·95 |
| ·937 | ·801 | 1.166 | 1.079 | 1.011 | ·90 |
| ·886 | ·752 | 1.176 | 1.063 | ·960 | ·85 |
| ·829 | ·709 | 1.166 | 1.079 | ·895 | ·80 |
| ·766 | ·668 | 1.145 | 1.068 | ·819 | ·75 |
| ·702 | ·629 | 1.114 | 1.054 | ·739 | ·70 |
| ·638 | ·591 | 1.077 | 1.036 | ·661 | ·65 |
| ·580 | ·553 | 1.046 | 1.021 | ·592 | ·60 |
| ·511 | ·514 | ·990 | ·993 | ·507 | ·55 |
| ·450 | ·476 | ·943 | ·971 | ·438 | ·50 |
| ·387 | ·436 | ·886 | ·939 | ·363 | ·45 |
| ·326 | ·397 | ·818 | ·906 | ·296 | ·40 |
| ·268 | ·357 | ·751 | ·866 | ·232 | ·36 |
| ·218 | ·317 | ·668 | ·816 | ·174 | ·30 |
| ·163 | ·277 | ·591 | ·766 | ·125 | ·25 |
| ·119 | ·238 | ·503 | ·708 | ·084 | ·20 |
| ·077 | ·193 | ·399 | ·630 | ·048 | ·15 |
| ·043 | ·148 | ·290 | ·540 | ·023 | ·10 |
| ·016 | ·100 | ·161 | ·400 | ·006 | ·05 |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | ·00 |




The egg or oval shaped profile of many of these sewers has a number of advantages over a circular profile:

- It allows the sewer to achieve self cleansing flow velocity at lower flow volumes, so the need for sewer flushing is minimised. This is particularly important in flat terrain like that of Christchurch;

- It is better able to support vertical loads than a circular sewer of equivalent capacity;

- The trench width required for its construction is less the width required for an equivalent circular sewer; (this factor is more important when the trench has to be dug by hand)

- In the larger sizes, the sewer height is sufficient to permit man entry for inspection and maintenance;

- It does not need reinforcing steel to achieve strength required for high vertical loads.

On the other hand, this type and form of construction suffers from a number of disadvantages, some of which become critical when sewers of this type are subjected to earthquake conditions

- It is labour intensive to construct, requiring skilled bricklayers, and it is not readily mechanised;

- The straight sections in the vertical walls are vulnerable to hydrostatic pressure, which increase by about 2.2 during liquefaction events;

- The mortar joints between the bricks loose strength, and provide entry points for infiltration and root penetration;

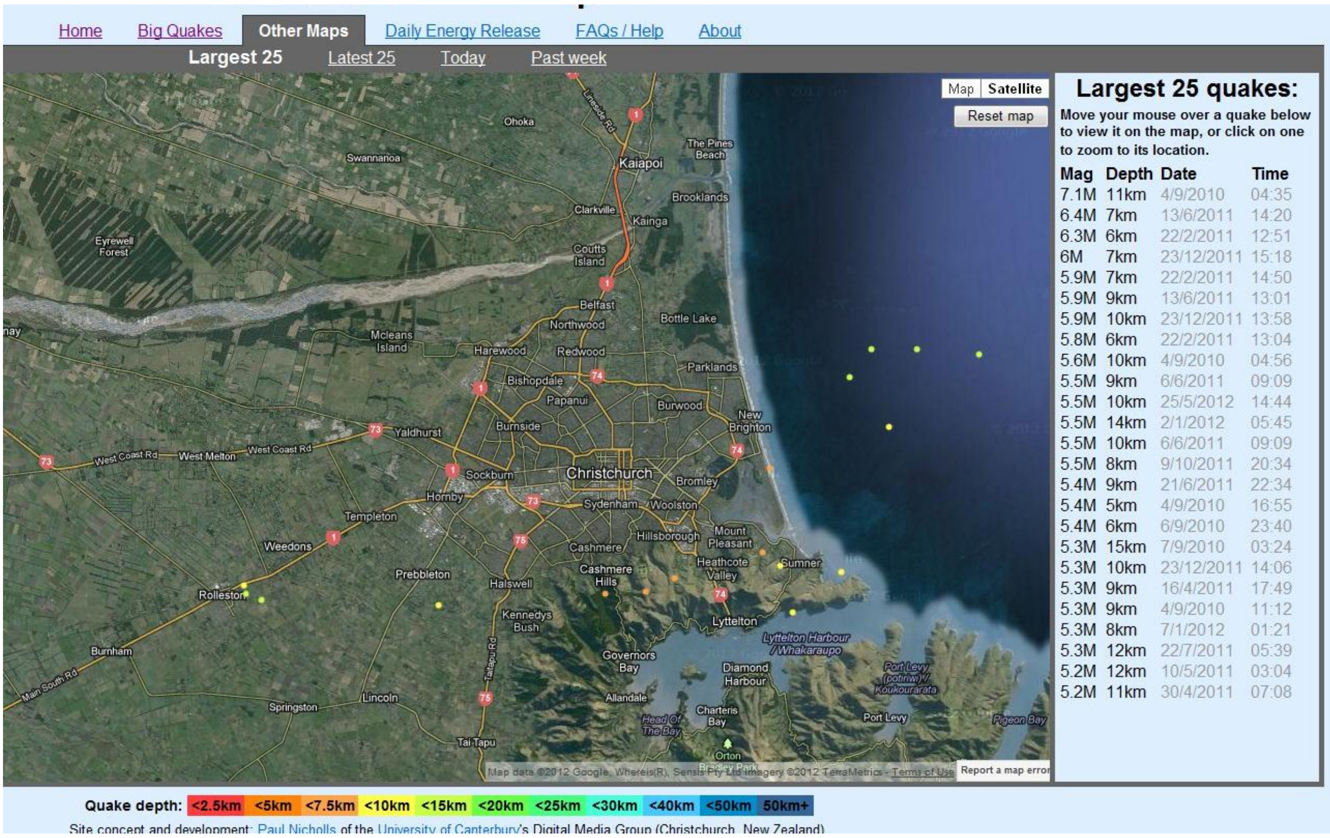
- As with brick masonry above ground, these unreinforced structures are vulnerable to shattering. This is because they have minimal tensile strength so discontinuities in the brickwork structures (such as lateral penetrations and manholes) act as stress raisers.

When powered construction machinery became available, it became more cost effective to construct large diameter pipelines in precast concrete pipe, and brick barrel construction went out of fashion for sewers. Typically, the life of such sewers is reckoned to be about 100 years, although their deterioration is generally gradual and some have lasted substantially longer.

# 3 CHRISTCHURCH EARTHQUAKES

The map below (Figure 4) shows the locations of the largest 25 earthquakes which have occurred since September 2010. Over 10,000 separate aftershocks have now been recorded by July 2012.

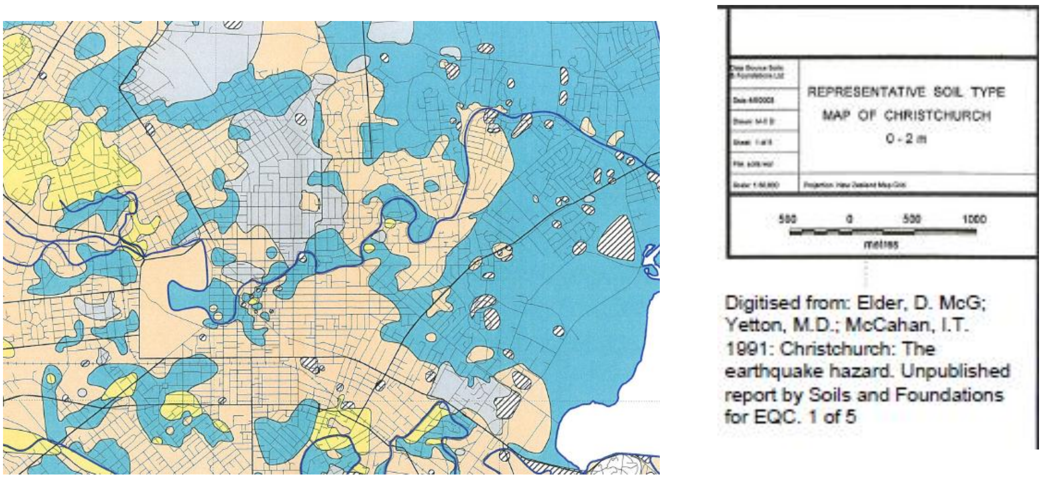
*Figure 4 - Christchurch Quake Map (University of Canterbury)*




## 3.1 SOIL CONDITIONS

As noted above, although the poor soil conditions in Christchurch were apparent to the earliest drainage engineers, they were not equipped to recognize the full significance of the silty soils.

*Figure 5 Soil type 0 to 2m (EQC)*




# 4 SEWER DEFECTS – CONDITION ASSESSMENT

Nearly all the Christchurch brick barrel sewers have now been surveyed at least once, and in some cases, where the original surveys could not be completed due to silt or other obstructions, the surveys have been repeated.

When the brick barrel sewers were exposed to seismic effects, they suffered a range of immediate damage from complete structural collapse in areas where ground displacement occurred, to cracking of varying degrees of severity. Figure 6 shows one example of a shear defect, in which the pipe has suffered a complete dislocation, and shattering of the brickwork structure.

Nearly all of the sewers inspected showed evidence of circumferential cracking as if the ground in which it was built had been exposed to a moving vertical displacement, or ground wave, as shown in Figure 7, where the damage is less severe but more widely distributed.

*Figure 6 - Shear defect*


*Figure 7- Circumferential & longitudinal cracking*


The defects shown in Figure 6 and Figure 7 were surveyed immediately after the pipeline sections containing them had been cleaned. It is not immediately obvious that the type of defect shown in Figure 7 is the cause of massive silting. The silt in the avenues area is very fine grained, and liquefaction conditions. It is clear that it can enter the sewers in enormous quantities, via defects that would normally be regarded as trivial in a storm water pipe network.

Figure 8 shows such a defect, and Figure 9, which is taken from a survey of the same sewer reach at a different time, shows the result. This is by no means the deepest layer of silt which we found in reviewing the video surveys. Long before the silt reaches such levels, the pipeline sections are impassable to cameras mounted on conventional CCTV survey tractors, because the wheels of such tractors simply sink into the silt, and the tractor chassis becomes stuck in the silt. Heavily silted sections are therefore usually surveyed with cameras mounted on floats, but in some cases, the pipeline sections were impassable even to float mounted cameras, because the remaining open area of pipeline was too small.

*Figure 8 - Silt infiltration via defective brickwork*


*Figure 9 - Silt deposits*

Silt also enters the sewers via lateral connections, most of which show obvious signs of earthquake damage, as in Figure 10

*Figure 10 Silt infiltration via laterals*


In the immediate aftermath of a significant seismic event, liquefaction occurs, and the volume of silt inflow is greatly increased. Many of the brick barrels require constant flushing, as shown in Figure 11 to maintain their flow capacity as a result.

*Figure 11 Flushing to remove silt by water jetting*

*Figure 12 Effects of water blasting*


Unfortunately, the silt very quickly turns to a substance with the consistency and strength of weak mortar when it is allowed to settle. The water blasting required to move it when it has reached this state is quite aggressive, and the silt also generally contains fragments of brick and concrete debris, so that the water blasting process has the undesired effect of grit blasting the remaining mortar which holds the brick barrels together.

The effect of this can be seen in Figure 12. Many of the wastewater sewers were constructed using trapezoidal shaped bricks. These sewers are relatively stable even when the mortar between the bricks is damaged or absent. However many of the storm water sewers were constructed using rectangular profile bricks and these are much less stable when damaged. It is common to see that the circular storm water sewers have deformed profiles as a result. These deformations often exceed the eccentricity values commonly used in conventional sewer lining designs, and impose practical difficulties for the designer and rehabilitation contractor.

*Figure 13 Deformed profiles in storm water brick barrels*


In addition to the visible effects of the silt infiltration as viewed from inside the sewer, there are also serious effects on the surroundings. The silt which enters the sewers has to come from somewhere else, and in the most obvious cases, this creates voids in the surrounding soil. In some cases these become sinkholes, but in all cases, there is an inevitable loss of strength in the side support to the sewer barrel. Over the long term there will also be changes in ground level. Many of these sewers lie under roads so the sinkholes create major traffic issues. They also lie close to other structures such as buildings, bridge abutments, retaining walls, and other underground pipelines, all of which are vulnerable to the effects of this soil movement by liquefaction. Figure 14 shows one example of this. The road surfaces along Christchurch's main roads show the effects on a larger scale, as many of them have obvious channels in the corridor immediately above these sewers, caused by the silt loss to the sewer system. The Burwood silt mountain shows the scale of this phenomenon, with thousands of tonnes added to it every day.

*Figure 14 Kilmore St sinkhole (photo- Christchurch CC)*


Following analysis of the video surveys, the results were classified into categories designed to facilitate the prioritisation of repairs, as shown in Figure 15. This figure also includes a table showing the definitions of the categories used in the assessment categories.

The New Zealand Pipe Inspection Manual is usually used to define the methodology for condition assessment of sewers in New Zealand, but its defect codes cannot be readily applied to brick barrel sewers. The manual takes no account of the subtle and complex issues that arise in reviewing surveys of sewers in the context of rehabilitation programme planning as required by the SCIRT remit. Therefore the authors of this paper have devised the system described to provide a rapid and consistent method of assigning ratings to the sewers, to permit essential remediation to proceed with a minimum of delay.

*Figure 15 Condition Assessment sample and grading legend*

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1109 10 | A | Kilmore | FS | 5/05/11 | Kilmore3 | Kilmore | 13244 | 13236 | Y | 234 | 1 | Lining | 1 | 600*400 | 50 |
| | B | Street_From | FS | | | | 13245 | 13244 | N | 73.6 | 1 | lining | 1 | 600*400 | 50 |
| | C | MH13244 to MH13236 | FS | | | | | | N | 10 | 1 | lining | 1 | | |
| 1109 11 | A | Madras Street #15282 #15291 | FS | 27/06/11 | 15282 | Otley Ave / Madras St | 14958 | 14967 | Y | 60 | 1 | Lining | | 1070*710 | 90 |
| | B | #15293 #15305 #15309 | FS | 27/06/11 | 15291 | Melrose / Madras | 14967 | 14974 | y | 57.1 | 1 | Lining | | 1070*710 | 90 |
| | C | | FS | 29/06/11 | 15293 | Moa Pl/ Madras St | 14974 | 14977 | Y | 46.2 | 2 | Lining | | 1070*710 | 90 |
| | D | | FS | 28/06/11 | 15305 | Madras St | 14977 | 14990 | Y | 154 | 1 | Lining | | 1070*710 | 90 |
| | E | | FS | 29/06/11 | 15309 | Madras St | 14990 | 14993 | Y | 21 | 1 | Lining | | 1070*710 | 90 |

**Legend**

**SW Pipe Scoring**

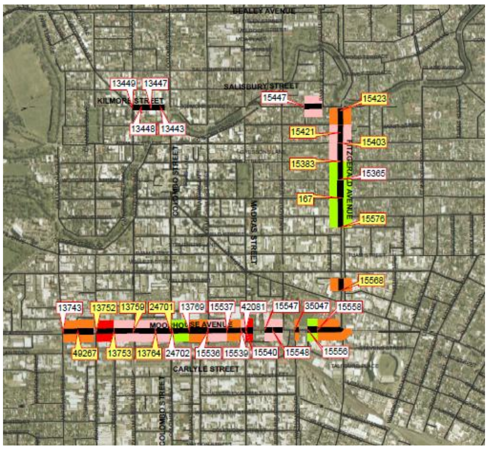
score

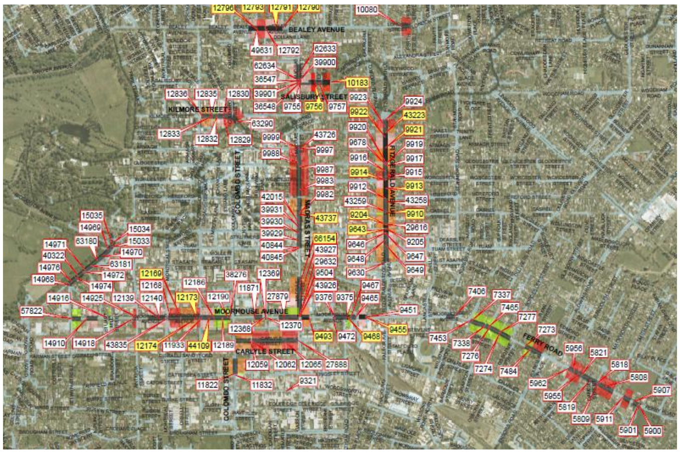
- 1 = Critical condition throughout
- 2 = Risk of collapse <= 2yrs
- 3 = Risk of collapse <= 5yrs
- 4 = Critical condition at isolated locations
- 7 = Collapse not imminent
- 8 = To be graded
- 9 = Resurvey

Figure 16 shows the results of this classification, as of early July 2012.

Approximately 5km of wastewater sewers and 15km of stormwater sewers had been surveyed and assessed by July 2012. The stormwater total greatly exceeds the wastewater total.

*Figure 16 Stormwater and wastewater sewer surveys completed by mid-July 2012*





# 5 REHABILITATION PROCESS SELECTION

Three high level options for the rebuild of the brick barrel pipes were identified. These were:

1. Replace the network in a different position to the existing.
2. Replace the brick barrel network with new pipes in the same position.
3. Rehabilitate the existing brick barrel pipes.

A multi criteria assessment was undertaken which identified rehabilitation of the existing brick barrel network as the favoured option, as it is quicker and less disruptive. It was the only option that would ensure that the works would be completed before the start of the vertical infrastructure rebuild. It was also the cheapest option.

# 6 DELIVERY MECHANISM

It was decided to undertake the works under a two stage process, with Stage 1 covering scoping and specification and Stage 2 being design and construction. This is a departure from SCIRT's standard process, where the design is fully completed by a design team prior to the delivery team starting construction. The reasons for adopting this two stage process were:

- To meet programme requirements.
- To reduce the time between the pipe being cleaned and the liner being installed. The pipe is at most risk of collapse during this time.
- To reduce interfaces between the Designer, CCTV Contractor and the Specialist Lining Contractor.

## 6.1 STAGE 1 – SCOPING AND SPECIFICATION PHASE

Scoping and specification works were undertaken by SCIRT's Orange Design Team. During this stage the Design Team liaised closely with the MacDow-Fletcher Delivery Team to obtain early contractor involvement, which ensured that potential issues were addressed in the specification and project scoping.

It was identified that the rehabilitation methods and product should:

- Provide resistance to hydrostatic pressure, including pressure due to silt liquefaction, at the depth of the sewer in which it is installed;
- Provide internal support to weakened sewer structures, up to the level of fully structural lining in the case of the worst damaged sewers;
- Provide resilience, to allow for minor ground movements and vibration which will probably continue to occur in the Christchurch area;
- Provide for a sealed junction between the lateral connections and the main sewer, to prevent silt infiltration;
- Provide a system which does not fail in a catastrophic manner (i.e. it should not collapse) if major earthquakes occur in the future.

Cured-In-Place Lining (CIPP) was identified as the only viable rehabilitation method for the egg shaped wastewater sewers and other non-circular pipes. For the circular stormwater pipes either CIPP or spiral wound liner were identified as suitable solutions.

Sliplining was not favoured, due to loss of cross-sectional area, and because of the cost and disruption from the excavations when gaining access to the pipes. It was also considered unlikely that sliplining would be a cheaper lining option.

Rehabilitation methods that required personnel to enter un-rehabilitated pipes were excluded due to the possibility of an earthquake causing a pipe collapse whilst personnel were inside the pipe.

The following points were considered at this stage and addressed in the technical specifications:

- Design life – liners are to have a design life of at least 50 years.
- Design Methodology – the WRc method was identified as the appropriate standard for liner design, as it specifically covers design of liners in brick barrel pipes, including egg-shape and oval pipes, as well as circular pipes.
- Liquefaction – Liquefaction had occurred in the vicinity of the brick barrel pipes and it was possible that further liquefaction could occur in future earthquake events. This was allowed for by using a density of $22kN/m^3$, as opposed to $10kN/m^3$, to determine the hydraulic load applied to the liner in a liquefaction event. This meant that the liners would be 2.2 times stronger than the liners that would normally be installed in these pipes if the liquefaction risk was not present.
- Condition of host pipe – round pipes are assumed to have a maximum ovality of 5%. All loose bricks, encrustations or protrusions that extend into the pipe bore by more than 5% are to be removed prior to lining.
- Hydraulic performance – an assessment of hydraulic performance confirmed that although the bore of the pipe will be reduced through the installation of the liner, the overall hydraulic performance will be improved, as the liner has a smoother surface than the existing brick barrel pipe.

## 6.2 STAGE 2 - DESIGN AND CONSTRUCTION PHASE

This stage is being managed by the MacDow-Fletchers Delivery Team, who have appointed Opus and AECOM to assess and design. Contractors have been engaged to complete.

- Cleaning and CCTV
- Lining
- Civil works

The key tasks being undertaken by the various parties are:

MacDow Fletchers

- Overall management and reporting

Assessment & Design

- Deciding which pipes require rehabilitation
- Setting design parameters
- Liaising with SCIRT's technical leads
- Preparing as-built drawings

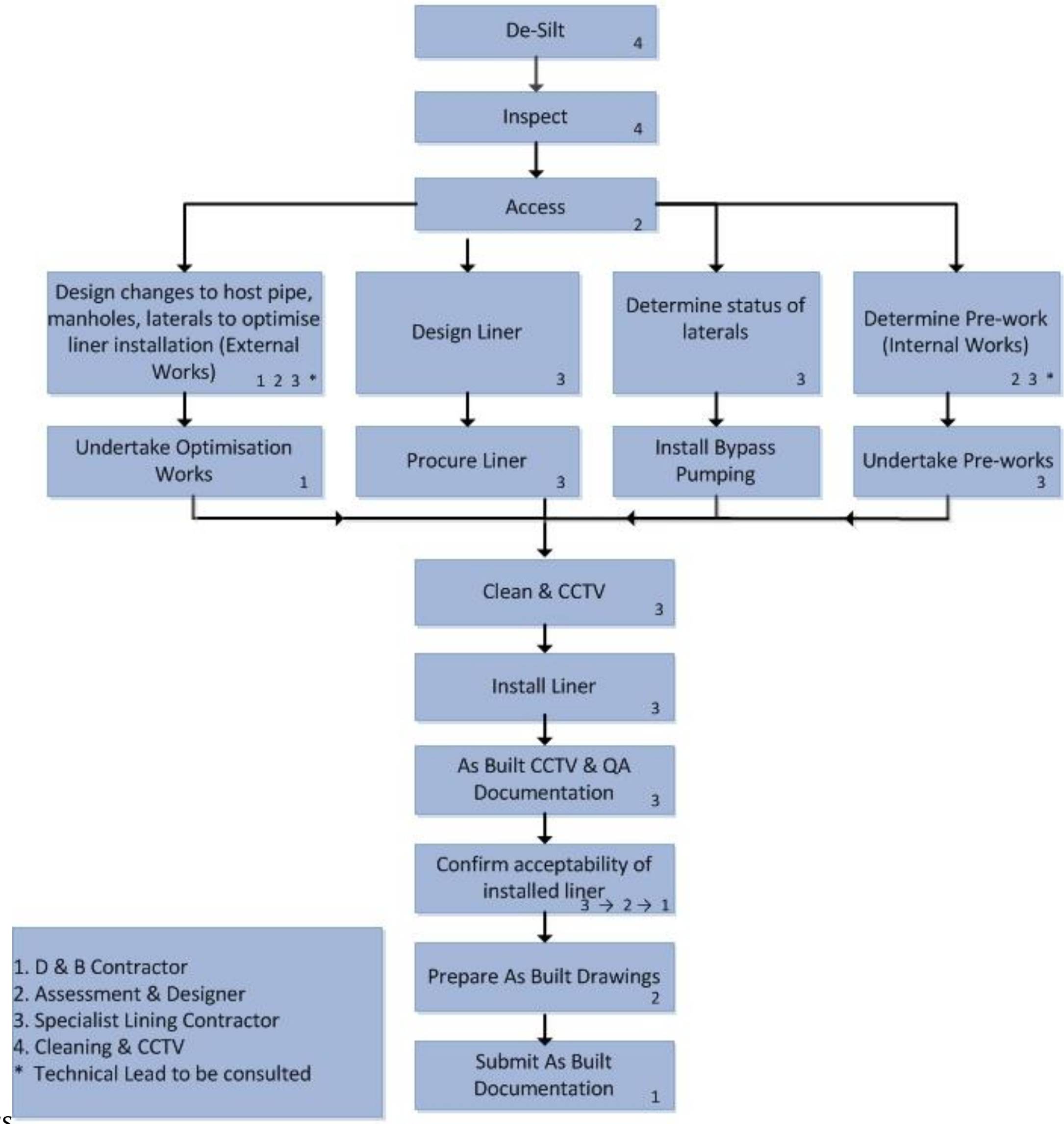
Specialist Lining Contractors

- Determining the required properties of the liner (e.g. liner thickness, size and resin strength), based on parameters set by the designer
- Installation of the liner

The need for pre-lining works to repair the host pipe or to gain access for lining is being determined with input from MacDow Fletchers, the Specialist Lining Contractor and the Designers.

The overall process for rehabilitation of the brick barrels is given in Figure 17.

*Figure 17 - Liner Installation*




*Process*

### 6.3 SPECIALIST LINING CONTRACTORS

The selection of the specialist lining contractors was critical to the success of the project. Programme constraints required that the lining contractors be appointed before pipe assessment had been completed and the scope of the contract fully defined. Therefore, a request for proposal (RFP) was prepared based on a sample of pipes that were required to be lined. The responses to these proposals are being used as the basis for negotiating contracts for rehabilitation of specific packages of work.

Four lining contractors submitted proposals. From these Interflow Pty Ltd, who offered a spiral would liner and Pipeworks, who provide CIPP lining, were appointed. The appointment was based on several evaluation criteria including value for money and demonstrated project performance, as well as their adherence to SCIRT's mindsets, values and behaviours.

Interflow started work on site in June 2012, lining the circular stormwater pipes. Pipeworks started in July 2012 and are lining egg-shaped wastewater pipes.

## 7 CONCLUSIONS

The series of earthquakes which has taken place in Christchurch since September 2010 has created damage to the city's underground infrastructure on a scale which is unprecedented in New Zealand, and comparable to the visible damage which has occurred in overground structures.

These effects may not be as immediately obvious, because they occur below ground, but they present a significant challenge to the city's rebuild programme, since the surface infrastructure rebuild programme cannot get underway at full speed until the condition of these critical wastewater and stormwater assets is stabilised, and their condition restored, so that they can be relied upon to provide continuing service into the future.

In order to meet this challenge, it has been necessary to develop mechanisms to provide for:

- Rapid and consistent assessment and condition grading of the sewers
- Design procedures for rehabilitation of earthquake damaged pipelines
- Provision for resilience in the event of further aftershocks or earthquakes
- Contractual arrangements for lining construction works on a scale greater than anything previously undertaken in New Zealand
- Implementation of the construction works in as short a timescale as practicable

These challenges have been met up to the point that the construction works have now been underway since July, and the pace of the pipeline rehabilitation is accelerating.

Approximately 60% of the stormwater and 90% of the wastewater brick barrels have now been assessed.

Contracts for lining works have been issued, and each of the two contractors is currently lining about 1km of pipework per month.

## ACKNOWLEDGEMENTS

SCIRT

Christchurch City Council

City Care Ltd

Fletcher Construction Ltd

Interflow NZ Ltd

Hydrotech Drainage & Plumbing Ltd

Drain Surgeons Ltd

## NONENCLATURE

| | | | |
|---|---|---|---|
| CIPP | Cured in place pipe | PE | Polyethylene |
| PVC | PolyVinyl Chloride | EQC | Earthquake commission |
| NZPIM | New Zealand Pipe Inspection Manual | | |

## REFERENCES

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John Wilson, Te Waihora Press, 1989