MacLeod Consulting

Barwon River Ovoid Sewer Aqueduct Engineering Study: Options for partial demolition and conservation of the structure

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CONTENTS

CONTENTS 3

EXECUTIVE SUMMARY 5

Part A REPORT OBJECTIVES AND BACKGROUND 7

A 1 Introduction 7
A 2 Objectives 7
A 3 Purpose of the Study 8
A 4 Background 8
A 4.1 History 8
A 4.2 Aqueduct Condition and Safety Issues 10
A 4.3 Barwon River Floodplain 11
A 4.4 Barwon River Parklands Project 11
A 5 Methodology of the Study Stages 12
A 6 Interim Report 13
Part B STRUCTURE AND LOADINGS 15

B 1 Structure Type 15
B 2 Structural Member Actions 15
B 3 Design of the original members (Considere system) 15
B 4 Ovoid Sewer Pipe Construction 17
B 5 Original Concrete - Strength 18
B 6 Original Structure Loadings 18
B 7 Performance of Structure and Members 19
Part C STRUCTURE CONDITION AND PREVIOUS REPORTS 21

C 1 Background 21
C 2 Deterioration of the Structure and Elements 21
C 3 Previous Reports 22
C 4 Site Inspection 24
Part D TECHNIQUES FOR ENHANCING STRUCTURAL RESILIENCE 25

D 1 Structural Background 25

D 2 Structural Capacity Enhancement 26
D 3 Structural Integrity Enhancement 27
Part E OPTIONS 29
E 1 General 29
E 2 Remediation of the cantilever spans and beam spans over the river. 29
E 3 Remediation Options 29
E 4 Partial Demolition/Partial Remediation Proposal 31
Part F SUMMARY OF ESTIMATED OPTIONS 33
References: 34

APPENDICES

A: PHOTOGRAPHS 2014
B: REHABILITATION TRIALS, BARWON RIVER OVOID SEWER AQUEDUCT, AUSTRALIAN CORROSION CONSULTANTS, JUNE 2009
C: PROPOSED DEMOLITION EXTENT AND PROCEDURE
D: REPAIR COST ESTIMATES
E: COST ESTIMATES OF DEMOLITION OPTIONS
F: ORIGINAL LAYOUT DRAWING AND STRUCTURE DRAWINGS, STONE & SIDDELEY (REDUCED TO A3 SIZE)
G: SUPPLEMENTARY SUPPORT PROPOSAL AND PROPOSED DEMOLITION EXTENT DRAWINGS

EXECUTIVE SUMMARY

1. This report is in response to the "Brief for Engineering Study of Long Term Management of the Ovoid Sewer Aqueduct as a ruin" prepared by the Steering Committee for the Barwon River Parklands project
2. The objectives are to:
    - Enable safe passage for persons moving along the Barwon River and its banks, opening up the area for recreational use; and,
    - Conserve the significant heritage value of the structure.
3. The conclusions of the report are:
    - The structural capacity and longevity of retained spans can be improved through introduction of jacked propping frames at the tips of the retained cantilevers to induce a reversal of the stress pattern within the cantilever trusses so that those compression members having longitudinal bars with corroded confining windings will have substantially reduced risk of buckling;
    - Demolition of the river spans between the south end of the Pier 8 cantilever and the north end of the Pier 13 cantilever is the preferred minimum demolition, retaining the towers at Piers 9, 10, 11 and 12 for their contribution to interpretation of the alignment and extent of the original Aqueduct;
    - Delamination/spalling of the surface concrete is advanced, with no prospect of being halted without significant intervention and ongoing expenditure. Opportunity exists to mitigate further decline through cathodic protection. Cathodic protection of the remaining structure elements with its associated surface repairs is a preferred rehabilitation process but greatly exceeds the target budget of $4 million;
    - Patch repair has been assessed to evaluate limited expenditure options. However, conventional patch repair requires significant present and future repair works to maintain the structure and will greatly exceed the target budget of $4 million; and,

- A propped structure will allow the degraded structure to last longer before eventual collapse or hopefully, further rehabilitation works funded by others.

4. Options that have been considered have been estimated for cost as follows:
    - Complete demolition of the entire structure including piers

      $3,644,900
    - Demolition of the river spans and complete cathodic protection of the remnant structures

      $25,756,300
    - Demolition of the river spans and propping of the remnant structures, capping of piers, fencing and an interpretation/viewing structure

      $2,918,900
5. The estimated 2016 cost to patch repair one span varies between $228,000 and $622,000, then the above minimum demolition option with propping and, say, two patch repaired spans at Piers 7 and 8 is estimated at **$3,738,900.**
6. The Steering Committee advised preferred option of minimum demolition (without cathodic protection or patch repair of any span) including propping of cantilevers, capping of piers, fencing and the interpretation/viewing structure falls within the advised budget at **$2,918,900**.

Part A REPORT OBJECTIVES AND BACKGROUND

A 1 Introduction

MacLeod Consulting was retained by Heritage Victoria and the Barwon River Parklands Project Steering Committee in response to the briefing document titled "Brief for Engineering Study of Long Term Management of the Ovoid Sewer Aqueduct as a ruin."

A 2 Objectives

The aim of the study is to identify a practical solution, both technically and financially viable, to meet two key objectives:

- Enabling safe passage for persons moving along the Barwon River and its banks, opening up the area for recreational use; and,
- Conserving the significant heritage value of the structure.

At the outset, both the Barwon River Parklands Steering Committee and Heritage Victoria had agreed that these objectives cannot be achieved in isolation to one another; a balance between the two is necessary. It was agreed that options must be achievable within realistically available funding; otherwise nothing will proceed to implementation (as has been the case with previous studies). A 'do-nothing' option would mean neither objective is achieved, as the full heritage value can only be attained by society if the Aqueduct is readily accessible for interpretation viewing.

Preliminary study discussions held 17 February 2014 between Mr Steve Reddington, Barwon Water, Mr Martin Zweep, Heritage Victoria and the author confirmed these objectives. An interim report was submitted to the Steering Committee representative and Heritage Victoria on 27 March 2014. A final report was submitted to the Steering Committee representative dated 19 August 2015 and an update with further cost estimates on 3 March 2016.

This final report dated 11 April 2016 incorporates further cost estimate clarifications as well as the Steering Committee's preferred approach for minimum demolition within a limited budget.

A 3 Purpose of the Study

The study aims to provide advice on the following:

- An assessment of the physical condition of each pier and each span with a view to ascertaining the nature, extent and cause of the deterioration as well as identifying the better elements;
- Proposals for conservation works that will inhibit ongoing deterioration, address its causes and make the place safer with the aim to arrest further deterioration rather than attempt to make the place appear "all shiny and new"; and,
- Identification of any parts of the structure that may require ongoing structural support and perhaps some proposals for support.

A 4 Background

A 4.1 History

The Barwon River Ovoid Sewer Aqueduct constructed between 1913 and 1915 served as the main sewer between Geelong and the treatment plant and ocean outfall at Black Rock. The aqueduct is 760 metres long and consists of 14 piers and balanced cantilevers of reinforced concrete truss design, with the ovoid sewer supported underneath the walkway. It was the only sewer crossing of the Barwon River until 1968 when a second main sewer, the McIntyre Bridge, was constructed. The Aqueduct was decommissioned in 1992, replaced by a nearby underground syphon.

The Barwon River Ovoid Sewer Aqueduct was added to the Victorian Heritage Register, Gazetted on 23 October 1991 (Victoria Government Gazette No. G41 23 October 1991

p.2938), affording it protection under the Historic Buildings Act 1981 (subsequently replaced by the Heritage Act 1995). The aqueduct is currently registered by Heritage Victoria (VHR H0895) and covered by a Heritage Overlay (HO56) in the Greater Geelong Planning Scheme.

The Victorian Heritage listings Statement of Significance (http://vhd.heritagecouncil.vic.gov.au/places/518) provides the following description:

"The Ovoid Sewer Aqueduct was constructed over the Barwon River at Breakwater in 1913-15 for the Geelong Waterworks and Sewerage Trust as part of a sewerage scheme to serve Geelong. The sewer extended south from the urban centre of Geelong to the coast at Black Rock to discharge into Bass Strait at the shoreline. The outfall sewer, which comprised a reinforced concrete pipe of ovoid shape, crossed the Barwon River at Breakwater and was conveyed across the flood plain by means of a long reinforced concrete aqueduct of innovative design.

The aqueduct and sewer were designed and constructed by Tasmanian engineer Edward Giles Stone and his partner Ernest J. Siddeley. A purpose-built factory was established nearby, adjacent to the railway, to manufacture the sections of sewer pipe, with production commencing in 1912.

The aqueduct is approximately 756 metres in length and carries the ovoid sewer pipe and a walkway. It consists of a series of trusses which cantilever from fourteen concrete, corniced piers. Girders bridge the gap between these trusses. The form of the aqueduct was inspired by an overseas rail bridge design, the steel Firth of Forth Bridge, Scotland, constructed by 1890.

One of the most innovative forms of concrete reinforcement used in Australia, the Considere system, was used in the construction of the aqueduct. Heavy spiral reinforcing bars were used to increase the compressive strength of the concrete core. E. G. Stone was the greatest individual exponent of this system and his design of the Dennys Lascelles Austin wool store at Geelong in 1909 (now demolished) was an excellent example of the application of this system. Stone was also a great innovator and this is evident in his application for a number of patents from 1908."

A 4.2 Aqueduct Condition and Safety Issues

The aqueduct has a long history of deterioration, as reported in the statement of significance: *'Cracks began to appear in the concrete work of the aqueduct as early as 1922 and initial repairs were made in 1923-24. Other repair works have been made since this time'*.

A Geelong and District Water Board internal report from 1990 reported that *'By 1976 significant deterioration of the superstructure was becoming apparent, as evidenced by cracked and spalling concrete in some structural members, exposing corroding reinforcement. Repairs were carried out, consisting of removing the loose concrete, cleaning the reinforcing steel and then casting new concrete around the members to protect the steel from future corrosion'*.

Despite extensive efforts to repair and maintain the aqueduct by Barwon Water, its condition continued to deteriorate and it was subsequently decommissioned in 1992. Since then there have been a number of investigations on the condition of the aqueduct and options for its repair, as well as repair trials undertaken on the structure. This included an Independent Panel of Inquiry, appointed by the then Planning Minister Robert McLellan, which submitted its report in May 1996. Costs estimates to repair the aqueduct have been suggested to be as much as $60 million, but with no guarantee of long term sustainability and structural integrity (GHD 2009). It is visually evident that many of the previous repairs have now also deteriorated to the point of failure.

It is difficult to predict when and how the Aqueduct might collapse; however the advice received by Barwon Water is that collapse could potentially occur at any time (Maunsell 1994). Twenty years on collapse has not occurred, indicating that the structure in its present decommissioned state retains some (indeterminate) structural capacity.

As with all structures, it is important to note that the aqueduct was never designed to have an unlimited lifespan. In the absence of its heritage value and listing, the aqueduct would have been demolished long ago by Barwon Water. The aqueduct has now entered its 'second life', as a heritage structure.

Due predominantly to the potential safety risks posed by the aqueduct, the structure, river and surrounding land is closed to public access. Barwon Water has determined that there is no access onto, or under the Aqueduct on either land or water for many years, preventing any access along the Barwon River and precluding the potential inclusion of the site as public parkland. The structure remains fenced off on all sides with no access permitted by any person inside the security fence line. There are also floating booms on the Barwon River upstream and downstream of the structure to restrict on-water access under the structure.

Resolution of the safety issue is a priority. This is not only for public safety, but to enable the heritage value of the aqueduct to be fully enjoyed by society. Although the aqueduct remains relatively intact physically, in a social sense the heritage value of the aqueduct is not being realised at all due to its isolated state.

A 4.3 Barwon River Floodplain

On the north side of the river, the aqueduct structure crosses an extensive floodplain, which contains significant remnant native vegetation and fauna habitat (Peeters 2012).

Barwon Water owns the majority of the floodplain, purchased from the Geelong Regional Commission in the 1990's. A crown reserve extends a short width from the northern bank of the river and is managed by the Corangamite Catchment Management Authority. The aqueduct also crosses an island, Goat Island, which appears to be unallocated crown land, with no defined land manager (i.e. defaulting to the Department of Environment, Land, Water and Planning).

A 4.4 Barwon River Parklands Project

The Barwon River Parklands project has a vision to achieve a public open space network stretching along the full length of the Barwon River from Geelong to Barwon Heads. With strong community interest, and urban growth in Armstrong Creek to the south opening up key land linkages, this vision is quickly progressing toward reality.

The Barwon River Parklands Strategy, developed in 2011, outlines potential future additions to public parkland along the Barwon River corridor. The strategy identifies the Barwon River Ovoid Sewer Aqueduct as an important link.

The aqueduct and adjoining land feature significant heritage and biodiversity values. The inclusion of these within the parkland network will not only complete a vital connection, but will enable the community to engage with and appreciate these significant values. With the aqueduct and adjoining land already in public ownership, resolution of the aqueduct's safety issues is the only major obstacle.

A 5 Methodology of the Study Stages

The discussions held on 16 April 2013 prior to MacLeod Consulting submitting a back-brief and proposal concluded that the methodology of the engineering study formed three stages:

1. Review the previous engineering reports and inspect the structure. Then to conceive of potential structural interventions and actions that can exploit potential redundancies of the structure and the residual strength now that it is the structure does not carry sewer and walkway loads. These engineering proposals for some differing structural interventions that might be considered for the conservation of a number of spans, with the partial or full removal of other parts of the Aqueduct, will be presented for comment and discussion by the Steering Committee with a preferred approach then to be instructed;
2. On the basis of the preferred structural interventions and the extent of the prospective works for conservation/partial removal, to ascertain the residual capacity of the remnant structure, after taking a view on the extent of the deterioration based on the previous engineering studies by others. Based on the anticipated capacities derived from analyses, to scheme structural proposals for the proposed conservation/partial removal of the Aqueduct, for comment and discussion by the Steering Committee; and,

3. Finalise the report upon the above matters based on the feedback from the Steering Committee.

A 6 Interim Report

An interim report was issued by MacLeod Consulting on 27 March 2014 to outline the proposed approach to the long term management of the Ovoid Sewer Aqueduct including canvassing with the Steering Committee the demolition of the five spans south from the north bank to the Marshall bank abutment.

In addition, the prospect of demolishing the sewer pipe and its supporting cantilever trusses and link spans, but retaining the pier towers was introduced by MacLeod Consulting. The background to this idea is to retain the visual link from north abutment to south abutment using the remnant towers to show the alignment of the structure where it is demolished.

The conclusions of the interim report were:

- Introduction of jacked propping frames at the tips of the cantilevers being retained to induce a reversal of the stress pattern within the cantilever trusses so that those compression members having longitudinal bars with corroded confining windings will have substantially reduced risk of buckling;
- Demolition of the spans between the south end of the Pier 8 cantilever and the Marshall abutment, retaining the towers at Piers 9, 10, 11, 12, 13 and 14 for their contribution to interpretation of the alignment and extent of the original Aqueduct; and,
- Cathodic protection of the remaining structure elements with its associated surface repairs as the preferred rehabilitation process.

It was understood that the Steering Committee was generally accepting of these proposals.

A 7 Final Report

The final report was submitted to the Steering Committee representative dated 19 August 2015 with a further update of cost estimates on 3 March 2016. Subsequently it is understood that the Steering Committee, in line with the brief for long term management of the Ovoid Sewer Aqueduct as a ruin, proposed that this report include their aims of:

- Minimum demolition of spans i.e. only spans 9 to 12 over the river to be demolished
- Propping (structural capacity enhancement) of all remnant spans
- Capping and minor repairs to all piers
- Security fencing of the remnant Aqueduct structures
- Construction of an interpretation and viewing structure
- The target expenditure for works is between $2 million and $4 million

Part B STRUCTURE AND LOADINGS

B 1 Structure Type

The Aqueduct structure has a similar structural form to the Firth of Forth steel bridge in Scotland. Prof. Colin O'Connor[1] describes the Aqueduct as follows:

> *It consists of an ovoid concrete pipe, with internal dimensions 1.3 metres high and 0.99 metres wide, supported by trusses of concrete reinforced on the Considere system. These cantilever out 20.7 metres from the centreline of each tower, leaving a gap of 1.2 metres to be spanned directly by the pipe; as a result the normal centre-to centre spacing of the piers is 53.7 metres. The bridge as a whole has the following spans – one of 35.4 metres, nine of 53.7, 41.4, three of 53.7 and one of 35.4 metres, totalling 756 metres. The shorter 41.5 metre span is where it crosses Goat Island; the cantilever arms virtually meet, and the unbalanced dead load is avoided by the use of counterweights.*

B 2 Structural Member Actions

In a classical steel framed balanced cantilever truss, truss action resolves the applied gravity and imposed loads into axial loads within the members (tension and compression).

In the case of the Aqueduct, the bulky nature of the joints between members results in end restraint being available to resist member buckling. This restraint reduces the buckling effective length and increases the inherent member compressive capacity. However, ultimate load behaviour will approach pure axial load actions in the members, similar to that in a steel framed truss.

B 3 Design of the original members (Considere system)

The Considere system used in the Aqueduct by the designer, E. G. Stone of Stone and Siddeley, Contractors, employed a heavier than usual helical winding around the longitudinal bars of the generally octagonal or circular compression members. The theory of the Considere system for compression members was based on experiments in which Considere

established that the compressive strength of the core concrete was increased by this containment helix.

In the specific Aqueduct design by Stone, the characteristics of the Considere system are apparent in the various members as follows:

- Bottom truss chord (compression member) – square section with rounded corners with eight longitudinal reinforcing bars placed within the circular helical winding in accordance with the Considere system
- Top truss chord (tension member) – square section with rounded corners with the longitudinal reinforcement placed within square ligatures (eight bars) and an additional five bars within the "core" concrete
- Vertical truss members (compression member) – square section with rounded corners with the six longitudinal reinforcing bars placed within the circular helical winding in accordance with the Considere system
- Diagonal truss members (tension member) – square section with rounded corners with the four longitudinal reinforcing bars placed within square ligatures
- Truss horizontal braces and ovoid pipe suspension brackets (beam members) – square section with rounded corners with the four longitudinal reinforcing bars placed within square ligatures
- Pier columns (compression member) – square section with rounded corners with the eight longitudinal reinforcing bars placed within square ligatures
- Pipe beam top chord (compression member) – square section with rounded corners with the eight longitudinal reinforcing bars placed within the circular helical winding in accordance with the Considere system
- Pipe beam bottom chord (tension member) – square section with the eight longitudinal reinforcing bars placed within the circular helical winding in accordance with the Considere system
- Pipe beam perforated web (shear member) – square sections between perforations with the four longitudinal reinforcing bars placed within square ligatures

It is primarily the compression members of this truss system that are at risk from corrosion of the winding reinforcement, as loss of confinement from the windings can ultimately allow the compression member bars to buckle. Another risk applies to the tension member bar laps, where the confining windings act to maintain the integrity of the tension transfer from lapped bar to lapped bar through the concrete. In these cases, loss of the confining windings will allow the bar laps to "unravel" and the tension member will then fail.

The original structure drawings of the Aqueduct are reproduced as Appendix E to this report.

B 4 Ovoid Sewer Pipe Construction

The ovoid pipes were precast and vacuum dewatered in a manufacturing plant established by Stone and Siddeley near to the present Marshall railway station.

There are no detailed measurements on the structure drawings of the ovoid pipe, but it appears that the pipe wall section is approximately 76mm thick. The concrete in the pipe sections is likely to be of similar mix to that used in the Aqueduct itself, but as the pipes were dewatered the pipe concrete grade is likely to be better than the Aqueduct due to the reduced water-cement ratio.

It is anticipated that the ovoid pipe section may have small diameter centrally placed bars forming a rectangular mesh (which would be consistent with the rust staining evident on some pipe sections). From the thickness of the walls of the pipe, these bars are expected to be nominal 6mm diameter bars which would result in cover concrete thickness of, say, 30mm or so.

It is common that unlined concrete sewer pipes will suffer from hydrogen sulphide gas attack above the waterline. From earlier inspection by the author (when walkway access was available) it appeared from viewing through the open inspection openings at the towers that the obvert of the pipe section had suffered some hydrogen sulphide attack.

The external surface of the pipes varies in condition from an smooth uncracked surface to that with cracks – primarily horizontal and aligned along the springing line of the obvert.

B 5 Original Concrete - Strength

The previous investigations of the deterioration have also investigated the likely concrete compressive strength of the Aqueduct.

Beauchamp reports that three tests from cores taken from spalled concrete collected from under the Aqueduct resulted in characteristic compressive strength of 18.5MPa, 26.0MPa and 27.0MPa.

Taywood-Maunsell 1990 has used a characteristic compressive strength of the concrete of 14MPa in their (theoretical pin-jointed truss) analyses. However, Van der Molen and Alsop contest this reduced characteristic compressive strength in their collapse load analysis. The author understands that Van der Molen and Alsop used 18Mpa for characteristic compressive strength of the concrete.

B 6 Original Structure Loadings

The loadings to which the Aqueduct was originally subjected are:

- Self-weight including the sewerage pipe (estimated by the author at 40kN/m)
- Sewer flow weight (estimated by the author at 8.7kN/m)
- Pedestrian walkway live loads (estimated by the author at 5.4kN/m)
- Wind loads
- Stream flow
- Seismic loads

Seismic loads are likely not to have been considered at the time of the aqueduct's construction due to the state of knowledge of the incidence and forces arising from seismic events in Australia. However, seismic loads are considered to be unlikely to be an issue with

this structure as engineered (and triangulated) structures are always more robust than masonry structures or non-engineered structures and by experience are therefore less affected by seismic events.

Stream flow occurs when the flood plain fills with stream flow and debris pressures being exerted primarily on the four inclined column piers. These piers have previously experienced such loads whilst the Aqueduct was fully functional carrying sewer loads without consequence.

The wind loading on this structure is low due to its open form and the effective gusseted arrangement of the bottom chords as well as the walkway deck slab acting as a horizontal girder resolving lateral loads into small axial loads within the cantilever truss system. Consequently, wind loads can be largely ignored in considerations for the imposed loading on the Aqueduct.

The sewer weight and pedestrian walkway loadings now not required to be carried now result in the unloaded structure being subject to only about 73% of the original in-service vertical loadings.

B 7 Performance of Structure and Members

Published discussion is documented on the appropriate structural modelling for the Aqueduct. In the author's opinion, the more precise and comprehensive analyses (which recognises the end restraint in the compression members) have been made by Van der Molen and Alsop 1997, with their published results indicating the decommissioned Aqueduct appears capable of sustaining 1.9 times its self-weight. These analyses are supported as appropriate by Beauchamp.

It is reported by Alsop that Considere did not assume the cover concrete as contributing to the member capacity; only the concrete within the main steel was accounted load bearing. Further, by comparison with modern compression member construction, confining

reinforcement is appreciated for its ability to provide ductility in the collapse mechanism of the member. This is especially important in seismic design and for the safety of an overall structure as well as the likely "collapse" behaviour of the decaying Aqueduct.

Notes by Alsop on points arising from the independent panel of inquiry 1996, state that the Considere method of construction not only includes helical confinement reinforcement of compression members, but casts the compression members first with the continuous reinforcing bars of the tension members taking load without any concrete around them.

Photographs of the construction of the Dennys Lascelles Woolstore show this progressive staged construction. A publication contemporaneous with the Aqueduct, Constructional Engineering, 1916, notes that for the Dennys Lascelles Woolstore the following:

> *The reinforcement throughout is of ordinary commercial steel rods, and the disposition of the bars throughout the structure is of extreme interest, the full tensile strength being taken up by the laps; in no place are they mechanically connected. The rods in the upper boom are arranged in concentric rings, the laps of which break joint along its length. The diagonals are in tension, and the ends of the rods through them are accurately bent around the rods in the upper and lower booms.*

These features of the Considere system are remarkably similar to modern reinforced concrete practice.

Although the Dennys Lascelles Woolstore project by Stone clearly follows the Considere method of sequential concrete placement, it is unknown if the tension member concrete in the Aqueduct was poured after completing the compression members. The reference to lapping of tension steel suggests that the tension members, diagonals and top chord may well have been poured immediately after the bottom chord was completed. Photographs of the formwork assembly would support this proposition.

Part C STRUCTURE CONDITION AND PREVIOUS REPORTS

C 1 Background

Beauchamp notes that cracking was reported in 1922 in the diagonal tension members and in the balustrade to the walkway supporting the ovoid pipe between the ends of the cantilever trusses. Stone is reported as attributing these cracks to poor quality of the cement supplied and lack of available skilled workers for the construction of the Aqueduct.

Repairs to the Aqueduct are known to have been undertaken by Barwon Water and its predecessor. Unfortunately, a record search within Barwon Water for the type and extent of these repairs has been unsuccessful. Anecdotally, the author is aware of various patch repairs being undertaken by contactors to Barwon Water and its predecessor in the period 1970's to 1980's using patch repair techniques, poured replacement concrete and sprayed concrete.

C 2 Deterioration of the Structure and Elements

As noted above, cracking in the diagonal tension members and the balustrade to the walkway beam was reported in 1922/23. If the diagonals and verticals of the cantilever trusses were poured after the bottom chord, then the top chord poured after the diagonals and verticals this sequence could explain the tensile stress cracking in the diagonals as they came under load from the sewer pipe self-weight and sewerage flow load. The top chord similarly is subject to concrete cracking as the tension forces are increased.

This is unlike the slightly later Dennys Lascelles Woolstore construction sequence adopted by Stone.

The progression of the corrosion of the reinforcement will cause increasing delamination of cover concrete, rusting through of the helical windings in the compression members, which then will allow the compression member reinforcing bars to buckle which will cause the member to fail.

Initially, the commencement of failure of members will include some load redistribution through the reinforced structure, but quite quickly eccentric forces will develop causing overload of the remaining principal members. However, Van der Molen and Alsop (a view held by this author) expect the collapse to be ductile i.e. the cantilever trusses will sag with increasing distortion rather than catastrophically falling.

In order to maintain the ductility of the concrete members, one approach to re-establishing the confinement reinforcement of compression members (due to rusting of the helical windings and the ligatures) without extensive intervention in the deteriorated reinforcement is to tightly wrap the relevant members with a titanium alloy mesh or titanium alloy bands at regular intervals. This highly corrosion resistant wrapping would then re-establish the ductility of the members thereby ensuring failure is exhibited as sagging, rather than rapid member collapse.

C 3 Previous Reports

In 1990 Taywood-Maunsell were engaged by Geelong and District Water Board to assess the condition of the operational Aqueduct and to provide cost estimates on proposed repairs to sustain the Aqueduct for a short time (3 years), medium term ((3 to 20 years) or for a long term (minimum 15 to 20 years). Repair techniques estimated included short term patch repairs and long term cathodic protection.

Taywood-Maunsell 1990 reported their investigations showing that measured carbonation depths exceed the depth of the outer reinforcement. This is typical of a reinforced concrete structure of the age of the Aqueduct and quality of concrete.

A subsequent report reviewing the options for the then decommissioned Aqueduct was prepared by Maunsell 1994. This report was based both on the earlier Taywood-Maunsell condition report and a current assessment. Detailed cost estimates of various options were provided in this report.

In 2009, Australian Corrosion Consultants Pty Ltd (ACC) was commissioned by Heritage Victoria to carry out trials on realkalisation and cathodic protection electrochemical repair systems and compare them against conventional patch repairs. As the previous Taywood-Maunsell investigation had revealed, carbonisation of the cover concrete is the mechanism of deterioration of the concrete and subsequent corrosion of the embedded reinforcing in the Aqueduct.

ACC undertook the following diagnostic investigation of a limited number of structure elements (excluding the ovoid pipe sections). These investigations included:

- Visual inspection and delamination testing
- Cover to reinforcing measurement
- Reinforcement continuity testing
- Equipotential mapping to establish the extent and rate of corrosion of the reinforcement
- Carbonation testing
- Inspection of reinforcement at reinforcement breakout locations.

These investigations by ACC showed that:

1. The defects on two selected spans had increased by 4% to 26% between the Taywood-Maunsell report of 1990 and 2009 (ACC have adopted the 26% increase in their estimates of defects in other spans)
2. Carbonisation of the concrete extends to beyond the depth of most of the embedded reinforcement in the members
3. Measured corrosion rates predicted 2009 sound areas of concrete surfaces would be delaminated and spalled within two years (i.e. 2011-2012)
4. Exposed-to-air reinforcement corrosion rates suggest that only 10% of the top and bottom chord main bar cross-section would be lost in 100 years
5. Cathodic protection with the associated surface based concrete repairs is the preferred repair technique and has the least cost as well as a proven track record.

C 4 Site Inspection

An assessment of the physical condition of each pier and each span of pipe with a view to ascertaining the nature, extent and cause of the deterioration as well as identifying the better elements was made by the author in 2014. Photographs of the sections and details of the Aqueduct are included in Appendix A.

The author has closely viewed the Aqueduct on several occasions since the mid-1990s with the most recent viewing in 2015. The irregular viewing has revealed that the degradation of the Aqueduct surfaces has markedly increased since the 2009 ACC trials.

Between 1990 and 2009, ACC estimated that a further 26% of the surfaces of the concrete members since 1991 had degraded due to reinforcement corrosion induced spalling when compared to the condition reported by Taywood-Maunsell in 1990. It is noted that ACC predicted in 2009 that the remainder of the unaffected surfaces would be affected within two years based on measured corrosion rates. This level of degradation of the surfaces is now manifesting with all surfaces now being effectively cracked and/or delaminated.

For current cost estimating, it is now considered that the entire surfaces of the structure are affected by delamination and loss of section of the winding reinforcement confining the compression bars and the tension laps.

Part DTECHNIQUES FOR ENHANCING STRUCTURAL RESILIENCE

D 1 Structural Background

The starting point for considering enhanced support of the existing structure to attenuate its current deteriorated state is based on the above distilled themes summarised as follows:

- The Considere system as applied to the Aqueduct provides for ductility in the compression members whilst the confining helical reinforcement remains largely intact;
- The Considere system as applied to the Aqueduct provides for ductility in the laps of reinforcement whilst the confining helical reinforcement remains largely intact;
- Carbonation has occurred to a depth that exceeds the embedded reinforcement;
- Relatively recent published collapse load analysis (Van der Molen and Alsop 1997) using an incremental loading and applying a corrosion model to account for the degraded state of the structure resulted in a calculated capacity of 1.9 times the self-weight at that time;
- This collapse load analysis identified the critical truss members are the tension (top) chord members at the end of the cantilever, and the end diagonal. These members have comparatively light reinforcement, so their strength is more sensitive to corrosion. However, the failure mode was seen to be ductile;
- Many of the sewer pipe hangers are degraded, possibly from hydrogen sulphide attack and/or leakage in and around the pipe joints;
- The degradation of the ovoid pipe sections is considered to be more severe than for the structure, due to the thin pipe wall and as the presence of hydrogen sulphide above the sewer waterline has led to some concrete decay;
- Each pier is piled with eight octagonal reinforced concrete piles reportedly driven to set except piers 4, 6, 13 and 14 which are founded on rock;
- Access to the river for public use has been denied since about the time of the decommissioning of the Aqueduct and concerns for spalling concrete falling on passing boat and canoe traffic; and,

- In and around Pier 14, supporting steel framing was introduced by Barwon Water (or its predecessor) due to some settlements of that pier, presumably due to pile settlements at Pier 14.

D 2 Structural Capacity Enhancement

Structural capacity enhancement will assist in the conservation of the extant structure as the induced stress relief improves the longevity of the deteriorated structure as the structural demand on the existing reinforcement arrangements is diminished.

Structural enhancement is considered to be desirable as the corrosion of the confining windings to the embedded main reinforcement of compression and tension members will eventually allow the compression bars to buckle when the bar confinement is completely lost and the reinforcement laps of the tension members to unravel. Ideally, if the structural member actions are altered (or diminished) with that the critical top and bottom chord member actions reversed so that the bar stresses are reduced to small values, then only limited confinement of compression and tension bars is required to maintain ductility of the structure.

Stress reversal in the Aqueduct structure can be achieved by propping and jacking of the ends of the cantilevers or by post-tensioning of the existing cantilever arrangement. These options for structural enhancement are illustrated in Appendix F.

Post-tensioning of the existing cantilevers is now discounted by the author as the extent of the degradation of the Aqueduct since 2009 has significantly increased which is in line with the predictions made by ACC based on the measured corrosion rates.

Propping and jacking the ends of the cantilevers will reverse the internal actions within the cantilever trusses and with careful proportioning of the induced movement from jacking, those bars now in compression and at risk of buckling when their confinement is lost, can be made to be stressed to close to zero stress. This stress reversal will preserve the structure

form whilst the general integrity of the core concrete within the top and bottom chord reinforcement remains.

Propping frames would consist of bored (or maybe driven) pile footings with reinforced concrete in-ground cross-heads (pile caps) and braced steel props placed at the ends each cantilever. Where there is a bridging span between the ends of the cantilevers, this would result in a pair of propping between each set of piers spans 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8 and the south end of the cantilever of Pier 8; the both ends of the cantilevers to Pier 13, as the spans of Pier 14 are already supported by propping (introduced by the GDWB). Between these propping frames is the opportunity to insert pedestrian cross-over points within, say, galvanised steel pipe or reinforced concrete culverts pushed into place under the structure.

These propping frames will also serve to provide the propping necessary for any further repair works on the structure (e.g. installation of cathodic protection) and allowed in the ACC cathodic protection installation cost budget.

D 3 Structural Integrity Enhancement

Structural integrity enhancement by the mitigation of the corrosion of the embedded reinforcement of the structure assists in the conservation of the structure as the loss of cross-section of reinforcement is controlled and the disruptive spalling mitigated.

Rehabilitation trials undertaken by Australian Corrosion Consultants Pty Ltd (ACC) on behalf of Heritage Victoria have reported as follows:

Conventional Patch Repairs

- Estimated 50 years life expectancy of the patched repairs before requiring re-patching
- Costly repair due to temporary support required during removal of carbonated concrete
- Patching limited in any one works program to spalled and delaminated areas

- Costs estimated in 2009 as $14.9 million for an average of only 17% of the concrete surface area to be patched and a further $2.2 million on a rolling 5 year interval maintenance program for ongoing corrosion.

Re-alkalisation

- Insufficient re-alkalinisation achieved in some locations (efficacy questioned)
- Economic repair over the life of the repair
- Requires all delaminated and spalled concrete to be removed and patched prior to re-alkalinisation
- Budget estimated (2009) $13.5 million excluding the ovoid pipe repairs and a further provision of $2 million on a rolling 10 year interval maintenance program for ongoing corrosion.

Cathodic Protection

- Economic repair over the life of the repair recognised as at least 30 years and efficacy well established
- Requires all delaminated and spalled concrete to be removed and patched prior to treatment
- Budget for cathodic protection and the associated surface repairs estimated (2009) $13.3 million excluding the ovoid pipe and a further provision of $18,000 per annum plus an allowance of $20,000 per annum for maintenance of the system.

As each of these systems assessed by ACC has a cost of about $15.5 million (2015 dollars) plus the necessary per annum additional costs, the prospect of full repair of the Aqueduct using any one of these systems is considered unlikely to attract the required funding.

Should partial repair be undertaken to a number of spans, then the preferred system is considered to be cathodic protection as its efficacy is well established as well as its ongoing costs being the least.

It must be noted that no one repair system can categorically exclude the possibility of future spalling, with the attendant risks to the public beneath those spans.

Part E OPTIONS

E 1 General

A limited range of rehabilitation options are available to meet the project objectives, based on the present condition of the structure, its location over the river and the remediation techniques available. With a notional unlimited budget, there are options that would maximise conservation of the structure, whilst providing for limited removal allows access along the river and banks to ensure public access on the river and immediate banks.

However, it is understood that potential funding availability is constrained and hence the focus must be on achieving a balanced outcome with the resources available.

E 2 Remediation of the cantilever spans and beam spans over the river.

Whether by patch and repair or cathodic protection, the remediation of the spans over the river is made more difficult and costly due to the safe work considerations over the river. Probable safe work techniques include barge access and platforms on the river.

In addition, neither repair system could categorically exclude the possibility of future spalling, with the attendant risks to the public beneath the spans.

Consequently, with expected limited funding, the additional cost and the public liability risks of repaired spans over the river have led to the conclusion that remediation of these spans is not viable.

E 3 Remediation Options

Engineering options for remediation that have been discounted as being viable within the objectives of this report are as follows:

1. Full remediation using the patch and repair process.

The patch and repair process is recognised as having a typical lifespan of the order of 15 to 25 years before additional patching is required adjacent to the previously patched work (corrosion cell propagation). These processes were previously used by Barwon Water and its predecessor, as they were intended to maintain the working structure for limited timeframes. The replacement sewer and syphon to replace the function of the Aqueduct was installed as the deterioration of the Aqueduct had compromised the viability of this main outfall sewer.

Full remediation of the Aqueduct using patch and repair has been identified by others at costs that various parties place at between $17 million (ACC 2009 estimate escalated to 2015) to above $60 million for the whole structure with ongoing annual rolling maintenance costs. It is perceived that this level of funding is unlikely to be attracted to this heritage structure, particularly as there would be future repair cycles to maintain the structure in perpetuity.

Partial remediation of the Aqueduct using patch and repair could be a possibility but the extent is likely to be limited by available funds and ensuring that the funds for those previously repaired areas were guaranteed for the rolling 5 year interval maintenance program for ongoing corrosion to maintain the previously repaired parts of the structure in perpetuity.

2. Full remediation using the cathodic protection process.

Cathodic protection of deteriorated structures effectively "turns off" the corrosion. Consequently, cathodic protection is currently viewed as the only viable long-term remediation process. Trials of passive cathodic protection (realkalisation) sponsored by Heritage Victoria were inconclusive due to the difficulty of maintaining the anode materials.

Trials of active (electric powered) cathodic protection sponsored by Heritage Victoria processes are seen to the most viable system of repairing the Aqueduct structure (but not the ovoid pipe due to its thin section and "awkward" overall shape). However,

the estimated costs are expected to be unlikely to be attracted to this heritage structure, particularly as there would be future (30 year) repair cycles to maintain the structure in perpetuity.

Partial remediation of the Aqueduct using cathodic protection could be a possibility but the extent is likely to be limited by available funds and ensuring that the funds for those previously repaired areas were guaranteed for the annual maintenance and the rolling 30 year interval maintenance program for anode renewal to maintain the previously repaired parts of the structure in perpetuity.

Reflecting on the above repair systems and costs, together with the aims of establishing conservation works that will inhibit ongoing deterioration, address its causes and make the place safer with the aim to arrest further deterioration rather than attempt to make the place appear "all shiny and new", has led to consideration of supplementary structural support of retained spans.

E 4 Partial Demolition and Propping Proposal

Removal of the river spans, retaining the Piers (9, 10, 11 & 12) is the minimum demolition for public safety and that requested by the Steering Committee.

To inhibit ongoing deterioration, all remnant piers should have the hollow tower cap weather protected with a new stainless sheet steel roof on a timber frame. This will keep out rain and reduce corrosion in the relatively thin cap elements.

The propping of the ends of the cantilevers may be combined with installation of corrosion resistant confining reinforcement (such as titanium mesh) to the outside of critical compression members but retaining all the towers to achieve a viable heritage outcome and a remnant structure on the flood plains that will slowly continue to deteriorate.

However, the rate of deterioration is expected to be relatively slow with the supplementary supports de-stressing existing members and assisting in a ductile overall structure behaviour and the exposed reinforcement corrosion loss of section low (ACC 2009).

For management of public liability, a supplemented structure would need exclusion fences to avoid public access under the remnant structure.

As the Steering Committee has specifically requested that options fall within target budgets of $2,000.00 and $4,000,000 plus GST, options have been assessed as follows:

- Complete demolition of the entire structure including piers (to establish a base cost)
- Demolition of the river spans and complete cathodic protection of the remnant structures (to establish an upper limit on cost), capping of piers, fencing and an interpretation/viewing structure
- Demolition of the river spans and propping of the remnant structures, capping of piers, fencing and an interpretation/viewing structure

Part F SUMMARY OF ESTIMATED OPTIONS

The April 2016 final report considers the following options:

1. Complete demolition of the entire structure including piers (to establish a base cost)
2. Demolition of the river spans and complete cathodic protection of the remnant structures (to establish an upper limit on cost), capping of piers, fencing and an interpretation/viewing structure
3. Demolition of the river spans and propping of the remnant structures, capping of piers, fencing and an interpretation/viewing structure

The summary of the estimated costs of these options is as follows:

1. Complete demolition of the entire structure including piers **$3,644,900**
2. Demolition of the river spans and complete cathodic protection of the remnant structures **$25,756,300**
3. Demolition of the river spans and propping of the remnant structures, capping of piers, fencing and an interpretation/viewing structure **$2,918,900**
4. As the estimated 2016 cost to patch repair one span varies between $228,000 and $622,000, then the above minimum demolition option with propping and, say, two patch repaired spans at Piers 7 and 8 is estimated at **$3,738,900.**

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APPENDIX A – PHOTOGRAPHS 2014

Photograph No.001 Jpeg No 2953

Location: General view of south end (Marshall bank)

Description:

- Piers numbered from left to right – 14, 13 and 12 (partially obscured by the tree)
- Note the steel frame propping the spans at Pier 14 (installed by Barwon Water circa 1970 to attenuate settlements)
- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes

Photograph No.002 Jpeg No 2960

Location: Detail view of south end (Marshall bank) with abutment LHS out of photograph

Description:

- Steel frame propping the spans at Pier 14 (installed by Barwon Water circa 1970 to attenuate settlements)
- Extensive delamination of cover concrete of the truss bottom compression chord associated with corrosion of the winding reinforcement
- Note the lapped longitudinal steel in the centre of the photograph with lapped bars starting to move apart now that the winding steel is being lost

Photograph No.002 Jpeg No2958

Location: Detail view of south end (Marshall bank) Pier 14

Description:

- Steel frame propping the spans at Pier 14 (installed by Barwon Water circa 1970 to attenuate settlements)
- Extensive delamination of cover concrete of the truss bottom compression chord associated with corrosion of the winding reinforcement for the Marshall bank side bottom chord indicating the variability of the original concrete

Photograph No.002 Jpeg No2959

Location: Detail view of north end of the cantilever at Pier 14

Description:

- Steel frame propping the spans at Pier 14 (installed by Barwon Water circa 1970 to attenuate settlements)
- Some delamination of cover concrete of the truss bottom compression chord associated with corrosion of the winding reinforcement
- Note the longitudinal splits in the top and bottom chord side faces steel associated with corrosion of the winding reinforcement

Photograph No.002 Jpeg No2957

Location: General view of the spans between Piers 14 and 13 south end of Aqueduct

Description:

- Note the steel frame propping the spans at Pier 14
- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes due to corrosion of hanger reinforcement within the concrete hangers from the walkway bridge beam

Photograph No.002 Jpeg No2952

Location: Detail view of the cantilever south from between Pier 13 (south end of Aqueduct)

Description:

- Hanger straps from walkway beam to suspended sewer pipes
- Delamination of cover concrete on the top edge of the pile cap base of Pier 13
- Former poured concrete repairs evident in Pier 13 legs
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No2955

Location: General view of the spans between Piers 13 and 12 south end of Aqueduct (Marshall bank)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No2956

Location: Detail view of Pier 12 (south end of Aqueduct – Marshall bank))

Description:

- Delamination of cover concrete on the top edge of the pile cap base of Pier 12
- Former poured concrete repairs evident in Pier 13 legs
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No 2954

Location: General view of Pier 12 (south end of Aqueduct – Marshall bank))

Description:

- Delamination of cover concrete on the top edge of the pile cap base of Pier 12
- Former poured concrete repairs evident in Pier 13 legs
- Delamination of some cover concrete to the truss bottom compression chord
- Longitudinal split evident in the side face of the bottom chord LHS of Pier12
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No 2951

Location: Detail view of Pier 12 (south end of Aqueduct – Marshall bank))

Description:

- Delamination of cover concrete on the top edge of the pile cap base of Pier 12
- Former poured concrete repairs evident in Pier 13 legs and pipe support at Pier
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Hanger strap to sewer pipe from walkway beam near expansion joint in sewer pipe
- Delamination of cover concrete to Pier top cap side faces

Photograph No.002 Jpeg No2950

Location: General view of the span between Piers 12 and 11 south end of Aqueduct with Goat Island RHS of photograph

Description:

- Longitudinal crack in sewer pipe centre of photograph
- Hanger straps from walkway beam to suspended sewer pipes

Photograph No.002 Jpeg No2949

Location: General view of Pier 11 with Pier 10 in background (both Piers on Goat Island)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of some cover concrete to the truss bottom compression chord
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier 11 top cap side faces

Photograph No.002 Jpeg No2916

Location: General view of Pier 10 with Pier 11 in background (both Piers on Goat Island)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of some cover concrete to the truss vertical
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier 10 top cap side faces
- Previous repair of Pier 10 legs evident (sprayed concrete)

Photograph No.002 Jpeg No2917

Location: Detail view of Pier 10 (Pier 10 north side of Goat Island)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of some cover concrete to the truss vertical
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier 10 top cap side faces
- Previous repair of Pier 10 legs evident (sprayed concrete)

Photograph No.002 Jpeg No2918

Location: Detail view of the span between Piers 10 (on Goat Island) and Pier 9 on Breakwater bank

Description:

- Longitudinal crack in sewer pipe centre of photograph
- Hanger straps from walkway beam to suspended sewer pipes
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Some delamination of some cover concrete to the truss bottom compression chord

Photograph No.002 Jpeg No2919

Location: General view of Pier 9 (Breakwater bank)

Description:

- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier top cap side faces

Photograph No.002 Jpeg No2920

Location: General view of span between Pier 9 and Pier 8 (Pier 8 in RHS background)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of some cover concrete to the truss diagonals
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier 9 top cap side faces
- Previous repair of truss end vertical evident (poured concrete)

Photograph No.002 Jpeg No2921

Location: Detail view of Pier 9

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Delamination of some cover concrete to Pier legs
- Delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span
- Delamination of cover concrete to Pier 9 top cap side faces
- Previous repair of Pier vertical evident (patch repair)

Photograph No.002 Jpeg No2922

Location: General view of cantilever at Pier 8 to Pier 7 (Pier 7 in RHS background)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Truss condition better than spans to south
- Some delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No2923

Location: Detail view of Pier 8

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Truss condition better than spans to south
- Some delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span

Photograph No.002 Jpeg No 2924

Location: General view of cantilever spans between Piers 7 and Pier 6 (Pier 6 in RHS background)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Truss condition better than spans to south
- Some delamination of the cover concrete to the truss end vertical (LHS)

Photograph No.002 Jpeg No 2925

Location: Detail view of Pier 7

Description:

- Truss condition somewhat better than spans to south
- Some delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span and the Pier top side face
- Delamination of the Pier vertical edge and previous repair (poured concrete evident in adjacent Pier leg)

Photograph No.002 Jpeg No 2926

Location: General view of Pier 7

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Truss condition somewhat better than spans to south
- Some delamination of the cover concrete to the bottom edge of the walkway beam within the cantilever span and the Pier top side face
- Delamination of the Pier vertical edge and previous repair (poured concrete evident in adjacent Pier leg)

Photograph No.002 Jpeg No 2927

Location: General view of cantilever spans between Piers 6 and Pier 5 (Pier 5 in RHS background)

Description:

- Hanger strap from walkway beam (link beam of structure) to suspended sewer pipes
- Truss condition better than spans to south

Photograph No.002 Jpeg No 2928

Location: Detail view of Pier 5

Description:

- Truss condition somewhat better than spans to south
- Delamination of the Pier vertical edge and previous repair (poured concrete evident in adjacent Pier leg)

Photograph No.002 Jpeg No 2929

Location: Detail view of part of the cantilever north of Pier 5

Description:

- Delamination of the truss top tension chord with some windings broken/fully corroded

Photograph No.002 Jpeg No 2930

Location: General view of the span between Pier 5 and Pier 4 (RHS of photograph)

Description:

- Trusses and walkway beams in better condition than south end of Aqueduct

Photograph No.002 Jpeg No2931

Location: General view of Pier 4

Description:

- Truss condition somewhat better than spans to south
- Some delamination of the cover concrete to the truss bottom compression chord
- Previous repair of Pier leg evident (sprayed concrete)

Photograph No.002 Jpeg No 2932

Location: Detail view of Pier 4

Description:

- Truss condition somewhat better than spans to south
- Far side truss top tension chord has delamination
- Near side truss top tension chord has longitudinal split adjacent Pier leg
- Previous repair of Pier leg evident (sprayed concrete)

Photograph No.002 Jpeg No 2933

Location: General view of cantilever spans between Piers 4 and Pier 3 (Pier 3 at RHS)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes
- Poured repair of sewer pipe section
- Truss condition better than spans to south

Photograph No.002 Jpeg No 2934

Location: Detail view of Pier 3

Description:

- Delamination of cover concrete evident in truss top chord, parts of bottom chord and verticals
- Near side truss top tension chord has longitudinal splits
- Previous repair of Pier leg evident (sprayed concrete)
- Deterioration of cover concrete to Pier 3 top side faces and cornice

Photograph No.002 Jpeg No 2935

Location: Detail view of Pier 3

Description:

- Delamination of cover concrete evident in truss top chord, parts of bottom chord and verticals
- Near side truss top tension chord has fully corroded winding
- Previous repair of Pier leg evident (sprayed concrete)
- Deterioration of cover concrete to Pier 3 top side faces and cornice
- Deterioration of cover concrete to gusset concrete at top of Pier

Photograph No.002 Jpeg No 2936

Location: General view of cantilever spans between Piers 3 and Pier 2 (Pier 2 at RHS)

Description:

- Hanger straps from walkway beam (link beam of structure) to suspended sewer pipes

Photograph No.002 Jpeg No 2937

Location: Detail view of the south end of the cantilever at Pier 2

Description:

- Some delamination of truss top chords, bottom chord, Pier legs and the Pier top side faces
- Longitudinal split in the side face of the near side top chord indicating cover concrete about to delaminate

Photograph No.002 Jpeg No 2938

Location: Detail view of the south end of the cantilever at Pier 2

Description:

- Some delamination of truss top chords, bottom chord, Pier legs, the Pier top side faces and the top edge (handrail) of the walkway beam
- Longitudinal split in the side face of the near side top chord indicating cover concrete about to delaminate
- Windings fully corroded at reinforcement lap in top chord

Photograph No.002 Jpeg No2939

Location: Detail view of the south end of the cantilever at Pier 2

Description:

- Some delamination of truss top chords, bottom chord, Pier legs and the Pier top side faces
- Longitudinal split in the side face of the near side vertical indicating cover concrete about to delaminate
- Windings fully corroded at reinforcement lap in top chord in far side top chord
- Previous repair evident in the near side vertical (poured concrete)

Photograph No.002 Jpeg No2940

Location: Detail view of Pier 2

Description:

- Delamination of cover concrete at vertical edge of Pier legs
- Previous patch repair of the Pier leg failing
- Delamination of cover concrete to vertical, bottom chord gussets and Pier top side faces and cornice

Photograph No.002 Jpeg No2941

Location: Detail view of the north end of the cantilever at Pier 2

Description:

- Delamination of truss top chords, bottom chord, verticals and pipe hangers
- Longitudinal split in the side face of the near side vertical indicating cover concrete about to delaminate
- Previous repair evident in the near side vertical (poured concrete)

Photograph No.002 Jpeg No 2942

Location: General view of the span between Pier 1 and Pier 2 (LHS of photograph)

Description:

- Delamination of walkway bottom and top edges
- Hanger straps introduced where pipe hangers delaminated

Photograph No.002 Jpeg No 2943

Location: Detail view of cantilever south of Pier 1

Description:

- Longitudinal split in side face of top chord
- Some delamination of walkway bottom edge, truss bottom chord and pipe hangers
- Previous sprayed concrete repair of Pier legs, truss verticals and diagonals evident

Photograph No.002 Jpeg No 2944

Location: Detail view of Pier 1

Description:

- Delamination of truss top tension chord RHS
- Longitudinal split in side face of top chord
- Some delamination of walkway bottom edge and the truss bottom chord
- Previous sprayed concrete repair of Pier legs evident

Photograph No.002 Jpeg No 2945

Location: North end of cantilever at Pier 1 (Breakwater abutment at RHS)

Description:

- Delamination of truss top tension chord
- Longitudinal splits in parts of members side faces indicating underlying steel corrosion

Photograph No.002 Jpeg No 2946

Location: Breakwater abutment detail plan view

Description:

- Settlement of abutment walkway slab (settlement of fill?)
- Crack indicates shortening of Aqueduct due to shrinkage/cold day

Photograph No.002 Jpeg No2947

Location: View along walkway from Breakwater abutment

Description:

- Longitudinal split in handrail indicating corrosion of embedded reinforcing

Photograph No.002 Jpeg No 2948

Location: General view from Breakwater abutment along the Aqueduct

APPENDIX B

REHABILITATION TRIALS, BARWON RIVER OVOID SEWER AQUEDUCT, AUSTRALIAN CORROSION CONSULTANTS, JUNE 2009

Australasian
Corrosion
Consultants

HERITAGE VICTORIA

BARWON OVOID SEWER AQUEDUCT
Breakwater, Victoria

REHABILITATION TRIALS

June 2009

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Executive Summary

Australasian Corrosion Consultants Pty Ltd was commissioned by Heritage Victoria to carry out trials on realkalization and cathodic protection electrochemical repair systems and compare them against conventional patch repairs. The aim of the project was to develop a preliminary Scope of Works and Cost Estimate of the 3 repair systems to enable Heritage Victoria to develop a program for formulating a repair using one of the tested techniques.

Repair trials under this project have been undertaken on sections of the major chords and minor stays of the structure using **Realkalization** and **Cathodic Protection**. Previous repairs have been undertaken on the structure using **Conventional Patch Repairs** and the 3 techniques are considered the only feasible options for the repair of the structure.

Conventional Patch Repairs are a proven technique for the repair of carbonated concrete:

The advantages are:

- An excellent life expectancy for the areas repaired (50 years plus).

The disadvantages are:

- The repair is expensive, partly because of the structural support required during the concrete removal and replacement.
- The repair system is only carried out on the spalled and delaminated areas and the remaining unrepaired sections of the structure will continue to corrode and spall.

The budget developed in this report totals

- $14.9m for an average of only 17% of the concrete surface area of the structure.
- $2.2m on a rolling 5 yearly interval maintenance repair program for ongoing corrosion.

Realkalization trial repairs proved effective in areas but insufficient levels of realkalization were achieved in some locations.

The advantages are:

- Economical repair over the life of the repair.
- Reduced structural support required during the concrete removal and replacement.

The disadvantages are:

- The system requires all spalling and delaminated concrete to be repaired prior to applying the realkalization treatment.
- Has a short history in Australia and the life of the system internationally has not been well documented.

The budget developed in this report totals

- $13.5m for the realkalization based repair (all concrete areas excluding ovoid pipe)
- A further provision for future repairs of $2.0m on a 10 year rolling interval.

Cathodic Protection (CP) based repairs proved effective with the trial repairs meeting Australian and International criteria for the corrosion protection of the reinforcement.

The advantages are:

- Economical repair over the life of the repair.
- Reduced structural support required during the concrete removal and replacement.
- Has a long history in Australia and internationally with a service life of 30 years plus.
- Use of internal anodes in the larger elements i.e. chords allows for some of the concrete repairs to be staged over an extended period. (Staging has not been considered in the budget).

The disadvantages are:

- The surface based concrete repairs are required prior to installing titanium ribbon surface anodes in the smaller elements.
- Periodic monitoring of the cathodic protection system is required.

The budget developed in this report totals

- $13.3m for the CP based repairs (excluding ovoid pipe).
- Monitoring the Cathodic protection system at $18K pa plus an allowance of $20K pa for maintenance of the system.

Definitions

- **Tower –** For the purpose of this trial and costing of the repairs a tower section includes all of the concrete tower pier above the ground level and one half of the span emanating on either side of the tower but excludes the ovoid pipe.
- **Span –** The elements of the span includes the trusses, the central girder forming the footway and the ovoid pipe hangers.
- **Truss –** The trusses are the cantilevered sections out from the towers and consist of the triangular frame each made up of an upper and lower chord, stiffened by vertical and diagonal members referred to in the report as stays.
- **Chord –** The chord members have been constructed of reinforced concrete using the Considere system.
- **Stay –** The stays are the vertical and diagonal reinforced concrete elements between the chords and have been constructed using the Considere system.
- **Mixed Metal Oxide Anode –** A MMO anode is a length of narrow titanium ribbon coated with a mixed metal oxide. The width of the ribbon is directly related to the current capacity of the anode per unit length. The mixed metal oxide has the ability to discharge a high electrical current over a long period of time. The consumption of the metal coating is a function of the current discharged and time and is commonly known as Faraday loss; hence the Faradic loss of the coating is extremely low for this type of anode.
- **Internal anode –** An internal anode is a short length of MMO anode placed within a chord element by drilling a hole into the centre of the chord, filling the hole with cementitious grouting and pushing the anode into the grouted hole. The anode is located in such a way that the protection current flows from the centre of the element out to the surrounding reinforcing steel.
- **Ribbon Anode –** A ribbon anode is a length of MMO anode placed in the surface concrete of the stays. The anode is installed by saw cutting 2 parallel lines anode width apart at a depth of approximately 20mm, removing the concrete between the saw cuts to form a slot, placing a layer of grout into the slot, placing the ribbon anode firmly into the grout and grout back filling to surface level.

1. Background

The Barwon Ovoid Sewer Aqueduct was constructed over the Barwon River in 1913-1915. The aqueduct carries the now de-commissioned ovoid reinforced concrete sewer pipe across the Barwon River from Leather St in Breakwater to Tannery Lane in Marshall. The length of the aqueduct is approximately 756 metres. The structure is owned by Barwon Water.

The aqueduct consists of 56 reinforced concrete trusses which cantilever from 14 concrete towers. The gap between the ends of the trusses is bridged by girders. In addition to the ovoid pipe the aqueduct also carries a walkway.

The steel reinforced elements of the aqueduct trusses were constructed using the "Considere" method for reinforced concrete which uses spirally wound reinforcement to increase the compressive strength of the truss elements.

Following several rehabilitation trials by others since 1991, ACC were commissioned by Heritage Victoria to trial realkalization and cathodic protection electrochemical repair systems and compare them against conventional patch repairs. The aim of this project was to develop a preliminary Scope of Works and Cost Estimate of the 3 repair systems to enable Heritage Victoria to develop a program for formulating a repair using one of the tested techniques.

Scope of Work

The Scope of Work agreed to for this project was to:

- Carry out a condition assessment of 1st Section of the Barwon Sewer Aqueduct.
- Supply, install and trial a limited realkalisation system and carry out a suitability assessment.
- Supply, install and trial a limited cathodic protection system and carry out a suitability assessment.
- Prepare a preliminary scope of works and budget for the repair of the structure using the systems trialled and also using conventional patch repair.

2. Investigations and Trials 2009

The objective of this project is to test the technical and economic performance of realkalization and cathodic protection systems against conventional patch repairs as part of repair techniques for the Barwon Ovoid Sewerage Aqueduct.

Access to the Barwon Ovoid Sewer Aqueduct in 2009 was limited due to OH&S concerns. Barwon Water, the owner of the structure, has in place an embargo which prohibits any person entering the area within the fenced area or anywhere on the structure itself. Following negotiations between interested parties it was agreed that ACC could access the structure by "boom" lift only and they were provided with a key to access the site in November 2008. As a consequence to the limited access ACC revised their program to conduct the trials on the east side of Tower 1 only, as the west side could not be approached with the boom. Further the detailed visual condition survey was modified because the delamination (drummy) test could not be carried out on the western side of the structure or on the aqueduct towards the river crossing. The visual survey was carried out on the following sections:

- General visual of the whole of the structure from the security fence perimeter.
- A detailed visual from the security fence on the following sections
    - Tower 1 eastern side.
    - Tower 2 eastern and western sides
    - Tower 3 eastern side
    - Tower 7 eastern side
    - Tower 8 eastern side
    - Tower 9 eastern side northern portion

The trials repairs undertaken were all carried out on the south- eastern side of Tower 1, as marked on figure 1.

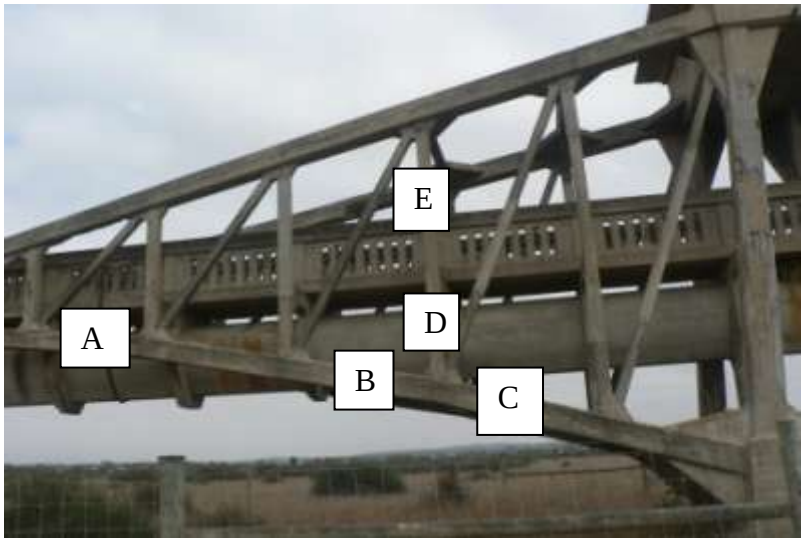


Figure 1

Trial locations on Tower 1 South - A, C & D – Realkalization; B & E - CP

2.1.Investigation

A diagnostic investigation of the structure was carried out on a limited number of elements on the Aqueduct only. The scope of the investigation included the following:

- Visual inspection and delamination testing
- Cover to reinforcement measurement
- Reinforcement Continuity Testing
- Equipotential mapping using the Galva Pulse system
- Carbonation analysis
- Inspection of reinforcement at breakout locations

2.1.1. Visual inspection

The aim was to record the extent of visible deterioration such as concrete cracks, spalls, delamination and other surface defects. The visual inspection was performed on all elements of Towers No 1, 2, 3, 7, 8 and 9 and the spans between the towers. The ovoid pipe was not included in the inspection. The results are recorded in Appendix B.

The results of this inspection in comparison to the 1991 investigation shows the defects on Tower 2 have increased by 4% and Tower 3 by 26% which generally gave the range over which the Aqueduct has deteriorated since 1991.

2.1.2. Concrete Cover Survey

The thickness of concrete cover to reinforcing steel was determined using a microprocessor-controlled reinforcement bar locater in accordance with ACC's Test Method Statement No 5 and by physical measurement of concrete cover at locations of exposed reinforcement.

The bottom chord of the structure contains 8 No ¾" (~20mm) longitudinal main bars with No.4 wire (~6mm) ligatures spiralled around them forming a round cage. Structure stay No. 2 contained 6 No ⅜" (~10mm) longitudinal bars and No. 5 wire (~5mm) spiralling wound ligature which also formed a round steel cage. The chords and vertical stays have been formed square in section and therefore the covers vary significantly. Further the steel in the vertical stay was found to be placed off centre within the section.

The minimum covers measured to the main bars were approximately 60mm and to the ligatures 36mm.

2.1.3. Reinforcement Continuity Testing

The in-situ continuity characteristic of the reinforcement was determined by DC resistance testing in accordance with ACC's Test Method Statement No 1.

The steel reinforcement is not electrically continuous between all longitudinal bars and the ligature wire in the bottom chord or the vertical stay. Resistance between the main bars of the major chord and in the minor vertical stay were commonly between 20 to 30 ohms, where the standard requires less than 2 ohms. Therefore all steel will need to be bonded together before any electrical treatment can be applied. This can most easily be done by welding in 6mm rod around the main bars.

Figure 2

2.1.4. Potential and Resistance Mapping

The level of corrosion activity affecting embedded reinforcement was determined by half-cell potential mapping and the relative ease with which current can flow through the concrete was ascertained by resistance mapping. The mapping was performed using the Galva Pulse system for potential and resistance mapping. All detailed results are included in Appendix A.

The corrosion potentials were measured and analysed in accordance with ASTM-C876-80 "Standard Test Method for Half Cell Potentials of Uncoated Reinforcing Steel in Concrete" The Standard provides a very general guide for classification of Half-Cell potential values based upon probability for corrosion. This guideline is presented in the following table:

POTENTIAL	PROBABILITY OF CORROSION
More positive than -0.20 volts	< 5%
-0.200 to -0.350 volts	About 50%
More negative than -0.350 volts	> 95%

Table 1

The analysis is presented in graphical format and colour coded to show the area of the test which fall into the three categories given in table 1.

2.1.4.1. Trial test Area "B"

Test area "B" at location shown in figure 1 was selected to trial the discrete anode cathodic protection system. The potential analysis was carried out in the form of a graph and is shown in figure 3. The graph shows the probability of corrosion is 50% for the test area with a small area considered to have a corrosion probability of 90%.

The same area was surveyed for concrete resistance. The results analysed are shown in figure 4 which indicates significantly resistance variation over the test area.

Equipotential. Aqua B

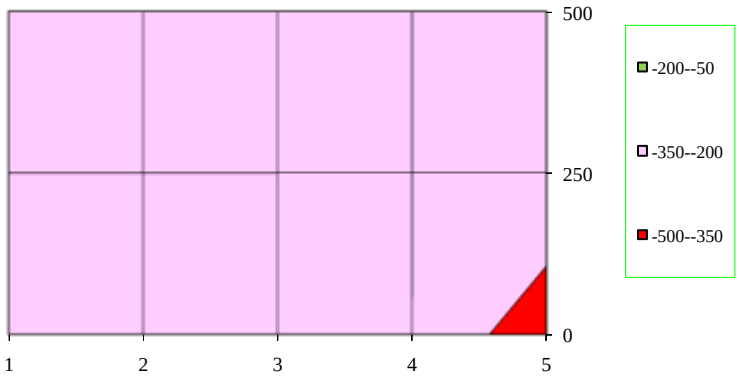


Figure 3

Resistance. Aqua B

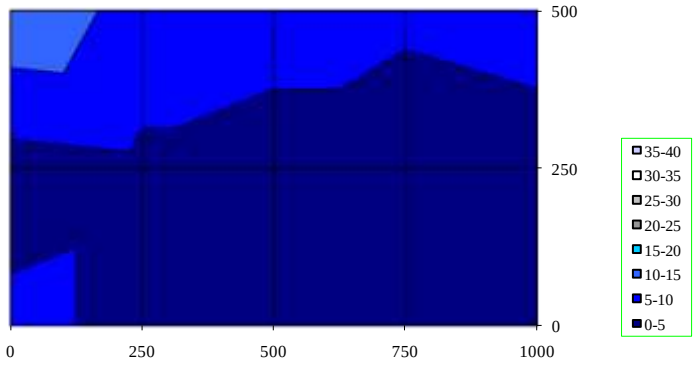


Figure 4

2.1.4.2. Trial test Area "C"

Test area "C" at location shown in figure 1 was selected to trial the realkalization process. The potential analysis as a graph is shown in figure 5. The graph shows the probability of corrosion for the whole area tested is 50%.

The same area was surveyed for concrete resistance. The graphed results are shown in figure 6 which indicates a relatively even spread of resistance over the test area with a high resistance in a relatively small area.

Equipotential. Aqua C

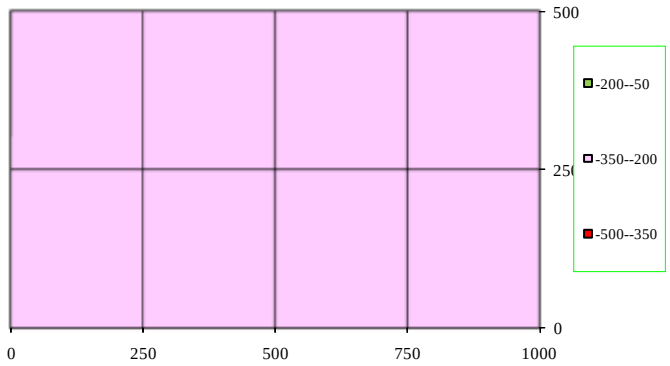


Figure 5

Resistance. Aqua C

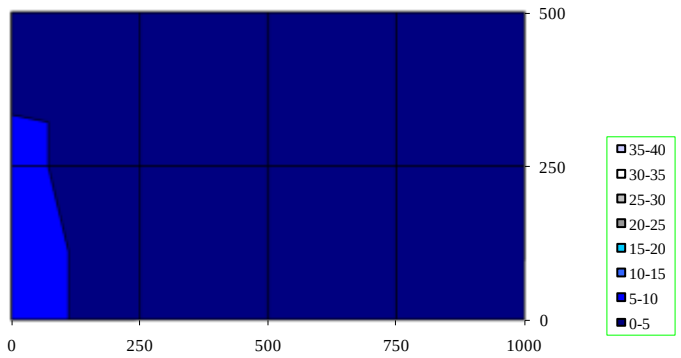


Figure 6

2.1.4.3. Trial test Area "D"

Test area "D" at location shown in figure 1 was selected to trial the realkalization process on the smaller vertical stay. The potential analysis was carried out in the form of a graph and is shown in figure 7. The graph shows the probability of corrosion is 50% for 75% of the test area and 25% of the area has a corrosion probability of 90%.

The same area was surveyed for concrete resistance. The analysed results are shown in figure 8 and indicated a low resistance over most of the test area.

Equipotential. Aqua D

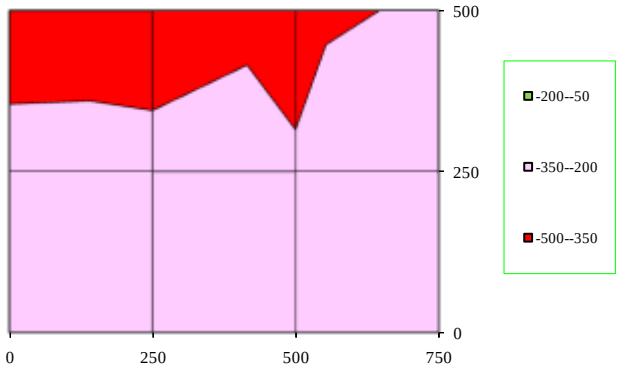


Figure 7

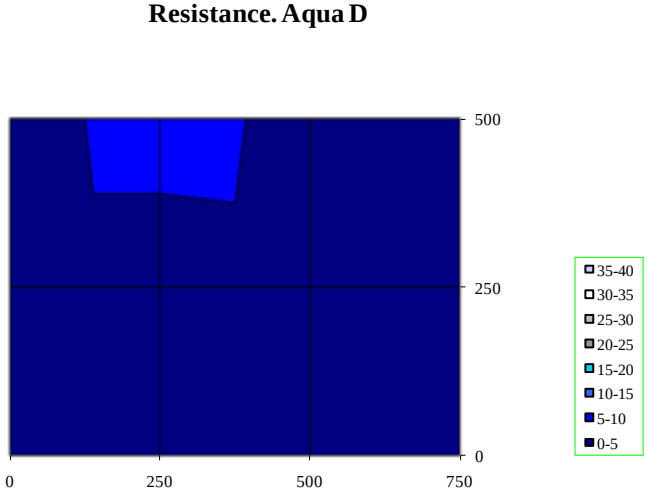


Figure 8

2.1.5. Corrosion rate measurement

The rate of corrosion was measured using the Galva Pulse system at the same time as the potential measurements were taken. The measurement was carried out without sensor control in this instance due to the high concrete resistance found in all test sites.

A published criterion by Broomfield for a system without sensor control is given as:

No corrosion expected: $I_{corr} < 0.2$ µA. cm^{-2}

Corrosion possible in 10 to 15 years: I_{corr} 0.2 to 1.0 µA cm^{-2}

Corrosion expected in 2 to 10 years: I_{corr} 1.0 to 10 µA cm^{-2}

Corrosion expected in 2 years or less: $I_{corr} > 10$ µA cm^{-2}

The corrosion rates were measured in zones “B”, “C” and “D” and are shown in table 2. When assessing the results against the corrosion rate criteria, a very high rate of corrosion is occurring in all zones, however the rates in zone “B” is less than half of those measured in zones “C” and “D”.

All corrosion rate values are given in µA/cm^2

Zone	Test 1	Test 2	Test 3	Test 4
“B”	17.53	9.82	8.32	7.95
“C”	47.77	23.90		
“D”	32.40			

Table 2

The measured corrosion rates were further analysed to estimate the loss of steel section and likelihood of further concrete cracking given the configuration of the test site, depth of cover, reinforcement bar size and layout etc. The measured results were used to calculate the corrosion rate in accordance with Faraday’s Law as shown below.

Calculation of Corrosion Penetration Rate

$$CR = \mathrm{K}_1 * \frac{i_{corr}}{\rho} * EW$$

Where:

CR is given in mm/yr, i_{corr} in µA/cm^2 as measured.
K_1 = 3.27 x 10^{-3}, mm g/µA cm yr.
ρ = density of carbon steel = 7.81 g/cm^3.
EW = Equivalent weight for carbon steel = 27.92.

The steel area is set by the test instrument in reinforcement bar size. The area was adjusted to account for the changing bar sizes and the configuration of the steel within the chord and stay elements. The revised estimated area was used to adjust the corrosion rate (i_{corr}) and the corrosion penetration rate calculated using the adjusted i_{corr}. The results of the calculations are show in table 3 for all measured sites.

Zone	Test ID	Measured corrosion rate i_{corr} (µA/cm^2)	Instrument set to test area bar = 16mm Ø length = 7cm (cm^2)	Estimated CR test area (cm)	Adjusted corrosion rate i_{corr} (µA/cm^2)	Corrosion Penetration Rate (CR) (mm/yr)	Corrosion Penetration Rate (CR) (µm/yr)
"B"	**Test 1**	17.53	35.2	359.1	1.7	0.020	20
	Test 2	9.82	35.2	359.1	1.0	0.011	11
	Test 3	8.32	35.2	359.1	0.8	0.010	10
	Test 4	7.95	35.2	359.1	0.8	0.009	9
"C"	**Test 1**	47.77	35.2	359.1	4.7	0.055	55
	Test 2	23.9	35.2	359.1	2.3	0.027	27
"D"	**Test 1**	32.4	35.2	381.0	3.0	0.035	35

Table 3

The corrosion rate tests show that the measurements on the chord element steel may range from 9 to 55µm/yr in the test areas and the single test on the stay at 35µm/yr. Therefore to loss 10% of the chord reinforcement steel section at the rate estimated requires more than 34 years and for the stay 26 years if the protection offered by the concrete remains valid.

With regard to further cracking Broomfield suggests section loss of 10µm is sufficient to cause cracking. It can be seen that at the measured corrosion rates cracking followed by delamination and spalling will occur in the areas which currently appear sound including at the lowest measured values of 9µm/yr within 2 years. When cracking, delamination and spalling does occur the steel will be subjected to atmospheric corrosion rates.

The Australian Standard "Guide to the protection of iron and steel against exterior atmospheric corrosion" AS2312-2002 gives a corrosion rate of 18µm/yr for steel in the atmosphere in a similar location as the Aqueduct. At this rate, it will require more than 100 years before 10% of section area is lost.

The corrosion rate analyses indicate the major reinforcement steel bars are losing sufficient section to be of concern. The corrosion rate analyse does not take into

consideration corrosion rates in areas such as crevices which hold moisture for long periods of time, micro climates or drainage systems which may be appreciably higher.

2.1.6. Carbonation Testing

Modified phenolphthalein indicator solution was used to determine the depth to which concrete has become carbonated. The test was performed in accordance with ACC's Test Method Statement No. 8. Carbonation has the effect of lowering concrete pH. The indicator solution is designed to change colour on contact with concrete with a pH more than 9.5 to 10.

The carbonation tests in visually solid concrete found a depth of carbonation of 60mm occurred in zone "A"; however a depth of only 12mm was measured in zone "B". These results confirm earlier reports on the cause of the deterioration.

2.1.7. Inspection of the reinforcement at the breakouts

The condition of the steel reinforcement is shown in figure 2. These show that the ligature wire on the chords has been lost in the delaminated areas however the main longitudinal bars have suffered little section loss. The reinforcement in the vertical stays displayed similar losses.

2.2.Trials

2.2.1. Electrical Continuity

Continuity was established by exposing the main bars in the main chord and the vertical stay by creating a transverse slot in the cover concrete to the steel and by installing crimp lugged cables screwed to the main bars as shown in figure 2.

Welding a continuity bar could be utilized establishing full electrical continuity to facilitate electrochemical protection in the future. This was not done due to the fire risk in the dry grass below the structure at the time of this installation.

It is expected that two continuity locations per chord per half span will be required for the major chord elements, with one continuity connection per minor stay element.

2.2.2. Realkalization System

The Aqueduct's reinforced concrete suffers mainly from Carbonation of the concrete, where the normally high alkalinity of the concrete protects the reinforcing steel from corrosion. With the carbonation extending well past the reinforcing steel, a conventional repair would require all of the carbonated concrete around the steel to be removed and replaced, an impossibly expensive and laborious operation.

Realkalization restores the original alkalinity of the concrete, by passing a direct current through the concrete generating alkalinity at the reinforcement surface as shown diagrammatically in figure 9. Also, an alkaline solution is "forced" into the concrete via electro-osmosis, completing the restoration of the alkaline nature of the original concrete.

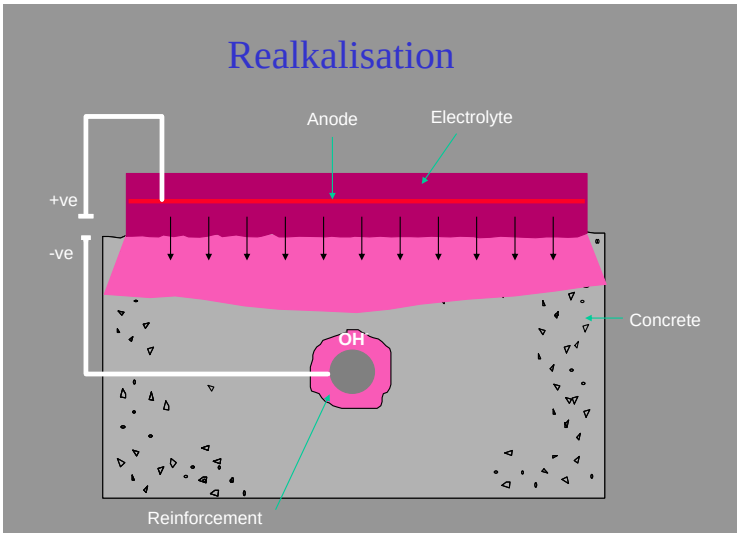


Figure 9

Realkalization is normally a short term treatment of less than 7 days duration, with current density in the order of 1 A/m^2 concrete surface. Realkalization must be completed on sound concrete, so that surface repairs are required over spalled or delaminated areas and crack repairs are required before the treatment. Reinforcement electrical continuity is required prior to undertaking the realkalization process.

The areas intended for treatment were 1m lengths of the bottom and top chord elements, plus a 0.5m length of the smaller vertical "truss" element.

2.2.3. The realkalization trials

Due to the restricted time and access available, the realkalization trials needed to be undertaken on non-spalling structure locations, as the time required for patch repair works to be completed and cured would be prohibitive given the access methods available. Selection of suitable sound locations on the major chords resulted in both areas being on the lower chord on the South-east side of Tower 1. The vertical stay section formed the trial location of the minor elements. The selected locations are shown in figure 1.

The realkalization was undertaken by using fibrous (woollen) fabric wrapped around the concrete, with the titanium or ribbon mesh anode placed outside the initial material. Another layer of woollen fabric was then placed over the anode, with plastic strapping firmly placed around the arrangement to keep the system in good contact with the concrete. (see photographs below). The "Soak-it" hoses are then positioned over the trial areas to keep the test area wet with the alkaline solution.

Test site D, bottom chord wrapped in wool blanket and covered in Titanium mesh anode	Anode is encapulated in woolen cloth
\	
Test site D with soak-it hose placed.	Test site D (left) and C (right) prior to wrapping in plastic.

The realkalization areas are saturated with the alkaline solution prior to wrapping the systems in plastic to keep them continually damp. The header tank is placed above the trial sites with the flow of solution to the sites controlled by an adjustable tap.

Test site C & D wrapped with plastic, with header tank for the solution	Test site A prior to wrapping in plastic.

The Realkalization trial areas were energized on 26/2/09 as detailed in Appendix A. Due to the restriction of battery power only, lower current than ideal was applied to the trial locations initially, with increased batteries allowing voltage increases as detailed in the results.

The ideal current density for realkalization is approximately 1 Amp/m2 concrete. Accordingly, the ideal current for realkalization trial areas A & C was 1.6 A, with the small trial area D being 0.3 Amp. As detailed in Appendix A, these currents were generally not achievable with the 48 volts available requiring the duration of the trial to be extended to closely achieve the recommended amp-hour application.

Note that the trial area A, only achieved approximately one-third the current of the similar sized area C. The concrete resistance of area C was shown to be low as indicated in figure 6. Other sections of this chord contained high and variable concrete resistance as shown in figure 4. Therefore the concrete resistance at area A may have been high resulting in a lower current being applied.

The trials were decommissioned on 10/3/09 and cored concrete samples were immediately taken to examine the extent of realkalization. The extent of realkalization achieved varied considerably across the trial locations. In all test areas, sample sites were found showing complete realkalization from the surface to full depth. However, each site also had areas of partial realkalization, where part depth realkalization only was achieved, as illustrated below.

Core drilling the realkalization test site C for testing of realkaliztion depth

Test site C, top side, indicating complete realkalization.

Test site A, top side, with excellent realkalization	Test site D, side near base. Result indicates incomplete realkalization possibly due to high concrete resistance.

We believe the range of realkalization achieved illustrates that the process itself works well, but the variation in the extent of realkalization is a real concern. The likely reasons for the partial depth realkalization in some areas are summarized as follows:

- The uniform realkalization of the elements requires the concrete to be uniformly damp with the solution. The shape and slopes of the elements results in difficulty in keeping all areas damp.
- Keeping the fabric in contact with the concrete is difficult, especially on the underside of the chords where gravity tends to pull the system away from the concrete. Further development of the realkalization method may assist in this area.
- Variations in resistivity (resistance) in the concrete as measured in the preliminary investigation, resulting in variations of the current and extent of realkalization achieved.

Despite the above, we conclude that realkalization of the elements of the aqueduct is feasible, given further development of the method and system for the structure. Further trialling should be undertaken to eliminate the variations in the extent of realkalization before adopting the system on a large scale. Realkalization using a one molar solution of potassium bicarbonate for 130Amp/hour per square meter should be sufficient to achieve full depth realkalization.

2.2.4. Cathodic Protection System

Cathodic Protection uses a small continuously applied direct current to stop the corrosion process. The current causes a net current flow onto the reinforcing steel turning off existing corrosion cells, “Polarizing” the reinforcement, repelling corrosion inducing chloride ions and generates alkalinity at the Reinforcement surface similarly to Realkalization.

We proposed a trial using “Internal” anodes, where the anodes are placed centrally in the element in drilled holes of approximately 30mm diameter. The current passed from the anodes to the reinforcement is therefore from the inside to the outside of the concrete element as shown in figure 10.

This results in the major advantage of this form of CP, in that the concrete repair of the elements, by far the greatest cost of the restoration project, is not required to be completed for the system to be effective. The CP current will protect any steel reinforcement in contact with sound concrete, so that only the exposed surface of the reinforcement at spalled areas will not be protected. When the spalled areas are subsequently repaired with cementitious repair mortar, protective currents will flow to all surfaces of the bar, giving complete protection.

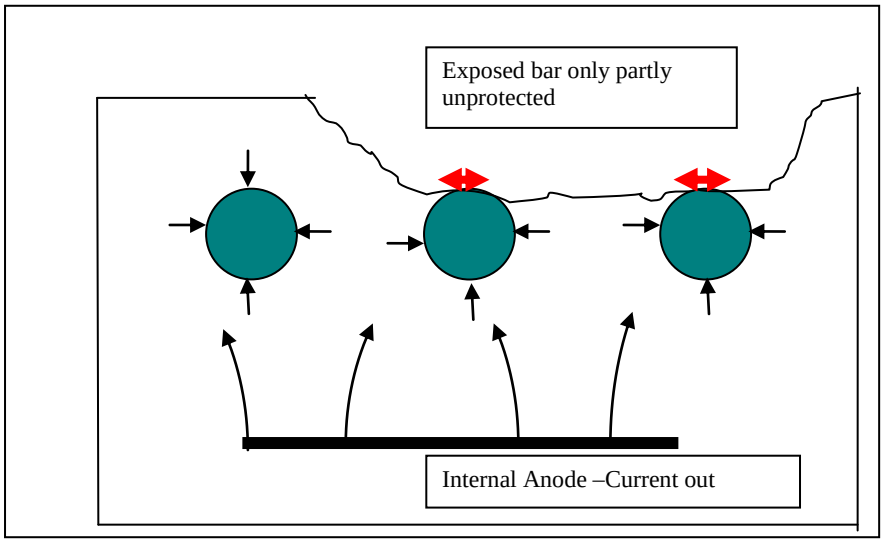


Figure 10

This system therefore allows the application of the CP system and the protection of the reinforcing steel in all major elements of the structure without having to complete the major cost operation of the concrete repair.

2.2.5. Cathodic Protection Trials Cathodic Protection- Internal Anode Trial

The CP trial was installed in a 1m length of the bottom chord element, Test Site B shown in figure 1, with the area selected to include some delaminated and spalled areas so as to demonstrate the system's application without first completing concrete repair. The internal anodes were placed at an average spacing of 200mm in 25mm diameter drilled holes. The anodes consisted of 2 layers of Elgard 150 ribbon anode 300mm long. The anodes were then connected in series with a positive cable. The arrangement is illustrated in the photographs below.

Test site B. Internal anodes are installed in drilled holes into the centre of the chord, at 200mm centres. Note exposed (spalled) section of concrete	Test site B. Internal anodes are connected in series and connected to positive power supply. Spalled concrete area cleaned of loose rust and treated with 2-3mm of repair mortar for "temporary" repair.

A typical minor vertical stay was the second CP test area located as shown in figure 1. Due to the small scale of the element, a longitudinal ribbon anode was installed in a slot on the mid section of the stay for a length of 1 m. The anode was an Elgard 150 titanium ribbon. The photographs below illustrate this arrangement.

Test site E, ribbon anode installed in slot on southern face of vertical stay	Test site E showing reference electrode installed on eastern face.

Both CP systems were energized on 25/2/09 through the 12 Volt battery powered CP controllers, with the batteries charged through a solar panel. The CP systems were monitored over a 3 month period, until the final monitoring on 5/6/09. All results are detailed in Appendix A and are summarized below.

System	Lower Chord Test Site B	Vertical Stay Test Site E
Ref. Natural Potential (mV)	-374	-225
CP Current applied (mA)	18	8
CP Voltage applied (V)	7.2	7.0
Instant off potential (mV)	-707	-718
4 hour decay (mV)	104	110
24 hour decay (mV)	153	133
Protection criterion achieved 100 mV Decay	YES	YES
Design Current (min) required Per Metre element (mA)	18	8
Anode arrangement (subject to final design)	Internal anode 200mm spacing 3.6mA/anode	Single ribbon 8mA/m

As detailed above, the main chord reinforcement was protected by internal anodes placed at a 200mm longitudinal spacing passing an average of 3.6mA per anode (18mA /m chord). The minor vertical stay was protected by a single ribbon anode longitudinally placed and passing 8mA /m. This information will be valuable in completing the design of a CP system to protect the structure and it is likely that a system similar to that trialled, with appropriately designed anodes, will be effective in protecting the elements of the Aqueduct.

3. Repair options

3.1. Conventional Repairs

3.1.1. Scope of Works

Conventional (Patch) repairs involve the removal of contaminated (carbonated) concrete from around the reinforcement, cleaning and repair of the reinforcement and replacement of the concrete with a new repair mortar.

The difficulty with this type of repair is the large degree of structural support required to stabilize the Aqueduct during the repair. In addition, assuming the patch repairs are only undertaken in visually defective areas (spalling), future deterioration of the non-repaired sections will continue requiring ongoing access and repair. The patch repair budget below is based on repair to all currently spalling areas, averaging only 17% of the concrete surface area, leaving 83% of the concrete surface unrepaired and continuing to corrode and spall.

3.1.2. Budget

The estimate for full depth patch repair is attached in Appendix B1 (ii). In this spreadsheet, the repair quantities are derived from the visual surveys undertaken on Tower 2 & 3, detailed in the Tower 2 & 3 worksheets. These surveys compare the surface area deterioration with that undertaken in the 1991 surveys enclosed in the Taywood – Maunsell report (1991). The cost of surface only repairs ($1500/m2 for electro-chemical EC repairs) for tower 2 & 3 are calculated in Appendix B1 (i) and these figures are used at the increased rate of $3000/m2 for full depth repairs.

Appendix B1(iii) then uses the 1991 repair budgets for each tower to approximate the relative condition of the towers today, including a 26% increase factor for the increased extent of repairs in 2009. This estimate gives a predicted $4.0m for the patch repair costs of all 14 towers.

To this base figure, we have added the costs of access, structural support, site establishment, supervision and margin to arrive at the $14.9m budget for the works. (Note- this budget is to repair spalling areas only, an average of 17% of the concrete surface area. The remaining 83% of the concrete that is not repaired will continue to deteriorate)

As the non-repaired areas will continue to spall, we have added the ongoing repair estimate of 15% of the original costs per 5 years, giving a $2.23m cost (5 yearly). The estimate of these ongoing costs must be considered as speculative.

3.2. Realkalization Repair

3.2.1. Scope of Works

The realkalization based repair requires the surface based patch repair (to the rebar, but not behind) of the concrete prior to the realkalization treatment. Accordingly, the budget for the realkalization treatment includes the surface based concrete repair costs.

The realkalization itself is estimated for all concrete elements excluding the ovoid pipe, which is considered separately.

3.2.2. Budget

The budget for the realkalization and surface repair is detailed in Appendix B1 (ii). The worksheet details the estimate of the surface areas of all elements in a typical tower (excluding the pipe). The calculation then estimates the materials, labour, access etc to calculate the realkalization cost of $675K per tower, or $9.5m for all 14 towers. Added to this is the surface concrete repair estimate from worksheet (i) $4.0m to give the final budget of $13.4m for the realkalization based repair.

As full realkalization is not expected in all areas and the life of realkalization is not proven, we suggest an additional allowance of 15% of the repair cost $2.0m is allowed on a 10 yearly interval for future repairs.

3.3. Cathodic Protection Repair

3.3.1. Scope of Works

The cathodic protection works again requires the similar extent of surface based concrete repairs to that for realkalization. As suggested earlier, CP using internal anodes does give the opportunity to stage the works with some concrete repair completed in future years. This staging possibility is not considered in the following budgets.

The scope of the CP is to protect all elements of the structure (except the ovoid pipe) using long life titanium anodes (50 year plus design life). The system is powered by solar cells with the control systems (and solar cells) placed inside the top of each tower (out of view). An alternative system using a mains power supply is expected to be a similar cost. The budget includes for the control systems to be remotely monitored via a web (www) based system.

3.3.2. Budget

The budget for the CP based repair is detailed in Appendix B1 (iv). The cost of the CP materials and labour is built in a separate spreadsheet named Appendix B2, which calculates the cost of the CP at $665K per tower. In Appendix B1 (iv) this figure is added to the surface concrete repair estimate to arrive at the total budget of $13.3m for the CP of all 14 towers.

Cathodic Protection requires monitoring and maintenance and we have made a separate allowance for

Annual monitoring and reporting	$18K pa
Annual maintenance	$20K pa

3.4. River Crossings- Special Consideration

The river crossings add significantly to the difficulty of the repair works for all repair options. Towers 9, 10, 11 & 12 are the river crossing towers, with towers 10 & 11 on the island.

The river spans complicate both the access and propping of the tower sections. The propping or structural support during repair will need to be considered by structural engineers prior to works in these areas. Similarly, the access to the river spans requires further consideration as there are several options possible, including the use of booms and/or increased levels of traditional scaffolding.

The full consideration of options to address the additional propping and access to the river spans is beyond the scope of this report. We suggest an additional budget allowance is made for the river crossing spans in the order of $200K in total.

3.5. Do-Nothing

The Do-Nothing option will see the continued deterioration of the structure, with continued spalling of cover concrete from all elements. This will result in an increasing risk of falling concrete and the corresponding risk to public safety.

The rate of continuing corrosion was addressed in section 2.1.5 of this report, and concludes that cracking will likely occur in most sound concrete areas within 2 years based on the measured corrosion rates. Spalling and delamination of the currently sound elements will follow the cracking, but may be in the order of 10 to 15 years before significant delamination occurs. The cost of future rectification will be mainly linked to the area of delamination and spalling.

The risk of deteriorating structural stability of elements of the structure is a matter for structural engineering input, beyond the scope of this report. In discussions with structural engineers Ken McLeod and Dick van der Molen, it is understood that the lower chord elements are likely the most critical elements as the corrosion proceeds. The spiral ligatures that are most affected by the corrosion to date are important especially in these lower chord compression elements. One way to limit the risk of any structural collapse is to prop the ends of the tower spans, to reduce the dead load on these critical elements and this work is recommended to proceed to limit the structural collapse risk. Engineering input is required to determine the method of propping. Propping becomes more difficult on the river spans of the structure.

4. Conclusions

The aqueduct structure suffers from carbonation initiated corrosion which has reached the depth of the reinforcement in the large majority of the surface, resulting large scale spalling and delamination of the concrete. The large extent of the corrosion has been confirmed with equipotential mapping and rate of corrosion found to be significant using the Galva Pulse instrument.

Repair trials under this project have been undertaken on sections of the major chords and minor stays of the structure with **Realkalization** and **Cathodic Protection**. Previous repairs have been undertaken on the structure using **Conventional Patch Repairs** and these 3 techniques are considered the only feasible options for the repair of the structure.

Conventional Patch Repairs are a proven technique for the repair of carbonated concrete with an excellent life expectancy for the areas repaired (50 years plus). Patch repairs are expensive, partly because of the structural support required during the concrete removal and replacement, with the budget developed in this report totalling $14.9m for an average of only 17% of the concrete surface area of the structure. The major disadvantage of this repair system is that the remaining unrepaired sections of the structure will continue to corrode and spall, requiring ongoing repairs, budgeted in this report in the order of $2.2m on a rolling 5 yearly interval.

Realkalization trial repairs proved effective in areas but insufficient levels of realkalization were achieved in some locations. Reasons of this variability have been proposed in the report and further trialling may conclude that the system could be utilized as the major repair system for the Aqueduct. The system requires all spalling and delaminated concrete to be repaired (surface based patch repair) prior to applying the realkalization treatment. The budget for the realkalization based repair totals $13.5m (all concrete areas excluding ovoid pipe) with a further provision for future repairs of $2.0m on a 10 year rolling interval.

Cathodic Protection (CP) based repairs proved effective with the trial repairs meeting Australian and International criteria for the corrosion protection of the reinforcement. The surface based concrete repairs (similar to repairs for realkalization) are required prior to installing titanium ribbon surface anodes, but if the internal anodes are utilized (for major chords and other large elements) some of the concrete repairs could be staged over an extended period. (Staging has not been considered in the budget). The budget developed for the CP based repairs totals $13.3m (all concrete areas excluding ovoid pipe) with an additional estimate of Monitoring the CP at $18K pa plus $20K pa for maintenance of the system.

5. Recommendation

Based on the investigation and trial works undertaken, we recommend the **Cathodic Protection** based repair as the preferred and most economical repair method for the Aqueduct Structure. The CP based approach could be utilized in a staged manner, with repair to one tower or all towers progressively. There is also the possibility of installing the CP systems initially and delaying some of the concrete repairs to future years.

The ovoid pipe has not been included in the repair budget using CP at this stage. The pipe is in relatively good condition compared to the rest of the Aqueduct structure and the large scale CP based protection of the pipe may not be warranted. We recommend some further investigation of the ovoid pipe, combined with some trial repairs using various CP or realkalization techniques before finally recommending the preferred repair and protection system for this element.

Appendix A
Investigation and Trial Results

FORCE Technology GalvaPulse

Aqua zone B

Ag/Cl calibrated to CuCuSO4 70 mV

Potential in mV

Y/X	0	250	500	750	1000
500	-282	-284	-310	-296	-309
250	-208	-280	-336	-314	-335
0	-243	-311	-333	-335	-361

Resistance in kohm

Y/X	0	250	500	750	1000
500	14	8	8	6	7
250	3	4	2	2	3
0	6	4	3	4	3

FORCE Technology GalvaPulse

Aqua B

Potential in mV to AgCL electrode

Y/X	1	2	3	4
1	-258	-266	-257	-259

Corrosion Current in uA/cm2 without guard ring

Y/X	1	2	3	4
1	17.5298	9.8193	8.3185	7.9455

Resistance in kohm

Y/X	1	2	3	4
1	4	3	3	2

FORCE Technology GalvaPulse

Aqua Zone C

AgCl electrode calibrated to CSE 70 mV

Potential in mV

Y/X	0	250	500	750	1000
500	-287	-296	-289	-261	-272
250	-272	-305	-287	-284	-279
0	-253	-292	-272	-274	-272

Resistance in kohm

Y/X	0	250	500	750	1000
500	1	0	0	1	3
250	7	0	0	1	2
0	9	0	0	0	1

Spacing 250mm

FORCE Technology GalvaPulse

Aqua C

Potential in mV to AgCL electrode

Y/X	1
2	-206
1	-195

Corrosion Current in uA/cm2 without guard ring

Y/X	1
2	23.9038
1	47.7746

Resistance in kohm

Y/X	1
2	1
1	2

FORCE Technology GalvaPulse

Aqua zone D

AgCl electrode calibrated to CSE 70 mV

Potential in mV

Y/X	0	250	500	750
500	-400	-414	-370	-336
250	-314	-311	-343	-276
0	-276	-285	-291	-274

Resistance in kohm

Y/X	0	250	500	750
500	1	9	2	4
250	0	0	1	2
0	0	0	1	1

agcl 70mV

FORCE Technology GalvaPulse

Aqua D

Potential in mV to AgCL electrode

Y/X	1
1	-241

Corrosion Current in uA/cm2 without guard ring

Y/X	1
1	32.4003

Resistance in kohm

Y/X	1
1	2

Realkalisation trial applied currents

Circuit ID:		A		C		D	
Location:		Lower cord southern end		Lower cord near tower		On vertical stay	
Area (m^2)							
Circuit cabling :		Structure steel	Anode	Structure steel	Anode	Structure steel	Anode
Cable colour:		Brown	Orange	Pink	Blue	Pink	Purple

Realkalisation outputs

Date	Time	Current (Amps)	Charge (A-hrs)	Current (Amps)	Charge (A-hrs)	Current (Amps)	Charge (A-hrs)
26/02/2009	8:30	0.121		0.526		0.22	
27/02/2009	9:00	0.092	2.208	0.401	9.624	0.164	3.936
27/02/2009	16:00	0.224		0.976		0.4	
28/02/2009	8:30	0.05		0.17		0.031	
28/02/2009	13:00	0.304	7.296	1.034	24.816	0.188	4.512
1/03/2009	10:00	0.04		0.136		0.025	
1/03/2009	11:00	0.3	7.2	1.023	24.552	0.186	4.464
3/03/2009	10:30	0.3	14.4	0.96	46.08	0.221	10.608
4/03/2009	12:00	0.25	6	0.855	20.52	0.156	3.744
5/03/2009	10:00	0.371	8.904	1.6	38.4	0.105	2.52
6/03/2009	Realkalisation off on arrival, system repaired and re-energised						
7/03/2009		0.374	8.976	1.43	34.32	0.143	3.432
8/03/2009		0.432	10.368	1.64	39.36	0.164	3.936
9/03/2009		0.402	9.648	1.5	36	0.155	3.72
Treatment Amp Hour			75		274		41
10/03/2009	Realkalisation system de-energised						

Cathodic protection trials results

Circuit ID:	B	E
Location:	Lower Chord	Vertical Stay

Anode current injection tests

Circuit ID:	B			E		
Location:	Lower Chord			Vertical Stay		
Applied voltage:	6.3 volts			6.3 volts		
	Anode ID	Current (mA)	Comments	Anode ID	Current (mA)	Comments
	A1	5.2	Pass	Strip	30	Pass
	A2	2300	Fail			
	A3	6.7	Pass			
	A4	7.8	Pass			
	A5	5.6	Pass			
	A6	12	Pass			

Cathodic protection potentials

Base/Native potentials			-374			-225
Circuit ID	B			E		
Circuit cabling :	Structure steel	Anode	Reference Electrode	Structure steel	Anode	Reference Electrode
Cable colour:	Black	White	Red	Green	Blue	Lt Blue
Results	ON Potential (mV)	Instant Off Potential (MV)	Applied Current (mA)	ON Potential (mV)	Instant Off Potential (MV)	Applied Current (mA)
25/02/2009	-570		21	-390		10
26/02/2009	-610		18	-424		6
27/02/2009	-572	-490	18	-468	-293	12
1/03/2009	-538	-482	12.5	-429	-295	5
2/03/2009	-538	-490	13.5	-461	-329	6
3/03/2009	-547	-500	14	-493	-355	7
4/03/2009	-527	-461	12 adjusted to 16	-439	-241	4 adjusted to 8
5/03/2009	-589	-514	15	-498	-270	7
6/03/2009	Cathodic protection off on arrival, system repaired & restored.					
7/03/2009	-574	-520	16	-508	-332	8
8/03/2009	-554	-506	15	-473	-300	8
9/03/2009	-591	-513	16	-574	-332	8
10/03/2009	-526	-462	17	-653	-326	8
7/04/2009	-612	-547	17	-797	-586	7
8/04/2009		-461			-422	
24 hour decay		86			164	
15/05/2009	-579	-538	10	-794	-626	6.5
16/05/2009		-478	reset to 18		-493	reset to 8
24 hour decay		60			133	
5/06/2009	-924	-707	17	-971	-718	7
5/06/2009		-603			-608	
4 hour decay		104			110	

Appendix B
Visual Assessment

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 1

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	3	70	30.00	15.00		
BOTTOM CHORD N.E.	3	20	31.00	7.00		
0-0' N.E.	1	10	14.40	2.00		
1-1' N.E.	0	0	2.90	0.00		
2-2' N.E.	0	0	2.60	0.00		
3-3' N.E.	1	10	2.10	0.20		
4-4' N.E.	1	10	1.70	0.20		
5-5' N.E.	0	0	1.30	0.00		
6-6' N.E.	1	10	1.00	0.20		
0-1' N.E.	1	10	46.00	0.50		
1-2' N.E.	0	0	3.70	0.00		
2-3' N.E.	3	15	3.10	0.70		
3-4' N.E.	1	10	2.50	0.60		
4-5' N.E.	3	35	2.10	0.70		
5-6' N.E.	0	0	1.80	0.00		
TOP CHORD S.E.	1	10	30.00	2.00		
BOTTOM CHORD S.E.	3	15	31.00	3.00		
0-0' S.E.	0	0	14.40	0.00		
1-1' S.E.	0	0	2.90	0.00		
2-2' S.E.	0	0	2.60	0.00		
3-3' S.E.	0	0	2.10	0.00		
4-4' S.E.	0	0	1.70	0.00		
5-5' S.E.	0	0	1.30	0.00		
6-6' S.E.	0	0	1.00	0.00		
0-1' S.E.	0	0	4.60	0.00		
1-2' S.E.	0	0	3.70	0.00		
2-3' S.E.	0	0	3.10	0.00		
3-4' S.E.	0	0	2.50	0.00		
4-5' S.E.	0	0	2.10	0.00		
5-6' S.E.	2	25	1.80	0.50		
TOP CHORD N.W.						
BOTTOM CHORD N.W.						
0-0' N.W.						
1-1' N.W.						
2-2' N.W.						
3-3' N.W.						
4-4' N.W.						
5-5' N.W.						
6-6' N.W.						
0-1' N.W.						
1-2' N.W.						
2-3' N.W.						
3-4' N.W.						
4-5' N.W.						
5-6' N.W.						
TOP CHORD S.W.						
BOTTOM CHORD S.W.						
0-0' S.W.						
1-1' S.W.						
2-2' S.W.						
3-3' S.W.						
4-4' S.W.						
5-5' S.W.						
6-6' S.W.						
0-1' S.W.						
1-2' S.W.						
2-3' S.W.						
3-4' S.W.						
4-5' S.W.						

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 1

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.						
N1-1						
N2-2						
S1-1						
S2-2						
TOWER TOP (WALLS)	3	20	31.00	5.00		
TOWER TOP (SOFFIT)	3	30	11.40	2.00		
TOWER BASE	3	30	53.90	3.00		
EXPANSION JOINT						
WALKWAY SOFFIT			98.80	90.00		
WALKWAY : 0-10m	1/0/2/0	75/0/20/0	20/36/14/18	2.00		
:10-20m	1/0/0/0	40/0/0/0	20/36/14/18	2.00		
:20-30m	1/0/0/1	50/0/0/5	20/36/14/18	1.00		
:30-40m	1/0/2/1	10/0/40/20	20/36/14/18	1.00		
:40-50m	1/1/1/1	10/20/25/20	20/36/14/18	1.00		
PIPE SUPPORT BRACK:						
1	3		5.31			
2	1		5.31			
3	3		5.31			
4	2		5.31			
5	3		5.58			
6	3		5.58			
7	2		8.33			
8	2		8.33			
9	3		8.33			
10	2		8.78			
11	3		9.33			
12	3		7.25			
13	2		7.25			
14	2		9.33			
15	3		8.78			
16	3		8.33			
17	2		8.33			
18	2		8.33			
19	3		5.58			
20	4		5.58			
21	3		5.31			
22	3		5.31			
SEWER PIPE						
				TOTAL	0	

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 2

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	1	25	30.00	2.25		
BOTTOM CHORD N.E.	1	50	31.00	4.65		
0-0' N.E.	1RM3	50	14.40	1.44		
1-1' N.E.	1/RM	25	2.90	0.15		
2-2' N.E.	3	75	2.60	0.39		
3-3' N.E.	3	100	2.10	0.42		
4-4' N.E.	2	75	1.70	0.26		
5-5' N.E.	0	50	1.30	0.13		
6-6' N.E.	R0	0	1.00	0.00		
0-1' N.E.						
1-2' N.E.						
2-3' N.E.						
3-4' N.E.						
4-5' N.E.						
5-6' N.E.						
TOP CHORD S.E.	4	75	30.00	6.75		
BOTTOM CHORD S.E.	3	100	31.00	9.30		
0-0' S.E.	3RM3	20	14.40	0.58		
1-1' S.E.	R0	0	2.90	0.00		
2-2' S.E.	R0	0	2.60	0.00		
3-3' S.E.	R0	0	2.10	0.00		
4-4' S.E.	R0	0	1.70	0.00		
5-5' S.E.	R0	0	1.30	0.00		
6-6' S.E.	R0	0	1.00	0.00		
0-1' S.E.	R0	0	4.60	0.00		
1-2' S.E.	R0	0	3.70	0.00		
2-3' S.E.	R0	0	3.10	0.00		
3-4' S.E.	R0	0	2.50	0.00		
4-5' S.E.	R0	0	2.10	0.00		
5-6' S.E.	R0	0	1.80	0.00		
TOP CHORD N.W.	2	100	30.00	9.00		
BOTTOM CHORD N.W.	3	5	31.00	0.46		
0-0' N.W.	R0	0	14.40	0.00		
1-1' N.W.	R0	0	2.90	0.00		
2-2' N.W.	R0	0	2.60	0.00		
3-3' N.W.	R0	0	2.10	0.00		
4-4' N.W.	R0	0	1.70	0.00		
5-5' N.W.	R0	0	1.30	0.00		
6-6' N.W.	R0	0	1.00	0.00		
0-1' N.W.	R0	20	4.60	0.14		
1-2' N.W.	R0	0	3.70	0.00		
2-3' N.W.	R0	0	3.10	0.00		
3-4' N.W.	R0	0	2.50	0.00		
4-5' N.W.	R0	0	2.10	0.00		
5-6' N.W.	R0	0	1.80	0.00		
TOP CHORD S.W.	1	30	30.00	2.70		
BOTTOM CHORD S.W.	3	20	31.00	1.86		
0-0' S.W.	3	20	14.40	0.58		
1-1' S.W.	R0	0	2.90	0.00		
2-2' S.W.	R0	0	2.60	0.00		
3-3' S.W.	R0	0	2.10	0.00		
4-4' S.W.	R0	0	1.70	0.00		
5-5' S.W.	R0	0	1.30	0.00		
6-6' S.W.	R0	0	1.00	0.00		
0-1' S.W.	R0	0	4.60	0.00		
1-2' S.W.	R0	0	3.70	0.00		
2-3' S.W.	R0	0	3.10	0.00		
3-4' S.W.	R0	0	2.50	0.00		
4-5' S.W.	R0	0	2.10	0.00		

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 2

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.	R0	0	1.80	0.00		
N1-1						
N2-2						
S1-1						
S2-2						
TOWER TOP (WALLS)	3	20	31.00	3.00		
TOWER TOP (SOFFIT)	3	30	11.40	4.00		
TOWER BASE	3	20	53.90	3.00		
EXPANSION JOINT	3	100				
WALKWAY SOFFIT	3	75	98.80	70.00		
WALKWAY :50-60m	1/0/1/1	40/0/20/30	20/36/14/18	2.00		
:60-70m	3/0/0/1	60/0/0/5	20/36/14/18	2.00		
:70-80m	3/2/1/1	20/10/10/50	20/36/14/18	2.00		
:80-90m	1/0/0/1	20/0/0/30	20/36/14/18	2.00		
:90-100m	1/1/0/1	30/20/0/20	20/36/14/18	2.00		
:100-110m	2/1/1/1	25/10/20/10	20/36/14/18	2.00		
PIPE SUPPORT BRACK:						
23	3	75	5.31	0.32		
24	2	75	5.31	0.32		
25	4	100	5.31	0.42		
26	3	100	5.31	0.42		
27	3	75	5.58	0.33		
28	3	75	5.58	0.33		
29	3	80	8.33	0.53		
30	2	50	8.33	0.33		
31	4	100	8.33	0.67		
32	2	25	8.78	0.18		
33	2	25	9.33	0.19		
34	0	-	7.25	0.00		
35	1	25	7.25	0.15		
36	3	75	9.33	0.56		
37	4	100	8.78	0.70		
38	3	100	8.33	0.67		
39	3	100	8.33	0.67		
40	3	50	8.33	0.33		
41	4	100	5.58	0.45		
42	3	75	5.58	0.33		
43	3	75	5.31	0.32		
44	2	25	5.31	0.11		
SEWER PIPE						
				TOTAL	0	

otal from 1991 hardcopy but all figures match in the cost estimate column therefore the totals on the hardcopy must be incorrect or approximate

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 3

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	3	40	30.00	6.00		
BOTTOM CHORD N.E.	4	30	31.00	5.00		
0-0' N.E.	3	40	14.40	3.00		
1-1' N.E.	3	20	2.90	1.50		
2-2' N.E.	3	50	2.60	2.00		
3-3' N.E.	1	10	2.10	0.50		
4-4' N.E.	3	30	1.70	1.50		
5-5' N.E.	1	-	1.30	-		
6-6' N.E.	0	-	1.00	-		
0-1' N.E.	R0		4.60			
1-2' N.E.	1		3.70			
2-3' N.E.	R0		3.10			
3-4' N.E.	R0		2.50			
4-5' N.E.	R0		2.10			
5-6' N.E.	3	20	1.80	0.50		
TOP CHORD S.E.	2	50	30.00	6.00		
BOTTOM CHORD S.E.	3	25	31.00	4.00		
0-0' S.E.	4	80	14.40	8.00		
1-1' S.E.	3	20	2.90	1.00		
2-2' S.E.	3	30	2.60	1.50		
3-3' S.E.	0	50	2.10	0.21		
4-4' S.E.	3	10	1.70	1.00		
5-5' S.E.	3	20	1.30	1.00		
6-6' S.E.	1	-	1.00	-		
0-1' S.E.	3	20	4.60	0.50		
1-2' S.E.	0	0	3.70	0.00		
2-3' S.E.	3	25	3.10	1.00		
3-4' S.E.	3	5	2.50	0.50		
4-5' S.E.	3	10	2.10	0.00		
5-6' S.E.	2	10	1.80	0.00		
TOP CHORD N.W.						
BOTTOM CHORD N.W.						
0-0' N.W.						
1-1' N.W.						
2-2' N.W.						
3-3' N.W.						
4-4' N.W.						
5-5' N.W.						
6-6' N.W.						
0-1' N.W.						
1-2' N.W.						
2-3' N.W.						
3-4' N.W.						
4-5' N.W.						
5-6' N.W.						
TOP CHORD S.W.						
BOTTOM CHORD S.W.						
0-0' S.W.						
1-1' S.W.						
2-2' S.W.						
3-3' S.W.						
4-4' S.W.						
5-5' S.W.						
6-6' S.W.						
0-1' S.W.						
1-2' S.W.						
2-3' S.W.						
3-4' S.W.						
4-5' S.W.						

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 3

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.						
N1-1						
N2-2						
S1-1						
S2-2						
TOWER TOP (WALLS)	3	60	31.00	10.00		
TOWER TOP (SOFFIT)	3	40	11.40	5.00		
TOWER BASE	3	10	53.90	2.00		
EXPANSION JOINT	-	20				
WALKWAY SOFFIT	3	25	98.80	5.00		
WALKWAY : 110-120m	3/0/2/1	100/0/50/5	20/36/14/18			
:120-130m	3/1/3/1	100/30/75/10	20/36/14/18			
:130-140m	1/3/1/1	20/75/20/15	20/36/14/18			
:140-150m	1/3/1/1	25/80/20/20	20/36/14/18			
:150-160m	1/3/1/1	20/75/25/20	20/36/14/18			
PIPE SUPPORT BRACK:						
45	3	25	0.11	0.11		
46	3	50	0.21	0.21		
47	4	75	0.32	0.32		
48	4	100	0.45	0.45		
49	4	100	0.45	0.45		
50	4	100	0.67	0.97		
51	3	50	0.33	0.33		
52	3	75	0.50	0.50		
53	3	25	0.18	0.18		
54	4	75	0.56	0.56		
55	4	50	0.29	0.29		
56	3	50	0.29	0.29		
57	3	50	0.37	0.37		
58	3	75	0.53	0.53		
59	4	75	0.50	0.50		
60	2	50	0.33	0.33		
61	4	100	0.67	0.67		
62	4	75	0.33	0.33		
63	4	50	0.22	0.22		
64	3	75	0.32	0.32		
65	3	80	0.34	0.34		
66	3	50	0.21	0.21		
SEWER PIPE						
				TOTAL		

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 7

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	2	15	30.00	3.00		
BOTTOM CHORD N.E.	3	20	31.00	3.00		
0-0' N.E.	4	60	14.40	7.00		
1-1' N.E.	-		2.90	-		
2-2' N.E.	1		2.60	-		
3-3' N.E.	3		2.10	1.00		
4-4' N.E.	0		1.70	-		
5-5' N.E.	0		1.30	-		
6-6' N.E.	0		1.00	-		
0-1' N.E.	3		4.60	1.00		
1-2' N.E.	0		3.70	-		
2-3' N.E.	3	10	3.10	0.50		
3-4' N.E.	3	10	2.50	0.50		
4-5' N.E.	1		2.10	-		
5-6' N.E.	0		1.80	-		
TOP CHORD S.E.	3	20	30.00	5.00		
BOTTOM CHORD S.E.	3	25	31.00	10.00		
0-0' S.E.	3	60	14.40	6.00		
1-1' S.E.	1		2.90	-		
2-2' S.E.	0/R0		2.60	-		
3-3' S.E.	1		2.10	-		
4-4' S.E.	1		1.70	0.50		
5-5' S.E.	2		1.30	0.50		
6-6' S.E.	2-3		1.00	0.50		
0-1' S.E.	3	25	4.60	2.00		
1-2' S.E.	3		3.70	2.00		
2-3' S.E.	3		3.10	0.25		
3-4' S.E.	-		2.50	-		
4-5' S.E.	-		2.10	-		
5-6' S.E.	-		1.80	-		
TOP CHORD N.W.						
BOTTOM CHORD N.W.						
0-0' N.W.						
1-1' N.W.						
2-2' N.W.						
3-3' N.W.						
4-4' N.W.						
5-5' N.W.						
6-6' N.W.						
0-1' N.W.						
1-2' N.W.						
2-3' N.W.						
3-4' N.W.						
4-5' N.W.						
5-6' N.W.						
TOP CHORD S.W.						
BOTTOM CHORD S.W.						
0-0' S.W.						
1-1' S.W.						
2-2' S.W.						
3-3' S.W.						
4-4' S.W.						
5-5' S.W.						
6-6' S.W.						
0-1' S.W.						
1-2' S.W.						
2-3' S.W.						
3-4' S.W.						
4-5' S.W.						

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 7

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.						
N1-1						
N2-2						
S1-1						
S2-2						
TOWER TOP (WALLS)	3	40	31.00	10.00		
TOWER TOP (SOFFIT)	4	100	11.40	10.00		
TOWER BASE	3	5	53.90	2.00		
EXPANSION JOINT	1	20				
WALKWAY SOFFIT	4	80	98.80	50.00		
WALKWAY : 330-340m	1/0/2/1	60/0/50/50	20/36/14/18	2.10		50%-70%
:340-350m	1/3/3/1	30/75/80/10	20/36/14/18	3.45		
:350-360m	0/3/2/1	20/75/25/20	20/36/14/18	2.86		
:360-370m	1/3/3/1	50/75/80/20	20/36/14/18	3.89		
:370-380m	2/3/3/1	70/40/80/30	20/36/14/18	3.38		
PIPE SUPPORT BRACK:						
133	3	75	5.31	0.32		
134	0	0	5.31	0.00		
135	4	100	5.31	0.42		
136	3	50	5.58	0.22		
137	3	75	5.58	0.33		
138	2	50	8.33	0.33		
139	1	25	8.33	0.17		
140	0	0	8.33	1.00		
141	3	75	8.78	0.53		
142	3	75	9.33	0.56		
143	2	25	7.25	0.15		
144	3	50	7.25	0.29		
145	3	75	9.33	0.56		
146	1	25	8.78	0.18		
147	1	25	8.33	0.17		
148	3	50	8.33	0.33		
149	2	50	8.33	0.33		
150	2	50	5.58	0.22		
151	0	0	5.58	0.00		
152	3	75	5.31	0.32		
153	3	25	5.31	0.11		
154	2	25	5.31	0.11		
SEWER PIPE	4	35	216.00	3.78		
				TOTAL		

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 8

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	1	12	30.00	3.00	1530	
BOTTOM CHORD N.E.	1	5	31.00	1.50	0	
0-0' N.E.	3	25	14.40	2.00	7344	
1-1' N.E.	3	25	2.90	1.00	500	
2-2' N.E.	1	0	2.60	-	500	
3-3' N.E.	0	0	2.10	-	0	
4-4' N.E.	0	0	1.70	-	500	
5-5' N.E.	RM0	10	1.30	0.50	0	
6-6' N.E.	4	100	1.00	1.00	680	
0-1' N.E.	3	25	4.60	1.00	587	
1-2' N.E.	3	10	3.70	0.50	500	
2-3' N.E.	0	0	3.10	-	0	
3-4' N.E.	1	0	2.50	-	500	
4-5' N.E.	1	5	2.10	0.50	500	
5-6' N.E.	1	5	1.80	1.00	0	
TOP CHORD S.E.	1	15	30.00	1.00	0	
BOTTOM CHORD S.E.	3	20	31.00	4.00	0	
0-0' S.E.	3	20	14.40	3.00	4896	
1-1' S.E.	1	5	2.90	0.50	500	
2-2' S.E.	1	5	2.60	0.50	707	
3-3' S.E.	1	5	2.10	0.20	500	
4-4' S.E.	0	-	1.70	-	0	
5-5' S.E.	0	-	1.30	-	0	
6-6' S.E.	0	-	1.00	-	0	
0-1' S.E.	0	-	4.60	-	500	
1-2' S.E.	0	-	3.70	-	500	
2-3' S.E.	1	-	3.10	-	500	
3-4' S.E.	1	-	2.50	-	500	
4-5' S.E.	3		2.10	0.50	0	
5-6' S.E.	0		1.80	-	0	
TOP CHORD N.W.			30.00			
BOTTOM CHORD N.W.			31.00			
0-0' N.W.			14.40			
1-1' N.W.			2.90			
2-2' N.W.			2.60			
3-3' N.W.			2.10			
4-4' N.W.			1.70			
5-5' N.W.			1.30			
6-6' N.W.			1.00			
0-1' N.W.			4.60			
1-2' N.W.			3.70			
2-3' N.W.			3.10			
3-4' N.W.			2.50			
4-5' N.W.			2.10			
5-6' N.W.			1.80			
TOP CHORD S.W.			30.00			
BOTTOM CHORD S.W.			31.00			
0-0' S.W.			14.40			
1-1' S.W.			2.90			
2-2' S.W.			2.60			
3-3' S.W.			2.10			
4-4' S.W.			1.70			
5-5' S.W.			1.30			
6-6' S.W.			1.00			
0-1' S.W.			4.60			
1-2' S.W.			3.70			
2-3' S.W.			3.10			
3-4' S.W.			2.50			
4-5' S.W.			2.10			

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 8

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.			1.80			
N1-1			6.28			
N2-2			6.28			
S1-1			6.28			
S2-2			6.28			
TOWER TOP (WALLS)			31.00			
TOWER TOP (SOFFIT)			11.40			
TOWER BASE			53.90			
EXPANSION JOINT						
WALKWAY SOFFIT			98.80			
WALKWAY : 380-390m			20/36/14/18			
:390-400m			20/36/14/18			
:400-410m			20/36/14/18			
:410-420m			20/36/14/18			
:420-430m			20/36/14/18			
:430-440m			20/36/14/18			
PIPE SUPPORT BRACK:						
155	3		5.31			
156	3		5.31			
157	2		5.31			
158	2		5.58			
159	1		5.58			
160	1		8.33			
161	3		8.33			
162	3		8.33			
163	0		8.78			
164	3		9.33			
165	3		7.25			
166	3		7.25			
167	3		9.33			
168	3R0		8.78			
169	2		8.33			
170	1		8.33			
171	1		8.33			
172	1		5.58			
173	3		5.58			
174	2		5.31			
175	2		5.31			
176	3		5.31			
SEWER PIPE			216.00			
				TOTAL		

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 9

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	3	20	30.00	3.00		
BOTTOM CHORD N.E.	3	15	31.00	3.00		
0-0' N.E.	3	20	14.40	2.00		
1-1' N.E.	R0	25	2.90	-		
2-2' N.E.	3	30	2.60	1.00		
3-3' N.E.	3	30	2.10	2.00		
4-4' N.E.	3	20	1.70	2.00		
5-5' N.E.	0	-	1.30	-		
6-6' N.E.	3R	10	1.00	0.50		
0-1' N.E.	3	10	4.60	0.50		
1-2' N.E.	1	10	3.70	0.50		
2-3' N.E.	0	-	3.10	-		
3-4' N.E.	3	20	2.50	1.50		
4-5' N.E.	3	30	2.10	1.50		
5-6' N.E.	1	5	1.80	-		
TOP CHORD S.E.			30.00			
BOTTOM CHORD S.E.			31.00			
0-0' S.E.			14.40			
1-1' S.E.			2.90			
2-2' S.E.			2.60			
3-3' S.E.			2.10			
4-4' S.E.			1.70			
5-5' S.E.			1.30			
6-6' S.E.			1.00			
0-1' S.E.			4.60			
1-2' S.E.			3.70			
2-3' S.E.			3.10			
3-4' S.E.			2.50			
4-5' S.E.			2.10			
5-6' S.E.			1.80			
TOP CHORD N.W.			30.00			
BOTTOM CHORD N.W.			31.00			
0-0' N.W.			14.40			
1-1' N.W.			2.90			
2-2' N.W.			2.60			
3-3' N.W.			2.10			
4-4' N.W.			1.70			
5-5' N.W.			1.30			
6-6' N.W.			1.00			
0-1' N.W.			4.60			
1-2' N.W.			3.70			
2-3' N.W.			3.10			
3-4' N.W.			2.50			
4-5' N.W.			2.10			
5-6' N.W.			1.80			
TOP CHORD S.W.			30.00			
BOTTOM CHORD S.W.			31.00			
0-0' S.W.			14.40			
1-1' S.W.			2.90			
2-2' S.W.			2.60			
3-3' S.W.			2.10			
4-4' S.W.			1.70			
5-5' S.W.			1.30			
6-6' S.W.			1.00			
0-1' S.W.			4.60			
1-2' S.W.			3.70			
2-3' S.W.			3.10			
3-4' S.W.			2.50			
4-5' S.W.			2.10			

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 9

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.			1.80			
N1-1			6.28			
N2-2			6.28			
S1-1			6.28			
S2-2			6.28			
TOWER TOP (WALLS)			31.00			
TOWER TOP (SOFFIT)			11.40			
TOWER BASE			53.90			
EXPANSION JOINT						
WALKWAY SOFFIT			98.80			
WALKWAY :440-450m			20/36/14/18			
:450-460m			20/36/14/18			
:460-470m			20/36/14/18			
:470-480m			20/36/14/18			
:480-490m			20/36/14/18			
PIPE SUPPORT BRACK:						
177	4		5.31			
178	3		5.31			
179	2		5.31			
180	2		5.58			
181	2		5.58			
182	1		8.33			
183	1		8.33			
184	3		8.33			
185			8.78			
186			9.33			
187			7.25			
188			7.25			
189			9.33			
190			8.78			
191			8.33			
192			8.33			
193			8.33			
194			5.58			
195			5.58			
196			5.31			
197			5.31			
198			5.31			
SEWER PIPE			216.00			
				TOTAL		

Appendix B1
Repair Budgets

all summed in man hours

1 Man hour Assumed at $100

	Units	Man hours Per Unit	cost
Internal anodes	1023	0.5	$51,150
Ribbon	2012.333333	1	$201,233
Conductor Bar	641.9	1	$64,190
Connections	100	2	$20,000
reference electrode	15	2	$3,000
Junction Box	3	3	$900
Transformer Rectifier	1	24	$2,400
cabling	1	80	$8,000
		totals	$350,873

(i) Aqueduct CP & Realkalization Concrete Repair Summary

Repairs for CP and Realkalization are "surface" patch repairs, where delamianted and spalled concrete is removed and replaced but sound concrete behind or over corroding reinforcement is not required to be removed. Accordingly, far less concrete is required to be removed, allowing the strcuture to be repaired with a minimum of structural weakening.
This repair assessment is based on a detailed visual assessment of Towers 2 & 3 (attached in the adjacent worksheets) with the 1991 repair asessment used as a relative guide for the condition of each tower

Tower	1991 Repair Assessment	Detail CP Repair 2009	% increase	CP Repair Estimate 2009	
1	114000		26	143253	
2	233000	241995	4	241995	
3	265000	333128	26	333128	
4	245000		26	308700	
5	283000		26	356580	
6	252000		26	317520	
7	236000		26	297360	
8	174000		26	219240	
9	231000		26	291060	
10	256000		26	322560	
11	252000		26	317520	
12	223000		26	280980	
13	154000		26	194040	
14	311000		26	391860	
	3229000		26	**4015795**	Total surface patch repair estimate for CP and Realkalization

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 3

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	3	40	30.00	6.00	9000	
BOTTOM CHORD N.E.	4	30	31.00	5.00	7500	
0-0' N.E.	3	40	14.40	3.00	4500	
1-1' N.E.	3	20	2.90	1.50	2250	
2-2' N.E.	3	50	2.60	2.00	3000	
3-3' N.E.	1	10	2.10	0.50	750	
4-4' N.E.	3	30	1.70	1.50	2250	
5-5' N.E.	1	10	1.30	0.50	750	
6-6' N.E.	0	10	1.00	0.20	300	
0-1' N.E.	R0		4.60		0	
1-2' N.E.	1		3.70		0	
2-3' N.E.	R0		3.10		0	
3-4' N.E.	R0		2.50		0	
4-5' N.E.	R0		2.10		0	
5-6' N.E.	3	20	1.80	0.50	750	
TOP CHORD S.E.	2	50	30.00	6.00	9000	
BOTTOM CHORD S.E.	3	25	31.00	4.00	6000	
0-0' S.E.	4	80	14.40	8.00	12000	
1-1' S.E.	3	20	2.90	1.00	1500	
2-2' S.E.	3	30	2.60	1.50	2250	
3-3' S.E.	0	50	2.10	0.21	315	
4-4' S.E.	3	10	1.70	1.00	1500	
5-5' S.E.	3	20	1.30	1.00	1500	
6-6' S.E.	1	10	1.00	0.50	750	
0-1' S.E.	3	20	4.60	0.50	750	
1-2' S.E.	0	0	3.70	0.00	0	
2-3' S.E.	3	25	3.10	1.00	1500	
3-4' S.E.	3	5	2.50	0.50	750	
4-5' S.E.	3	10	2.10	0.00	0	
5-6' S.E.	2	10	1.80	0.00	0	
TOP CHORD N.W.		90	30.00	27.00	40500	
BOTTOM CHORD N.W.		6	31.00	1.86	2790	
0-0' N.W.		20	14.40	2.88	4320	
1-1' N.W.		75	2.90	2.18	3262.5	
2-2' N.W.		50	2.60	1.30	1950	
3-3' N.W.		50	2.10	1.05	1575	
4-4' N.W.		100	1.70	1.70	2550	
5-5' N.W.		0	1.30	0.00	0	
6-6' N.W.		100	1.00	1.00	1500	
0-1' N.W.		75	4.60	3.45	5175	
1-2' N.W.		60	3.70	2.22	3330	
2-3' N.W.		25	3.10	0.78	1162.5	
3-4' N.W.		25	2.50	0.63	937.5	
4-5' N.W.		75	2.10	1.58	2362.5	
5-6' N.W.		75	1.80	1.35	2025	
TOP CHORD S.W.		70	30.00	21.00	31500	
BOTTOM CHORD S.W.		30	31.00	9.30	13950	
0-0' S.W.		90	14.40	12.96	19440	
1-1' S.W.		30	2.90	0.87	1305	
2-2' S.W.		20	2.60	0.52	780	
3-3' S.W.		50	2.10	1.05	1575	
4-4' S.W.		20	1.70	0.34	510	
5-5' S.W.		100	1.30	1.30	1950	
6-6' S.W.		60	1.00	0.60	900	
0-1' S.W.		25	4.60	1.15	1725	
1-2' S.W.		30	3.70	1.11	1665	
2-3' S.W.		25	3.10	0.78	1162.5	
3-4' S.W.		50	2.50	1.25	1875	
4-5' S.W.		50	2.10	1.05	1575	

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 3

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.		50	1.80	0.90	1350	
N1-1		50	6.28	3.14	4710	
N2-2		50	6.28	3.14	4710	
S1-1		50	6.28	3.14	4710	
S2-2		50	6.28	3.14	4710	
TOWER TOP (WALLS)	3	60	31.00	10.00	15000	
TOWER TOP (SOFFIT)	3	40	11.40	5.00	7500	
TOWER BASE	3	10	53.90	2.00	3000	
EXPANSION JOINT	-	20			0	
WALKWAY SOFFIT	3	25	98.80	5.00	7500	
WALKWAY : 110-120m	3/0/2/1	100/0/50/5	20/36/14/18	30.00	45000	All walkway
:120-130m	3/1/3/1	100/30/75/10	20/36/14/18	0.00	0	inc
:130-140m	1/3/1/1	20/75/20/15	20/36/14/18	0.00	0	inc
:140-150m	1/3/1/1	25/80/20/20	20/36/14/18	0.00	0	inc
:150-160m	1/3/1/1	20/75/25/20	20/36/14/18	0.00	0	inc
					0	
PIPE SUPPORT BRACK:					0	
45	3	25	0.11	0.11	165	
46	3	50	0.21	0.21	315	
47	4	75	0.32	0.32	480	
48	4	100	0.45	0.45	675	
49	4	100	0.45	0.45	675	
50	4	100	0.67	0.97	1455	
51	3	50	0.33	0.33	495	
52	3	75	0.50	0.50	750	
53	3	25	0.18	0.18	270	
54	4	75	0.56	0.56	840	
55	4	50	0.29	0.29	435	
56	3	50	0.29	0.29	435	
57	3	50	0.37	0.37	555	
58	3	75	0.53	0.53	795	
59	4	75	0.50	0.50	750	
60	2	50	0.33	0.33	495	
61	4	100	0.67	0.67	1005	
62	4	75	0.33	0.33	495	
63	4	50	0.22	0.22	330	
64	3	75	0.32	0.32	480	
65	3	80	0.34	0.34	510	
66	3	50	0.21	0.21	315	
SEWER PIPE						
				TOTAL	333127.5	

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 2

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
TOP CHORD N.E.	1	25	30.00	2.50	3750	
BOTTOM CHORD N.E.	1	50	31.00	4.65	6975	
0-0' N.E.	1RM3	50	14.40	2.00	3000	
1-1' N.E.	1/RM	25	2.90	1.00	1500	
2-2' N.E.	3	75	2.60	2.00	3000	
3-3' N.E.	3	100	2.10	2.00	3000	
4-4' N.E.	2	75	1.70	2.00	3000	
5-5' N.E.	0	50	1.30	0.13	195	
6-6' N.E.	R0	0	1.00	0.00	0	
0-1' N.E.					0	
1-2' N.E.					0	
2-3' N.E.					0	
3-4' N.E.					0	
4-5' N.E.					0	
5-6' N.E.					0	
TOP CHORD S.E.	4	75	30.00	10.00	15000	
BOTTOM CHORD S.E.	3	100	31.00	5.00	7500	
0-0' S.E.	3RM3	20	14.40	1.00	1500	
1-1' S.E.	R0	0	2.90	0.00	0	
2-2' S.E.	R0	0	2.60	0.00	0	
3-3' S.E.	R0	0	2.10	0.00	0	
4-4' S.E.	R0	0	1.70	0.00	0	
5-5' S.E.	R0	0	1.30	0.00	0	
6-6' S.E.	R0	0	1.00	0.00	0	
0-1' S.E.	R0	0	4.60	0.00	0	
1-2' S.E.	R0	0	3.70	0.00	0	
2-3' S.E.	R0	0	3.10	0.00	0	
3-4' S.E.	R0	0	2.50	0.00	0	
4-5' S.E.	R0	0	2.10	0.00	0	
5-6' S.E.	R0	0	1.80	0.00	0	
TOP CHORD N.W.	2	100	30.00	10.00	15000	
BOTTOM CHORD N.W.	3	5	31.00	3.00	4500	
0-0' N.W.	R0	0	14.40	3.00	4500	
1-1' N.W.	R0	0	2.90	0.00	0	
2-2' N.W.	R0	0	2.60	0.00	0	
3-3' N.W.	R0	0	2.10	0.00	0	
4-4' N.W.	R0	0	1.70	0.00	0	
5-5' N.W.	R0	0	1.30	0.00	0	
6-6' N.W.	R0	0	1.00	0.00	0	
0-1' N.W.	R0	20	4.60	0.14	210	
1-2' N.W.	R0	0	3.70	0.00	0	
2-3' N.W.	R0	0	3.10	0.00	0	
3-4' N.W.	R0	0	2.50	0.00	0	
4-5' N.W.	R0	0	2.10	0.00	0	
5-6' N.W.	R0	0	1.80	0.00	0	
TOP CHORD S.W.	1	30	30.00	2.00	3000	
BOTTOM CHORD S.W.	3	20	31.00	2.00	3000	
0-0' S.W.	3	20	14.40	0.58	870	
1-1' S.W.	R0	0	2.90	0.00	0	
2-2' S.W.	R0	0	2.60	0.00	0	
3-3' S.W.	R0	0	2.10	0.00	0	
4-4' S.W.	R0	0	1.70	0.00	0	
5-5' S.W.	R0	0	1.30	0.00	0	
6-6' S.W.	R0	0	1.00	0.00	0	
0-1' S.W.	R0	0	4.60	0.00	0	
1-2' S.W.	R0	0	3.70	0.00	0	
2-3' S.W.	R0	0	3.10	0.00	0	
3-4' S.W.	R0	0	2.50	0.00	0	
4-5' S.W.	R0	0	2.10	0.00	0	

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

TOWER No. 2

Element Description	Condition Rating (Code)	Damage Rating (% Surface Area)	Member Area (m2)	Extent of Defects (m2)	Cost Estimate ($)	Remarks
5-6' S.W.	R0	0	1.80	0.00	0	
N1-1				2.00	3000	
N2-2				2.00	3000	
S1-1				2.00	3000	
S2-2				2.00	3000	
TOWER TOP (WALLS)	3	20	31.00	3.00	4500	
TOWER TOP (SOFFIT)	3	30	11.40	4.00	6000	
TOWER BASE	3	20	53.90	3.00	4500	
EXPANSION JOINT	3	100			0	
WALKWAY SOFFIT	3	75	98.80	70.00	105000	
WALKWAY :50-60m	1/0/1/1	40/0/20/30	20/36/14/18	2.00	3000	
:60-70m	3/0/0/1	60/0/0/5	20/36/14/18	2.00	3000	
:70-80m	3/2/1/1	20/10/10/50	20/36/14/18	2.00	3000	
:80-90m	1/0/0/1	20/0/0/30	20/36/14/18	2.00	3000	
:90-100m	1/1/0/1	30/20/0/20	20/36/14/18	2.00	3000	
:100-110m	2/1/1/1	25/10/20/10	20/36/14/18	2.00	3000	
PIPE SUPPORT BRACK:						
23	3	75	5.31	0.32	480	
24	2	75	5.31	0.32	480	
25	4	100	5.31	0.42	630	
26	3	100	5.31	0.42	630	
27	3	75	5.58	0.33	495	
28	3	75	5.58	0.33	495	
29	3	80	8.33	0.53	795	
30	2	50	8.33	0.33	495	
31	4	100	8.33	0.67	1005	
32	2	25	8.78	0.18	270	
33	2	25	9.33	0.19	285	
34	0	-	7.25	0.00	0	
35	1	25	7.25	0.15	225	
36	3	75	9.33	0.56	840	
37	4	100	8.78	0.70	1050	
38	3	100	8.33	0.67	1005	
39	3	100	8.33	0.67	1005	
40	3	50	8.33	0.33	495	
41	4	100	5.58	0.45	675	
42	3	75	5.58	0.33	495	
43	3	75	5.31	0.32	480	
44	2	25	5.31	0.11	165	
SEWER PIPE						
				TOTAL	241995	

. from 1991 hardcopy but all figures match in the cost estimate column therefore the totals on the hardcopy must be incorrect or approximate

(ii) Patch Repair Estimate

Full depth patch repair is estimated to be approximately double the cost for surface based repairs.
The following calculation uses the CP based surface repair cost x 2 to estimate the full depth patch repair cost
In addition, additional falsework and support costs are added to structuarally support the tower

Tower	1991 Repair Assessment	Detail CP Repair 2009	% increase	CP Repair Estimate 2009	Full depth repair
1	114000		26	143253	$286,506
2	233000	241995	4	241995	$483,990
3	265000	333128	26	333128	$666,256
4	245000		26	308700	$617,400
5	283000		26	356580	$713,160
6	252000		26	317520	$635,040
7	236000		26	297360	$594,720
8	174000		26	219240	$438,480
9	231000		26	291060	$582,120
10	256000		26	322560	$645,120
11	252000		26	317520	$635,040
12	223000		26	280980	$561,960
13	154000		26	194040	$388,080
14	311000		26	391860	$783,720
	3229000		26	**4015796**	**$8,031,592**

Full Depth patch Repair Estimate Item	Qty	Unit	Rate	Amount	
Full depth patch repair	1	No	$8,031,592	$8,031,591.66	
Structural support during repair	14	No	65000	$910,000.00	
Access	14	No	55000	$770,000.00	
Prop span	14	No	10000	$140,000.00	
Site establishment	14	No	12000	$168,000.00	
Supervision - Daily	14	No	75000	$1,050,000.00	
Supervision - Senior	14	No	36000	$504,000.00	
Contingency	14	No	25000	$350,000.00	
				$11,923,591.66	
Contractor Margin (??)	25%			$2,980,897.92	
Total				**$14,904,489.58**	Total
5 yearly additional patch repair costs	**15%**			**$2,235,673.44**	

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

(iii) Realkalization Estimate

Realkalization costs are based on the surface area of concrete to be treated, with the rate per m2 calculated below

The concrete repair costs for realkalization are similar to the CP concrete repair costs (surface repairs), with these costs included from worsheet (i)

Realkalization Estimate					
	Qty	**Unit**	**Rate**	**Amount**	**Notes**
Materials	1109	m2	105	116,445	Titanium $60, Chemical $10, Other $35
Labour Install	1980	manhours	100	198,000	6 man days per 30m2 (major cord)= 1.8MH/m2x 1100
Labour Monitor (7 days)	143	manhours	100	14,300	4 mh per 30m2= 0.13mh/m2 x 1100
Labour remove	277	manhours	100	27,725	1.5 man day per 30m2
Continuity	1	item	6000	6,000	
Access - Fixed scaffold	1	item	12000	12,000	
Access - Scissor lift	80	day	300	24,000	
Prop span	1	item	5000	5,000	
Site establishment	4	months	2000	8,000	
Supervision- Daily	85	day	800	68,000	
Supervision- Senior	20	day	1800	36,000	
Contingency	1	item	25000	25,000	
SUB-Total				540,470	
Margin (contractor??)			0.25	135,118	
Realkalization Estimate (per tower)			**Total**	**675,588**	
Realkalization Estimate all tow	14	No	675588	9,458,225	
Surface Concrete Repair (from	1	No	4015795	4,015,795	
Total Realkalization Repair Budget				**$13,474,020**	**Total Realkalization Based Repair Estimate**

Allowance for Future Repairs (15% each 10 years) **$2,021,103**

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

Tower Surface Area of Elements

Element Description	Member Area (m2)
TOP CHORD N.E.	30.00
BOTTOM CHORD N.E.	31.00
0-0' N.E.	14.40
1-1' N.E.	2.90
2-2' N.E.	2.60
3-3' N.E.	2.10
4-4' N.E.	1.70
5-5' N.E.	1.30
6-6' N.E.	1.00
0-1' N.E.	4.60
1-2' N.E.	3.70
2-3' N.E.	3.10
3-4' N.E.	2.50
4-5' N.E.	2.10
5-6' N.E.	1.80
TOP CHORD S.E.	30.00
BOTTOM CHORD S.E.	31.00
0-0' S.E.	14.40
1-1' S.E.	2.90
2-2' S.E.	2.60
3-3' S.E.	2.10
4-4' S.E.	1.70
5-5' S.E.	1.30
6-6' S.E.	1.00
0-1' S.E.	4.60
1-2' S.E.	3.70
2-3' S.E.	3.10
3-4' S.E.	2.50
4-5' S.E.	2.10
5-6' S.E.	1.80
TOP CHORD N.W.	30.00
BOTTOM CHORD N.W.	31.00
0-0' N.W.	14.40
1-1' N.W.	2.90
2-2' N.W.	2.60
3-3' N.W.	2.10
4-4' N.W.	1.70
5-5' N.W.	1.30
6-6' N.W.	1.00
0-1' N.W.	4.60
1-2' N.W.	3.70
2-3' N.W.	3.10
3-4' N.W.	2.50
4-5' N.W.	2.10
5-6' N.W.	1.80
TOP CHORD S.W.	30.00
BOTTOM CHORD S.W.	31.00
0-0' S.W.	14.40
1-1' S.W.	2.90
2-2' S.W.	2.60
3-3' S.W.	2.10

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

Tower Surface Area of Elements

Element Description	Member Area (m2)
4-4' S.W.	1.70
5-5' S.W.	1.30
6-6' S.W.	1.00
0-1' S.W.	4.60
1-2' S.W.	3.70
2-3' S.W.	3.10
3-4' S.W.	2.50
4-5' S.W.	2.10
5-6' S.W.	1.80
N1-1	10.00
N2-2	10.00
S1-1	10.00
S2-2	10.00
TOWER TOP (WALLS)	31.00
TOWER TOP (SOFFIT)	11.40
TOWER BASE	53.90
EXPANSION JOINT	
WALKWAY SOFFIT	98.80
WALKWAY :50-60m	50.00
:60-70m	50.00
:70-80m	50.00
:80-90m	50.00
:90-100m	50.00
:100-110m	50.00
PIPE SUPPORT BRACK:	
1	5.31
2	5.31
3	5.31
4	5.31
5	5.58
6	5.58
7	8.33
8	8.33
9	8.33
10	8.78
11	9.33
12	7.25
13	7.25
14	9.33
15	8.78
16	8.33
17	8.33
18	8.33
19	5.58
20	5.58
21	5.31
22	5.31
SEWER PIPE	
	1109.18

GEELONG AND DISTRICT WATER BOARD
OVOID SEWER BRIDGE

(iv) Cathodic Protection Estimate

CP installation costs are calculated in detail in Appendix B2 (a)

The concrete repair costs for CP are included from worsheet (i)

Note the annual CP monitoring and maintenace costs

Cathodic Protection Installation (from App B2 (a)	1	No	665680	665680
CP Estimate (per tower)			**Total**	**665,680**
CP Estimate all towers	14	No	665680	9,319,520
Surface Concrete Repair (fromsheet (i)	1	No	4015795	4,015,795
Total CP Repair Budget				**$13,335,315**

Monitoring CP (ANNUAL) $18,000
Maintenance (ANNUAL) $20,000

Appendix B2
CP BUDGETS

Cathodic Protection Installation Cost Budget

Excludes Concrete Repair

Quantities
From earlier worksheets

CP Materials per Span

Internal Anodes	ribbon ano	Conductor ba	connection	Reference	Electrodes
1023	2012.333	641.9	100	15	
30	15	11	60	350	cost per unit
30690	30185	7060.9	6000	5250	totals

Estimate- CP Supply and Install

	Qty	Unit	Supply Rate	Supply	labour Rate	labour Amount
Internal Anodes	1023	No	30	30690	60	61380
Ribbon anodes	2012	m	15	30185	60	120740
Conductor bar	642	m	11	7060.9	20	12838
Connections	100	No	60	6000	60	6000
Reference	15	No	350	5250	120	1800
Junction boxes	3	No	700	2100	500	1500
T/R	1	No	22000	22000	2000	2000
Solar/Batteries	1	Item	8000	8000	2000	2000
Cabling	1	Item	8000	8000	5000	5000
Grout	4	m3	4000	16000		0
Sundry materials	1	Item		10000		15000
				145285.9		228258 Sub-total labour
Supply (carried over)						145286 Sub-total materials
Continuity						6000
Access - Fixed scaffold	1	item			12000	12000
Access - Scissor lift	80	day			300	24000
Prop span						5000
Site establishment	4	months			2000	8000
Supervision- Daily	85	day			800	68000
Supervision- Senior	20	day			1800	36000
SUB-Total						532544
Margin (contractor??)					0.25	133136
TOTAL CP (EXCL REPAIR)						665680

5 Man crew for 85 days

Appendix B2-CP budget.xls

Ian Godson & Associates

1/4 span (one half of one side of a span)

Bottom chord

length across			height		length of member		section 1			section 2			section 3			section 4		
ft	m		ft	m	ft	m	a	b	c	a	b	c	a	b	c	a	b	c
	64.0	19.5	10.0	3.1	64.8	19.8	16.0	3.5	16.4	16.0	2.9	16.3	16.0	2.3	16.2	16.0	0.6	16.0

sum

a	b	c
64.0	9.2	64.8	19.8

top chord

length across			height		length of member		
ft	m		ft	m	ft	m	
	64.0	19.5	13.5	4.1	65.4	19.9	step size top
							1.7

cross member #1

distance from top across			height		length of member		length on paper	ratio paper/calc
ft	m		ft	m	ft	m		
	8.0	2.4	21.0	6.4	22.5	6.9	92.0	13.4

cross member #2

distance from top across			height		length of member			
ft	m		ft	m	ft	m		
	8.0	2.4	17.7	5.4	19.4	5.9	73.0	12.3

cross member #3

distance from top across			height		length of member			
ft	m		ft	m	ft	m		
	8.0	2.4	14.5	4.4	16.6	5.1	60.0	11.9

cross member #4

distance from top across			height		length of member			
ft	m		ft	m	ft	m		
	8.0	2.4	11.4	3.5	13.9	4.2	52.0	12.3

cross member #5

distance from top across			height		length of member			
ft	m		ft	m	ft	m		
	8.0	2.4	8.6	2.6	11.7	3.6	44.0	12.3

cross member #6

distance from top across			height		length of member			
ft	m		ft	m	ft	m		
	8.0	2.4	5.8	1.8	9.9	3.0	38.0	12.6

vertical member #1

length								
ft	m				tower support			
	19.3	5.9			ft	m		average
					21.3	6.5		12.5

vertical member #2

length		
ft	m	
	16.0	4.9

Appendix B2-CP budget.xls

Ian Godson & Associates

1/4 span (one half of one side of a span)

Bottom chord																						
length across			height		length of member		section 1			section 2			section 3			section 4					
ft	m		ft	m	ft	m	a	b	c	a	b	c	a	b	c	a	b	c			
64.0	19.5		10.0	3.1	64.8	19.8	16.0	3.5	16.4	16.0	2.9	16.3	16.0	2.3	16.2	16.0	0.6	16.0			

vertical member #3
length
ft m
12.8 3.9

vertical member #4
length
ft m
9.7 3.0

vertical member #5
length
ft m
6.9 2.1

vertical member #6
length
ft m
4.1 1.2

main vertical support
height
ft m
21.5 6.6

cross members (1/2 length) 2 of
ft m ft m
5.9 1.8 5.5 1.7

pipe support1 3.3
length
ft m
6.3 1.9

pipe support2
length
ft m
5.9 1.8

pipe support3
length
ft m
5.5 1.7

pipe support4
length
ft m
5.1 1.6

pipe support5
length
ft m
4.7 1.4

pipe support6

Appendix B2-CP budget.xls

Ian Godson & Associates

1/4 span (one half of one side of a span)

Bottom chord																							
length across			height		length of member		section 1			section 2			section 3			section 4							
ft	m		ft	m	ft	m	a	b	c	a	b	c	a	b	c	a	b	c					
	64.0	19.5	10.0	3.1	64.8	19.8	16.0	3.5	16.4	16.0	2.9	16.3	16.0	2.3	16.2	16.0	0.6	16.0					
length																							
ft	m																						
	4.3	1.3																					
pipe support7																							
length																							
ft	m																						
	3.9	1.2																					
pipe support8																							
length																							
ft	m																						
	3.5	1.1																					
pipe support9																							
length																							
ft	m																						
	3.1	0.9																					

	1/4	One Span	totals	
Upper Boom Length	19.94639955	79.7856		
Lower Boom Length	19.76671077	79.06684	158.8524	boom
Xmember1	6.854022542	27.41609		
Xmember2	5.910991641	23.64397		
Xmember3	5.0542895	20.21716		
Xmember4	4.240961483	16.96385		
Xmember5	3.574982242	14.29993		
Xmember6	3.006724593	12.0269	114.5679	x members
Veritcal member 1	5.89221875	23.56888		
Veritcal member 2	4.871104167	19.48442		
Veritcal member 3	3.91353125	15.65413		
Veritcal member 4	2.955958333	11.82383		
Veritcal member 5	2.100052083	8.400208		
Veritcal member 6	1.244145833	4.976583	83.90804	Vertical members
Pipe Support 1	1.931666667	7.726667		
Pipe Support 2	1.807760417	7.231042		
Pipe Support 3	1.683854167	6.735417		
Pipe Support 4	1.559947917	6.239792		
Pipe Support 5	1.436041667	5.744167		
Pipe Support 6	1.312135417	5.248542		
Pipe Support 7	1.188229167	4.752917		
Pipe Support 8	1.064322917	4.257292		
Pipe Support 9	0.940416667	3.761667	51.6975	Pipe Supports
OB1	1.807760417	7.231042		
OB2	1.683854167	6.735417		
UB1	1.807760417	7.231042		
UB2	1.683854167	6.735417	27.93292	lateral beams
main tower support	6.506666667	26.02667	26.02667	main tower
total	115.7463636	462.9855		

Appendix B2-CP budget.xls

			Cost
Internal Anodes required for Major Chords			
Upper Chord Length (m)	80		
Lower Chord Length (m)	80		
Tower Supports (m)	26		
Total Major Chord length (m)	186		
Allowance	1.1		
Internal anode spacing (m)	0.2		
No. of Anodes	1023	Anode costs	$30,690.00

Ribbon anode length required for minor chords			
Vertical Support length (m)	84		
Cross Member Length (m)	115		
Walkway Support Length (m)	84		
Lateral Beam Length (m)	28		
Total Minor Chord Length (m)	311		
Allowance	1.1		
Length Required	342.1	Ribbon anoc	$5,131.50

CP Materials per Span

Internal Anodes	ribbon anode length (m)	Conductor bar length (m)	connections	Reference Electrodes	
1023	2012	642	100	15	
$30.00	$15.00	$11.00	$60.00	$350.00	cost per unit
$30,690.00	$30,185.00	$7,060.90	$6,000.00	$5,250.00	totals

Materials budget
$79,185.90

Conductor Bar Length Required			
Bar #1(for internal anodes)			
Upper Chord Length (m)	80		
Lower Chord Length (m)	80		
Tower Supports (m)	26		
Total Major Chord length (m)	186		
Allowance	1.15		
Length Required	213.9	Conductor Ba	$2,352.90

Bar #2 (for ribbon anodes)			
Upper Chord Length (m)	80		
Lower Chord Length (m)	80		
Total Major Chord length (m)	160		
Allowance	1.5		
Length Required	240	Conductor E	$2,640.00

Unit costs

Internal Anodes ($/each	$30.00
Ribbon Anodes($/m)	$15.00
Conductor bar ($/m)	$11.00
Postive Connections ($e	$60.00
Negative Connections ($	$60.00
Reference Electrodes ($	$350.00

Walkway base and sides.			
Base	1.5		
Sides x 2	2.5		
Total width	4		
Length	52.8	176	0.3
Total area	211.2		
Ti ribbon @ 200mm	1056	$15,840.00	
Conductor	75	$825.00	

Tower base & top			
Base (3 x2 + 7x2)x1.5	30	m2	
Top (6x2 +3 X2)1.5 + 18	48		
Total Area	78		
Ti ribbon @ 250mm	312	$4,680.00	
Conductor	60	$660.00	

0	Pipe hangers		
	Length	4	
	Span	53	
	Spacing	2.4	
	No per span	22.08333333	
	Ti ribbon	88.33333333	$1,325.00
	Conductor	53	$583.00

Connections Required			
For Internal Anodes			
Bottom Chords	8		
Top Chords	8		
Tower Supports	4		
Allowance	1.1	Connections cost	
positive	22		$1,320.00
negative	22		$1,320.00
total	44		$2,640.00

For Ribbon anodes			
Bottom Chords	8		
Top Chords	8		
Allowance	1.1		
positive	17.6		
negative	17.6	Connections cost	
total	35.2		$1,056.00
			$1,056.00
			$2,112.00

Reference Electrodes Required			
Major Chords (excluding tower su	4		
Minor Chords	4		
tower supports	2		
		Reference Electrodes cost	
Allowance	1		
total	10		$3,500.00

Total Cost
$49,066.40

Grout Usage m^3								
Internal Anodes (tower supports)	Internal Anodes (horizontal major chords)	Conductor Bar	Ribbon	total grout	Allowance	grout cost per L	Cost	
0.005605387	0.030661944	0.3114	0.3078	0.655467	1.3	$6,666.67	$5,680.72	
					0.852108			

gout cost per L	$6.67	
per m^3	$6,666.67	

Internal Anodes
Horizontal Chords 160 of

Grout per anode								
diameter of hole (m)	area(m^2)	fraction through	width of	width of me	length of ho	volume of materia	volume of material (L)	
0.03	0.000706858	0.666666667	16	0.406667	0.271111	0.000191637	0.1916372	

Tower Supports 26 of

Grout per anode								
diameter of hole (m)	area(m^2)	fraction through	width of	width of me	length of ho	volume of materia	volume of material (L)	
0.03	0.000706858	0.666666667	18	0.4575	0.305	0.000215592	0.2155918	

Ribbon 311 m
Grout per m

strip size(mm)	strip size(m)	Area (m^2)
30	0.03	0.0009

Conductor bar 346 m
Grout per m

strip size(mm)	strip size(m)	Area (m^2)
30	0.03	0.0009

APPENDIX C: DEMOLITION EXTENT AND PROCEDURE

PROPOSED DEMOLITION EXTENT v3

The minimum proposed demolition extent of the Aqueduct structure that is understood to be considered acceptable to Heritage Victoria at this stage, is from the north end of the cantilever supported by Pier No. 13 (Marshall bank) to the south end of the cantilever of Pier No. 8 (north river bank) i.e. the balanced cantilever and link spans of spans 9 to 12.

The Piers for each cantilever truss are proposed to be retained, to maintain the visual link from the Breakwater to Marshall abutments to allow for interpretation of the significance and scale of the Aqueduct.

This extent of demolition leaves eight cantilevers intact on the north river bank and two cantilevers intact on the south river bank (including span 14 which has steel supports already in place at each cantilever node point). The cost of the rehabilitation works to these ten spans and the remaining towers at Piers Nos. 9, 10, 11 and 12 standing after demolition of the cantilevers may well prove too costly for all of them to remain.

The ovoid sewer pipe segments were precast with wall thickness of approximately 76mm. The sewer pipe was not lined as is current practice so there has been some degradation of the interior obvert of the pipe from gases. A number of pipe segments fell from the Aqueduct during its operational life and many of the hanger frames have significant corrosion.

Rehabilitation of the pipe segments and the hangers is judged to be expensive as the total surface area of the pipe and the hangers is large and the pipe is structurally degraded from gases. Consequently, within the context of limited rehabilitation funds, no remedial works are proposed to the sewer pipe and the hangers.

Consequently, it is expected that, similar to retained spans that do not have cathodic protection, the ovoid pipe segments and hangers will break from time-to-time, and that the whole remnant structure and pipe will degrade and eventually fall. The expected last span to

fall apart is span 14 (Marshall abutment), due to the extent of existing steel propping installed when the Aqueduct was operational.

DEMOLITION PROCEDURE (RETAINING PIERS)

The Aqueduct structure is a balanced cantilever construction with link spans between the ends of the cantilevers except for between spans 10 & 11 on Goat Island. The demolition needs to be a balanced de-construction of the balanced cantilevers so that the remnant Piers remain intact and the partially demolished structure comes down evenly.

The proposed demolition procedure requires the use of long reach excavators with concrete shears to cut through the structural members in the air, allowing the rubble to fall to the ground (or barges) from which it cleaned away for recycling. Long reach excavators allow site work whilst keeping the operators well clear of the structure being demolished.

Step 1 for demolition of spans, retaining piers:

> Using a long reach excavator with hydraulic hammer, break down the sewer pipe under the link span, followed by the sewer pipe under the cantilever. A single excavator will be acceptable for this component of the demolition, as the load from the empty pipe is small relative to the weight of the structure.
>
> The estimated time to demolish the sewer pipe for one link span and one cantilever is one week as there are some awkward approaches through the cantilever framing.

Step 2 for demolition of spans, retaining piers:

> Using four long reach excavators with concrete shears evenly and simultaneously cut through the balustrade of the link span close to its junctions with the cantilevers, then the deck of the link span. Estimated time for link span demolition is one day.

With the link span demolished, use the four long reach excavators with concrete shears to evenly demolish the cantilever up to the Pier. Estimated time for the cantilever, walkway and remnant pipe hangers is one week per cantilever.

Progressively remove rubble using a long reach excavator with bucket to scrape away from the demolition zone and load out onto tip trucks.

Step 3 for demolition of spans, retaining piers:

Working from a suspended man box on a crane, hand tidy up the sheared ends of the cantilever truss framing by trimming, cutting back reinforcement and patching for corrosion protection.

This stage is estimated to take two man weeks.

Over water work for demolition of spans, retaining piers:

The above works over the water will require a barge to support each of the four long reach excavators as well as two more barges to catch the demolition rubble. An additional excavator will be required to unload the barges and load out to tip trucks.

It is estimated that the time taken over water will be three times the time taken over land due to manoeuvring of barges.

Costs are based on the following components:

- Long reach excavator hire $220 per hour including shears or hydraulic breaker fitting
- Mobile crane with man box hire $250 per hour
- Barges allowance including floating in/out to site, say $10,000 per week per barge including tug boat costs for pushing barges into location (indicative costs obtained from East West Dive and Salvage) based on six barges for four weeks
- Labour rates are estimated at $80 per hour

COST ESTIMATE FOR DEMOLITION FOR TYPICAL LAND SIDE SPAN (RETAINING PIER)

Item		Rate	Units	Subtotal
Sewer pipe demolition for link span and cantilever	Hydraulic breaker Labour	$220 $80	40 40	$8,800 $3200
Rubble removal for sewer pipe	Scrape and load out Labour Removal to recycling	$220 $80 $3000	16 16 1	$3520 $1,280 $3000
Balanced demolition of cantilever	Sheared demolition Labour Removal to recycling	$880 $80 $3000	40 40 4	$35,200 $3200 $12,000
Trim up at Pier	Hand work Crane hire	$80 $250	80 80	$6,400 $20,000
Subtotal for land side span demolition (retaining pier)	Per span			**$96,600**
Contingency 15%				$14,500
Contractors preliminaries 12% and profit 10%				$21,300
Subtotal				$132,400
GST				$13,300
Total estimate for demolition of typical land side span				**$145,700**

COST ESTIMATE FOR DEMOLITION FOR FOUR OVER WATER SPANS (RETAINING PIERS)

Item		Rate	Units	Subtotal
Typical land side span demolition (retaining pier)	Per span			**$96,600**
Subtotal for spans			**4**	**$386,400**
Over water works (weeks)	Four barges for excavators Four excavator extra time Labour extra time	$40,000 $35,200 $12,800	4 4 4	$160,000 $140,800 $51,200
Over water works (weeks)	Two barges for rubble collection Labour	$20,000 $6,400	4 4	$80,000 $25,600
Over water works (weeks)	Excavator for load out Labour Rubble removal to recycling	$8,800 $3,200 $3000	4 4 8	$35,200 $12,800 $24,000

Subtotal for over water works extra over				**$529,600**
Subtotal for proposed demolition of spans 9 to 12				**$916,000**
Contingency 15%				$137,400
Contractors preliminaries 12% and profit 15%				$201,500
Subtotal				$1,254,900
GST				$125,500
Total estimate for demolition spans 9 to 12 (retaining piers)				**$1,380,400**

OTHER ELEMENTAL COSTS ASSOCIATED WITH REMNANT AQUEDUCT

Propping of Typical Cantilever Frame Tip

The concept for the propping frames at the ends of the cantilevers is sketched on drawing 2151 – SK1. Cost estimates for the propping and jacking of one end of the cantilever truss, excluding GST are as follows:

End of cantilever propping works	**Units and rates**	**Total**
Fabricated galvanised steel mass supply and erect	1.6 tonnes @ $8000 per tonne	$12,800
Four CFA piers 500mm diam., nominal depth 13m to rock	52 metres @ $300 per metre	$15,600
Reinforced pile cap 2.75m x 3.6m x 500mm	5 cu.m @ $500	$2,500
Jacking and grouting (access from boom)	Item	$2,500
Subtotal for End of cantilever propping works		**$33,400**
Contingency	15%	$5,000
Preliminaries	15%	$5,000
Total for one end		**$43,400**

Capping and Minor Repairs to Retained Tower

The proposal for the capping of the hollow cap of the towers is to introduce some treated timber framing and a stainless steel sheet roof, turned down at the edges to exclude rainwater. Cost estimates for the minor works to the towers, excluding GST are as follows:

Capping and Minor Repairs to Towers	**Units and rates**	**Total**
Water blast tower cap internally and remove detritus	Item	$2,500
Install treated timber roof frame with suspended weights to prevent uplift	Item	$1,800
Install stainless steel roof	Item	$1,500
Patch repair tower external faces	Item	$15,000
Access boom	Item	$1,200
Subtotal for Capping and Minor Repairs to Towers		**$22,000**
Contingency	25%	$5,200
Preliminaries	15%	$3,100
Total for one tower		**$30,300**

Fencing to Aqueduct

The present fencing uses a mesh that allows for easy foot holds for climbing. It is proposed that the fencing be replaced with less easily climbable chain link, 2.1m high with three rows of barbed wire. The remnant towers on Goat Island will also require fencing for public safety. As the towers are 12.65m tall above their pile caps, it is recommended that the new fencing be aligned so the width of the fenced area is twice the local height of the Aqueduct plus 4.5m (the width of the towers).

Cost estimates for the minor works to the towers, excluding GST are as follows:

Fencing to Aqueduct	**Units and rates**	**Total**
Breakwater abutment to river	810m @ $65	$52,700
Marshall abutment to river	280m @ $65	$18,200
Individual piers 9 to 12	120m times 4 @ $65	$31,200

Clearing for fencing	Item	$6,000
Subtotal for Fencing to Aqueduct		**$108,100**
Contingency	5%	$5,400
Preliminaries	12%	$13,000
Total for all fencing of Aqueduct		**$126,500**

Interpretation and Viewing Structure

The Barwon River Parklands should include an interpretation and viewing structure for the Aqueduct to record the early introduction of a sewerage system for Geelong, the use of precast vacuum-dewatered pipe segments in the sewer from Geelong to Black Rock, and the unusual and significant construction techniques adopted in the Aqueduct itself.

Interpretation display items include the many photographs of the construction of the Aqueduct, as well the remnant sewer pipe moulds that remain at the casting site next to the Marshall Railway Station.

An interpretation and viewing structure located in the Park is estimated to be of the order of **$250,000** plus GST

BASE COSTS FOR COMPLETE DEMOLITION OF THE AQUEDUCT

The cost for complete demolition of the entire Aqueduct is given to provide a base cost for comparison with other options that have retained the heritage value of the Aqueduct.

Cost Estimate for Demolition for Entire Aqueduct (retaining piers)

Item		Rate	Units	Subtotal
Sewer pipe demolition for link span and cantilever	Hydraulic breaker Labour	$220 $80	40 40	$8,800 $3200
Rubble removal for sewer pipe	Scrape and load out Labour Removal to recycling	$220 $80 $3000	16 16 1	$3520 $1,280 $3000

Balanced demolition of cantilever	Sheared demolition Labour Removal to recycling	$880 $80 $3000	40 40 4	$35,200 $3200 $12,000
Trim up at Pier	Hand work Crane hire	$80 $250	80 80	$6,400 $20,000
Subtotal for land side span demolition (retaining pier)	Per span			**$96,600**
Subtotal for spans			**14**	**$1,352,400**
Over water works (weeks)	Four barges for excavators Four excavator extra time Labour extra time	$40,000 $35,200 $12,800	4 4 4	$160,000 $140,800 $51,200
Over water works (weeks)	Two barges for rubble collection Labour	$20,000 $6,400	4 4	$80,000 $25,600
Over water works (weeks)	Excavator for load out Labour Rubble removal to recycling	$8,800 $3,200 $3000	4 4 8	$35,200 $12,800 $24,000
Subtotal for over water works extra over			4	**$529,600**
Subtotal for proposed demolition (retaining piers)				**$1,882,000**
Contingency 15%				$283,300
Contractors preliminaries 12% and profit 10%				$414,000
Subtotal				$2,579,300
GST				$257,800
Total estimate for demolition spans (retaining piers)				**$2,837,100**
Fencing	14 piers, fence length per pier (120m)	$65		$109,200
Clearing for fencing	Item			$5,000
Fencing contingency, preliminaries and profit	17%			$19,400
Capping piers and minor repairs	14	$30,300		$424,200
Interpretation structure	Item			$250,000
Total Estimate for demolition spans (retaining piers)				**$3,644,900**

APPENDIX D: CATHODIC PROTECTION

REPAIR COST ESTIMATES v2

Australian Corrosion Consultants Pty Ltd 2009 escalated the surface areas for repairs for cathodic protection by 26% from that identified by Taywood-Maunsell 1990.

Using the ACC 2009 estimate for cathodic protection, adjustments to that estimate include increasing the "prop span" cost from $5,000 to $87,000 for the proposed propping and jacking frame for stress reversal in the structure for enhanced structural reliability, and grout and sundry materials increasing from $26,000 to $120,000 to provide for the increased area of surface deterioration since 2009. Labour and access costs are escalated from 80 days to 120 days for each span.

These sub-total escalated 2009 costs are therefore increased by $250,000 i.e. the sub-total becomes $782,544 and the total escalated CP cost excluding repairs becomes $979,930 (excluding GST) per pier span.

The associated repair cost used by ACC 2009 were based on an escalated Taywood-Maunsell 1990 cost estimate to reflect the increased deteriorated surface area at 2009. For this present estimate, the affected surface area is now viewed to be 100% increased from 1990, resulting in the following repair costs per pier span as follows:

Pier No.	1991 Repair Assessment	% Increase	CP Repair Estimate at 2009 Costs
1	$114,000	100	$228,000
2	$233,000	100	$466,000
3	$265,000	100	$530,000
4	$245,000	100	$490,000
5	$283,000	100	$566,000
6	$252,000	100	$504,000
7	$236,000	100	$472,000
8	$174,000	100	$348,000
13	$154,000	100	$308,000
14	$311,000	100	$622,000

Rawlinson's' Construction Cost Guide reports building cost index between 2009 and 2016 increase of 16%. Hence the total costs for cathodic protection with associated repairs including the propping/jacking of the structure excluding the ovoid pipe sections at 2009 costs are:

Pier No.	**CP Repair Estimate**	**CP Estimate**	**Total 2009 Costs**	**2009-2016 Escalation**	**2015 Estimate**
1	$228,000	$979,930	$1,207,930	$193,270	$1,401,200
2	$466,000	$979,930	$1,445,930	$231,370	$1,677,300
3	$530,000	$979,930	$1,509,930	$241,570	$1,751,500
4	$490,000	$979,930	$1,469,930	$235,170	$1,705,100
5	$566,000	$979,930	$1,545,930	$247,370	$1,793,300
6	$504,000	$979,930	$1,483,930	$237,470	$1,721,400
7	$472,000	$979,930	$1,451,930	$232,370	$1,684,300
8	$348,000	$979,930	$1,327,930	$212,470	$1,540,400
13	$308,000	$979,930	$1,287,930	$206,070	$1,494,000
14	$622,000	$979,930	$1,601,930	$256,070	$1,858,000
Sub total					$16,626,500
Contingency	15%				$2,494,000
Option 2 (ref App E)					**$2,918,900**
Subtotal					$22,039,400
GST					$2,203,900
TOTAL					**$24,243,300**

On-going costs for the structure excluding the ovoid pipe sections are escalated from the ACC 2009 budget to $50,000 per annum. For the projected 50 year cathodic protection design life, this equates to a further $1,375,500 plus GST i.e. $1,513,000 using a discount rate of 3%. Hence, estimated total costs including GST for the demolition of

the spans at Piers 9 to 12, retaining the towers at 1 to 8, 13 and 14, and repair costs to the remainder of the Aqueduct totals **$25,756,300**.

By way of comparison, demolition of the entire Aqueduct, excluding all the towers and no use of cathodic protection is estimated to be **$3,644,900** including GST (refer Appendix C).

APPENDIX E: COST ESTIMATES OF DEMOLITION OPTIONS

OPTION 1: COST ESTIMATE FOR DEMOLITION FOR ENTIRE AQUEDUCT (RETAINING PIERS AND NO CATHODIC PROTECTION)

Item		Rate	Units	Subtotal
Sewer pipe demolition for link span and cantilever	Hydraulic breaker Labour	$220 $80	40 40	$8,800 $3200
Rubble removal for sewer pipe	Scrape and load out Labour Removal to recycling	$220 $80 $3000	16 16 1	$3520 $1,280 $3000
Balanced demolition of cantilever	Sheared demolition Labour Removal to recycling	$880 $80 $3000	40 40 4	$35,200 $3200 $12,000
Trim up at Pier	Hand work Crane hire	$80 $250	80 80	$6,400 $20,000
Subtotal for land side span demolition (retaining pier)	Per span			**$96,600**
Subtotal for spans			**14**	**$1,352,400**
Over water works (weeks)	Four barges for excavators Four excavator extra time Labour extra time	$40,000 $35,200 $12,800	4 4 4	$160,000 $140,800 $51,200
Over water works (weeks)	Two barges for rubble collection Labour	$20,000 $6,400	4 4	$80,000 $25,600
Over water works (weeks)	Excavator for load out Labour Rubble removal to recycling	$8,800 $3,200 $3000	4 4 8	$35,200 $12,800 $24,000
Subtotal for over water works extra over			4	**$529,600**
Subtotal for proposed demolition (retaining piers)				**$1,882,000**
Contingency 15%				$282,300
Contractors preliminaries 12% and profit 10%				$414,000
Subtotal				$2,579,300
GST				$257,800
Total estimate for demolition spans (retaining piers)				**$2,837,100**
Fencing	14 piers, fence length per pier (120m)	$65		$109,200

Clearing for fencing	Item			$5,000
Fencing contingency, preliminaries and profit	17%			$19,400
Capping piers and minor repairs	14	$30,300		$424,200
Interpretation structure	Item			$250,000
Total Estimate for demolition of all spans (retaining piers)				**$3,644,900**

OPTION 2: COST ESTIMATE FOR DEMOLITION FOR RIVER SPANS 9 TO 12 (RETAINING SPANS 1 TO 8, 13 & 14, RETAINING ALL PIERS AND NO CATHODIC PROTECTION)

Item		**Rate**	**Units**	**Subtotal**
Total estimate for demolition spans 9 to 12 (retaining piers)				**$1,380,400**
Propping of remaining spans	17 propping frames (2 abutments)	$43,400	17	$737,800
Fencing		$65		$126,500
Capping piers and minor repairs	14	$30,300		$424,200
Interpretation structure	Item			$250,000
Total Estimate for demolition spans (retaining piers)				**$2,918,900**

If there was a desire to patch repair, say, one span, the estimate of 2016 cost per span varies between $228,000 and $622,000 (refer to Appendix D). Hence the above minimum demolition option with propping and, say, two patch repaired spans at Piers 7 and 8 is estimated at **$3,738,900.**

By way of comparison, including on-going costs for cathodic protection of the structure, excluding the ovoid pipe sections, for the projected 50 year cathodic protection design life, estimated total costs including GST for the demolition of the river spans at Piers 9 to 12

(retaining those four piers), retaining the spans at 1 to 8, 13 and 14 totals **$25,283,000** (refer Appendix D).

APPENDIX F

ORIGINAL LAYOUT DRAWING AND STRUCTURE DRAWINGS, STONE AND SIDDELEY (REDUCED TO A3 SIZE)

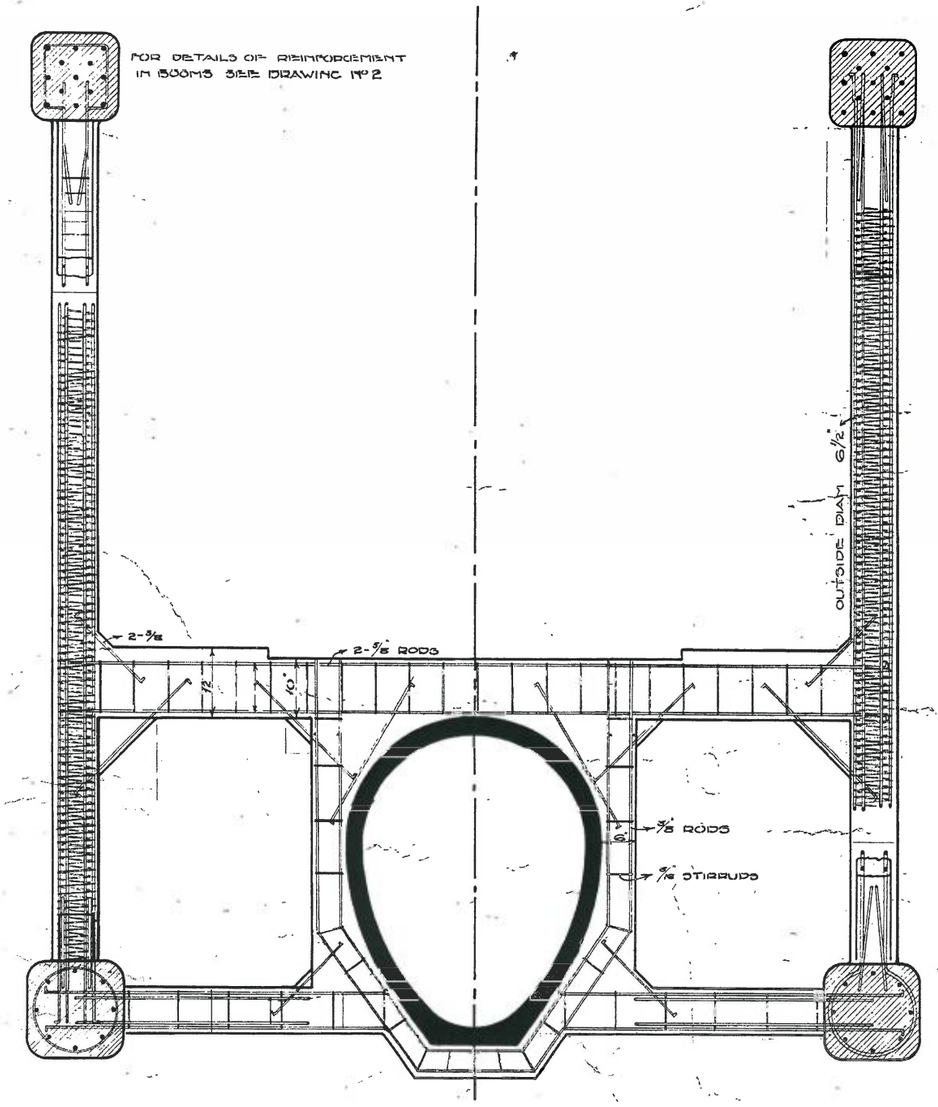
NFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON.

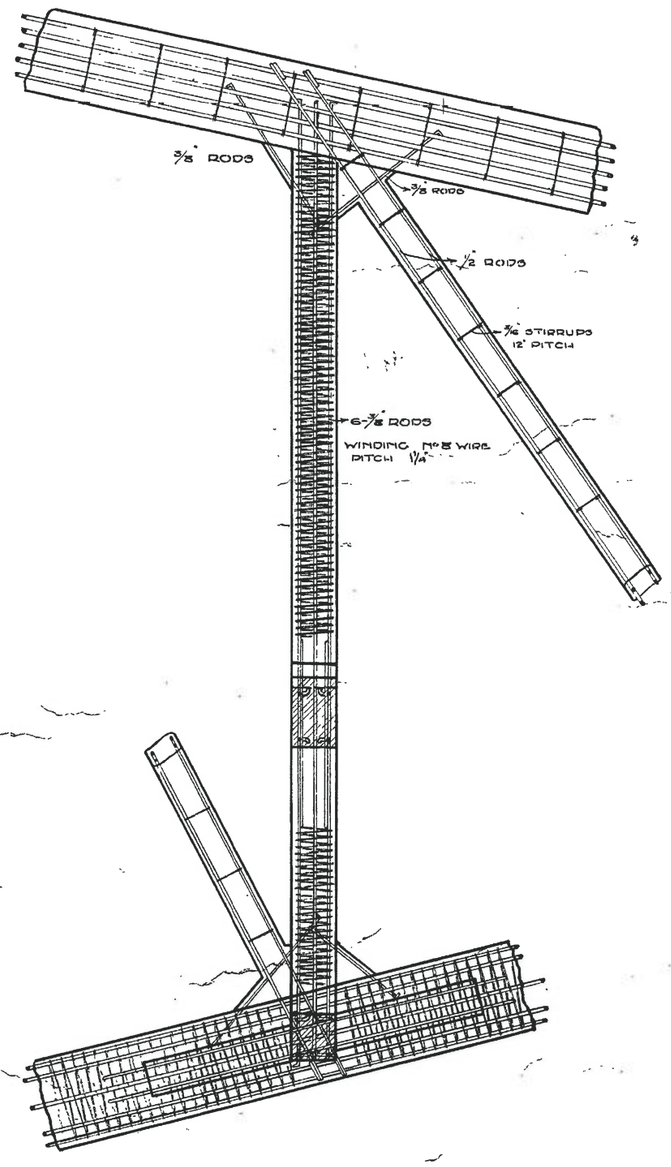
LONG WATERWORKS AND SEWERAGE TRUST CONTRACT Nº 4

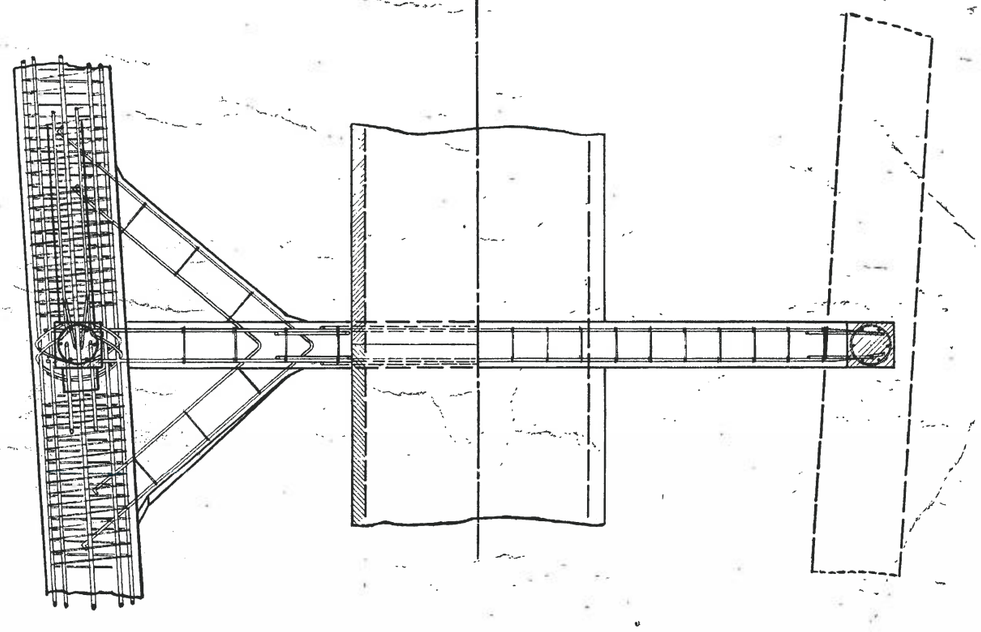
TAILS OF REINFORCEMENTS IN MEMBERS AT JOINT Nº 3

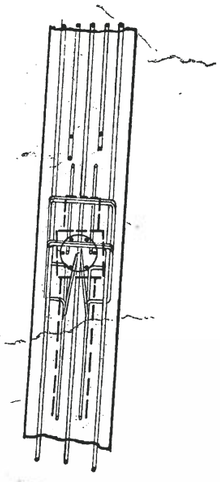
ALE ONE INCH TO ONE FOOT

DESIGNED BY STONE & SIDDELEY
REINFORCED CONCRETE SPECIALISTS









EINFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON

ELONG WATERWORKS AND SEWERAGE TRUST CONTRACT No 4

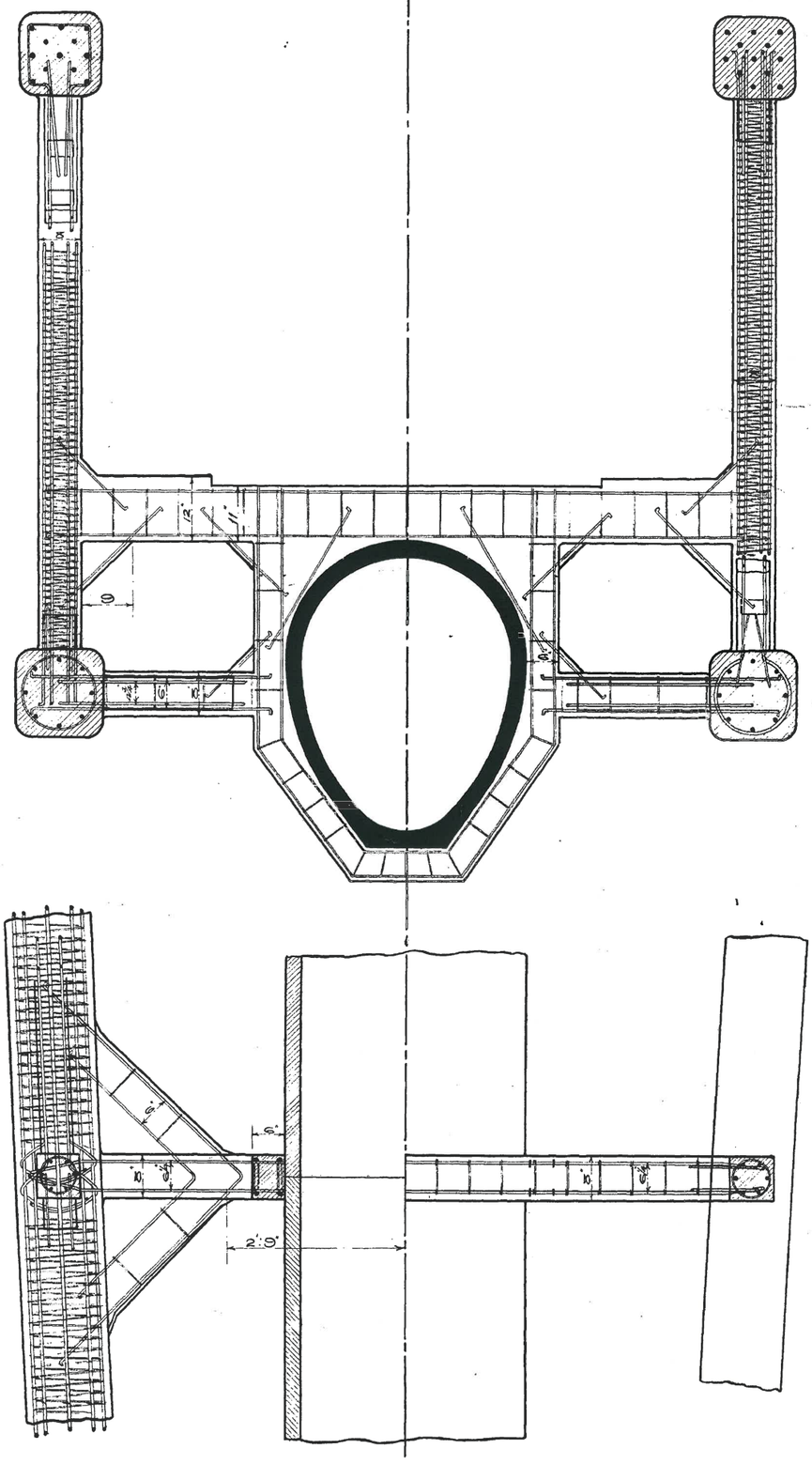
ETAILS OF REINFORCEMENTS IN MEMBERS AT JOINT No4

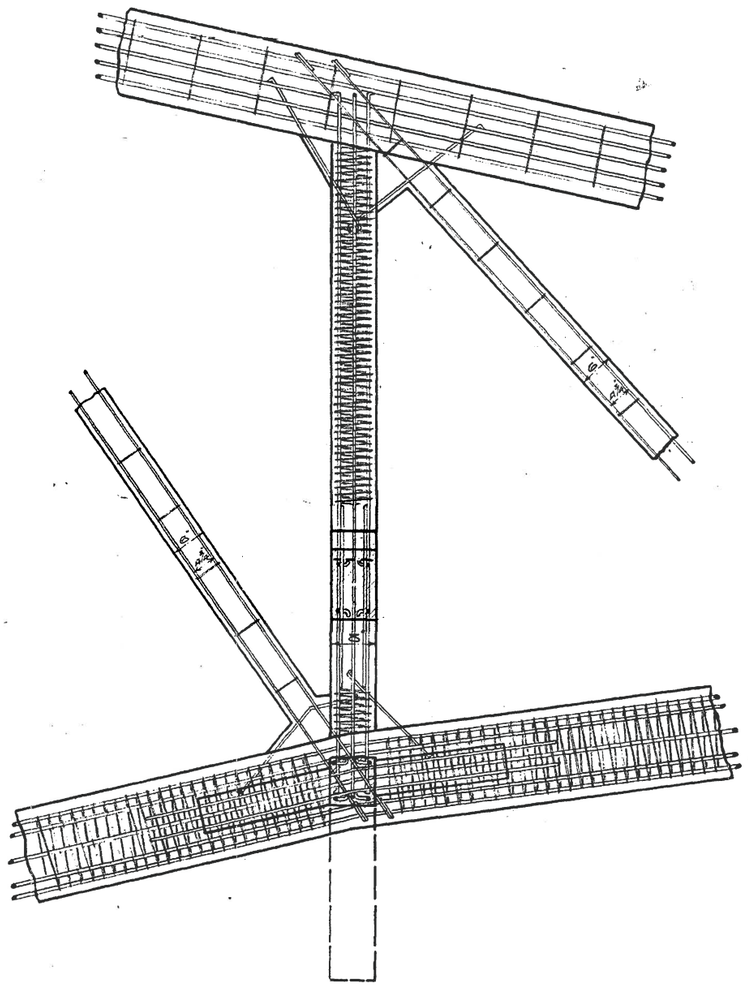
CALE ONE INCH TO ONE FOOT

DESIGNED BY STONE & GIDDELEY

REINFORCED CONCRETE SPECIALISTS

Edward P. Stone





NFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON

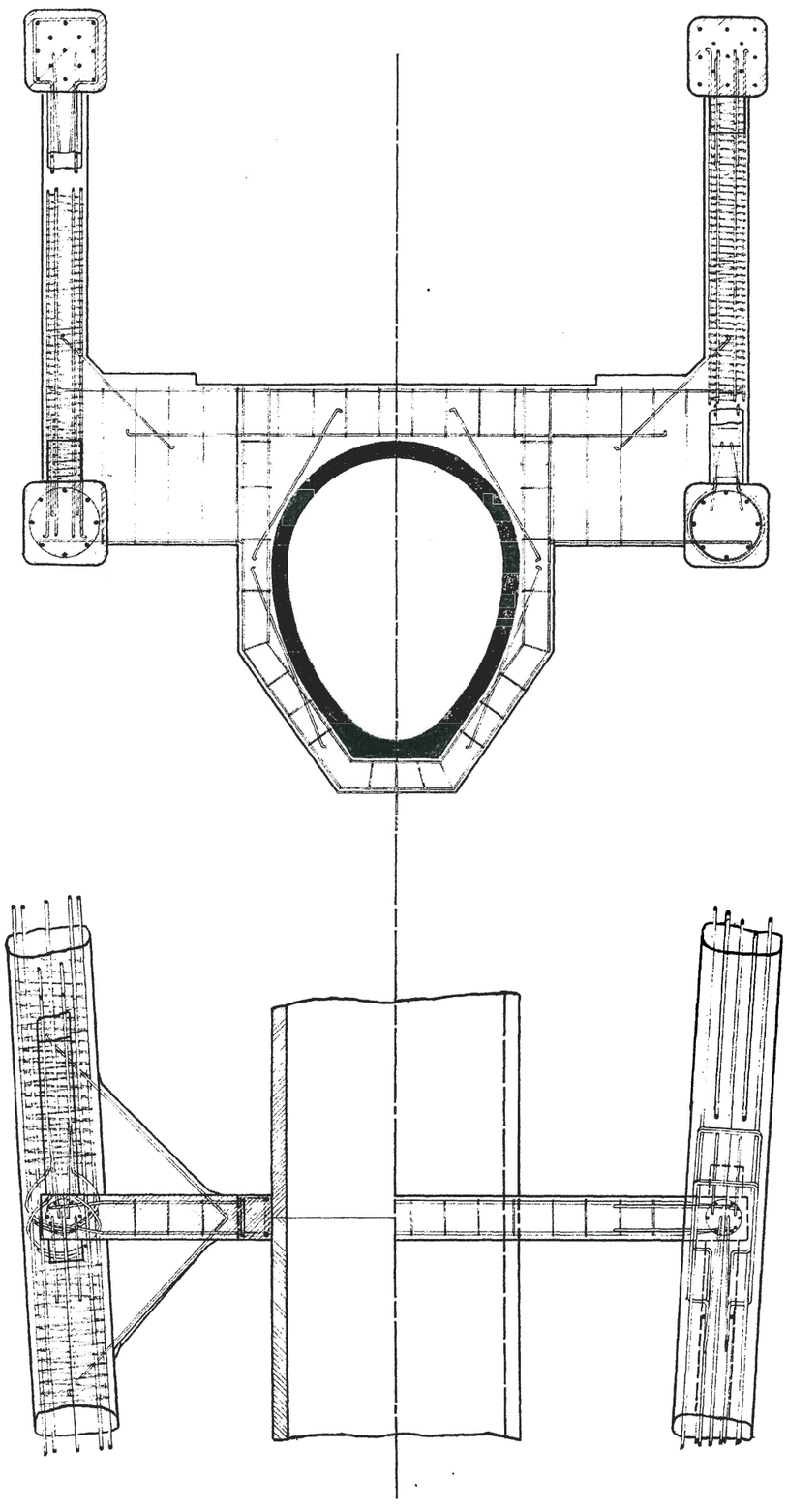
LONG WATERWORKS AND SEWERAGE TRUST CONTRACT Nº 4

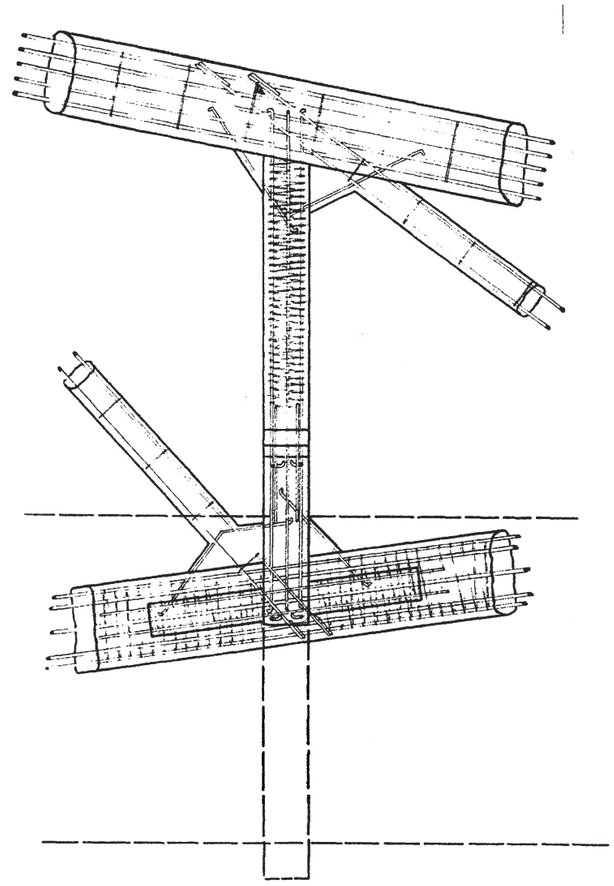
TAILS OF REINFORCEMENTS IN MEMBERS AT JOINT Nº 5

ALE ONE INCH TO ONE FOOT

DESIGNED BY STONE & SIDDELEY

REINFORCED CONCRETE SPECIALISTS



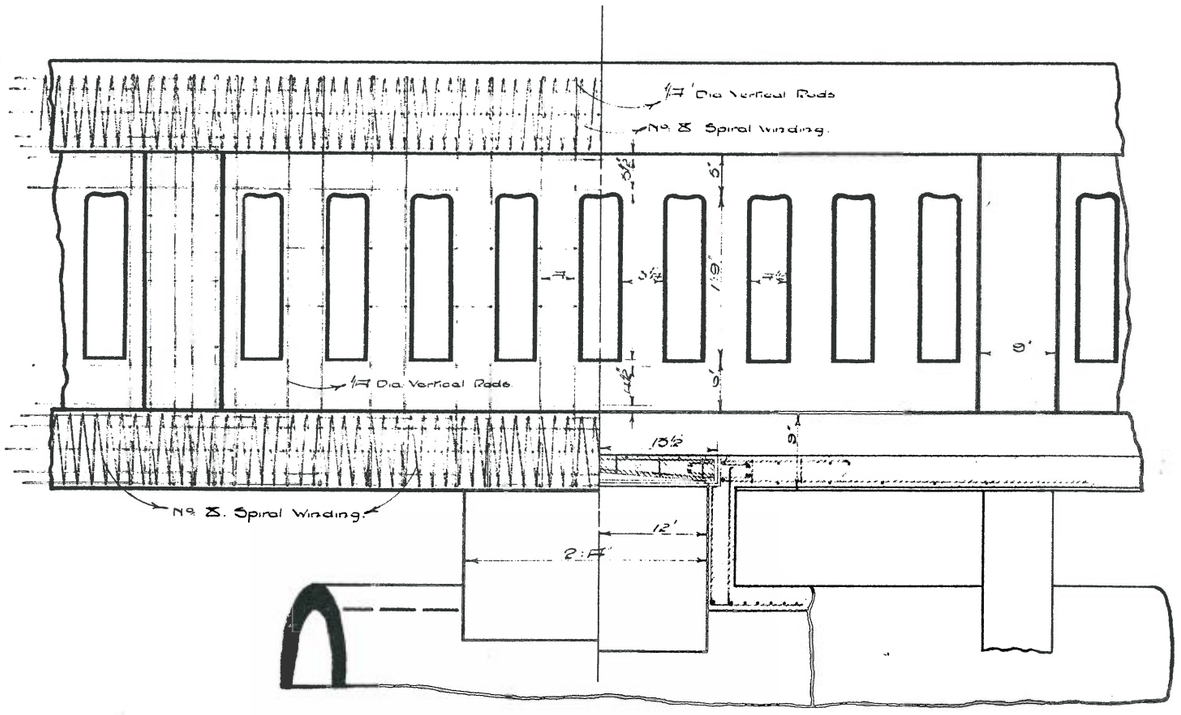


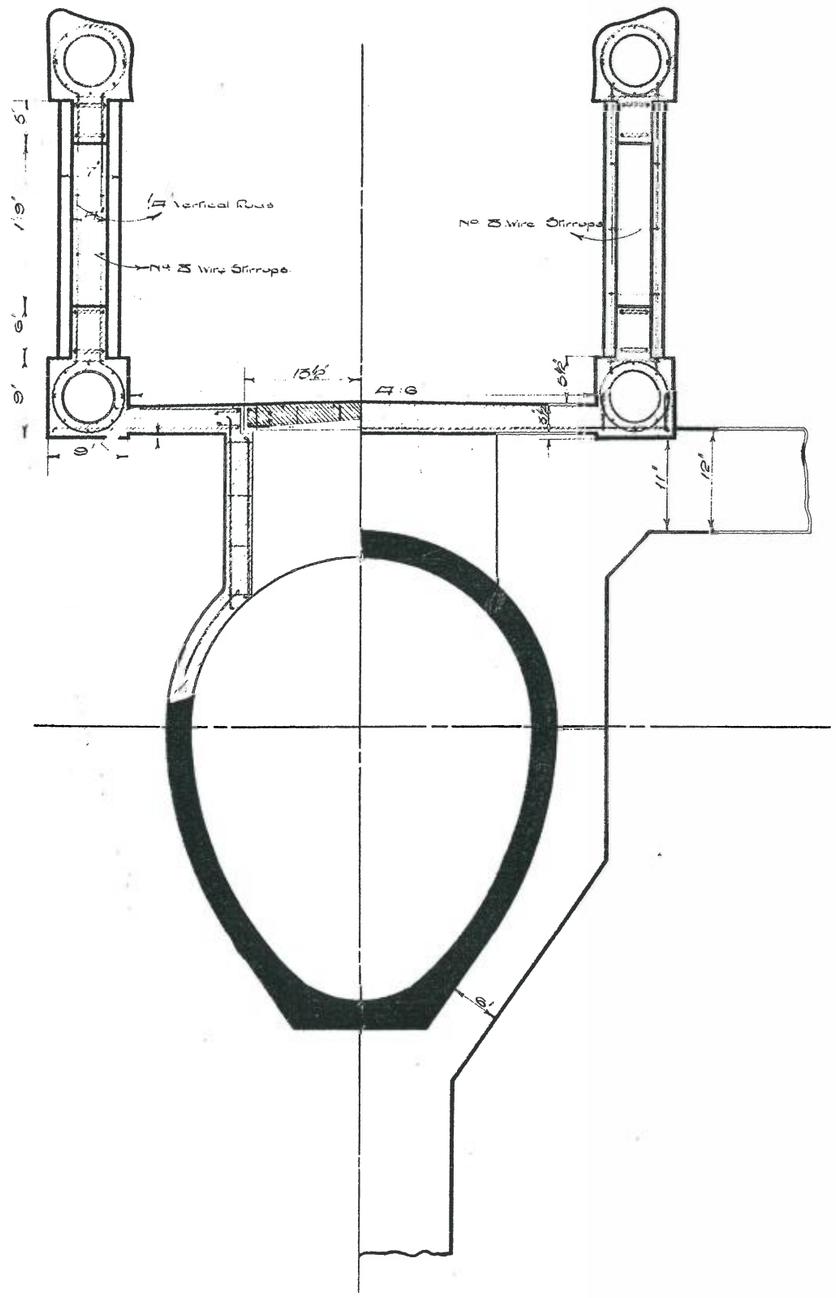
GEELONG WATERWORKS AND SEWERAGE TRUST. CONTRACT No 4.

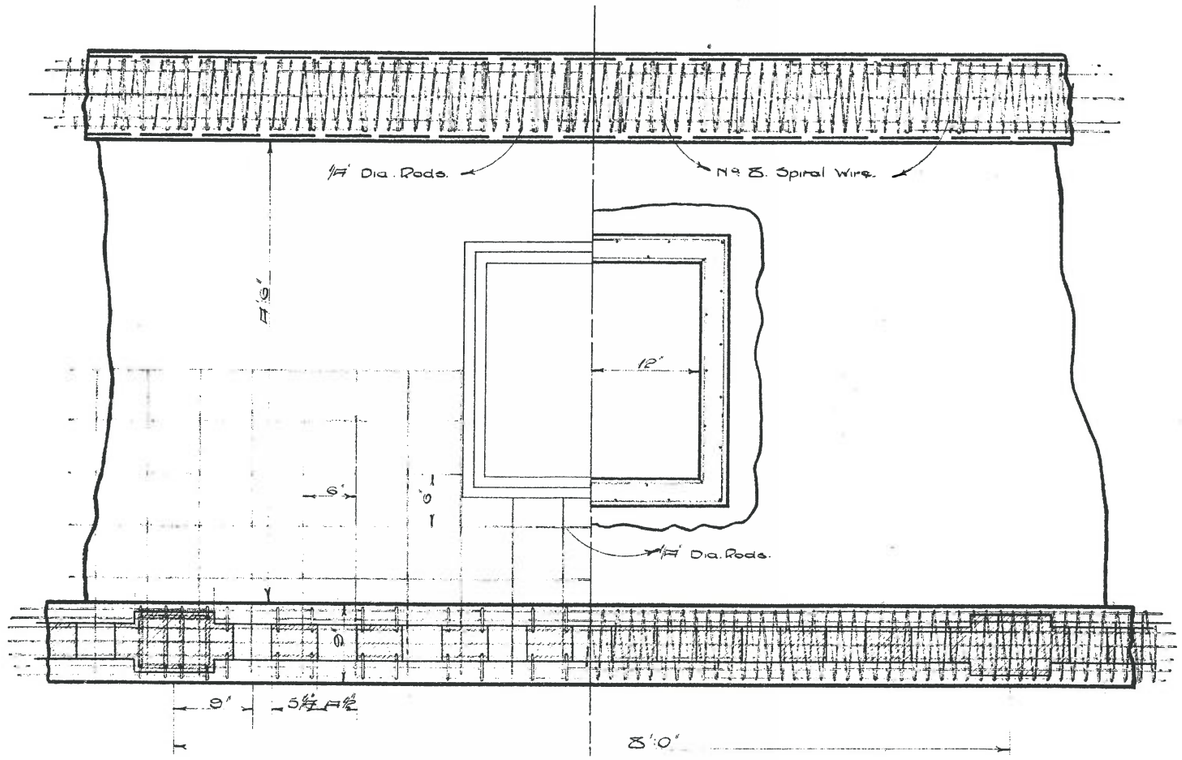
DESIGN FOR INSPECTION MANHOLES.

SCALE :- 1½ INS TO ONE FOOT.

DESIGNED BY.
STONE AND SIDDELEY.
REINFORCED CONCRETE SPECIALISTS.







:INFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON

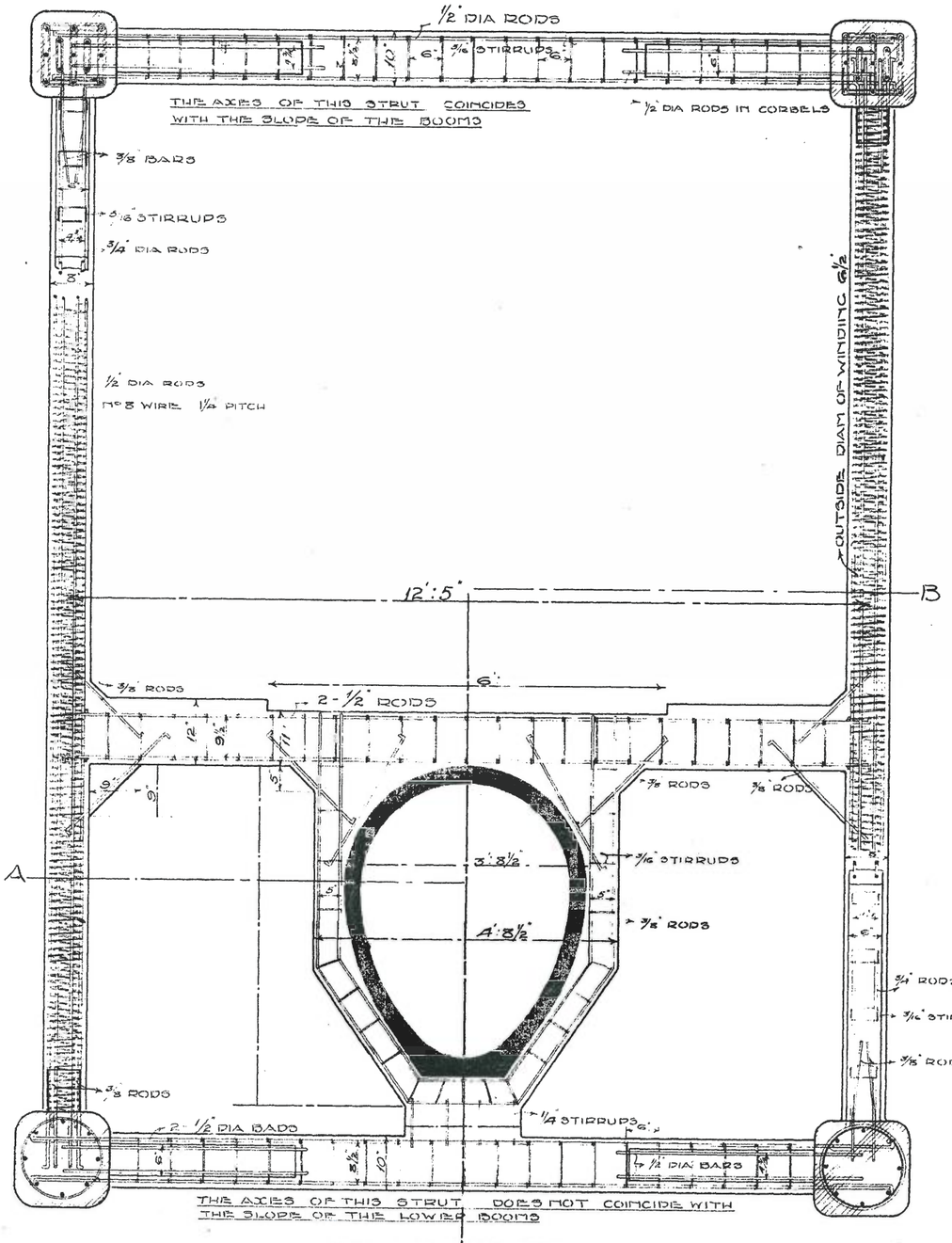
:LONG WATERWORKS AND SEWERAGE TRUST CONTRACT Nº 4

:TAILS OF REINFORCEMENTS IN MEMBERS AT JOINT Nº 2 SEE GENERAL DESIGN

:CALE ONE INCH TO ONE FOOT

DESIGNED BY STONE & SIDDELEY

REINFORCED CONCRETE SPECIALISTS



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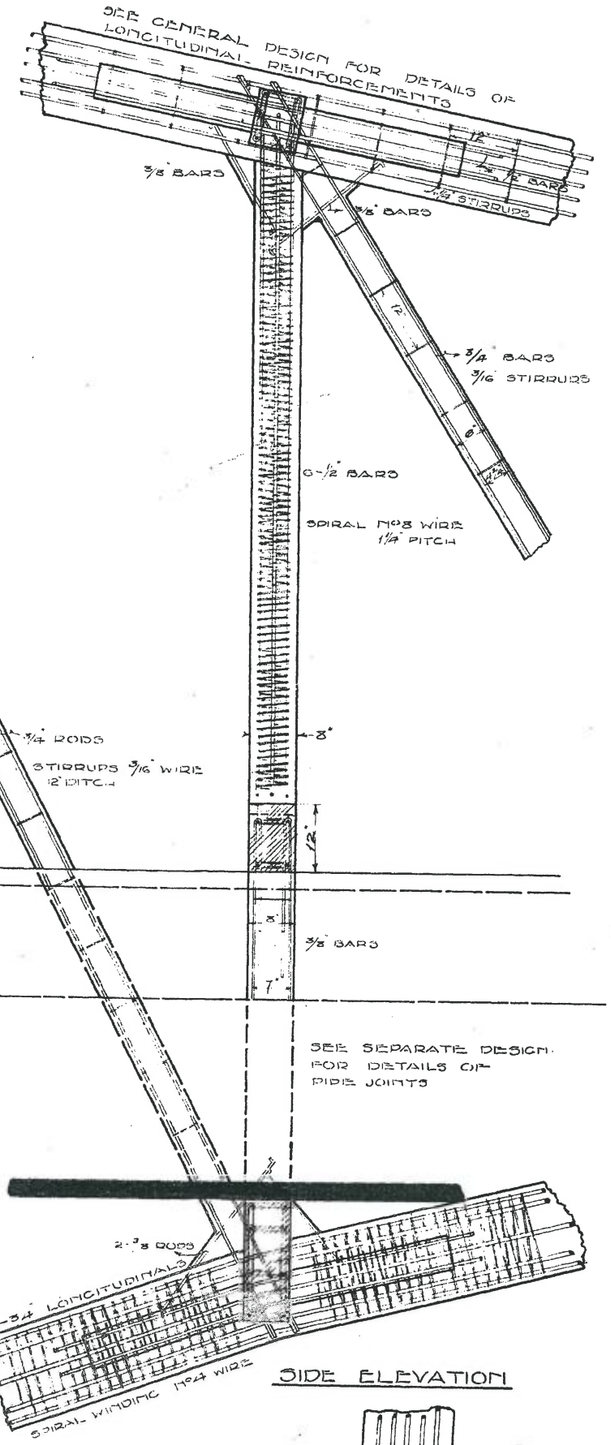
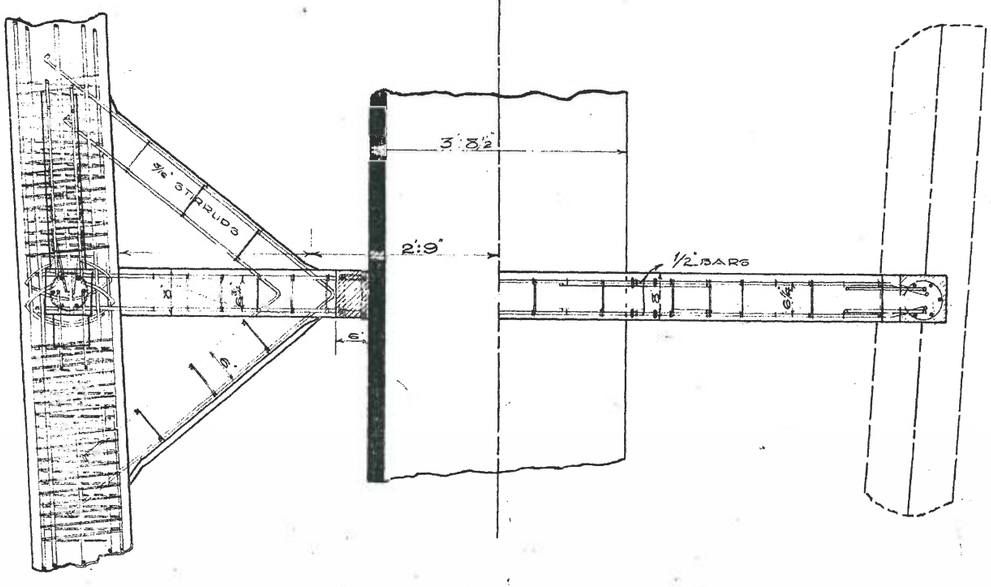
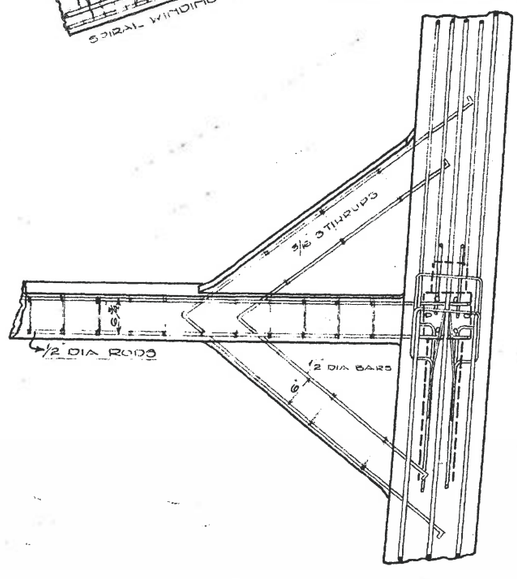


SIDE ELEVATION

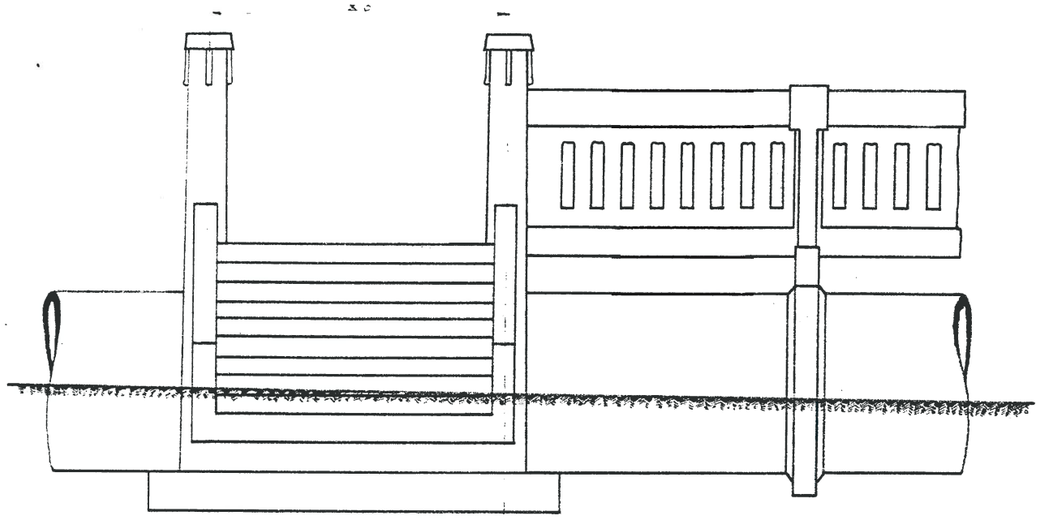


PLAN ON LINE A-B



PLAN SHEWING REINFORCEMENT IN MEMBERS JOINING UPPER BOOM

DRAWING Nº 47



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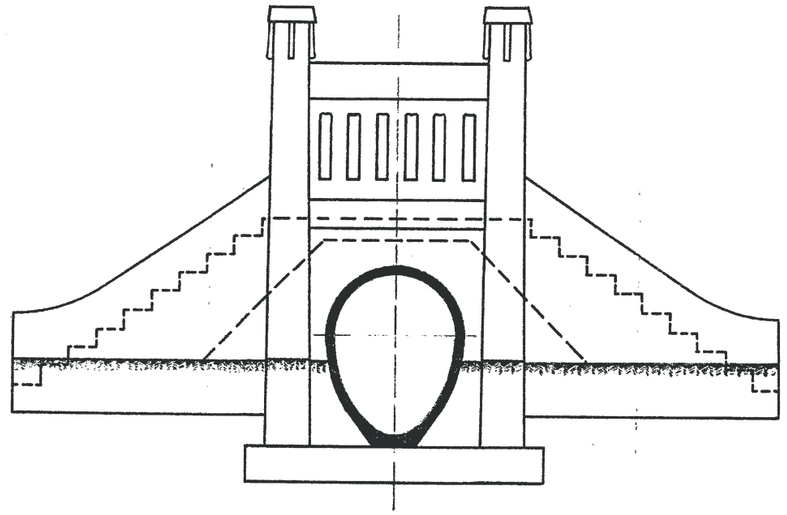

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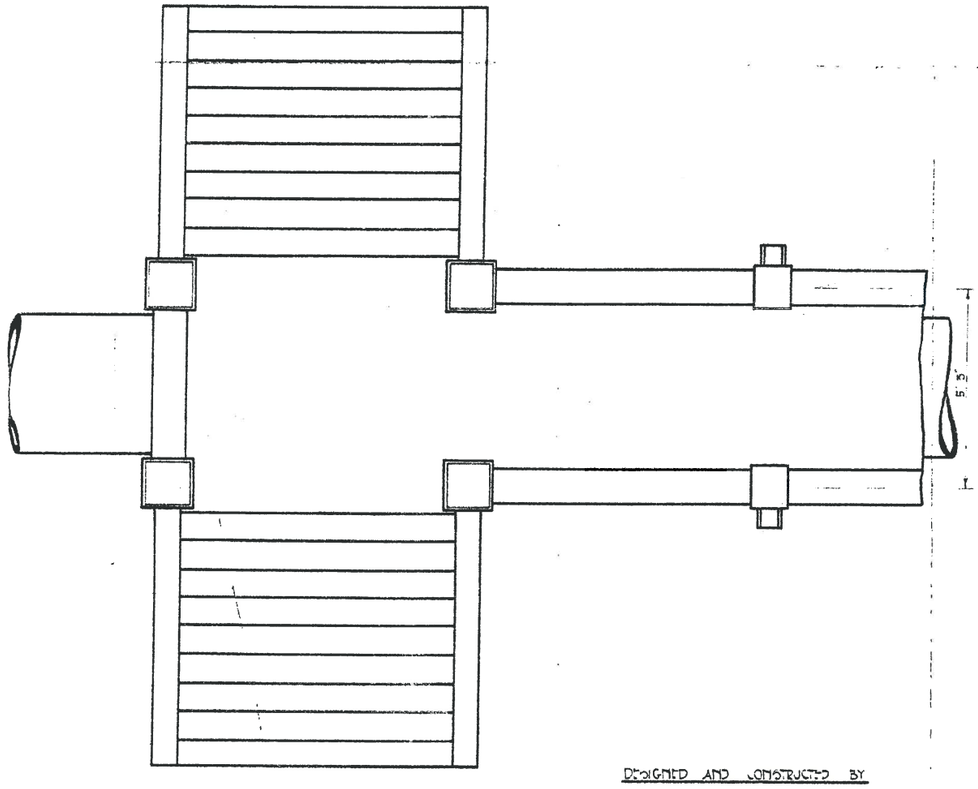


PLAN

DESIGNED AND CONSTRUCTED BY

STONE AND SIDDELEY.

REINFORCED CONCRETE SPECIALISTS.

ADELAIDE, SYDNEY AND MELBOURNE.

REINFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON.

GEELONG WATERWORKS AND SEWERAGE TRUST CONTRACT No. 4.

DESIGN FOR ENTRANCE TO AQUEDUCT.

SCALE — 2 FEET TO ONE INCH.

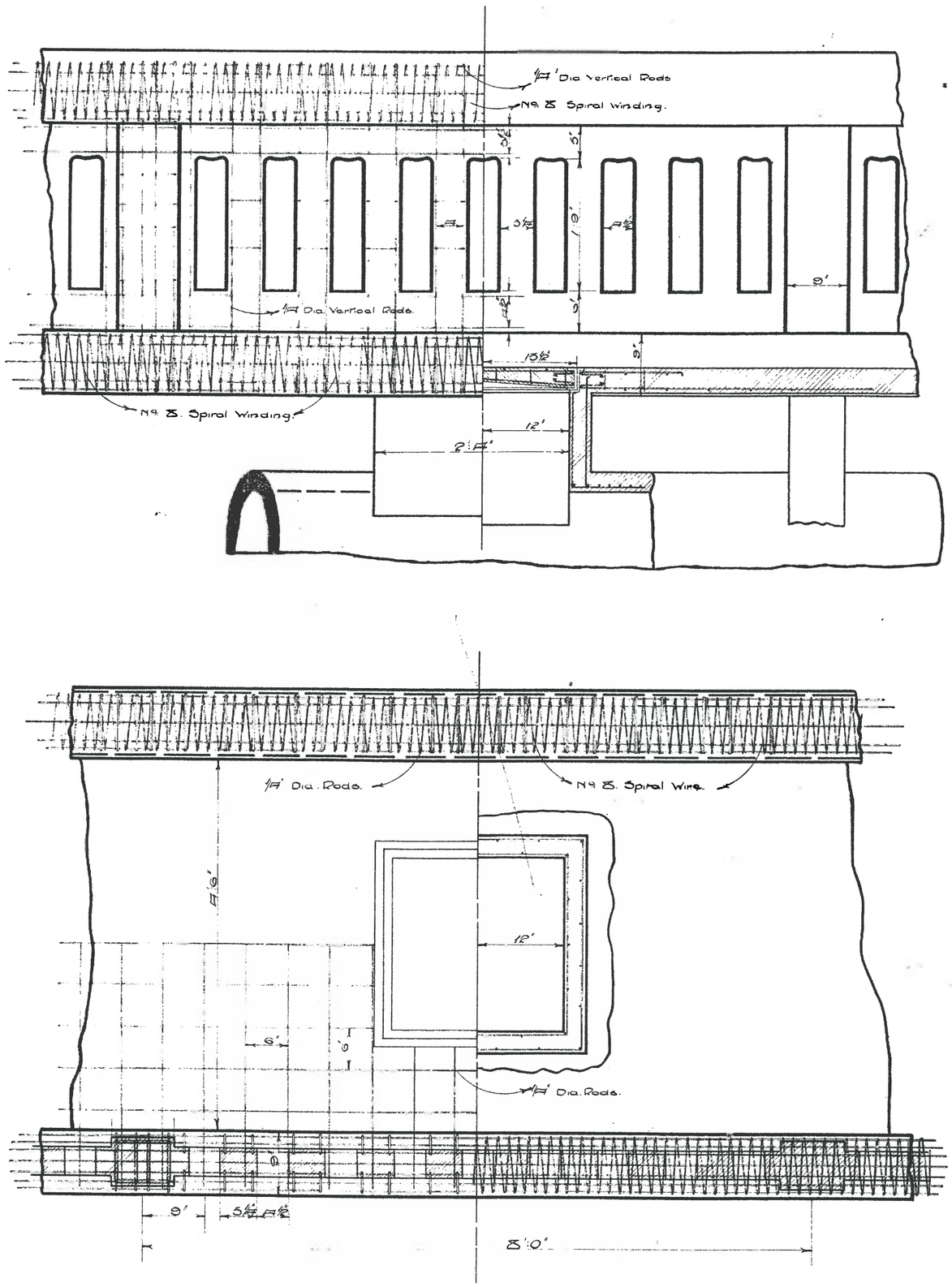
STONE & SIDDELEY
CONSULTING AND CONSTRUCTIONAL ENGINEERS
REINFORCED CONCRETE SPECIALISTS
HINDMARSH SQ. ADELAIDE

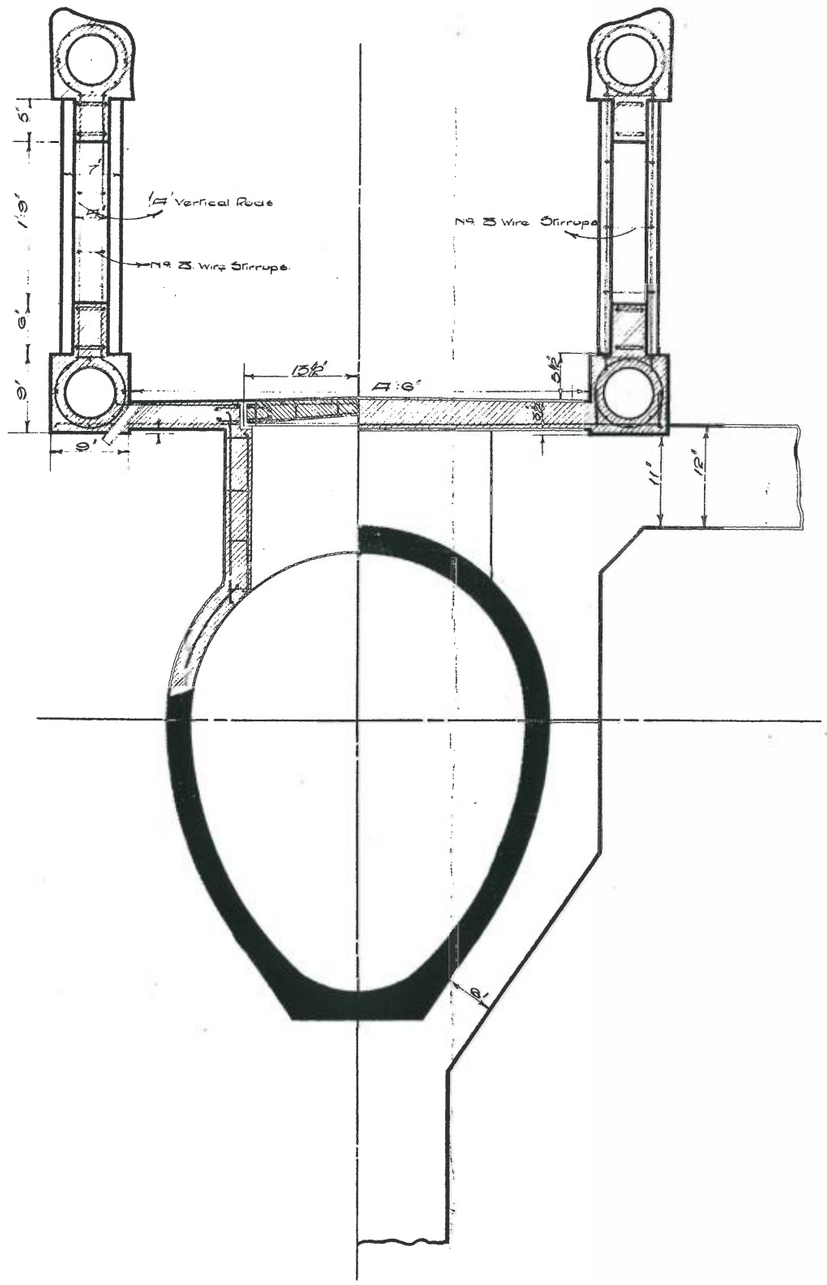
GEELONG WATERWORKS AND SEWERAGE TRUST. CONTRACT No 4.

DESIGN FOR INSPECTION MANHOLES.

SCALE :- 1½ INS TO ONE FOOT.

DESIGNED BY.
STONE AND SIDDELEY.
REINFORCED CONCRETE SPECIALISTS.





REINFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON

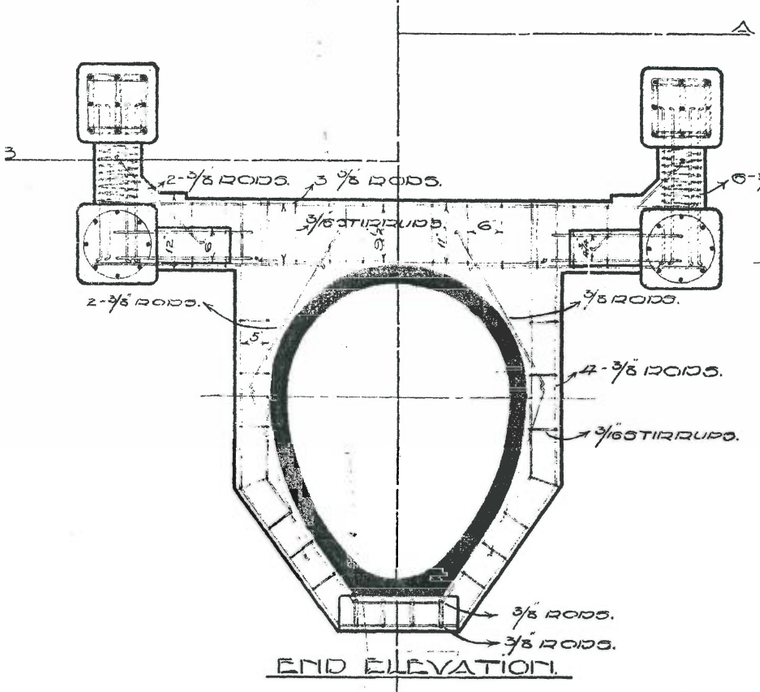
BELONG WATERWORKS AND SEWERAGE TRUST CONTRACT Nº 4

DETAILS OF REINFORCEMENTS IN MEMBERS AT JOINT Nº 7.

SCALE ONE INCH TO ONE FOOT.

DESIGNED BY STONE & SIDDELEY.

REINFORCED CONCRETE SPECIALISTS.



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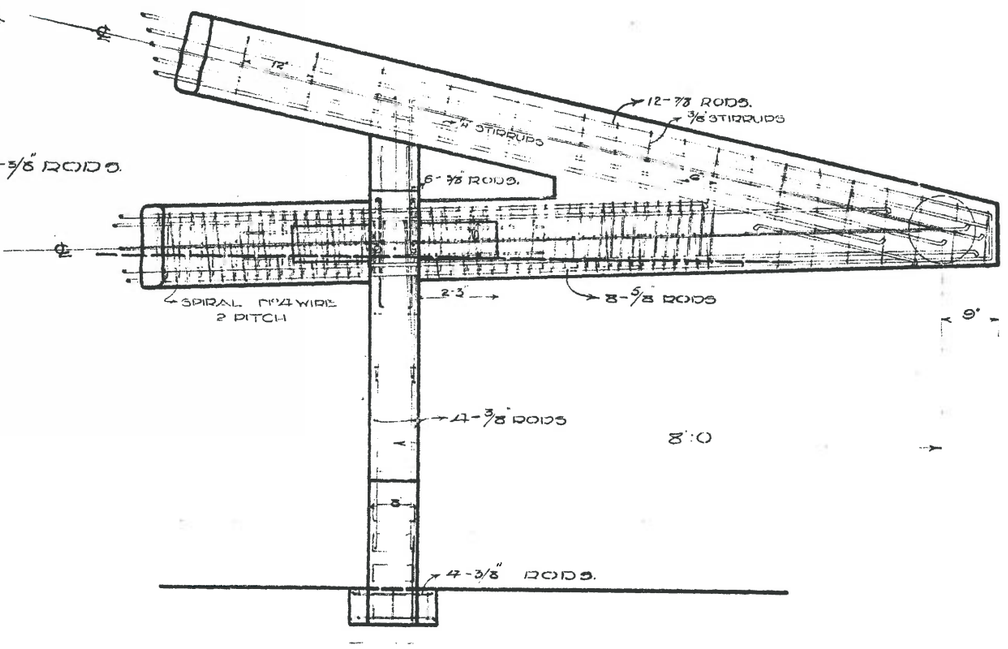
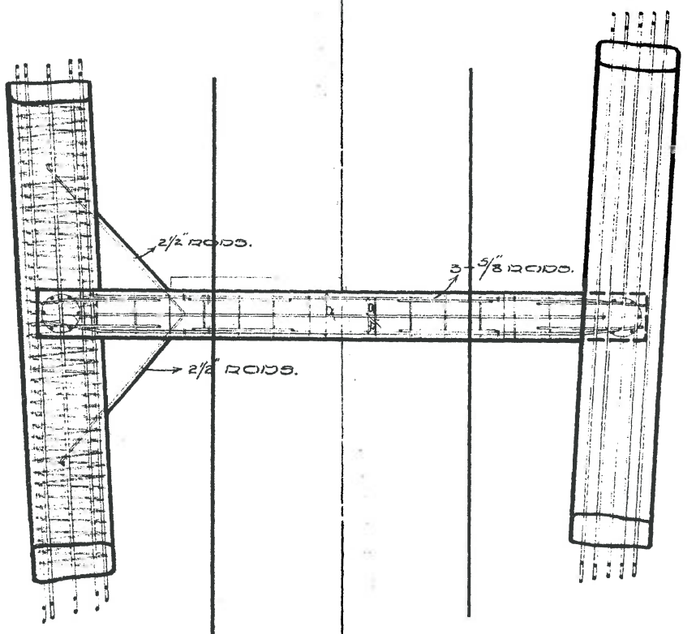


SIDE ELEVATION.



PLAN ON LINE A-B.

CEILING

NOTE — COLUMN REINFORCEMENTS TO BE STRONGLY STIRRUPED FOR THE FIRST 2'10" FROM

SIDE ELEVATION

END ELEVATION

THIS SPACE TO BE FILLED WITH POOR CONCRETE

THIS FACE IS PARALLEL TO THE ℄ OF COLUMNS

℄ OF COLUMNS

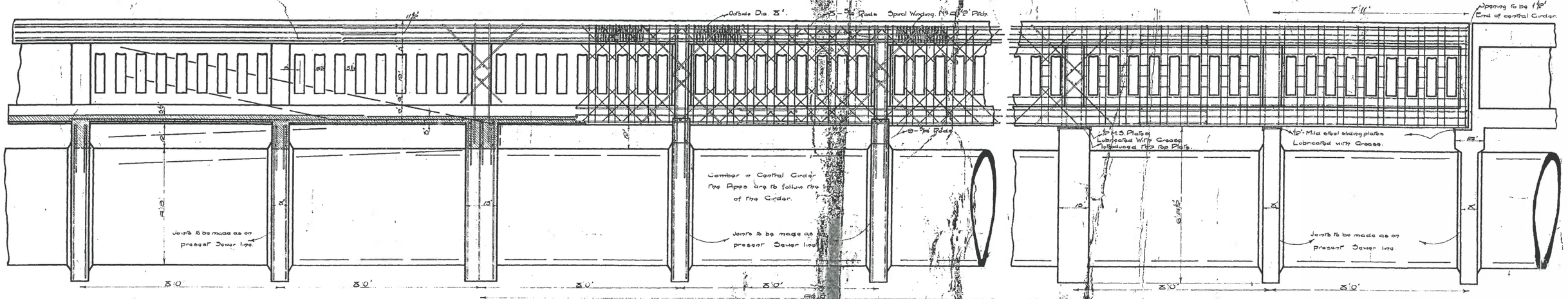
REINFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON.

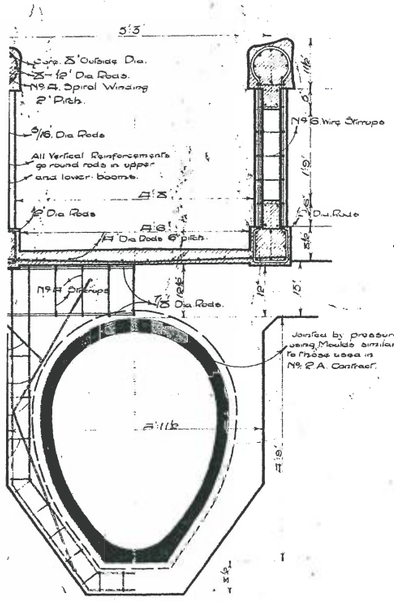
GEELONG WATERWORKS AND SEWERAGE TRUST. CONTRACT. No. 4

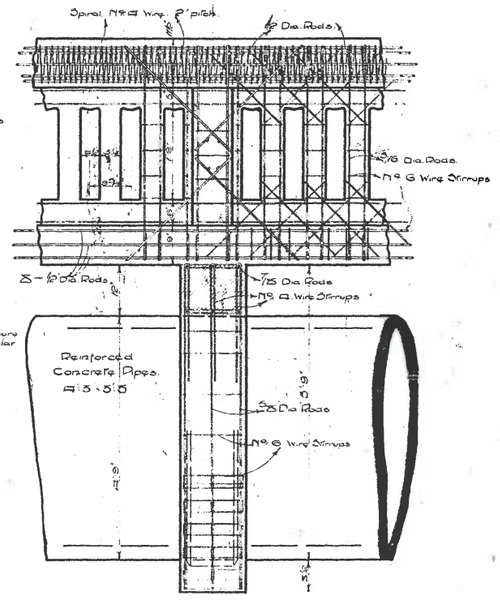
DESIGN AND DETAILS FOR CENTRAL GIRDER.

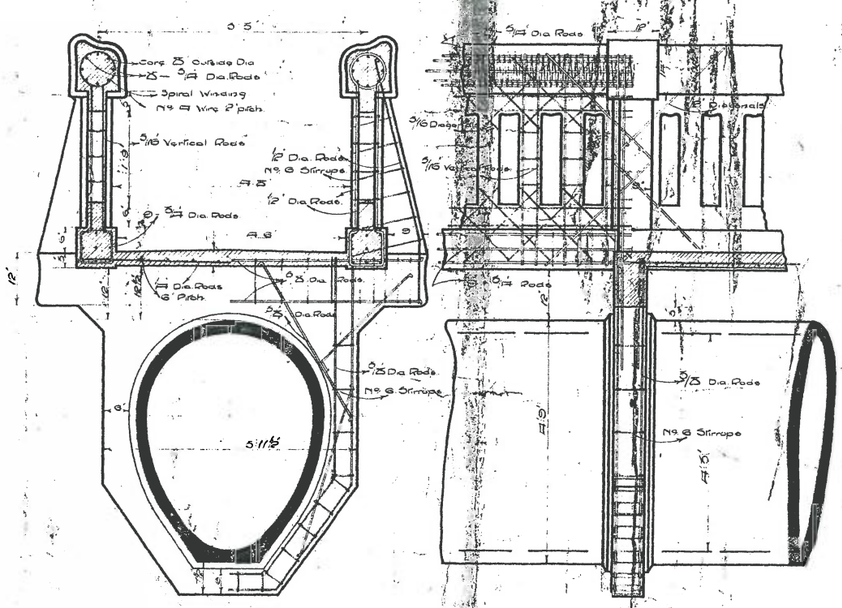
SCALE :- GENERAL DESIGN. 3/16 INCH. DETAILS. ONE INCH TO ONE FOOT.

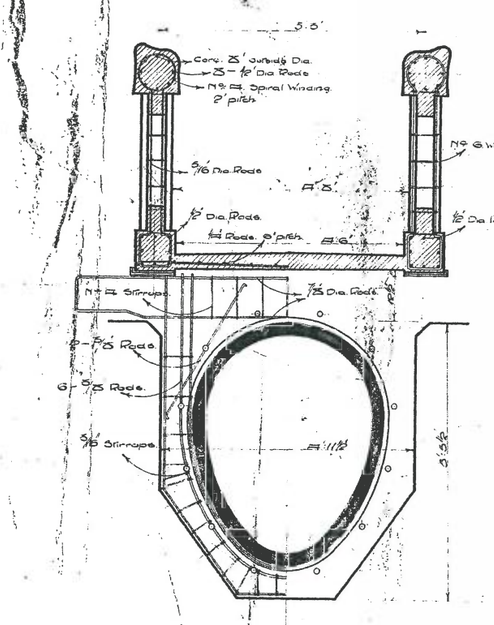
DESIGNED BY
STONE AND SIDDELEY
REINFORCED CONCRETE SPECIALIST.

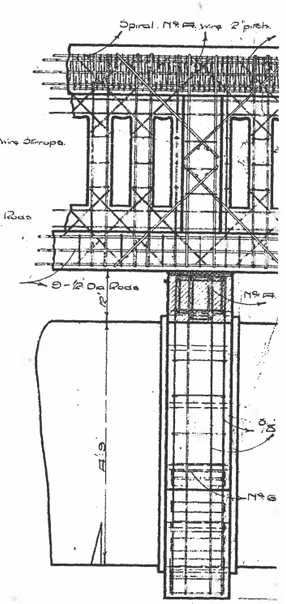


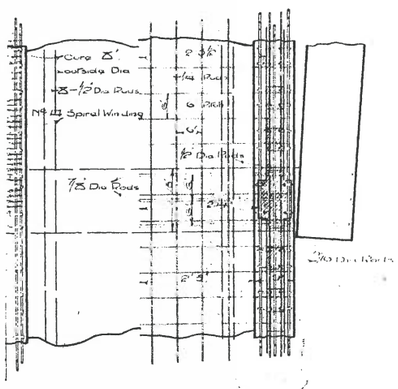


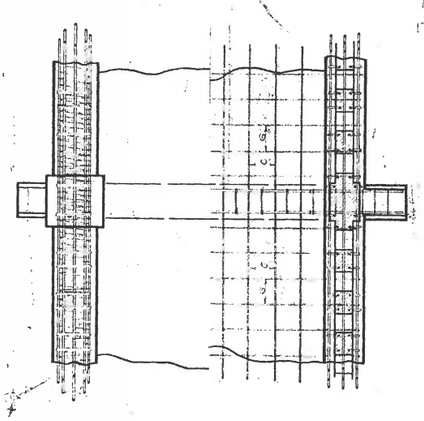


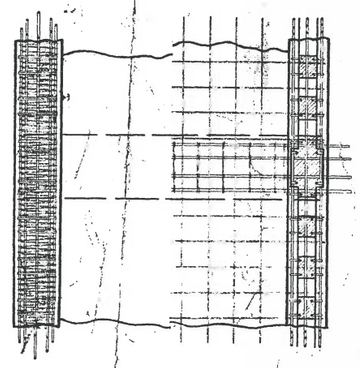


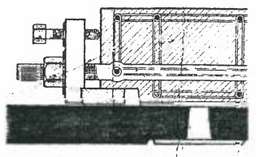




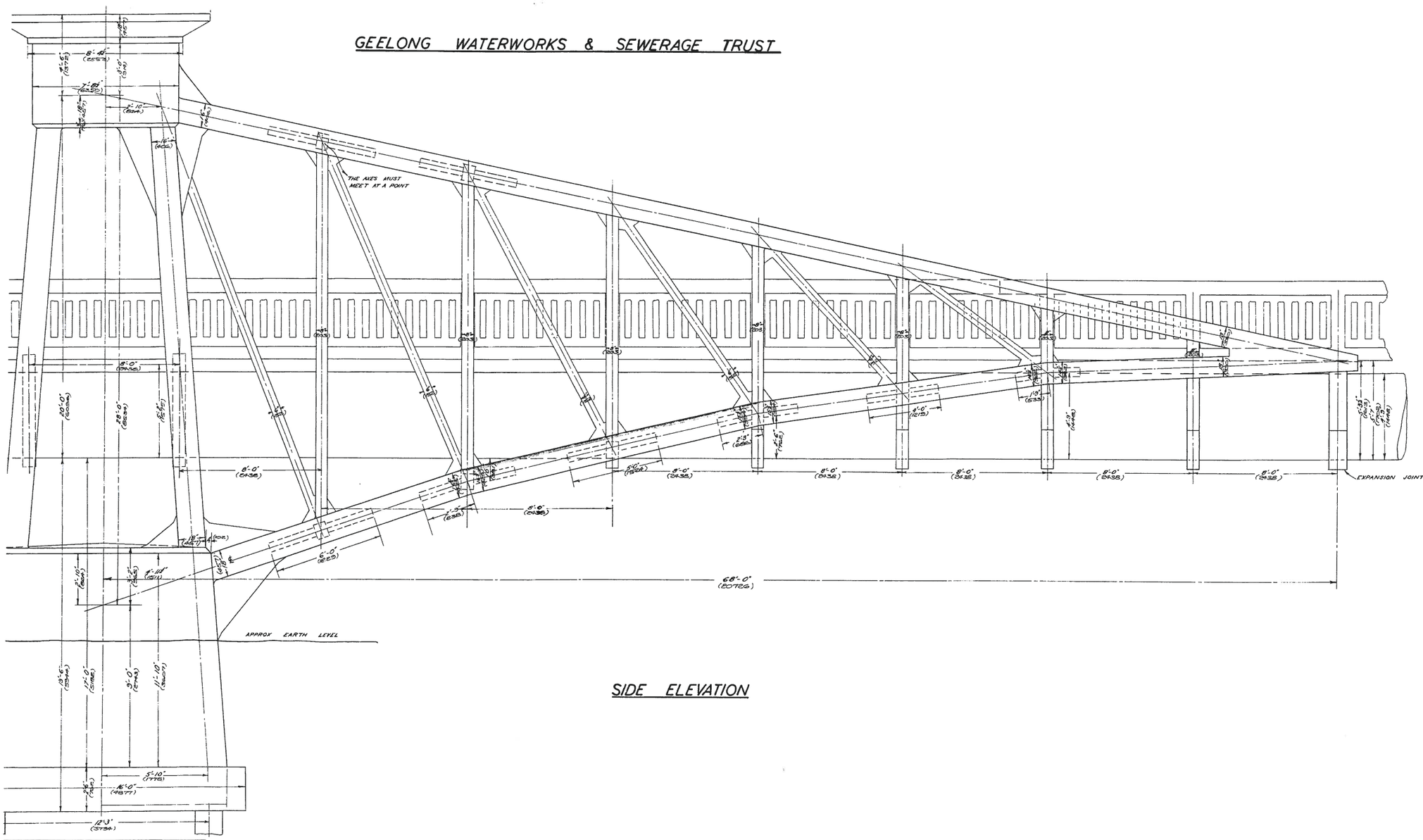




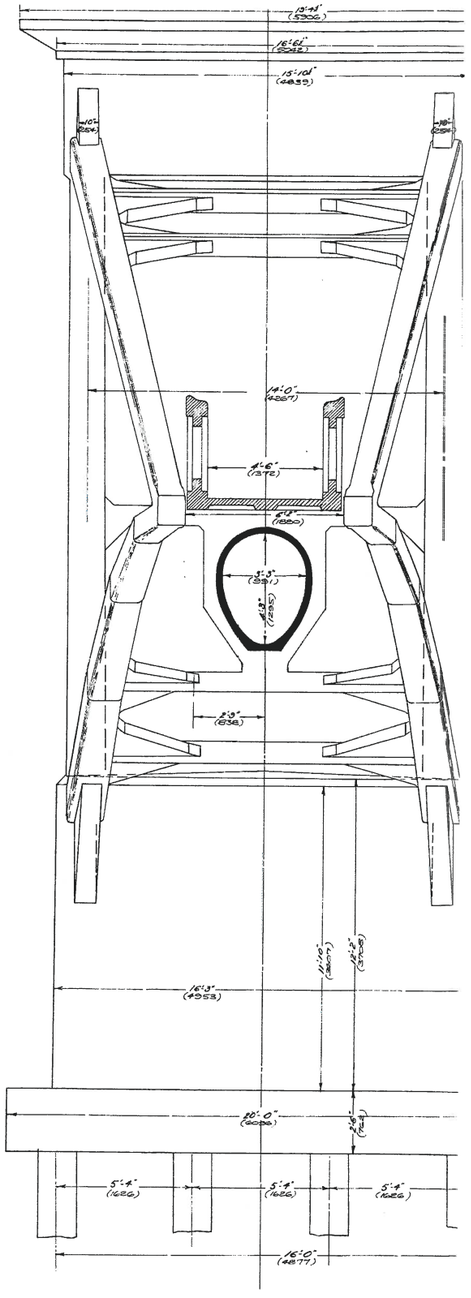




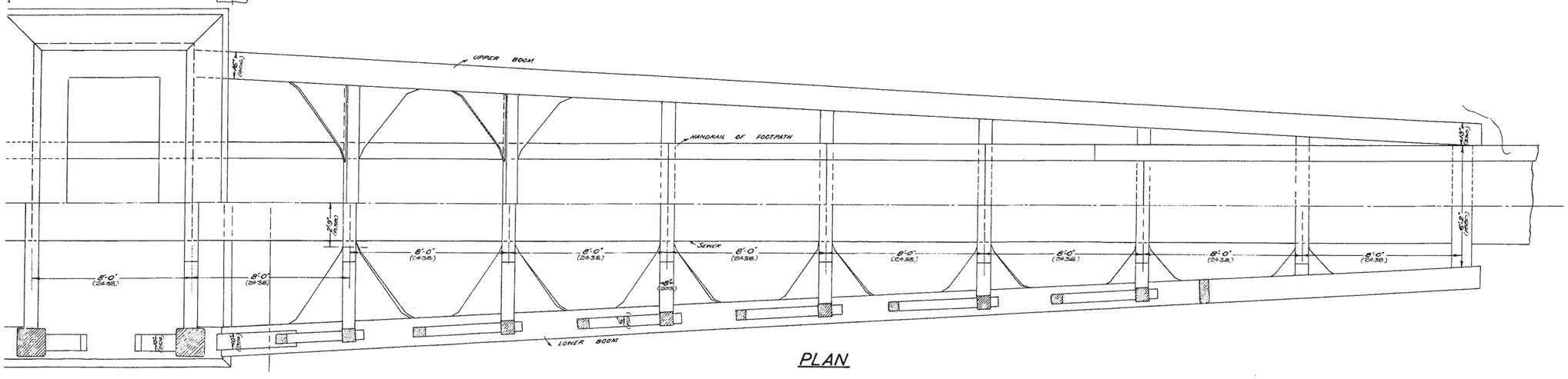
GEELONG WATERWORKS & SEWERAGE TRUST



SIDE ELEVATION



END ELEVATION



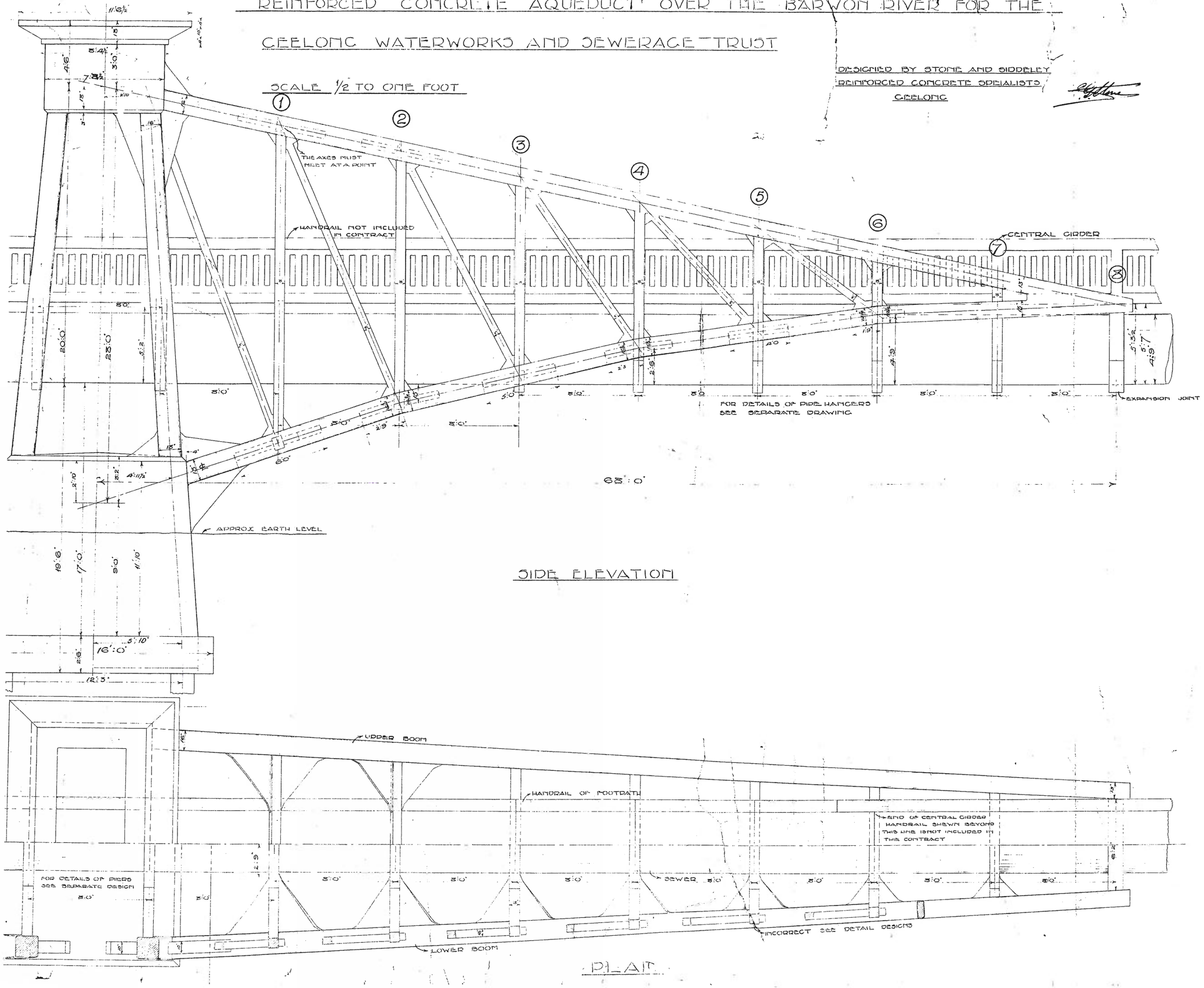
PLAN

TRACED OFF ORIGINAL BLUE PRINT
BY G.P. PLUMMER 23-9-1936

REINFORCED CONCRETE AQUEDUCT OVER THE BARWON RIVER FOR THE GEELONG WATERWORKS AND SEWERAGE TRUST

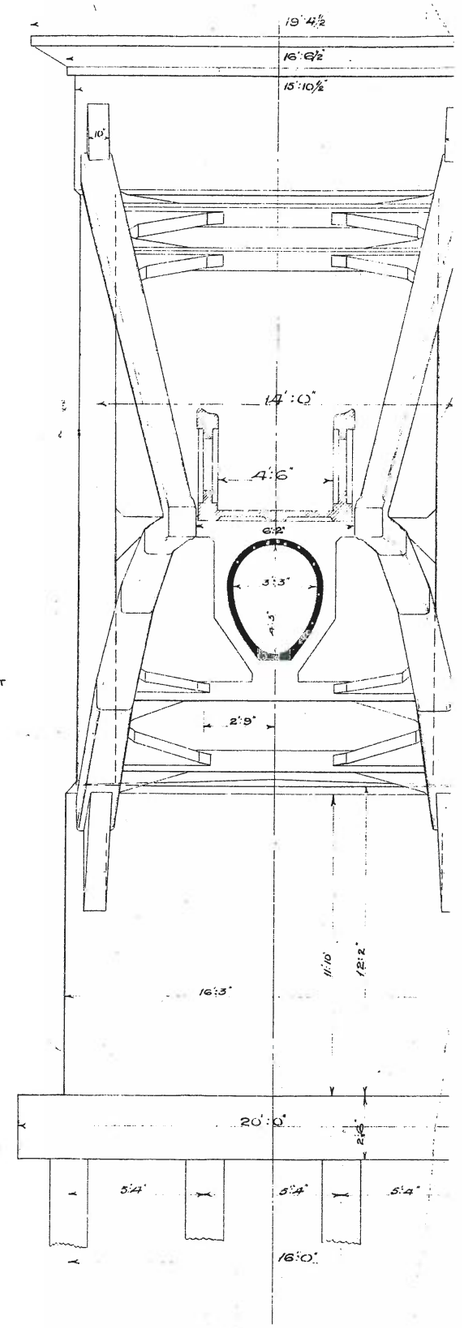
SCALE ½ TO ONE FOOT

DESIGNED BY STONE AND SIDDELEY
REINFORCED CONCRETE SPECIALISTS
GEELONG



SIDE ELEVATION

PLAN



END ELEVATION

STONE &
REINFORCED CO

INFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON.

ELONG WATERWORKS AND SEWERAGE TRUST. CONTRACT No 4.

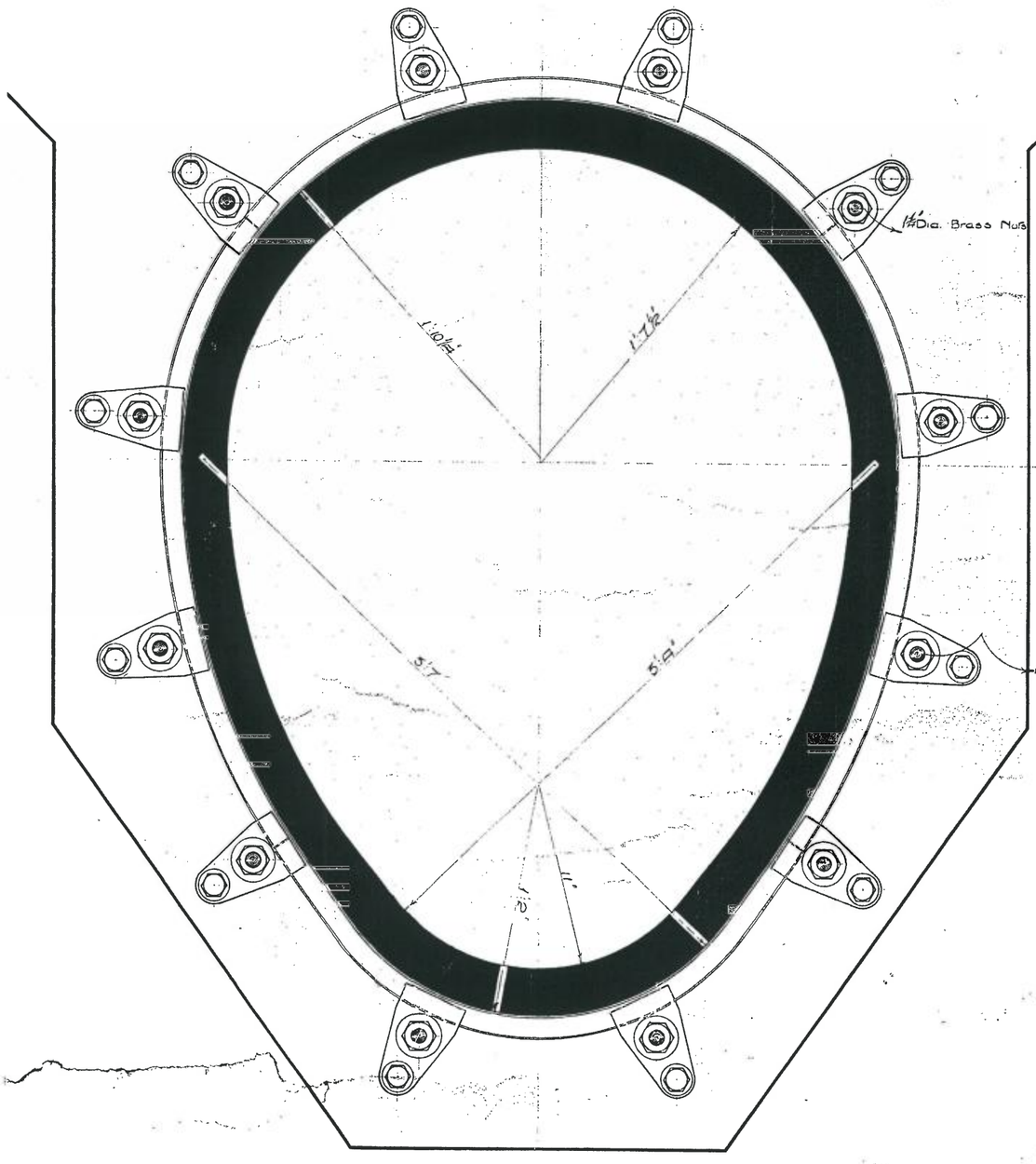
ESIGN OF EXPANSION JOINT.

CALE:- 3 INS. TO ONE FOOT.

DESIGNED BY

STONE AND SIDDELEY

REINFORCED CONCRETE SPECIALISTS.



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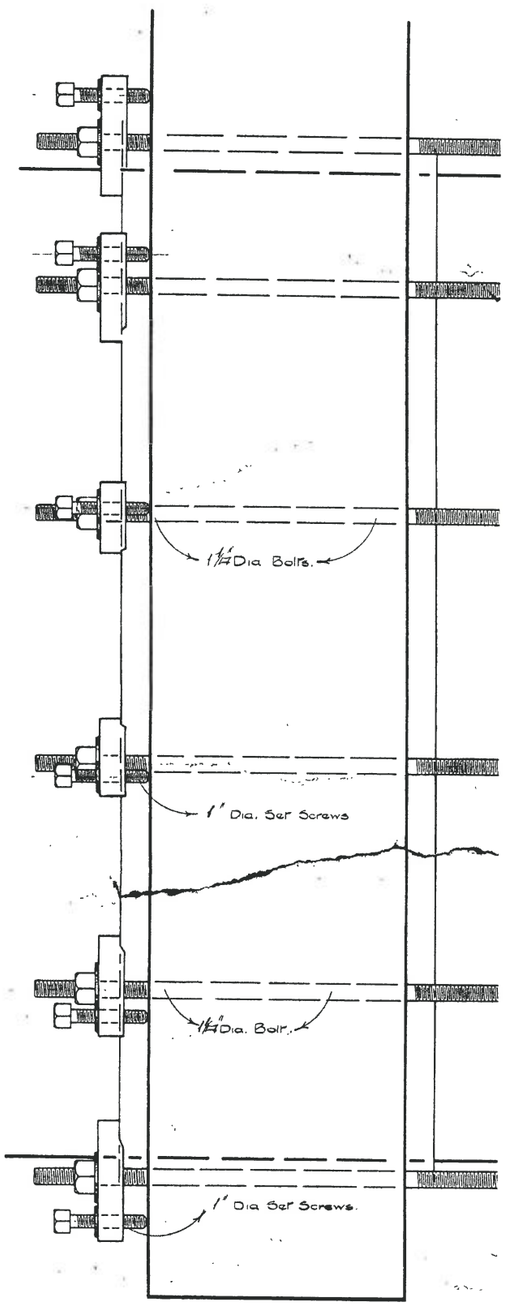

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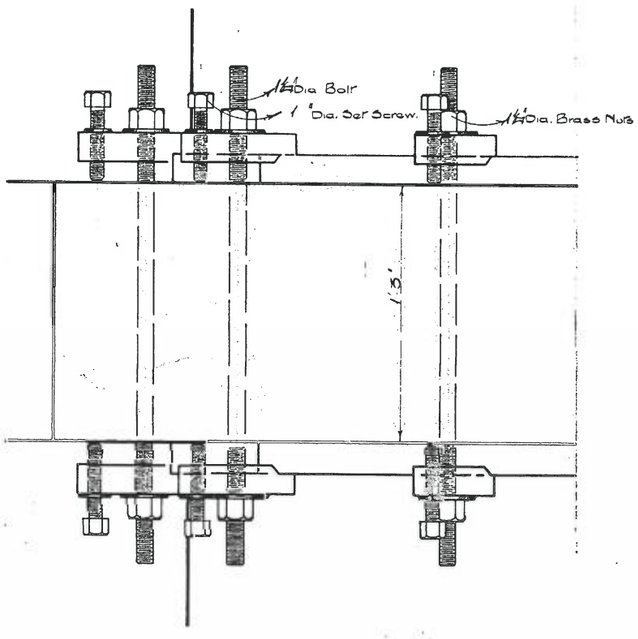
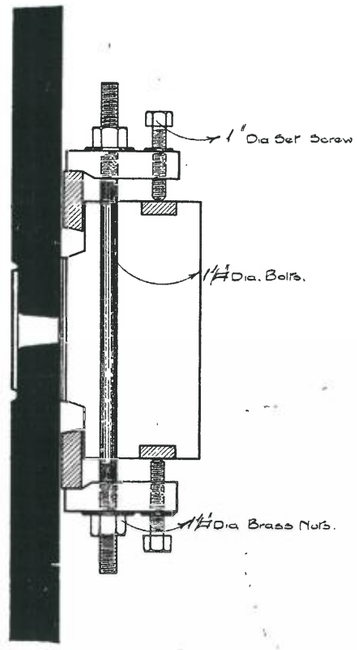




PLAN

FORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON.

ONG WATERWORKS AND SEWERAGE TRUST. CONTRACT No. 4.

SIGN OF EXPANSION JOINT.

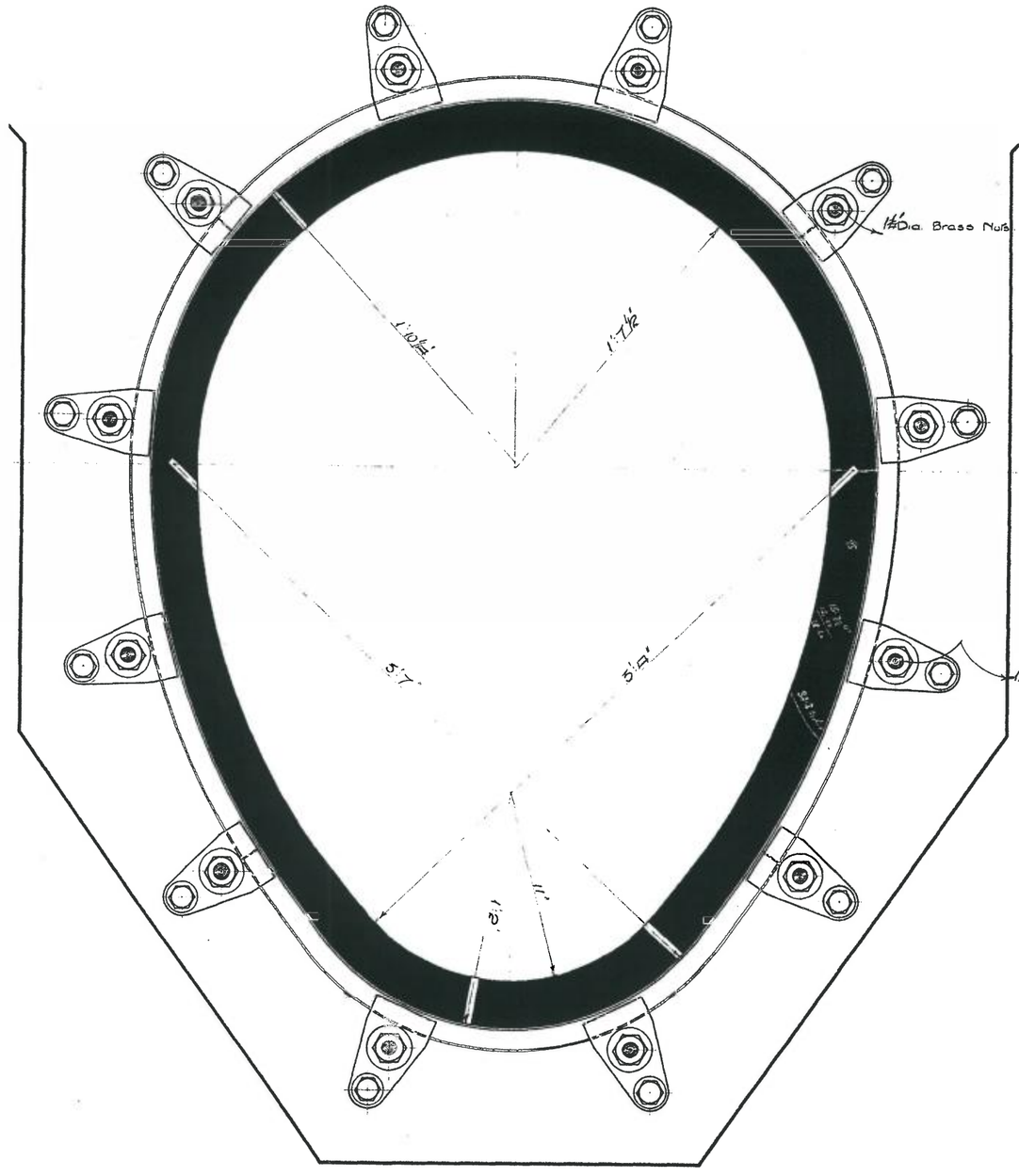
LE:- 3 INS. TO ONE FOOT.

DESIGNED BY

STONE AND SIDDELEY

REINFORCED CONCRETE SPECIALISTS.

Stone Siddeley.



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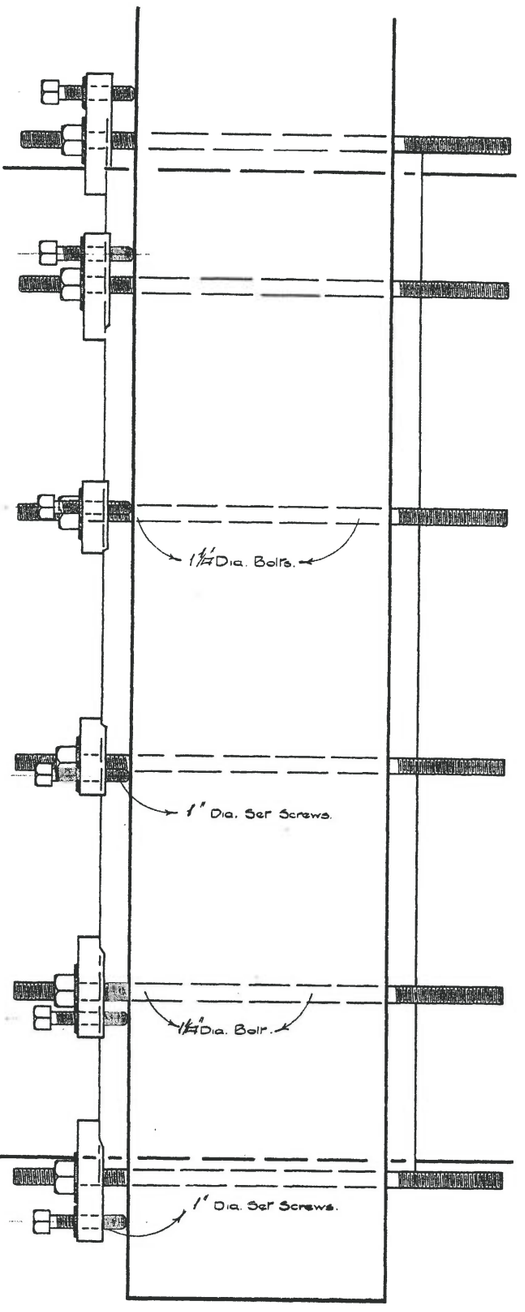

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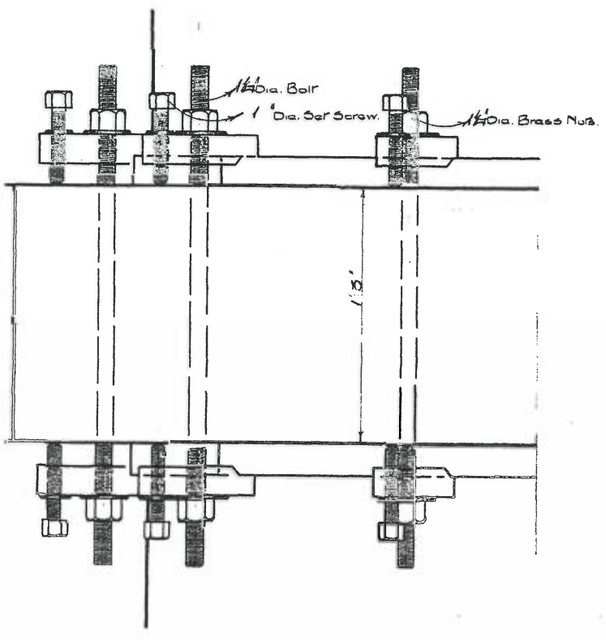
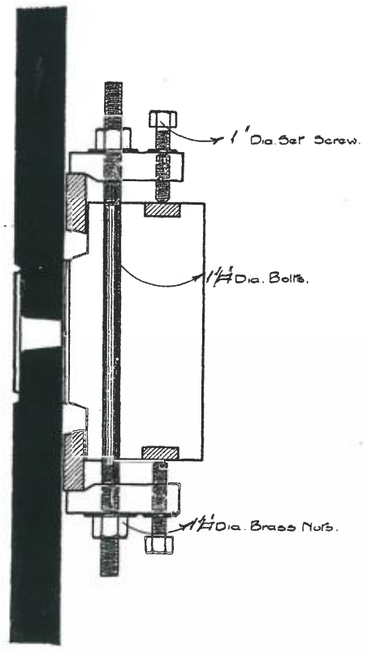




PLAN

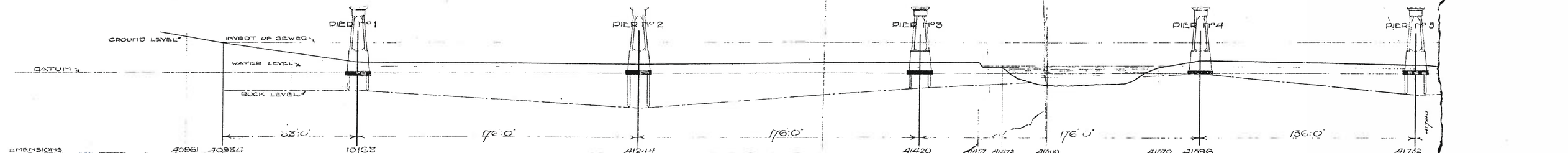
FORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON

C WATERWORKS AND SEWERAGE TRUST

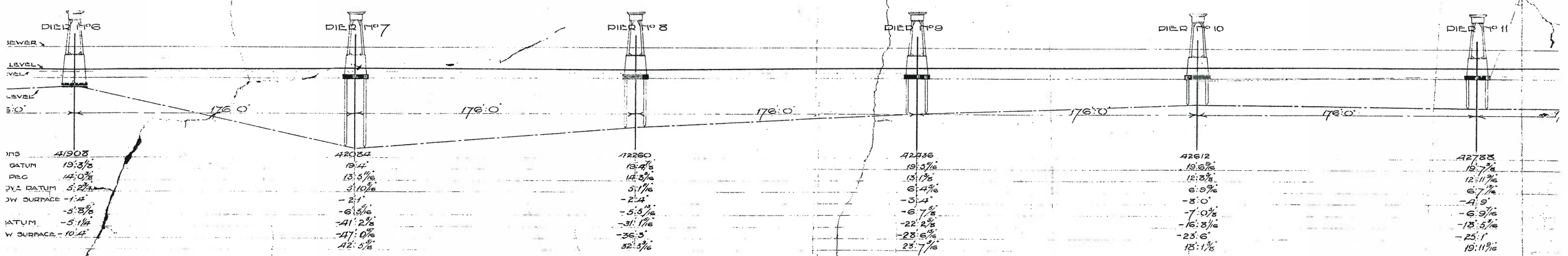
FUDINAL SECTION SHEWING ROCK LEVELS ETC

NTAL AND VERTICAL SCALE 20:0 TO ONE INCH

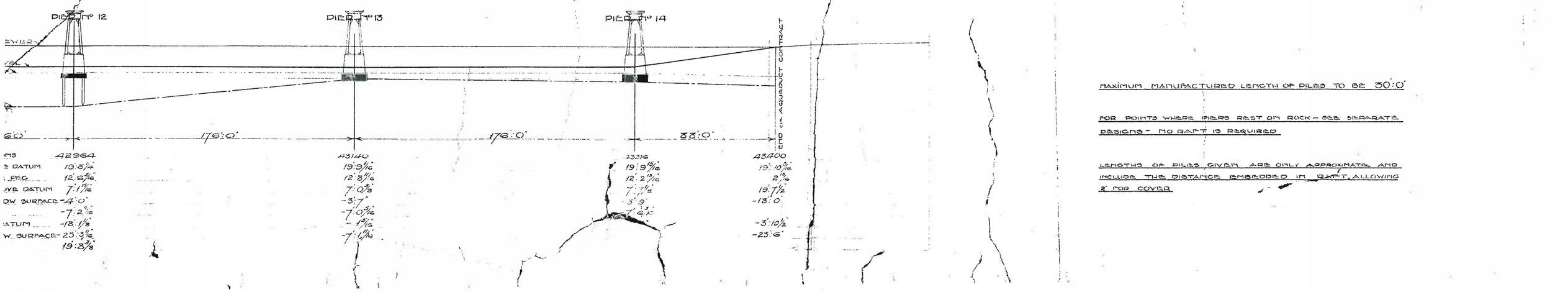
STONE AND SIDDELEY
REINFORCED CONCRETE SPECIALISTS
GEELONG



IMENSIONS	A0961 -70934	10:08	A12:14	A1420	A1417 A1472	A1500	A1570 A1596	A1732
BOVE DATUM	18:10⅝ 18:10¾	18:11⅛	19:0	18:0⅜			19:1⅜	19:2⅝
BOVE PEC		12:0⅝	13:6⅜	12:4¼			11:0⅜	13:2⅝
ABOVE DATUM	22:8⅝ 18:10⅜	6:10⅛	5:5½	6:7⅜			8:1	5:4¾
BELOW SURFACE	-15:6	- 2:9	- 1:9	- 3:0			3:9	- 2:0
URFACE PEC		- 7:8⅜	- 6:2⅛	- 7:4¼			- 8:8⅜	- 5:11⅞
O DATUM	- 11:7⅜	-11:7⅜	-22:4⅜	- 9:4⅛			- 1	- 13:3¼
BELOW SURFACE	-30:0	-18:6⅛	-27:9⅜	-16:0			- 8:2	- 18:8
LES		12:5⅜	23:3⅜	10:3¼				14:4⅞



ONS	41908	42084	42260	42436	42612	42788
DATUM	19:3⅛	19:4	19:4⅞	19:3⅛	19:6⅛	19:7⅛
PEC	14:0⅝	13:5⅛	14:3⅛	13:1⅝	12:8⅝	12:11⅛
VE DATUM	5:2¾	5:10⅜	5:1⅞	6:4⅝	6:9⅛	6:7⅛
OW SURFACE	-1:4	- 2:1	- 2:4	- 3:4	- 8:0	- 4:9
	-5:8⅝	- 6:5⅛	- 5:5⅛	- 6:7⅞	- 7:0⅝	- 6:9⅛
ATUM	-5:1⅛	-41:2⅝	-31:1⅞	-22:2⅝	-16:3⅛	-13:5⅛
W SURFACE	-10:4	-47:0⅛	-36:3	-28:6⅛	-23:6	-25:1
		A2:5⅞	32:5⅛	23:7⅛	18:1⅜	19:11⅛

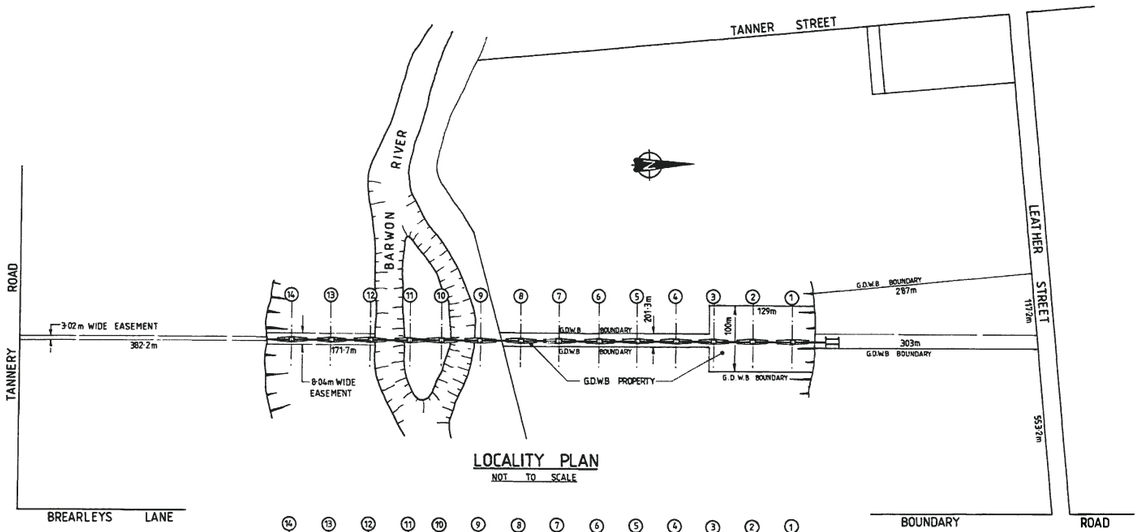


ONS	42964	43140	43316	43400
E DATUM	19:5⅛	19:9⅛	19:9⅞	19:10⅝
PEC	12:8⅝	12:8⅛	12:2⅞	2⅛
VE DATUM	7:1⅞	7:0⅝	7:7⅛	19:7½
OW SURFACE	-4:0	-3:7	3:9	-18:0
	-7:2⅛	-7:0⅜	7:6⅜	
ATUM	-18:1⅛	- 1⅜	13	-3:10½
W SURFACE	-25:3⅜	-7:1⅛	16	-25:6
	19:8⅜			

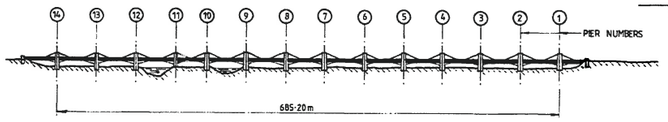
MAXIMUM MANUFACTURED LENGTH OF PILES TO BE 30:0

FOR POINTS WHERE PIERS REST ON ROCK - SEE SEPARATE DESIGNS - NO RAFT IS REQUIRED

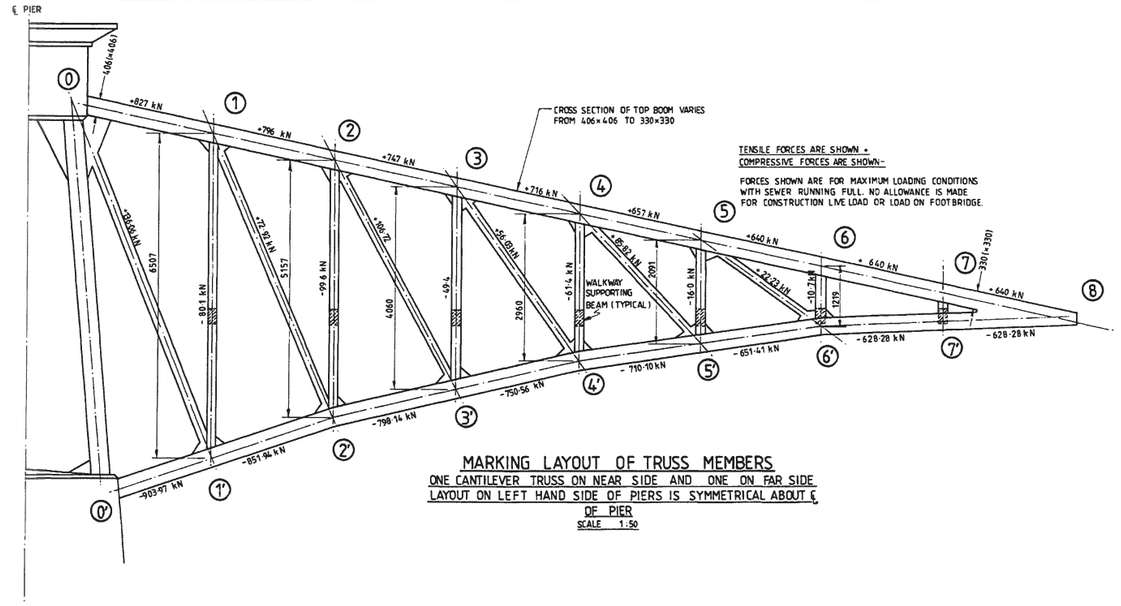
LENGTHS OF PILES GIVEN ARE ONLY APPROXIMATE AND INCLUDE THE DISTANCE EMBEDDED IN RAFT, ALLOWING 2' FOR COVER



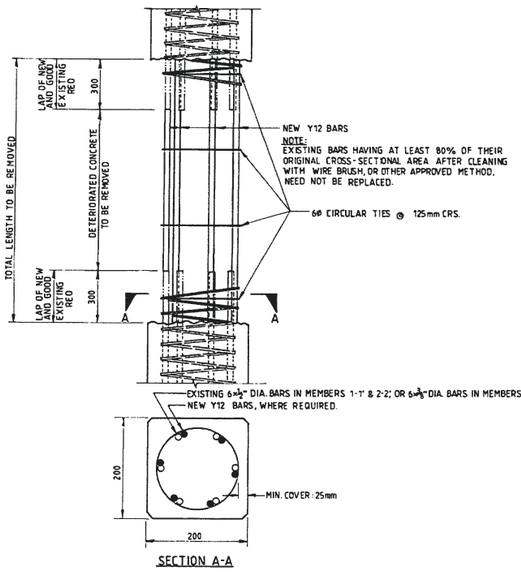
LOCALITY PLAN
NOT TO SCALE



SIDE ELEVATION
(LOOKING WEST)
NOT TO SCALE

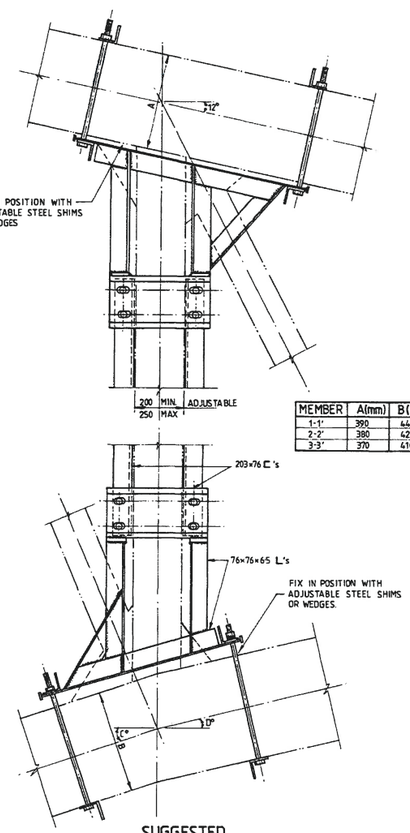


MARKING LAYOUT OF TRUSS MEMBERS
ONE CANTILEVER TRUSS ON NEAR SIDE AND ONE ON FAR SIDE
LAYOUT ON LEFT HAND SIDE OF PIERS IS SYMMETRICAL ABOUT ℄ OF PIER
SCALE 1:50



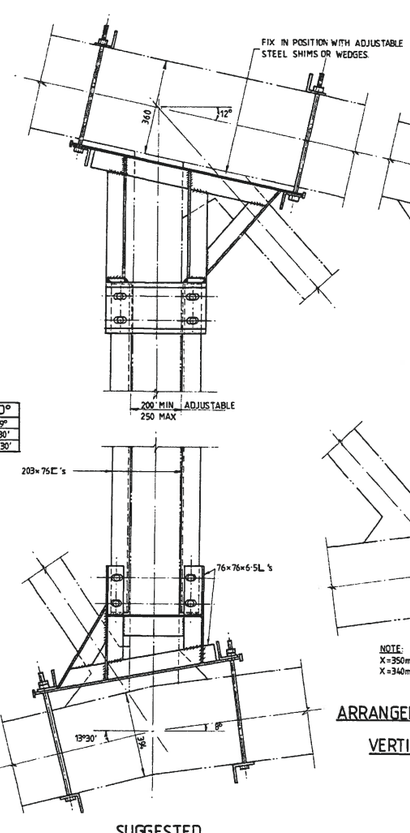
SECTION A-A

METHOD OF REPAIR FOR VERTICAL MEMBERS
SCALE 1:5

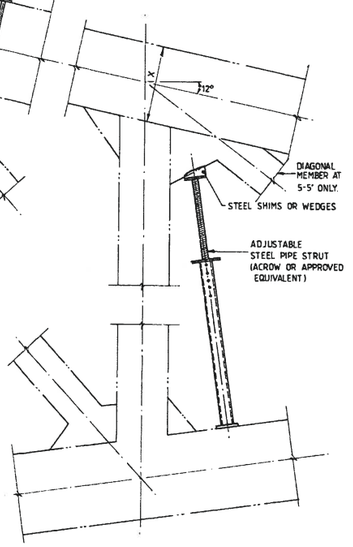


MEMBER	A(mm)	B(mm)	C°	D°
1-1'	390	445	19°	19°
2-2'	380	425	19°	13°30'
3-3'	370	410	13°30'	13°30'

SUGGESTED ARRANGEMENT OF TEMPORARY STEEL STRUTS FOR VERTICAL MEMBERS 1-1', 2-2' AND 3-3'
SCALE 1:10



SUGGESTED ARRANGEMENT OF TEMPORARY STEEL STRUTS FOR VERTICAL MEMBER 4-4'
SCALE 1:10



NOTE:
X=350mm FOR VERTICAL MEMBER 5-5'
X=340mm FOR VERTICAL MEMBER 6-6'

SUGGESTED ARRANGEMENT OF TEMPORARY STEEL STRUT FOR VERTICAL MEMBERS 5-5' AND 6-6'
SCALE 1:10

NOTES

1. ALL VERTICAL MEMBERS WHICH REQUIRE REPAIR WILL BE EXAMINED BY THE SUPERINTENDENT BEFORE AND AFTER REMOVAL OF LOOSE AND DETERIORATED CONCRETE TO ASCERTAIN THE EXTENT OF REPAIR REQUIRED FOR EACH NUMBER.
2. TEMPORARY STRUTS REQUIRED FOR THE VERTICAL WEB MEMBERS MAY BE INSTALLED IN ACCORDANCE WITH THE SUGGESTED ARRANGEMENTS ON THIS DRAWING. HOWEVER THE CONTRACTOR MAY SUBMIT IN HIS TENDER AN ALTERNATIVE METHOD OF TEMPORARY STRUTTING FOR APPROVAL BY THE SUPERINTENDENT. THE TEMPORARY STRUTS SHALL BE ADJUSTED TO TAKE A SMALL INITIAL COMPRESSION BEFORE THE REMOVAL OF CONCRETE FOR REPAIR PURPOSES.
3. LENGTHS AND COMPRESSIVE FORCES IN VERTICAL MEMBERS ARE SHOWN IN THE "MARKING LAYOUT OF TRUSS MEMBERS." THE TENSILE FORCES IN THE TOP BOOM ARE ALSO SHOWN.
4. EXISTING AND NEW REINFORCING BARS SHALL BE CLEANED OF ALL RUST, DIRT, OIL SLAG etc. BY MEANS OF WIRE BRUSHING OR APPROVED METHOD. ACID CLEANING SHALL NOT BE USED.
5. THE VERTICAL MEMBERS SHALL BE RESTORED TO THE REQUIRED SHAPE AFTER THE EXISTING CONCRETE HAS BEEN REMOVED AND REINFORCING REPAIRED. WHERE NEW CONCRETE IS TO BE JOINED TO EXISTING CONCRETE, THE TYPE AND METHOD OF APPLICATION OF BONDING AGENT SHALL BE SUBJECT TO APPROVAL BY THE SUPERINTENDENT.
CONCRETE CHARACTERISTIC STRENGTH: 25MPa AT 28 DAYS.
MAXIMUM SLUMP: 80mm MINIMUM COVER: 25mm MAXIMUM AGGREGATE SIZE: 20mm.
CONCRETE SHALL COMPLY WITH AS 1480-1982, REINFORCING BARS WITH AS 1302-1982, HARD DRAWN STEEL WIRE WITH AS 1303-1984.
WHERE FACES OF TEMPORARY STEEL STRUTS WILL HAVE CONTACT WITH FRESH CONCRETE, THESE FACES FACES SHALL BE COATED WITH OIL.

NOTE: THIS DRAWING SUPERSEDES DRAWING No.16109A.

REFERENCES		REVISIONS				
DRG. No.	TITLE	No.	DATE	DESCRIPTION	BY	APP'D

SURVEY
SURVEY BY .....
DETAIL PLAN No. .....
FIELD BOOK No. .....
LEVEL BOOK No. .....
P.S.M.'s .....
.....
T.B.M.'s .....
.....

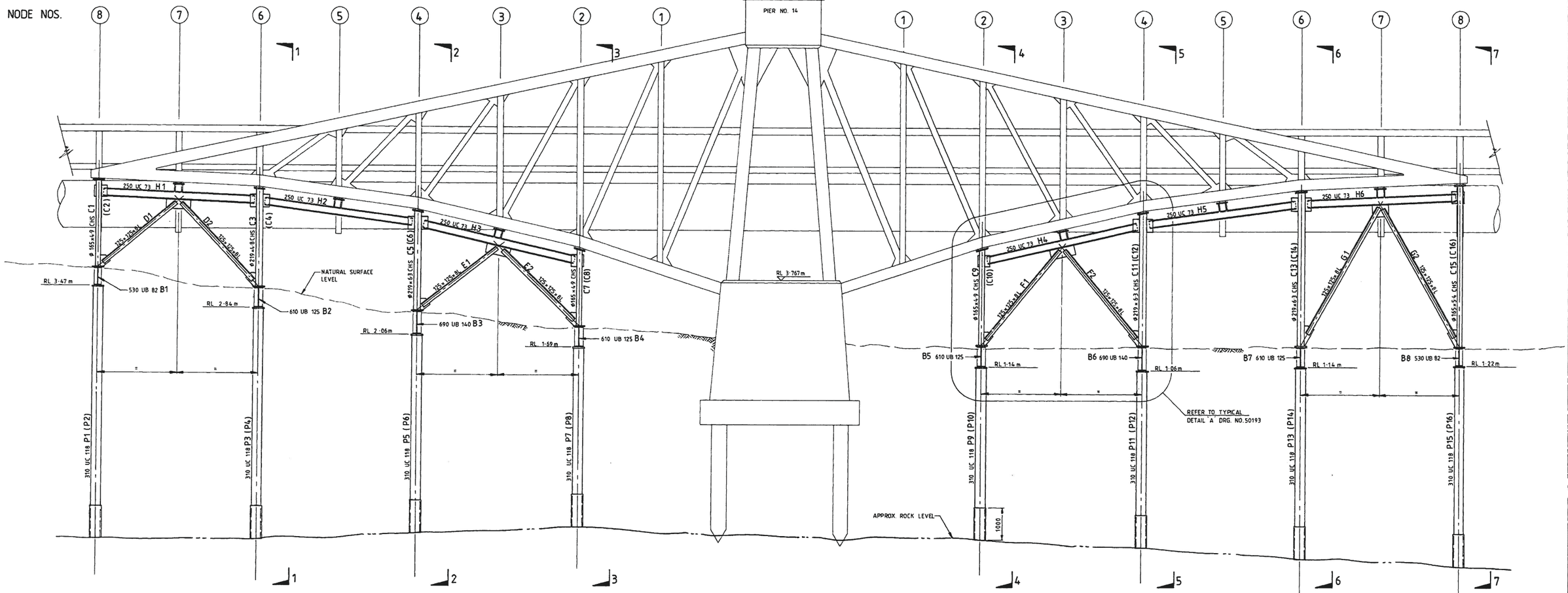
GEELONG AND DISTRICT WATER BOARD
61-67 RYRIE STREET
GEELONG 3220
TEL. (052) 262500
TELEX AA39187
FAX. (052) 218236

OVOID SEWER AQUEDUCT
LOCALITY PLAN AND SUGGESTED ARRANGEMENT OF TEMPORARY STRUTS FOR REPAIR OF VERTICAL MEMBERS

50 182

DESIGNED	DRAWN	CHECKED	SCALES
	P. JOSIPOVIC JUL '87	15/1/88	'AS SHOWN'
ENG. MGR. 15/1/88	EXECUTIVE MGR.	BOARD ENG. 15-1-88	PLAN: SECT: HORIZ: VERT:

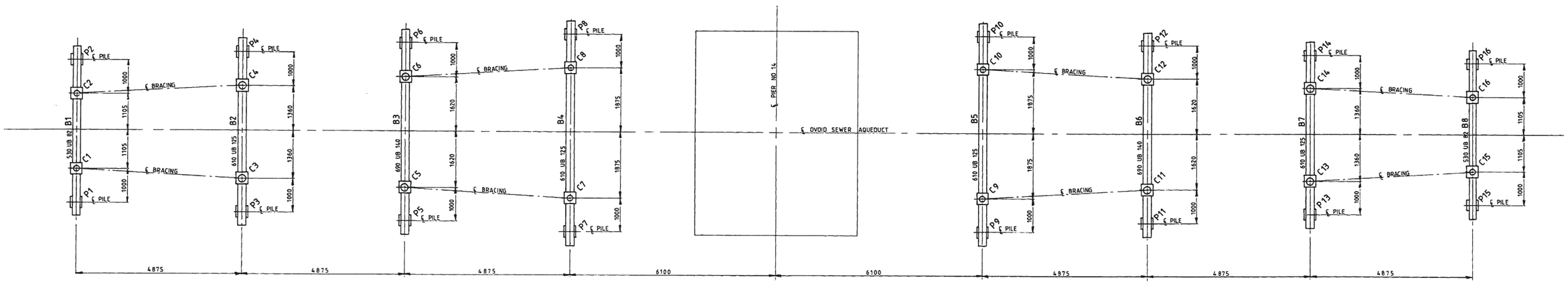
81



EAST ELEVATION PIER NO. 14 SOUTHERN END

SCALE; 1:50

NOTE FOR SECTIONS 1-1 2-2 3-3 4-4
5-5 6-6 & 7-7 REFER TO DRG. NO. 50192



FOOTING PLAN

SCALE; 1:50

NOTES

FOR GENERAL NOTES REFER TO DRG. NO. 50193

REFERENCES

DRG. No.	TITLE
50192	STEELWORK DETAILS SHEET 1 OF 2
50193	STEELWORK DETAILS SHEET 2 OF 2

REVISIONS

No.	DATE	DESCRIPTION	BY	APP'D

SURVEY

SURVEY BY ..... S. SIM
DETAIL PLAN No. .....
FIELD BOOK No. .....
LEVEL BOOK No. .....
P.S.M.'s .....
.....
T.B.M.'s .....
.....

GEELONG AND DISTRICT WATERBOARD
61-67 RYRIE STREET
GEELONG 3220
TEL. (052) 262500
TELEX AA39187
FAX. (052) 218236

OVOID SEWER AQUEDUCT
PIER NO. 14 SUPPORT STRUCTURE
GENERAL ARRANGEMENT

50191

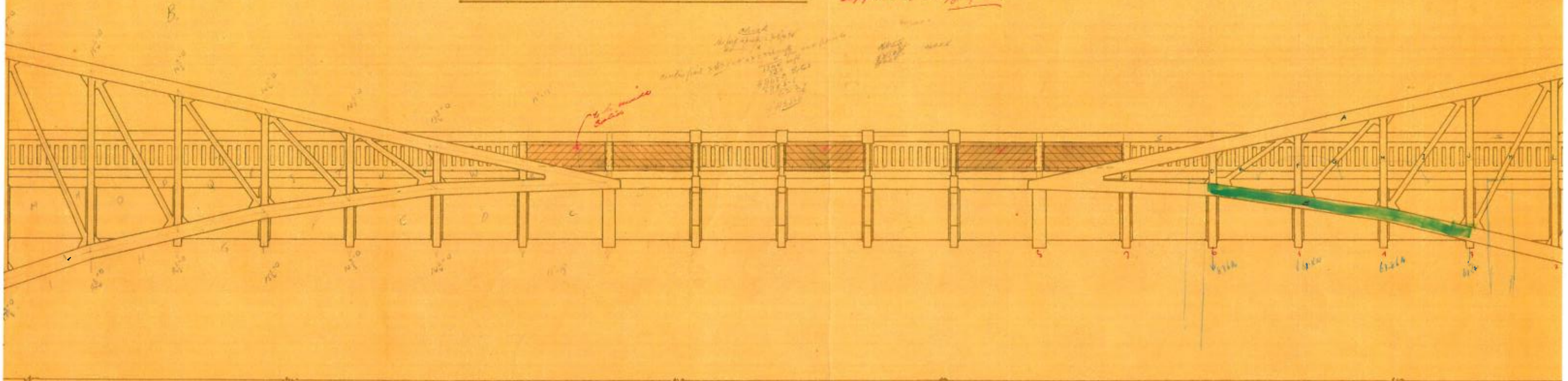
DESIGNED	DRAWN	CHECKED	SCALES
R.LANGEDIJK.	A.HODGSON AUG'89		AS SHOWN
ENG. MGR. 16-10-89 J.R.Jackson	EXECUTIVE MGR. M.B.Hunter 3/1/03		PLAN REGT. HORIZ: VERT:

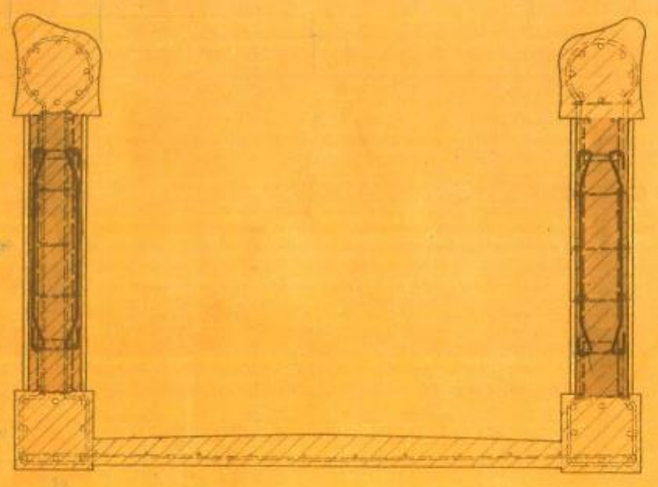
B1

REINFORCED CONCRETE AQUEDUCT OVER THE RIVER BARWON
GEELONG WATERWORKS & SEWERAGE TRUST.

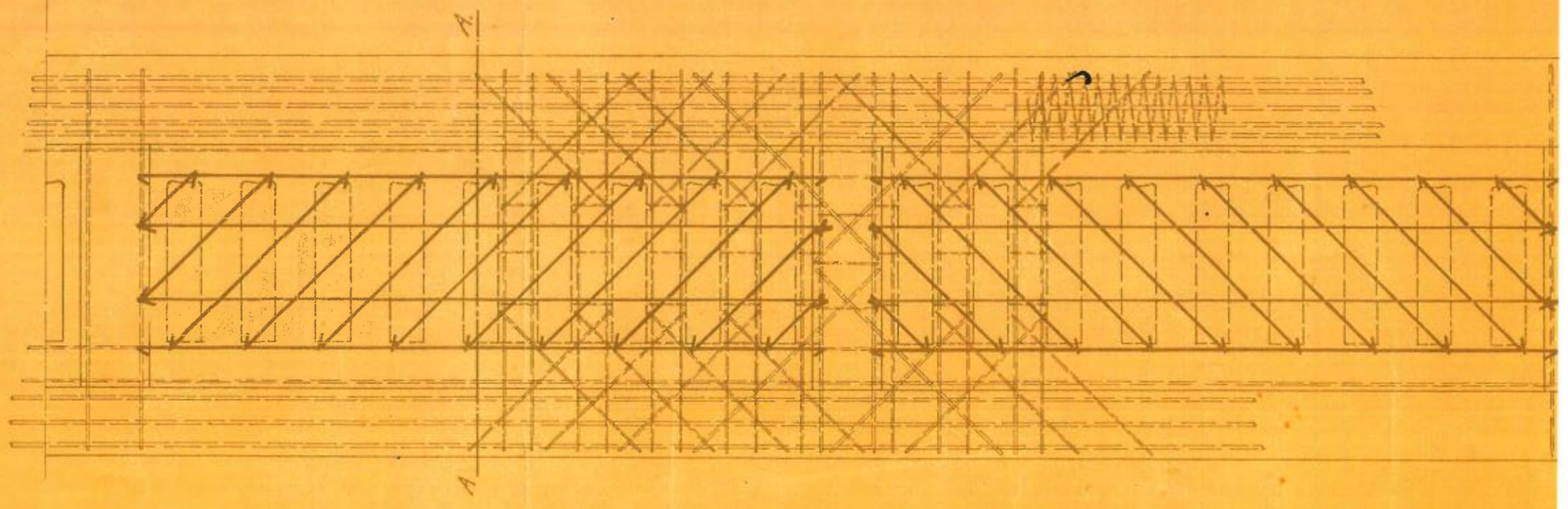
SCALE ¼ IN. & 1½ INS TO ONE FOOT.

Copy of Tracings supplied to G.W.S. Board 10-9-23





SECTION A–A.



ELEVATON of CENTRAL GIRDER at POINT OF SUPPORT

Existing Reinforcement shewn dotted
Additional Rods shewn full.

DESIGNED BY STEEL AND CONCRETE CONSULTANTS
SWITCHGEAR CONSTRUCTION
GRAVATOMIC

SCALE 3/4" TO ONE FOOT

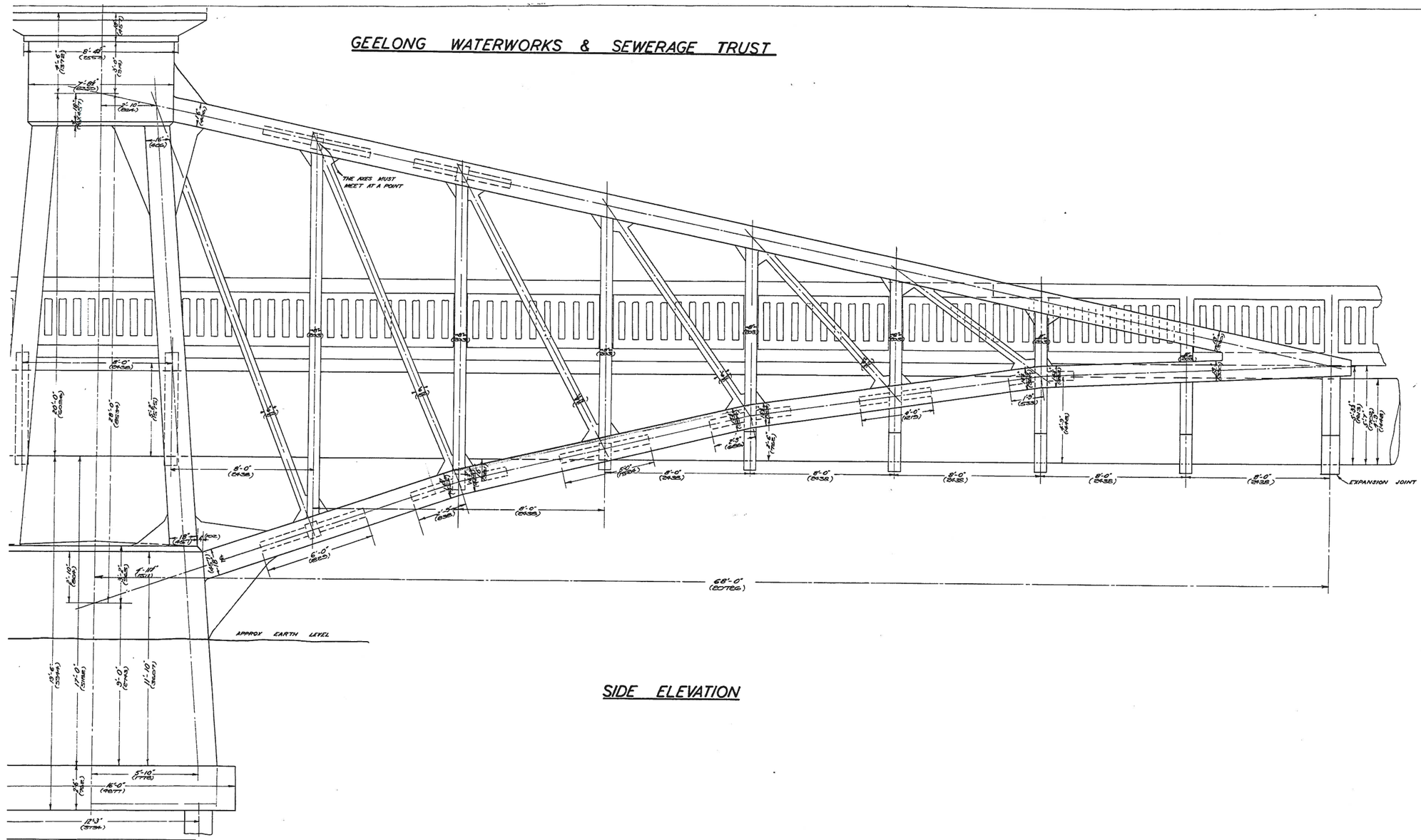
NOTE— DISTRIBUTION OF LOADS IN UPPER BOOMS ARE SUBJECT TO ALTERATION

NOTE— COUNTERWEIGHTS TO BE STEPPED STRUCK AS SHOWN THUS

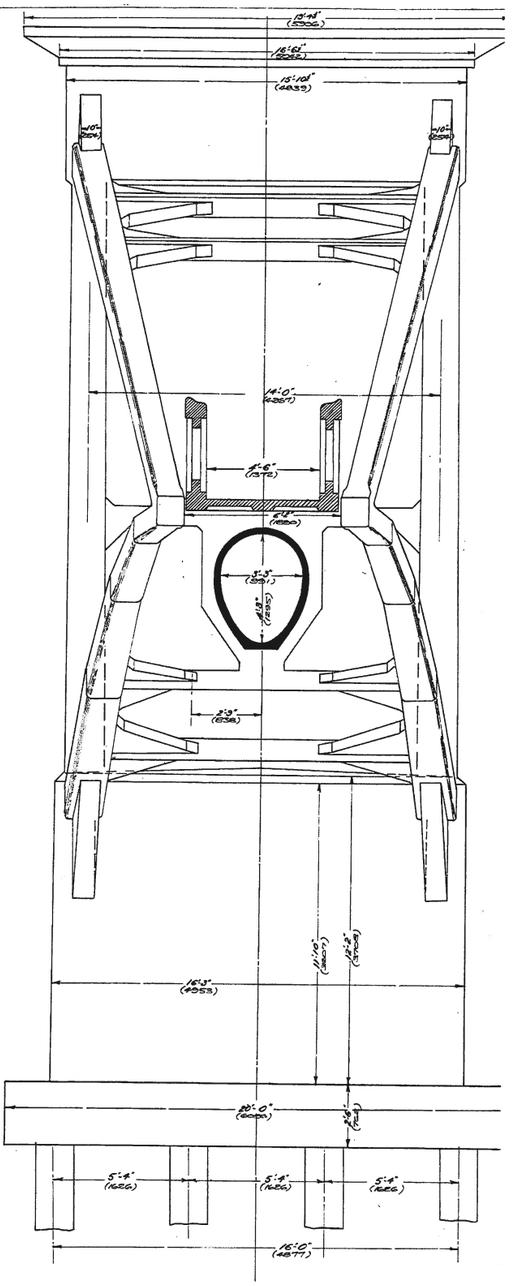
END ELEVATION

SIDE ELEVATION

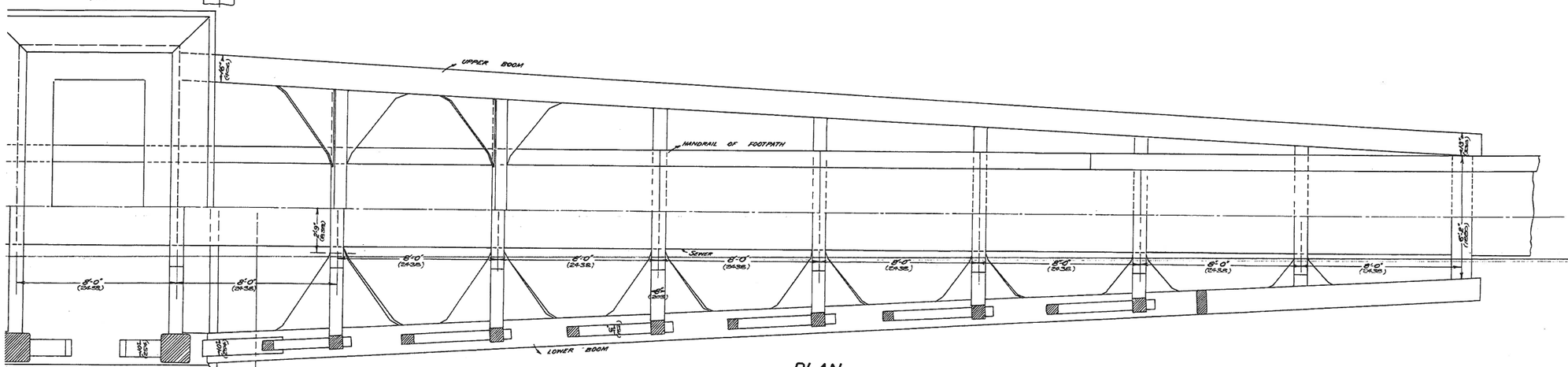
GEELONG WATERWORKS & SEWERAGE TRUST



SIDE ELEVATION



END ELEVATION

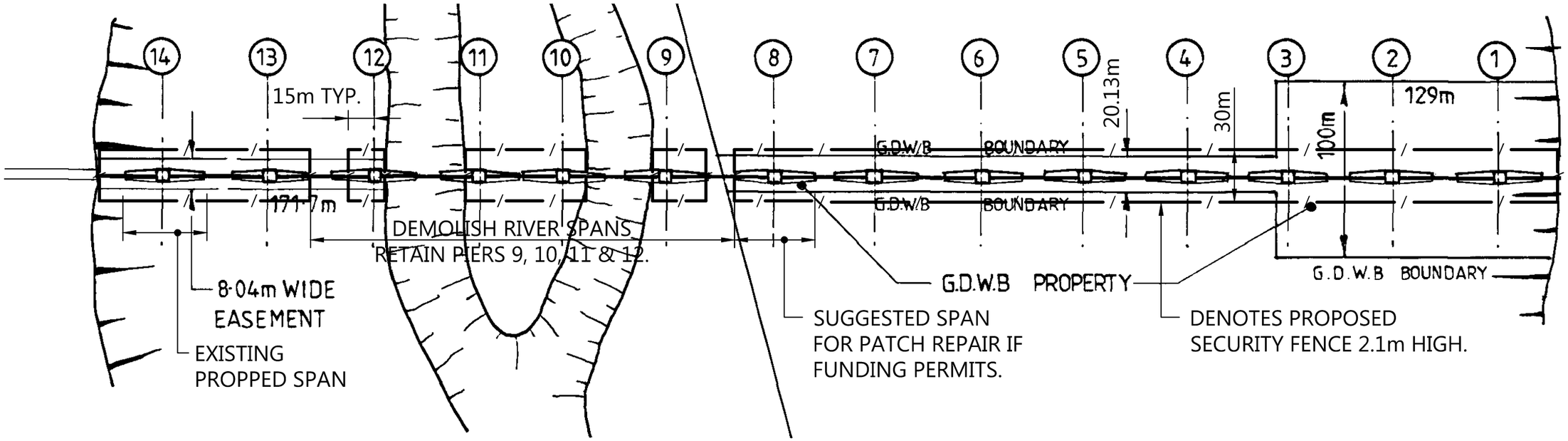


PLAN

TRACED OFF ORIGINAL BLUE PRINT
BY G.R. PLUMMER 23-8-1956

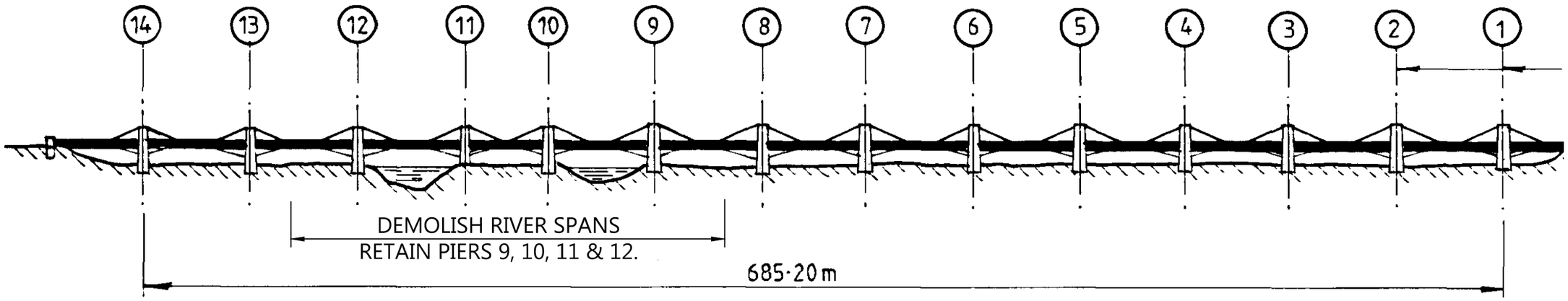
APPENDIX G

SUPPLEMENTARY SUPPORT PROPOSAL AND PROPOSED DEMOLITION EXTENT DRAWINGS



LOCALITY PLAN

SCALE 1:2500



SIDE ELEVATION

SCALE 1:2500

Issue	Description	Drwn	Ckd.	Appd.	Date
P1	CONCEPT - NOT FOR CONSTRUCTION	A.C.	K.M.	K.M.	11.04.16

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North

Client: BARWON RIVER PARKLANDS STEERING COMMITTEE

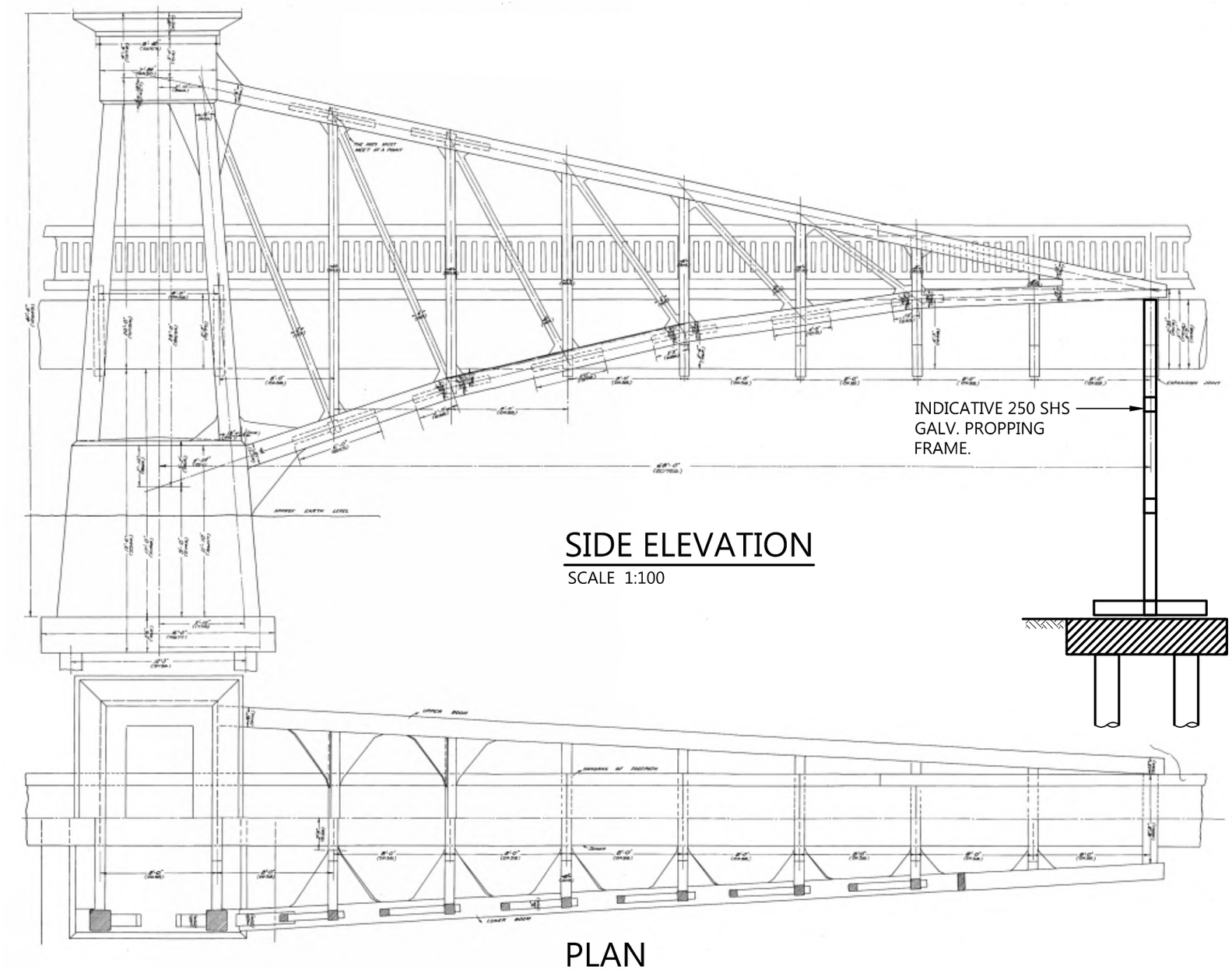
Project: BARWON RIVER AVOID SEWER AQUEDUCT, BREAKWATER ----

Title: PROPOSED MINIMUM DEMOLITION EXTENT

Designed by: K.M.
Drawn by: P.P.N.
Date: APRIL 2016
Scale: 1:2500 @ A3
Status: CONCEPT

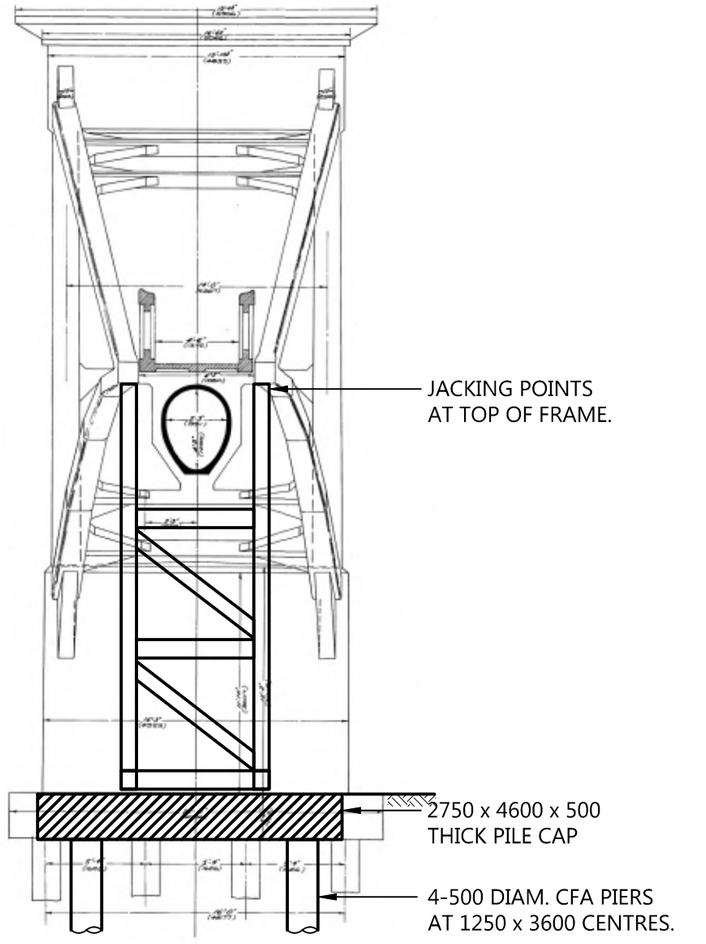
MacLeod Consulting
Suite D, 450 Chapel Street
South Yarra, Vic. 3141
Ph: 03 9234 1140
macleodconsulting.com.au

Project No. 2151
Drawing No. SK1
Rev. P1



SIDE ELEVATION

SCALE 1:100



END ELEVATION

SCALE 1:100

PLAN

SCALE 1:100

Issue	Description	Drwn	Ckd.	Appd.	Date
P1	CONCEPT - NOT FOR CONSTRUCTION	A.C.	K.M.	K.M.	11.04.16

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North

Client: BARWON RIVER PARKLANDS STEERING COMMITTEE

Project: BARWON RIVER AVOID SEWER AQUEDUCT, BREAKWATER ----

Title: PROPOSED STRUCTURAL CAPACITY ENHANCEMENT

Designed by: K.M.
Drawn by: P.P.N.
Date: APRIL 2016
Scale: 1:100 @ A3
Status: CONCEPT

MacLeod Consulting
Suite D, 450 Chapel Street
South Yarra, Vic. 3141
Ph: 03 9234 1140
macleodconsulting.com.au

Project No.: 2151
Drawing No.: SK2
Rev.: P1