Preserving our Cultural Heritage
Rehabilitation of the Church Street Bridge

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SYNOPSIS

The Church Street Bridge is an 85 year old elegant three span reinforced concrete arch structure spanning over the Yarra River and CityLink (Monash freeway) in Melbourne. The bridge is on an important arterial route connecting the inner municipalities of Yarra and Stonnington and carries vehicular traffic, trams, pedestrians, cyclists and extensive services. In 1998 the northern span was modified to increase the height clearance over CityLink. The bridge was granted heritage status by Heritage Victoria in 2001.

Following the granting of heritage status to the bridge in 2001 and the reclassification of Church and Chapel Streets from local roads to an arterial road in 2004, VicRoads assumed responsibility for the maintenance of the bridge and is currently undertaking extensive rehabilitation works.

A number of major investigations have been undertaken to determine the nature and extent of deterioration in the bridge and this paper outlines their findings. These investigations have established that the bridge is characterized by concrete of low compressive strength, high porosity and permeability and is significantly carbonated in all areas of the bridge structure, leading to corrosion in the reinforcement and associated significant spalling and cracking of the concrete.

The paper provides details of the remedial options considered and the rehabilitation methodology adopted which includes conventional concrete patch and crack repairs, the application of a high performance protective coating and waterproofing of the bridge deck.

The works had to be planned to accommodate stringent project requirements in regards to public safety, heritage requirements, impact on traffic and environmental constraints. Works commenced in 2005 and are scheduled to be completed in 2010. The paper also provides an overview of progress to date.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

The Church Street Bridge is an 85 year old three span reinforced concrete arch structure (Fig 1). The bridge, which is situated on the boundary of the municipalities of Yarra and Stonnington in Melbourne, carries a busy arterial road (Church and Chapel Streets) over CityLink (Monash Freeway) and the Yarra River. The bridge provides for pedestrians, cyclists, motor vehicles and trams and also carries extensive services located under the deck.

Prior to 2001, maintenance of the bridge had been the responsibility of the local municipalities. Following the granting of heritage status to the bridge in 2001 and the reclassification of Church and Chapel Streets from local roads to an arterial road in 2004, VicRoads took over responsibility for the management of the road and the bridge. Funds have been allocated to complete extensive rehabilitation of the bridge including making provision for permanent access under the bridge deck to facilitate ongoing inspections and improved maintainability.

A number of investigations have been undertaken over the last 10 years to establish the condition of the bridge and the type and extend of deterioration. These also included detailed mapping of the defects to enable more accurate scoping of the works and improved estimates of repair costs to be made.

The investigations established that the bridge was characterized by concrete of low compressive strength, high porosity and permeability and was significantly carbonated in all areas of the bridge structure, leading to corrosion in the reinforcement and associated significant spalling and cracking of the concrete. The deterioration in the structure was significantly exacerbated by the presence of cracks in the deck soffit (made worse due to the dynamic effects of trams passing over the bridge) and leakage of the deck joints that allowed moisture to seep into the concrete elements below the deck.

Various rehabilitation options were assessed based on a life cycle costing analysis including waterproofing of the bridge deck, conventional patch repairs with and without anti-carbonation coatings, impressed current electrochemical re-alkalisation and the ‘do nothing’ alternative which was quickly discounted. Based on this detailed assessment the final adopted works included ‘make-safe’ works which required the removal of all delaminated concrete on the bridge soffit and construction of a permanent maintenance access walkway under the bridge deck (Stage 1); waterproofing of the bridge deck and construction of a new concrete overlay, replacement of balustrades and expansion joints, construction of new concrete traffic barriers and replacement of the old tramlines (Stage 2) and finally, conventional patch and crack repairs and the application of protective coatings to all concrete elements (Stage 3).

This paper reports on the condition investigations undertaken, the alternative remedial treatments considered and the treatment finally approved. The rehabilitation works which are currently underway are also described.
2 BRIDGE DESCRIPTION

2.1 Bridge Geometry
The bridge comprises two 29.6m end spans and one 32.3m centre span with an overall length of approximately 105m. The overall width of the bridge is 20.1m between faces of balustrades and provides for two 2.7m footpaths, two 1.2m bicycle lanes and four traffic lanes of average width of 3.1m. The two inner traffic lanes are shared with trams (Fig 2).

2.2 Structural Details

Superstructure
All spans comprise 3 pinned arches which support transverse reinforced concrete walls (crosswalls) which in turn support the reinforced concrete deck. The spans over the river each comprise 7 No. reinforced concrete arch ribs carrying 10 No. crosswalls. The span over CityLink comprises 6 No. steel box arch ribs and 2 No. outer steel L shaped arch fascia ribs, similarly carrying 10. No. crosswalls (Fig 3). The deck contains 9 transverse expansion joints, which are located directly above the arch pins.

Substructure
All piers and abutments are of reinforced concrete construction down to just below the arch springings. Below the arch springings the pier and abutment pilecaps appear to be constructed of mass concrete.

Foundations
The pier foundations consist of reinforced concrete piles driven to bedrock with the southern pier foundation further strengthened with 6 No. 2.1m diameter cylinders, also founded on bedrock. The abutment foundations were originally designed to be carried on piles driven to bedrock. The piled foundations design was subsequently changed to a design which specified 2 No. caissons of 9.1m diameter and12m deep, at each abutment (Ref 1).

Design Load
The bridge was designed to be able to support a four wheeled 50 ton tractor pulling two 20 ton, four wheeled wagons (total weight: 90 ton). This compares with modern loadings such as M1600 loading, (160 tonne) or T44 loading, (44 tonne).

3 HISTORY

By the early twentieth century the need for a new bridge over the Yarra River was evident as the existing iron box girder bridge was inadequate in terms of traffic and structural capacity. In 1919 the local councils Prahran and Richmond (now Stonnington and Yarra) and Melbourne, the Tramways Board and the State government agreed to share the cost of construction of a replacement bridge and a competition for its design was held.
The competition was won by prominent Melbourne architects of the time, Thomas Ashworth & Harold Desbrowe Annear. The bridge was designed by a team headed by John Laing an engineer who had started his career with Sir John Monash. Three pinned arch construction was adopted because of the ease of analysis and because it would allow for minor settlements of the foundations.

In 1921 the Reinforced Concrete & Monier Pipe Company (set up by Sir John Monash) won a contract to build the bridge for approx £88,000. The bridge was opened on 8 July 1924, at a final cost of £101,727-10 shillings of which £2,450 was the architectural and engineering fee (i.e. 2.4% of cost of bridge).

In 1998 the northern span was modified to increase the clearance over the CityLink section of the Monash Freeway. As part of these modifications, concrete repairs were carried out to this span and stairs were also constructed at the northern pier connecting the top of the bridge with a bicycle path adjacent to CityLink below.

The bridge is now the only remaining 3 pin arch bridge in Victoria (Ref 1 and Ref 2).

4 HERITAGE LISTING

The Church Street Bridge was granted heritage status on the 8 August 2001 and is listed on the Victorian Heritage Register, VHR No. H1917.

From the beginning, the committee set up to procure the design and construction of the bridge insisted upon, quote: (Ref 2) ‘a substantial, beautiful and permanent structure that would be an investment in the future and contribute to Melbourne’s already considerable architectural legacy’.

As such, the bridge contains many decorative features including reliefs depicting the coats of arms of Victoria and Melbourne on the piers, and, reliefs of the coats of arms of the Cities of Richmond and Prahran (now Cities of Yarra and Stonnington respectively) on the abutments (since removed). Pier bases have been formed into prow-like cutwaters and eight lighting columns on the deck include decorative wreaths, scrolls and finials and support lanterns carried on ornate elaborate metal work. The central span is slightly longer for visual balance. The bridge is of particular historical and architectural significance because, quote (Ref 2):

**Historical**

The bridge is a major metropolitan bridge which crosses a major river and forms a major functional role in linking two densely populated inner suburbs, and the bridge is credited with a civic role in beautification of the city (i.e. it employs the use of classical forms and ornament, symbolising a relationship with a glorious past).
Architectural
The bridge is a fine example of the application of reinforced concrete technology applied to a bridge structure. This technology is clearly expressed in the separate ribs of the main spans and the open spandrels above, clearly distinguishing it from a bridge of traditional masonry construction. Through composition, proportioning and ornamental treatment in a grand, if sparse, classically inspired manner, the bridge gained a professional quality and symbolic importance as a major urban river crossing. The bridge is an example of a large institutional work by important Melbourne architects.

5 INVESTIGATIONS, CONDITION ASSESSMENT AND TREATMENT OPTIONS

5.1 General
Various investigations, including visual surveys, laboratory testing and load capacity assessments of the bridge have been undertaken over the past 10 years. Recent investigations have been carried out to determine as-built details and the condition and structural adequacy of various bridge components including the balustrades, expansion joints and footpath deck slab. More comprehensive mapping of faults and trialing of repair methods and materials have also been undertaken. A key issue that has emerged from these investigations is the poor quality of the concrete.

5.2 Initial Investigation (1998)
A condition survey report was prepared in 1998 (Ref 3) for Transfield Obayashi Joint Venture (builder of CityLink) in regards to the proposed modifications to the north span. The report included a detailed presentation of defects throughout the structure (i.e. concrete spalling, delaminations and cracking, Fig 4) and findings on the likely causes of the deterioration based on diagnostic study and associated laboratory testing.

The 1998 condition survey report stated that:
• the primary cause of the deterioration was due to the very low strength, highly porous, permeable and carbonated concrete leading to the corrosion of the underlying reinforcement, with corrosion accelerated by water penetration, particularly through the deck slab and expansion joints;
• the level of corrosion in the reinforcement was not high and that generally little loss of section had occurred; and
• chloride levels were generally low except at the level of the pier pile caps but that this was not expected to pose a problem as the pile caps, appear to be unreinforced.

Tabulated below are some typical test results:

<table>
<thead>
<tr>
<th>Concrete/Steel Properties</th>
<th>Test Results</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>13.5 - 21.5 MPa</td>
<td>Uniform throughout structure</td>
</tr>
<tr>
<td>Cement content</td>
<td>180 - 265 kg/m³</td>
<td>Very low</td>
</tr>
<tr>
<td>Water/Cement ratio</td>
<td>0.77 – 1.11</td>
<td>Very high</td>
</tr>
<tr>
<td>Density</td>
<td>2,200 - 2,320 kg/m³</td>
<td>Uniform throughout structure</td>
</tr>
</tbody>
</table>
5.1 Concrete/Steel Properties (cont)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Results (cont)</th>
<th>Comments (cont)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonation depth</td>
<td>40 - 100 mm</td>
<td>Very high</td>
</tr>
<tr>
<td>Chloride content:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck</td>
<td>1748 (coulombs)</td>
<td>Moderate content</td>
</tr>
<tr>
<td>&quot;</td>
<td>5778 &quot;</td>
<td>High content</td>
</tr>
<tr>
<td>Sorptivity (deck &amp;</td>
<td>0.351 &amp; 0.187</td>
<td>High porosity</td>
</tr>
<tr>
<td>pier)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphate content</td>
<td>&gt; 2% generally</td>
<td>Low content</td>
</tr>
<tr>
<td>Corrosion rate</td>
<td>(0.001-0.031) 10^-6</td>
<td>Very low</td>
</tr>
</tbody>
</table>

The report recommended the following remedial measures be undertaken:

- sealing (waterproofing) of the deck surface;
- conventional patch and crack repairs,
- application of a protective anti-carbonation coatings to all bridge elements above water level; and
- application of a silane or silane-siloxane coating to the piers at the waterline/splash zone.

Whilst the 1998 report considered various remedial options including concrete realkalisation as well as conventional repairs plus protective coatings, the recommendations were based on a qualitative assessment of these options as a life cycle cost assessment (LCCA) was not undertaken.

5.3 Initial Specification and Cost Comparisons of Remedial Options (2002)

A subsequent 2002 report (Ref 4) to VicRoads presented a LCCA for the following remedial options:

- Option 1: conventional repairs and application of a high performance protective coating;
- Option 2: conventional repairs with full realkalisation and application of a decorative coating; and
- Option 3: conventional repairs with partial realkalisation and application of a decorative coating.

This LCCA which was based on the 1998 condition survey report and limited information on rates for remedial works, assumptions on traffic management and access and mobilization costs, showed that Option 2 was the most expensive option, but that the difference in life cycle costs between Options 1 and 3 was too small (i.e. $6.4M compared to $6.9M (i.e. within 10%) to justify recommending one option over the other.

The report therefore recommended that the LCCA be revised once more accurate information was available.

5.4 VicRoads Assessment & Approved Rehabilitation Strategy (2005)

In March 2005, VicRoads approved funding ($9.0M) for implementation of a rehabilitation and long term protection strategy for the bridge (Ref 5).
VicRoads undertook a further LCCA of Option 1 and based on the results of this assessment and the work carried out in 2002 (Ref 4) approved the adoption of Option 1, namely, conventional patch and crack repairs, provision of a waterproofing membrane to the deck and application of a high performance protective coating to all concrete elements.

The electrochemical realkalisation related options were not considered favorably due to a lack of confidence in achieving full restoration of the alkalinity of the cover concrete and the zone around the steel reinforcement over such large full scale works. The initial cost outlay in conjunction with the life cycle costing analysis also influenced the decision to not proceed with the realkalisation options. The approved delivery strategy required the works be completed in 3 main stages over a period of 4 to 5 years and to meet the following objectives:

- Public Safety: ensure that motorists, pedestrians and river traffic are safe from concrete spalls falling from the bridge.
- Design Life: provide for a design life in excess of 55 years.
- Heritage: maintain the bridge’s heritage status by satisfying all heritage requirements.
- Environment: satisfy noise, air, water and land pollution control standards.
- Financial: minimise capital rehabilitation costs and on-going maintenance costs.
- Traffic: minimise disruption to all traffic on or under the bridge.

5.5 Additional Investigations

Following the commencement of remedial works in 2005, additional investigations and surveys have been carried out in order to address latent conditions arising during these works and to refine the scope and cost estimates for the works to be completed under Stage 3. These investigations included:

‘As-built’ details
- Bridge geometry;
- Location and status of service authorities’ assets;
- Expansion joints (i.e. clarify, condition and extent of each joint across the bridge deck and spandrel walls);
- Footpath slabs, (i.e. clarify condition and structural capacity of the footpath slabs and determine if strengthening was required); and
- Balustrades (i.e. determine capacity of balustrade to support temporary access scaffold; determine the containment capacity of the balustrade and the necessity to upgrade the balustrade or to provide an additional traffic barrier).

Detailed mapping of cracks and defects

The initial limited surveys as reported in the 1998 condition survey report (Ref 3), were undertaken under less than ideal conditions and further deterioration would have occurred since then. In 2005, revised defects drawings were produced based on another recent and more comprehensive survey of the defects. This information was required to enable more accurate estimates of repair quantities and associated costs to be made.
**Detailed visual examination and a defects survey (2008)**
Following the detailed mapping of faults referred to above, a further more detailed survey (Ref 6) was carried out on four selected representative cells to better understand the nature of any deterioration and its causes and to confirm that the adopted repair strategy (i.e. conventional patch and crack repairs and coatings) was still appropriate.

The 2008 survey included a detailed visual examination and a defects survey of each cell, as well as half-cell potential mapping, concrete cover surveys and condition surveys of reinforcement in areas where the concrete was visually in good condition. The investigation report noted that the concrete in the deck soffit is significantly carbonated to depths beyond the steel reinforcement and that there exists the possibility of corrosion of the reinforcement if moisture is present. It was also noted that the cover to the soffit reinforcement was only (20 – 40 mm). This was particularly evident in the areas of the soffit directly under the tram rails.

Whilst this report favored the replacement of the entire soffit cover concrete as a more long lasting repair, (compared with conventional patch and crack repairs) the report noted that other factors (e.g. constructability at this particular site, structural implications) would need to be also considered in determining an appropriate repair strategy.

**Trial remedial works**
Trialing of various methods and materials for surface preparation, application of fairing coats, crack repairs and coatings were undertaken in one cell of the bridge to determine optimum repair methods and to gain Heritage Victoria’s approvals to any proposed surface finishes and coatings. These trials provided more detailed information from which improved estimates of quantities and costs for the Stage 3 works could be prepared (Fig 5).

**Pier pile cap and piles**
A condition inspection of the river pier pile cap, at and below water level was undertaken. This examination revealed that these elements are in good condition and only require minor treatment to mitigate the development of scour in the future. The pilecap is subject to chloride ingress as the river is in the tidal zone at this location. This is not considered a problem because, based on a cover meter survey of the pilecap no reinforcement was detected.

**Lighting columns**
A detailed inspection of the lighting columns is planned to determine appropriate repair methodologies for the many concrete features including decorative entablatures, scrolls, wreaths, finials and the decorative metal lanterns. Heritage Victoria approval is required to any proposals which may involve modifications to these elements. The existence of lead paint on the metal (copper or copper alloy) further complicates any proposed remedial works (Fig 6).
6 STATUS OF REHABILITATION WORKS

6.1 Stage 1
A number of ‘make safe’ works have been undertaken over the last 10 years, the most recent completed by VicRoads in late 2005, just prior to the Melbourne Commonwealth Games. These works were required to reduce the risk of spalled concrete and debonded render falling onto CityLink, pedestrians/cyclists and river traffic. Most of the deteriorated concrete removed was from the soffit of the bridge deck. A small number of other concrete elements needed to be treated including service slabs, spandrel walls and arch ribs.

The long term maintenance strategy assumes that regular inspections of the bridge will be carried out and that it is expected that minor repairs and recoatings will be required every 10 years 15 years. To facilitate future inspections of the bridge a light steel framed maintenance access walkway which extends along the full length of the bridge and which has transverse branches at the expansion joints has been constructed (Fig7). Whilst the entire bridge deck cannot be viewed at close range from this walkway, it nevertheless will enable a reasonably close-up view of the majority of the soffit and any suspect areas can be followed up using appropriate access.

6.2 Stage 2
Stage 2 works which include rehabilitation of the bridge elements above the deck (with the exception of the ornate lighting columns), were completed under two contracts as follows:

Contract 1
These works required the existing surfacing over the roadway (asphalt and concrete encased tramrails) to be removed. Repairs were then undertaken to the top surface of the concrete deck and the expansion joints. This was followed by laying of new tramlines, application of a high performance waterproofing membrane to the top of the deck (Fig 8) and finally, reinstatement of the surfacing by means of a continuous reinforced concrete overlay. The overlay was debonded from the deck at all expansion joints to account for differences in articulation between the ‘continuous’ overlay and the ‘simply supported’ deck. Protection of the original deck slab against ingress of water was further enhanced by the addition to the overlay concrete of fibre reinforcement to minimize potential cracking and a waterproofing admixture to further improve impermeability.

These works were particularly challenging as they had to be completed within a tight time frame and under a full bridge closure of only 18 days. High liquidated damages were included in the contract because of the risk of incurring high OPR (i.e. Operational Performance Regime) penalties from the State government’s Department of Infrastructure at the time, should the trams passing over the bridge not be able to resume services as originally programmed.
Contract 2
These works which included rehabilitation of the footpath and balustrades were also challenging because of the high risk associated with the safe removal of the old concrete balustrades and the erection of precast replicas without impacting on traffic under the bridge (Fig 9).

During the works it was discovered that the condition of the footpath deck slab had greatly deteriorated and that strengthening of the slab was required. The other major item under this contract included the construction of new traffic barriers along both kerbs. The addition of barriers presented a number of conflicting road safety issues which needed to be balanced, i.e. the safety needs of tram users, cyclists, pedestrians and motorists on the bridge verses safety needs of traffic under the bridge (Fig 6).

A number of latent conditions were encountered during the works, namely the extent and condition of the expansion joints (i.e. they were not always continuous over the full width of the bridge) and the condition of the deck slab. Existing details encountered at the ends of the bridge adjacent to the abutments were also different to what was anticipated based on the limited documentation available. All works under both contracts have now been completed.

6.3 Stage 3
Preconstruction activities for the Stage 3 rehabilitation works are almost complete (March 2009) and the works are scheduled to be completed by June 2010. The works include rehabilitation of the eight lighting columns and repairs to the remaining concrete elements including the deck soffit and the substructure.

Lighting columns
In addition to conventional patch and crack repairs to the lower plain sections of the lighting columns (i.e. rectangular and ionic profiles), the lighting columns require specialized repairs to the many ornate features incorporated in the upper sections (i.e. scrolls, wreaths, finials and entablature). Final specifications for the specialized repairs and the restoration of the metal lanterns and outreaches assemblies, including the treatment of the lead paint, are subject to the findings of a detailed investigation currently underway.

Deck Soffit and Substructure
These works include conventional patch and crack repairs and protective coatings to the deck soffit and substructure elements such as the spandrel walls, crosswalls, arches, piers (to water level), abutments and associated wingwalls, and the stairs at the northern pier. Some decorative features (coats of arms, plaques, brackets incorporated into the cantilever slabs supporting the footpaths) will need similar specialised repairs similar to the lighting columns. Other works required to bring the structure to current environmental and OH&S standards, include the provision of a drainage system (to capture deck runoff through the deck scuppers and any seepage through the expansion joints at the piers and abutments) and the provision of lighting in the pier cavities.
These works present a number of access, traffic management and OH&S challenges including the undertaking of repairs to the structure at a significant height above water and traffic, and adjacent to many services (gas, water, power, communications and motor traffic and trams).

6.4 Costs
The revised estimated cost of this project is $13.9M. This compares with the original estimated cost of $9.0M in 2005, prior to the completion of the additional investigations and detailed design referred to in earlier in this report.

Additional costs have resulted due to the following:
- lack of bridge records and few original design drawings available;
- lack of drawings of subsequent modifications (with the exception of the modifications carried out to the span over CityLink);
- updated detailed defects surveys of the bridge were obtained after VicRoads approved the project strategy;
- a decision to replace the existing concrete balustrades with replicas as opposed to the original plan to repair the balustrades;
- the need for additional structural improvements including strengthening of the footpath deck slabs and the addition of a concrete barrier along both sides of the bridge;
- additional works due to a number of latent conditions encountered during construction as referred to earlier in this paper;
- higher tendered prices for the works associated with costing in additional risk and constraints due to location of the works and the many affected stakeholders; and
- delivery of the works under various contracts and over a number of years, due to funding constraints, compared to delivery of the works under one contract.

7 CONCLUSIONS

This paper has provided an outline of the history of the Church Street Bridge and why it has been heritage listed. The paper has described the condition assessments carried out, the various rehabilitation options considered, the remedial treatment adopted and finally, the works completed to date.

The paper has also detailed the challenges and difficulties faced in regards to planning and carrying out rehabilitation works on this bridge due to a lack of documentation, the poor quality concrete used in its construction, the requirements of the many stakeholders and funding constraints.

This rehabilitation project has demonstrated the importance of completing thorough condition investigations and trial repairs, and, completing an as-built survey of the entire structure prior to embarking on detailed designs, specifications and delivery of the works.
8 REFERENCES

1. Church Street Bridge *(Notes provided by D Beauchamp, Forensic and heritage Consultant, based on information from City of Stonnington, records, undated).*

2. Church Street Bridge *(Victorian Heritage Database, VRH No. H1917).*


4. VicRoads Church Street Bridge, Report on Cost Comparison of Remedial Options *(GHD, June 2002).*

5. Project Business Case – Church Street Bridge Rehabilitation *(VicRoads Project Review Committee Presentation, 24 March 2005).*

6. Investigation of concrete and rehabilitation needs for the Church Street Bridge: Consolidated Report *(A Shayan, A Xu & R Salamy, ARRB, Jan 2008)*

Figure 1: View of the east side of Church Street Bridge from the south bank
Figure 6: Barriers, balustrades and Lighting columns

Figure 7: Maintenance access walkway

Figure 8: Deck Rehabilitation and waterproofing

Figure 9: Replacement of existing traffic barriers with replicas