William Barak Bridge

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Peter Hensley is the Principal Bridge Engineer for Kellogg Brown & Root Pty Ltd (KBR). Prior to joining KBR Mr Hensley was employed by VicRoads where he gained extensive experience in the design and construction of roads and bridges. He has designed and managed design teams for over 500 bridges, including some 290 bridges in India, Cambodia, New Zealand and Western Samoa. For the majority of his career he has managed and supervised numerous design teams in the design of structures for many road and rail projects in Victoria, Australia.

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Arvind David is a senior project manager for Major Projects Victoria which a project delivery agency for the Government of Victoria. Arvind was the project manager responsible for the development and management of the William Barak Bridge project from planning, concept and funding stages through to the final delivery and commissioning of the project. He was the Superintendent for the delivery of the construction works.

Synopsis

The William Barak Bridge connects Birrarung Marr and Yarra Park. It was a critical piece of infrastructure for staging of events in the Sports & Entertainment Precinct during the 2006 Commonwealth Games and provides an important link for pedestrian movements between the sports and entertainment precinct and the adjoining parkland, Melbourne’s CBD, and Southbank.

The pedestrian link is approximately 525 m long and incorporates a series of bridge structures and a pedestrian plaza with terminations linking into landscaping elements in Yarra Park, at its eastern end, and Birrarung Marr at the western. The structural elements include:

- a bridge emanating from landscape elements in Yarra Park and passing over Brunton Avenue
- a connecting bridge over the rail corridor spanning from Brunton Avenue to an elevated pedestrian plaza adjacent to Batman Avenue
- a pedestrian plaza incorporating a tram stop on the lower level and providing access to Batman Avenue and Melbourne Park
- a connecting bridge from the pedestrian plaza over Batman Avenue terminating in landscape elements in the Birrarung Marr parkland.

The design and construction of the project required a high degree of integration between the architectural, structural, services engineering and railway engineering design. Importantly the very complex bridging structures were designed documented and constructed around the constraints of the operational requirements of one of Melbourne’s busiest railway corridors.
1. Introduction
The William Barak Bridge connects Birrarung Marr and Yarra Park. It was a critical piece of infrastructure for staging of events in the sports and entertainment precinct during the 2006 Commonwealth Games and provides an important link for pedestrian movements between the precinct and the adjoining parkland, Melbourne’s CBD and Southbank. One of the most memorable gold medal achievements at the Games was Australia’s Kerryn McCann taking the lead in the marathon in the final leg across the William Barak Bridge.

The bridge is now a key piece of pedestrian infrastructure. Prior to its construction Brunton Avenue, the arterial road in East Melbourne adjacent to the MCG, was closed for local resident access after major events due to the peak pedestrian flows across the roadway. The bridge has also helped reduce waiting times at Richmond Station after major events as it provides a direct pedestrian link to Melbourne’s Flinders Street Station. Through careful analysis of pedestrian movement patterns and desire lines for pedestrian movement in the sports and entertainment precinct the bridge has successfully improved the amenity for local residents, cycling commuters, event patrons and road traffic.

This complex project was delivered within 16 months from contract award which included the completion of working drawings and commissioning. It was delivered under a novated design-and-construct contract to an immovable date for completion which was set by the staging of the 2006 Commonwealth Games. Practical completion was achieved in time for the 2005 Boxing Day test match at the MCG and the Australian Tennis Open in January 2006, around two months before the Commonwealth Games. The success of the delivery program has been attributed to the positive approach to partnering between the Client, the Contractor, the Key Stakeholders (including the train and tram franchisees) and the Designer. The project received the cooperation of the venue operators in the sports and entertainment precinct, the toll road operator, and the local city council and other stakeholders (16 in total). The project is an exemplar case study for the state government in the successful management and coordination of stakeholder inputs for the delivery of major projects in Victoria.

2. Project Summary
The William Barak bridge comprises five types of bridge structures and a building structure rolled into one project. The overall length of the project is 525 m. The significant elements of the project include the following:

*The connection between Birrarung Mar and the Podium:* in this section the structure also provides a connection between the Lower and Middle Terraces of Birrarung Mar and a bridge structure over Batman Avenue.

*The Podium:* this is a structure providing 1000 m² of paved area about 10 m above ground level. It is located over a tram stop at the western end of the tennis complex. This area can be regarded as the hub of the project from a functional point of view as it is accessed by bridges from the MCG on the east side and Birrarung Mar to the west, a lift providing pedestrian connection between the tram stop below and the
The deck of the Podium, and three staircases connecting Batman Avenue and the Rod Laver Arena to the Podium.

The crossing of 14 train tracks: at ground level between Flinders Street and Ringwood stations and three underground rail tunnels. These tracks provide access to all eastern and south-eastern rail lines and are some of the busiest sections of the Melbourne suburban network. This section of the project posed the biggest challenges to the design, construction and the ongoing operations of public transport and events in the sports precinct.

The connection between the rail corridor and Yarra Park: construction of four spans of bridge works over railway land, Brunton Avenue and Yarra Park.

3. Structural Details

Birrarung Marr to the Podium

The length of this section of the project is about 150 m extending from the Lower Terrace of Birrarung Mar to the Podium. Two of the significant architectural features in this area were the use of custom made rock basket walls through Birrarung Mar and the smooth surface of steel girders for the bridge over Batman Avenue and public open space to the Podium. The baskets for the rock basket walls were made of a galvanised weld mesh filled with 75 to 200 mm rocks to provide a relatively smooth textured façade. The structural design of the bridges therefore had to be able to accommodate this feature (refer Figure 1).

![Rock filled basket walls](image)

Figure 1: Rock filled basket walls

The structure between the lower and middle levels of Birrarung Mar was designed with sufficient width to enable circus trucks to access the Middle Terrace and in this portion of the project the structures were designed for T44 truck loading. All other structures were designed for pedestrian loading of 5 kPa and were required to carry an emergency vehicle of 2 t (the 5 kPa load case was dominant for all structures). The width of the bridges in this section varies from 4 to 6 m. The section between the Lower Terrace and Middle Terrace had to provide adequate width for the circus vehicles to manoeuvre between the terraces.
In this section there are three different structural forms:

**Lower Terrace to Middle Terrace of Birrarung Marr:** at this location the structure straddled the batter between the terraces and a reinforced concrete slab was constructed. This slab was cut into the batter on the Middle Terrace side and supported directly on a specially prepared sub-base. On the Lower Terrace side the slab support was provided by the adoption of a piled foundation (refer Figure 2).

![Figure 2: Middle to lower terrace typical cross-section](image)

**Middle Terrace:** adjacent to Middle Terrace, two spans of conventional Super-T beams with composite cast-in-place reinforced concrete decks were constructed. The beams were concealed by the rock filled baskets as was the concrete structure between Middle and Lower Terraces.

**Middle Terrace to the Podium:** in this region three spans of steel box girders were adopted. The steel boxes were tapered in profile to satisfy urban design requirements. The original concept design incorporated Super-T beam and composite concrete slabs for all spans from Birrarung Marr to the Podium. However, Pier No. 2 had to be relocated further away from the east bound running lanes of Batman Avenue to satisfy road safety design requirements. As a result, this pushed the original Super-T beam concept beyond the limits of these beams.

The construction of this box girder over Batman Avenue, a toll road, required the closure of a major road tunnel into Melbourne. It required the dates for erection to be established six months in advance of the closure and required the cooperation of the private road operator. The box girder was installed over two weekend closures and had to work around the construction constraints imposed on other parts of the project, major events such as the Melbourne Fun Run, the Australian Tennis Open and the Melbourne Formula 1 Grand Prix.

The span adjacent to the Middle Terrace is a simply supported span on elastomeric bearings at both ends of the beam. The steel box beam used here varied in depth from 1000 mm at the east end to 2000 mm at the west end. The spans over Batman Avenue and the public open space to the Podium are continuous over Pier No. 2. At the western support the beam depth is 1000 mm to match that of the eastern end of the simply supported span. The depth of the superstructure varied from 2200 mm at Pier No. 2 to 300 mm at the Podium connection.
In order to maintain the continuous simple lines of the bridge profile over these spans, it was necessary to conceal the cross-head at Pier No. 1B. To achieve this a recessed steel box cross-head was used. The box beam was anchored to the top of Pier 1b using stress bar and the beam recessed into the steel box girders on either side of the pier (refer Figure 3).

![Figure 3: Steel box pier crosshead](image)

At Pier No. 2, the superstructure was connected directly into the pier column by a reinforced concrete pier diaphragm rather than plate steel diaphragms. This solution was adopted mainly for structural reasons and was more economical to build than the steel diaphragms.

**The Podium**

The Podium is a focal point of the project from a functional point of view as it has bridges connecting into it from the east (Birrarung Mar) end and the west (Yarra Park) end; three stairways providing access from Batman Avenue and the tennis precinct (Rod Laver Arena); and a lift for abled and disabled access from the tram stop under the Podium and Batman Avenue to the Podium.

As this project was a key part of the Commonwealth Games, there was an emphasis on its visual aspects. The urban design required some of the following details of the Podium:

- Inclined pier columns. One inclined at 17 degrees and all others either vertical or inclined at 5 degrees.
- Piers to be of steel appearance with painted finishes using various colours.
- Sloped ceiling to the Podium structure.
- No visible form of the method of construction for the superstructure.
At the preliminary design stage two options were considered, and an initial a pre-stressed concrete beam and slab option was eventually discarded in favour of a structural steel option. The former was discarded for structural reasons (large earthquake loadings on the substructure detail required in the urban design) and because there was no repetition in the structural detail, which led to significant costs.

The shape of the Podium is irregular and the layout of the structural elements was complicated by the restrictions on locating the column supporting the structure because of tram, road and pedestrian traffic at ground level. As a result several different types of structural steel elements were adopted to frame up the superstructure. These elements include:

- three steel box girders spanning upwards of 27 m. Two of these girders (the north and south box girders) extend into the rail corridor
- steel plate girders used as primary members across the Podium deck
- universal and welded beams for the majority of the secondary steel work
- steel trusses making up the remainder of the secondary steel framework (refer Figure 4).

The Podium structure is clad in a painted fibre board based façade because of issues in relation to electrification of the structure by potential displacement of tram pantographs.

To construct the Podium the tram corridor had to be shut down for three weeks and other public transport provided. Closure of the tram corridor and management of pedestrian access during construction of this part of the project were critical to its success and had to be planned and executed eight months prior to the closures and between the Australian Tennis Open events which relies heavily on this route.

The substructure consists of circular reinforced concrete columns supported on a piled foundation. The columns were formed up with steel tubes which were painted to provide the visual effect required in the urban design.
The lift structure is constructed out of pre-cast concrete side panels secured to a steel frame and is glazed on the front and back faces. The main staircase providing a direct connection to the Podium from Batman Avenue was constructed using steel girder and composite concrete deck whilst the other two staircases were constructed using reinforced concrete beams and columns. The main staircase is an architectural feature that addresses the CBD. It is clad with match cast, honed polished pre-cast concrete façade and Alucabond.

**Crossing the Rail Corridor**

Crossing the rail corridor was the most challenging part of the project from both a construction and design point of view. The overall length of the section constructed over the rail corridor is about 140 m. The deck width is 9 m. The design challenges included:

- locating piers so that vertical and horizontal clearances from the rail infrastructure are met
- avoiding conflict with one of the tunnels of the underground rail loop
- vertical geometry constraints
- minimising impact on rail assets which would have a significant impact on project costs and rail operations
- a significantly skewed structure (over 60 degrees skew)
- a structural format which has inherent dynamic issues
- designing a structural system which could be built over this area of very difficult access
- satisfying all stakeholder requirements
- integrating services for public lighting and public art.

The superstructures comprised a span of twin steel box girders. These are an extension of the north and south box girders forming part of the Podium structure. The balance of the crossing consists of two spans of steel tubular trusses with a total length of about 100 m.

The overall layout of the railway yard is congested with 14 rail tracks and several crossovers, numerous overhead traction structures, and one underground tunnel plus a ramp access into another tunnel.

Pier Nos. 3 to 6 are located in the rail corridor. Pier No. 3 is located on the boundary line of the corridor. Piers 4 and 5 are located between tracks with minimum allowable clearances from tracks. Alternative locations for these piers were not possible due to track clearances. Because clearances from the adjacent tracks are on the limits narrow blade piers, 750 mm wide, were adopted.
Pier No. 6 was originally located parallel to and along the eastern edge of the Burnley Tunnel exit ramp. However, closer investigation revealed that this was not possible because the Caulfield–Sandringham tunnel is located under the original position of Pier No. 6. Instead of adopting a conventional pier supported on a piled foundation, Pier No. 6 was built over the centerline of the Burnley Tunnel Exit Ramp using 19 pre-cast concrete crown units stressed together, with each leg supported directly over the walls of the ramp (Figures 5 and 6). It was necessary to stress the units together to provide a single ‘monolithic’ structure capable of withstanding the rail impact loads.

A series of longitudinal and transverse transfer beams were cast over the pre-cast members to transfer the superstructure loads down the walls of the crown units into the ramp structure. It is noted that the ramp structure is founded on the weak and compressible Coode Island silt and extensive modelling of this structure in its final form was carried out to assess the bearing pressures and settlements under the new loading regime. The total additional SLS loads added to the existing structure amounted to about 500 t and estimated settlement was only about 3 mm.
The cross-section for the superstructure in the trussed spans shows a main central trusses with height varying from 3.5 m to 7 m and two side trusses of overall depth of 2.25 m. About 80% of the total dead and live load is carried by the central truss (Figure 7). The trusses are also continuous for about 50% of the dead load and all of the live load. The central truss has a 610 mm diameter top chord, 500 mm diameter webs and the bottom chord is a fabricated box girder box section. The side trusses are fabricated from 356 mm diameter steel tubes.

Figure 7: Typical cross-section through the truss spans

The three trusses are interconnected using 250 UBs at 2 m centres and a composite concrete deck which also has direct connection to the side trusses as well as to the 250 UBs.

One of the problems we encountered was the assessment of the likely dynamic loading that a crowd of pedestrians could impose. The dynamic component of a single pedestrian's footfall is well known, but that of a large group of pedestrians walking at random is much less explored. The individual footfalls from members of the group will tend to cancel each other out, but (statistically) they will not exactly cancel each other. The Australian Bridge Design Code (AS 5100:2004) gives no guidance here, and the literature is very sparse, so we undertook our own theoretical statistical study. This study concluded that the most likely dynamic effect of \( N \) pedestrians walking at random is equivalent to \( 0.8(N)^{1/2} \) pedestrians walking in total synchronicity, and that the effect that would be exceeded only 10% of the time is equivalent to \( 1.65(N)^{1/2} \) pedestrians walking in total synchronicity. We adopted this latter loading for our design.
When we applied this loading as a harmonic load to our Strand7 model, it predicted a vibration amplitude of $\pm 13$ mm, occurring at the outer edges of the deck slab near the middle of the longer span. Several mitigation techniques were investigated, and of these we opted for tuned mass dampers (TMDs). We specified four identical TMDs, each with 0.5 t of suspended mass, able to be site-tuned to any frequency within $\pm 10\%$ of the calculated natural frequency value of 2.41 Hz. These TMDs were to be placed immediately under the deck of the longer span, entirely within the depth of the girders to preserve the train clearance. In plan they needed to be near the middle of the long span, as far out from the bridge centreline as possible, two per side. We opted for two pairs of TMDs rather than merely one pair (each of twice the mass) for two reasons: redundancy in the event of malfunction or removal for periodic maintenance; and allowance for the possibility of an additional, unpredicted, vibration mode.

When we modified our Strand7 model to incorporate the TMDs and repeated the harmonic analysis, the predicted vibration amplitude was reduced to $\pm 2$ mm. Because of the different ways in which Strand7’s different analysis types allow for damping, we also carried out a transient dynamic analysis. This confirmed the prediction of $\pm 2$ mm.

During the construction phase, installation of the TMDs was delayed until as late as possible in order to allow the deck concrete to age-stiffen as much as possible. Then we needed to measure the actual natural frequency of the bridge in order to ‘T’ the MDs’. Accelerometers were attached to the bridge, then it was dynamically excited using a set of semi-synchronised biological oscillators. The decay curve after this excitation ceased showed a natural frequency of 2.44 Hz. The TMDs were then tuned to this frequency. In the nearly three years that the bridge has now been open, there have been no reports of any disconcerting vibrations.

During the design stage, a study into possible construction methods of the spans over the railway corridor was carried out. Emphasis was placed on minimising impact of the construction of these two spans on rail operations. To this end, emphasis was place on using weekend shutdowns where impact on operations would be reduced. Lowering of overhead traction equipment to any more than one pair of operating tracks was not to be considered as it would have been very difficult to restore these for normal weekday operations for the Monday morning peak. Two possible options were investigated:

- Construct and assemble the trusses adjacent to the rail reservation and then crane them into position from the west side of the corridor. It was proposed to lift them in two sections and then join them together over Pier No. 5. The crane required for this operation was a 1200 t track crane and there was only one such crane of this type in Australia. This machine was in use on another project in Victoria and there was a very high risk of it being unavailable when required for this project.

- Launch the assembled trusses across previously constructed decks from each side of the corridor and then join them together at Pier No. 5. At this stage, it was recognised that they could not be launched totally from one side because of the kink in the vertical geometry of the deck at Pier No. 5.
The contractor ultimately elected to launch the trusses totally from the east (Yarra Park) side. The temporary works designer therefore required the trusses to be assembled in a straight horizontal alignment to enable them to be pushed out over Pier No. 5 to Pier No. 4. We then designed large mechanical co-linear hinges in all three bottom chords of the trusses at the ultimate Pier No. 5 location so that, when pushed out to its final position, the top chords were cut and the ends of the trusses were lowered onto Piers Nos. 4 and 6. The top chords of the three trusses and affected web members were then welded to provide the continuous trusses from Pier No. 4 to Pier No. 6 (refer Figure 8).

**Figure 8: Truss spans over the rail corridor**

The section over the rail corridor includes a unique public art feature which is a soundscape that plays a unique compilation of anthems and traditional music recorded by artists from the 53 nation participating in the Commonwealth Games and living in Australia. The soundscape is triggered by people walking past electronic sensors concealed within the steelwork. The balustrade is a custom made aluminium panel on to which a calligraphic motif has been painted.

The feature lighting on the bridge is continuous array of dimmable fluorescent lights integrated into custom made stainless steel handrail fittings to address issues concerning light spill whilst providing an unique feature for the city (refer Figure 9).

**Figure 9: Truss span and podium feature lighting**
**Brunton Avenue Section**
The remaining length of the project extending from the rail corridor over Brunton Avenue into Yarra Park consists of four spans of Super-T beam construction and a reinforced concrete landing faced with rock basket wall cladding similar to that used in Birrarung Marr. The span adjacent to the steel truss spans over the rail corridor has the 60 degree skew at the Pier No. 6 location transition to zero skew at Pier No. 7. This span contained six 1200 mm deep beams varying in length from 25 m on the south side to about 48 m on the north side. A simple dynamic analysis was carried out to ensure that there were no dynamic issues arising from this slender northern beam. It is further noted that this beam experiences about the same design bending moments as the 36 m beams in the adjacent spans simply because the very high skews shortens the actual load path.

A second feature of this section of the project is the support mechanism of Pier No. 7. This structure was, as for Pier No. 6, affected by the presence of the emergency egress structure for the Caulfield–Sandringham tunnel. The adopted solution for this pier was to partially support the pier on three bored piles alongside the emergency egress structure and then use the existing underground structure to provide the remaining support.