ELIZABETH QUAY WATERFRONT DEVELOPMENT – ISLAND VEHICLE ACCESS BRIDGE, PERTH, WA

Brian Lord, Arup Pty Ltd, Australia

ABSTRACT

Elizabeth Quay is a development by the Metropolitan Redevelopment Authority (MRA) for the State Government of Western Australia to revitalise the city of Perth and return the city's focus to the Swan River. The development covers nearly ten hectares of riverfront land with a 2.7 hectare inlet surrounded by a split level promenade with a garden island located within the inlet, providing additional public amenity. The managing contractor for the development is Leighton Broad with ARM Architecture as the lead architect and Arup the lead structural design engineer. This paper outlines some of the key issues and considerations in the both the design and construction of the Vehicle Bridge. The Vehicle Bridge is an approximately 15m single span simply supported bridge over the Elizabeth Quay inlet. The bridge is designed to provide a flowing access to the island, transitioning from the paved promenade to the garden island. The bridge allows for pedestrian movement from the eastern promenade to the man made island in the inlet, access for services to the island, with an allowance for service vehicle loading and includes garden beds. The key challenge was to design a durable bridge with abstract geometry, garden beds and co-ordinated architectural features that could be constructed efficiently, potentially over water and integrated with the waterfront development edge wall.

INTRODUCTION

Elizabeth Quay is a development being delivered by the Metropolitan Redevelopment Authority (MRA) on behalf of the State Government of Western Australia, to revitalise the city of Perth and return the city's focus to the Swan River. The development covers nearly ten hectares of riverfront land with a 2.7 hectare inlet surrounded by a split level promenade. The managing contractor for the development is Leighton Broad with ARM Architecture the lead architect and Arup the lead structural design engineer. The man made island within the quay is accessible by the Island Vehicle Access Bridge from the eastern promenade and from the double inclined arch cable pedestrian bridge from the western promenade. The Island Vehicle Access Bridge is an approximately 15m single span simply supported bridge over the Elizabeth Quay inlet. The bridge allows for pedestrian movement with an allowance for service vehicle loading, garden beds and services.

Figure 1: Site Location

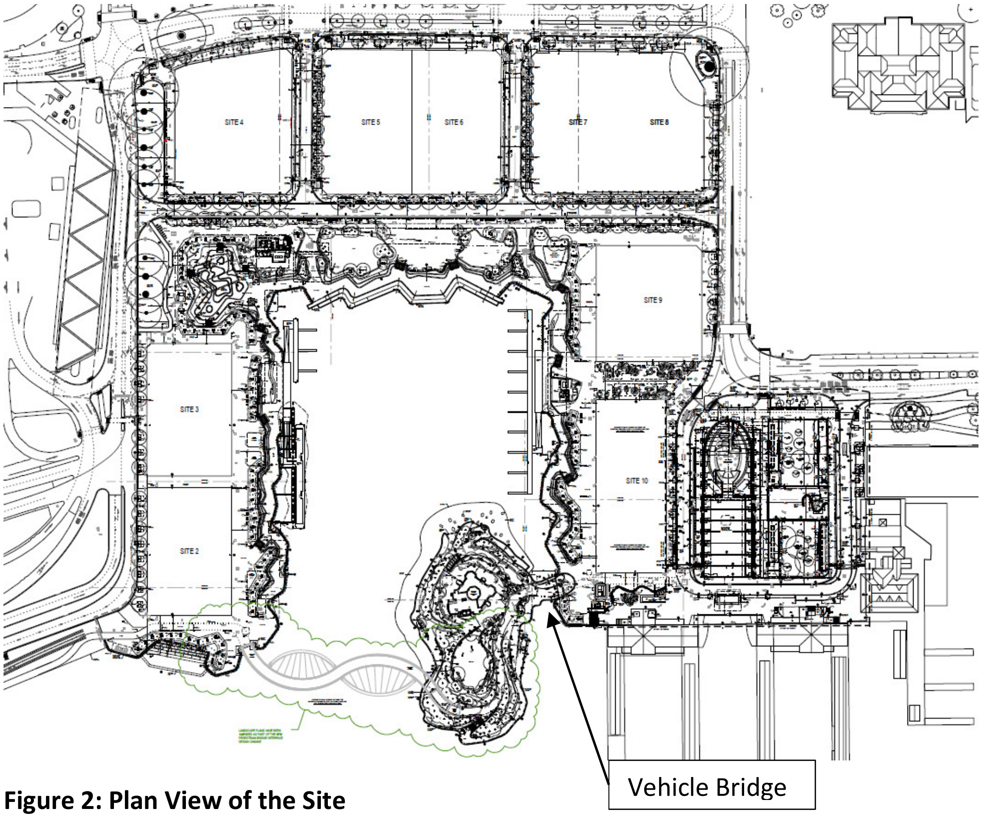

Figure 2: Plan View of the Site

Figure 3: Artist Impression of the Site Looking North

Figure 4: Artist Impression of Site Looking South East

Island Vehicle Access Bridge

A key challenge for the Vehicle Bridge was to design a durable bridge with abstract geometry with a minimum depth to allow a 1.2m clearance from HAT to the bridge soffit for kayak access beneath the bridge. The curved edge profiles of the bridge were created by ARM Architects and the shape of the bridge integrated with the profile on the eastern and western promenades. The curved profile of the bridge required careful consideration be given to the form of the bridge. In-situ-concrete post tensioning and steel beams made composite with a deck slab were considered however pre-cast deck units made composite with a deck slab were adopted. At the time of the design it was unclear whether the bridge would be constructed in the dry or whether the bridge would be constructed in the wet ie after the inlet had been flooded. Given this uncertainty, precast deck units were considered the most appropriate construction form as they offered a safer and more efficient construction option over water. The curved profile of the bridge resulted in a cantilever being required on each side of the bridge due to the straight profile of the deck units. The cantilever varied on each side of the bridge up to a maximum 2.58m length.

Initially Arup were engaged by ARM Architects to undertake the design of the Vehicle Bridge. The original design of the inlet perimeter wall, by others, was a sheet pile and anchor solution. The design of the substructure of the vehicle bridge thus was a continuation of this wall type. A corrosion allowance was used in the design along with cathodic protection. Fascia concrete panels and infill concrete between the steel sheet piles and the concrete fascia panels was also proposed. Upon Leighton Broad being awarded the Managing Contractor's role Arup were novated to Leighton Broad to complete the design of the vehicle bridge. As part of a value engineering exercise it was decided that steel sheet piles and anchors were deemed too expensive and brought with it associated problems in relation to anchoring into the zone of potential future building piles and footings and a complex anchor layout due to the architectural shape of the inlet perimeter wall. Future maintenance of the anchors was also seen as problematic. Thus other options were explored including contiguous flight auger (CFA) secant piled walls and diaphragm walls. Diaphragm walls were adopted as the preferred solution.

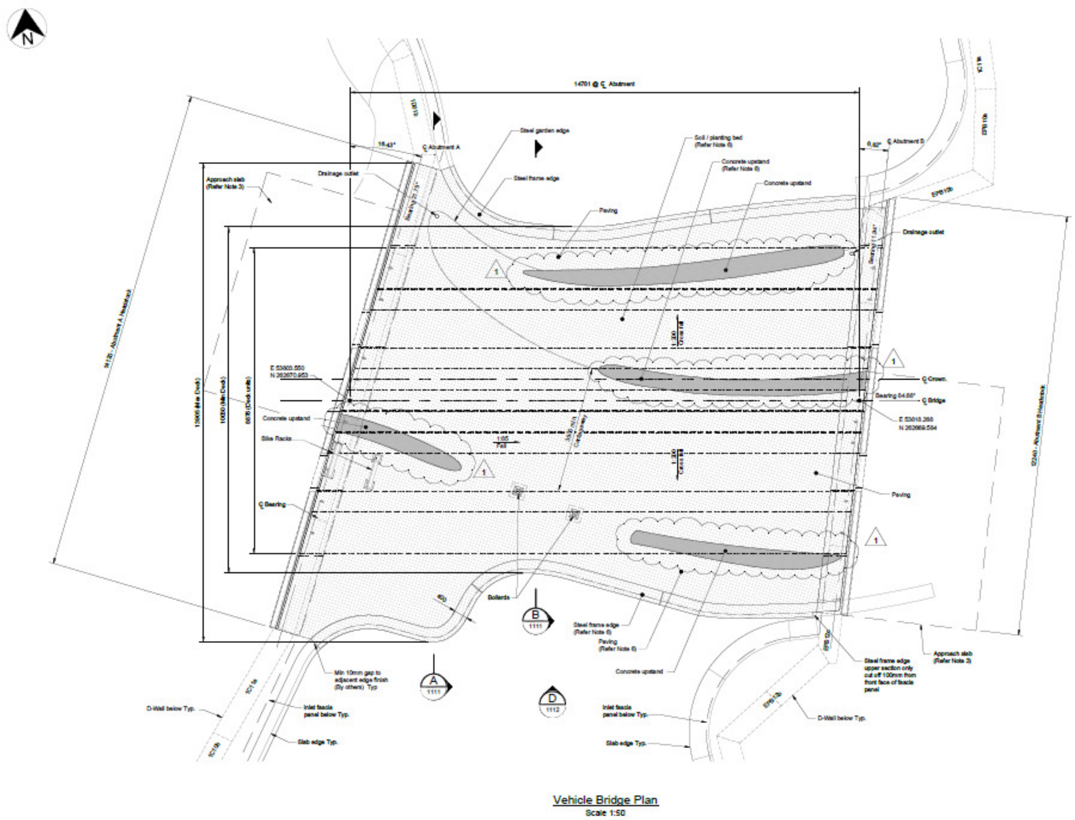

Figure 5: Plan View of the Island Vehicle Access Bridge

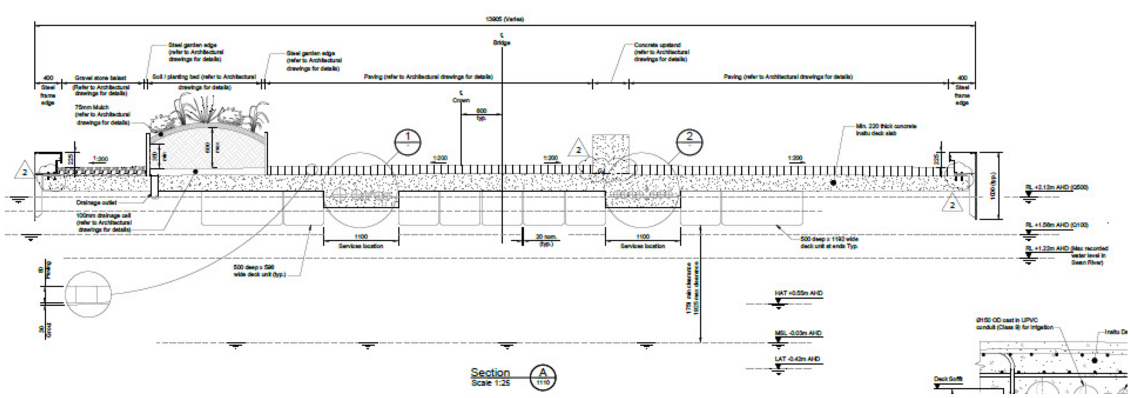

Figure 6: Cross Section of the Island Vehicle Access Bridge

Figure 7: View of Vehicle Bridge Looking South

Figure 8: View of Vehicle Bridge Looking North

Figure 9: View From Vehicle Bridge Looking North

Figure 10: View From Vehicle Bridge Looking South

Design Vehicle

A key design input for the Vehicle Bridge was what design vehicle should be allowed for in the design. The bridge needed to be able to support a rubbish truck, an ambulance, a fire engine or utility vehicles accessing the man made island. A two axle 18 tonne M18 vehicle in accordance with AS5100-7 was thus decided upon as a satisfactory design vehicle which satisfied the needs of the island. Refer to Figure 11 below for the M18 vehicle.

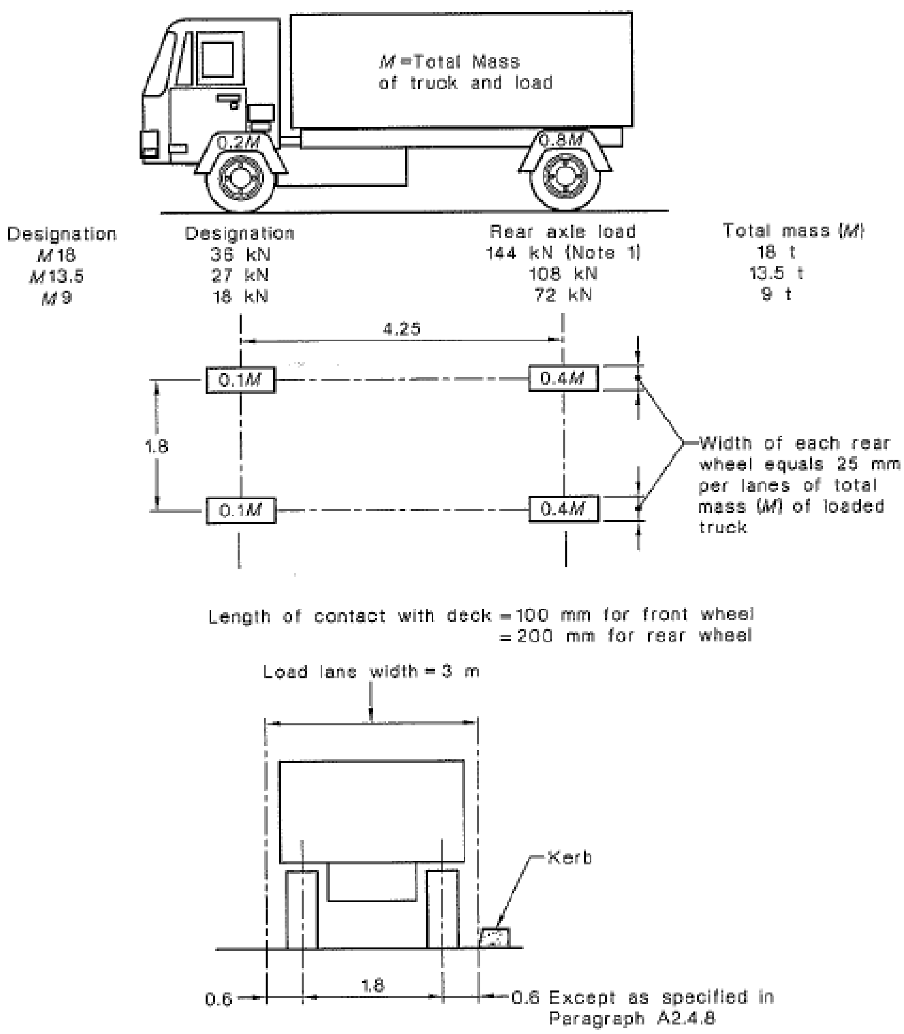

Figure 11: M18 Vehicle

Construction

Diaphragm Wall

Diaphragm walls were the preferred method for construction of the inlet perimeter walls as mentioned above. GFWA were awarded the sub-contract for the diaphragm wall construction. Diaphragm walls are commonly used for sea walls and have the benefit of a high control of verticality due to the bucket grab and guide wall system. Refer to Figure 12 below for the construction staging of the diaphragm walls. The walls were typically 600mm thick with a maximum panel length of approximately 6m. The walls utilised shear keys with a water stop between adjacent wall panels. Glass fibre reinforced plastic (GFRP) reinforcement was used on the inlet face of the walls without architectural fascia panels for durability purposes.

The lateral deflection of the diaphragm walls was a significant design consideration for the performance of the wall and associated paving and works forming the promenade behind the inlet wall. Two conditions were outlined in the perimeter wall specification. The first condition permitted an allowable deflection of δ/H of 0.75%. The second condition permitted an allowable deflection of δ/H of 0.25%. Condition one was the wall deflection upon completing the backfilling behind the wall and excavation in front of the wall. Condition two was the increment of the wall deflection which occurs in response to applying the settlement sensitive pavement structure and the design surcharge loading behind the wall.

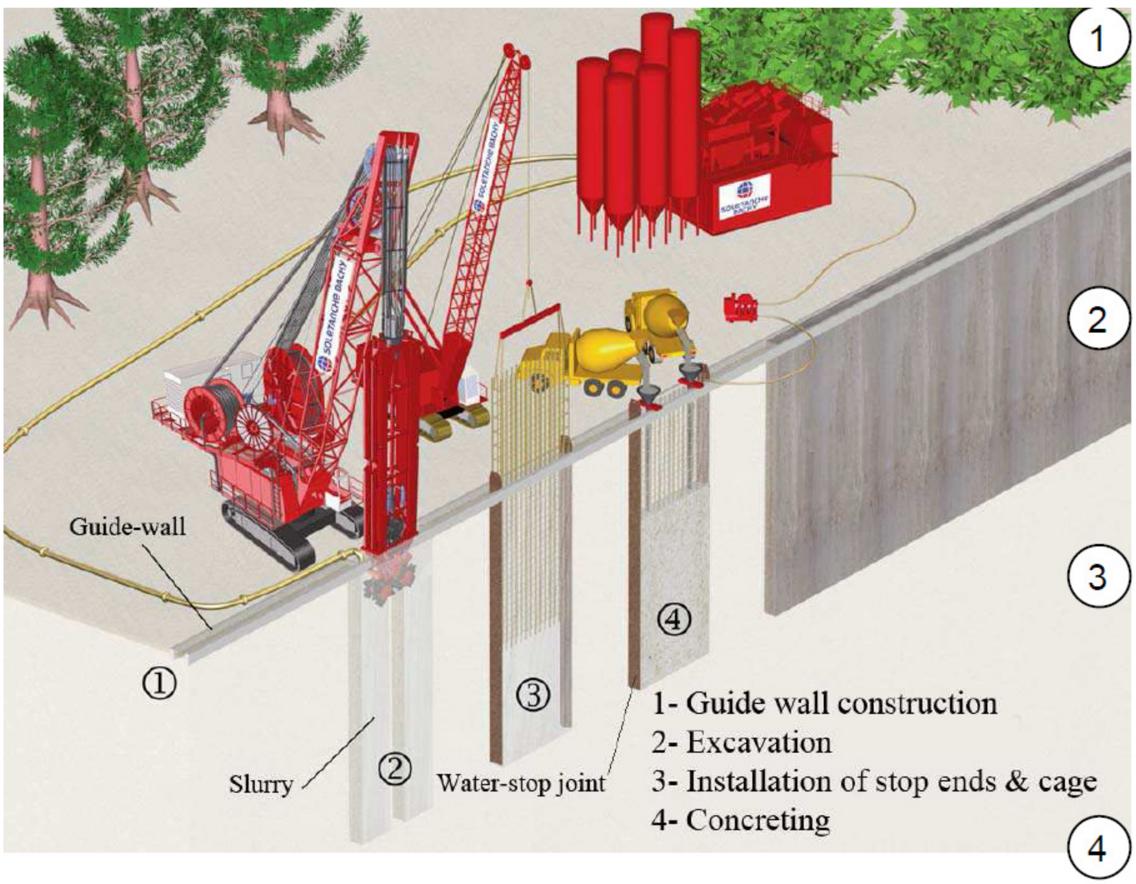

Figure 12: Diaphragm Wall Construction Methodology

Architectural Fascia Panels

The architectural fascia panels were located facing the majority of the diaphragm walls constructed as the perimeter of the inlet. The architectural fascia panels were typically 150mm minimum thickness with patterned protrusions. Moulds were fabricated of the patterned protrusions. The fascia panels were constructed at Civmec's fabrication yard in Henderson, WA, which allowed a high quality finish to be achieved. Refer to Figure 14 for the quality of finish typically achieved in the fabrication yard. Visual inspections were undertaken of each fascia panel once cured and repair work was undertaken to the protrusions where required (refer to Figure 16). The fascia panels were then delivered to site and installed. Two methods were used to install the fascia panels, the first with strong back beams (refer to Figure 17) and the second method used via cantilever rigging frame (refer to Figure 18) where access in front of the perimeter inlet wall was constrained. The architectural fascia panels were constructed with ferrules cast in on the back side (refer to Figure 15). This allowed L-shaped starter bars to be threaded in, which provided a connection between the fascia panel and the in-situ concrete cast in the void between the back of the fascia panel and the front of the diaphragm wall (refer to Figure 19). The fascia panels typically extended to 0.5m below LAT and were generally installed in the dry.

Figure 13: Architectural Fascia Panels Being Constructed in Fabrication Yard

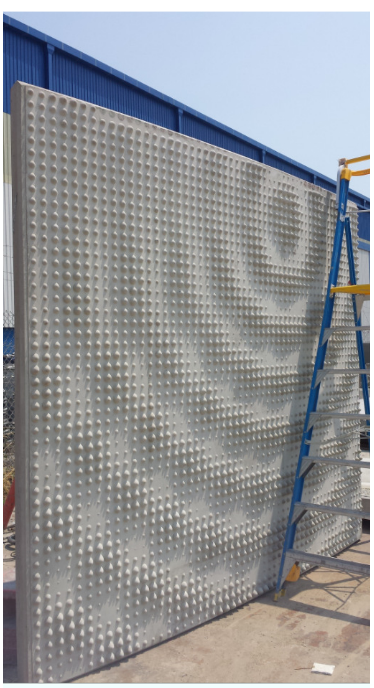

Figure 14: Architectural Fascia Panel in Fabrication Yard

Figure 15: Rear View of Architectural Fascia Panel in Fabrication Yard

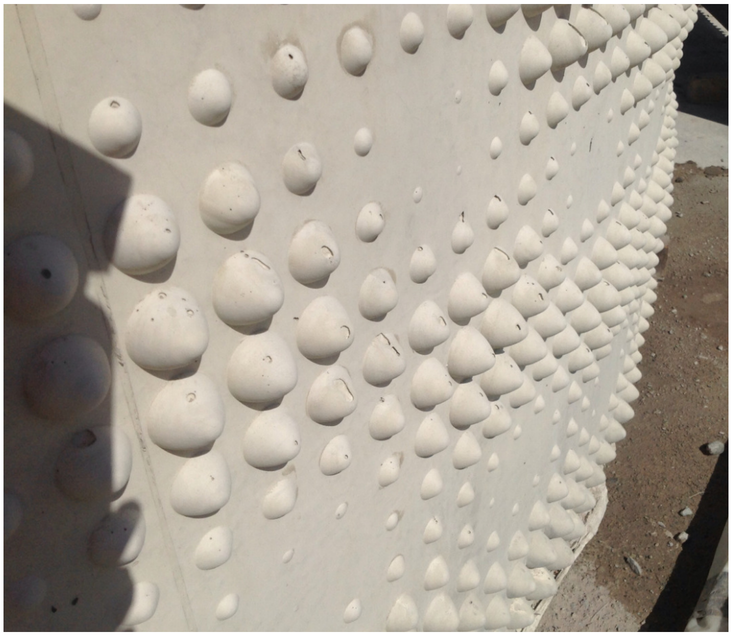

Figure 16: Surface Damage to be Repaired to Architectural Fascia Panel in Fabrication Yard

Figure 17: Architectural Facia Panel Being Installed with Strong Back Beam

Figure 18: Architectural Facia Panel Being Installed with Cantilever Rigging Frame

Figure 19: Joint in Architectural Facia Panel Prior to Concrete In Fill Pour

Deck Units

The deck units used on for the Vehicle Bridge were prestressed precast concrete and were constructed at Delta Corporation's fabrication yard in Herne Hill, WA. Refer to Figure 20 and 21 below. The cross section of the bridge consisted of nine 500mm deep deck units. The nine deck units comprised two 1192mm wide and seven 596mm wide deck units. The double width 1192mm wide deck units were located at the ends and were required due to the large cantilevers of the deck slab. The deck units were connected to the headstock via a cast in place dowel (refer to Figure 22), which was then grouted up.

Serviceability was the governing limit state for the design of the deck units. The underside of the deck units were designed for an exposure classification of B2 in accordance with AS 5100-5. This required the concrete at each strand level of the deck units to be in compression under a serviceability limit state load combination that comprised permanent effects plus 50% of the serviceability live load.

During the detailed design period the stressing bed which the design had previously considered was advised that it was now unavailable for use. This was a significant issue. The design of the deck units had previously assumed that the construction would be undertaken during the wet ie when the inlet had been flooded. Now that a stressing bed with a reduced stressing capacity was required to be used, this meant that there was insufficient prestress in the beams to satisfy the B2 exposure classification clause of AS 5100-5. Through close collaboration with Leighton Broad and Civmec it was agreed to prop the deck units whilst the deck slab was constructed. Once the deck slab had reach sufficient strength and the deck units had become composite with the deck slab then the props could be removed. This solution meant that the deck units did not have to support the self weight of the wet deck slab concrete and thus allowed the amount of prestress in the deck units to be reduced which was within the stressing capacity of the available stressing bed.

Figure 20: Deck Unit in Fabrication Yard

Figure 21: End of Deck Unit in Fabrication Yard

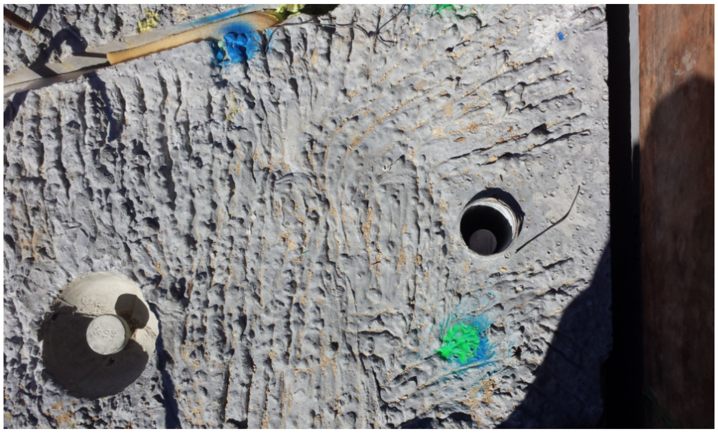

Figure 22: Dowel Connecting Abutment Headstock to Deck Unit

Figure 23: Temporary Propping of Deck Units

Figure 24: Temporary Propping of Deck Units

Deck slab

The curved profile of the deck slab was the main architectural feature of the Vehicle Bridge. Silane coating was specified to be applied to the underside of the cast in place reinforced concrete deck slab in addition to the soffits and external vertical faces of the deck units to increase durability performance.

Numerous services were required to transverse the bridge through the deck slab including;

- 1 x 200 OD conduit for fire
- 1 x 150 OD for irrigation
- 1 x 125 OD for gas
- 1 x 110 OD for sewer
- 1x 110 OD for water
- 1 x 50 OD for irrigation
- 3 x 110 OD for power
- 1 x 110 OD spare for power
- 1 x 110 OD for NBN
- 1x 110 OD spare for comms
- 1 x 110 OD spare for A/V
- 1 x 50 OD for CCTV
- 1 x 50 OD for comms

They were divided into two service corridors 1100mm wide each, refer to Figure 26 as an example. Due to the number and size of the conduits required the deck slab was thickened at the service corridors and the deck units removed at these locations. The thickened deck slab then spanned between the adjacent deck units. Punching shear was checked to confirm that the deck had sufficient capacity given the service corridor did run along a portion of the M18 vehicle path.

Figure 25: Steel Reinforcement for Deck Slab

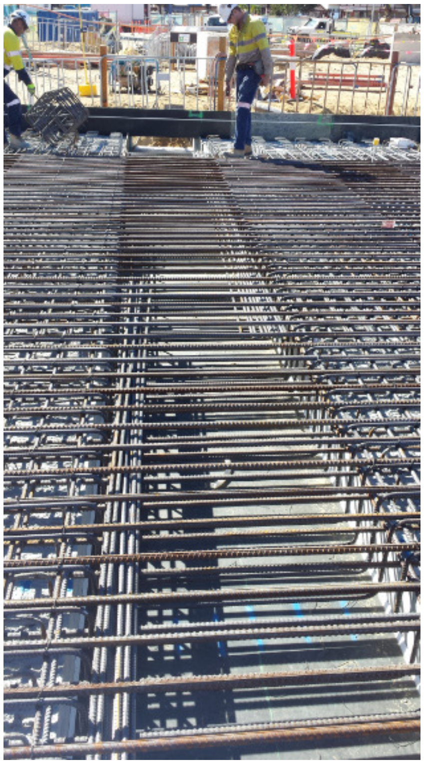

Figure 26: Steel Reinforcement for Deck Slab at Service Void Location

Figure 27: Formwork for Curved Deck Edge Profile

Steel Edge Beams

The vehicle bridge steel edge beams were fabricated at Alltype Engineering in Naval Base, WA, before being transported to site and installed on the bridge deck. The installation on site used a small crane to hold the steel edge beams in place over the chemically anchored permanent hold down bolts. The small crane was also used to confirm the positioning of the steel edge beams before the permanent hold down bolts were installed (refer to Figure 30). Temporary hold down bolts to ensure the locality of the steel edge beam were used before the permanent chemically anchored hold down bolts were constructed (refer to Figure 31).

The detail on the inside face of the steel edge beam as shown in Figure 32 below incorporated a steel mesh which acts to prevent debris from falling into the inlet below, whilst allowing water to drain into the inlet from the surfacing paving. Whilst the paving is not shown in Figure 32 the top of the paving will be at approximately the top of the vertical leg of the equal angle. No hand railing was proposed for the vehicle bridge which was consistent with the remainder of the promenade, however the connection of the steel edge beam was designed such that a pedestrian balustrade could be installed on top in the future if required.

Figure 28: Steel Edge Beam in Fabrication Yard

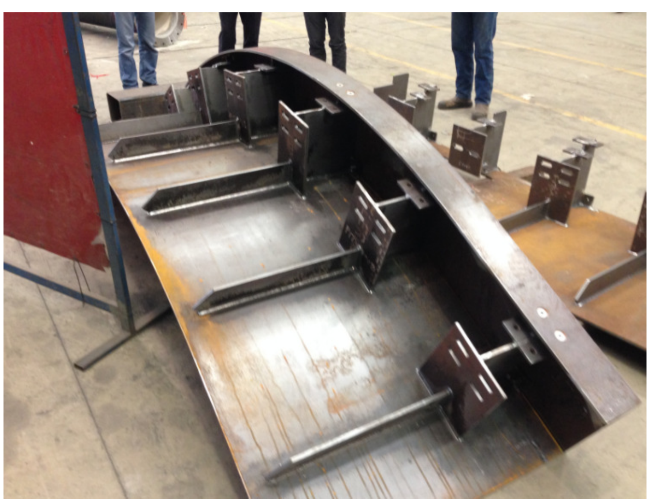

Figure 29: Steel Edge Beam in Fabrication Yard

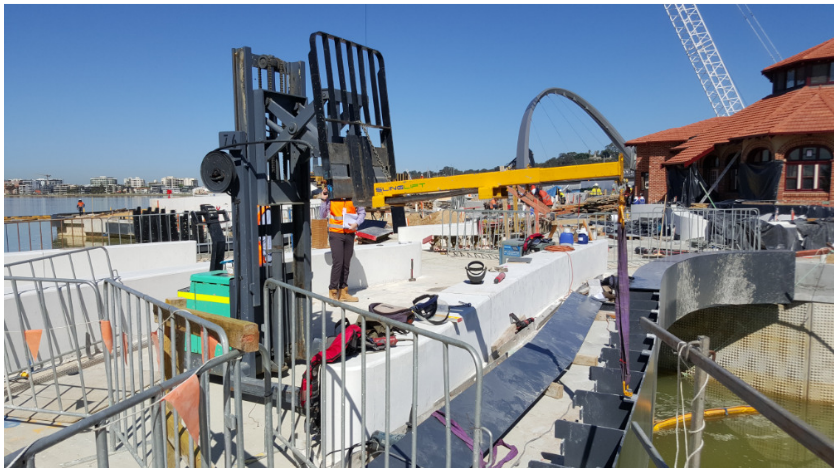

Figure 30: Steel Edge Beams Being Constructed on Site

Figure 31: Temporary Hold Down Bolts for Steel Edge Beams

Figure 32: Edging Detail at Steel Edge Beam

Figure 33: Northern Edge of Vehicle Bridge Looking East

Figure 34: Southern Edge of Vehicle Bridge Looking West

Figure 35: Southern Edge of Vehicle Bridge Looking East

Earthworks

Significant earthworks were required for Elizabeth Quay. A sea bund was constructed to facilitate construction of the man made island as shown in Figure 37 below. The inlet was flooded before the island construction had been completed as seen in Figure 37 below to enable construction of the maritime infrastructure such as floating walkways and mooring and berthing facilities.

Figure 36: Aerial View of Site Looking South East

Figure 37: Aerial View of Site Looking South

Miscellaneous

An unusual feature of the Vehicle Bridge was a garden bed detailed by ARM Architects located on the deck, Refer to Figure 6 above. A drainage cell was detailed along with the cross fall and longitudinal fall of the bridge served to transport water from the garden bed off the bridge and protect the waterproofing. Waterproofing of the deck slab in the form of Bituthene 3000 was also detailed under the garden bed.

Other miscellaneous items located on the vehicle bridge deck include removable bollards, which allows utility vehicle access through to the Duyfken ship mooring and berthing area located immediately to the south of the bridge. Figure 38 below shows the square footings for the bollards being constructed. Bike racks are also included on the western end of the bridge. Architectural concrete upstands are located on the bridge deck and also a steel frame which encompasses the garden bed. Paving as shown off the bridge in Figure 39 below is also the finished surface on the majority of the Vehicle Bridge. Close collaboration between the architect, civil and structural designers, managing contractor and client was required throughout the project to co-ordinate the many detailed interfaces across the precinct.

Figure 38: Architectural Concrete Upstands and Bollard Footing Locations

Figure 39: Paving Off the Bridge

CONCLUSION

The design and construction of the Island Vehicle Access Bridge as part of Elizabeth Quay required close liaison with numerous stakeholders. Close collaboration was required between the project architects, the construction team, diaphragm wall sub-contractors, other design consultants and the design team and was a key catalyst for the successful completion of the bridge. Significant design and construction challenges included; the diaphragm walls, the architectural fascia panels, the temporary propping required for the deck units, the cantilevering of the deck slab, the architectural profile of the edge of the deck slab and subsequently the profile of the edge deck units and the significant earthworks required on site. The project when completed will act as a tourist destination in Perth and will allow people to interact closely with the Swan River.

REFERENCES

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2. *The Design and Construction of Elizabeth Quay Inlet Wall*, B. Hamidi, GFWA, Australia
3. www.mra.wa.gov.au
4. www.abc.net.au

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- WGE

AUTHOR BIOGRPAHIES

Brian Lord has an MBA and is a chartered Senior Civil Structural Engineer in Arup's Transport and Resources team in Perth with approximately 11 years' experience. During this time Brian has worked on numerous road, rail and pedestrian bridges and a variety of maritime structures through concept stage through to construction. Brian was the Structural Lead for the Island Vehicle Access Bridge for the Elizabeth Quay project.