THE DESIGN OF THE SOUTH ROAD SUPERWAY

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ABSTRACT

The South Road Superway is a building block in the South Australian Government’s 78 km long Adelaide North South corridor which will eventually deliver a high speed transport network to speed up already congested freight movements through Adelaide’s western suburbs. The $825M project is the largest investment in road infrastructure in South Australia and will deliver a 4.8 km long free flow expressway standard section of the corridor.

The project includes a 2.8 km long match cast segmental viaduct which carries up to eight lanes of traffic above the existing South Road. The viaduct features striking curved piers, a 12 m clearance to the soffit and spans ranging from 50 m to 83 m. Deck articulation is provided by mid span needle beam joints – the first use of this type of joint in Australia.

The paper provides an overview of the project from the tender design phase through detailed design and construction focussing on design challenges and solutions which were required to deliver this stunning piece of infrastructure.

INTRODUCTION

The South Road Superway is a 4.8 km section of the South Australian Government’s 78 km long north south corridor upgrade project linking the Port River Expressway with the existing South Road south of Regency Park. When completed, the corridor will provide a high speed arterial link through Adelaide’s western suburbs significantly reducing travel times and increasing road user safety. Figure 1 shows the Superway’s position in the north south corridor including completed projects and sections still at the planning stage.

In the short term, the project will provide critical congestion relief to the northern part of the corridor, remove an at-grade rail crossing and bypass three major signalised intersections improving access to this industrial precinct for commercial and private road users. The project includes on/off ramps at Grand Junction Road, one of the city’s major east west links.

The $825M project includes a 2.8 km long elevated viaduct carrying up to eight lanes of traffic above a reconfigured at-grade South Road which carries a further four lanes of traffic through an extremely congested and heavily trafficked site. The project specification required that the viaduct achieve a high standard of architectural finish, have minimum spans of 50 m and provide a 9 m clearance to the soffit to provide an open and attractive undercroft area.

Design and construct tenders for the Superway were invited by the South Australian Department of Planning, Transport and Infrastructure (DPTI) in early 2010 based on a reference design completed by Aurecon. Urban Superway Joint Venture (USJV) were shortlisted with John Holland Construction, MacMahon and Leed Construction as joint venture participants. GHD were the lead consultant for the joint venture with SMEC and International Bridge Technologies (IBT) as subconsultants. Wood Marsh provided architectural design with Tract providing urban design and landscaping.
Figure 1: Adelaide’s North South Corridor

TENDER PHASE DESIGN

USJV’s design effort commenced in late 2009 as part of the expression of interest phase of the project, before the final tender documents were issued. One of the first key decisions was to base the tender design on an amended concept with the angular piers of the reference design replaced with elegant curved piers and monolithic construction between the piers and deck. This was a major departure from the reference design and was recognised as a critical risk item for the tender as it was not certain that this would be received favourably by the Client. Figure 2 provides an overview of the viaduct layout with typical sections along the alignment with Figure 3 showing a view of the completed viaduct.

The viaduct was designed with a match cast segmental deck constructed by the balanced cantilever method. Typical spans varied from 60 m to 69 m with end spans of 50 m and a standard 3.5 m box depth used across the project. Two basic box sections were used, a 13 m wide box in the southern area and a 19 m wide box in the wider northern area. The main span over Grand Junction Road was extended from the minimum 70 m specified for this crossing to 83 m to allow for a fast diamond intersection (with simultaneous right turns). This provided for significant traffic performance improvements in the intersection but required the depth of the box to be increased to 5 m for the extended span. At bifurcations, the boxes were tapered in width to allow a seamless transition between the twin boxes at the ramps with wider northern boxes at transition piers. The Grand Junction on-ramp was also moved northwards in the tender design which improved access to local businesses and reduced land take.

The project specification required that the viaduct carry two lanes on each carriageway in the southern section and three lanes north of the ramps and to allow for ‘easy widening’ to carry an additional lane each way in the future. While it would be possible to construct a narrower bridge deck in the initial construction and widen the deck in the future, the savings associated with the
reduced width were limited to 3.5 m of deck cantilever and the post tensioning required to carry the additional lane loading. In addition, constructing the full ultimate width of deck now allowed for more flexibility in traffic management during construction as each carriageway of the deck could carry both carriageways of the existing South Road traffic under traffic management. Therefore, the team made the decision to base the tender design on constructing the full width of the deck now with no requirement for future widening.

Figure 2: Viaduct Layout Plan with Key Sections
In the southern section of the viaduct, both carriageways were supported on single Y shaped piers with curved outer profiles. The superstructure was monolithic with the piers with the top of the Y shaped piers tied together with curved post tensioned cross beams. This basic structural form was carried through the length of the viaduct with variations in pier geometry required to meet the complex geometry of the alignment and ramps. In the wider northern section, the carriageways were carried on separate piers with a similar appearance to the southern section.

Articulation of the deck was achieved by the use of mid span expansion joints with needle beams used to allow for mid span vertical and longitudinal movements while restraining the joints from differential vertical movement and rotation across the joint. Joints were placed every fourth or fifth span with longitudinal forces resisted by the portal frame action of the four or five span frames. The mid-span needle beam joints are discussed in more detail later in the paper.

A key factor in the successful tender design was the co-location of the design and construction teams during the tender (and detailed design phase). Specialist sub-contractors were engaged to provide expertise in deck erection methods and equipment, formwork requirements and traffic management planning. As the design of the permanent works is closely linked to the erection methodologies, it would be impossible to deliver the design of this type of structure without extremely close coordination between designers and constructors.

DETAILED DESIGN PHASE

USJV were awarded the contract to design and construct the Superway in November 2010 with the 120 strong design team immediately mobilised to a combined site office to commence the detailed design phase. Critical early tasks were piling design, confirmation of erection equipment requirements and the design and construction of the casting yard facility.

Again, co-location of the design and construction team with the Client’s team allowed for close integration between designers, constructors and verifiers to speed up the delivery of design packages. The design was completed by GHD and its sub-consultants (SMEC and IBT) with Hyder Consulting engaged by USJV as the proof engineer and Aecom engaged by DPTI as the independent reviewer.

The construction program required delivery of the design on multiple fronts simultaneously. Therefore, it was not possible to complete the design of the viaduct in sequence and the design was split into three teams working concurrently. While this allowed for a faster design delivery, it did present coordination issues as all three teams needed to adopt the same box shapes and detailing. This proved to be a major coordination exercise which required dedicated staff to liaise between design teams and produce a uniform design. While not preferred, it was impossible to avoid these coordination issues and still meet the delivery programme.

Global demand for the design was generated using Bentley’s RM bridge, Larsa 4D and Midas software. These programs are multi-purpose structural analysis packages specifically written for bridge analysis. The packages allow for time dependent and staged construction analysis. This allowed the detailed construction methodology and sequence agreed with USJV to be incorporated in the bridge design. They also allowed for changes to the sequencing to be reviewed during construction with adjustments to prestressing and geometry calculated as erection progressed.
Seismic loads were calculated in accordance with AS5100.2 [1] and AS/NZS1170.4 [2], using the parameters and amendments listed in the Project Specific Technical Requirements and the Design Criteria. A Dynamic Response Spectrum Analysis (RSA) was performed for critical directions as described in the codes. For dynamic analysis, a Structural Response Factor (μ/Sp) of 2.6 was assumed based on expert advice and AS/NZS1170.4. For vertical seismic response μ/Sp was set equal to 1.0 [3].

If the section strength is adequate for earthquake forces calculated with a Structural Response Factor of 2.6 then special detailing for ductility is considered not required. Potential non-ductile failure (failure of the pier to superstructure, pier to pile cap connection or pile to pile cap connection) would avoid being designed these regions for earthquake forces calculated with a Structural Response Factor of 2.6 instead of a Structural Response Factor of 6.0, significantly reducing reinforcing congestion.

Constructability and safety in design reviews were conducted on design packages with attendance by all parties including verifiers, the proof engineer and DPTI asset management representatives. This process ensured that verifiers and reviewers were fully aware of the design basis and considerably speeded up the design approval process.

**Foundations**

Continuous flight augur (CFA) piling was selected as a suitable foundation system following a test piling program conducted by DPTI during the tender phase. The interbedded sands and clays across the site proved suitable for this piling method where a hollow stem augur is screwed into the ground to the required depth with super-workable concrete pumped into the void as the augur is withdrawn. The reinforcing cage is then lowered into the wet concrete and hung at the required position. A total of 740 1050 mm diameter piles were installed to a depth of 27 m. 50 MPa concrete was used with a durability enhancing admixture to provide the 150 year minimum design life required for buried elements of the viaduct [4]. An advantage of the CFA piling method is the speed of construction with production rates of up to nine piles per day being achieved.

**Deck Erection Equipment**

Due to the heavily trafficked and constrained site, the deck erection team wanted flexibility in the deck erection process. While the tender design included a detailed erection plan, it was inevitable that this would need to be adjusted to accommodate technical issues and traffic management requirements. Three forms of deck erection were adopted: erection by crane, deck mounted lifting frames and a deck erection gantry. As the lifting frames and erection truss had a significant lead time, the design parameters for these elements were fixed early in the design process. These then formed constraints on the detailed design as the size and weight of all segments were limited by the capacity of the erection equipment.

Figure 4 shows a view of the 140 m long deck erection truss.
Casting yard

A total of 2201 deck segments were used in the deck of the elevated viaduct. Segments were typically 3 m long with segment weights varying from 65 tonnes to a maximum of 90 tonnes to meet erection equipment and handling limitations. A large site was allocated by DPTI adjacent to the alignment to allow construction of the casting facility and storage of completed segments. As this site was close to a residential area, a fully enclosed casting facility was required to limit noise impacts, particularly during night work.

A total of 10 segment casting machines were housed in a 230 m long by 26 m wide by 17 m high purpose built casting shed. The building included space for reinforcing cage assembly and used eight gantry cranes to transport materials and completed reinforcing cages into position.

Prefabrication of cages used the ‘slice’ method where transverse reinforcing cages were prefabricated in typical slices of the overall cage on a flat table with pre-positioned guides. The slices were then hung in storage until required for a segment. They were then dropped into place in the mould and tied together with short longitudinal bars.

All casting machines within the casting shed used the short line casting method where new segments were cast against the previous segment to ensure an accurate fit and create the geometry of the final structure. The initial segment is moved out of the casting machine and positioned to form the formwork for one end of the following segment.

As noted previously, at bifurcation locations, segments were tapered in plan to allow narrow twin boxes to line up with wider single segments. These tapered spans were cast using the long line casting method within a single long line casting bed. The long line method uses a form which moves along the segments, and this allowed the sides of the form to be moved inwards and form the tapered span.

The design and construction of the casting yard facility was a significant project in its own right with the entire facility designed, constructed and commissioned within six months of contract award. The casting building was designed to allow future subdivision into industrial units following decommissioning of the casting machines. Figure 5 shows an aerial view of the casting yard facility.

![Figure 5: Casting Yard Facility](image)

DESIGN CHALLENGES AND FEATURES

In such a complex project, there were numerous design challenges to overcome. Some of the key challenges and unusual features of the design are discussed below.
Pier detailing and construction

The form of the piers supporting the viaduct deck was a key signature feature of the project. The piers were curved in both elevation and in cross section with the outside edge of the piers maintaining a constant radius to meet the outside edge of the deck box segments. As the viaduct deck rises from the abutment ramps to the maximum height, the pier legs join to create a single stem. This created the effect of the piers rising from the ground and narrowing to a slender stem evoking an image of trees rising from the ground.

The use of a curved elevation allowed for maximum use of the tight road corridor with up to four at-grade traffic lanes fitted into the space below the curved legs of the piers. At the narrowest point, ten lanes of traffic were squeezed into a 30 m wide road corridor, four lanes at-grade with a further six lanes on the viaduct. The restricted space in the corridor required the viaduct soffit to be elevated to 12 m clear of South Road in the southern section to allow traffic to fit into the curved profile of the pier.

While striking in appearance, the curved profile of the piers combined with a complex road geometry presented several design and construction complications. The outside curve of the pier profile was maintained at a constant radius with steel formwork elements curved in three dimensions required to form the required shape.

Typically piers were 2.2 m thick and up to 12 m high with widths varying from 6 m wide at the pilecap to 12 m wide at the underside of the box. The void between the pier legs and cross frames provided an openness which reduced the visual bulk of the piers.

Pier reinforcing was delivered to site in large prefabricated sections. These were then craned into position and fixed to the previous starter bars. Typically, vertical cages were delivered in sections from the bottom of the Y split to the top of the vertical reinforcing in the pier head section. Vertical steel was curved to the required radius in the pier body with bars cranked near the top of the pier section to meet the required alignment in the pier head section. Figure 6 shows a typical reinforcing layout for the piers and tie beam and the interaction of the pier reinforcing with the pier head units.

Figure 6: Typical Pier Reinforcing Arrangement

The pre-stressed tie beam was delivered to site as a single prefabricated unit with the pre-stressing ducts in place. Horizontal ligatures were then individually placed in the lap zones and pre-stress strand/anchors fixed before the front and rear face forms were installed. A number of variations in lap location and detailing were trialled on the initial piers while the installation
process was refined. This was an advantage of the design and construction delivery model as feedback from the first few piers construction was used to refine the reinforcing layouts of later piers.

Due to the pier size and complex geometry, concrete placement required careful planning. A 200-250 mm slump concrete was placed using a removable tremmie. Fixed vibrator guides were used in the pier body with external form vibrators on the curved forms. This allowed concrete placement to occur successfully with minimal defects.

The 2.2 m thick pier cross section provided a stiff longitudinal frame which would generate large bending moments and shears in the piles due to longitudinal movements in the deck (primarily due to temperature, creep and shrinkage). In order to reduce these forces, it was decided to introduce a split at the centre of the pier legs from the pilecap to the underside of the cross beam at the final pier adjacent to most movement joints.

At the top of each pier, the precast pier head segments effectively provided the formwork for an in-situ pier head element where the vertical reinforcing from the pier was made monolithic with the horizontal reinforcing and post tensioning of the deck. This removed the need for a formed and cast in place diaphragm element with associated formwork and falsework. However, the arrangement required coordination of the vertical reinforcing from the pier and horizontal reinforcing projecting from the precast box sections. Combined with the requirement to anchor the vertical pier reinforcing near the top of the deck section using headed bar terminators and avoid longitudinal pre-stressing ducts in a very constrained location, this presented a difficult design and detailing exercise.

Detailed pier reinforcing shop drawings were required to achieve the required bar positions and levels. Transverse ligatures were set in standard templates to provide ‘standard’ set out positions for these bars and allow coordination with longitudinal post tensioning ducts through the area.

**Deck erection and sequencing**

The use of monolithic pier to deck connections with two decks cast onto each Y shaped pier presented unique challenges to the closure pour and continuity stressing sequencing. The tender design was based on the completion and opening to traffic of one carriageway in its entirety ahead of completion of the closure pours and continuity stressing for the second carriageway.

During the detailed design, it was found that the stiffness of the piers meant that nearly half of the continuity post tensioning force applied to the second deck would transfer into the first carriageway resulting in 150% of the continuity stressing force in the first carriageway and 50% remaining in the second carriageway.

The construction sequence was adjusted to allow almost simultaneous construction of the closure pours and prevent transfer of pre-stress between the girders. Both deck girders were constructed on each section of the deck between movement joints before any closure pours were cast. The first closure pour was then cast with nominal continuity pre-stress to counter thermal movements, construction forces and parasitic effects only. The second closure was then cast and nominally stressed. Once all closures in a deck section were cast, full continuity pre-stress was applied in a pre-determined sequence to achieve the final stress profile. This adjustment to the sequencing resulted in significant reductions in the total pre-stress strand quantity and the locked in forces in the piers.

A further complication associated with the monolithic construction was the impact of creep and shrinkage where deck segments and cantilevers were constructed months apart. This was recognised in the construction engineering with adjustments to the pre-stress levels calculated as construction of the viaduct progressed.

The different erection methods employed were also an important factor with the design of each cantilever based on the planned erection methodology. As construction progressed, various issues arose which required changes to the method of erection planned for particular cantilever. This required re-analysis and adjustment of pre-stress layouts and forces by the design team to
accommodate the changes. Figure 7 shows the balanced cantilever erection at Grand Junction Road with the maximum out of balance condition of one carriageway only constructed.

Figure 7: Grand Junction Road Showing Maximum Out of Balance Stage

**Deck articulation**

As noted earlier, longitudinal movements of the deck due to thermal effects, shrinkage and creep were accommodated by the use of mid-span needle beam expansion joints, typically every four to five spans. This method of jointing was well suited to balanced cantilever construction and allowed the deletion of bearings under the deck boxes.

The needle beam joint consisted of a pair of 13.5 m long steel beams supported by two lines of bearings contained within guide frames cast into special segments in each cantilever on either side of the expansion joint. The combination of guided bearings and keeper bearings allowed for longitudinal translation while restraining vertical movements and rotations across the joint. Two beams were used at each joint to provide the torsional resistance required to prevent the cantilever ends from twisting under differential traffic loadings.

Figure 8 shows a typical needle beam layout and deck cross section at the needle beam locations. The needle beams were installed into the first cantilever to be constructed adjacent to a movement joint and pushed back inside the cantilever. Following construction of the opposing cantilever, the needle beam was jacked into position across the joint after which the bearings and keepers were installed.

In the future, bearing replacement can be achieved by the use of small hydraulic bottle jacks applied at nominated jacking points inside the deck boxes. This was the first use of needle beam joints in Australia and significantly reduced the inspection and maintenance requirements for the bridge. Inspection and replacement of the bearings using the needle beam system could be achieved entirely within the box with no impact on either the elevated or at-grade South Road. This was seen as a major benefit in the constrained project corridor where jacking of the deck to remove large bearings would have required lane closures on the heavily congested at-grade South Road.

The use of expansion joints every 240 - 320 m also allowed for the use of simple finger plated joints instead of the modular joints typically required on a viaduct of this length. This both reduced joint cost and maintenance requirements in the future.
FINISHING WORKS AND ARCHITECTURAL FEATURES

The viaduct deck was completed using concrete barriers with steel top rails. The barrier units were precast in 6 m sections and joined to the deck with an in-situ stitch cast following erection and final positioning. The barriers had a fluted outside profile and were cast using a white pigmented concrete.

The outer curve of the pier profile was extended to the underside of the deck using a lightweight curved composite plastic unit which completed the overall architectural effect and provided space for drainage pipes and services.

Additional features added to the viaduct included coloured plexi-glass noise and feature walls, signature light columns and gantries to carry signage and ITS equipment and internally lit ‘totem’ poles at gantry locations. Figure 9 shows a view of the completed viaduct soon after opening.

Finally the at-grade undercroft area was landscaped with a mixture of hard and soft treatments to cater for the shaded environment and provide an attractive environment for road users and local businesses.
CONCLUSION

The South Road Superway presented a number of interesting challenges to both the design and construction teams. The project specifications required a striking solution to meet the Client’s requirements.

A project of this nature requires a design which is closely linked with the construction methodology requiring close coordination between the design and construction teams at all stages in the process, from tender design, through detailed design and the construction phase. The design and construct methodology allowed for an integrated design and construction team with co-location of all parties in the design and construction process critical to the successful delivery of this complex project in a very tight timeframe.

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REFERENCES


AUTHOR BIOGRAPHIES

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Peter Selby Smith has over forty years’ experience in the design and construction of bridges in Australia and overseas. After initially working with contractors, he has been a bridge designer with Maunsell, Corcoran Shepherd and GHD. He has had major roles on Bowen Bridge and Sorell Causeway in Hobart, West Gate Freeway, the Barwon River Bridge, and the new Echuca Rail Bridge in Victoria, the first Mekong River Bridge, drafting the New Rail Bridge Code and AS 5100 and the Eleanor Schonell Bridge in Brisbane. He has been GHD’s Bridge Director for the South Road Superway, through tender, detailed design and construction phases.

Lucas Wise is a senior bridge engineer with International Bridge Technologies in Dubai. He spent three and a half years working on the tender, detailed design and construction phases of the South Road Superway in Adelaide with GHD. Lucas was responsible for parts of the superstructure design of the viaduct and for the last two years has provided technical advice on site for erection of the superstructure, including modifications of erection pyramids/displacements, cambers and erection control.
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