GATEWAY SOUTH

2020 Australian Construction Achievement Award

DARLINGTON UPGRADE PROJECT

Off-Line bridge construction and use of self-propelled modular transporters

Technical Paper

Abstract

The Darlington Upgrade Project is a critical piece of infrastructure that will form a key part of Adelaide's North-South Corridor. The development of the corridor, a non-stop 78-kilometre major transport route between Gawler in the north of Adelaide and Old Noarlunga in the south, is a direct result of a government strategic objective to reduce Adelaide's urban road congestion.

The project involves the design and construction of an upgrade of approximately 3.3 kilometres of Main South Road, including a non-stop motorway between the Southern Expressway and north of Tonsley Boulevard and the construction of eight bridges.

The project is being delivered on behalf of the Department of Planning, Transport and Infrastructure (DPTI) by Gateway South, a joint venture between Laing O'Rourke Australia Construction Pty Ltd and Fulton Hogan Construction Pty Ltd. Design was undertaken by a joint venture of Jacobs Group (Australia) Pty Ltd, Kellogg Brown & Root Pty Ltd and SMEC Australia Pty Limited.

Construction commenced in early 2016, with the project scheduled for completion in mid 2020.

This paper focuses on the innovative design, construction and installation approach adopted for three of the eight bridges delivered as part of the project.

The three long-span steel box girder bridges were constructed off-line on temporary towers and then transported and installed using self-propelled modular transporter (SPMT) technology.

An Australian first for a civil construction project of this scale, this unique construction and installation approach resulted in significant reductions to community and traffic impacts. It also demonstrated greater flexibility in accelerated bridge construction, when combined with extensive engineering analysis and construction planning.

Introduction

The North–South Corridor is one of Adelaide's most important transport corridors and serves as a major route for commuter and freight vehicles between the township of Gawler in the north, and Old Noarlunga in the south, distance of 78 kilometres.

The development of a non-stop North–South Corridor for Adelaide is part of a strategic initiative to reduce Adelaide's urban traffic congestion and to stimulate economic growth by providing an efficient transportation link to strategic ports and interstate destinations in the region.

The Darlington Upgrade project is a key part of the delivery of the corridor and involves the design and construction of an upgrade of approximately 3.3 kilometres of Main South Road, including a non-stop motorway between the Southern Expressway and north of Tonsley Boulevard and the construction of eight bridges, which will result in the removal of five sets of traffic lights.

Approximately 73,000 vehicles per day travel along Main South Road through the Darlington precinct. This section of road is also home to four of South Australia's busiest intersections, with 98,000 vehicles per day using the Main South Road/Sturt Road intersection.

This section of road is frequently congested for northbound traffic in the morning peak period and southbound traffic in the afternoon peak period.

The project site is also highly complex in relation to stakeholders, with two major hospitals, a university, three local councils, small and large businesses and residents of varying ages and cultural backgrounds calling the area home.

A design and construct contract for the Darlington Upgrade Project was awarded in December 2015 to Gateway South, a joint venture between Laing O'Rourke Australia Construction Pty Ltd and Fulton Hogan Construction Pty Ltd. The design joint venture for the project consists of Jacobs Group (Australia) Pty Ltd, Kellogg Brown & Root Pty Ltd and SMEC Australia Pty Limited.

During the tender phase, Gateway South identified that minimising disruption for the community and travelling public during the construction phase was a key driver for the client, Department of Planning, Transport and Infrastructure (DPTI). Committed to delivering on this objective, the team analysed and reviewed bridge construction options across the highly trafficked and complex stakeholder project site.

It was clear from the outset that adopting a traditional bridge construction method for three of the eight structures would result in significant traffic and community impacts, given the complexity and size of the intersections where they were to be located: the Southern Expressway/Main South Road and Ayliffes Road/South Road/Shepherds Hill Road intersections.

Alternative bridge construction solutions were investigated and, as a result, the off-line bridge construction and SPMT installation approach was adopted for these three structures

Investigations showed that designing, constructing and installing the bridges in this innovative way, rather than traditional methods, would reduce the number of weekend road closures from at least seven per structure, to one single closure per bridge.

The use of this accelerated bridge construction method represented an Australian first for the installation of fully completed, three-span bridge structures.

At the time of contract award in late 2015, SPMT bridge design industry standards in Europe and America related only to the development and implementation of single-span bridges between 500 and 1,000 tonnes in weight and two-span structures with an average weight of 2,000 tonnes. With regard to three-span structures, methodologies trialled at that point in time accounted for steel bridge components only and weights significantly less than 3,000 tonnes.

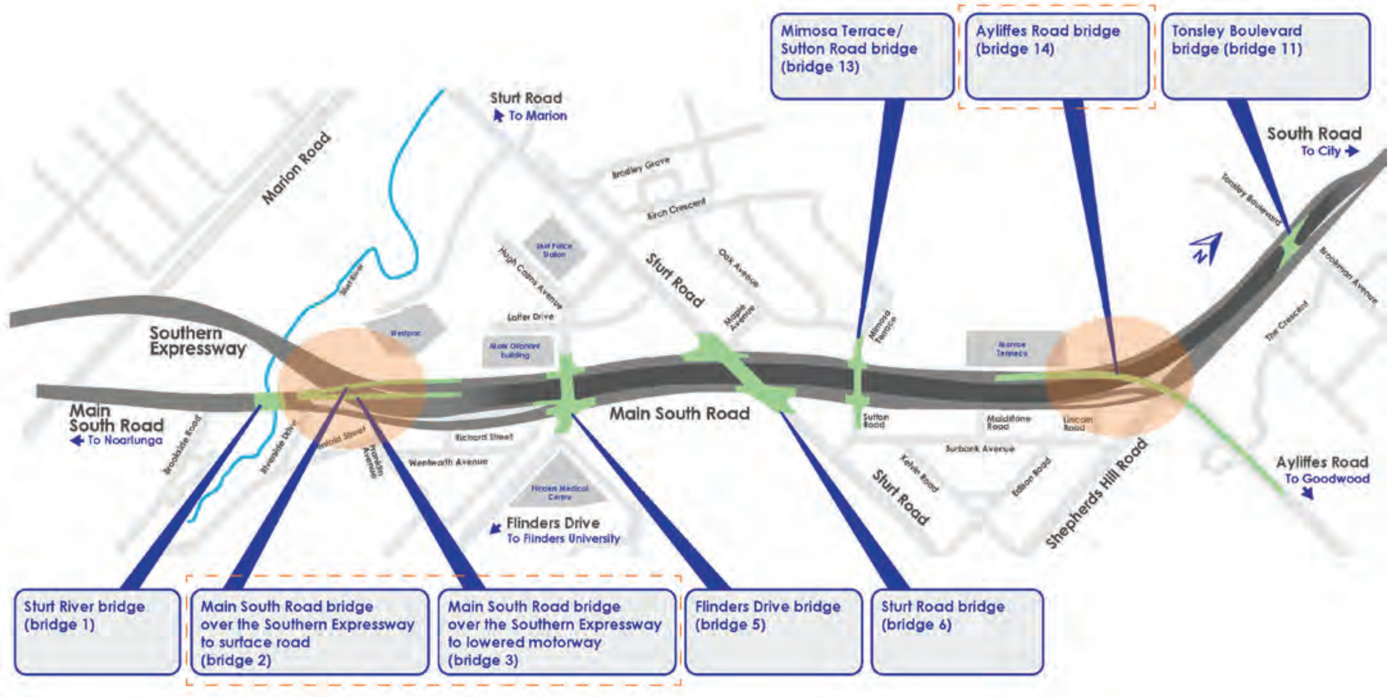


Figure 1: Location of Darlington Upgrade Project bridges

The Darlington Upgrade Project structures were unique as they were completed with steel girders, concrete deck and parapets in place prior to being transported.

In addition to this, previous full bridge installations around the world using SPMTs had been on flat ground with the structure moving only a short distance. The Darlington Upgrade Project required the transportation of the structures along the existing road network over a distance of approximately 400 meters per bridge, with significant cross fall and longitudinal grade. A transition down-grade to flat and then up-grade created a difficult concave geometry for the overall bridge travel path.

The successful installation of the three 3-span bridges weighing between 3,000 and 3,200 tonnes and varying in length between 180 and 197 metres, was therefore not only an Australian first but a significant achievement in the global civil construction industry.

Due to the unprecedented complexity of the activity, the impact of the new methodology on the structural design limits was unknown. As a result, the project team was required to develop innovative methods to pre-wire the structure before transporting it in order to monitor any changes in stress or strain, in real time through its movements.

Gateway South has generated new knowledge in relation to the off-line construction of three-span bridge structures and successful transportation using the SPMT method. Knowledge was also gained in relation to conducting this activity with minimum disruption to the local roads and businesses. This paper will provide specific details on the design of the bridges, the off-line construction method and use of SMPTs for installation of the structures.

The location of the three bridges is shown in Figure 1. Refer to: 'Main South Road bridge over the Southern Expressway to surface road (Bridge 2)', 'Main South Road bridge over the Southern Expressway to lowered motorway (Bridge 3)' and 'Ayliffes Road bridge (Bridge 14)'.

Note: Only the northern half of the Ayliffes Road bridge was constructed off-line and installed via SPMTs. The southern half was constructed in situ as it was located outside of the intersection, and thus able to be built without affecting traffic at this critical intersection.

Bridge design

Overview

The three-span steel structures consist of spans ranging in length from 40 to 75 metres, with twin composite steel box girders and concrete decks. None of the structures are symmetrical, which created issues due to differing loads and supports at each location.

Deck road geometry did not vary greatly across the three bridges. In its final alignment, Bridge 2 will have a single carriageway with a single lane and a two way shared path along the western edge. It is 8.9 metres wide between traffic barriers. Bridge 3 has a single carriageway with two lanes and is 9m wide between traffic barriers. Bridge 14N also has two lane carriageways and varies in width between 7.2 and 8.9 metres.

Bridge 2 is a 180m long overpass structure that carries the northbound carriageway of Main South Road over the existing Southern Expressway, onto the surface road.

Bridge 3 is a companion bridge of Bridge 2 and also a 180-metre long overpass structure that carries the Main South Road northbound traffic over the Southern Expressway, onto the lowered motorway.

Bridge 14 carries northbound Main South Road and lowered motorway traffic over the intersection of Shepherds Hill Road and South Road, onto Ayliffes Road. The bridge was constructed in two halves, with the southern half built in situ and the 195-metre northern half (Bridge 14N) built off-line and installed via SPMTs. The southern and northern girders are separated by an expansion joint in the deck at the central pier.

BRIDGE 2

180m

- 180m
- 3000 tonnes
- Overpass structure
- Main South Road to surface road

BRIDGE 3

180m

- 180m
- 3000 tonnes
- Overpass structure
- Main South Road to lowered motorway

BRIDGE 14N

195m
(northern half)

- 195m
- 3200 tonnes
- Expansion joint at central pier
- Main South Road to Ayliffes Road

Figure 2: Aerial view of Bridges 2 & 3, looking south

Figure 3: Aerial view of Bridge 14, looking south

Girder section and profile

Maintaining the same details across the three steel bridges provided significant design and constructability benefits.

The typical bridge cross-section, as shown in Figure 4, comprises twin steel box girders consisting of 350 MPa grade steel, measuring 2.1-metres wide with straight vertical webs and inclined at 3% so the webs are perpendicular to the deck crossfall to create a subtle visual impact.

The girder top flanges vary from 635 millimetres wide at the piers to 500 millimetres wide within the spans. The 635-millimetre wider flange is slocated in the flange compression regions in accordance with American Association of State Highway and Transportation Officials (AASHTO) flange proportion limit of keeping the width greater than or equal to 1/6 of the web depth. This ensures that the stiffened web panel within the section can develop post-buckling shear resistance due to tension field action. This requirement is not covered by AS5100.6 Bridge Design - Steel and Composite Construction.

Girder webs are a uniform 16-millimetre thickness. This minimum thickness was adopted to avoid unsightly distortion in the web when welding stiffeners to the internal web surface, which can occur for thinner web members. All girder segments contain internal K-bracing and top flange lateral bracing. At greater girder depths towards the piers, there are two levels of K-bracing.

Girder spacing is between 3.65 m and 4.65 m for all three structures. Girder diaphragms at abutments and piers are combinations of steelwork bracing members and stiffened vertical plates. The exception is the section of diaphragm directly over the single-column pier column, where a reinforced concrete diaphragm provides a large plan surface area to transfer diaphragm forces into the spherical bearing below. Steel diaphragms were the preferred option, to enable the platework inside the girders to be welded in place in the fabrication workshop.

The bracings between girders have bolted connections to assist with constructability, allowing them to be assembled on site while the girders were located on the temporary towers.

The detail at the bottom of the vertical stiffener, as shown in Figure 5, is a product of early constructability involvement between the designers and fabricators regarding potential manufacturing issues and solutions to meet both design standards and fabrication outcomes.

The design required the vertical stiffener to be in full contact and directly welded to the bottom flange, following the AASHTO provision to retain the cross-sectional configuration of the girder when subjected to torsion and also avoid the localised bending within the web. This design consideration was not covered by AS5100.6 Bridge Design - Steel and Composite Construction.

Fabricators requested to terminate the stiffener approximately 350 millimetres above the bottom flange to allow access for the welding machine to execute the continuous welding of the web and the bottom flange.

The agreed solution was a welded closer plate to fill the gap between the bottom flange and stiffener plate.

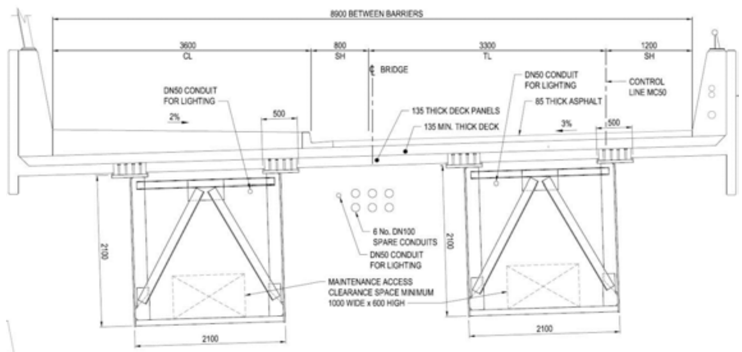


Figure 4: Typical cross-section

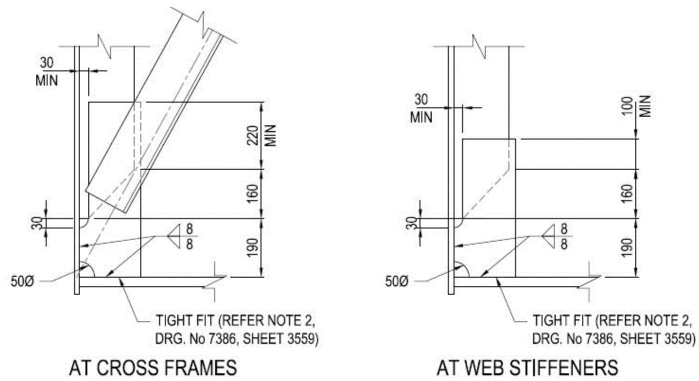


Figure 5: Typical vertical stiffener-bottom flange detail

Girder depths vary from a minimum of 2.1m at abutments and mid-span to 3.8m at piers. Span lengths vary over a wide range for all three bridges, from 40m to 75m.

In order to maintain the uniform profiles, structural parameters were optimised across the three bridges for top and bottom girder flange thicknesses, which vary from 20mm to 40mm. Bottom flange reinforced concrete was also used where required over some internal piers.

Typical details of precast deck panel

The precast bridge deck panels are 135 millimetres thick with pockets for shear stud placement. The required concrete strength for the precast deck panel was 50MPa, with 40MPa required for the 135-millimetre in situ deck poured on top of the precast portion.

The outer shell of the traffic barrier was made integral with the precast deck panel to expedite construction and reduce worker hours on site, by eliminating the need for temporary works. This design consideration also provided distinct safety benefits for workers.

Barriers were cast with a small angular tilt inward on both sides to allow for deflection from casting position to the final in situ resting place. The precast panels span the entire width of the bridges and are approximately 2.4 metres wide as shown in Figure 6. Installation of the precast transfloor panel can be seen in Figure 7.

After the deck panels were placed on the girders, a grout layer was poured into the shear stud pockets to ensure there were no air gaps underneath the precast and structural steel.

The topping slab has a single layer of longitudinal reinforcing bars, which acts as tensile reinforcement in the negative bending moment regions and as general crack control reinforcement for the positive moment regions.

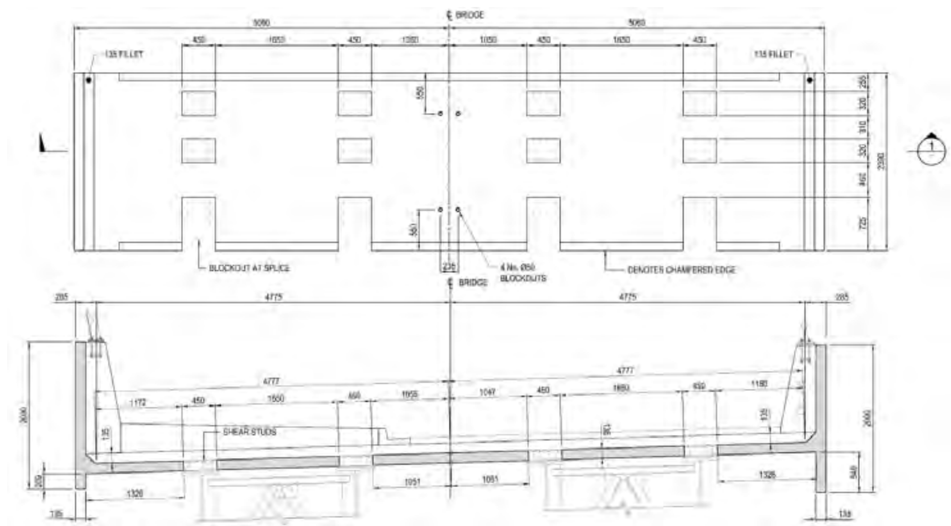


Figure 6: Typical precast transfloor panel

Figure 7: Precast transfloor panel during installation

Substructure

The bridge abutments are conventional 2,000-millimetre thick blade walls up to the underside of the girder bearings. This wall retains backfill of the in situ reinforced soil structure (RSS) wall forming part of the approach embankment. The wall transitions into a 300-millimetre thick fender wall behind the ends of the girders and the diaphragms.

Bridge 2 and 3 superstructures are supported mid-span by two piers. Pier 1 is a single 2,000-millimetre diameter column and pier 2 comprises twin 1,500-millimetre diameter columns. Figures 8 and 9 show these typical pier details supporting the steel bridge superstructure.

Steel box girders are supported on spherical bearings with lateral fixity provided by one bearing per abutment/pier and longitudinal fixity achieved at one location which is top of one of the two twin pier columns. Expansion joints are installed at both abutments of Bridge 2 and Bridge 3. Bridge 14 has an additional expansion joint which aligns the two halves.

All abutments and piers are connected to pile caps and two rows of 1,050-millimetre diameter Continuous Flight Auger (CFA) piles to resist the large moments and forces that will be transferred.

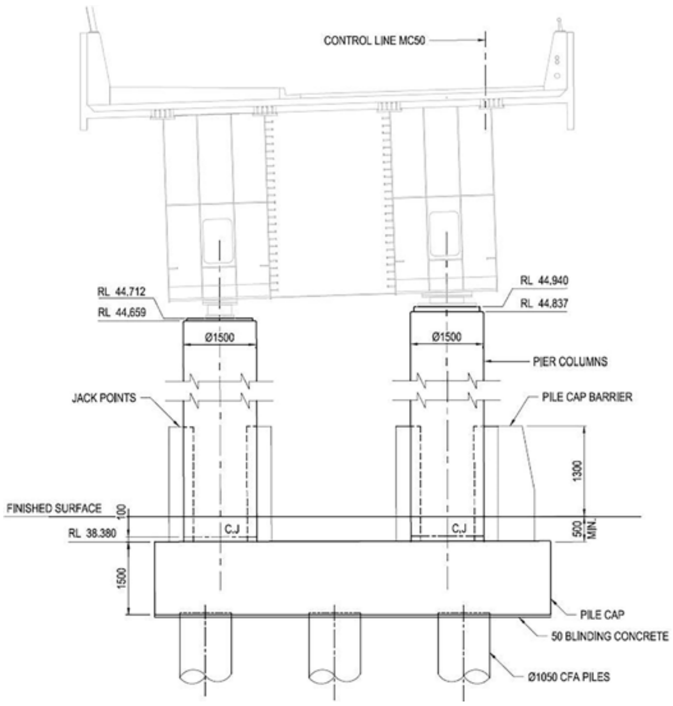


Figure 8: Typical single pier

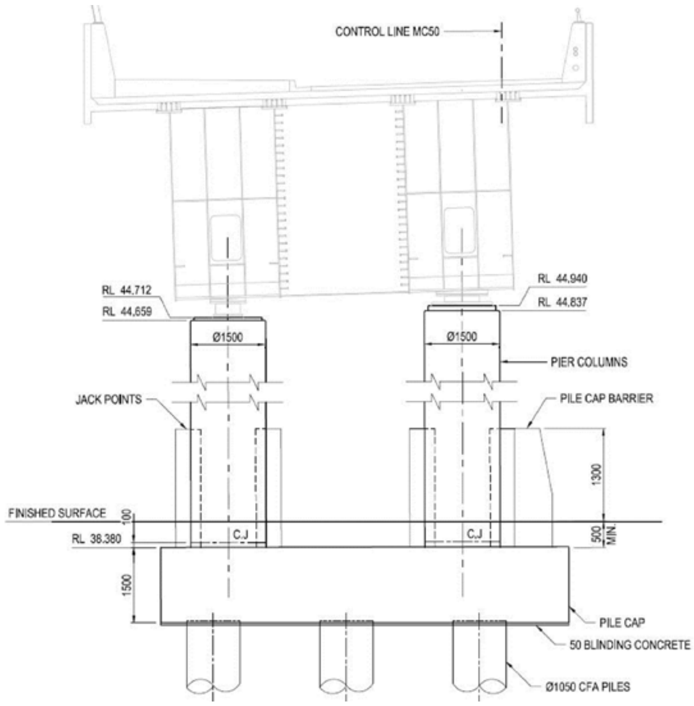
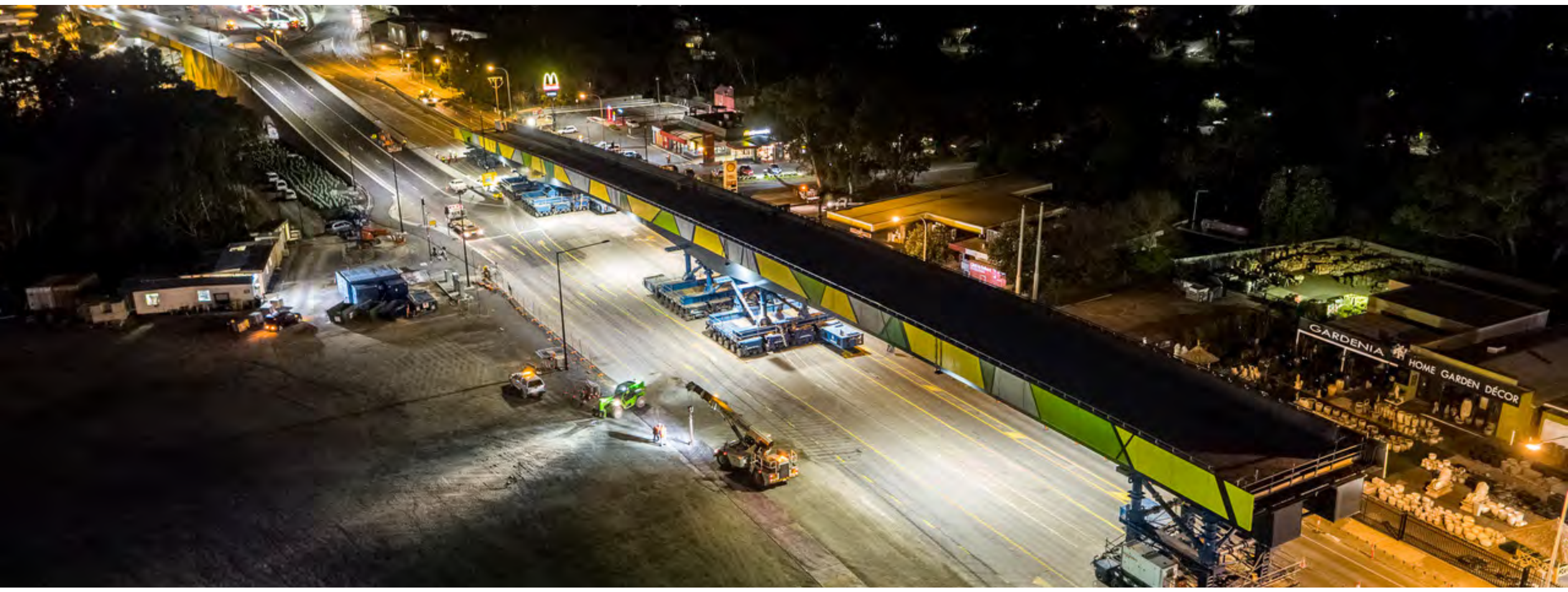


Figure 9: Typical twin piers



Bridge modelling

Finite element modelling for SPMT moves

A full 3D finite element model of the substructure and superstructure of each of the three bridges was developed with MIDAS Civil software to undertake the comprehensive analysis required for the SPMT bridge moves. This included specific parameters such as the curve of intersection for the installation of Bridge 14N, the 3% change in transverse gradient on the travel path for Bridges 2 and 3 and the temporary bridge crossing. Further details on the temporary bridge crossing can be found in the 'Off-line construction' section.

The full construction sequence, including construction on temporary supports to the final SPMT moves, was modelled in the Construction Stage Analysis module of MIDAS.

This involved hundreds of load combination scenarios reflecting the actions and movements likely to be experienced by the three bridge structures within the allowable stress limits for reinforcement, concrete and plate steel. From this analysis, the vertical, horizontal and torsional movement limits were established.

The design also considered the analysis of local design actions to specific structural members such as the internal bracing members, top flange lateral bracing, and points of local support for the SPMT move.

The transverse self-weight distribution of the precast panels over the girder top flanges was also analysed. Due to the presence of the integral barrier at the end of the panels, the exterior girder flanges carried a higher portion of the precast panel self-weight than the interior flanges. The unbalanced loads on the girder flanges led to an increase in the top flange lateral bracing, which was accounted for in the design.

The analysis for local design actions was performed via finite element analysis with a model that contained the true representation of the superstructure with its internal bracing, transverse and longitudinal web stiffeners and the deck on its non-composite and composite state, as shown in Figure 10.

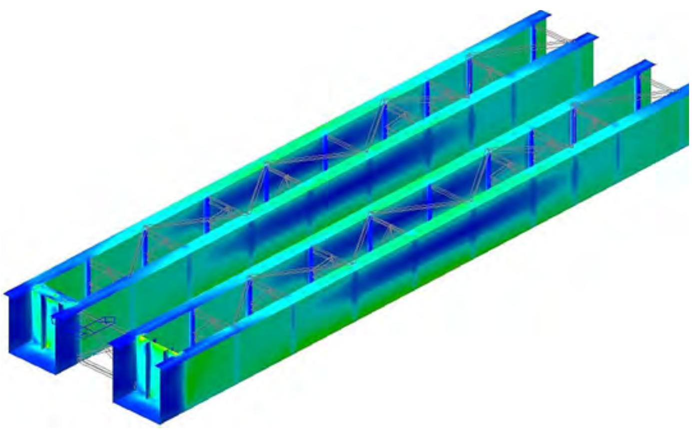


Figure 10: Bridge 2 3D finite element model

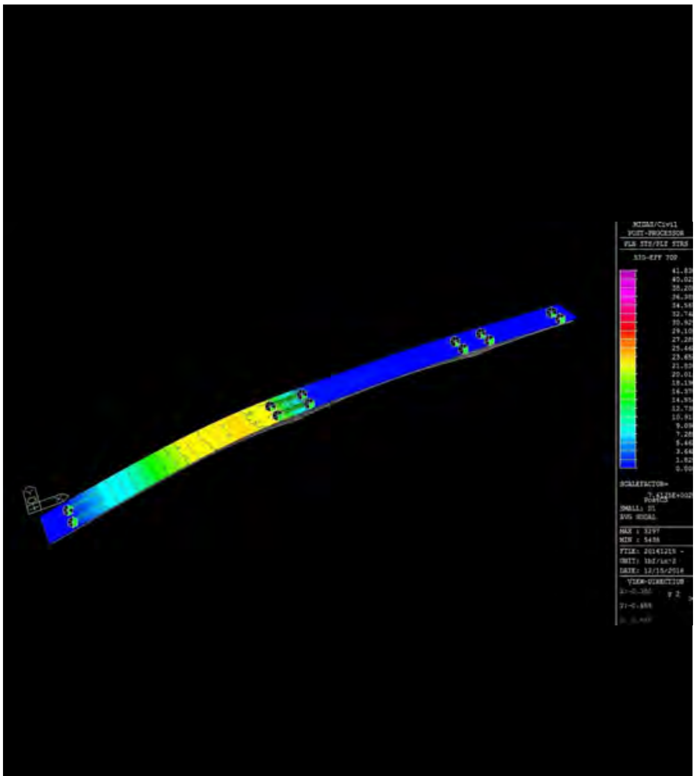


Figure 11: Vertical displacement MIDAS results for Bridge 2

Structural analysis

A detailed structural analysis of the bridge superstructures was performed to validate that the permanent works design could accommodate the proposed construction methodology within the defined limits. This included determining the effects of support settlement that might occur during SPMT transport.

Support settlements ranging in magnitude were applied at the abutments and at the piers. The design actions due to support settlement were extracted from the structural analysis model and compared to allowable serviceability limits.

This analysis established the operational deflection limits for the SPMT bridge moves.

The structural analysis also investigated the state of stress in the concrete deck, steel box and bracing elements as well as at SPMT bearing locations. In addition, the analysis investigated the effects of twisting on the superstructure that might be caused by differential movement along a single line of SPMT supports.

The twisting effects on the bridge superstructure were also used in assessing the state of stress on the concrete deck, steel box and bracing elements and at the SPMT support locations.

Figure 11 shows the MIDAS results for Bridge 2 vertical displacement.

Off-line construction

Bridges 2 and 3 were constructed on temporary towers on a parcel of land directly adjacent the project site, approximately 400 metres from their permanent location. Bridge 14N was constructed in an off-line location within the project site, also approximately 400 metres from its permanent location.

The steel box girders for the three structures were installed on temporary work towers and bolted together to form the complete steel troughs. Following steelwork assembly, the precast deck slabs were installed, the deck top slab was poured, barriers were constructed and fixtures installed.

The height of the temporary towers was selected to ensure the bridge profiles were exactly as they would be positioned in their final permanent position—with each support point at the correct position to their final pier and abutment locations.

The height also needed to allow the SPMT transporter to move freely under the near-completed bridges in the assembly locations so that they could lift the bridge girders off the temporary towers and move them to their final bridge position unimpeded. Temporary works design was undertaken by Robert Bird Group.

Figure 12 shows the temporary towers constructed for Bridge 14N, prior to bridge construction.

Figure 13 shows the construction yard for Bridges 2 and 3, with transportation of Bridge 2 commencing and Bridge 3 being constructed on temporary towers.

Figure 12: Temporary towers for Bridge 14N

Figure 13: Bridge 3 being constructed on temporary towers completed Bridge 2 being moved by SPMTs

Temporary works

Due to the size of the structures and the complex urban environment surrounding the project site, suitable off-line construction yards were difficult to find. The project team settled on a parcel of land between the Southern Expressway, Main South Road, Marion Road and the Sturt River for Bridges 2 and 3, which provided the required size but posed a technical issue. The yard was located south of an adjacent concrete bridge over the Sturt River, which the structures would need to traverse in order to reach the installation site.

This structure was built in the early 1960s and, although in good condition, the design standards of the time created two main issues. The original design of the structure showed that the connection between the deck and the abutment was weak and had the potential to allow the top of the abutment to rotate under load when the soil block behind the abutment was loaded. The top layer of reinforcement within the deck was also reviewed and deemed to be insufficient to take the load as the new structure passed over it.

Several options were proposed and investigated to address this issue; however, the majority of these impacted on the flow of the river and could not be adopted due to the potential (albeit highly unlikely) for a significant rain event, meaning a bridge protection solution was required to be above the flood zone. It was from here that the solution to build a temporary bridge over the existing 1960s structure was born.

The temporary design transferred the load from the mid span of the existing structure vertically down the piers and the abutments, rendering the existing planks and deck redundant. This approach required large universal beams to be welded together and then braced into units. Steel plates were then welded onto the top of these units to provide a new traffic surface. These large beams also extended past the ends of the bridge and onto new spread footings to allow the earth block behind the abutment to not take any load. This solved the issue of the possible abutment rotation, as the load was transferred back behind the zone of influence.

Small asphalt ramps were created on top of the existing road surface to bring the traffic up to the new deck height. Figure 14 provides details of the temporary bridge design.

Detailed monitoring of the temporary bridge was undertaken prior to, during and after installation of Bridges 2 and 3 to measure displacement and ensure that the weight of the SPMT and structures did not affect the structure's serviceability lifecycle.

This temporary protection structure remained in service for nearly 12 months until it was removed shortly after Bridge 3 was installed.

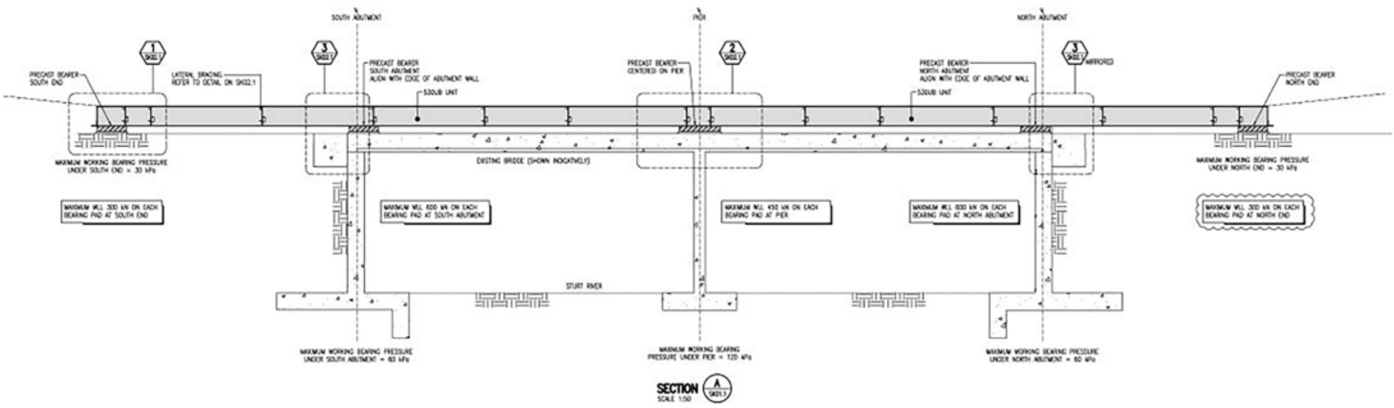


Figure 14: Cross-section of temporary structure

SPMT bridge installation

Gateway South engaged specialists from Sarens, a global leader in heavy lifting and engineered transport, to provide expert advice, technical services and equipment to manage the bridge installations.

To install the three bridge sections, twenty-two 6-axle Kamag 2406 SPMT units were used in two different configurations (18-axle and 24-axle setups) – with a total of 132 axles used.

Additional climbing jacks were required on the two outermost units for the installation of Bridges 2 and 3. This allowed the abutment groups to float the load through the challenging gradients along the permanent road; the long grade was 5% with the cross fall greater than 3%.

Figure 15 shows the number of jacking movements required at designated chainages during the transportation of Bridge 2.

Live monitoring of the structures during transportation allowed the team to better understand practical limits and subsequently minimise the number of jacking movements – thereby saving time on the installation program without compromising the structural integrity.

Figures 16 and 17 show the transportation of Bridge 14N via SPMTs.

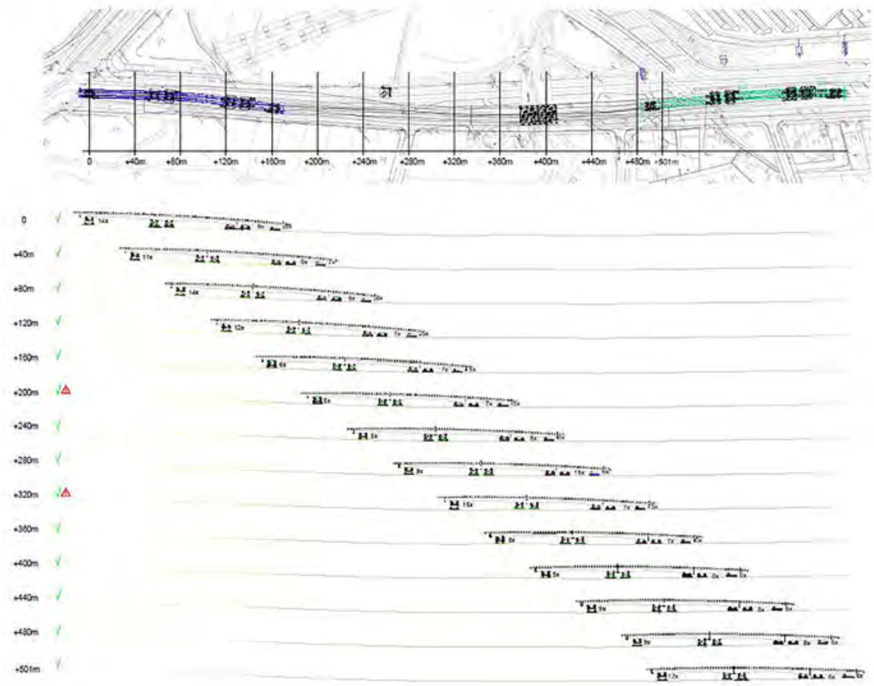


Figure 15: jacking requirements for transportation of Bridge 2

Figure 16: Bridge 14N during transportation

Figure 17: Bridge 14N during transportation

Real-time monitoring

The team worked with a specialist instrumentation partner, Aquamonix, to develop a state-of-the-art monitoring system which used vibrating wire gauges and lasers to provide real-time information on the structural performance of the bridges during transportation.

Most logistics contractors rely on hydraulic gauges located on the SPMTs for load monitoring; however, this information is not logged or collected. The Gateway South team undertook to better this standard, and a secondary and tertiary system of monitoring the structure was designed.

Although the structures had decks and parapets fully cast, they allowed for movement during transportation. This flexibility, combined with the monitoring system, allowed for further movement before having to adjust the jacking system.

This resulted in a reduction from 20 jacking movements to just two, effectively halving the installation duration from 50 hours to just 21 hours.

The monitoring portal and strain gauge positions for Bridge 2 are shown in Figure 18. The maximum limits were set at 80% of the working limit specified by the design team. The values were then split into 75% for green, 20% for orange and 5% for red. This conservative approach ensured that the team had room to adjust even in the instance of the monitoring showing red.

The green in Figure 18 to the right indicates that the limits for both strains and deflections were well below the established limits. This colour would change to orange if the actual readings were approaching the limit, while red would indicate that the limit was imminent.

The real-time monitoring greatly assisted the SPMT operator and designers to quickly intervene if the readings were nearing maximum limits.

The portal's functionality and limits were refined for the installation of Bridges 3 and 14N, through lessons learnt and continuous improvements.

Detailed crack mapping of the three structures was undertaken with the client prior to and after each bridge move to validate the live monitoring information. This process showed that the off-site construction and SPMT installation methodology did not affect the structural integrity or serviceability of the bridges.

Analysis

Following the first bridge move, monitoring data was collated and reviewed in detail against the design parameters of the bridge. The data was represented through plots of strains recorded at a particular section of the bridges, with gauges measuring reinforcing bar and flange strain limits.

The gauge reached a maximum compression of about 200με. The top flange limits were never exceeded. The reinforcing bar strain limits were also never exceeded. The maximum strain was about 560με in the reinforcing bar which represents a stress of less than 120MPa.

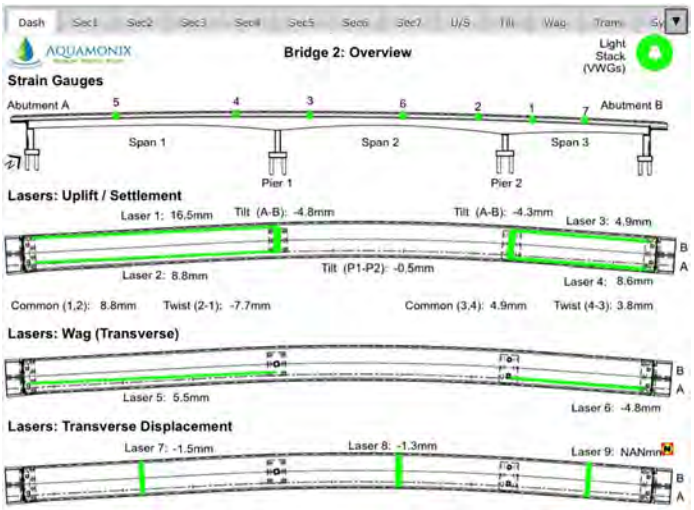


Figure 18: Strain gauge monitoring portal

Conclusion

The Darlington Upgrade Project's off-line assembly of three 3-span steel box girder bridges and their transportation and installation using SPMT technology significantly reduced road closures and traffic disruption.

All works were completed within the required timeframes, with the first bridge installation completed 21 hours ahead of schedule – a significant achievement for a weekend installation program.

An Australian first for a civil construction project of this scale, this unique construction and installation approach resulted in significant reductions to community and traffic impacts. It also demonstrated greater flexibility in Accelerated Bridge Construction, when combined with extensive engineering analysis and construction planning.

Acknowledgements

Department of Planning, Transport and Infrastructure (DPTI) - Owner

Laing O'Rourke Australia Construction Pty Ltd and Fulton Hogan Construction Pty Ltd - Contractors

Jacobs Group (Australia) Pty Ltd, Kellogg Brown & Root Pty Ltd and SMEC Australia Pty – Designers

Robert Bird Group – Temporary works design

COX Architecture – Bridge rendered images

Timelapse Adelaide – photography

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