Port River Expressway – Road and Rail bridges
Design and Construction Challenges

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SYNOPSIS

The Port River Expressway (PRExy) bridges are part of the multi-stage Port River Expressway project which is an $A270M investment linking South Australia’s major port and rail terminals and export enterprises at Port Adelaide with interstate road and rail links to Perth, Darwin and Sydney. The project is a major component of a massive program of transport and infrastructure works targeted to improve South Australia’s port and industry-related developments and support the future growth in exports.

The single leaf bascule* bridges - one for road traffic and one for rail – are the major elements of Stages 2 and 3 of the PRExy project. The construction of these bridges involved the contractor, Abigroup Contractors Pty Ltd, integrating a team of designers across a range of disciplines in America and throughout Australia, managing significant off-site fabrication and developing innovative construction techniques, especially when working over the active waterway in the Inner Harbour. The rail component, Stage 3, was multi-faceted, with an involved scope - several elements were world firsts.

The complexity of the project provided challenges which resulted in some innovative engineering solutions, particularly associated with the fabrication, assembly and balancing of the bascule spans and with the rail works. Other challenges involved the geotechnical conditions, pier protection and environmental management considerations.

1.0 PROJECT BACKGROUND

Stage 1 of the PRExy project, a 5.5km four-lane expressway with three major overpasses, was opened to traffic on 19 July 2005 at a cost of $A91.5M. Stages 2 and 3 comprise opening road and rail bridges across the Port River, with the four-lane, single leaf opening road bridge and the single-track dual-gauge, single leaf rail bridge being completed and opened to traffic in August 2008.

The State Government preferred the high-level opening bascule bridges option, with the height of the bridges sufficient to minimise the number of openings for marine traffic and hence reduce delays for road and rail traffic using the bridges. This option will maintain the Inner Harbour as an active waterway and provide flexibility for future development opportunities. Both bascule bridges provide a 10m high clearance to mean sea level which caters for most frequent marine users. The bridges are the first opening bridges built in Australia since the early 1990’s.

The PRExy project complements many other significant projects in and around Outer Harbor including a new grain terminal and wharf, deepening of the main shipping channel to cater for Panamax ships and infrastructure works associated with the $A8B Air Warfare Destroyer project.

The opening regime for the bridges gives priority to road and rail freight traffic during the week whilst recognising the increased weekend and public holiday use by recreational marine users. The weekday opening times are 6.00 am and 7.00 pm, with the weekend and public holiday opening times being 10.00 am, 3.00 pm and 6.00 pm, with a further opening at 10.00 pm during daylight savings.

* Bascule is a type of bridge raised and lowered by counterweights. French origin – bascule = ‘see-saw’, from battre ‘to bump’ and cul ‘buttocks’
1.1 Contract details

The Design Construct and Maintain (DCM) contract for PRExy Stages 2 and 3 was awarded to Abigroup Contractors Pty Ltd in early July 2005 and at the time was the largest transport related contract entered into by the South Australian Government. The maintenance period for the two bridges is 10 years. The contract required an independent Project Verifier and Sinclair Knight Merz was appointed to this role.

Piling work in the Port River commenced in November 2005 for the two bascule piers. The two opening bridges and associated upgrades and connections to the local road and rail networks were constructed at a total project cost of $A178M.

2.0 DETAILS ON DESIGN ELEMENTS

2.1 Road bridge design

The road bridge cross-section comprises four traffic lanes and a separate 2.5m wide shared pedestrian/cyclist path on the southern side, giving it an overall width of approximately 20m. The fixed section of the road bridge consists of four nominal 30m spans for both the western and eastern approaches to the central bascule span. The overall length of the bridge is 303m, with an opening span of 43.7m (providing a 29.5m clear navigation channel) and weighs 874t without the counterweight. This bridge has been named after Tom ‘Diver’ Derrick, a local war hero and VC winner.

The bridge superstructure typically comprises nine pre-cast, pre-stressed concrete ‘T-Roff’ girders per span. An in-situ reinforced concrete deck acts compositely with the girders. The girders in turn are supported at the internal piers by an in-situ reinforced concrete crosshead beam located in the same plane as the girders to give an aesthetically pleasing line to the bridge. The twin pier columns have the same rectangular form as the single rail bridge columns.

The bascule span on the road bridge consists of two welded steel box girders which are positioned to minimise the live loads on the cross-beams. Connections to the box girders are predominantly bolted joints rather than welded connections – a design detail preferred by Hardesty & Hanover, the New York based opening bridge designer. Where welded connections were required, they were limited to fatigue resistant types. The floor system of the road bridge bascule is a conventional stringer and floor beam system supporting a welded steel plate deck with a bonded aggregate riding surface.

A lateral bracing system on the road bridge opening span transmits wind loads and increases the capacity to further assist with supporting the deck when open. The span is fully counterweighted with only a small forward residual imbalance, which provides a self-closing tendency. The road bridge bascule span has a forward floor-break which decreases the live load span length.

For live loads, the road bridge bascule span acts as a two span continuous beam supported at three locations. One support is located at the live load bearings at the rest pier, the second support at the forward live load bearings located 3.7m forward of the trunnion bearing on the bascule pier and the third support at the trunnion bearing itself. The bridge is designed to SM1600 loading as per AS5100.
2.2 Rail bridge design

The rail bridge (or elevated rail structure) is a significant structure comprising a variety of different elements, with a total length of 1000m, including the opening span. This span is 47.25m in length with 13.75m of deck over counterweight, weighing 555t without the counterweight. This makes it one of the largest bascule rail bridges in the world. The length of the structure is 770m, excluding the pre-cast concrete deck planks at the eastern end.

The rail bridge has been named after Sister Mary MacKillop, the founder of the Josephite Order of nuns which began in South Australia and subsequently spread to other parts of Australia and New Zealand.

From the west, the elevated rail structure consists of seven spans of twin pre-cast T-Roff’s 1500mm deep and 30.6m in length. The structure changes from these pre-cast T-Roff beams to four spans of 2m deep steel box girders, 35.7m in length. These four box girders span across the Port River until reaching the bearing support pier or rest pier in the middle of the river where the bascule span is located.

Steel box girders continue east from the bascule span for another four spans, 30.8m in length. The elevated structure then transitions back to pre-cast concrete T-Roffs – eight spans each 28.7m in length. These T-Roffs are used up to the transition pier where the rail track diverges into two separate tracks, the northern leg continuing to Port Flat Yard, with the southern leg (main line) continuing to Dry Creek. The elevated rail structure in this section consist of a composite structure of a reinforced concrete.
in-situ deck supported by pre-cast pre-stressed reinforced concrete planks 10m in length. The single pier columns are generally rectangular, but rotated to the line of the bridge which gives an aesthetically pleasing 'blade column' look.

The rail bascule is a U-shaped through girder configuration that consists of two welded steel box-girders. These girders have a length of 60.1m, with a depth of 4.0m at the counterweight end and 2.9m at the rest pier end. (see Figure 2). The two bascule girders and trunnions are similar in design to those used on the road bridge, but with a modified geometry. The bascule span for the rail bridge is fully counterweighted, similar to the road bridge. The span is supported at two locations, acting as a simply supported beam under live load. The span is supported at the rest pier and trunnion bearing itself.

2.3 Opening mechanism design

The opening elements of the bridges produced the greatest challenges for the designers. Both the road and rail bridges incorporate two trunnion shafts on each span.

A trunnion shaft with two pivot points is attached to each of the two bascule box girders (see Figure 3). Each trunnion shaft is connected to a box girder with the aid of connecting bolts and an interference fit which is described in more detail in Section 4.3.

The trunnions facilitate the hinging operation of the bridge and transfer the weight of the girder and counterweight to the pier (see Figure 4).

Each trunnion consists of a plain-sleeve bronze bearing mounted on either side of the bascule box girder (see Figure 3). Hence there are four plain bearings on each leaf. Steel towers founded on the bascule pier for each bridge support the trunnion bearings.

2.4 Pier Protection design

The eastern fendering was designed to contain an ANZAC class Frigate, displacing 4600t, travelling at 0.2 m/sec, tug assisted, through the channel. The fendering provides a 29.5m clear navigation channel and extends 40m and 20m beyond the bridge piers on
the eastern and western sides respectively. The western fenders have been designed to take 50% of the energy of the eastern fenders because of the prevailing winds.

All river based bridge piers have been assessed to be able to resist impact from a Design Vessel having a maximum displacement of 325t, travelling at a velocity of 2.0 m/sec (approximately 4 knots). This was based on the Dolphin Explorer, a tourist boat and frequent user of the Port River.

2.5 Bridge operating motors

There are three electric motors of various sizes and configurations that can be used to raise or lower the spans - primary, auxiliary and emergency gear drive. The three motors act as a staged backup system and each stage is designed to operate independently of the other stages. The capacity of the primary electric motor for the road bridge is 114kW (150hp), while the primary electric motor for the rail bridge is 75kW (100hp).

Both bridges have an auxiliary drive motor that can be used if the primary drive motor fails. In addition, there are low power emergency gear drive motors which are engaged using a direct-on-line start. In an emergency, these motors can be run by a portable generator and operated independently of the control system, but at a much slower speed (approximately 30 minutes to open the bridges).

3.0 PROJECT DESIGN CHALLENGES

The PRExy project was complex in scope and unique in many aspects. There were many challenges faced by Abigroup from the initial design and procurement phases through to the construction work and finally with the balancing of the bridges and commissioning of the control systems and rail signalling works. Some of the challenges are outlined below.

3.1 Design and procurement phases

As the PRExy project was Abigroup’s first major contract in South Australia, they had a significant establishment task which involved relocation of existing staff from the eastern states and recruitment of many local specialised professional staff, plant operators and construction workers in a tightening labour market. In addition, Abigroup did not have a relationship with the pool of consultants, sub-contractors and suppliers in South Australia, nor the differences in the culture of undertaking business in transport projects in this state.

The project called for a wide range of specialist design consultants, including civil, mechanical, electrical, systems, rail, urban design, landscape and the co-ordination of these was complex. The opening bridge elements were designed by the American company Hardesty & Hanover which has more than 100 years of experience in moveable bridge engineering. The design of the fixed elements of the road bridge was undertaken by Dare Sutton Clark, a local engineering and project management firm and the elevated rail structure was designed out of the Melbourne office of Maunsell Australia Pty Ltd.
The contract period of 28 months for Stage 2 (Road) and 24 months for Stage 3 (Rail) appeared adequate, however it was essential that the design work was well resourced and the input of the various consultants and disciplines be integrated. The complexities of the scope and differences in approach of the designers resulted in delays which in turn caused subsequent set backs to fabrication, with some of the machinery and steelwork having long lead times due to the specialised requirements and tolerances. In addition, the market had received significant forward orders due to the mining boom and funding of many infrastructure projects in South Australia and Western Australia and could not meet the desired timelines.

3.2 Pier Protection

There were challenges associated with the protection of the bridges, particularly the bascule and rest piers, where the main issue was the impact of vessels both on the fenders and the piers.

There were considerable discussions on the approach to bridge protection between Abigroup and its designers, SKM, the Project Verifier, and DTEI representatives as the slender, ribbon like, rail structure was downstream of the road bridge and therefore more susceptible to collision from the large commercial vessels which can berth within 200m of the rail bridge (see Figure 1). It proved prohibitively expensive and not practical to limit the damage to that specified in the Scope of Works and Technical Criteria (SWTC) so after significant research and a risk management evaluation, a compromise collision requirement was determined.

As a result, most of the rail bridge piers required dolphin structures to be constructed to protect them from ship impact, deflecting and slowing down errant vessels which may approach the bridge away from the navigation span.

3.3 Geotechnical

The geotechnical conditions encountered in the project site needed close attention, with much of the land on both sides of the river being reclaimed having been the site of former heavy industries which degraded the area with varying levels of contamination. The overlying marine sediments have been recognised as requiring detailed consideration of their response under embankment loads and earthquake effects, which includes the possibility of soil liquefaction. Because of the low bearing strength and settlement characteristics of the materials on site, the designers extended the elevated rail structure on both sides of the river rather than rely on earth fill embankments. Any embankments used on the project site (mainly the approaches to the road bridge) were the subject of extensive pre-loading and monitoring.

The substructures for the bascule and rest piers were founded on 900mm diameter reinforced concrete piles. The stiff load bearing layers were the Hindmarsh Clays which were located at approximated AHD -25.0m which meant that piles for the bascule piers were driven in excess of 15m into the river bed. Initially, hollow steel tubes were driven into the river bed and then excavated or ‘mucked out’ to 5m below river bed level. A reinforcing cage was inserted into the tubes before being filled with concrete. The steel tubes are sacrificial and do not contribute to the design strength of the concrete piles.
A sheet-pile coffer dam was then formed around each pier position and then filled with select stone fill. A 300mm thick concrete blinding layer was poured over the stone fill to act as a working platform.

The bascule piers had a 2.5m thick reinforced concrete pile cap cast on this work platform and located just below the tidal zone (AHD -2.0m to -4.6m). (see Figures 4 & 5).

Figure 5 - Road bridge coffer dam prior to forming the pile cap

3.4 Environmental

The Port River is home to a much-loved and high profile pod of dolphins. To minimise the impact of the bridge works on these dolphins and other marine fauna, Abigroup developed an Environmental Management Plan which incorporated an innovative ‘bubble curtain’ around the pile group that reduced noise and vibration when they were being driven into the river bed. First used in Vancouver in 2000, the bubble curtain pumped compressed air to the river bed and expelled it through holed tubing.

A Masters student in Marine Biology from Flinders University was also engaged to monitor dolphin numbers and behaviour before and after the construction work in the river as part of her studies. She found that dolphin numbers and behaviour did not seem to be adversely affected by the works.

3.5 Rail design complexities

Stage 3, the rail component, was complex in itself; however it was the first time that DTEI had managed the construction of significant rail infrastructure. The input to the SWTC was largely the responsibility of a third party, the Australian Rail Track Corporation (ARTC), the organisation which owns or long term leases the assets and operates the signalling systems. Several design elements of the rail infrastructure were very complex on the PRExy project due to the unique and differing characteristics of the adjacent rail network on each side of the river and the opening bridges concept.

The tracks in this area consist of both broad gauge and standard gauge. To complicate matters further, the third rail was not on the same side of the tracks on each approach to the rail bridge. This required both dual gauge turn-outs and a common rail transfer, both of which required completely new designs. The latter was the first of its kind to switch the common rail side of a broad/standard gauge track at a design speed of 60 km/h.
In this vicinity there were three large acid tanks which were within a few metres of the elevated rail structure – one tank can be seen in Figure 6. The risk assessment and attention to safety in all aspects of the design for this location was very demanding.

Other items required New Equipment Approval, or ‘type approval’, from ARTC as they had never been used on the ARTC rail network previously. These included mitre joints on the opening span, expansion joints, bi-directional derailers and slab track construction using VIPA baseplates on the concrete deck of the elevated rail structure. The type approval process was challenging due to the complex nature of the rail works and risk adverse nature of the rail industry with their staff not having direct control over the design and construction work. After slow initial progress with the rail design, improvements were made through Abigroup engaging a retired rail employee familiar with industry practices and ARTC’s internal processes.

The use of mitre rail joints (a proprietary product) for the rail bridge was an Australian first. These joints had previously been used in the United States and were designed to lift and transfer the train wheels across the expansion gap in the rails between the fixed and opening spans. The mitre joint allows for expansion of the rails between the rail bascule span and the rest pier. Adelaide recently experienced temperatures in excess of 45°C and the mitre joint performed in accordance with all the design assumptions with the rail temperature as high as 65°C.

The rail track was designed for 1800m long trains with double stacked wagons travelling at a maximum speed of 60km/h on the main line and 35km/h elsewhere - concrete sleepers were used predominately, apart from Port Flat Yard and Gillman Junction. The specification called for 50kg/m head hardened rail. The turn-outs were hardened using a technique that involved placing 2mm sheets of plastic explosive on the top of the rail and detonating it. This specialised work was undertaken by the Army.

### 3.6 Control systems

Scope items such as opening bridges, variable and changeable message signs, co-ordinated traffic signals and rail signalling meant that the electronic control system element of PRExy was very involved. Abigroup engaged subcontractor Nilsen Electric (S.A.) Pty Ltd to develop and install the control systems associated with the PRExy bascule bridges and associated traffic management systems. Nilsen worked closely with Hardesty & Hanover to ensure a robust and high integrity control system was implemented. Programmable logic controllers (PLC) form the heart of the bridge control system and are programmed to ensure commands by operators do not result in hazardous situations or equipment damage.
An additional independent PLC system is located in the Operations Management and Control System (OMCS) building located on the wharf near the bridges and is used as a monitoring and supervisory PLC.

The opening spans of the two bridges are controlled via fibre-optic cable from the department’s Norwood Traffic Management Centre (NTMC) which is 14kms away on the other side of the Adelaide metropolitan area. There are closed-circuit television cameras on both bridges to monitor road, rail and marine traffic. On the road bridge, these cameras allow the operator to scan the site to ensure that the opening span is not raised until safety barriers are in place and any pedestrians or cyclists have moved behind them. The bridges take 70 seconds to raise and 70 seconds to lower and can operate independently of each other.

The changes in technology associated with the operating systems and signalling equipment from July 2005 when the contract was awarded to mid 2008 when the systems were commissioned was significant and proved a moving target for the designers.

3.7 Safety considerations

With the differing requirements and operating characteristics of the road, rail and marine sectors, addressing the safety concerns of all sectors was critical in ensuring the success of the project. A guiding principle for controlling safety for the Port River bridges was the use of Australian Standard AS 61508, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems*. AS 61508 is a non-industry specific document that has been developed largely out of experiences in the oil and gas industry. The document takes a project lifecycle approach to safety, specifying activities that must be undertaken through all phases of a project including the concept, design, construction, maintenance and decommissioning phases.

In accordance with AS 61508, Safety Integrity Levels (SILs) were assigned to a number of key functions associated with the opening bridges. To achieve these SILs, an independent control layer or safety instrumented system (over and above the PLCs) was introduced into the control system for each bridge. To illustrate this process for the road bridge:

- unless the system determines that the barrier gates are down and locked (preventing vehicles crossing the bridge), the system will block any attempt by the basic control system to raise the bridge span.
- An output error by the basic control system, which may otherwise cause the span to rise out of sequence, is prevented by the independent safety instrumented system.

The bridges and traffic management systems are primarily operated from the department’s NTMC. However, the system can be operated from other locations, including the purpose-built OMCS building located next to the two bridges and from the inside of the bascule pier. There have been strict protocols developed between the NTMC and the ARTC’s Train Control Centre at Mile End to ensure the fail-safe operation of the rail network. The opening sequence cannot be commenced by DTEI unless control has been handed over to ARTC. Unless there is a bridge opening event, the turn-outs on the approach to the rail bridge are not set to take trains onto this line.
3.8 Traffic management

When the bridges are raised, road and pedestrian traffic is temporarily stopped on the bridge approaches on either side of the Port River. Railway style boom gates are used to control road traffic, while separate pedestrian gates are used on the shared pedestrian/cycle path. A secondary set of road barrier gates will stop errant vehicles travelling at speeds up to 80km/h. The pedestrian/cycle path can be closed independently of the road traffic lanes to allow extra time for pedestrians and cyclists to clear the bridge.

Twenty-three cameras have been installed around the PRExy site. These enable operators from the department’s NTMC to have comprehensive video surveillance of the marine, rail, road and pedestrian traffic to ensure the safe opening and closing of the bridges.

4.0 PROJECT CONSTRUCTION CHALLENGES

The nature of bascule bridges means that it is essential for all components to be fabricated and installed to high standards and very tight tolerances to ensure uniform wear and minimise the long term maintenance costs. The requirements for bascule bridges demanded that close attention be paid to the balancing operation to ensure that this was achieved.

4.1 Construction in a marine environment

The placement of the four opening bridge girders was a real challenge to ensure that all the requirements of the SWTC could be met. Abigroup assembled the opening spans in the fabricators yard to ensure that any issues that may arise were resolved prior to final placement being made in the river. Transport to the site involved placing the girders, which were in excess of 60m long, on multi-axle load platforms and travelling at night under police escort with the route cleared of obstructions.

The Port River is subject to a three metre tidal range and high winds. The successful completion of many critical tasks was highly sensitive to the weather and conditions on the water which led to frustrations on several occasions – often early morning starts were necessary to avoid the wind. There was a 1 in 40 year king tide in mid 2006 which could have had disastrous consequences if it had occurred earlier in the contract.

The capacity to land a girder weighing in excess of 200t to the tolerances required demanded innovative construction techniques using a 600t capacity barge mounted crane and tugs to locate the barge and hold it in place. An iterative balancing process was used as the construction work proceeded on the bridge superstructure, adding weight to the two girders for each bridge.

Figure 7 – 600 tonne capacity crane placing the second rail girder

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An assessment of the weight and location in the structure of elements as small as the bridge handrails was required when determining the amount and positioning of steel billets and concrete in the counterweight box. Stainless steel shims, some only 0.5mm thick, were used to ensure that the bascule spans were balanced in line with the design requirements.

After experiencing numerous iterations to satisfy the tolerances required for the alignment and balancing of the rail opening span utilising their Structures team, Abigroup engaged specialist mechanical installers from the mining industry. This approach was very effective in saving time during the installation of the opening span for the road bridge.

4.2 River closures

The Port River is an active waterway in the vicinity of the PRExy bridges and at the time the contract was awarded to Abigroup there was a sailing club, tug fleet, a few boat builders, the fire boat as well as tourist cruise boats which operated regularly through the project site. Abigroup had to liaise closely with the mariners to ensure their activities were safe and not adversely affected.

To assist with the timely completion of the bridges, DTEI relaxed the requirement for virtually continuous access into the Inner Harbour. This enabled Abigroup to develop more efficient construction processes with the erection of the river spans and balancing of the bascule spans. The pro-active communications approach and a range of business assistance strategies and compromises that were negotiated enabled the mariners to operate on a restricted basis – a significant challenge that was overcome against the odds. The end result was that few, if any, mariners considered that the river closure was a major problem.

4.3 Shrink fit process

One of the major challenges was in achieving all the design requirements for the connection of the trunnion shaft to the box girder by way of an interference fit.

This was facilitated by a combination of cooling (shrinking) the shaft and heating (expanding) the trunnion hub bore. The trunnion shaft was cooled in a bath of ethanol and dry ice (minus 78ºC) to achieve 0.5mm shrinkage over the 550mm diameter shaft.

The local temperature of the girder around the trunnion was raised to 140ºC using gas heating from below, combined with electric ceramic heaters above. An insulating blanket was placed over the electric heaters (see Figure 8).
The lifting mechanism consists of a mechanical drive train with curved rack and pinion drives, electric motors and gearboxes (see Figure 9).

Each component in the drive train has its own factor of safety dependent upon materials and frequency of use. The bridge designers – Hardesty & Hanover – did not opt for a hydraulic lift system because of the corrosive marine environment and the low number of lifting cycles expected each day. The drive pinions and curved racks are made of forged alloy steel. The pitch circle diameter of the racks is in excess of 4.5m. They were manufactured by Falk Engineering in Newcastle.

Figure 9 – Pinion drive gear

5.0 CONCLUSION

The delivery of the PRExy opening bridges has been challenging from the initial concept development phase of the project when debates about whether opening or fixed bridges were the preferred scope were very topical. Managing stakeholders and traffic matters from three sectors – road, rail and marine – took considerable experience and effort to minimise disruption and adverse impacts and positive co-operation was received from the community.

When the complexity of the project scope and the response time of local suppliers and fabricators looked like resulting in a slippage of contract completion dates, concessions were granted (especially around river closures) to ensure the delivery of the opening bridges that would operate efficiently and meet all of the project’s objectives in the long term. This enabled Abigroup to concentrate on the complexities of the construction task without undue pressure from the client.

DTEI and Abigroup faced many challenges during the design and construction phases and the contractor successfully overcame these with some innovative approaches to deliver a first class addition to the South Australian transport network.

References

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