Kingsgrove to Revesby Rail Quadruplication – Design and Construction of the Overbridges

Gillian Sisk¹, Sally Cox², and John Steele¹

¹ Sinclair Knight Merz, Sydney
² Leighton Contractors, Sydney

Abstract This paper provides a high level overview of the Kingsgrove to Revesby Quadruplication Project. This project is being delivered by Transport Construction Authority (TCA) in an alliance with Leighton Contractors, AECOM (formerly Maunsell Australia), Sinclair Knight Merz, MVM Rail and Ansaldo STS (the K2RQ Alliance). The project scope includes constructing two additional fast tracks between Kingsgrove and Revesby stations (approximately 7.2km) on the Sydney rail network. It is currently under construction in NSW. The additional tracks will allow the complete physical separation of local and express services operating on the East Hills Line. The Alliance was presented with a number of challenges from site and operational constraints, the staging of the works and the linear nature of the works. This necessitated the incorporation of many interesting innovations in the design and construction processes. This paper’s focus is on those innovations adopted for extending the existing King Georges Road Overbridge to accommodate the two additional tracks underneath. This, in particular, presented enormous challenges, in relation to the construction staging which was driven by limited track possessions, limited road closures due to the disruption this caused to the local community and very limited area for works due to the proximity of live traffic, rail boundaries and nearby buildings. Examples of innovations in the design include developing innovative overbridge pier design and steel strengthening solutions and using parts of the existing structures to limit the amount of work required. This, combined with the construction methodology and close collaboration between the Alliance, RailCorp (rail operator and owner) and the Roads Traffic Authority (RTA), ensured the works were able to be delivered to program with no impact on the operational railway and with limited disruption to road users and pedestrians.
Introduction

The Kingsgrove to Revesby Quadruplication (K2RQ) Project scope includes the construction of two additional tracks between Kingsgrove and Revesby (each 7.2 km long), construction of 11 new rail bridges, modification or replacement of five existing overbridges, upgrades to Revesby Station, new overhead wiring and associated civil and rail system works. The additional tracks will allow the complete physical separation of local and express services operating on the East Hills Line. The purpose of K2RQ was to:

- provide a more reliable rail service
- reduce conflicting train movements and potential for delay
- allow operations to be simplified to enable an increase in rail services to meet future demand
- increase capacity to terminate trains at Revesby Station.

In order to achieve these goals, the K2RQ Alliance undertook substantial multidisciplinary works within the constraints of an existing operational rail corridor and working alongside an ethane gas pipeline (EGP). Rather than attempt to describe all the multidisciplinary works and associated constraints in detail, the following sections will focus on the salient features of the bridgeworks, in particular the overbridge at King Georges Road. The paper describes how constraints were addressed and were overcome through careful planning and close collaboration between the Alliance and RailCorp and the Roads and Traffic Authority (RTA). This led to a number of innovative design and construction solutions.

King Georges Road Overbridge

King Georges Road Overbridge comprises two bridges, one accommodating the southbound carriageway and the other the northbound, abutted together but not connected. The southbound bridge structure is a 1930s two-span, brick and concrete ‘jack-arch’ superstructure supported by a central brick pier and brick abutments. The newer northbound structure was constructed in the 1960s as a four-span, prestressed, concrete plank bridge supported on reinforced concrete piers and abutments.

The existing road is a key arterial route for the RTA into Sydney, with 70,000 vehicle movements per day. It was vital to ensure that two southbound lanes and three northbound lanes of traffic were maintained in each direction throughout the works whilst still having adequate room for construction and ensuring the safety
of the general public, road users and construction team. To add to the complexity, the existing bridge also provides access to the existing station at Beverley Hills, with 1000 pedestrian movements at peak time. Access was via staircases off each side of the bridge to the platform and had to remain open at all times as well as providing disabled access. In addition, on the northbound carriageway, two streets exited King Georges Road at junctions just off the end of the bridge on the north and south.

The Alliance was presented with a number of challenges from site and operational constraints, the staging of the works and the linear nature of the works at King Georges Road. Through close collaboration between the construction and design teams, a design and construction methodology was developed to address the constraints. The subsequent sections describe how in detail.

**Design Response**

King Georges Road Overbridge comprised two very different bridge structures which required two very different design solutions to be developed to satisfy the time and rail and road occupancy constraints, as well as to accommodate the construction staging.

**Southbound Bridge**

As stated above, the existing southbound bridge provided a two-span crossing of the existing two tracks with a central pier on the platform at Beverly Hills Station.
This seventy year old structure is simply supported on a brick pier and abutments. As part of the design development for the southbound bridge, a detailed value engineering process was undertaken to consider the design options to settle on a preferred design. The criteria used to select the preferred design mainly comprised constructability, program, cost and minimising disruption to rail and road users.

The two main options under consideration were to remove the existing spans and replace them with longer precast concrete plank spans or to keep the existing bridge and add additional span behind the abutments to accommodate the additional tracks. The preferred option was to retain and extend the existing bridges (refer to Figure 3) to accommodate the additional tracks. The key benefits achieved by retaining the existing bridge structure and extending in lieu of full replacement were:

- it allowed five lanes of traffic to remain open at all times during the bridgeworks which minimised impact on road users
- It avoided the need to raise the existing road levels to accommodate the deeper superstructure for longer spans over two tracks and
• it required a fewer number of rail track possessions during construction, which greatly facilitated the overall construction program and reduced costs.

However with this option, a number of design implications needed to be addressed. These mainly involved modifying the existing masonry abutments to support the new end spans and strengthen them to withstand train collision loading as per AS5100. In addition the design had to facilitate replacing the existing deck structure in the future.

**Design Philosophy**

The philosophy behind the design of the new end spans was that of a semi-integral bridge. In this situation the new deck structure is supported on a strip bearing at each abutment and pier. This facilitates rotation of the bridge deck relative to the substructure but removes the need for an expansion joint. Galvanised steel bolts at 600mm centres transfer horizontal loads to the abutment and pier and are designed to resist the design longitudinal loading in shear and the 500 kN train collision uplift load case. This articulation enables the deck to be utilised as a prop to reduce the loads carried by the piles and abutment, particularly when subject to the horizontal train collision loading perpendicular to the track. In addition the bearings eliminate the problems associated with moment continuity and rotation due to creep.

![Fig 3: Longitudinal section though existing southbound bridge](image)

During construction the deck was supported on a slip bearing at the abutments to allow the piles to deflect forward when subject to earth and surcharge lateral loading during the excavation works in front of the piled wall abutment. This limited the locked in propping forces in the deck which will be important to limit the bending and deflection of the piers when the original jack arch spans are lifted out and replaced in the future. The pile deflections were monitored during the excavation works and were generally found to be lower than the deflections...
estimated. After these works were complete and the pile deflections had tapered off, the final pour at the abutment was completed, thus forming the integral connection between the deck and substructure. The over-sized formed hole will accommodate creep and shrinkage movement and thermal movements but will allow the dowels to resist the collision and longitudinal bridge loading in shear.

**Masonry Piers**

The existing masonry abutments for the southbound bridge are retained and utilised as the pier supports for the new end spans. As the abutments were being modified for this new use, their capacity had to comply with current bridge design standards. In particular they had to be capable of withstanding rail collision loads on both sides (Main and Local Lines) as per AS5100.2.

Assessing the capacity of the brickwork to withstand the large impact forces was not a straightforward exercise. The material properties of the bricks and mortar, the anisotropic nature of the brickwork, the extent that existing cracking in the brickwork would limit load distribution, the potential internal actions due to the thickness of the brickwork that could benefit load distribution and the potential for the train to gouge out some of the brickwork under impact which could weaken the pier all needed to be taken into account in the analysis. AS3700 Masonry Code was not written for these sorts of structures and load case and was considered too conservative to adopt for the bending and shear capacity of the pier.

Cores were taken from the masonry abutments to test the compressive and tensile strength of the existing masonry and to validate our design assumptions. We determined the characteristic compressive strength to be 12MPa and the characteristic flexural tensile strength to be 0.29MPa using the method set out in Appendix H of the Australian Standard for Masonry Structures AS3700-2001.

Previous work conducted by Hobbs et al (2009) comprised carrying out full scale impact load tests on masonry parapets for a limited range of wall and reinforcement configurations to validate numerical models which could then be applied to a wider range of scenarios. Artificially high values for the unit mortar shear and tensile strengths had to be used to provide good correlation with the wall test results. An enhancement factor of approximately 3 was applied to correlate the test results. This ties in with the work carried out by Burnett et al (2007). They conducted a test on masonry joints to dynamic tensile loading. The strain rates of the tests ranged from 0.89 to 1.52/s which is representative of the low rate dynamic loads such as impact and earthquake. On this basis we have applied a factor of 3 to the characteristic tensile strength of the masonry as determined from the core testing to represent the higher tensile strengths of the masonry when
subject to a dynamic load in lieu of a quasi-static load. Other research also shows that most materials demonstrate increase in strength as the loading rate or strain increases Hao and Tarasov (2008).

Based on the above research, we adopted an upper limit of 0.9MPa for the tensile strength (based on DIF of 3 and the Characteristic Flexural Tensile Strength of 0.29MPa determined from the tests. In addition from the full scale tests carried out by Hobbs et al, they demonstrated that reinforcing systems are capable of enhancing the ability of plain masonry to resist impacts by developing a ductile response to the transient loading.

![Fig 4: Results showing local failure under impact load](image)

This pier was modeled using finite element analysis (FEA) with block elements to model the bricks within the wall. The initial full finite element model was analysed under the full collision loads as per AS5100 (refer to Figure 4). The wall was assessed for strength under these loads, and the local areas of masonry which failed were removed from the model. The partially failed wall was assessed for strength under ultimate vertical loads. From these strength assessments, the strength of the wall following collision was measured. The results suggest that the abutment as designed has the capacity to withstand a derailment collision and continue to carry the vertical loads from the bridge above, despite limited local failure.

Reinforcement was however added to the pier to introduce some ductility to brickwork. Galvanised steel vertical anchor bars were installed from road level to provide an effective internal reinforcement system for strengthening the masonry piers from rail collision loads. In addition, the vertical anchors provide lateral...
restraint at the base of the pier as the anchors are grouted into the underlying
bedrock. An in-situ concrete headstock was constructed behind the old brick
abutments to support the new deck. Dowel bars tie the two elements together. The
new pier was designed for SM1600 loading on both the new and existing bridge
structures to facilitate replacement of the existing bridge deck at a future date.

The leading face of the southbound masonry piers was rounded as required in the
RailCorp Overbridge Standard ESC 320. This was achieved with the construction
of a reinforced concrete nosing that is tied to the masonry pier via dowels and
anchored into the founding rock via 56mm diameter stress bars. The nosing
provided additional restraint to the masonry pier and attracts load due to the
relative stiffness of the concrete in comparison to the masonry. It also has the
potential to deflect a derailed train to minimise the impact force on the structure
and train occupants.

Northbound Bridge

The northbound bridge, although comprising a four-span configuration suitable for
the four tracks, still required extensive modifications works, which were quite
complex in design and construction (refer to Figure 5). The existing abutment
founding levels were above the proposed new track levels and were founded on
weak shale. Excavating in front of the pad footings in stages and soil nailing and
shotcreting the face was considered in the design. The risks to safety and the road
and rail operations were such that it was deemed to be too risky to attempt in such
poor quality rock.

Fig 5. Longitudinal section though existing northbound bridge

Therefore, new abutments had to be constructed behind the existing abutments to
support the existing bridge deck and enable these existing footings to be
demolished. These works were in very close proximity to the EGP and very tight
controls were required on site to manage this risk. The new abutments consisted
of 750mm diameter bored cast in place piles with a reinforced concrete capping
beam. The area in front of the existing abutments was then excavated down to the top of the pad footing level to allow construction of cast in situ concrete corbels from the new piles. The gap between the corbels and the existing abutment headstock was then grouted and the columns and pad footings demolished. The gaps between the new piles were then shotcreted in stages down to the new track level.

Construction

Extension of the bridge at King Georges Road gave the construction team some enormous challenges, in particular the staging which was driven by limited track possessions, limited road closures due to the disruption this caused to the local community, and very limited area for works due to the proximity of live traffic, RailCorp boundaries and nearby buildings. Before construction started, liaison was necessary between the construction team, RailCorp Station Liaison Group, RailCorp, RTA, buses and stakeholders (including local businesses) to consult on the proposed methodology and impact. Part of the scheme included the partial closure of the two adjacent roads, Morgan Street and Tooronga Terrace. New bus stops had to be provided and consultation undertaken on agreed bus diversions.

The team developed a proposal that required the works to be carried out in three key traffic management phases. This involved removing the existing median, including removal and storage of the palm trees, and surfacing this area to allow the traffic to be pushed to the west side of the existing bridges. A compound was then created on the east side of the bridge, allowing the bridge to be replaced below. Once complete, the traffic was then moved to the opposite side of the road and the process repeated. Finally, a compound was created in the central section of the bridge.

The utilities, including Energy Australia, Telstra and Optus Services, in the existing bridge deck, running north to south, needed to be diverted to allow for the construction of the deck extensions. These services were diverted to the northbound bridge to allow the southbound construction to proceed. In addition, running east to west just behind the new south abutment was the high pressure EGP. This represented a large risk to the project and site constraints meant that piling had to be carried out within three metres of the buried pipe. Potholing to locate the pipeline throughout the site was carried out to limit the risk and strict processes, including specific inductions for anyone working within five metres of the pipeline, were implemented.

The design had been detailed to minimise the impact on the operational railway. The constraints imposed on construction of the 1930s bridge (southbound bridge)
and the 1960s (northbound bridge) were very different and the key points will be discussed below.

Southbound Bridge

The southbound bridge, as described in the design section above, is a two-span bridge, supported on a brick pier and brick abutments (refer to Figure 3). Piling for the new abutments was carried out from road level after the services had been diverted. Running parallel with the construction of the new abutment, alterations to the existing bridge abutment were required as this would be needed to support the new bridge deck and hence become a ‘pier’. Tying in to this existing structure was particularly difficult for both the design and construction teams. Record drawings of the existing bridge had to be relied on for the initial design but when these elements were uncovered the design had to be refined to reflect what was currently there. Close liaison was crucial between the designers and constructors.

The design allowed for pre-cast planks to form the deck for the new bridge. These were installed during partial closures of the road at night, reducing the number of lanes open and allowing a crane to be used for installation. The use of pre-cast planks as permanent formwork enabled a quicker program and overcame constructability issues as there was no easy access to install a traditional scaffold falsework. Once the planks had been installed the reinforcement could be fixed and the deck poured.

As soon as the new deck construction was completed, the earth fill under the new deck was excavated from track level and removed from site along the existing rail
corridor (refer to Figure 6). As it was removed, the piles were exposed, trimmed and then shotcrete applied. The rear of the existing abutment was also exposed as the excavation works progressed. This revealed extensive cracking in the existing abutment. In order to provide a 100 year design life and realise the design intent for the new structure, extensive stitching and grout injection of the new pier was required.

**Northbound Bridge**

The northbound bridge had very different challenges. The existing bridge, built in the 1960s was a four-span, pre-stressed, concrete plank bridge supported on reinforced columns founded on spread footings. Although the existing abutments were set back with sufficient room to accommodate the new tracks, they were founded on the embankment above track level (See Figure 7) which meant new abutment supports had to be constructed.

![Fig 7: Views of northbound bridge prior to construction](image)

To protect the works from the operational railway the existing columns had a shutter erected during a weekend closure of the railway on the track side to provide a solid wall, enabling work to carry on behind it. This shutter served a dual purpose. Whilst it protected the workforce, it was also required to support the concrete between the columns in the final solution to enable the deflection wall to be constructed.

As mentioned above, the two end spans needed a new support in place of the shallow existing abutments. Bored piles were installed behind the existing
abutment from road level with couplers in the reinforcement. Once the piles had been completed, working with limited headroom under the existing bridge span, the couplers were exposed and a reinforced cantilevered headstock was constructed tying into the piles. With the construction tolerances on the piles and the necessity to have dowel bars connecting the piles to the headstock, the buildability of this section of works was reviewed. Changes were made on site in conjunction with the design team to enable the headstock steel to be prefabricated, making it easier to install whilst still maintaining the design intent.

Once the headstock was completed, transfer of the load from the existing foundations to the new piled foundations was carried out, under live traffic conditions. This was done by injecting grout between the headstock and the existing bridge deck. Once transfer of load was complete the existing footing was removed and excavation could be carried out to track level.

The innovative design, combined with the construction methodology, allowed the works to be delivered to program with no impact on the operational railway and with limited disruption to road users and pedestrians.

Conclusion

Construction of the King Georges Road Overbridge involved some innovative solutions to address time and rail and road occupancy constraints. It was a challenging design, due to the site constraints and the construction staging. Using parts of the existing structures limited the amount of work required and, combined with the construction methodology, ensured the works were able to be delivered to program with no impact on the operational railway and with limited disruption to road users and pedestrians. The combination of pre-cast and cast in situ elements in the deck overcame the problem of limited road closures and facilitated faster deck construction. The success of the bridge structure was a breakthrough for the team, stemming from collaboration between the Alliance partners, RailCorp and the RTA during all phases of the project.
Fig 8: View of completed bridge from platform level

References

