Widening of the Existing Bridge over Reservoir Road on the M4 Smart Motorway Project, Sydney

Kenny Luu, Amey, Australia,
Chang Liu, Amelia Agnew, Arup, Australia

ABSTRACT

The M4 Smart Motorway project aims to introduce an Intelligent Transport Systems (ITS) along the M4 Motorway between Pitt Street overpass at Mays Hill and Russell Street at Lapstone in Sydney. As part of this project, the existing Bridge over Reservoir Road is required to be widened.

The proposed widening section comprises 3 No. 1200mm deep Super-T precast girders supported on new sill beams to emulate a similar structural behavior to the existing bridge. The widening section is proposed to be made integral with the existing bridge via a longitudinal stitch pour at the deck level and a doweled joint between the existing and new sill beams. The new sill beams were sized to satisfy the onerous eccentricity and bearing pressure requirements by the New South Wales Road and Maritime’s Specification R57 for both dead and live serviceability load combinations.

The existing Reinforced Soil Walls at both bridge abutments are required to be partially demolished and reconstructed to accommodate the alignment of the bridge widening. A Plaxis model was develop to predict the differential transverse settlements between the existing bridge and the widening section due to live loads. These predicted differential settlements were then considered in the bridge design. A detailed discussion of the design and proposed construction staging aspects of the bridge widening is provided herein.

Key words: Smart Motorway; bridge widening; Reinforced Soil Wall; differential settlement

1. INTRODUCTION

The M4 Smart Motorway project aims to introduce an Intelligent Transport Systems (ITS) along the M4 Motorway between Pitt Street overpass at Mays Hill and Russell Street at Lapstone in Sydney to:

- Enhance travel time and improve journey time reliability
- Enhance traffic throughput, efficiency and productivity, and
- Enhance traffic safety.

The scope of the project encompasses 23 entry and 6 exit ramps along the study length of the motorway. At the interchange over the Reservoir Road, the existing westbound entry ramp, is required to be widened from a single lane into a two-lane configuration to accommodate the required storage. The westbound main line carriageway in this section of the motorway will also be modified to allow for provisions for future “hard shoulder running”. Hard shoulder running, in summary is an allowance for an additional temporary lane configuration. The existing Bridge over Reservoir Road will be widened to facilitate these modifications.
The widening design of the existing Bridge over Reservoir Road was a challenging balance of the various constraints, in particular:

- the compatibility with the construction of the proposed widening, particularly the substructure
- the interface with the geometry of the proposed widening,
- the capacity of the existing structure and resolving issues associated with differential settlement between the existing bridge and the new widening works.

This paper discusses the main challenges surrounding the bridge design and the key design and proposed construction staging solutions proposed.

2. Existing Bridge over Reservoir Road

The existing Bridge over Reservoir Road (Roads and Maritime Bridge Number 8038) is a 25 m single span structure carrying both the Eastbound and Westbound Mainline Carriageways of the M4 Motorway over Reservoir Road. In addition to the mainline carriageways, the structure also provides for the single lane Westbound Entry Ramp at Reservoir Road. The Work-as-Executed (WAE) drawings provided by Roads and Maritime are dated 1991 and specify that the structure was designed for T44 loading. Figure 1 and Figure 2 provide an elevation and section of the existing Bridge over Reservoir Road.

Figure 1 Existing Bridge over Reservoir Road elevation
2.1. Superstructure

The superstructure of the existing bridge over Reservoir Road comprises 12 No. prestressed concrete trough girders, 1200 mm deep and spaced at nominal 2800 mm. Each girder is detailed with a skewed end of 40° to the longitudinal axis and placed at a skew of 1.3° to the abutment. Interestingly, the girders were designed for the Twin Bridges over Powells Creek at Concord West, as identified on the WAE drawings, but repurposed for the existing Bridge over Reservoir Road.

The total deck width varies between a minimum width of 33.39 m and a maximum width of 34.69 m. The existing deck is 200 mm minimum thickness and has a two-way cross-fall of 3%. The cross-fall is achieved by varying the depth of the abutments. Figure 3 provides a typical section through the deck of the existing Bridge over Reservoir Road.

A load rating of the existing bridge over Reservoir Road was undertaken in accordance with AS5100-2004, which confirmed the capacity of the structure was sufficient for its original design load, T44. The only identified issue is that the anchorage of the existing longitudinal reinforcement does not meet the requirement of AS5100.5 Clause 8.1.8.3. It should be noted that the anchorage of the longitudinal reinforcement is required to sufficiently develop the shear capacity of the girder and...
thus the shear capacity may be compromised by this deficiency in detailing.

Confirmation of the existing condition of the girders would some confidence in the performance of the deck. Due to the limited access to inspect the girders ends no historical records have highlighted any issues, and further no inspections have been undertaken as part of this commission. The inspections will require some level of intrusive measures and has been left as an outstanding item to be confirmed during construction.

The bridge superstructure is not rated for SM1600 or HLP400.

2.2. Substructure

The substructure of the bridge is a concrete sill single beam at both abutments which resides on a reinforced earth wall, refer Figure 4. A 500 mm cement stabilised levelling layer is provided beneath the sill beam. A nominal 2800 mm high back wall and 3500 mm long wing walls are provided for soil retention.

Figure 4 Existing Bridge over Reservoir Road substructure section

The reinforced earth wall at Abutment A is 61.220 m long and 5.250 m high, and the Abutment B reinforced earth wall is 58.220 m long and 5.265 m high. The reinforced earth walls at both abutments taper down over a length of 7.630 m as per Figure 5, and are set on a radius of 20.0 m in plan. The strap lengths are at maximum 7.0m for the layers directly under the bridge and subsequently reduced to 6.0 m and 5.0 m in the deeper layers.

An assessment of the existing reinforced earth wall, using the information presented on the WAE drawings, was undertaken in accordance with RMS specification R57 for the existing T44 design loading. It was identified that the existing reinforced earth wall does not comply with the current RMS specification R57 even for T44 loadings with the governing failure mode in the soil/strip bond strength. However, it is worth noting that the construction of the structure precedes the issue date of this specification.
2.3. Articulation

The deck is articulated with a restraint system comprising a single point of transverse restraint at Abutment A and a single point of both transverse and longitudinal restraint at Abutment B. The restraint mechanism's position is approximately central along the length of abutment. Refer Figure 6 for restraint system details.

Figure 5 Existing Bridge over Reservoir Road reinforce earth wall elevation

Figure 6 Existing Bridge over Reservoir Road restraint system detail
3. Proposed Bridge over Reservoir Road Widening

3.1. Design Constraints and Traffic Loadings

The major constraints to the widening of this structure are:

- Compatibility with the construction of the proposed widening, particularly the substructure
- Interface with the geometry of the proposed widening,
- Capacity of the existing structure and resolving issues surrounding differential settlement.

The design of the widening is to comply with all RMS bridge technical policies and requirements. The widened portion of the superstructure was to be made structurally integral with the existing bridge via a stitch pour in the deck. In addition, the widened section was also required to carry the current design loads of SM1600 and HLP400, which are significantly heavier than the original design loads of T44. The increase in design loading requirement presents a design challenge in minimising the load transfer from the new widening work to the existing bridge, which is rated neither for SM1600 nor HLP400.

In addition, the construction of the widened section will require that the existing reinforce soil wall to be partially demolished and rebuilt. This requirement poses a great risk in that the existing bridge, being supported on a shallow sill beam, can be undermined. It is therefore critical that a monitoring regime of the existing bridge during construction is implemented to detect any issue early so that rectification measures can take place.

3.2. Superstructure

The proposed widening of the Bridge over Reservoir Road will widen the existing bridge deck by 7475 mm at Abutment A and 8750 mm at Abutment B, making the overall deck width 40780 mm at Abutment A and 40770 mm at Abutment B. Figure 7 provides a section showing the proposed widening.
The proposed widening of the deck maintains the existing cross fall, which reduces the vertical clearance over Reservoir Road from 5700 mm at the existing bridge to 5350 mm at the bridge widening, maintaining the vertical clearance requirements in accordance with AS5100.1 Clause 9.7, refer Figure 8.

**Figure 8 Proposed bridge widening elevation**

The widening is achieved by installing three 1200 mm deep pre-tensioned concrete Super-T girders on a splayed alignment acting in composite with a 200mm minimum in-situ concrete slab. The girder spacing varies from 2300mm minimum at Abutment A to 2800mm maximum at Abutment. However, the girder flange width was kept at 2500 max to minimise false work during casting of the girders. The 1200 mm deep girders suits the widening as they match the existing girder depths, creating a clean
soffit line. The girders were arranged to maximise utilisation of the girder capacity and minimise the lateral distribution of the SM1600 / HLP loading from the proposed widening to the existing bridge. Figure 9 provides the indicative girder plan layout showing the splayed arrangement.

Figure 9 Indicative girder plan layout

As the deck concrete levels (and abutment levels) cannot be picked up from survey during design, the design has allowed flexibility where possible and utilised the work-as-executed drawings as well as survey to best interpret the existing levels. Some existing levels requiring confirmation after demolition have been articulated to the contractor.

3.3. Stitch Pour Detail

The continuity between the existing and proposed superstructures will occur through exposing existing reinforcement to allow for a narrow concrete in-situ stitch pour, refer Figure 10.

Figure 10 Stitch pour reinforcement detail

The proposed line of demolition for the concrete stitch pour is along the line formed by the footprint of the existing girder edge. The demolition will need to expose the
existing reinforcement to enable a lap spliced connection with new reinforcement from the widened deck for continuity. This position is ideal as it will both allow for sufficient length of reinforcement to achieve a full welded splice within the proposed widened deck and will create sufficient working space for the position of a temporary barrier required to maintain traffic use of the ramp during construction. The method utilised for lapping is dictated by the existing bridge geometry, and the ability to obtain full contact laps. Where full contacts laps are not achievable welded laps are proposed.

The detailing of the stitch pour both allows for a reinforcement arrangement which can vary to suit levels found on site. The flexibility allows for adjustments depending of the actual deck levels, whilst maintaining the minimum clearance of 5300mm from Reservoir Road below. Figure 11 provides the proposed deck concrete arrangement.

![Figure 11 Deck concrete arrangement cross section](image)

The stitch pour is proposed to be constructed after the initial elastic settlement due to the dead load of the widened section has taken place in the new substructure to reduce the differential settlement between the existing and widened sections of the bridge in its final service conditions. In addition, during the construction of the stitch pour, traffic will be kept a minimum 7.0m away from both sides of the pour in the first 12 hours of casting concrete to minimise the impact of traffic induced vibrations on the freshly cast concrete. The traffic restrictions will be gradually reduced as the concrete in the stitch pour gains its strength.

3.4. Articulation

Articulation of the widened superstructure is proposed to be emulate the existing articulation. To achieve this the existing deck restraint articulation is matched by the use of an additional large diameter shear dowel cast into a lateral restraint block on the proposed widened section at Abutment B. To prevent inducing transverse loading into the deck, the proposed shear dowel is detailed such that it allows transverse movement. Abutment A provides no mechanical means of longitudinal or transverse restraint.

Longitudinal braking forces will be transferred to the substructure through a combination of the existing dowel and proposed dowel. The intent of the proposed additional dowel will be to more evenly distributed longitudinal forces across the length of the Abutment B sill beam. Transverse restraint will be provided by the existing restraint system.
Figure 12 shows the proposed longitudinal restraint dowel.

**Figure 12 Longitudinal restraint dowel detail**

3.5. Sill Beam

As the proposed bridge widening will be structurally connected to the existing bridge at the deck level, and given that the existing bridge is supported on a shallow sill beam on a reinforced earth wall, feasible foundation types of the proposed widening are limited. A sill beam foundation has been selected for the widened section rather than a piled foundation because this configuration matches the existing bridge’s behavior. This arrangement also facilitates the ease of construction of the foundations. The sill beam has been designed such that it has the ability to accommodate differential settlement between the interfaces of the existing and new sill beams, whilst not overloading the existing sill beam.

The proposed reinforced concrete sill beam, 1900 mm wide, with a 4400 mm nominal heel base slab, will sit directly onto the widened reinforced earth wall. The sill beam has been sized to provide the adequate restraint against the longitudinal and transverse forces from the superstructure. In addition, the sill beam has been designed to satisfy the stringent requirements by RMS specification R57 Clause 4.6.7, in that, under the serviceability load case, the maximum permissible vertical pressure at the underside of the sill beam must be

(a) 150 kPa for dead loads only;

(b) 200 kPa when other loads are included.

In addition, the eccentricity $e$ of resultant must not exceed:

(a) $B/8$ for dead loads only;

(b) $B/6$ when other loads are included.

where $B$ is the sill beam dimension in the span bridge direction

The heel slab has been tied into the wing wall to provide a robust system under collision loading. Figure 13 provides an elevation of the proposed sill beam and wing
To prevent differential settlement across the interface between the existing and new sill beam, which would translate into deformation in the deck slab, a dowelled connection is provided. The connection allows for a staged construction, such that the dowelled connection will only be engaged once initial estimated elastic vertical settlement in the reinforced soil wall has taken place during construction to minimise the total differential settlement between the existing bridge and the widened section in their final in service condition.

3.6. Reinforced Soil Wall and Differential Settlement

The proposed widening of the bridge over Reservoir Road will be supported on an extension to the existing reinforced earth wall and thus requires the demolition and subsequent reconstruction of a new portion of the reinforced earth wall along a deviated alignment. The extension of the reinforced earth wall will accommodate the geometry of the widened bridge as well as the replace the wall where a higher design capacity is required. To minimise impact to the operation of the motorway and to reduce construction risks, the design aims to conserve as much of the existing wall as possible.

The existing reinforced earth wall assessment has identified that the wall is not compliant to the requirements of current Roads and Maritime specification R57, for the existing loading condition as well as the proposed widening loading conditions. Several options to achieve the required capacity in the reinforced earth wall block, underneath the widened deck were investigated with the intention of retaining more of the existing wall. The final outcome of the investigations has determined the most appropriate solution for the wall extension is to demolish and replace the wall beneath the widened structure, refer Figure 14.
The geotechnical investigation at the bridge site indicates that the extension of the reinforce soil wall would be founded directly on a thin layer of class V shale overlaying class IV shale or better. An assessment of the external stability of the wall in accordance with RMS specification R57 indicates that a minimum block size (strap lengths) of 8.0m would satisfy all external stability criteria. The internal stability of the block under the bridge loads will be undertaken taken by the specialist contractor as per the contract requirement.

One of the most critical aspects of the bridge design was to accurately predict the total differential displacement between the existing and the widened parts of the bridge and to make sure this differential displacement is adequately accommodated in the design of the superstructure. As the widened structure will not be connected to the existing bridge until all the initial deflection due to dead load has taken place, the total differential settlement that requires design considerations is the settlement of the widened section due to the effect of live loads. Given the reinforced soil block is founded on bed rock, this settlement is primarily due to the residual deformation of the soil block under the live load effects.

A Plaxis model was developed to predict the deformation of the soil block under the bridge live loadings (Refer Figure 15)
All the construction stages were also considered in the modelling to accurately capture the likely construction effects and the soil stress state. This enabled the displacement components due to dead and live loads to be estimated for each corresponding stages.

Based on the analysis, the maximum differential settlement due to the live load effects were estimated to be approximately 6.0mm. This differential settlement effect was applied in the bridge structural model as a displacement induced load case and the bridge superstructure was checked accordingly.

To verify the predicted settlement, a monitoring regime was developed in consultation with the RMS. In this regime, the bridge movements during and after construction will be monitored to ensure the stability of the existing bridge and the performance of the bridge as a whole after the widening works.

The reinforced earth wall extension to the existing reinforced earth wall is proposed to be a similarly patterned panel to meet urban design requirements. The interface between the existing and new panels will not interlock to prevent damage to the panels in the event of settlement.

3.7. Construction Staging Consideration

To resolve many of the design issues surrounding the widening of the existing Bridge over Reservoir Road careful construction sequencing was developed. This sequencing laid out the minimum requirements for additional investigations required, staging of the elements, in particular the staging of the connecting interfaces and monitoring requirements. The sequencing aims to dissipate as much of the soil deformations as possible during construction, minimising adverse impact to the deck slab.

3.8. Temporary restraint to deck

Due to the final articulation arrangement, prior to forming a continuous connection the
structure will need to be restrained until the permanent configuration can provide the lateral restraint. Prior to curing the stitch pour, widened structure will not be trafficable.

3.9. Performance Monitoring during and after construction

The performance monitoring during the demolition / construction of the existing reinforced earth wall and ongoing performance was investigated carefully. Several stages of monitoring have been stipulated:

- The demolition of the reinforced earth wall will be monitored to such that the temporary shoring, does not impact the existing structure and motorway.
- Monitoring the total immediate settlement of the wall under dead load was nominated to allow for the dowels connecting the sill beam to be connected.
- Longer term monitoring of the reinforced earth wall and the sill beam have been allowed for by providing survey marks at critical locations for record upon completion of the structure. The intention is to provide Roads and Maritime with the ability to accurately monitor the structure against the predicted design movements.

4. CONCLUSION

The design of the widening of the existing Bridge over Reservoir Road required careful consideration of number of constraints. The design proposed is sympathetic to the existing bridge, considering the compatibility of the bridge’s geometry and capacity, whilst allowing for a constructible design.

Several solutions were implemented to achieve this which this paper discusses including:

- Providing flexibility in the design to account for unknown information during design,
- Specifying monitoring to provide tangible measurements to characterise the structures real behavior
- Provision of careful detailing and detailed construction staging to ensure design intent is translated to the contractor, and
- Identifying and accepting that modification of existing structures do create certain issues the risk of which needs to be translated to the asset owner.

At the time of writing this paper the widening work of the Bridge over Reservoir Road construction is planned to be completed in 2018.

REFERENCES

AS5100 Set – 2007 Bridge Design Set (excluding AS5100.5)
AS/RMS5100.5 May 2015 – Interim Australian Standard /Roads and Maritime Bridge Design. Part 5: Concrete
QA Speciation R57, Design of Reinforced Soil Walls, Roads and Maritime Services

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the NSW Roads and Maritime Services for their permissions to use the widening design of the Reservoir Road bridge in the discussion of this paper. The authors also would like to acknowledge the colleagues from Arup and Amey who have contributed to the design development of the M4SM project.

AUTHOR BIOGRAPHIES

Author: Kenny Luu
Kenny is a principal civil engineer and a bridges and structures team leader with Amey Australia. He has over 16 years of combined research and industry experience with a strong focus in the concept and detailed design of bridges, earth retaining structures and other civil structures. On the M4 Smart Motorway project, Kenny was the discipline leader for bridges and structures.

Co-Author: Chang Liu
Chang is a senior bridge engineer with Arup in Sydney with 9 years of experience covering many technical and non-technical facets of engineering. Chang has a wide range of experience with different clients on projects of varying scope. On the M4 Smart Motorway project, Chang was responsible for the delivery of the widening over Reservoir Road.

Co-Author: Amelia Agnew
Amelia is a bridge engineer with Arup in Perth. Since graduation from the University of Western Australia in 2014 with a Bachelor of Engineering and Bachelor of Science, she has worked on a number of civil engineering projects with a primary focus on the modelling, design and review of bridges and civil structures. On the M4 Smart Motorway project, Amelia was responsible for the design of the widening over Reservoir Road.