

UNDERPINNING THE CONCORD ROAD BRIDGE UNDER TRAFFIC – WESTCONNEX M4 EAST PROJECT

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ABSTRACT

WestConnex is the largest transport infrastructure project in Australia. It is part of the Australian Federal Government and New South Wales Government's efforts to ease congestion on Sydney's roads by widening existing motorways and constructing new tunnels and bridges. M4 East is the section of WestConnex which extends from Haberfield to Homebush and includes the new Concord Road Interchange (currently under construction). The Concord Road Interchange is a complex junction of new bridges, cut-and-cover tunnel portals, retaining walls, widening and altering the alignment of the existing M4 Motorway lanes. Part of the works involves altering the alignment of the eastbound and westbound lanes under the existing Concord Road Bridge. To facilitate these works, the bridge needs to be underpinned with permanent support. The existing bridge abutments are founded on piles which are to be supported on a rock ledge permanently supported by rock bolts and prestressed ground anchors. Further, it is a requirement of the project that the Concord Road Bridge remain open to traffic for the duration of the works. Tight deflection criteria were imposed due to structural requirements at expansion joints. Additionally, the existing Concord Road Bridge was designed and constructed in the 1980s and there was limited information on the ground conditions and as-built founding levels of the bridge abutment piles. These factors, in addition to the requirements for working with low headroom under the bridge, were some of the key challenges during the detailed design and construction support of the works. This paper focuses on the methodology that was adopted to address these challenges during the design and construction phases of the project.

1 INTRODUCTION

A 'population and employment projections for NSW' study carried out by the NSW Department of Planning and Environment in 2014 estimates that the population in Sydney will grow by approximately 1.6 million by 2031 (reported in the 'WestConnex Updated Strategic Business Case'). As the population in Sydney increases, it places increasing demand on the existing transport infrastructure. A traffic study carried out by the Sydney Motorway Corporation (SMC) found that average weekday traffic volumes on existing transport infrastructure could increase by up to 45% by 2031. The traffic study also found that "sections of the Sydney surface road network are currently approaching or exceeding capacity". Therefore, existing infrastructure needs upgrading to cope with the increased demand. Upgrading of existing transport infrastructure in developed areas is becoming increasingly common. This phenomenon can be witnessed in metropolitan cities across the globe in places such as London and Singapore, where significant effort is being put into upgrading transport infrastructure to meet growing demand.

It is typically preferred for upgrade projects to be carried out in a staged manner which will have controlled impacts on current traffic conditions. One such road upgrade is the WestConnex M4 East Project. WestConnex is the largest transport infrastructure project in Australia. It is part of the Australian Federal Government and New South Wales Government's efforts to ease congestion on Sydney's roads by widening existing motorways and upgrading the road network by constructing new tunnels and bridges. An overview of WestConnex is shown in Figure 1. WestConnex is made up of sub-sections, namely M4 Widening, M4 East, Iron Cove Link and Rozelle Link, M4-M5 Link, Sydney Gateway, the New M5, and the King Georges Road Interchange Upgrade. M4 East is the section of WestConnex which extends to approximately 6.5 km, from Haberfield to Homebush and includes the new Concord Road Interchange (currently under construction). Valued at approximately \$3.8 billion, WestConnex M4 East aims to increase the capacity of current transport infrastructure to meet the growing population and also improve connectivity between existing major road transport routes. Carrying out large-scale construction activities in densely populated urban areas, however, comes with its own set of challenges.

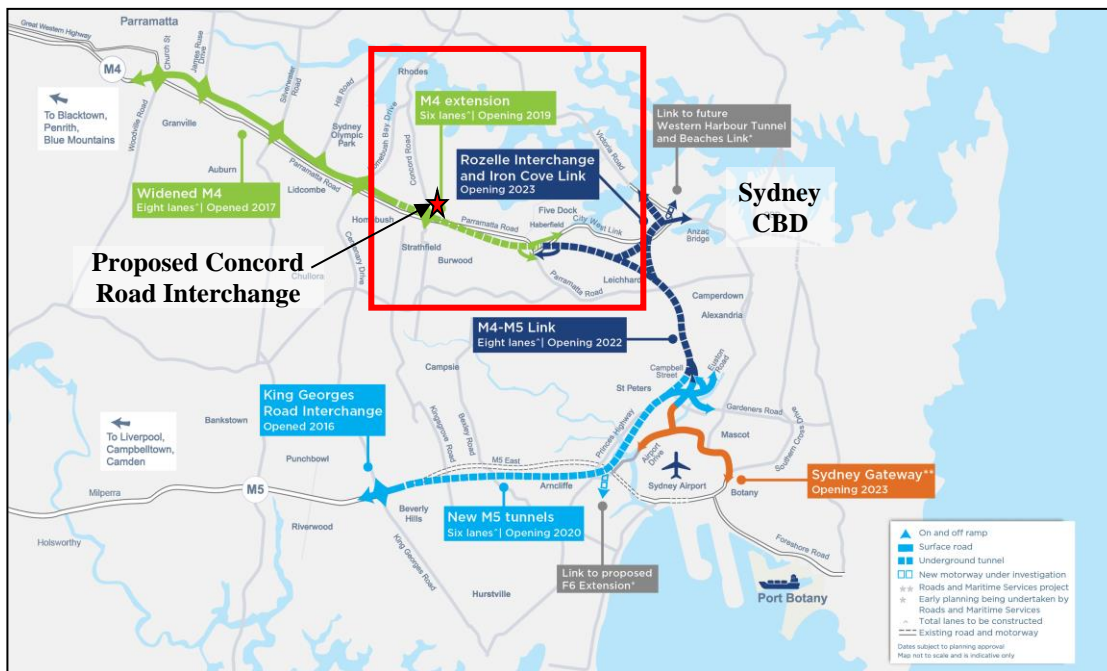


Figure 1: Overview of WestConnex Project and the Proposed Concord Road Interchange

2 CHALLENGES IN TRANSPORT INFRASTRUCTURE IN URBAN AREAS – THE PROPOSED CONCORD ROAD INTERCHANGE

2.1 OVERVIEW

Challenges to construction of transport infrastructure in developed areas arise due to issues such as space constraints and requirement to minimise disruption to existing traffic flow. Space constraints are especially critical in built-up areas where new construction works aim to have minimal impact on existing structures. The issue of disruption to traffic flow is especially critical in areas such as Sydney, where existing transport infrastructure is already struggling to meet demand. New works aim to minimise disruption to the existing traffic conditions and the surrounding communities. While efforts are made to work around these issues, there are locations where these issues are more critical and it therefore becomes increasingly challenging to minimise disruption to existing traffic conditions and surrounding communities. One key area in the WestConnex M4 East project where these issues arise is the proposed Concord Road Interchange.

2.2 THE PROPOSED CONCORD ROAD INTERCHANGE

The proposed Concord Road Interchange is located approximately 10 km west of the Sydney Central Business District (CBD) (Figure 1). It is a complex junction of new bridges, a cut-and-cover tunnel portal, retaining walls and modifying the existing M4 Motorway lanes. An artist’s impression of the proposed Concord Road Interchange is shown in Figure 2. The locations of the new structures are marked up in the figure for ease of reference.

The interaction of new and existing structures is shown in Figure 3. The new structures are located within close proximity of each other as well as existing structures. New bridges connect the existing Concord Road to tunnel portals and newly-widened M4 lanes. Retaining walls run parallel to the newly-widened M4 lanes, passing alongside and underneath bridge structures. The existing Concord Road Bridge is located in the midst of the proposed Concord Road Interchange.

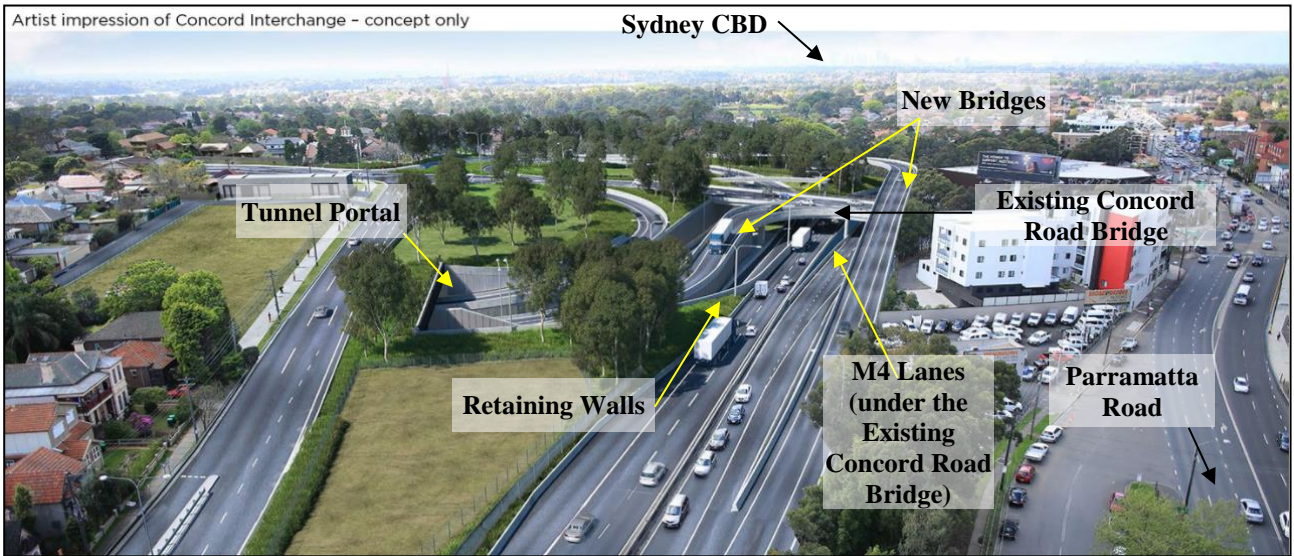


Figure 2: Artist Impression of the Proposed Concord Road Interchange – Concept

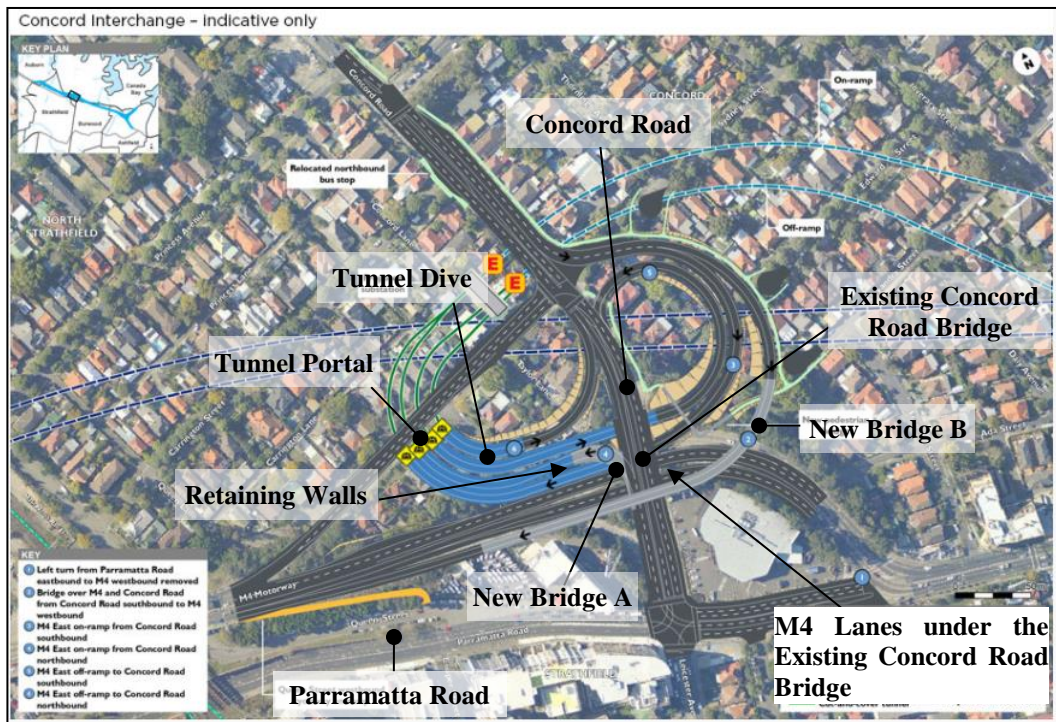


Figure 3: Proposed Works at the Proposed Concord Road Interchange – Indicative

3 THE EXISTING CONCORD ROAD BRIDGE

3.1 BACKGROUND

The existing Concord Road Bridge was designed and constructed circa 1984. It has a pre-tensioned continuous concrete bridge deck with three spans approximately 5 m above the M4 Motorway. The middle and end spans are 30 m and 10 m long, respectively. The bridge comprises four through lanes, with two lanes each way, as well as a turning lane in the southbound direction. There are 2 m-wide footpaths located along both sides of the bridge. These features are shown in plan view in Figure 4. An elevation of the bridge is shown in Figure 5. The bridge is articulated with the continuous deck rigidly connected to two piers and expansion joints at the abutment ends. The shorter end spans of the

superstructure span over the approximately 1(V):2.5(H) cut batters. The two piers comprise twin columns supported on independent spread footings. The abutments are supported on 900 mm-diameter cast-in-place bored piles at 4 m centres. The existing M4 Motorway crosses under this bridge, between the northern and southern piers. Upgrade of the M4 Motorway requires modification works to the existing Concord Road Bridge.

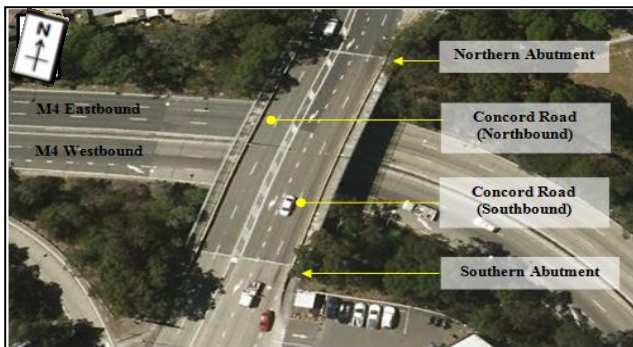


Figure 4: Plan view of the existing Concord Road Bridge circa April 2016 (Google Earth, 2017)



Figure 5: Elevation view of the existing Concord Road Bridge circa April 2016 (Google Earth, 2017)

3.2 SCOPE OF MODIFICATION WORKS

The scope of modification works for the Concord Road Bridge include altering the alignment of the M4 Motorway below, as well as the construction of a new bridge adjacent to it ('New Bridge A') as shown in Figure 6. The existing batter at the southern abutment of the existing bridge will be cut back to accommodate the new westbound M4 carriageway under the bridge. The existing batter at the northern abutment of the bridge will be cut back to accommodate the new southbound carriageway under the bridge. Construction of these works would impact on the stability of the abutment piles, and hence it would be necessary to underpin and provide lateral restraint and underpin the existing bridge. These works presented several geotechnical design and construction challenges for the project team.

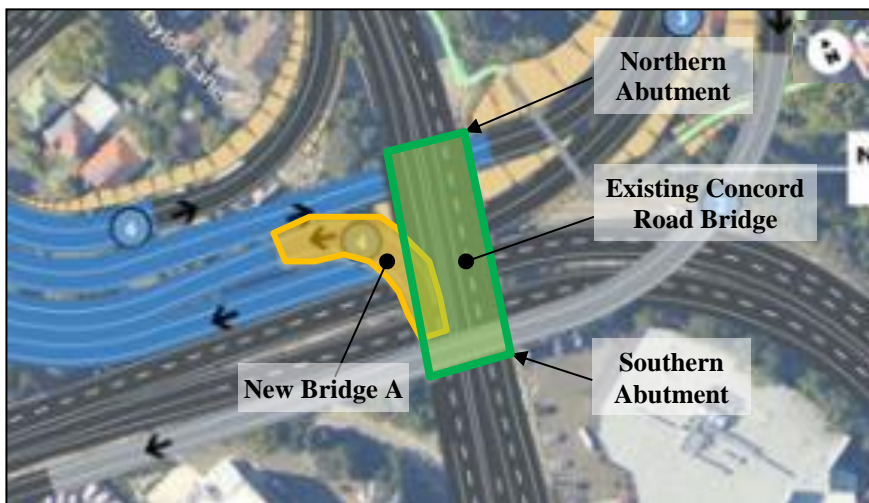


Figure 6: Proposed new bridge adjacent to the existing Concord Road Bridge – Indicative

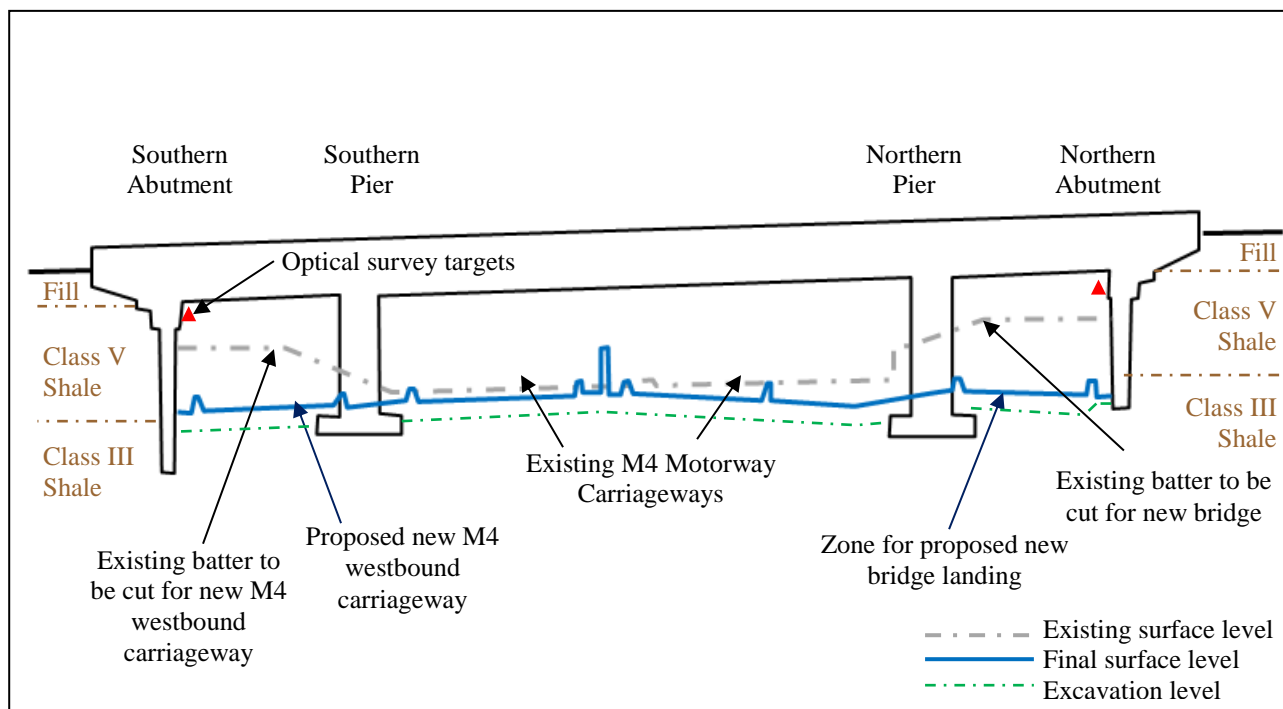


Figure 7: Sketch of elevation of existing and final surface level under the existing Concord Road Bridge.

4 GEOTECHNICAL DESIGN AND CONSTRUCTION CHALLENGES

4.1 GEOTECHNICAL DESIGN CHALLENGES

Prior to the commencement of design of the modification works, the design team reviewed the original 1984 design drawings of the existing bridge. These drawings provided information on the general arrangement of the bridge, structural details, foundation layout, rock socket requirements for piles, and geotechnical borehole details.

There were a number of technical challenges to carrying out the design of the bridge underpinning works. These related to the limited information available for the existing Concord Road Bridge and the performance criteria required for the modification works. These included:

- Drawings for the original bridge indicate design loads in accordance with NAASRA 1976 (National Association of Australian State Road Authorities) were used for design. The design standard applicable during design of the Concord Road Bridge modifications was AS5100-2004, the Bridge Design Standard, and there are differences between these standards.
- The founding materials for the bridge piers and abutments were uncertain based on the available information. The soil and rock material classification system current at the time of the original design, and shown on the original design drawings, is not consistent with current material classification systems. Rock materials were described in terms of weathering grade and strength, however the terminology used to describe rock strength (e.g. weak, moderately strong, strong.) was not consistent with the current Australian Standard (AS1726) for rock strength descriptions (e.g. low, medium, high). Additionally, defect spacing information, which is critical for the commonly adopted classification system by Pells et al (1998) for Sydney Sandstone and Shale was not given on the drawings.
- The as-built pile founding levels were uncertain based on the available information. The bridge design drawings provided the design founding levels for the abutment piles, however there were no available records of modifications to these levels during construction. The design founding level of the abutment piles at the northern abutment was +17.5 m RL.
- The design finished surface level for the modification works in front of the northern abutment was very close and about 1m above the design founding level of the abutment piles. The excavation level in front of the piles at the northern abutment to construct the pavement was minimum 300mm above the design pile toe levels. This information is also shown in Figure 7. Hence the as constructed pile founding levels were crucial for

design of the modification works as they dictated the extent of underpinning and lateral support that would be required.

- The structural assessment, carried out by the bridge engineers, identified that there was an expansion joint, approximately 20 mm wide, between the bridge deck and the headstock at the abutment. This gap needed to be maintained throughout the design life of the structure and therefore only very limited lateral movement could be tolerated at the abutment piles. The stringent deflection criterion imposed on the abutment piles could not be exceeded at any time during construction either as there was limited opportunity to implement remedial works.
- The structural assessment of the existing piles found that these had very limited capacity to take additional structural loads. Modification of the bridge substructure therefore needed to be designed in such a manner as to minimise any increase in shear force or bending moment in the abutment piles. The impact of drilling through the existing piles for anchoring and the potential loss of helix ties and main reinforcement at the drill hole location has been considered in the structural assessment of the piles.

4.2 CONSTRUCTION CHALLENGES

The primary construction challenge for this project was that the existing Concord Road Bridge had to remain open to traffic for the duration of construction. This requirement together with the stringent deflection criterion meant that the construction staging adopted for this project was critical.

A further construction challenge was the limited headroom below the bridge. The clear distance between the existing M4 Motorway pavement and the underside of the existing Concord Road Bridge is approximately 5 m. This controls the type of machinery and equipment that could be used for the construction works under the bridge.

These challenges had significant geotechnical implication, thereby requiring a robust design and construction methodology.

5 GEOTECHNICAL DESIGN METHODOLOGY

5.1 DESIGN STANDARDS AND GROUND MODEL

The Sydney Motorway Corporation (SMC) and Roads and Maritime Services (RMS) require new bridge works to be carried out in accordance with bridge design standards and specifications current at the time of design. This was also a contractual requirement in the project scope of works and technical criteria (SWTC). Hence AS5100-2004 the Bridge Design Standard was used for design of the bridge modification works.

To develop a geotechnical ground model for design at the bridge site, the borehole details from the original 1984 design were compared with current project borehole logs and geological long-section for the area. This design ground model is presented in Figure 7. The rock classification system by Pells et al (1998) was adopted for geotechnical design. Design parameters provided in the project geotechnical interpretative report (GIR) were adopted for the material at the bridge abutments with judicious incorporation of information given in the 1984 design drawings.

5.2 GEOTECHNICAL ANALYSIS OF UNDERPINNING WORKS

To enable cutting back of the existing batters at the bridge abutments, additional lateral restraint was required for the abutment piles. This restraint was provided in the form of prestressed ground anchors installed through the piles (i.e. 10 anchors at the northern abutment and 5 anchors at the southern abutment) and rock bolts and shotcrete to support the shale between the piles. The prestressed ground anchors were designed to AS5100.3-2004. The rock bolts were designed to BS8006-2:2011 and the methodology presented by Anderson, D and Pells, P – “An approach to the support of vertical cuts in Wianamatta Shales”.

The end bearing capacity of the piles was assessed to be sufficient for the axial loads applied to them (axial loads determined by the structural design engineer) as long as the piles were founded in Class III Shale or better rock. Therefore, no excavation was allowed within the pile base zone of influence.

Geotechnical analysis of the soil-structure interaction was carried out using finite element (FE) analysis in both PLAXIS 2D and PLAXIS 3D (version 2015). The PLAXIS 2D analysis was carried out initially to assess the feasibility of the design solution. A plane strain condition was assumed in the analysis. The 15-node elements, using the Mohr Coulomb constitutive soil models were used to simulate the soil and rock behaviour. The piled abutments were modelled using plate elements. Interface elements with reduction factor of 0.67 were used to simulate the contact between the piles and the soil / rock. Analysis was undertaken considering the short term and long term bending stiffness of the piles to account for additional deflections due to creep under sustained loading. Seismic analysis was

also undertaken using the pseudo-static approach by Mononobe-Okabe, described in AS4678. An example PLAXIS 2D model and output is shown in Figure 8 to Figure 11.

The PLAXIS 3D analysis was carried out to provide a better estimation of earth pressures and 3D effects acting on the piles and taken up by the intermediate rock bolts. An example PLAXIS 3D analysis is shown in Figure 12. The anchor spacing and prestress forces were adjusted in this analysis to optimise the design, primarily to assess if pile bending moment, shear force and deflection were within the capacity assessed by the structural design engineer.

The PLAXIS outputs, including earth pressures, shear forces and bending moments along with ground anchor forces and wall deflections were provided to the structural design engineer for input into the bridge structural analysis model.

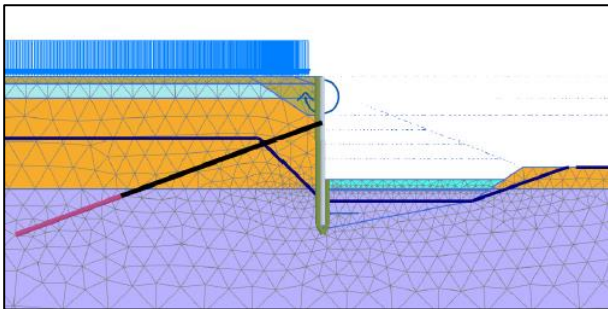


Figure 8: Example PLAXIS 2D model at southern abutment

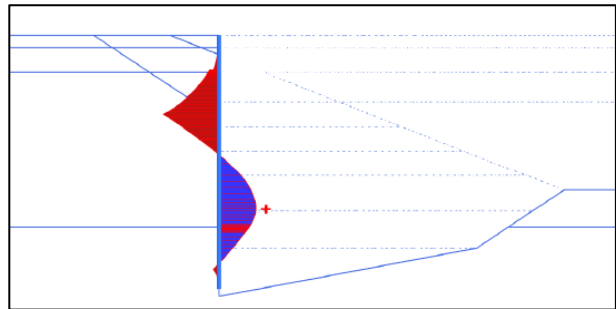


Figure 9: Example bending moment profile from PLAXIS 2D

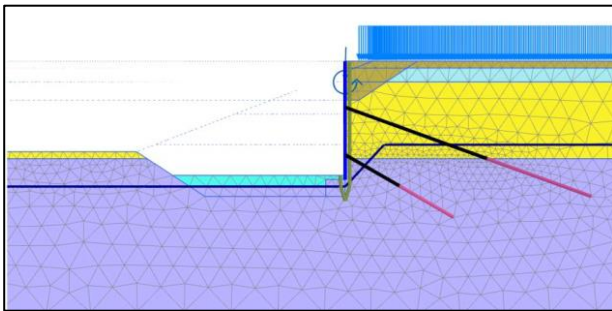


Figure 10: Example PLAXIS 2D model at northern abutment

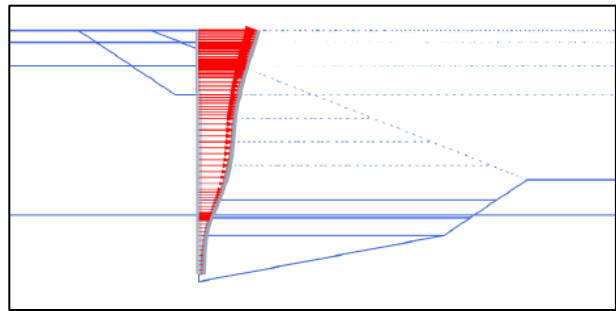


Figure 11: Example deflection profile from PLAXIS 2D

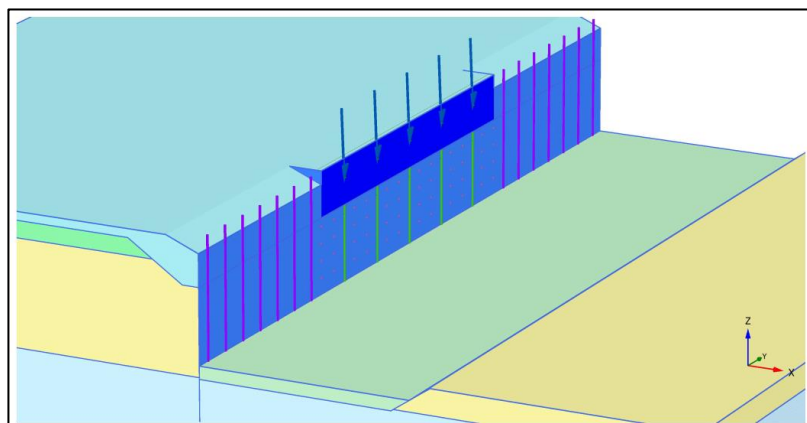


Figure 12: Example PLAXIS 3D model

5.3 VERIFICATION OF DESIGN ASSUMPTIONS

Further site investigation was carried out behind the bridge abutments prior to the commencement of construction works to assess the existing ground conditions and verify the assumptions in the geotechnical ground model. Findings from the investigation provided confidence in the ground model that was adopted for design.

Verification of the assumption regarding the abutment pile toe levels could only be carried out during the construction stage due to site access constraints. The space between the underside of the bridge deck and the existing batter between the abutments and the piers was not sufficient for setting up the necessary plant and carrying out the verification works prior to construction. Therefore, this verification was included as a necessary step in the construction staging.

The design was based on the assumption that the abutment pile toe levels were founded at the levels given on the 1984 design drawings. As the final surface level of the cut back batter is very close to the design toe of the abutment piles, the design also included detailed construction staging, monitoring and a contingency plan to address the risk of actual pile toe levels being shallower than the levels shown on the 1984 drawings.

5.4 CONSTRUCTION STAGING AND MONITORING

Careful construction staging, under the supervision of experienced geotechnical and structural engineers, was critical to the successful completion of the modification works. Conditions were imposed on the depth of excavation lifts and methods of excavation. The excavated slope and rock face at the end of each excavation lift and installation of the permanent supports was inspected by the site geotechnical engineer to identify any variation from the design ground conditions, before proceeding to the next excavation.

As identification of the abutment pile toe levels was critical in maintaining stability, it was proposed to excavate locally in front of each pile to verify the pile toe levels. Alternative methods for identifying pile toe levels such as downhole magnetometer testing were allowed for, subject to the approval of the experienced geotechnical and structural engineers on site.

Additionally, boundary lines for excavation for pavements and drainage trenches were defined on the project drawings so that no excavation occurred within the zone of influence of the pile toe, thereby maintaining sufficient pile end bearing capacity.

Monitoring instruments were installed on the bridge abutments prior to commencement of construction works. These comprised of optical survey targets on the abutment headstock (Figure 7). Trigger review levels were defined for headstock deflection during construction. A ‘Monitoring and Infrastructure Protection Report’ was prepared, which detailed the actions required at each trigger review level. A summary of the trigger review levels is provided in Table 1. Monitoring was undertaken and reported at each excavation level. The optical survey targets can be used for the long-term monitoring if required.

Table 1: Trigger review levels for optical survey targets.

Trigger Review Level	Deflection (mm)
Background (70%)	5
Alert (100%)	7
Alarm (125%)	10

5.5 CONTINGENCY PLAN

A contingency plan was prepared to account for the possibility of the abutment pile toe levels being above the levels in the 1984 drawings but still below the final excavation level (i.e. excavation did not undermine the pile toe). If this scenario was to occur, additional lateral support would be required to underpin the abutment piles. Geotechnical capacity checks were carried out to determine the type of support required for the piles in order to maintain sufficient capacity. Additional permanent anchors and rock bolts were proposed near the pile toe level to provide the required lateral support for the structure. In addition, conditions were imposed on the method of excavation where any excavation occurring near the pile toe had to be carried out using equipment which will not cause damage to the rock face and rock ledge in front of the pile toe, in order to maintain the pile end bearing capacity.

With the contingency plan available, the geotechnical site engineer could supervise execution of this plan with material and equipment already present on site. This prevents significant delay to the construction programme. However, if pile toe levels were found to be above the excavation level (i.e. excavation undermined the pile toe), works would have to cease and the designer was to be contacted for further instruction.

6 CONSTRUCTION

Construction works for the proposed Concord Road Interchange commenced in 2016. Figure 14 shows the extent of construction works as at December 2016. Preparatory work for surface works was being carried out at that time. Figure 15 shows that the works have since progressed substantially by April 2017. By this time, the M4 lane realignment works had already begun, as shown in Figure 15. Parts of the cantilevered bored pile retaining walls adjacent to the existing Concord Road Bridge had also already been constructed by that time, as shown in Figure 16.



Figure 13: Construction works at the proposed Concord Road Interchange in December 2016 (site photo).



Figure 14: Extensive construction works at the proposed Concord Road Interchange in April 2017 (site photo).

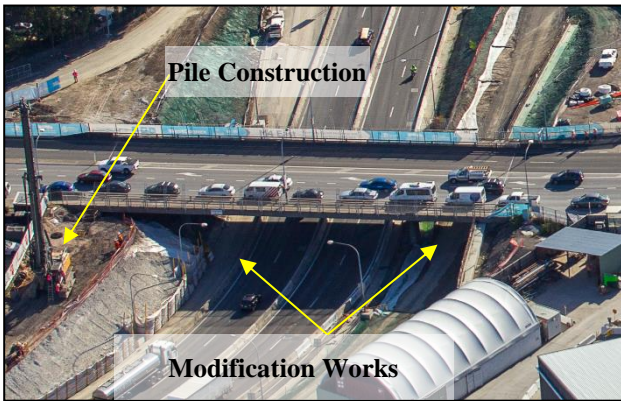


Figure 15: Pile construction and M4 lane works at the existing Concord Road Bridge in April 2017 (site photo).



Figure 16: Cantilevered bored pile retaining wall along the northern side of the existing Concord Road Bridge in April 2017 (site photo).

The existing Concord Road Bridge has been monitored for potential movements due to construction works at the proposed Concord Road Interchange. Measurements from optical survey targets on the bridge have been recorded and reviewed to assess whether the structural movements were within the allowable limits. These measurements were also compared against the calculated design movements.

Measurements from optical survey targets on the northern and southern abutments of the existing Concord Road Bridge are shown in Figure 17 and Figure 18, respectively. It can be seen from these figures, that the measured movements of the bridge abutments are smaller than the movements estimated during the design phase. This difference between the measured and estimated abutment movement could potentially be due to the presence of stiffer material behind the bridge abutments than what was assumed for the base case during the design phase.

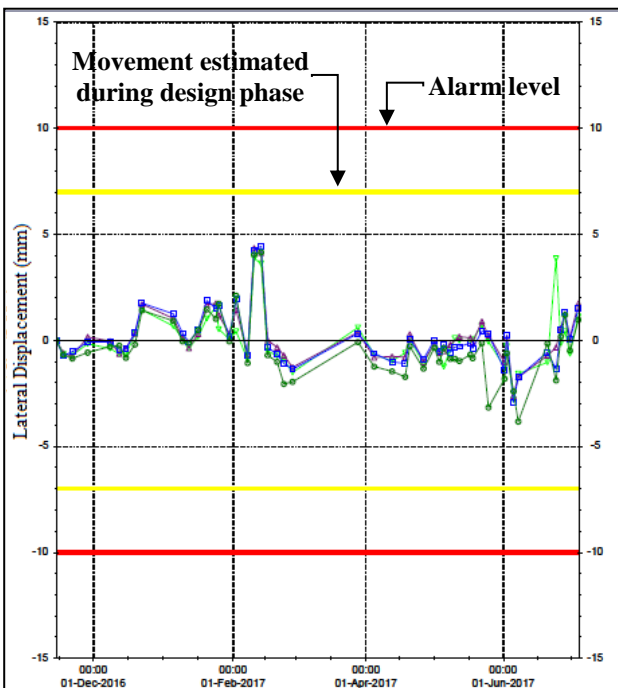


Figure 17: Measurements of optical survey targets on the northern abutment of the existing Concord Road Bridge.

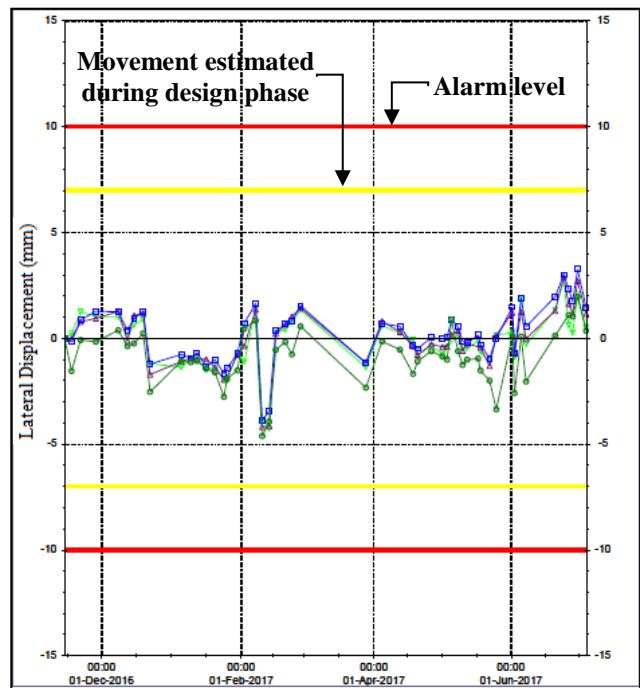


Figure 18: Measurements of optical survey targets on the southern abutment of the existing Concord Road Bridge.

7 CONCLUSIONS

The proposed modification works to the existing Concord Road Bridge posed several key design and construction challenges to the project team. Limited information regarding the as-built condition of the bridge foundations and the ground conditions behind the bridge abutments were the key geotechnical challenges which had to be addressed. The primary construction challenges for this project were that the existing Concord Road Bridge had to remain open to traffic for the duration of construction together with the stringent deflection criterion. These challenges were overcome by an integrated approach to geotechnical and structural design and construction.

The bridge required underpinning with permanent lateral support in order to remain operational during the construction of the proposed Concord Road Interchange. A robust design and construction methodology was developed to address these challenges.

Geotechnical analysis of the modification works was largely carried out using numerical modelling to assess soil-structure interaction. A comparison of field monitoring data with the estimated movements from the numerical models showed that the abutment movements were within the design estimates.

The design and construction challenges associated with this project are expected to become increasingly common in cities such as Sydney as further projects to upgrade existing infrastructure are carried out. Geotechnical design engineers will need to consider to an increasing extent, the implications of designs on temporary conditions and develop designs which minimise disruption to existing infrastructure.

8 ACKNOWLEDGEMENTS

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