DESIGN AND CONSTRUCTION OF MOTORWAY BRIDGES OVER LITTLE DORIS CREEK – IPSWICH MOTORWAY

Peter Masterson, Principal Bridges,
Russel Odendaal, Bridge Engineer, BG&E

ABSTRACT

The Little Doris Creek Bridge is a single 25m propped span consisting of Department of Transport and Main Roads (TMR) deck units with a composite deck. The bridge crosses Little Doris Creek, Oxley which has an existing eight cell box culvert structure to be removed during the staged construction works. The bridge is supported by closed ended steel driven tubes, which are later filled with reinforced concrete. Shotcrete facing spans between the piles, and a rock filled berm was specified in front of the vertical abutment wall for additional robustness.

This paper describes the design journey and construction challenges faced in developing the final design solution which ranged from options to retain and strengthen the existing eight cell box culvert structure through to the final single span bridge solution being presented. The staged construction involved top down excavation and thus a temporary tie back system using tied sheet piles was required, to support a 5m deep vertical excavation facilitating the culverts removal and associated earthworks.

The design considerations and solutions are presented below including temporary staging/works, a non-standard piling system requiring TMR approval, sensitivity analysis of the rock filled berm support, flooding/rapid draw down effects, durability of steel driven piles and addressing client concerns.

The Little Doris Creek Bridge forms part of the $400 million, jointly funded Australian and Queensland governments, Ipswich Motorway Upgrade: Rocklea to Darra – Stage 1 project.

1 Introduction

Little Doris Creek currently flows under the Ipswich Motorway between Factory Road and Bannerman Street, Oxley (Figure 1).

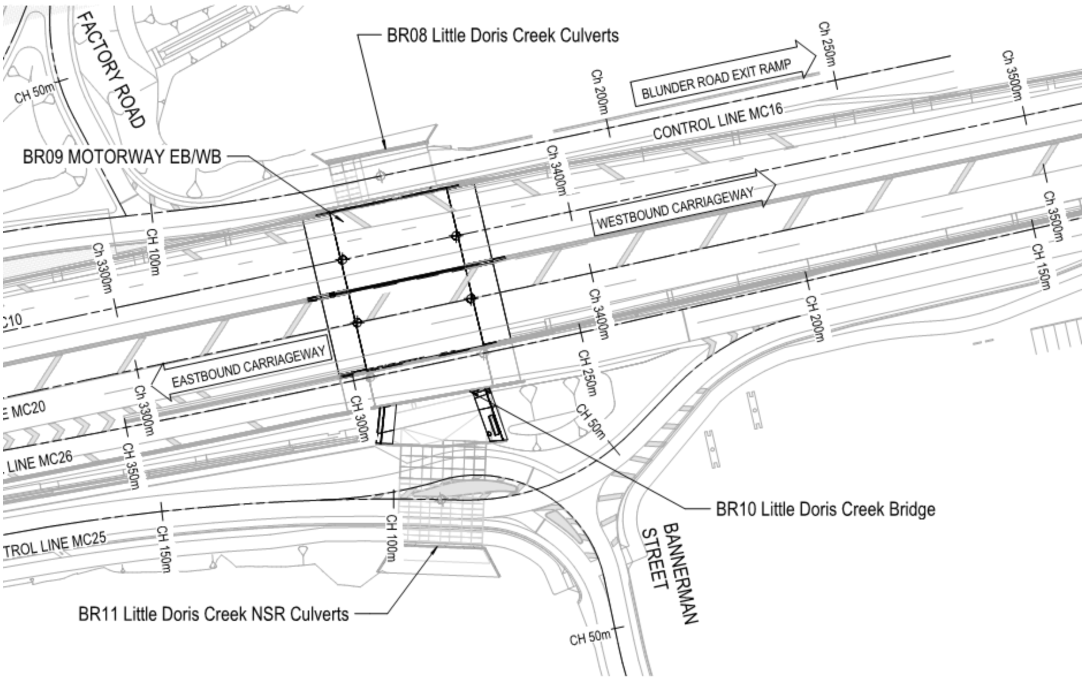

Figure 1: Little Doris Creek Location

The existing Ipswich Motorway consists of four lanes, two lanes carrying traffic westbound and two lanes eastbound. A dual lane service road is located north of the eastbound motorway carriageway approximately 2m lower than the motorway. A single lane exit ramp is located south of the westbound carriageway. The motorway, service road and exit ramp all span over the creek utilising culvert units. The culverts had been modified over the years after the original construction in the early 1970s and had now become a hybrid of new precast units and original in-situ unreinforced and reinforced concrete (

Figure 2).

Figure 2: Original culverts over Little Doris Creek

The Little Doris Creek Culverts as shown in **Figure 2** formed part of the Ipswich Motorway Upgrade: Rocklea to Darra – Stage 1 project. This $400 million project is being delivered by TMR,and is jointly funded on a 50:50 basis by the Australian and Queensland governments.

TMR is upgrading the eastern end of the Ipswich Motorway between Rocklea to Darra in a staged approach, reducing traffic congestion and delivering value for money on one of Queensland's major motorways. The key improvements include:

- upgrading the motorway from four to six lanes
- higher bridges over Oxley Creek, including seven new bridges
- new 1.5km Boundary Road Connection Road linking Boundary Road, Rocklea across the Oxley floodplain through to the Blunder Road intersection at Oxley
- new northern service road over the Oxley Creek floodplain
- new traffic signals at the Suscatand Street intersection.

The above requirements meant the structures over Little Doris Creek would now need to accommodate an extra lane of traffic in each direction with a total of six lanes. In addition, the levels of the motorway would have to increase by approximately 2.5 m to ensure flood immunity for Q_{100} and Q_{2000} Oxley Creek floods.

2 Design options

The different design options considered to satisfy the design requirements outlined in Section 1 are presented below.

2.1.1 Existing Culvert Design Review

The existing culverts at Little Doris Creek consist of a 6 / 2135 x 2135 precast culverts and a twin cell culvert 2400 x 2400 on the western most side. The culverts were constructed over two stages between the late 1980s and early 1990s and were a replacement of the original 6 / 7' x 7' culverts which were constructed in the 1960s.

The available drawings showed that the six cell culverts are supported by a 200mm thick reinforced concrete base slab, 305mm thick unreinforced concrete walls and simply supported reinforced concrete roof slabs which are pinned to the unreinforced concrete walls. The walls are also pinned at the base into the RC base slab by Y20 bars at 300mm centres.

The twin culverts to the east are double cell reinforced concrete culverts with haunches and reinforcement details but the sizes and spacing's were unknown as the drawings referred to standard bars but have insufficient detail to determine the size of the bars.

Based on the current known details of this culvert it has been determined that the existing six cell culverts have sufficient structural capacity to support the increased fill heights of 2.0m. The unreinforced concrete walls were also found to have sufficient strength to support the vertical loads and the lateral thrust loads at the ends.

2.1.2 Retention of Existing Culverts

Based on the existing information and initial design assessment, it had been considered during design development to explore the possibility of retaining the existing culverts under the Ipswich Motorway. However, this option was ultimately discarded as it was considered that they would not meet the SWTC (Scope of Works and Technical Criteria) requirements to meet the 100 year design life and be returned to a condition state 1. The description of the option to retain the culverts, however is described below.

The proposal to retain the existing eight cell culverts involved making them structurally redundant yet partially functional by allowing them to pass floodwater. This involved proposing new smaller size reinforced concrete pipe culverts to be pushed through each cell and filling up the remaining annulus space with flowable fill. Therefore, the existing culvert structure would become structurally redundant.

As the hydraulic capacity of this option was greatly reduced due to the partial filling of each cell, additional culverts would have been required to compensate for the lost capacity. The proposal involved placing eight additional culvert cells (3600 x 2100 RCBC's) over the top of the existing cells to provide the additional required waterway area.

However, after due consideration, this option was not progressed further as the risk of achieving compliance from a flooding and service design life perspective were considered too high.

A new bridge structure has therefore been proposed at Little Doris Creek as described below in Section 2.1.3.

2.1.3 New Bridge Construction

Having considered options to retain the existing culverts, a new bridge design was found to be the most cost effective and low risk option moving forward. A new single span bridge was designed and developed for the Little Doris Creek Bridge crossing consisting of a single 25m span utilising standard 1100mm deep x 596mm wide QLD Deck Units with a 200mm minimum thick composite concrete deck (**Figure 3**).

The bridge is propped at the abutments for longitudinal movements and supported on steel driven tube piles filled with reinforced concrete. The steel driven tubes are unique in their design as they are not in accordance with the TMR specification MRTS64 which specifies an open steel tube pile. A closed steel tube pile allows for quicker construction as no earth material will be inside the tube at the end of piling,eliminating the process of having to remove it. The pile design however was originally to be bored piles 1.05m in diameter at 3.0m centres but was changed during the design journey as further geotechnical design data became available. This unique pile design required TMR approval and was approved on the basis that it did not set a precedence for use on other TMR delivered projects. Other pile design options were explored to find the most cost-effective option which would suit the unique design constraints and the underlying ground material. A discussion on the pile design options is described in section 2.1.3.1 below.

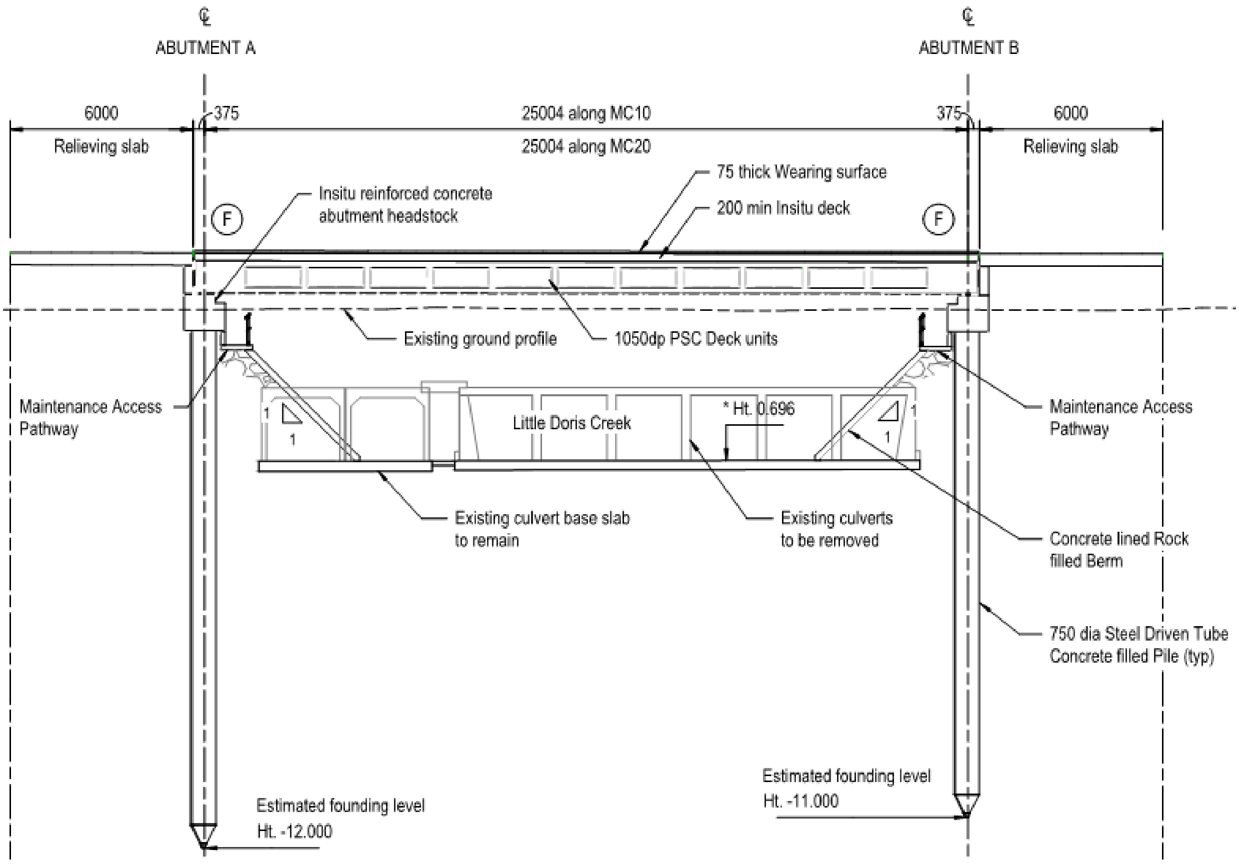

Figure 3: New Bridge Elevation

The main complexity of the bridge design and construction was the construction method and staging to maintain continuous flow of the Ipswich Motorway traffic in the east and westbound directions. The existing culverts at Little Doris Creek are to remain functioning for as much of the construction period as possible to minimise any risks of flooding local stakeholders during construction. Due to these constraints, the bridge is constructed from the top down and in stages to allow continuous flow of the Ipswich Motorway traffic.

2.1.3.1 Pile Options

The design of the bridge required a top down construction method and thus a pile option was required that would serve the purpose during construction to support the lateral loads from the excavation and then to support the bridge vertical and longitudinal loads. The underlying materials consist of an extensively weathered profile with the presence of weakly cemented sedimentary rock. This varies from mudstone, siltstone and sandstone.

The following four options were considered and discussed with TMR during design workshops in the early stages of design to gain an appreciation of the most cost-effective solution while maintaining client "buy in" such that an efficient design and approval process could be achieved. The four options considered were as follows:

1. 1050mm diameter Cast in Place (CIP) bored piles with permanent steel casing to the top of weathered rock
2. 550mm Octagonal pre-stressed concrete (PSC) driven piles with a soil nail wall constructed during top down excavation
3. 1050mm diameter Cast in Place (CIP) bored piles with temporary steel casing and a polymer drilling fluid to support the excavation
4. 750mm diameter steel driven tube, closed ended, with a precast concrete driving shoe and a cast in-situ reinforced concrete plug.

A qualitative pile options assessment was undertaken comparing the technical efficiency, constructability, risk and cost for each option. This assessment is summarised in the **Table 1** below:

Table 1: Pile Options Comparison (Extract from Reference 1)

Option	Pile Type	Vertical Loading	Lateral Loading	Construction	Risk	Cost	Overall
1	CIP Bored Pier with Permanent Liner	4 Long Socket	1	4 Socket collapse Shotcrete bond to steel liner	4 Socket collapse and extension Tremmie pour	3 Liner plus Long socket	4
2	Driven PSC pile with soil nail retention[1]	1 High founding level. Piles tested for capacity	4 Separate retention system	3 Separate system for vertical and lateral load	3 Soil-structure interaction between PCS and soil nails	4 Two systems	3
3	CIP drilled with polymer and temporary liner[2]	3 Longer pile length compared to driven options	1	2 Polymer management	2 Option 1 with reduced risk of socket collapse	1 Polymer with no liner	2
4	Driven, closed end steel tube[2]	1 High founding level. Piles tested for capacity	1	1 Shotcrete bond to steel liner for temporary works	1 Relatively low construction risk. Needs appropriate design for durability.	2	1

Notes: [1] PSC and other combinations may also apply such as CFA or other ground stiffening options.
[2] Not currently approved by TMR.

The table above indicates that the driven closed ended steel tubular piles were the best solution from an overall project perspective. The solution was discussed with TMR and it was agreed that it could be adopted for this scenario. Following this, the detailed design of the piles was undertaken. The detailed design consisted of a bridge grillage model to determine the overall axial load, moments and shear forces on the pile members in the permanent scenario subject to loading requirements of AS5100:2-2004. The results were supplied to our geotechnical consultants (FSG) to determine the overall pile lengths for lateral stability and vertical resistance. The geotechnical consultants also conducted independent modelling to confirm the loading provided.

The structural design of the piles in the permanent scenario were undertaken using simple spreadsheets and hand calculations treating the piles as simple reinforced concrete columns. TMR had requested that the steel liner be ignored for structural capacity calculations to allow for any corrosion that may occur during the life of the structure. As the piles were a non-standard TMR pile type, a bespoke specification was prepared by FSG as MRTS64 could not be used.

The installation effects on the pile due to driving were also investigated. FSG undertook a pile driving analysis and provided the expected compressive and tensile forces the pile would likely undergo during installation. A finite element analysis **(Figure 4)** was then undertaken to check the stresses and forces within the concrete and steel elements against the AS5100 code requirements.

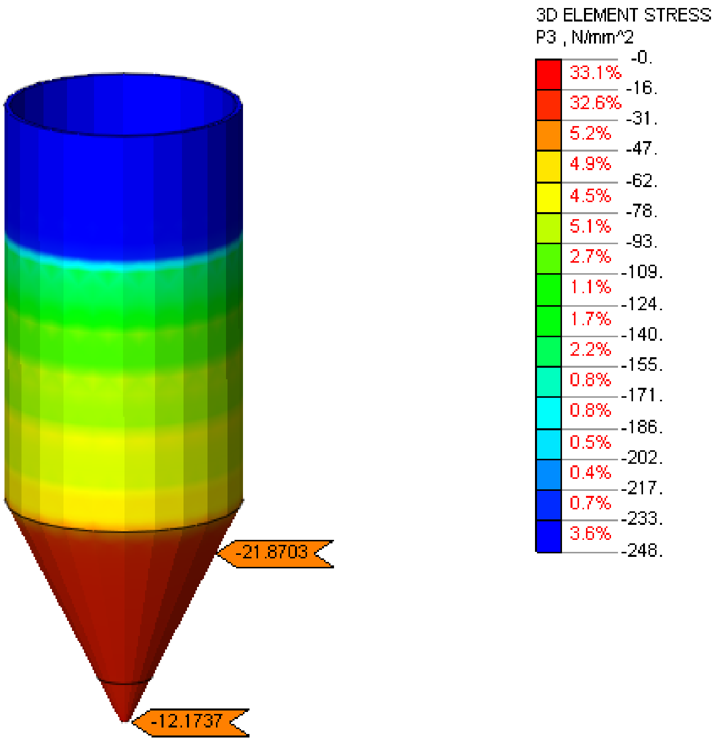

Figure 4: Pile driving shoe FEA analysis

2.1.3.2 Temporary Works

The closed ended steel tubular piles in conjunction with temporary ties and shoring provided sufficient strength to allow top down vertical excavation in front of the abutments to enable partial removal of the existing culverts. The temporary tie system was designed to carry a minimum ultimate lateral load of 110 kN/m width of retained abutment and serviceability load of 72kN/m width of abutment with a corresponding deflection of less than 5mm. The staged analysis of the top down construction was undertaken by our geotechnical consultants FSG utilising WALLAP analysis software. Collaboration between the bridge designers and geotechnical engineers was essential to agreeing on the analysis input data and validation of the results. The bridge engineers then undertook the structural design of the temporary tie system. A 3D render of the temporary works is shown in **Figure 5,** and a typical section is shown in **Figure 6.**

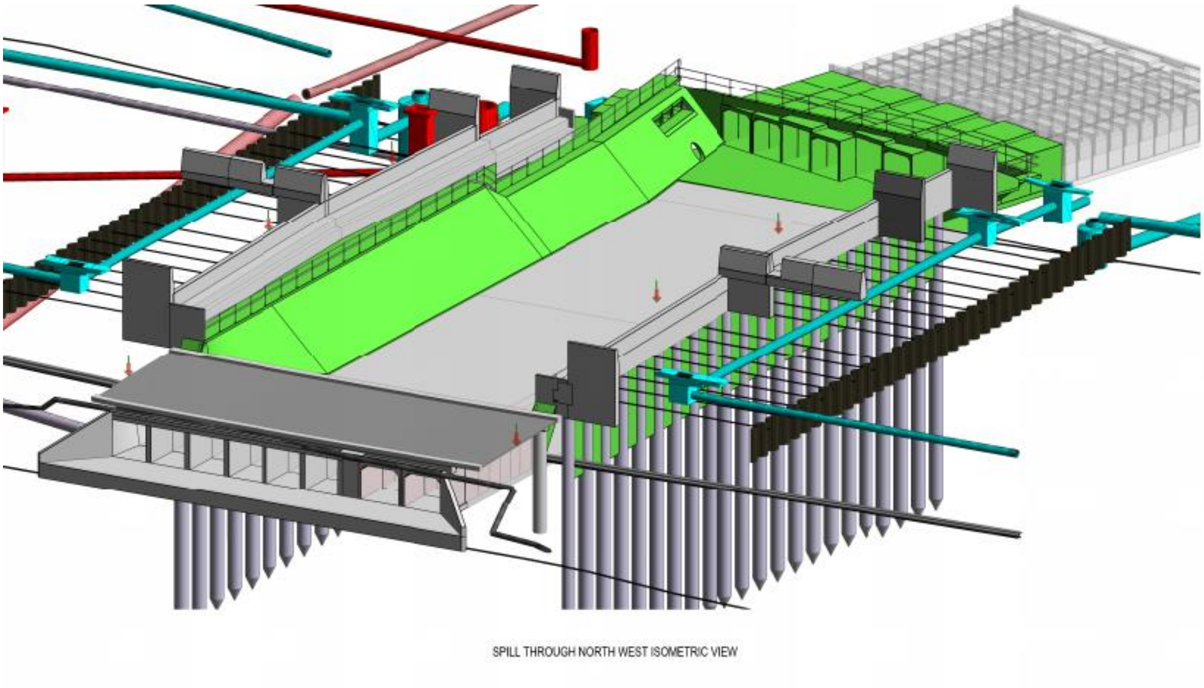

Figure 5: 3D render showing temporary works

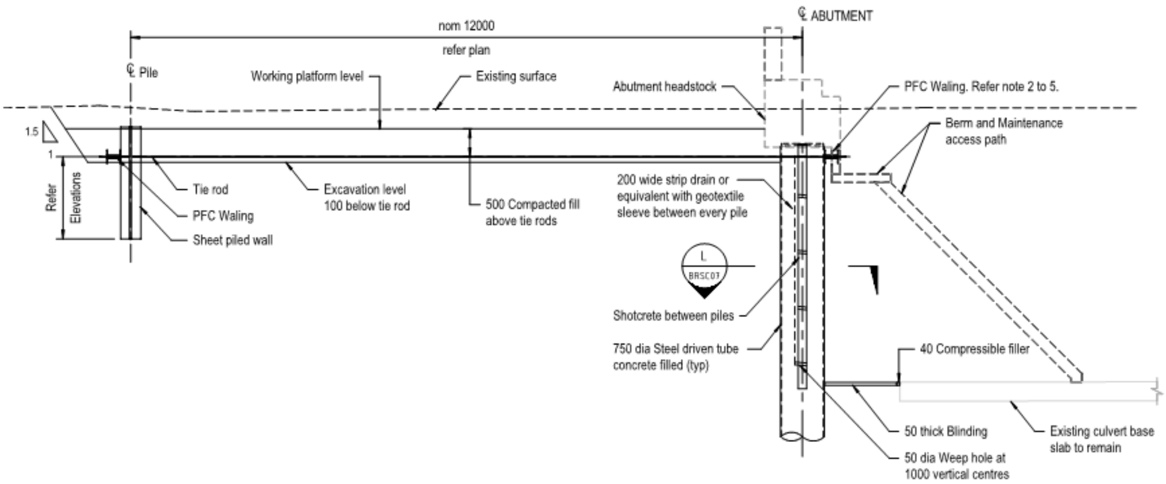

Figure 6: Typical section of tie back system

The temporary tie system consisted of a dead man anchor with 2.5m to 5.5m deep steel sheet piles and 20/28mm diameter steel tie rods at 0.875m centers connected to a steel PFC waler member. A shotcrete facing was designed between the piles to enable the top down vertical excavation. The shotcrete facing is connected to the outside face of the steel driven tubes via steel welded studs. Some of the typical temporary works details are shown in **Figure 7** below.

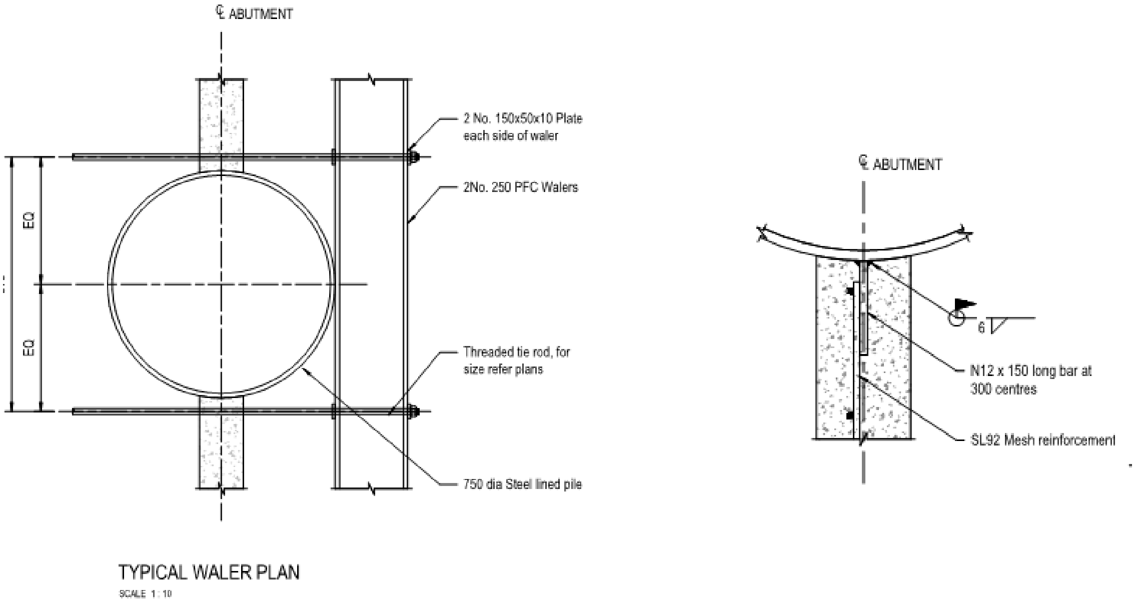

Figure 7: Typical temporary works details

The specified construction sequence for installation of the temporary works is outlined below:

1. Drive steel tubular piles. Install reinforcement cages and place infill concrete. Allow 7 days for sufficient concrete strength to be reached.
2. Drive steel sheet piles.
3. Install tie rods, walers and tension the system.
4. Begin top down excavation in front of the piles in 1m stages. Weld shotcrete connecting studs onto the pile liner and install shotcrete and reinforcement mesh as work progresses.
5. Once the underside of the existing culverts has been reached (approximately 5m depth) remove existing culverts.
6. Construct rock-filled protection berm with reinforced concrete facing and maintenance platforms.
7. Install bridge girders and holding down bolts and ensure holes are fully grouted. Ensure grout has achieved a minimum of 7 day strength.
8. Remove temporary tie system.
9. Complete remaining bridge works in traditional fashion.

2.1.3.3 Flooding/Rapid Drawdown Effects

One of the critical load cases during construction of the vertical top down wall are those due to extreme events such as flooding or accidental water main rupture.

Based on the potential for flooding and imbalance of water levels between the retained and excavated sides of the wall, a worst-case rapid drawdown groundwater level differential of two-thirds the retaining height has been adopted. This scenario represents a rapid drawdown from flood conditions. For normal operating conditions, the long-term groundwater level at RL +1.0m has been adopted. This groundwater level has been adopted for both SLS and ULS conditions.

Based on AS5100, the following ultimate and serviceability limit state load cases have been considered within the construction sequence:

ULS (Short Term)

1. Normal operating groundwater level (H = RL+1.0) + Active and Passive Horizontal Soil Effects +Vehicle Surcharge (10 kPa)

ULS (Long Term)

1. Rapid drawdown groundwater differential (2/3H) + Active and Passive Horizontal Soil Effects + Vehicle Surcharge (10 kPa) + ULS Braking/Thermal Loads
2. Normal operating groundwater level (H = RL+1.0) + Active and Passive Horizontal Soil Effects + Vehicle Surcharge (20 kPa) + ULS Braking/Thermal Loads

SLS

1. Normal operating groundwater level (H = RL+1.0) + Active and Passive Horizontal Soil Effects + Vehicle Surcharge (10 kPa) + SLS Braking/Thermal Loads

2.1.3.4 Rock Filled Berm Support

A berm support will be constructed against the completed vertical pile wall and will consist of compacted rock fill with a 200mm thick concrete facing, reinforced with an SL81 mesh. Weep holes will be provided behind the concrete facing to facilitate drainage of the retained embankment. The berm consists of an 850mm wide bench at the top to facilitate safe access to the abutments during maintenance and has a batter slope of 1.0 horizontal to 1.0 vertical. The rock filled berm batter has been tapered at each side of the bridge to ensure the flow area of the culverts is not compromised. This has been allowed for in the flood modelling with no detrimental effects. It is noted that the use of such a berm to provide lateral resistance is not to be used as a precedence for TMR delivered projects.

The additional lateral support offered by the berm to the bridge abutments has been ignored due to the possibility of separation during the life of the structure as a result of cyclic expansion and contraction of the bridge. The existing culvert base slab, which is remaining in place for simplicity of demolition, has also not been relied upon and a compressible filler has been detailed between the existing and new base slabs to ensure no additional load transfer occurs. Therefore, the closely spaced piles have sufficient structural capacity to withstand all the lateral loads assuming the berm was completely removed, and horizontal propping is provided solely by the deck.

The berm with its smooth concrete facing although ignored for lateral support, was still required as it provided a number of important functions which are summarised as follows. The berm:

- Offered a constricted waterway area with controlled surface roughness for the flood design. The flooding through this bridge was very sensitive to up and downstream effects on local stakeholders and the correct balance was required to meet the design afflux requirements of 10mm.
- Provided an access to the abutment shelf for easy maintenance during the life of the structure.
- Provided some lateral restraint in the bottom third of it mass although conservatively ignored.
- Provided an improvement to the lateral spring stiffness of the soil immediately below it due to the additional vertical component of confining earth pressure.

2.1.3.5 Key Project Risks

The design process for the delivery of the bridge involved design submissions at 15%, 50%, 85% and 100% (IFC) design stages. Each design stage was submitted to TMR for comments. A collaborative approach was implemented which involved meeting with TMR on a number of occasions through informal meetings at key design stages and formal design workshops to assist in closing out client comments and mitigating key project risks early.

A summary of the key project risks and how they were mitigated are as follows:

Choice of piles – Early in the design process the choice of piles became a point of contention as some of the options being considered were nonstandard piles that would require TMR approval. As discussed in section 2.1.3.1 of this report, a pile options study was undertaken where the steel driven closed ended tube filled with reinforced concrete was found to be the most effective solution following a multi criteria analysis. As this type of pile was similar to the steel tube driven pile described in TMR specification MRTS64 – Driven Tubular steel Piles, the difference was that the proposed design utilised a precast concrete pile toe such that excavation of material inside the driven tube after installation could be avoided. To address all the client and contractor concerns for this nonstandard pile, a supplementary specification was prepared by the geotechnical design team FSG which involved TMR review and approval.

Berm Lateral support – Initially the design was reliant on the rock filled berm to provide lateral support to the piles during the service life of the bridge, albeit only the bottom third was considered to be effective. The concern from TMR was that the full depth of the berm should be ignored as they considered that it would become ineffective over time due to cyclic movements of the bridge causing separation between the berm and the bridge piles and shotcrete wall. Upon review of this request, it was found that the number of piles only had to be increased by 15% and thus the pile spacing was reduced from 2.0m to 1.75m, providing an additional level of robustness to protect the bridge from extreme events.

Future Bearing Replacement – As the bridge is fully propped for translational movements, the deck supports a lateral compressive force from the retained embankment as a result of the top down construction method. It was a concern from TMR that during jacking of the bridge to replace the elastomeric bearings, the propping action could be lost or any wedges used to temporarily prop the bridge during jacking could be difficult to remove. This concern was mitigated by removing the elastomeric bearings and instead using a high strength cementitious grout, removing the need for future bearing replacement. TMR agreed to this design exception, considering the unique challenges of this project. The grout pad was checked for local stress concentrations due to the live load rotations of the deck units and was sized accordingly.

2.1.3.6 Construction Staging

The construction staging methodology of bridge structures over the Little Doris Creek is described below. This has been developed to facilitate the temporary works requirements.

Construction Stage 1

1. Maintain existing Motorway traffic.
2. Extend existing culverts below Blunder Road Exit Ramp (BR08) under local traffic controls.
3. Construct RC wall MR 16 and temporary reinforced soil slope and widen existing westbound carriageway embankment.

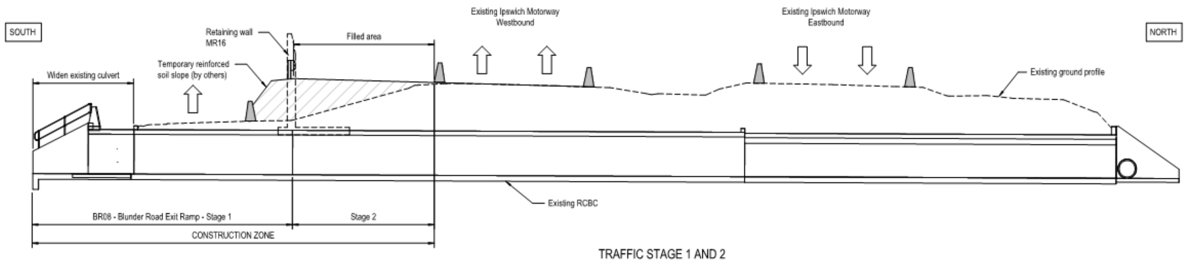

Figure 8: Construction and traffic Stage 1 and 2

Construction Stage 2

1. Construct temporary slope adjacent to the proposed left and right shoulder of the Ipswich Motorway Westbound carriageway.

2. Construct widened embankment to the south of the existing westbound Ipswich Motorway carriageway.
3. Install temporary PCB's.

Construction Stage 3

1. Shift existing Ipswich Motorway Westbound and Ipswich Motorway Eastbound traffic to widened embankment.
2. Construct substructure BR09 EB and BR10.
3. Construct RC Retaining wall MR26.
4. Install temporary work anchor system.
5. Excavate to base slab level, remove culvert units, place rock filled berms.
6. Construct temporary reinforced soil slope in median and temporary batter over existing culverts to stabilize the westbound carriageway.
7. Construct bridge superstructure BR09 EB and BR10.
8. Construct approach embankment evenly from both sides.

Construction Stage 4

1. Shift Ipswich Motorway Eastbound onto BR09 EB.
2. Construct temporary reinforced soil slope to facilitate completion of BR09 EB approaches.

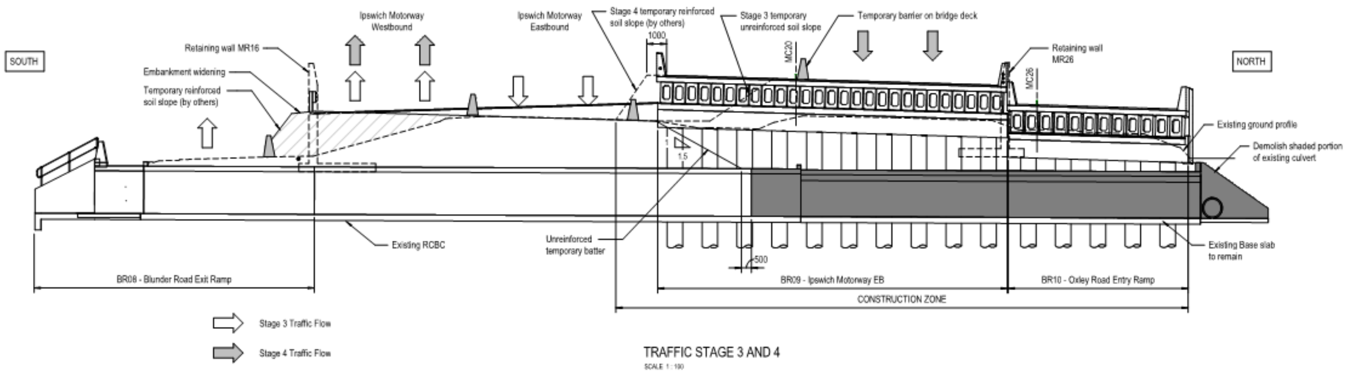

Figure 9: Construction and traffic Stage 3 and 4

Construction Stage 5

1. Shift Ipswich Motorway and Oxley Road Ramp traffic to newly constructed bridges BR09 EB and BR10.
2. Construct bridge substructure for Ipswich Motorway Westbound BR09 WB.
3. Install temporary work anchor system.
4. Demolish temporary retaining wall and remove fill over existing culvert units.
5. Remove remaining culvert units up to the limit of demolition required to build Ipswich Motorway Westbound.
6. Place rock filled berms.
7. Construct bridge superstructure BR09 WB.
8. Construct maintenance path and concrete lining layer on rock filled berms.
9. Complete Blunder Road Exit Ramp and associated culvert and maintenance path works.

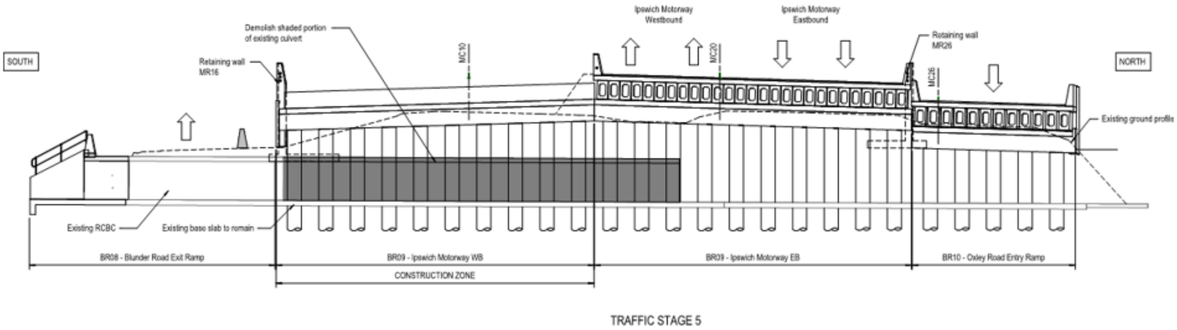

Figure 10: Construction and traffic Stage 5

Construction Stage 6

1. Shift Motorway traffic to configuration shown and complete earthworks to approaches

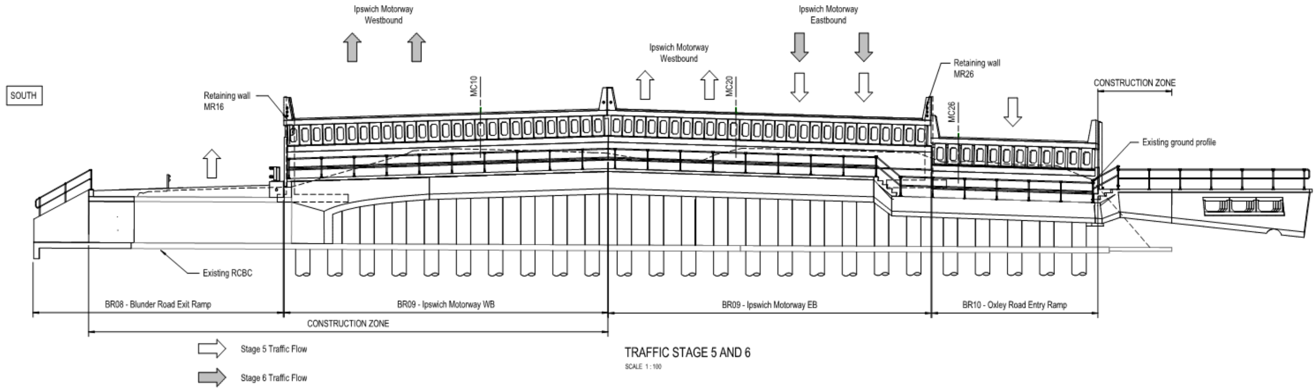

Figure 11: Construction and traffic Stage 5 and 6

3 Conclusion

The final design presented a neat single span solution which represents a typical TMR Deck Unit Bridge at the surface, however with complex and non-standard substructure designs and temporary works to enable the simplest solution to be realised. The design challenges for this bridge and the requirement to develop a cost-effective structure in the design and construct environment have resulted in a challenging design with unconventional solutions. Several challenges were overcome including approval of a non-standard piling system, a top down construction requiring a temporary tie back system and a detailed construction and demolition methodology, use of a rock filled berm for additional robustness and use of grouted bearings to avoid future bridge jacking.

The design effort to achieve the desired outcome required a high performing design team involving close collaboration between all design disciplines including structural, geotechnical (FSG), road design, drainage and PUP and a positive working relationship with the construction joint venture Bielby, Hull and Albem (BHA) and TMR.

4 References

- Ref 1 - FSG Technical Advice Note – Little Doris Creek Bridge Piling Options – 2173-AN-502-B.

5 Acknowledgements

The Little Doris Creek Bridge forms part of the $400 million, jointly funded Australian and Queensland governments, Ipswich Motorway Upgrade: Rocklea to Darra – Stage 1 project.

We would like to acknowledge and thank the following companies and departments for allowing use of photos and other included materials:

1. The Department of Transport & Main Roads
2. Bielby Hull Albem Joint Venture
3. FSG Geotechnics and Foundations Specialists
4. Cardno

6 AUTHOR BIOGRAPHIES

Peter Masterson is the Principal Bridge Engineer for the BG&E Brisbane office and is the Design Lead for the structures on the Ipswich Motorway Upgrade: Rocklea to Darra – Stage 1 (R2D) project. Peter has over 24 years design experience on steel and concrete bridges of various forms and complexity and has had structures team lead roles on numerous large projects throughout QLD including the Northern Busway, Ipswich Motorway D2G, Ipswich Motorway R2D and Smithfield Bypass in Cairns.

Russel Odendaal is a Bridge Engineer for the BG&E Brisbane office. Russel has over 8 years' experience in the analysis, design and construction of various structures from integral prestressed concrete bridges and viaducts to braced excavations. Russel has worked on large scale projects in Australia the UK, Asia and the Middle East.