Widening Existing Transversely Stressed Concrete Bridges

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ABSTRACT

To support the growing population and subsequent demand on road infrastructure, ongoing upgrade of Queensland’s transport network is being undertaken. These upgrade works require design consideration to maintain the existing level of service during construction, as well as maximize the retention of the existing assets in order to provide the most viable solution. In terms of bridge assets, this requires the widening the existing decks on many of the existing structures.

In some cases, bridge designers allow for future widening of the structures, however, it often happens that the envisaged widening provision falls short of the updated performance criteria and the needs of the future. Thus, widening of existing bridges presents a multitude of challenges during each phase, from planning and scheduling to design and construction. Key issues to address are to minimise impact on the existing structure, manage construction constraints, retain existing bridge elements, ensure that the required durability is achieved, and to provide an asset that can be readily inspected and maintained by the relevant authority.

This paper addresses widening of existing bridges on the Logan Enhancement Project undertaken by CPB Contractors and GHD/SMEC led design JV, which was completed for Transurban Queensland, the client. The paper aims to provide an insight into some of the key challenges encountered during the design and construction and provides recommendations to address these challenges, with the intention of advancing industry knowledge to ultimately improve the design and construction approach on future upgrade works.
1 INTRODUCTION

As our population grows, the transportation infrastructure needs to improve to meet this demand. Maintaining road serviceability during infrastructure upgrades as well as maximizing the retention of the existing assets are key considerations during these improvements and upgrades. In terms of bridge assets, this has resulted in widening a number of existing structures to yield the most effective solution.

Though provision for future widening has been made on a number of bridges throughout Queensland, the unknowns surrounding the future performance criteria for the widened structure can result in the provisions becoming redundant by the time widening works eventuate. Thus, widening of existing bridges presents a multitude of challenges during each phase, from planning and scheduling to design and construction. Key issues to address include the design of various structural elements to minimise impact on the existing structure and achieve construction constraints, retaining existing bridge elements into the widened structure, ensuring the required durability is achieved, and providing an asset that can be readily inspected and maintained by the relevant authority.

In Queensland, there will likely be a rise in the requirement for bridge widenings as brownfield infrastructure upgrades are undertaken in the future. This paper aims to provide an insight into some of the solutions devised to address the key challenges encountered during the different stages of the design and construction, with the intention of advancing industry knowledge to ultimately improve the design and construction approach on future upgrade works.

1.1 Project Overview

The Logan Enhancement Project (LEP) is a $512 million Transurban Queensland (TQ) project to deliver a safer and more efficient motorway network by relieving local traffic congestion, reducing travel times and enhancing connectivity with other major road networks within Brisbane and Logan. Construction is undertaken by CPB Contractors and is still underway with only the last few phases remaining. This project is a Design and Construct (D&C) contract with GHD and SMEC as the design joint venture (DJV) responsible for delivering the bulk of the engineering design for this project.

The project includes road civil infrastructure works to the following elements:

- Logan Motorway;
- Gateway Motorway and Gateway Extension Motorway;
- Logan Motorway Gateway Extension Motorway Interchange;
- Logan Motorway / Beaudesert Road / Mt Lindesay Highway Interchange;
- Mount Lindesay Highway/ Beaudesert Road;
- Logan Motorway / Wembley Road Interchange;
- Wembley Road Intersections;
- Compton Road / Gateway Extension Motorway Interchange;
- Pedestrian and Cyclist Infrastructure; and
- Other associated road civil infrastructure works.

1.2 Bridge Widenings on the Project

The project included three pairs of existing bridges that were proposed to widened: BR01, BR02 and BR03. Refer to Figure 2. As a case study, this paper discusses the widening of an existing pair of Scrubby Creek Bridges, abbreviated BR03 on the Gateway Extension Motorway. The existing Scrubby Creek Bridges are dual carriageway structures that each consist of eight spans on a horizontal curve. The bridge superstructure consists of transversely post tensioned, prestressed concrete deck units with an asphalt deck wearing surface. The total length of each bridge is approximately 170 m over Scrubby Creek. The existing substructure comprises of reinforced concrete abutments and piers, each consisting of a reinforced concrete headstock supported by eight precast, prestressed concrete driven piles. The articulation of each of the Scrubby Creek bridges consists of an expansion joint at the middle pier; with the abutments and remaining piers having fixed type joints. The bridges were built in 1996.
Figure 1 - Logan Enhancement Project Structures Layout Plan
1.3 Project Workflow for Bridge Widening

The project had a Tender Design phase which formed the basis of the Detail Design phase. The assumptions used for the Tender Design were later validated through more detailed information supplied at the Detailed Design phase. Figure 7 illustrates the simplified workflow for bridge widenings on this project, following project award and engagement of the DJV for the Detailed Design.

Figure 2 - Simplified Project Workflow for Bridge Widening
2 BACKGROUND INFORMATION AND DESKTOP STUDIES

2.1 Existing Bridge Drawings

During the detailed design phase of the project, the existing bridge drawings made available by the client were reviewed as part of the gap analysis. All available technical details, subsequent revisions and retrofitting work details were reviewed. Through this review, it was discovered that the deck unit details for the existing bridge were missing; this included: number, type, size, location and jacking force of the strands; size, grade, shape and spacing of the shear reinforcement; and size, grade, and location of the longitudinal reinforcement. In lieu of this information, the client approved that assumed details could be adopted for the design based on the now obsolete standard drawings of a similar vintage and superstructure type to the existing bridge. Typical details from the existing bridge drawings have been provided in Figure 3, Figure 4 and Figure 5.

Figure 3: Northbound Bridge Elevation from Existing Bridge Drawings

Figure 4: Deck section through the mid-span for Northbound and Southbound Scrubby Creek Bridges also showing future widening at the centre.

Figure 5: Typical Abutment Headstock and Piles
2.2 Level 1 and Level 2 Inspection Reports

In addition to existing technical details, previous Level 1 and 2 structural inspection reports were reviewed. The content and presentation of these reports were in line with the TMR Structures Inspection Manual (September 2009). The Level 2 inspection reports were dated 2008 and 2012, while the Level 1 inspection report from 2015 was made available.

The key observations from these inspection reports are summarised as follows:

- The Northbound and Southbound structures were reported to be in Fair Condition (CS3);
- Extensive cracking in the wearing surface, especially adjacent to the fixed joints above each pier was found;
- The expansion joint at Pier 4 showed a separation between the gland and the nosing. In the Southbound structure, the gland was depressed approximately 100 mm below the nosing over a length of approximately 0.5 m; and
- Vegetation growth was also noted at the headstocks.

The inspection reports made the following recommendations:

1. Resurface in conjunction with the application of deck waterproofing.
2. Repair joint details in wearing surface, including replacement of joints suitable for bridge articulation requirements.
3. Remove vegetation growth at the headstocks.
4. Consider replacement of the existing approach side guardrail.

Figure 6 - Northbound Level 2 Inspection- Crack on Surfacing and Vegetation at Headstocks

Figure 7 - Southbound Level 2 Inspection- Water leaks, Vegetation at Headstock, Partial Replacement of Expansion Joints
2.3 Rehabilitation and Condition Verification

Prior to the inception of LEP and based on some of the recommendations from the record Level 1 and 2 inspection reports, the client undertook rehabilitation works for the deck surfacing and Pier 4 expansion joints. In late 2015, GHD provided TQ with a detailed design methodology report for these works. The rehabilitation works report included the inspection report, limited as-constructed bridge drawings, a ground penetrating radar report, and an asphalt coring report. Site inspection of the pavement condition was conducted and the extent and location of cracking was mapped. Part of the works also included non-destructive integrity testing of the transverse post-tension bars using the RokTel test system in June 2015. In total, 93 bars were tested from the accessible end of the structure by the specialist testing sub-contractor, which revealed that the majority of the 93 post-tensioned bar ends tested were in a ‘good’ condition at the time of testing.

The articulation of the Scrubby Creek bridges consists of one expansion joint (allows longitudinal translation and rotation, but restrains transverse translation) at Pier 4 (Pier E on the as-constructed drawings), with the two pairs of abutments and remaining six pairs of piers being fixed (no translation, but allows rotation). The Pier 4 expansion joint design was carried out by a third party designer in 2015. Following the 2016 construction of these works, issues were identified with the replacement bridge deck joints installed above Pier 4 at each of the Scrubby Creek Bridges. From Figure 8, it appears that the existing joint had locally failed in adhesion, leading to separation of the seal material from the steel angles. The condition verification concluded that the recently installed Pier 4 bridge deck joints required replacement so that the expansion joints could function as intended.

![Figure 8 - Loss of Adhesion between the Seal and Steel Angles at Pier 4 Expansion Joint](image)

The deck wearing surface (DWS) was documented to be in a poor condition. Widespread longitudinal and transverse cracking was observed on both bridges (refer Figure 9). The recommended repair option for the DWS was to remove the existing DWS and replace it with AC14H, a new high strength polymer modified dense graded asphalt.
2.4 Review of Tender Designs Documents

During the Tender Design phase of the project, various options for the bridge widenings were devised and refined to identify the preferred solutions for the Tender Design submission. The Tender Design solutions needed to comply with the requirements of the D&C Deed, which included the Scope of Works and Technical Criteria (SWTC). During the Tender Design period, TQ issued several addenda to the SWTC documents, and the DJV and CPB discussed these changes with TQ and the Queensland Department of Transport and Main Roads (TMR), as a key stakeholder.

The SWTC for widened bridges had some unique requirements although was generally in accordanc with the requirements of the TMR Design Criteria for Bridges and Other Structures (August 2014) and the Australian Standard for Bridge Design, AS 5100 (2004 version). The DJV elected to use the more up to date concrete structures standard, AS3600-2009, for selected design aspects and the design was qualified as such. In particular, this included the more onerous creep and shrinkage requirements. The bridge Tender Design drawings, design report and technical details formed the basis of the Detail Design phase.
3 DETAIL DESIGN AND FURTHER INVESTIGATIONS

3.1 Design Objectives

The following aspects were targeted as design objectives:

- Sustainable reuse/rectification of existing structures where possible;
- Optimisation of structural design where possible to improve outcomes;
- Future proofing the relevant bridges for potential widening;
- Reducing construction impacts on the toll road; and
- Ensuring safety throughout design, construction, operations, maintenance and decommissioning.

Provision was made in the original design for future widening in the gap between the two existing bridges. Future widening provisions incorporated in the original design included surplus headstock width and additional driven piles. For various reasons discussed further below, the original widening strategy was not considered appropriate. Instead, the proposed widening strategy for BR03 consisted of widening both the Northbound and Southbound carriageways on the eastern sides of each existing bridge. This was required to achieve the required additional 4.5m on both the Northbound and Southbound bridges.

The widening requirements were as follows:

- **Southbound bridge** – Construct a new cast-in-place pile to the east of the existing bridge at each existing abutment and pier substructure and extend the existing headstock.
- **Northbound bridge** – Confirm suitability to retain the existing driven piles between the two bridges through Pile Driving Analyzer (PDA) hammer assessment. This would determine whether the existing piles provided in the original widening provision could be retained, or alternatively, construct one additional cast-in-place pile to the selected piers to support the proposed bridge widening.

The structural design for the LEP was based on a co-ordinated and value-driven approach that overcame major constraints. The approach focused on robust design and optimised arrangements to improve the overall functionality, constructability and maintenance aspects of the proposed bridges. Commensurate with TQ’s project requirements, rather than opting to replace all existing bridges, one of the project aims was to retain structures where possible in an effort to minimise project costs and embrace sustainable re-use and rectification of existing bridges.

3.2 General Scope of Works for Widening

The general scope of works for widening of existing bridges as set out in ‘Exhibit A: Scope of Works and Technical Criteria, Appendix 24-Bridges and Other Structures’. Key design parameters were:

i. Assessment of the condition of all existing transverse stressing bars utilising a non-invasive bar integrity testing system capable of identifying faults in grout encapsulation, degree of corrosion in the bar and presence of any bar fracturing. Condition assessment of the thread quality and the availability of sufficient thread to enable coupling of stress bars required for widening.

ii. To determine the residual life of the existing structure using durability modelling, assessment of PT bars and correlating the results with physical evidence identified during the replacement of PT bars.

iii. Submit a detailed report to TQ

iv. The connection between the existing and widening was required to be accessible for future inspections and maintenance.

v. The widening detail needed to make provision for future stress bar replacement.

vi. The structural type of the widening must consist of a composite insitu reinforced concrete slab (i.e. extending the existing bridge with additional transversely stressed bars was not acceptable).
3.3 Design Deliverables

The design was delivered in the following stages:

- Developed Concept Design (DCD) – Roughly 25% Complete Design;
- Substantial Design Development (SDD) – Roughly 65% Complete Design;
- Final Design Development (FDD) – 85% Complete Design; and
- Issued for Construction (IFC) – 100% Complete Design, incorporating all comments.

The DJV worked closely with CPB to develop the Detailed Designs for each submission gate. Each design stage was submitted for review and comments were incorporated into subsequent submissions culminating in the final IFC submission. The approval gates implemented throughout the LEP ensured a quality design outcome. As per industry standard practice, independent verification of the Detailed Design was undertaken in conjunction with the reviews by TQ and TMR.

3.4 Design Methodology

A key feature of the design philosophy was that the connection between old and new deck must be rigid enough to limit differential movement between the two structures at the interface. The challenge to overcome was that the new portion will tend to shorten more longitudinally, based on the time dependent shrinkage and creep effects between new and old concrete.

Since the connection between the existing and the widening extension needed to be accessible for inspection and maintenance operations, the transverse stress bar extensions were projected through the new ‘interface’ deck unit and past the adjacent deck units. The extension will project to the external face of the widened bridge transversely stressed deck units and therefore the transverse stress bar bearing plate, nut and exposed thread will be exposed for inspection and maintenance. The stress bar is extended by way of couplers attached to the existing stress bars, the existing bearing plate and nut are removed prior to coupling. This allows for potential future coring of the stress bar from the existing side of the bridge (opposite the widening).

The end of the stress bar on the unwidened side of the bridge projects from the outside of the existing deck units, and is thus readily accessible for inspection, maintenance and future coring operations. To meet durability requirements, the exposed ends of the bars including the nut and plate, were treated with a high build epoxy coating in accordance with AS 2312.1 and MRTS74 for protection against corrosion.

The design of the transverse stressing bar connection and stress bar extension has allowed for the connection to be fully encased and grouted within the deck units, which provides a similar environmental exposure as a typical transverse stressing bar. To ensure the durability at this location a proprietary non-shrink grout was nominated to minimise the risk of shrinkage cracking at the interface and along the stress bar extension.

The widened deck units have a topping slab of minimum 200mm thickness which is connected to the interface unit with the help of steel reinforcement bars that are coupled to the interface deck units. Refer to Figure 10 and Figure 11 for these details.
The connection detail was studied to investigate the long term effects due to shrinkage and creep along the interface between old and new deck units and headstocks, and to verify that these effects could be accommodated or resisted. The existing decks were built approximately 20 years ago, as such it was conservatively assumed that no additional shrinkage and creep movement would occur.

To achieve the necessary longitudinal shear capacity at the interface, the faces of both the existing and new deck units were appropriately roughened and the grout used between the deck units was a high strength grout with a minimum strength of 50 MPa. The design recommended to ‘lock in’ (i.e. transversely stress) the new deck units with the existing deck units at least 100 days after the manufacture of the new deck units. This was specified in order to reduce the amount of shrinkage and creep effects, and thus reduce the shear forces generated at the interface of the existing and new deck structures, as well as the shear forces generated at the deck and headstock hold down bolt connections. Additional load effects on the existing bridge piles were also reduced by increasing the earliest lock in time from the industry standard 30 days up to 100 days after deck unit manufacture.

### 3.5 Geotechnical and Pile Foundation Assessment

Geotechnical design was carried out by Golder Associates. Rigorous analyses during the Detailed Design phase sought to determine whether there was an adequate geotechnical reduction factor for the existing Northbound bridge piles to be retained as part of the proposed widening. This geotechnical reduction factor was back calculated based on the safe working load and a factor of safety of 2.5 specified on the as-constructed pile drawings for the existing bridge.

Based on the pile loads from the proposed bridge widening, it was concluded that the geotechnical reduction factor for the abutments exceeded the limit specified in the TMR Geotechnical Design Standard - Minimum Requirements (February 2015). However, the geotechnical reduction factor for the existing pier piles was found to exceed the TMR limit.
Therefore, to include the existing piles into the new design for the widening of the Northbound structure, further testing including PDA testing and analysis using the Case Pile Wave Analysis Program (CAPWAP®) was undertaken in order to assess the actual ultimate geotechnical capacity of the existing piles. Due to access and time constraints, this testing could not be conducted prior to the Detailed Design phase. As such, two design options were developed for the Northbound structure: one using the existing piles and another option with a new bored cast-in-place pile between the existing piles. The latter involved breaking back some extent of the piles to isolate them from the new headstock and disregard any load share of the existing piles in the widened area. To complicate things somewhat (from an analysis and documentation perspective) these two piling options considered various permutations to account for the fact that out of the seven piers, the testing may reveal that none, some or all of the piers may need to have a new cast in place pile.

The Southbound bridge widening was much simpler – the bridge was widened towards the east with a new, single, cast in place pile at each pier which was designed to support the widened deck.

All structural modelling was based on the soil spring stiffness values provided by Golder Associates, which were calibrated to the pile loads provided by the DJV. Producing quality documentation in a timely fashion required close collaboration between the DJV and Golder Associates. Some iteration of data between Golder Associates and the DJV was required to determine the optimum project designs.

### 3.6 Design Constraints and Residual Risks

A number of challenges were encountered during the Detailed Design process. For example, the approval system delayed the engagement and collaboration with major stakeholders, which made it difficult to capture the comments early in the design. The approach of utilising the existing substructure with so many unknowns was also a major design constraint which lead to the consideration of alternate options. Nevertheless, some components carried the risk which can only be dealt with and mitigated accordingly during the construction. An example of such a case was the condition of the bearing plates and stress bars, which was later confirmed by non-destructive testing.

Several Safety in Design (SiD) workshops were held during the design phase and these workshops covered a range of risks for design, construction, operation and demolition operations based on each of the design disciplines, including structures, drainage, roads, temporary traffic management, geotechnical, etc. SiD workshop highlighted some of the potential risks and additional control measures were devised to manage such risks. The residual risks were also highlighted and transferred to the corresponding asset owner or maintainer.

### 3.7 Further Investigations

To determine the extent of the existing structure which could be incorporated in the widening, further investigations were necessary. Specifically non-destructive testing (NDT) of the existing transverse stressing bars and PDA testing of the existing piles. These investigations have been further discussed in the following sections.

#### 3.7.1 NDT for Transverse PT-Bars

##### 3.7.1.1 Approach

Prior to the extension of the existing transverse stressing bars, a condition assessment of the existing bars was undertaken. The assessment sought to determine the condition of the existing bars, which included identifying faults in grout encapsulation, degree of corrosion in the bar and presence of bar fracturing. Condition assessment of the thread quality and the availability of sufficient thread to enable coupling of stress bars also needed to be carried out. A testing methodology was determined by the DJV in collaboration with CPB to carry out the NDT procedure and to provide the basis of the conditional assessment of the stress bars. Figure 12 illustrates the NDT procedure for the testing of stress bars. The outcome of the NDT testing and site observations are discussed in 3.7.1.2.
For 2 nos PT bars on Scrubby Creek Bridges that were identified as condition state of 3 in previous NDT report as per SWTC:

Undertake design check and core out, remove bars for visual assessment, unless other bars identified as more representative

Are the bars in satisfactory condition based on visual inspection?
Yes ➔ No further rectification work required for the remaining PT bars
No ➔ No

Identify the location and assess the nature of the observed defects. Assess overall bar condition and Level 2 inspection assessment, apply engineering judgement to determine appropriate actions

Bridge capacity adequate without Category 3 bars?
Yes ➔ Provide a desktop analysis advising client of future maintenance requirements for PT bar monitoring and replacements
No ➔ Core out, remove and replace the worst Condition State 3 PT bar

The actual condition of the PT bar and grout satisfactory?
Yes ➔ No further rectification work required for the remaining PT bars
No ➔ Any additional Category 3 PT bars identified?
Yes ➔ No
No ➔ No

Figure 12: Flowchart for the procedure of Non Destructive testing of PT-Bars
3.7.1.2 Testing and Results
A specialist testing sub-contractor undertook the testing using their non-invasive ‘RokTel’ system. The RokTel system records vibrational responses of the post-tensioned bar following an imparted impact, which sends an impulse signal through the entire length of the bar. Subsequent analysis of the reflected impulse signal identifies if the bars are anomalous (i.e. fully encapsulated, corroding or broken). The system can indicate the degree of loss of section to the bar or the presence of voided grouting.

This testing was undertaken on all widened bridges to provide an indication of the condition of the post-tensioning bars. The condition of the bars were categorised based on the results of the NDT testing into categories as follows:

- **Category 1** – Bar intact, minimal free length detected, no obvious loss of contact detected.
- **Category 2** – Bar has good anchorage, good embedment and load transfer along the length, with only minor loss of concrete / grout / bar contact.
- **Category 3** – Bar has some deficiencies, free length detected, some loss of contact detected between concrete / grout / bar. Potential for corrosion.

If the NDT testing indicated that the bars fell within these categories, the bars were considered acceptable for inclusion in the final design given the chloride free, low corrosivity and protected environment within the deck units. Where NDT testing indicated significant signs of corrosion, section loss or failure, the bars were considered as “unsuitable” and were required to be completely removed.

Following NDT testing on Scrubby Creek the majority of the tested bars were within Category 1-2 with two bars identified as Category 3. No bars were found to be unsuitable. As a condition of the contract, to validate the NDT integrity results, bars which were identified as category 3 (i.e. bars which showed the most significant deterioration based on NDT) required visual inspection to confirm the extent of deterioration to validate the NDT data.

The removal process required use of a rail-mounted hydraulic core drilling system. Two stress bars on BR03 were removed for verification. Prior to stress bar removal, a structural assessment was undertaken, considering the implications of the bar removal with respect to the structural integrity of the bridge. Visual assessment confirmed that the removed bars were in a good condition (refer to Figure 13 for photographic record of condition) hence it could be reasonably concluded that the existing PT bars were in an equivalent or better condition than the removed bars and satisfactory for the widening.

To provide confidence in the robustness of the widening, recommendations were made to monitor the condition of the stress bars via NDT at 5-10 year intervals, to verify the condition and possible future corrosion of the bars. The design of the bridge widening has made provision for one end of the bar to be accessible to provide a location for ongoing testing. In addition, the existing bearing plates and nuts at the interface of the new to old bridges were removed as part of the widening operation to more readily allow for future coring works, noting that this was also a TMR requirement.
3.7.2 PDA Testing of the Existing Driven Piles

PDA testing of the existing 550 mm octagonal pre-stressed concrete driven piles was undertaken by a specialist subcontractor. The piles were tested by impacting a force to the top of the pile using a Junttan HHk 7/9 SS pile driving hammer in 9 t configuration. To ensure the load application was uniform, the tops of the piles were trimmed and prepared for the hammer. In accordance with the subcontractor’s procedure, the 9 t hammer was lifted to the required drop height and remotely controlled to strike the pile.

The pile was struck from various drop heights to demonstrate pile resistance. Following field measurements the CAPWAP® modelling software was utilized to predict soil behaviour and static load capacity. PDA testing of the existing piles revealed that the existing piles were not suitable for incorporation into the new design and hence additional cast in place bored piles were required.
4 CONSTRUCTION

Retrofitting existing structures presented a number of construction challenges, which are further amplified when taking into consideration tight construction tolerances, incorporating precast elements, tying in to an existing structure and operating in a limited workspace adjacent live road traffic.

4.1 Works Staging and Site Access

The contract documents stated that the Gateway Extension Motorway was required to remain serviceable during the construction of the works. This meant that a staged construction approach to minimise impacts to road traffic users was necessary. For each of the traffic stages, temporary road re-alignment of the bridge approaches was undertaken to enable permanent works to be installed safely.

As a result of the staging, access to the bridge was limited to the staged approach. Design involvement during construction was therefore restricted to a constrained time window commensurate with the construction staging.

4.2 Northbound Bridge Piling

Two options for the Northbound Bridge were developed during the detailed design to enable construction to progress immediately following onsite testing and verification of the existing pier piles; one using the existing piles and another option with a new bored cast-in-place pile between the existing piles. As discussed in Section 3.7.2 following PDA testing the option with the new cast-in-place piles was required at each pier. As illustrated in Figure 11, these new piles were required to be constructed adjacent to the existing piles.

Figure 14 - Cast-in-Place Pile for Northbound Structure

Inherent to driven pile installation, many of the existing piles were found to have been installed out of tolerance from the design vertical alignment which introduced additional risks to the piling subcontractor for the construction of the new cast-in-place piles. To minimise the risk of hitting the adjacent existing driven piles and damaging the existing structure, the following revised construction procedure was developed to extract selected existing driven piles:

- Existing piles were trimmed down from the headstock level to improve access and removal.
- A temporary steel casing was placed over the existing piles and the casing was driven into the ground to help break the skin friction bond between the driven pile and the ground.
- One pile per pier was removed to enable a large gap to fit the new cast in place pile.
- Loose material within the steel casing was removed
- Pile hole was filled with low strength flowable fill/stabilised sand to limit ground loss.
- Temporary steel casing was removed prior to the fill material being set.
- New pile constructed once stabilised sand was set.
- New pile location shifted 340 mm outward from original design position to provide sufficient horizontal clearance from existing infrastructure and to satisfy the positional and verticality tolerance of the new and existing piles, thereby mitigating the risk of clashes with the infrastructure.
4.3 Visual Inspection of the Bar Ends

A visual inspection for the ends of the transverse post-tensioning stress bars (TSBs) was undertaken to confirm the extent of deterioration or corrosion to the ends of the bars, end plate and nut. To confirm that the stress bar could be coupled and extended, the existing bar diameter and type of stress bar was also inspected.

This inspection revealed that following challenges:

- No exposed thread projecting beyond the existing bearing plate and nut assembly was evident on the majority of TSBs – this required the bearing plates and nuts to be removed to permit coupling and extending the TSBs.
- Some of the nuts were seized onto the bars – these nuts were removed through the use of heat on the nuts to loosen them with careful control measures (e.g. laser thermometers and heat indicating crayons) to ensure that overheating of the high tensile bars did not occur.

4.4 Connection to the Existing Substructure

To create a positive connection to the existing substructure, the abutments were widened through drilling and chemically anchoring reinforcement into the existing abutments. During this drilling process, the existing reinforcement in the headstocks was struck multiple times and the dowelled connection could not be installed as per the original design. A revised design was developed on site, which provided greater tolerances to achieve the connection design requirement.

Accounting for deck unit hogging (i.e. vertically upwards deflection of the deck units due to eccentric prestress strands) variability was another challenge on site. The structure was sensitive to hogging because the prefabricated beams needed to hog within a specified design range in order to both fit the transverse stressing bars and make provision for an adequate composite deck slab thickness and asphalt thickness for the widened superstructure portion. As such, some allowance was made during the design phase to provide mortar pad heights that could be adjusted to accommodate the actual hog values. To minimise complications on site, there should be a focus on discussing these sensitivities between the design and construction teams during the design phase. Both the design and construction teams should be cognisant that the new deck units are ‘fit critical’. For example, the design team needs to document the deck unit hogs, oversized stress bar holes and mortar pad thicknesses based on an agreed range of hog tolerances. The construction team should undertake detailed survey of the existing stress bars and measure the actual deck unit hog immediately prior to erection to validate the design tolerances and to give confidence that fit can be achieved on site so far is reasonably practical. This task includes monitoring the early hog data to view trends, which can help mitigate issues with large hog variances.

Further to the above considerations, additional challenges were faced on site due to the following:

- Some TSB ends were concealed by existing traffic barriers and could not be surveyed; and
- Geometric model assumed perfectly straight bars – the bars might be curved.

Some lessons learnt from this project includes:

- A more robust procedure for checking the new deck units for tolerance, checking fit before installation and ensuring accurate alignment during installation would have benefitted construction; and
- Limitations in x-ray equipment meant that the reinforcement could not be completely located, which resulted in some reinforcement clashes when dowelling into the existing structure. Smaller embedment depths and using a larger number of smaller diameter bars was preferred to minimise clashes.

5 Conclusion & Recommendations

Undertaking a bridge widening is not as simple as it seems, even if the bridge has had provision for widening in the original design. Gaps in record information, performance criteria, margin in structural
capacity, the residual life of the structure, and constructability challenges are all just part of the many design and construction risks that should be taken into account as early as possible.

Clients should strive to provide as much record information as possible (e.g. bridge condition inspection reports, bridge as-constructed drawings). Client should also be explicitly clear in the SWTC regarding bridge widening design requirements.

The design approach should be well communicated between the designer, asset owner and contractor. Early and ongoing engagement and collaboration with the asset owner, road authorities, contractor and technical reviewers to coordinate the design is highly recommended.

Achieving successful project outcomes is dependent on establishing effective design approval systems – it is imperative that review feedback (from the asset owner, road authority, IV, other stakeholders) is received in a timely fashion and that all parties seek to reduce the impact of changes on the design and construction throughout the approval process – this is especially true in a D&C environment.

A trial and error approach to the design and construction aspects of bridge widenings should be avoided where possible – the use of modern techniques and proven technology should be adhered for optimal project success.

For current road bridge designs attempting to make provision for future widening, special care should be taken as the emerging technology, design standards and client requirement may all change over time. The additional upfront cost for future widening provisions may not receive the full value for money if the proposed widening is not efficiently planned during the design stage of the bridge. The design of the future bridge widenings should integrate with the strategic development masterplans – this will lead to a better understanding of the potential future use of the road and the design should have enough redundancy to deal with a degree of contingencies.

The asset information and the as-constructed data should be well preserved with the help of new and improved digital tools like Building Information Modelling (BIM). The advancements in technology, modern transport mode integration and sustainability should be kept in mind while designing for any future widening provisions.

There is an opportunity to study the wider impact and undertake a detailed assessment once the project is completed. All other various aspects of the project which are not covered in this paper e.g. community and stakeholder management, integration of the widenings with the existing urban design, commercial and financial aspects from an asset management perspective and the use of digital engineering, etc., can be further explored on this project and a lesson learned session could be shared to improve and add more value to such bridge widening projects in the future.
6 AUTHOR BIOGRAPHIES

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Shariq is a Senior Bridge Engineer working within the Bridges and Materials Technology Team of GHD. He has more than 12 years of experience in bridge design and worked on a variety of bridge projects in the Middle-east Asia and Australia. He worked on the Logan Enhancement Project as a senior design engineer on the bridge widening package that included six widened bridges.

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Palisa is a Senior Bridge Engineer working within the Bridges and Materials Technology Team of GHD. Palisa has more than five years of experience in structural engineering with a focus on bridge design. Palisa was involved in the detailed design of the Logan Enhancement Project and was later deployed to site to provide construction phase design services, which included design support for the six widened bridges.