Achieving Simplicity for Continuous Teeroff Bridges

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ABSTRACT

Bridges comprising continuous precast Teeroff beams offer several advantages and have been used increasingly on projects in Western Australia (WA). Typical methods of achieving continuity rely on specialised construction techniques (such as post tensioning) or extensive formwork for the construction of in-situ diaphragms. To maximise the combined benefits of a continuous design and precast Teeroff beams, the design of the stitch detail needs to be as simple as possible.

On NorthLink Central Section, a new method of achieving continuity for the highly skewed multi-span bridges was developed. The design innovatively used the standard Teeroff geometry and a voided end block to construct a cast in-situ continuity stitch without any additional onsite formwork. The geometry of the stitch eliminates the need for couplers in the Teeroff beam or bars protruding through the stitch formwork.

This paper presents the detail used for NorthLink Central Section bridges, outlining its development during the tender phase and how the challenges that arose during detailed design were overcome.

1 INTRODUCTION

1.1 Background

Continuous bridges are inherently more efficient compared to simply supported bridges as they are more highly utilised along their length. This results in reduced material requirements, which designers can use to achieve longer spans or a thinner deck. Given these advantages, continuous bridges such as concrete boxes, voided slabs, and voided and solid tee bridges had become common practice in Australia for short and medium span “highway type” bridges at least until the 1980’s and 1990’s. These bridges were generally cast in-situ using large amounts of formwork and falsework.

Bridges over existing infrastructure, where the installation of falsework was not possible, were typically launched box girders or voided slab bridges, steel composite bridges, or pretensioned I-girder bridges. Launching is expensive for short bridge lengths due to the cost of the launching bed and equipment, and steel composite bridges and pretensioned I-girder bridges require additional formwork to cast the deck.

The increased urbanisation of our cities and the requirement to frequently construct bridges over existing roads and other infrastructure, together with the increasing cost of fabricated steel, onsite labour, and increased importance placed on construction safety, resulted in the development and popularity of the pretensioned precast concrete Teeroff type bridges. The key difference with these types of bridges was the elimination of deck formwork, resulting in reduced onsite works, reduced cost and increased safety.

While Teeroff bridges were becoming increasingly common on the East Coast of Australia at this time, Teeroff bridges were only introduced into Western Australia (WA) on the Northam Bypass Project in 2001. Since then, simply supported Teeroff beams have become the preferred superstructure form for almost all highway type bridges with spans between 20 m to 45 m for both brownfield and greenfield sites.

1.2 Continuous Teeroff Bridges in WA

For simplicity in design and ease of construction, Teeroff bridges are typically constructed as simply supported with a link slab providing a continuous concrete running surface without any intermediate deck joints. However, continuous Teeroffs have become increasingly common in WA in the last five years, primarily in response to project specific constraints such as limitations on pier width and structural depth, and heavily loaded edge beams on Single Point Urban Interchange (SPUI) bridges.

The various methods and projects where continuous Teeroff bridges were used are summarised below:

1. Construct full height and full width in-situ transverse diaphragms at piers and using couplers cast into the Teeroff beam to achieve continuity (Gateway WA).
2. Overhang the beams and cast an in-line formed stitch away from the pier which requires propping to one of the beams (Reid Highway Duplication Over Mitchell Freeway).
3. Overhang the beams and cast an in-line internal partial moment stitch away from the pier with a temporary halving joint to support the adjacent beam during construction (Mitchell Freeway Extension).
4. Construct an in-line grouted joint between adjacent beams which is subsequently post-tensioned (NorthLinkWA Northern Section Project and previously adopted in Melton Highway Bridge, Victoria).

1.3 NorthLinkWA Project

NorthLink WA is a $1.12B extension of Tonkin Highway connecting the Perth northern suburb of Morley to the suburb of Muchea located in the Shire of Chittering, approximately 40 km north of Perth. The overall project is divided into three sections, with a 16 km Central Section taking Tonkin Highway from Reid Highway in Malaga to Maralla Road, north of Ellenbrook. This Section included the Reid Highway/Tonkin Highway interchange, WA’s first full systems interchange of two major highways.

This paper relates to the bridges constructed as part of the NorthLink Central Section Project. The Central Section Project was a D&C Contract with BGC/Laing O’Rourke Joint Venture (GNC) as the main contractor, and AECOM/Arcadis Joint Venture (AAJV) as the principle designers.

The structures in the Project included 15 road bridges, 1 fauna land bridge, 3 footbridges, 6 underpasses, approximately 12 km of noise and screens walls, and numerous gantries and retaining walls.

Of the 15 road bridges, 5 of these were Teeroff bridges made continuous with a new and innovative type of inline stitch that does not require any additional formwork, couplers, post tensioning operations or other specialist construction techniques.

This paper presents the detail used for the stitch, summarising the key reasons why and how it was developed along with a summary of the detailed design and construction aspects.

2 TENDER DESIGN PHASE

1.4 Why Continuous?

Five of the Project bridges had relatively long spans (up to 42 m) on highly skewed (up to 50 degrees) and curved alignments. Highly skewed Teeroff bridges often utilise cast in-situ diaphragms over the piers to reduce the load effects on the link slab. In addition, highly skewed link slabs are more complicated to design and are often heavily reinforced.

The contractor asked what could be done to eliminate the typical requirement for pier diaphragms at value engineering sessions. This was to avoid the need for couplers cast into the ends of the Teeroff beams, which are expensive and difficult to install due to reinforcement congestion, and the requirement for onsite formwork and falsework. Whilst it may have been possible to design the deck and link slab without pier diaphragms, it was clear that making the beams continuous eliminated these issues entirely. The additional structural benefits to be gained by making the bridge continuous were considered secondary benefits at this stage.

1.5 Review Previous Methods

The method of achieving continuity had to be cheaper and simpler to construct than the pier diaphragms and links slabs in a highly skewed simply supported Teeroff bridge. The methods outlined in Section 1.2 did not meet this objective for the following reasons:

- Method 1 required extensive falsework and formwork to construct the transverse diaphragm.
- Method 2 required formwork to construct the inline stitch and falsework to support the beams away from the pier (albeit less than Method 1). It also would not have been possible for the span configuration and curved bridges on the Project.
- Method 3, as with Method 2, was offset and would therefore not have been possible with the span configuration and curved bridges. This method also required additional Teeroff strengthening to accommodate the hog moments at the pier in the temporary stage.

- Method 4 requires specialist post tensioning activities following erection of the beams.

1.6 Development

In review of these methods, a non-post tensioned inline stitch (i.e. no transverse diaphragm) located at the pier was needed to achieve the design objective. The technique adopted evolved from this realisation via several interrelated steps as follows:

1. It was thought that if the Teeroff end block was pushed forward and the standard voided section was continued to the end of the beam, the resultant void could be used to house an internal inline stitch without the need for any additional formwork. Ordinary reinforcement would be placed within the stitch concrete.
2. However, this significantly reduced the effective depth of the stitch reinforcement since the Teeroff bottom flange is typically 310 mm to 360 mm thick for beams of this length. So, the second step was to block out the concrete where the strands are located (for the length of the stitch) to increase the lever arm of the stitch reinforcement.
3. A thin bottom flange containing one row of strands was retained to avoid the need for any formwork at the beam soffit. Shear ligatures already provided adequately supported the weight of the stitch concrete above.
4. The thin bottom flange was stopped at the edge of the bearing top plate. This ensured the full depth of the section could be utilised and allowed the stitch concrete to be cast directly on top of the bearing, eliminated the need for tapered bearing plates and allowed for construction tolerances.
5. Tensioned strands were retained in a widened web to enable the beams to be supported close to or at the pier.
6. A short end block was located at the end of the stitch for the transfer of prestress, locating the lifting loop, and to act as internal formwork for the continuity stitch.
7. Temporary props at the pier support the beams during erection.

These details are diagrammatically shown in Figure 1 below:

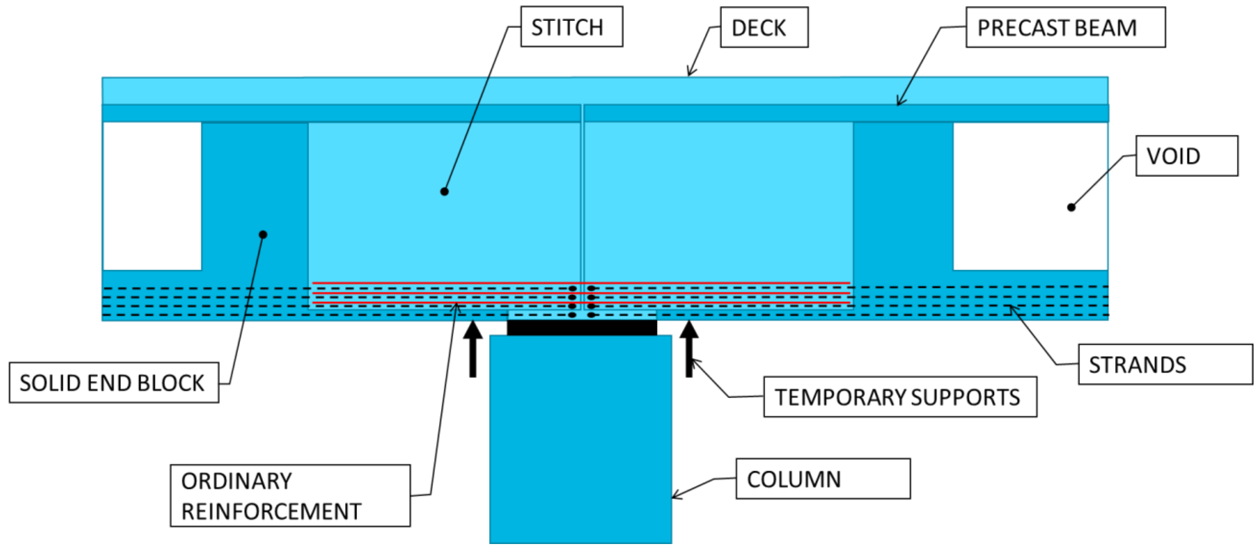

Figure 1

As shown in Figure 2, a soffit width of 1400 mm was adopted, which is common in WA, resulting in a 900 mm wide internal blockout at the base for the stitch and 250 mm widened web with fully tensioned strands. The maximum Teeroff beam depth was 2100 mm.

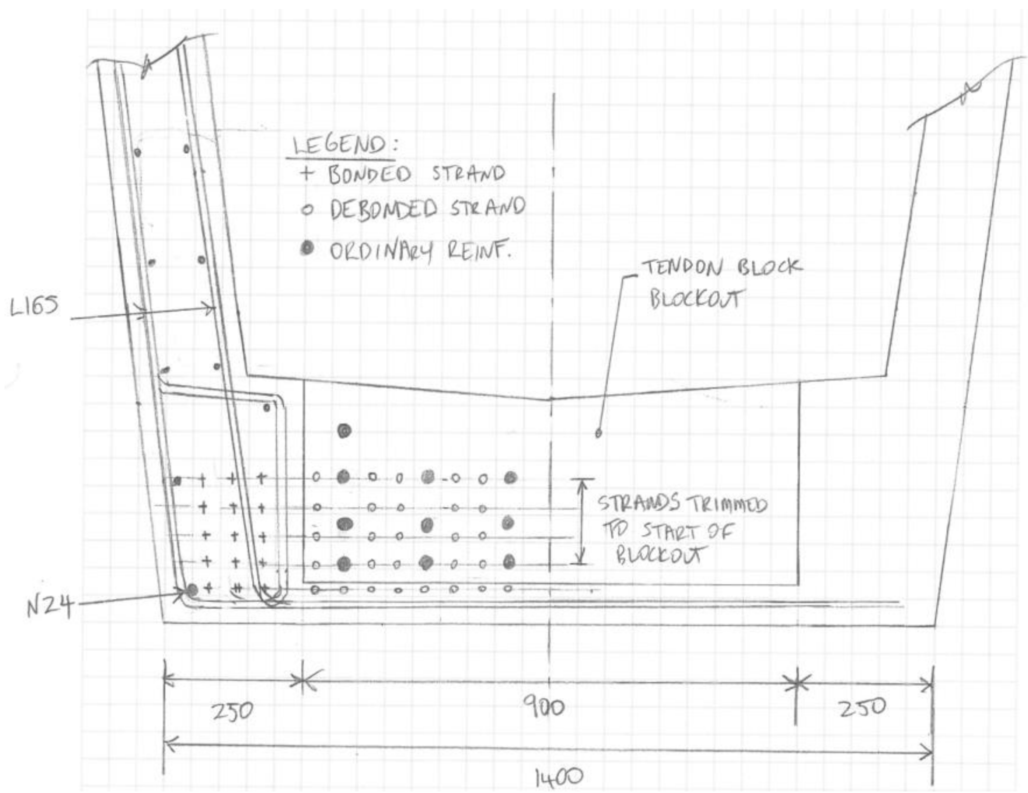

Figure 2

The deck was assumed to be cast in two stages as per Figure 3.

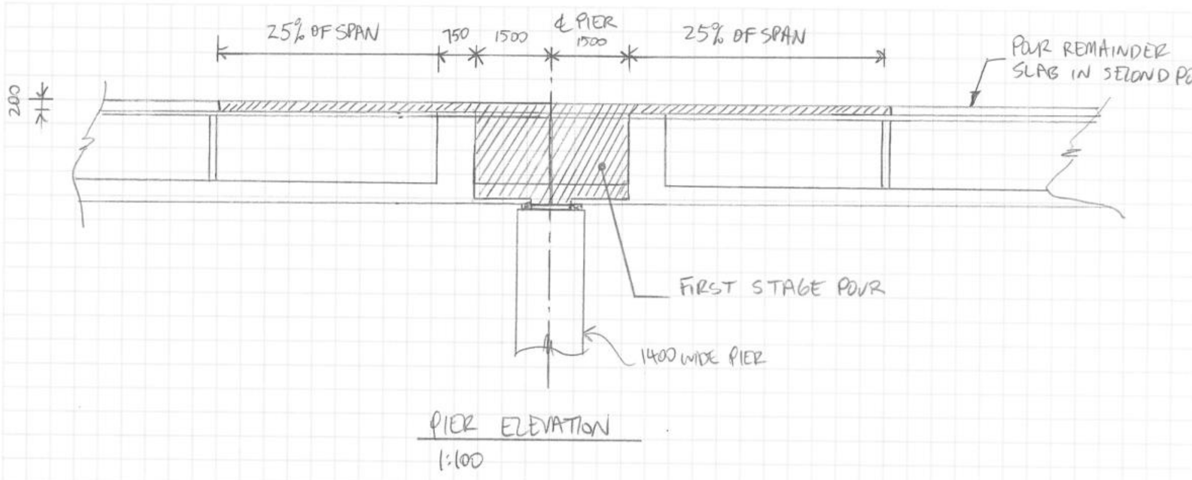

Figure 3

At the pier, the stitch is cast directly on top of the circular pier bearing with a square steel bearing plate located on top of the bearing (Figure 4).

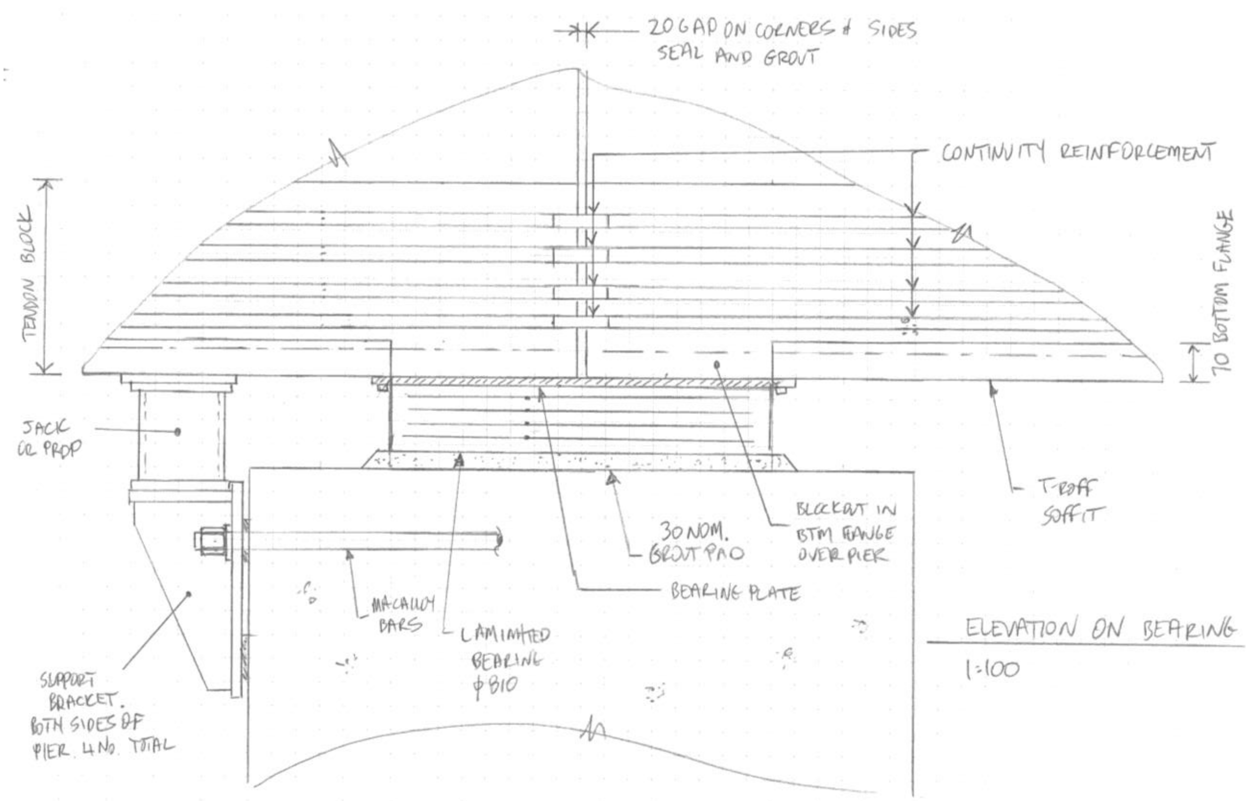

Figure 4

1.7 Benefits

Making the beams continuous resulted in the following improvements compared to the simply supported alternative:

- Eliminates the need for cast in-situ transverse diaphragms at the piers.
- Eliminates the need for link slabs.
- Reduced number of bearings at the piers.
- Reduced pier width.
- Reduced the structural depth which reduced fill quantities and retaining wall lengths.
- Reduced the quantity of prestress strands which reduced the minimum concrete strength at transfer, and eliminated the need for top prestress strands (all of which increased the beam production rate).
- Improved aesthetics from a shallower structural depth and reduced pier size.
- The benefits of this method of achieving continuity versus the other methods outlined above were as follows:
- No requirements for post tensioning, jacking equipment or other specialist operations on site.
- No requirement for any on site formwork.
- No grouting of the stitch joint required.
- No additional reinforcement in the Teeroff beams to accommodate the temporary construction condition.
- Eliminated tapered bearing plates and allowed for construction tolerances in beam rotations.

While the stitch had some significant benefits, a few risks or disadvantages were identified as follows:

- Potential disagreement on approach and methodology with the various internal and external reviewers during detailed design.
- Temporary supports were required until the deck and stitch are cast.
- Teeroff end form needed to be modified to create the stitch.

3 DETAILED DESIGN PHASE

1.8 In-house Design Guide

An in-house design guide was prepared during the initial design phase to achieve consistency across the five bridges (and four designers), and mitigate against the risk of potential disagreement on the design approach.

The design guide was submitted to Main Roads, the Internal Verifier, the Independent Certifier and the External Verifier. This was found to be beneficial as there were very few queries from the reviewers at the detailed review phase that related to the stitch or the continuous design.

1.9 Changes from Tender Design

The main change from the tender design phase was how shear would be transferred between the precast beam and the stitch. At the tender stage, it was envisaged that reinforcement would be cast at zero cover on the inside edge of the stitch and bent into position across the interface. However, it was discovered the number of bars and lap length required would have made this impractical.

A few alternatives were considered as follows:

1. Cast in steel plates with shear studs either side of the interface. This option had the added benefit of the plate acting as permanent formwork for the inside edge of the stitch void.
2. Bars projecting from web in various configurations. This would have made removal of the Teeroff edge form very difficult, which most probably would have needed to be sacrificial.
3. Cast in couplers. While this option would have reduced formwork costs, a significant number of couplers would be required.

These alternatives would have added costs which was not allowed for at the tender stage.

Developing Option 2 further, it was realised that the loss of sacrificial formwork could be eliminated if the bars projecting from the web were concentrated in one location and encapsulated in the precast concrete; in effect creating a shear corbel, eliminating the need to rely on interface shear.

As well as the shear corbel, the following refinements were also made at detailed design:

- ‘Onion’ type anchors were used to reduce the development length of the strands projecting into the void.
- The length of the end diaphragm was increased to 1500 mm to contain the lifting anchors and necessary reinforcement.
- The bottom flange thickness in the stitch section increased from 70 mm to 100 mm to provide cover to reinforcement.
- Removed second row of strands (from the bottom) to allow placement of ligatures with appropriate cover within the stitch.
- Single stage deck pour for the smaller bridges where the deck and stich concrete could be cast in a single pour.

In terms of construction details, proprietary off the shelf props braced to the columns and founded on the ground were preferred over custom designed temporary support brackets cantilevering from the top of the columns or increasing the size of the pier.

1.10 Three-Dimensional Model

To assist visualising the stitch, and to check reinforcement clashes and clearances, a three-dimensional CAD model (Figure 5) and three-dimensional print of a typical beam were created.

These tools assisted the designers, contractors and sub-contractors and were invaluable during the design and construction process.

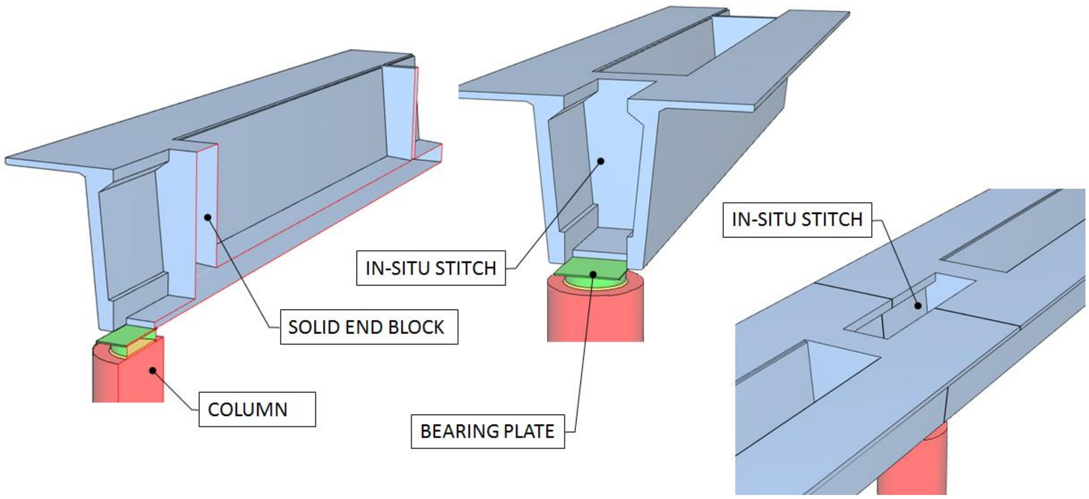

Figure 5

1.11 Design Philosophy

Flexural and torsional shear from the Teeroff beam is transferred to the support through the stitch which works as an ‘indirect support’. The stitch was designed using a strut and tie model in accordance with Section 7 AS5100 Part 5 2017. A simplified 2D strut and tie model representing the behaviour is presented in Figure 6.

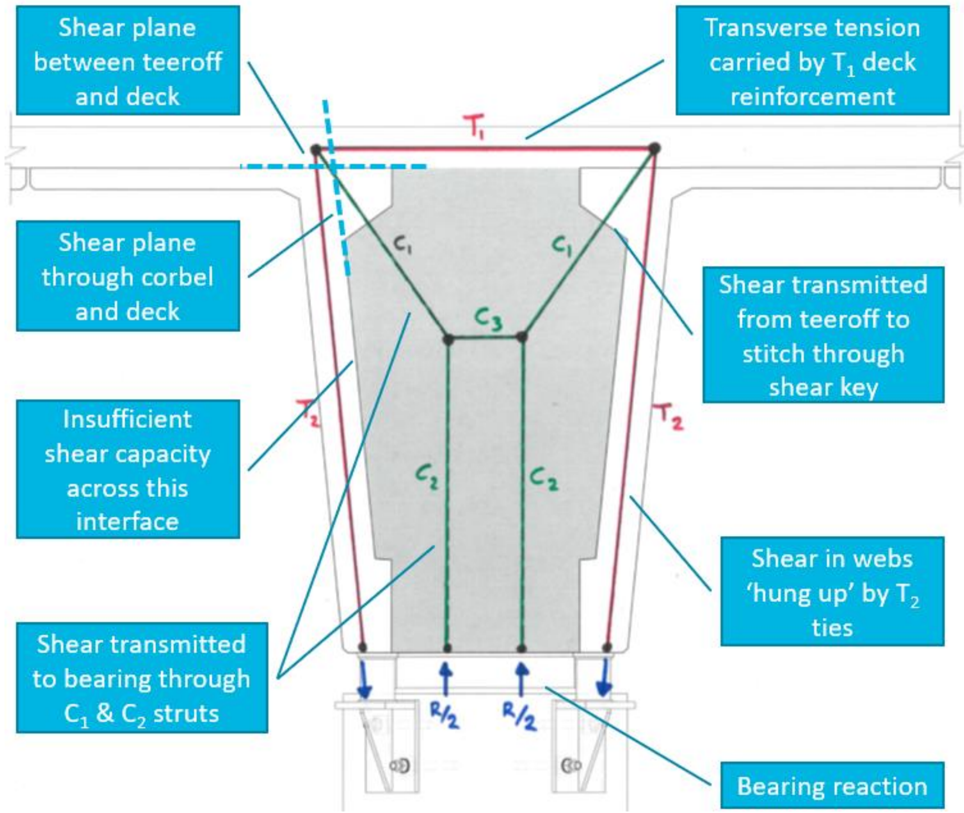

Figure 6

A shear key is cast monolithic with the Teeroff web to transfer the shear from the Teeroff into the stitch. The face of the shear key is aligned perpendicular to the compression strut to avoid transverse shear across the interface.

The stitch length was governed by the development length of the untensioned stands protruding from the Teeroff beams. 'Onion' anchors, formed by unravelling the ends of the strands, were used to reduce the strand development length and subsequently the stitch length.

'Onion' anchors contribute additional bond capacity through the increases surface area of the individual wires, and mechanical resistance from the bending and straightening of the individual wires. 'Onion' anchors were easily formed by the precaster and offered a cost-effective option over proprietary alternatives. The untensioned strands were fanned into an array to avoid clashes between adjacent strands and allow the placement of additional ordinary reinforcement (Figure 7).

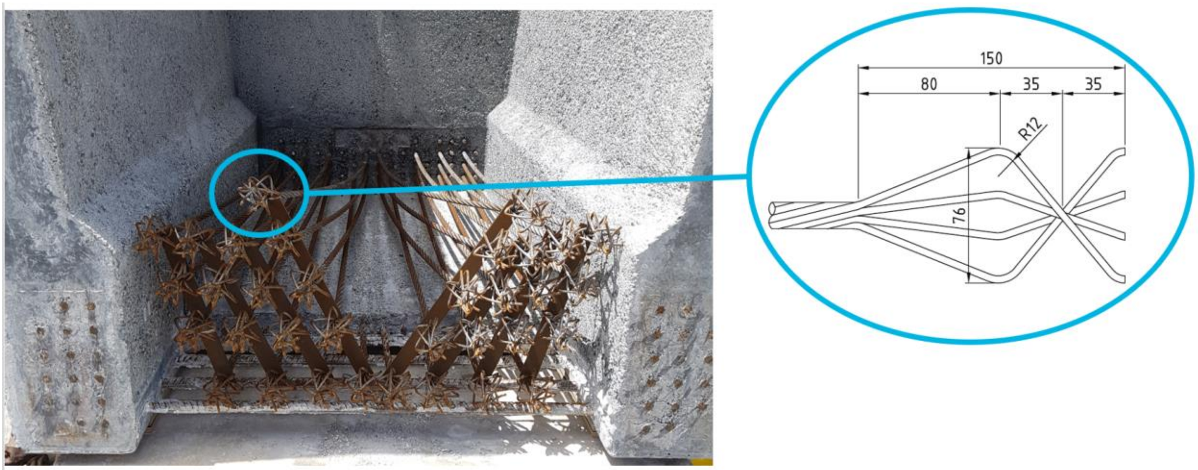

Figure 7

Compression continuity across the pier is via the stitch concrete as the gap between adjacent Teeroff beams is not grouted. This resulted in additional tension in the bottom of the precast web which was carried by fully tensioned strands and ordinary reinforcement located in the bottom of the precast web.

A key design consideration was the anchorage of positive moment reinforcement during construction and in-service once the stitch has been constructed and the temporary props removed. During construction, fully tensioned strands and ordinary steel reinforcement located in the bottom of the Teeroff web (Figure 8) provided the required anchorage.

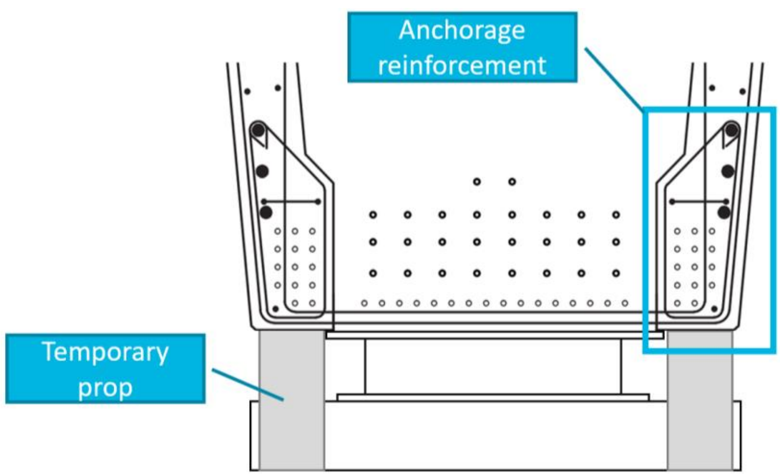

Figure 8

In service, bonded stands projecting from the precast end block are extended to the end of the stitch, and ordinary steel reinforcement is placed between the ends of the adjacent beams (Figure 9). Utilising prestressing strands, which are already required for sag moments, eliminates the need for couplers cast into the precast end block to provide tension continuity.

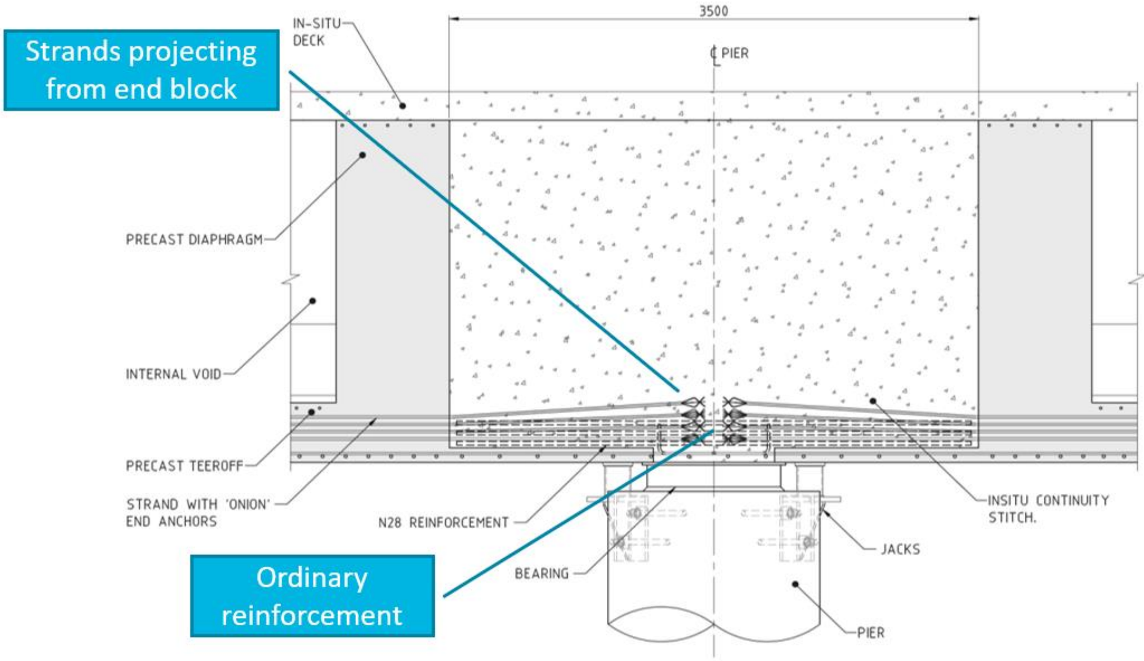

Figure 9

The geometry and detailing of the voided end block results in the stitch utilising the full structural depth of the beam. This reduces the quantity of reinforcement at the stitch location as there is no reduction in lever arm, with the stitch capacity matching the capacity of the Teeroff beam. This permits the stitch to be located at the point of maximum bending moment over the centreline of the pier.

The stitch geometry resulted in additional transverse tension in the deck slab which is co-existent with tension forces due to longitudinal shear (Figure 6). Additional transverse reinforcement was placed across the stitch, within the deck slab, to accommodate this force.

1.12 Durability Design

To minimise the risk of thermal cracking, primarily caused by the temperature differential through the stitch during curing, the top of the concrete above the stitch was insulated following the concrete pour. The insulation remained in place until the temperature difference between the stitch core and the average ambient temperature was less than 25°C.

The relative thickness of the stitch to deck concrete also presented a risk of plastic cracking that becomes apparent at early age. This was managed by saturating the Teeroff beams prior to pouring the stitch and recompacting the concrete if cracks were observed.

The design included a waterproof membrane above the stitch as some level of cracking, taking the form of early age plastic cracking and later age (up to a week) thermal/shrinkage cracking would be hard to prevent (Figure 10). However, no cracking was evident on the first two bridges and the waterproof membrane was deemed unnecessary for the remaining bridges on the Project.

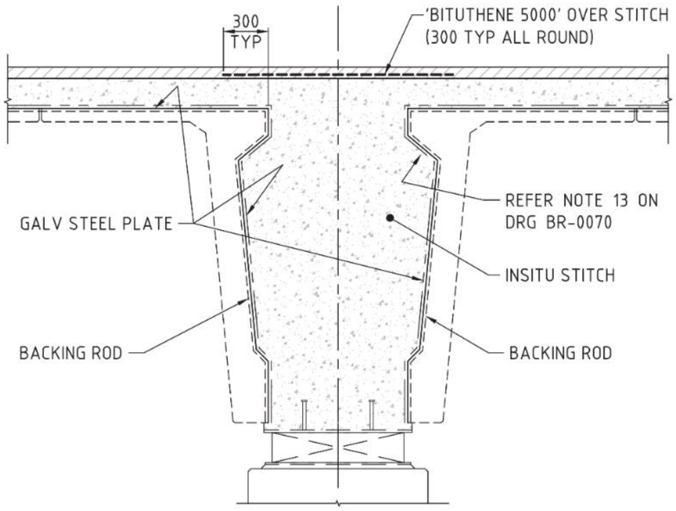

Figure 10

4 CONSTRUCTION

The Teeroff beams were supported on temporary props at the piers prior to being made continuous. The props were required due to the geometry of the stitch (block-out above permanent bearing) and the size of the pier columns (Figure 11).

Figure 11

The deck and stitch were typically cast in a single pour, and the temporary props released once the concrete had achieved the required strength. For the two largest bridges on the project, the deck and stitch were cast in multiple stages as the concrete volume exceeded what could be achieved in a single pour. Stage 1 included the stitch and 15% of the deck either side of the pier centreline. The temporary supports were then removed, and the remainder of the deck cast.

The two-stage deck pour resulted in a more efficient design by achieving continuity at an earlier construction stage, and by inducing a permanent hog above the pier which reduced the effects of residual creep and shrinkage (which resulted in a permanent sag above the pier).

The two-stage deck pour could also be used with span-by-span construction which was done on the largest 3 span structure (approximately 120 m long and 44 m wide). This sequencing compressed the construction program as the Teeroff beams were cast sequentially, and hence construction of the deck could commence once the beams in Span 1 and 2 were on site. In reference to Figure 12, Pour 1 and 2 could be completed once the Teeroff beams in Span 1 and 2 were erected.

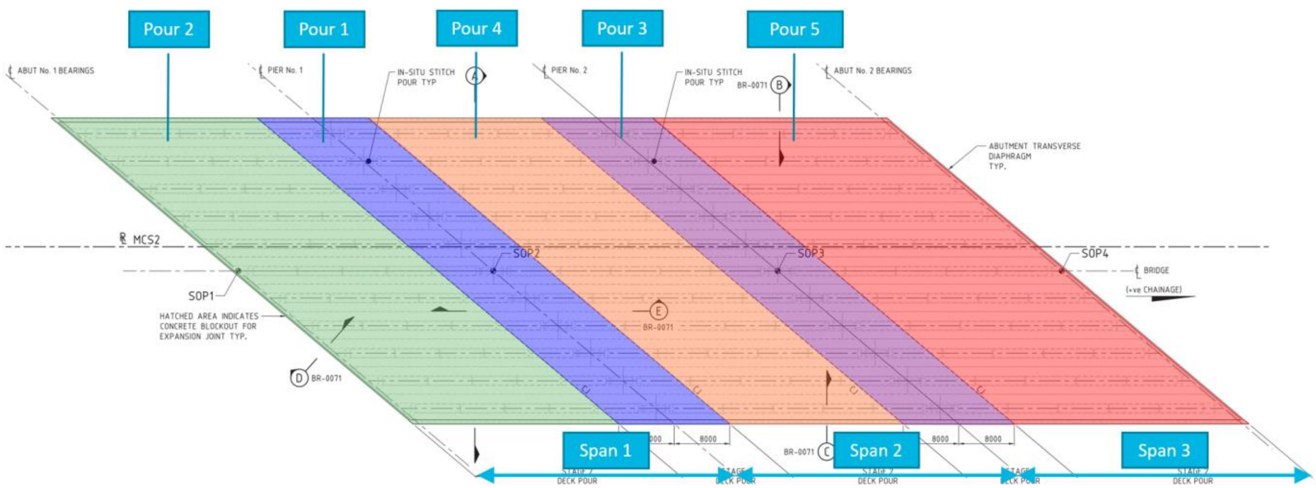

Figure 12

The temporary supports comprised proprietary props which were braced against the pier column (Figure 13). The props supported the temporary personnel access platform required for installation of the bearings and landing the Teeroff beams. The props also restrained the beams during the deck pour.

Figure 13

The gap between adjacent Teeroff beams was nominally set to 50 mm above the bearing. The large gap allowed for construction tolerances in the beam length and rotation due to beam hog (which closes the gap at the top of the beam). The gap was sealed with a backing rod and galvanised steel sheet prior to casing the stitch (Figure 14).

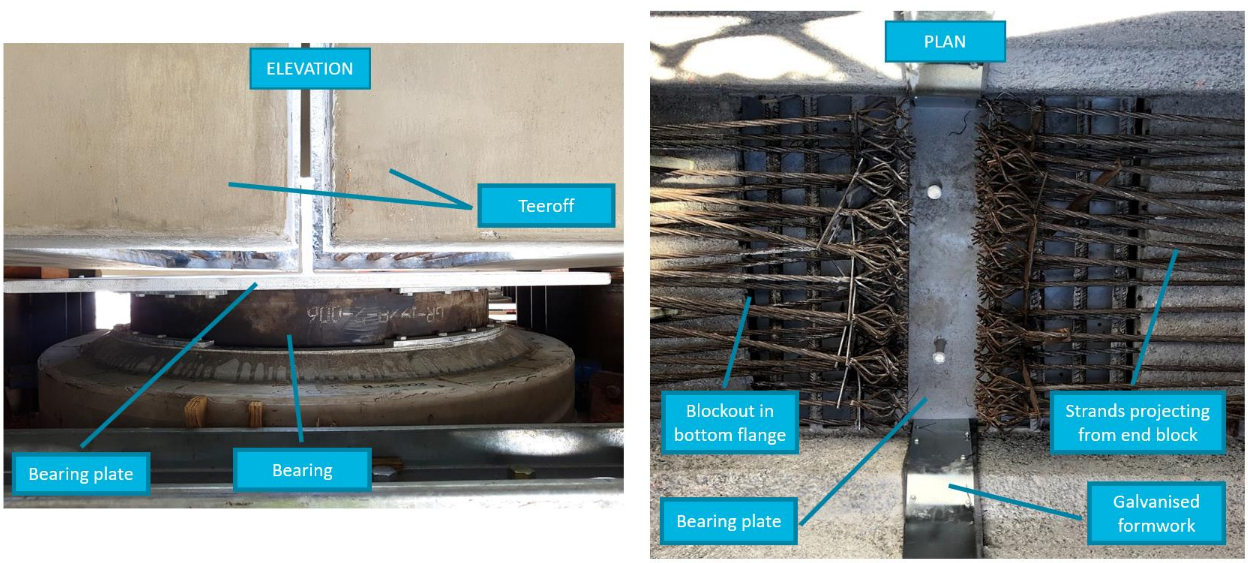

Figure 14

Figure 15

5 CONCLUSION

Continuous Teeroff bridges have been used with increasing frequency in Western Australia in recent years to solve specific project related issues, including restrictions on pier width and minimising structural depth. In the case of NorthLink Central Section, the primary aim was to eliminate the need for temporary formwork for transverse diaphragms at the piers of the highly skewed bridges.

Previous methods of achieving continuity were reviewed and were considered either not feasible or required complex formwork or specialist on site activities. This would have resulted in a design more complex than a conventional simply supported bridge, which would not have achieved the design objective.

The simple solution developed for this Project achieved the objective with few downsides allowing the benefits of Teeroff beams made continuous to be fully realised. The simplicity of this solution means that continuous Teeroffs can now be contemplated for any multi-span Teeroff bridge.

6 REFERENCES

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7 ACKNOWLEDGEMENTS

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Trinder (BG&E) as the durability consultant. GHD as independent verifiers and APP as independent certifiers.

8 BIOGRAPHIES

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