

A New Post-Tensioned Continuity Detail for Super Tees

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Abstract

Connecting prestressed precast concrete girders for continuity over a pier can reduce the structural depth required for superstructures of a given span. The resulting continuous superstructure can result in significant cost savings where long retained approaches are required, or where there is a constrained vertical envelope. In Australia, Super Tee girders are often made continuous with a cast in place stitch pour, with non-prestressed reinforcement projecting out of the girders and lapped to provide positive moment resistance.

This paper presents new a post-tensioned continuity detail that has been used on the Melton Highway Level Crossing Removal Project for a three-span continuous rail overbridge carrying Melton Highway over the Sunbury/Bendigo Line at Sydenham, Victoria. Using this detail resulted in an increased span for future track duplication, minimised the height of the retained earth approaches and reduced the stitch width to eliminate falsework, which would have impacted the rail corridor. Additionally, this paper identifies design and construction challenges for the detail and compares the new post-tensioned continuity detail with both post-tensioned and non-post-tensioned continuity details used elsewhere.

1. Continuous Connections

Making multi-span prestressed precast concrete girder bridges continuous has a number of advantages. An initial driver for this form of construction was to eliminate joints over the piers. Eliminating joints reduces bridge maintenance requirements. In Australia this has become less of an advantage, as in multi-span bridges, joints over the piers are commonly eliminated by using link slabs with sufficient flexibility to have the spans designed as simply supported.

A more relevant advantage of continuous connections is that they allow for a reduced structural depth. The depth can be reduced due to the more efficient bending moment distribution they allow for as well as reduced deflections compared to a simply supported span. A reduced structural depth can be worth the additional complexity associated with continuous spans where there are restricted structural envelopes and where the depth impacts other costs.

2. History

During the early 1960s, the Design and Research Section of the Portland Cement Association in Skokie, Illinois conducted extensive research into the design of continuous bridges with precast, prestressed concrete girders (Oesterle, Glikin, & Larson., 1989). They established that a multi-span bridge made up of precast, prestressed girders could be made continuous with a cast in situ stitch pour over the piers, with reinforcement projecting from the girders to provide continuity in the stitch pour. This means that the superstructure is simply supported for girder and deck dead loads and continuous for live loads and superimposed dead loads.

The degree of continuity is limited by cracking in the stitch pour. As the stitch pour restrains the ends of the girders from rotating due to long-term creep and shrinkage positive moments are induced over the pier. This restraint moment can crack the stitch pour, reducing the continuity of the connection. To ensure that the superstructure is continuous for live load, sufficient positive moment capacity needs to be provided over the pier to resist long-term restraint moments. Freyermuth presents design procedures for this type of bridge (Freyermuth, 1969).

Yin identifies the following types of continuity connections (Yin, 2004):

- Full-length post-tensioning;
- Partial post-tensioning; and
- Reinforced concrete connections.

Full-length post-tensioning uses girders with sufficient prestress for self-weight, then connects them with a profiled post-tensioning cable for the full length of the bridge. Abdel-Karim & Tadros (Abdel-Karim & Tadros, 1992) present an example of this type of bridge using a modified PCI Bulb-Tee, see Figure 1.

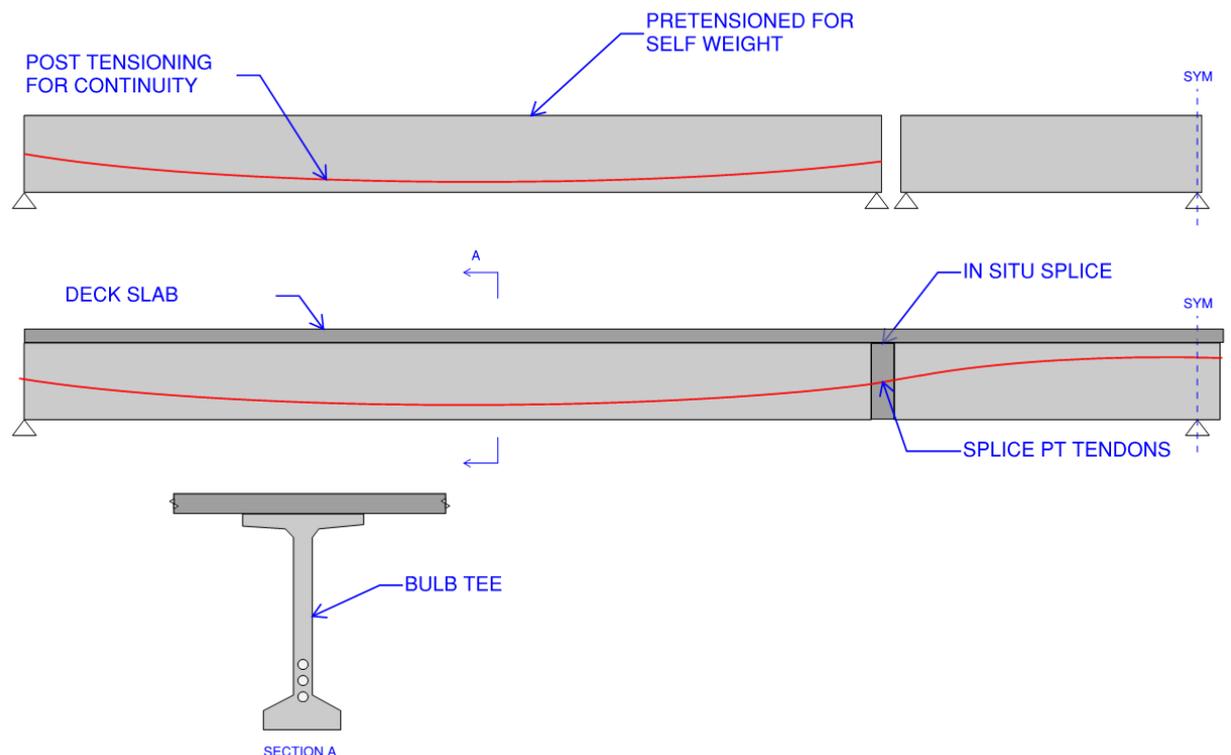


Figure 1: Full-Length Post-Tensioning - Spliced Bulb Tee Example (Abdel-Karim & Tadros, 1992)

Yin describes partial post-tensioning as only post-tensioning a portion of the span. Some examples of this type of splice detail are presented in Figure 2. Some other examples include:

- Coupling strands projecting from the top flange, jacking apart, and casting an in-situ stitch before releasing (Tadros, Ficenec, Einea, & Holdsworth, 1993); and

- Jacking one end of a girder, connecting the opposite end to its neighbour by welding together plates cast into the ends of the girders, lowering the raised end to induce a moment in the connected girders (Bishop, 1962)

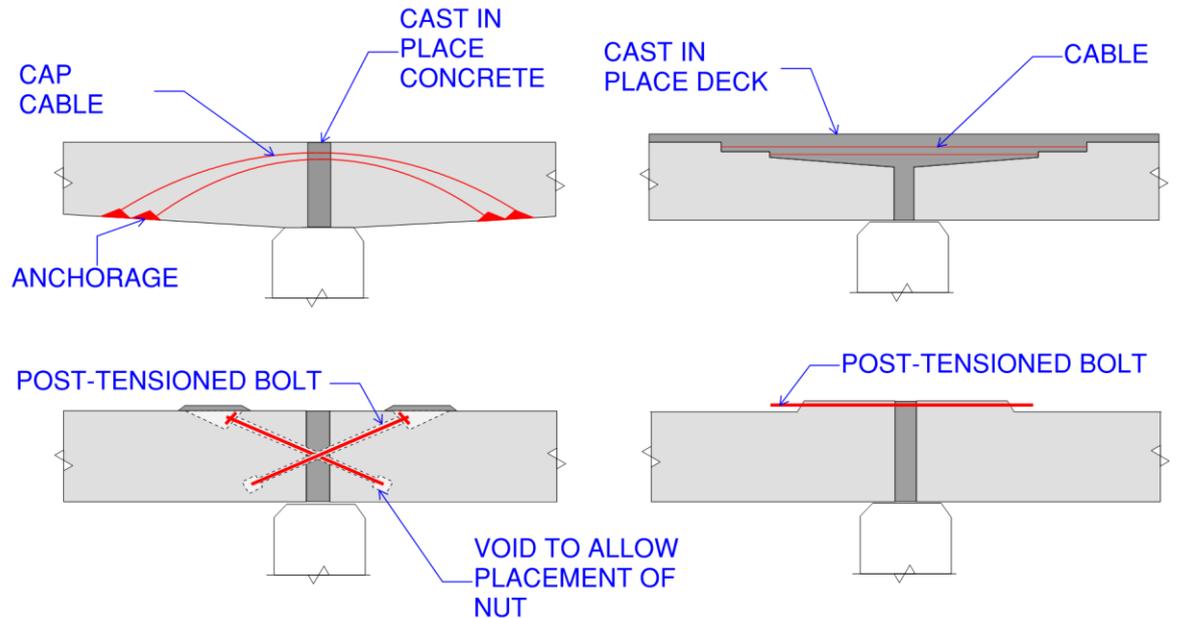


Figure 2: Partial Post-Tensioned Connection Examples (Figure 1.3 (Yin, 2004) - Redrawn)

Reinforced concrete connections are the most common in Australia. Freyermuth (Freyermuth, 1969) shows this type of connection with short clogged bars projecting from the bottom flange of girders to provide positive moment capacity. AS5100.5-2017 requires these bars to be fully anchored, increasing the required width of the stitch connection.

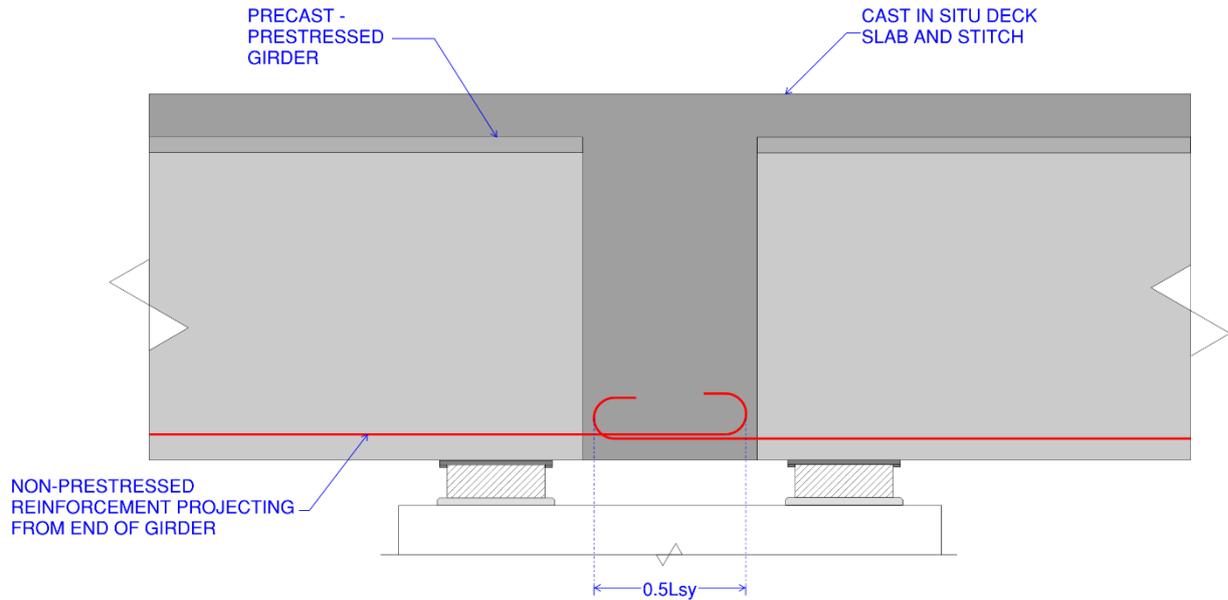


Figure 3: Cast In Situ Stitch

3. Melton Highway Bridge

3.1 Structure Description

Melton Highway Bridge, over the Sunbury/Bendigo Line, has geometric and engineering requirements that make it suitable for the post-tensioned continuity connection described in this paper. The bridge was part of the Level Crossing Removal Project, replacing existing rail level crossings with grade separated crossings. At this site, the shallow, high strength, basalt meant that tunnelling was not a cost-effective option. A road bridge over the rail, with mechanically stabilised earth approaches, was determined to be the best option. The 38° skew and allowance for four rail lines in the future configuration meant that a 38 m span over the rail lines was required. The western span was set at 34.595 m, to allow for viewing distances for the local road under. The eastern span was set at 37.375 m to avoid an existing bank of communications conduits and to increase the amenity of the pedestrian underpass.

The mechanically stabilised earth approaches meant that increases in structural depth would cause a significant increase in cost. The approaches have to get both higher and longer to accommodate the increased height. That would increase both material cost and the worksite area. By using continuous superstructure rather than simply supported it was possible to use 1500 mm deep Super Tees rather than 1800 mm deep.

The wide rail corridor set a minimum central span. Any falsework to support the girders temporarily would need to be outside of the rail corridor, increasing the span and girder depth. A wide stitch pour, which is required for lapping bars in a non-prestressed stitch pour, would also increase the span and depth.

Access to install the central span girders was limited to rail occupations only. The ability to land the girders on already placed temporary jacks helped maximise the number of girders that could be placed in a single occupation. Once the girders were placed, all work required to form the connection could take place outside of a rail occupation.

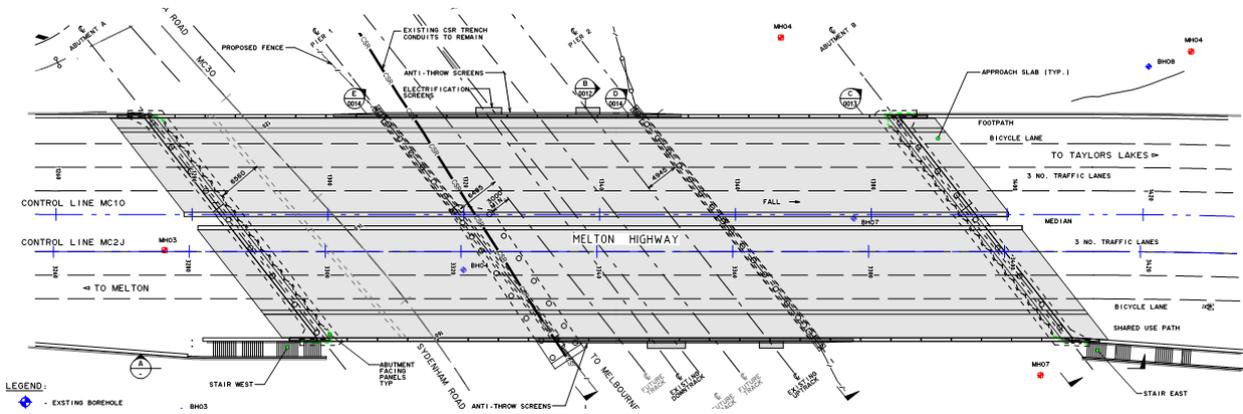


Figure 4: Melton Highway Bridge Plan

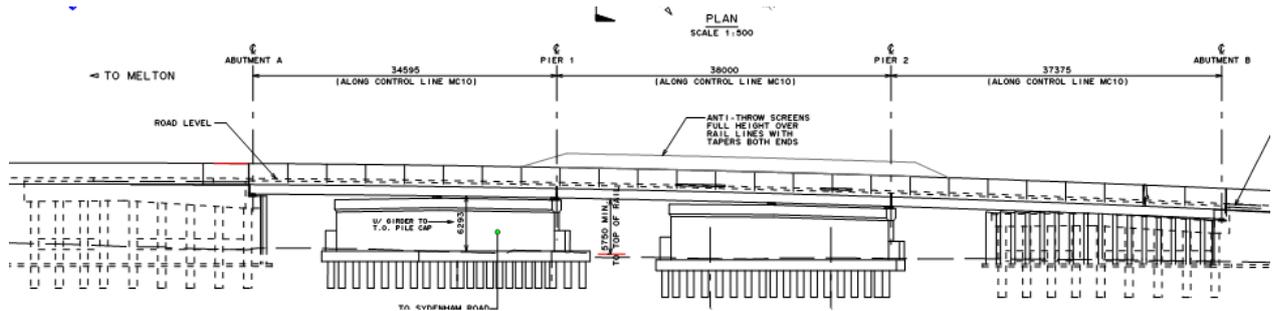


Figure 5: Melton Highway Bridge Elevation

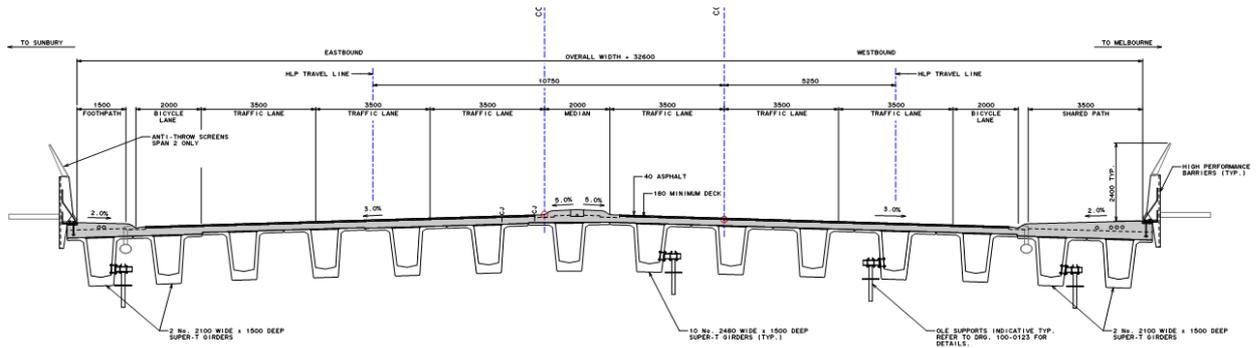


Figure 6: Melton Highway Bridge Deck Cross Section

3.2 Post-Tensioned Detail

The post-tensioned detail uses six stress bars to connect the ends of two Super Tees together. The stress bars bear against the girder end block, which has been detailed with recesses for the bearing plates as well as anti-bursting and –splitting reinforcement. The girders were detailed with a setback to provide a vertical end face after accounting for hog and grade. The gap between the vertical faces is 50 mm and is grouted with a flowable, shrinkage compensated, high early strength grout. The same grouting operation also fills the gap between the girder soffits and the bearing top plate as well as the cast in ducts. In the permanent condition, both girders sit on the same bearing after being temporarily supported prior to stressing. Secondary ducts are provided with the stress bars to leave them un-grouted prior to stressing.

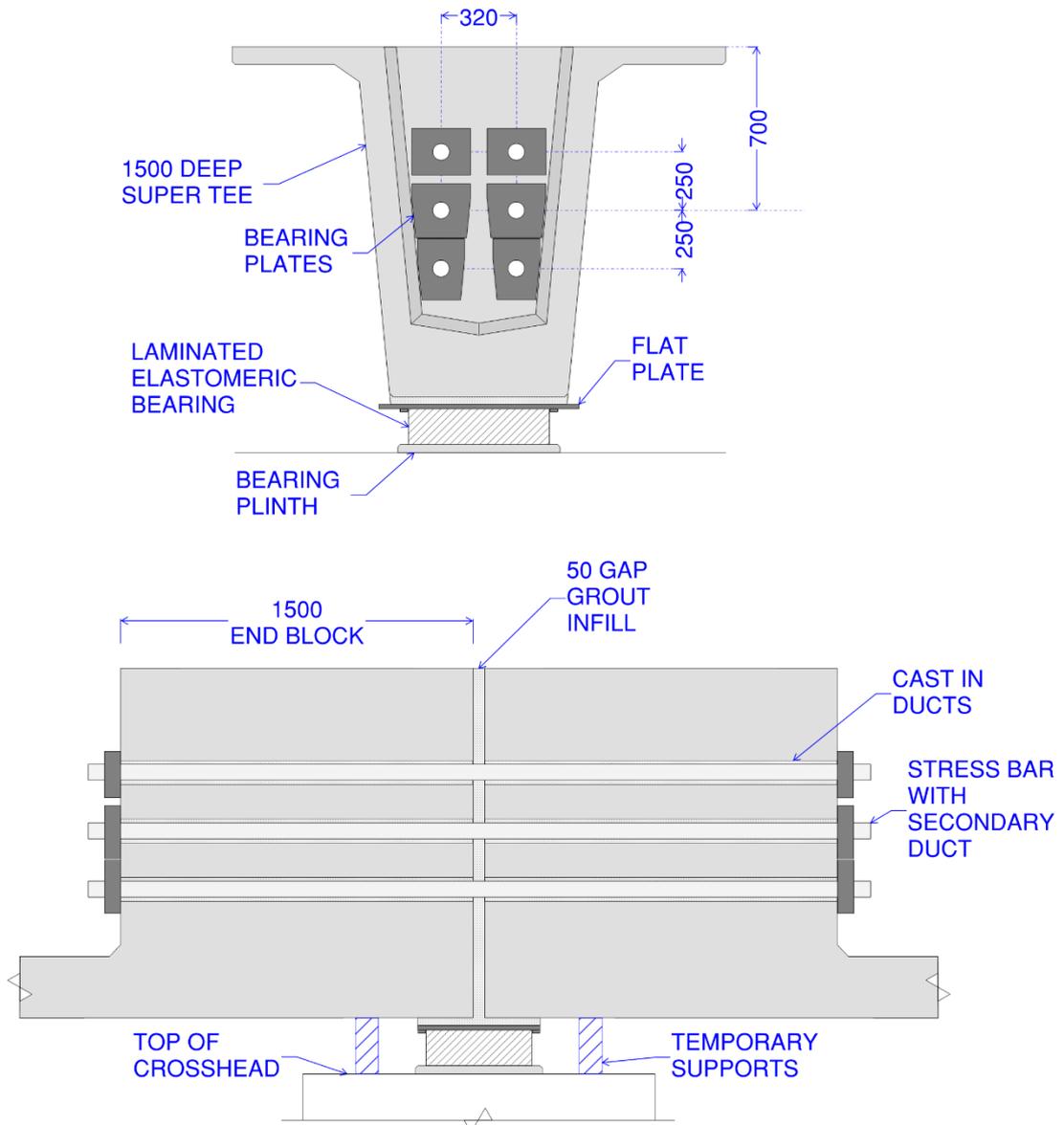


Figure 7: Post-Tensioned Detail

The connection is formed with the following construction sequence:

- Place bearing on grout pad;
- Fix keeper plates to top of pier crosshead;
- Place bearing flat plate on top of bearing;
- Install temporary supports on either side of bearing;
- Place girders on temporary supports and ensure gap width is correct;
- Install stress bars;
- Attach formwork to girders using provided ferrules; this also forms up the gap between the girder soffits and the bearing flat plate;
- Grout, filling gap between girder soffits and bearing flat plate, gap between girder end faces, and cast in bar ducts;
- After grout has reached required strength (around 24 hours) tension stress bars;
- Grout secondary stress bar ducts;
- Cover anchor heads in concrete for durability; and
- Remove temporary supports, transferring load to permanent bearing.

Figure 8 shows the steps from the installation of the stress bars to stressing.

Having the stress bars bear on the end block means that fully developed steel can cross the joint without having to lap as required for a conventional reinforced concrete stitch. This allows the gap between girder end faces to be as narrow as possible, minimising joint and crosshead width.

Supporting the girders on temporary bearings on the pier crosshead eliminates the need for falsework to support the girders prior to transfer to the permanent bearing. Bridge geometry determines the required width of crosshead to allow for the temporary supports. In this case, the high skew gave ample space with a relatively narrow crosshead.

The stress bars have to fulfil two roles structurally. As the deck is being cast the connection will experience negative moment, so the upper bars have to resist this action. In the long term creep, shrinkage, and temperature effects can cause a positive moment, which the lower stress bars need to resist. Additionally, this reverse in moment drives the post-tensioning design, with the need to maintain compression across the top of the joint while the slab is being placed as well as at the bottom of the joint in the long term for positive moments over the pier. For this reason, the stress bars are positioned centroidally, giving an even compression across the joint before the deck slab is poured.

In the final case, reinforcement in the deck slab provides capacity for negative moments from live load and superimposed dead load. The stress bars provide capacity for the positive restraint moments from creep, shrinkage, and temperature.

The arrangement of stress bars in this connection detail takes advantage of the Super Tee's geometry in comparison with AASHTO I-Girders. The trough girder shape, with an end block, gives a place for the PT bearing plates to bear. AASHTO I-Girder end blocks are much narrower than a Super Tee end block, giving a restricted bearing area for stress bars.

Due to the limited size and tapering shape of the end block, it was not possible to use square or rectangular PT bearing plates. To avoid a clash with the chamfer between the girder web and the end block the middle and lower rows of bearing plates were 6-sided, with the lower half tapered to match the taper of the girder web. The hole for the stress bar was located at the centroid of the plate to ensure even bearing stress.

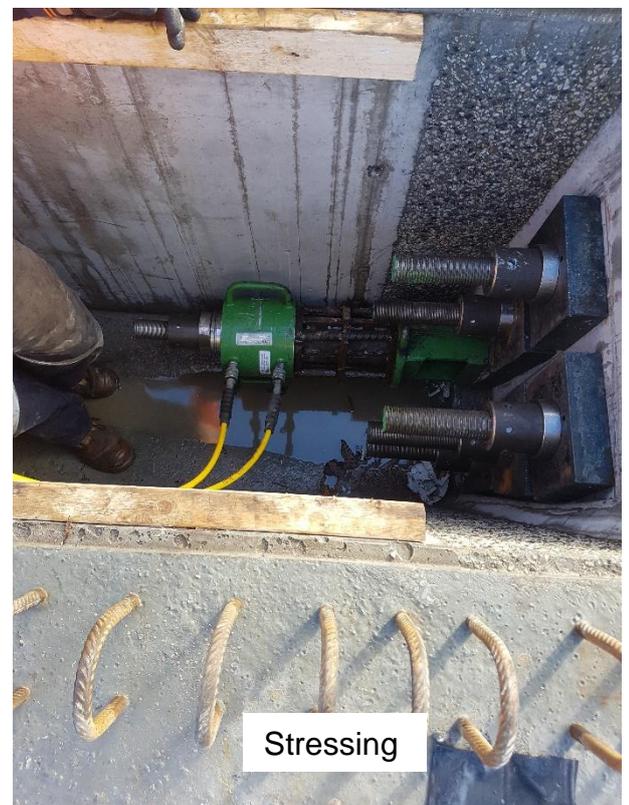


Figure 8: Stressing of joint

As the Melton Highway Bridge is on a vertical curve, the girders are on different grades at each span. That means that there is a discontinuity in the soffit slopes at the connection. This makes taper plates less attractive for attaching the girders to the bearings as they can't have a constant fall defined by the four corner heights. Filling the gap between a flat attachment plate and the girder soffits with the same grout used to fill the gap between girder end faces avoids this problem. Additionally, the grout can be high early strength, allowing the stressing to take place 24 hours after grouting.

In combination, these details provide the following advantages:

- No falsework required;
- Narrow stitch reduces the width of headstock required;
- Single bearing reduces the width of headstock required;
- High early strength grout means stressing can be completed quickly; and
- All stressing work can be done from the top of the girder, without a rail occupation.

3.3 Code Issues

This joint was designed to AS5100.5-2004. Appendix E of AS5100.5-2004 "Composite Concrete Members Design Procedures" includes the clause E3.3.2 with the condition:

"Where positive moments occur at the supports, fully anchored non-prestressed longitudinal reinforcement shall be cast into the ends of the precast beams to enable subsequent connection of the bottom flanges of adjoining beams at supports when erected."

We argued that the post-tensioned joint was outside of the scope of Appendix E due to the limited scope defined in E1:

"In this Appendix, a continuous composite member shall consist of a succession of simply supported prestressed concrete beams made continuous by the provision of non-prestressed reinforcement in the cast in place concrete over the intermediate supports."

Based on the above, we considered that the detail is compliant with AS5100.5-2004.

The recently released AS5100.5-2017 has integrated Appendix E into the main body of the standard. Clause E3.3.2 has been transferred to Clause 8.10.10.3.3.2 "Positive moment connection at supports":

In addition to those positive moments due to live load, support settlement and thermal effects, positive moments can develop due to the combined effects of differential creep and shrinkage. Where positive moments occur at supports, fully anchored non-prestressed longitudinal reinforcement shall be cast into the ends of the precast beams to permit the connection of the bottom flanges of adjoining beams at supports.

Without being able to say the connection is outside the scope of the clause it this detail has to be approved on a case by case basis by the relevant authority according to Clause 1.9 "Use of Alternative Materials or Methods":

“Where alternative materials, methods of design or construction are used, and provided that the requirements of Section 2 are met, the designer shall satisfy the relevant authority as to their use.”

The code committee should consider making clause 8.10.10.3.3.2 less prescriptive to allow alternate methods of achieving the required positive moment capacity at supports in continuous members.

3.4 Construction

For stability during construction, it was identified that the central span girders would require longitudinal articulation while supported on the temporary supports. The supports themselves would not allow any longitudinal movement, and when the central girders were supported on one at each end, it could lead to either high longitudinal forces in the girders or uncontrolled slipping of the girders. To avoid this, a construction sequence was developed using a sliding support to ensure that the girders always had one end that was free to move longitudinally, see Figure 9.

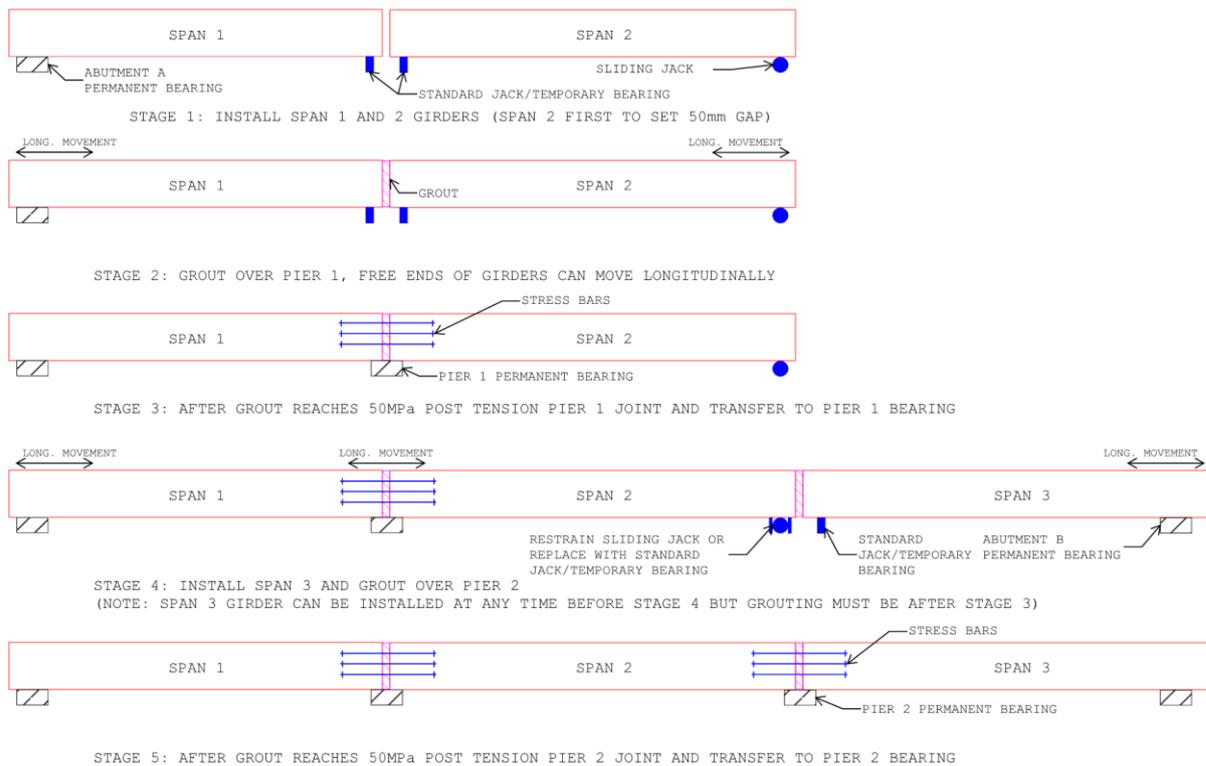


Figure 9: Construction Sequence for Girder Articulation

This construction sequence used the permanent bearings where possible to permit longitudinal movement. At Span 2, one sliding bearing was used to permit longitudinal movement during stages 1 and 2. This was done using a Teflon sliding plate incorporated into the temporary support.

4. Conclusion

This post-tensioned joint is a different type of continuity joint to the other examples presented in Section 2. It takes advantage of the Super Tee's geometry to achieve a narrow joint that can be constructed without falsework, maximises above-deck construction, and achieves full capacity quickly. In circumstances where structural depth is limited, where construction access below a span is limited or dangerous and where a narrow pier crosshead is advantageous this detail may provide an economical solution.

5. Recommendations

The AS5100.5 code committee should consider changing the wording of AS5100.5-2017 8.10.10.3.3.2 to be less prescriptive to allow alternate methods of achieving the required positive moment capacity at supports in continuous members.

6. Acknowledgements

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7. References

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