Design and Construction of Toorak Road Multi-span Rail Bridge

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ABSTRACT

The Toorak Road Level Crossing Removal Project (LXRP) removed and replaced the existing level crossing with two U-Trough elevated rail viaducts. The design drew on what had been developed for previous LXRP designs but introduced refinements and accommodated the project specific features.

The U-Trough solution provides many advantages over other systems such as Super-T and concrete box girder sections. This solution enables minimisation of the height difference from the soffit level to the top of track and hence provides a lower vertical grade separation height and minimises the required earthworks. In the event of derailment, the train will be contained within the structure, which provides a significant safety benefit.

The full viaduct structure was modelled in 3D Revit which facilitated interfacing with other disciplines and accommodation of services. Precast units for both the U-Trough and the crosshead were utilized to minimise construction activities during the limited rail occupation. The majority of the structures were constructed offline to minimise disruption to train services.

1 INTRODUCTION

1.1 Background

The project was undertaken by the South Eastern Program Alliance (SEPA) and included the design and construction of works for removal of the level crossing and rail system upgrades.

The Works included:

- Trackwork;
- Rail signaling;
- Overhead line electrification;
- Traction power systems;
- Structures;
- Civil works;
- Urban design and landscape architecture;
- Sustainability features; and
- Human factors integration.

The Toorak Road crossing is approximately 8.5km south-east of Melbourne, and immediately to the west of the Monash Freeway entry and exit ramps. Refer to **Figure 1** for the project location.

The level crossing was removed and replaced with a rail bridge comprising a 10-span U-Trough viaduct passing over Toorak Road. The rail bridge was constructed completely clear of the existing rail track to minimise disruption to the Glen Waverly line rail services.

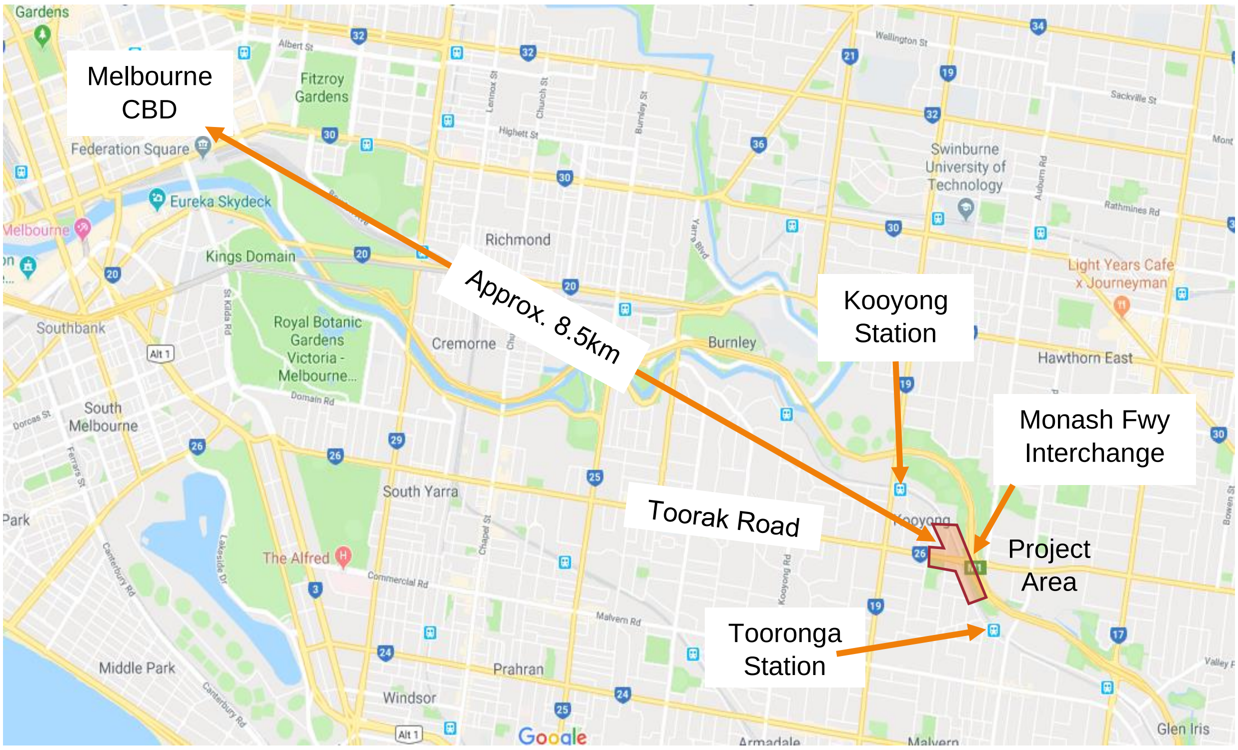


Figure 1: Toorak Road LXRP Location

The design elements of the project included:

- New rail bridge structure over Toorak Road;
- Modifications to Toorak Road including provision of new off-structure barriers;
- Reconfiguration of Talbot Crescent;
- Removal of existing level crossing equipment including boom barriers, flashing lights and pedestrian gates;
- An approach embankment at each end of the elevated structure
- Relocation of the existing Combined Services Route (CSR), signaling and track circuits;
- Relocation and enhancement of bicycle and pedestrian routes; and
- Urban design and landscaping elements.

1.2 Structural Elements

The following lists the structural elements associated with the new crossing:

- U-Trough prestressed girders;
- Elastomeric bearings;
- Lateral restraints;
- Precast concrete crossheads;
- Abutments;
- Abutment piles Φ1050 mm;
- Columns Φ1700 mm;
- Pier monopiles Φ2100 mm;
- Deflection walls;
- Precast concrete retaining walls along the sides of the approach embankments
- Precast fascia panels;
- Maintenance and detraining stairs
- Balustrades- for detraining and maintenance access.

The new twin rail viaducts comprise separate up and down track structures to replace the existing level crossing at Toorak Road, Kooyong on the Glen Waverly Line. Each viaduct is approximately 270m long and comprises 8 No 27m approach spans, a 23.85m make-up span and a 31m main span over Toorak Road. The 31m main span crossed Toorak Road with the adjacent piers staggered to provide sufficient lateral clearance to the road which passes under the bridge on a skew. The minimum vertical clearance over the roadways is 5.4m.

The 23.85m and 27m spans were made up from two pre-tensioned precast L-shaped beams longitudinally stitched together following erection with a steel fibre reinforced concrete stitch, as well as additional longitudinal bars to limit crack widths under the design load to an appropriate value.

The 31m span U-Trough is similar to those used on other projects. It comprises two pre-tensioned precast L- shaped beams joined by a longitudinal reinforced concrete stitch cast after erection of the L-beams. The complete U-Trough profile span was then post tensioned on site, soon after the stitch was cast.

The stitch width is typically 850mm but is up to 968mm to make the U-Trough wider and provide the required lateral clearance to rail traffic. Lateral clearance complies with the standard rail kinematic envelope and takes account of cant and curve effects and construction tolerances. A 150mm diameter conduit is cast into the top flange of girder for services.

The U-Troughs are simply supported on laminated elastomeric bearings. Lateral and longitudinal restraint of the superstructure is provided by interaction between reinforced concrete upstands cast into the top of the pier crosshead, and a reinforced concrete down stand projecting below the U-Trough stitch at both ends of each span. There is a 20 mm gap between the down stand of the U-Trough and the restraint blocks. As a result, a small component of the lateral forces from the superstructure is taken by shearing of the support bearings, but the majority of the design lateral force transmitted from the superstructure to the piers is transferred through the restraint blocks. Steel cover plates are provided over the transverse joints between adjacent spans.

For deck drainage, a crossfall is provided on the top face of bottom flange of U-Trough so that stormwater flows to the two sides then longitudinally to the piers where water is collected in a transverse grated trench and transferred to a vertical pipe cast into the pier crosshead.

The superstructure is supported at each pier on a precast concrete crosshead on a 1700 mm diameter, cast in-situ, reinforced concrete column founded on a single 2100 mm diameter, cast in-situ, reinforcement concrete monopile. Each abutment comprises 8 no reinforced concrete cast in-situ bored piles, a cast in-situ reinforced concrete pile cap, abutment upstand and approach slab. Each abutment also includes substantial deflection walls to mitigate the risk of collision against the end of the U-Trough.

Figure 2 shows the cross-section of the twin rail bridges.

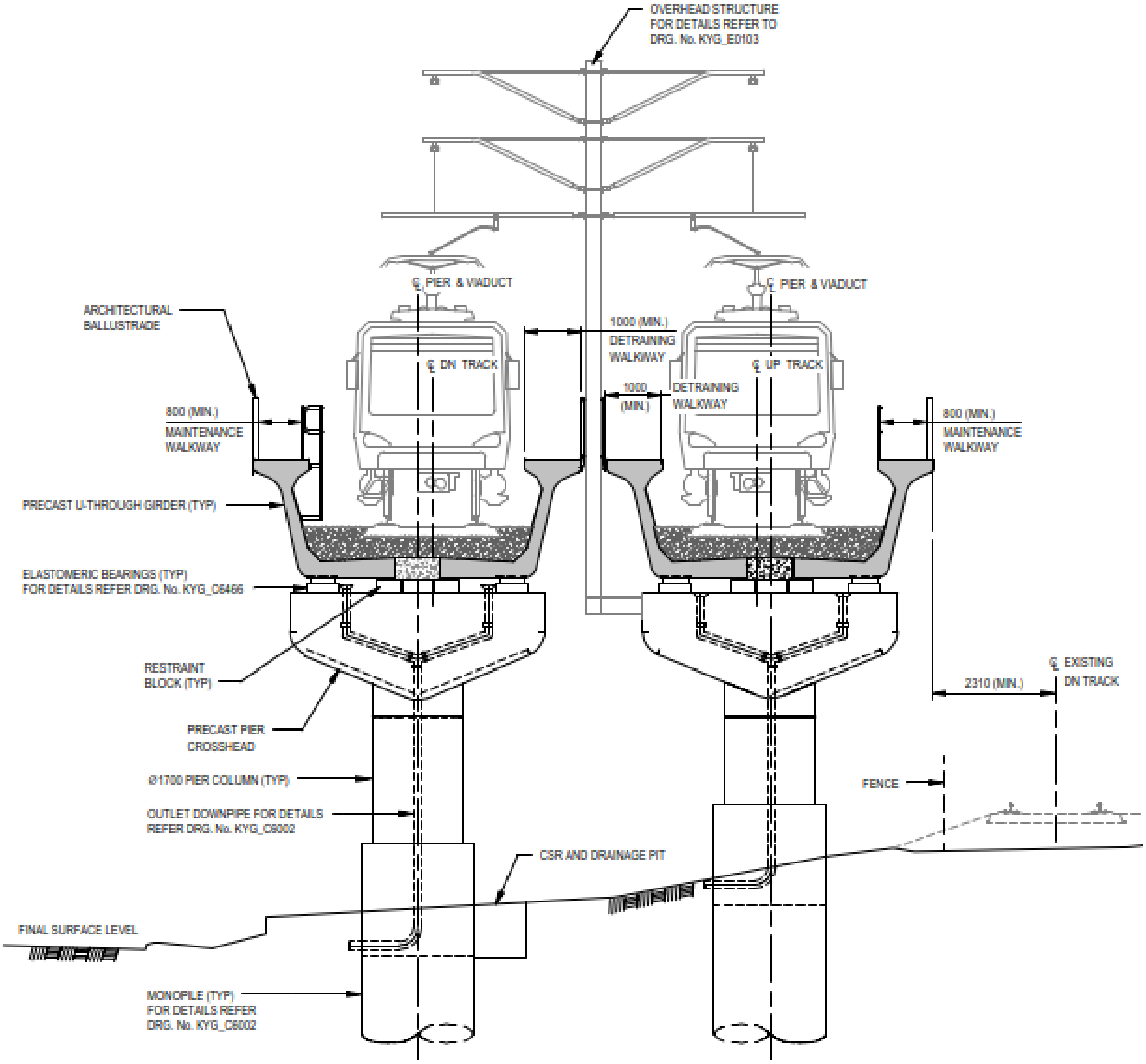


Figure 2: Typical completed Toorak Road Bridge cross section

1.3 U-Trough Solution

Prior to the Toorak Road project, the Level Crossing Removal Authority (LXRA), now called the Level Crossing Removal Project (LXRP), had set-up a U-Trough Joint Design Group (JDG) to develop a standardized design for the U-Trough and associated substructure elements.

The primary objective with the development of the standard U-Trough was to accommodate the online construction requirements of the overall LXRP program of works throughout metropolitan Melbourne for which speed of construction along existing rail corridors is critical.

The alliances teams participating in the LXRP works had decided to adopt a U-Trough solution as opposed to previously developed and tested local market solutions such as Super T beams and box section. This decision was been based upon the fact that the U-Trough solution had gained acceptance from stakeholders and was regarded as satisfying the design, construction, operational and maintenance objectives of rail infrastructure.

Figure 3 shows the differences between Super Tee, Box Section and U-Trough (extract from the JDG Report)

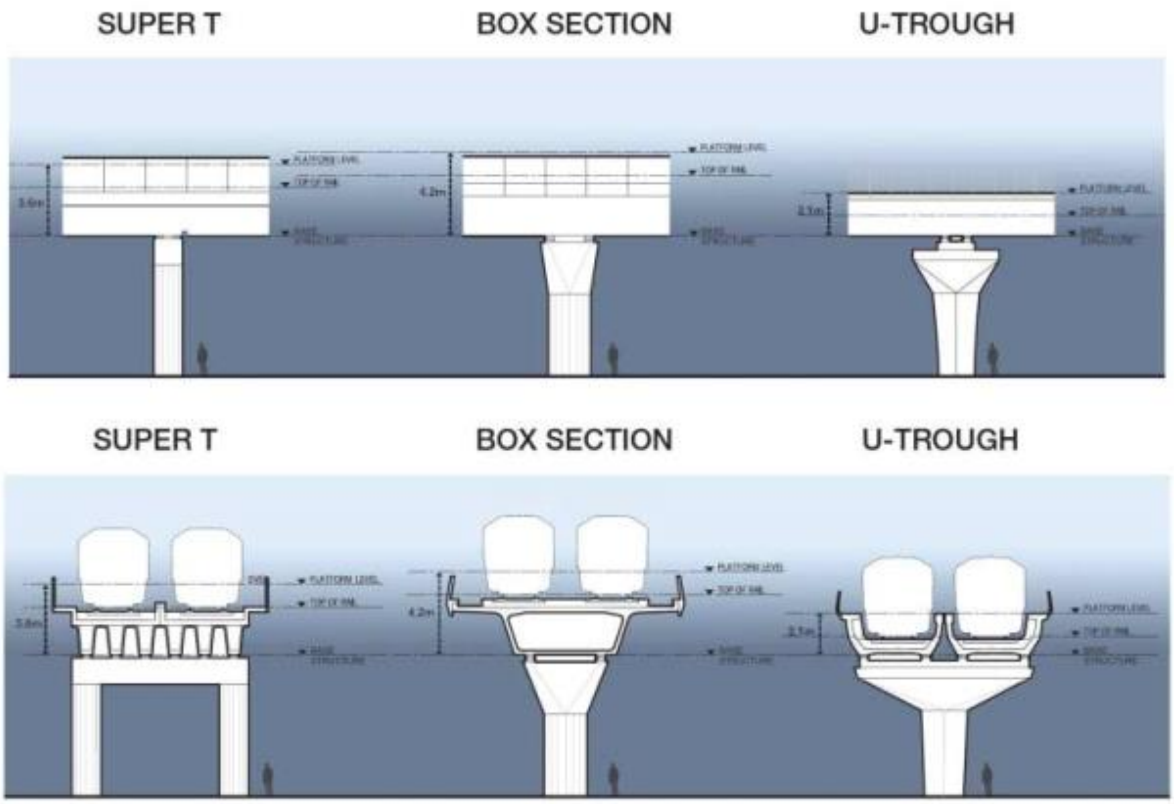


Figure 3 Different structural forms (extract from the JDG Report)

The U-Trough offers the opportunity to reduce the required structural depth from the soffit level to the top of track with the train travelling within the structural depth. This provides significant saving in the required earthworks quantities. In the event of a derailment, the train will be contained within the structure; hence it provides a significant safety benefit as well.

In addition, with the track contained within the U-Trough, the visual impact and apparent structural mass is reduced, thereby providing a better urban design outcome and reduced overshadowing. Having the track form contained within the U-Trough also helps to mitigate transmission of train noise to the surrounding areas.

The weight of the U-Trough is lower than an equivalent Super Tee structure arrangement and the level at which horizontal loads, particularly earthquake loads, are applied is lower thereby providing economies for the substructure design.

The essential strategy with the U-Trough was to design and cast two L-shaped sections in the precast yard, transport them to site, erect them and then join them together with a central in-situ stitch to provide an integral structure. The L-shaped sections are designed to optimise size and weight having regard for handling, transport and erection at site and at the casting yard.

1.4 Design Approach

1.4.1 23.85m and 27m Spans U-Troughs

The design of U-Trough girder for the 23.85m and 27m span differs from that of the JDG U-Troughs. Instead, SEPA adopted a design similar to that developed by the North Western Program Alliance (NWPA) for the High Street Reservoir level crossing removal. The L-Beams are pre-tensioned in the casting yard. The release of tendons causes hog and bow in the girder which has been allowed for in the structural design.

The stitch acting compositely with the U-Trough girders also differs from the JDG's design in that the completed U-Trough is not post tensioned but employs steel fibre reinforced concrete (SFRC) for the stitch.

The use of SFRC provides an acceptable level of control over cracking in the stitch and elimination of the post-tensioning following erection provided substantial cost and time savings.

The stitch in the U-Trough includes a combination of steel fibres and longitudinal bar reinforcement for control of the width of cracks due to tensile strains resulting from restraint applied by the adjacent precast concrete and the short term and long term applied loads. The stitch design satisfies the following performance requirements.

Requirements	Permanent Effect (PE)	PE + 245LA
Crack Width Limit	0.20 mm	0.30 mm
Differential Creep and Shrinkage Tensile Strain, ε	0.00012	0.00012
Tensile Strain due to applied loading ε	0.00010	0.00023

Note:
1. Basic Shrinkage Strain for L-girder is assumed to be 0.0006
2. Basic Shrinkage Strain for stitch is assumed to be 0.0005
3. Actual shrinkage strains can vary by +/- 30% in accordance with the AS5100.5
4. Stitch width of 850mm min to 1000mm max

- Steel fibre is DRAMIX 4D 65/60 BG;
- Steel fibre dosage rate is 35 kg/m^3;
- Longitudinal reinforcement is N20-100; and
- Stitch must be cast within 200 days of casting L-beam

Figure 4 shows the typical precast L-shaped girder concrete and strand details whereas **Figure 5** shows the typical in-situ stitch details.

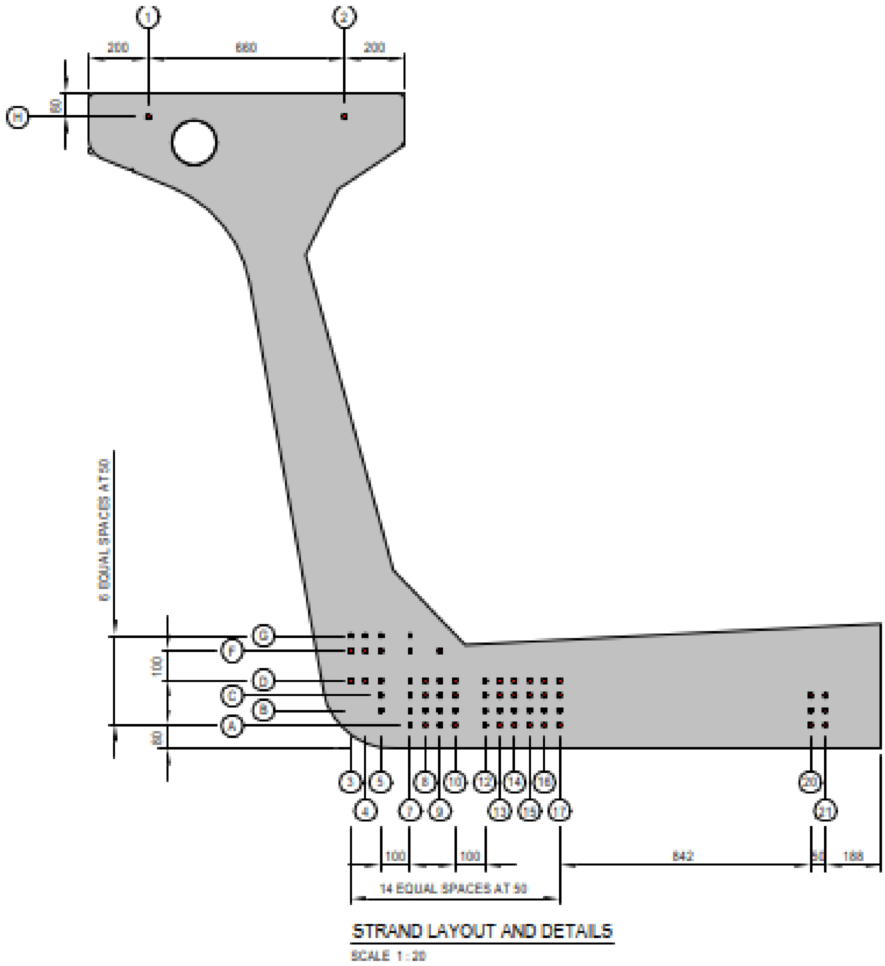


Figure 4: Typical precast L-shaped girder

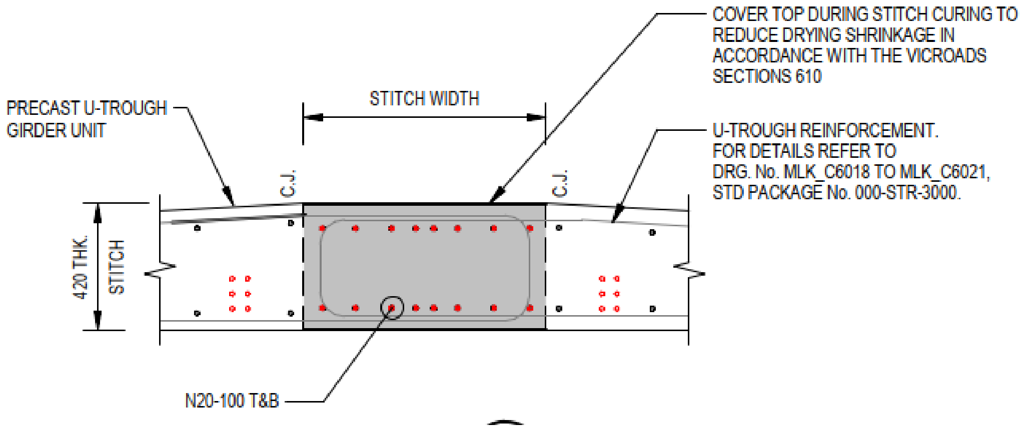


Figure 5: In-situ stitch details

1.4.2 31m Span U-Trough

A single span of 31m is provided to bridge Toorak Road, similar to the Seaford Road Bridge LXRP design. Two pre-tensioned, precast halves of the U-Trough are made composite by casting a longitudinal, in-situ concrete ‘stitch’, joining them together. To satisfactory control cracking in the stitch at the serviceability limit state for this longer span, the bottom flange of the U-Trough is post-tensioned soon after the stitch has been cast.

1.4.3 Precast Crosshead

The superstructure is supported at each pier by a precast, reinforced concrete crosshead. The concept and detailing of the crossheads are similar to those developed by NWPA for the High Street Reservoir level crossing. Corrugated, steel ducts are cast vertically in an arrangement that matches the layout of the reinforcement projecting from the top of the cast in-situ concrete column. The crosshead is lifted into the place, with the ducts sliding over the projecting reinforcement. The annulus between the reinforcing bar and the inside of the duct is then grouted.

The crossheads have been designed using the Strut-and-Tie model. Horizontal reinforcing bars are required to control cracking in the crosshead due to bursting forces in the concrete ‘struts’ under the serviceability limit state in accordance with AS5100-2017.

Lateral restraint to the superstructure, in both transverse and longitudinal directions, is provided by a reinforced concrete down stand, cast as part of the in-situ stitch between each L-shaped girder of the U-Trough. The down stand projects between and engages reinforced concrete upstands, cast on the top of the crosshead. There are elastomeric pads between the down stand and the upstand.

1.4.4 Pier

Pier Columns are cast in-situ reinforced concrete. Piers assessed as at risk of impact from errant road traffic on Talbot Crescent or Toorak Road are designed for the Road Collision design action specified in AS5100.2-2017.

There is a period, following construction of the first viaduct, during which trains are still running on the adjacent track. Because of their proximity to the live track, the piers supporting this viaduct are designed for a rail collision load.

1.4.5 Piles

Golder provided the geotechnical advice for the project. Based on site specific characteristics, particularly the geology and the proximity of the existing operating tracks, bored pile foundations were seen as the best option. Single large diameter bored monopiles were adopted for the piers and bored pile groups for the abutments.

Figure 6 shows the precast crosshead with in-situ pier and monopile.

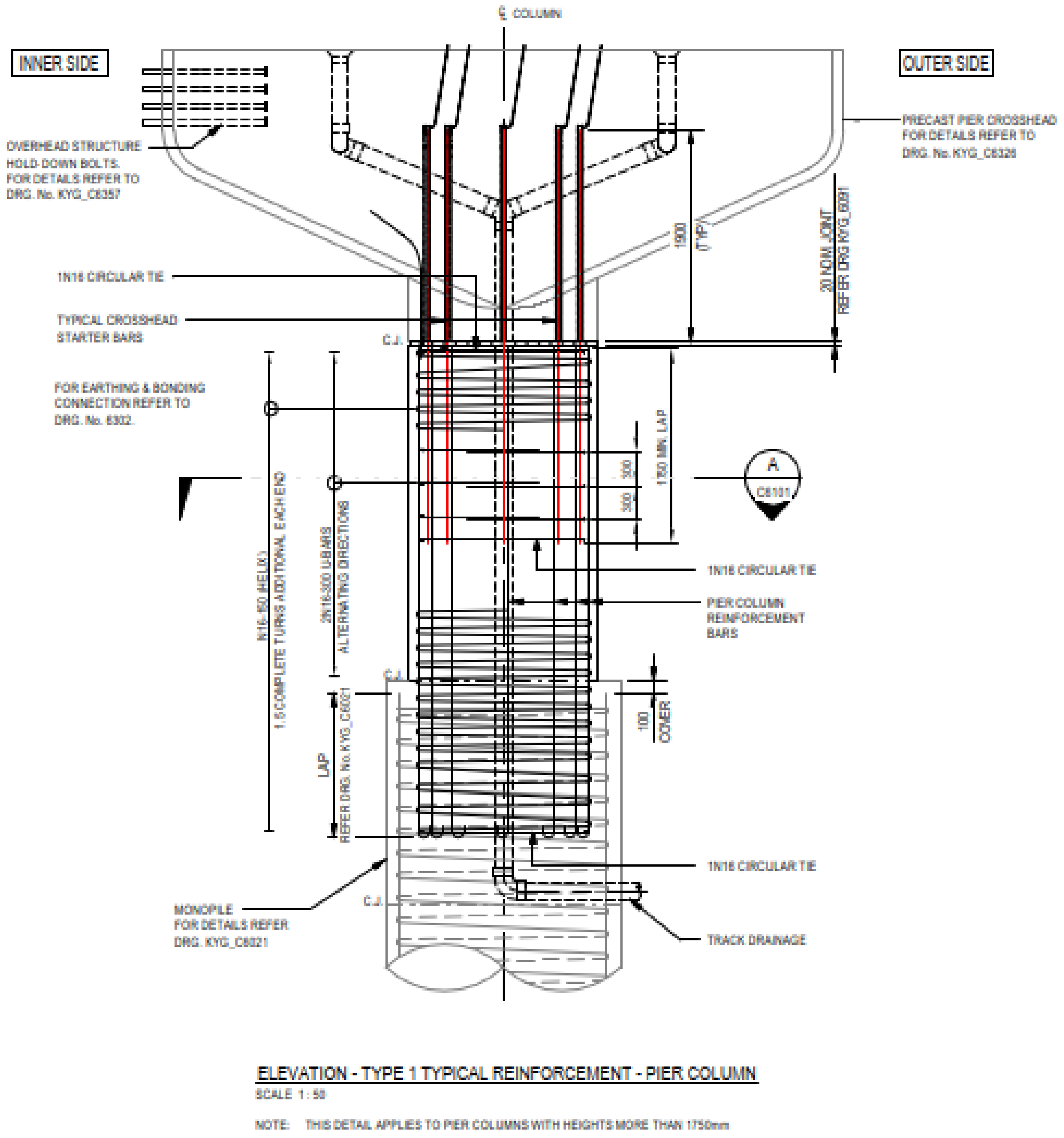


Figure 6: Precast crosshead with in-situ pier and monopile

1.4.6 Maintenance and Detraining Access

A designated maintenance access pathway has been provided along one side of the rail tracks. A separate detraining access pathway has also been provided on the opposite side should emergency detraining be required.

An access pathway has been provided along the top flange of the U-Trough for inspection and maintenance. A clear width of 1000mm is provided for the detraining access and 800mm for the maintenance access.

Access to the abutment and pier bearings would be by means of an elevated work platform.

1.5 3D Modelling

The complete viaduct structure was modelled using 3D Revit software. The model facilitated interfacing and collaboration with various disciplinary elements. The 3D model provided quality improvement of the product and helped to minimise any “surprises” during construction. Precast units for both the U-Trough and the crosshead were utilised to minimise in-situ construction activities during the limited rail occupation and the reinforcement cages of the precast elements, including all the inserts, were included in the 3D model to improve the construction efficiency.

Over the length of the elevated structure the track is curved in both plan and elevation. The U-Troughs generally follow the alignment of the track and are tilted transversely to be parallel to the canted track. The elastomeric support bearings are horizontal in both the longitudinal and transverse direction. The resulting geometry is complex. The 3-D model included a tapered shim between each bearing and the U-Trough soffit. The shims were tapered in two directions the working drawings included details of each shim including their orientation.

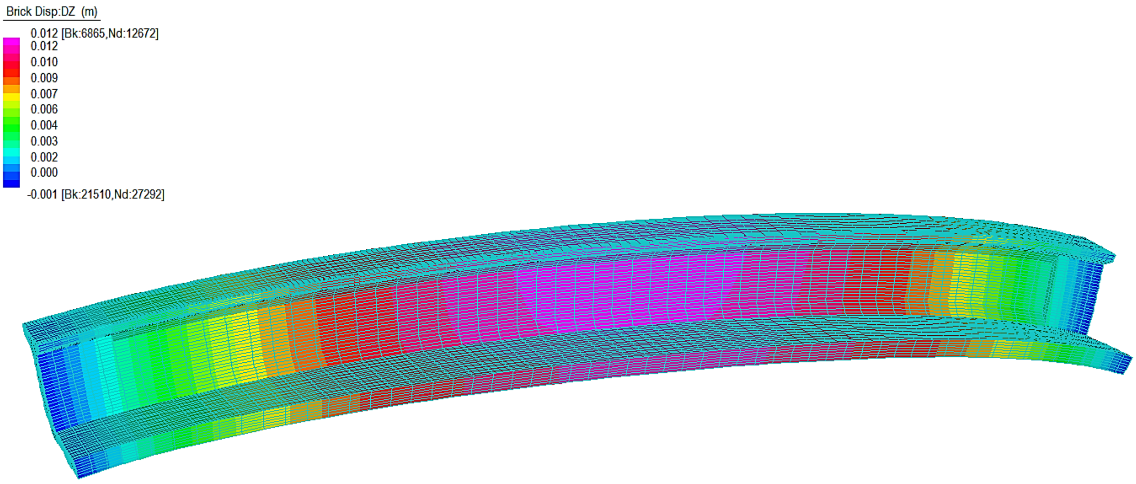
1.5.1 Precast L-Shaped Girder

At the start of the project a 3D model of the superstructure was developed and overlaid with rail vehicle to ensure the clearance satisfied the kinematic envelope requirement. The kinematic envelope is the outline of the space occupied by a rail vehicle when in motion. A kinematic analysis was completed to determine the minimum dimensions of the stitch and the distance from top of rail to top of superstructure. This was undertaken by running multiple case trains at various speeds while considering both curve and cant effects of the track geometry in multiple combinations to determine the worst-case kinematic envelope.

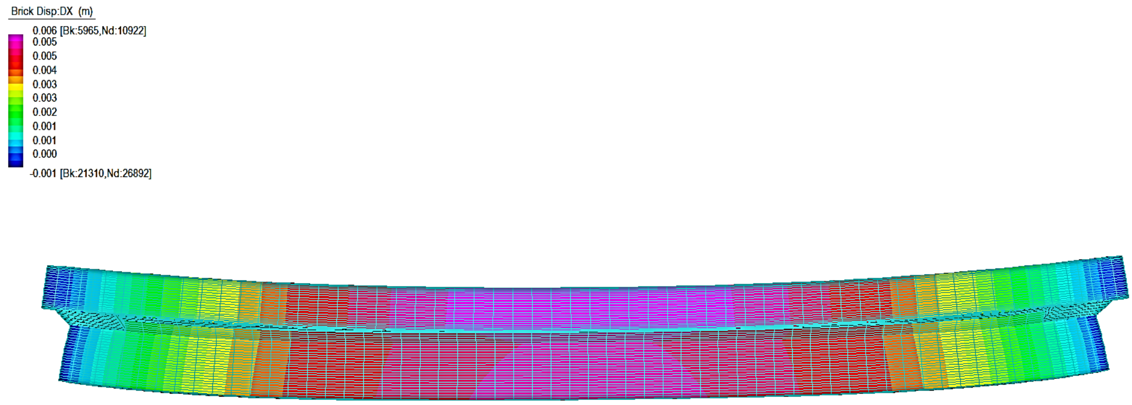
The prestressing strands for the U-Trough L-girder are concentrated at the web and bottom flange junction in order to satisfy the longitudinal design actions. Due to the highly unsymmetrical profile of the L-girder, the prestressing causes the girders to hog vertically and bow horizontally. The bow and hog of the girder was included in the 3D model to ensure the kinematic envelop is satisfied.

Ferrule insert for all the architectural balustrades and handrailing were also modelled to capture the final precast L-girder to be delivered to site and avoid any site drilling.

Figure 7 shows the hog and bow of the L-girder.



Snapshot of hog at transfer stage (Shown exaggerated)



Snapshot of bow at transfer stage (Shown exaggerated)

Figure 7: FE model of L-girder with hog and bow

1.5.2 Precast Crosshead

Crossheads are precast reinforced concrete with corrugated steel ducts cast vertically in an arrangement that matches the layout of the reinforcement projecting from the top of the in-situ concrete pier/column. The crosshead is lifted into the place, with the ducts sliding over the projecting reinforcement. The annulus between the reinforcing bar and the inside of the duct is then grouted. Lateral and longitudinal restraint between the superstructure and substructure is provided by reinforced concrete upstands or restraint blocks cast into the top of the pier crosshead and a reinforced concrete down stand projecting down from the U-Trough superstructure at both ends of each span.

Overhead structures are bolted to the crosshead.

A reinforcement clash test was carried out prior to the casting of the crosshead in the precast yard. 3D software Navisworks was used to model all the reinforcement of the crosshead to include the corrugated steel ducts, lateral restraint blocks, drainage pipes and the HD bolts for the overhead structures.

Figure 8 shows the complex 3D Navisworks model of the crosshead.

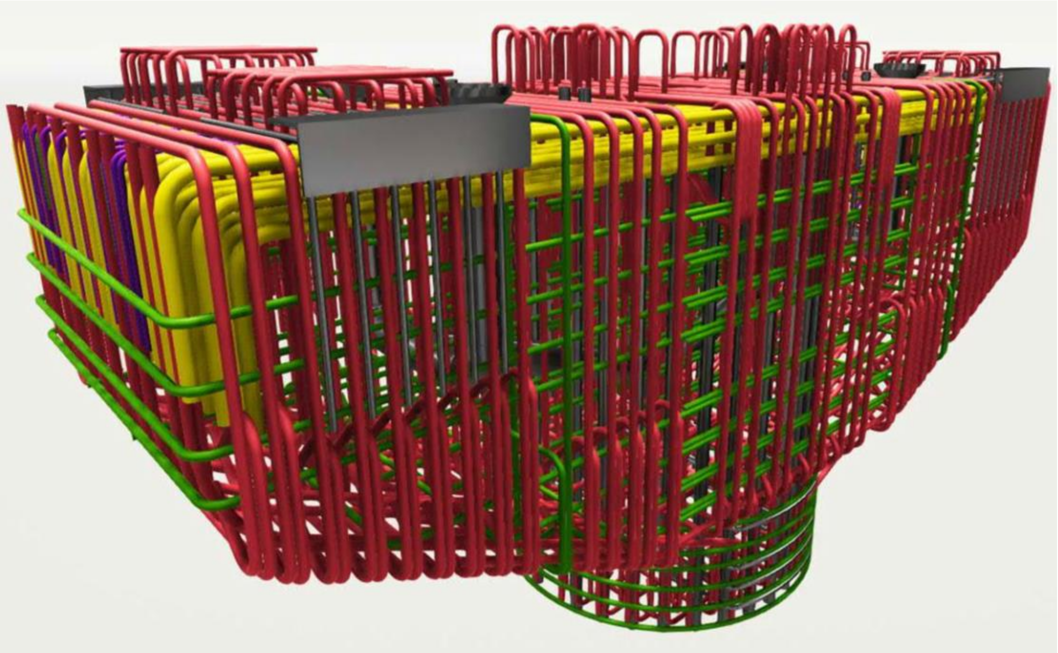


Figure 8: Precast crosshead with reinforcement

2 CONCLUSION

The Toorak Road LXRP was successfully delivered six months ahead of schedule through the adoption of the U-Trough elevated rail viaduct with refinements and accommodated the project specific features.

The full viaduct structure was modelled in 3D with the reinforcement clash tested to include elements from other disciplines. This allowed a seamless installation of viaduct structures and minimised in-situ construction activities during the limited rail occupation period.

3 REFERENCES

- Level Crossing Removal Project: **U-Trough Standardisation Design**, LXD-NEA-REP-CEC-000001, 2017
- MTM**: MTM Standard L1-CHE-STD-040 Bridge Standard** version 2, 2018
- Standards Australia: **AS 5100 Bridge Design**, 2017

4 ACKNOWLEDGEMENTS

The Toorak Road Level Crossing Removal Project was completed for rail services to commence in April 2020. This success was only possible through close collaboration and a positive and constructive working relationship between all the members of the alliance, which comprised LXRP, MTM, Laing O’Rourke and Jacobs.

5 AUTHOR BIOGRAPHY/IES

Daniel Pang, a CPEng Principal Structural engineer and Subject Matter Expert of Metro Trains Melbourne with close to 25 years’ experience in engineering, working on a variety of developments in Australian transport and mining infrastructure. Daniel is currently the structures lead on the level crossing removal projects for the South Eastern Program Alliance, and recently completed that role on the successful Toorak Road Level Crossing Removal Project.

John Noonan’s career includes periods with consultants and government. His particular areas of competence include the design of road and railway bridge structures and maritime engineering. His experience includes bridge design, appraisal and inspection. Projects on which he has served as Design Manager include the West Gate Bridge Strengthening, Eddy Whitten Bridge and the Melbourne Docklands Trunk Infrastructure structures.