An Overview of the Widening Design of the Super-T Girder Bridges on the M7-M12 Integration Project, Sydney

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Abstract

The M7-M12 Integration project (M7M12IP), in collaboration with contractor, John Holland and on behalf of WSO Co and Transport for NSW, aims to provide a toll-free connection between the new M12 Motorway, the M7 Motorway, Elizabeth Drive and Wallgrove Road at Cecil Hills. The project is also to alleviate the current and future congestion on the M7 Motorway via the median widening of the 26 km section of the existing motorway between Richmond Road and the M5 Interchange. The project features the widening of 41 existing bridges in a very congested urban motorway environment.

Twenty existing Super-T girder bridges are to be widened to accommodate one or two additional lanes into the median. The widening bridges are proposed to comprise of Super-T girders with size similar to that of the existing which aim to emulate the existing bridge behaviour. The widening bridge decks are made fully integral with the existing bridges via longitudinal closure strip to enhance road users' safety and to eliminate future maintenance which otherwise would be required if a longitudinal joint was proposed to keep the widening bridge independent of the existing bridge.

The widening design was required to be compatible with the existing in that the widening bridges will be integrally connected to the approach Continuously Reinforced Concrete Pavement (CRCP) at both ends. This seamless pavement arrangement is predicted to generate a compression or tension force on the bridge when the system expands or contracts, respectively. The Super-T girder design was required to account for the effect of this axial force.

The widening bridge is proposed to be supported by independent piers on piles to minimise impacting on the existing pier structures. The widening abutments are made fully integral with the existing abutments to avoid any differential movement and to utilise the integrated abutment system to resist the traffic impact load on the wing wall barrier, thus achieving an economical design for the widening abutment pile. Bespoke substructure solutions are required to accommodate existing site constraints for bridges over Great Western Highway (Infra 27.0/27.1), over Woodstock Avenue (Infra 32.0/32.1) and bridges over Waste Services Access Road (Infra 25.1/25.11).

The longitudinal closure strip was designed to enable construction under live traffic. Design checks were undertaken for the closure strip when concrete strength reaches 20 MPa and f'c (50Mpa) respectively. Carbonation modelling was also undertaken to demonstrate that the stitch pour will meet the 100-year design life requirements despite the reduced cover to existing reinforcement in the closure strip, which is governed by the existing condition.

The paper will present an overview of the widening design of the Super-T girder bridges.

Keywords: M7M12 IP, Super-T, bridge widening, longitudinal closure strip

1.0 Project Overview

The M7-M12 Integration project (M7M12IP), in collaboration with contractor, John Holland and on behalf of WSO Co and Transport for NSW, aims to provide a toll-free connection between the new M12 Motorway, the M7 Motorway, Elizabeth Drive and Wallgrove Road at Cecil Hills. The project is also to alleviate the current and future congestion on the M7 Motorway via the median widening of the 26km section of the existing motorway between Richmond Road and the M5 Interchange.

The Project consists of three (3) principal areas as per **Figure 1.**

- **M7 Widening** – M7 motorway widened into the median from Richmond Road overpass to the M5 interchange providing additional laneway in either direction.
- **M7M12 Interchange** – Interchange between M7 motorway and entry ramp from Elizabeth Drive to the M12 motorway
- **Elizabeth Drive Connection (EDC)** – Upgrade of Elizabeth Drive, realignment of Wallgrove and Cecil Roads, and an exit ramp from the M12 motorway.

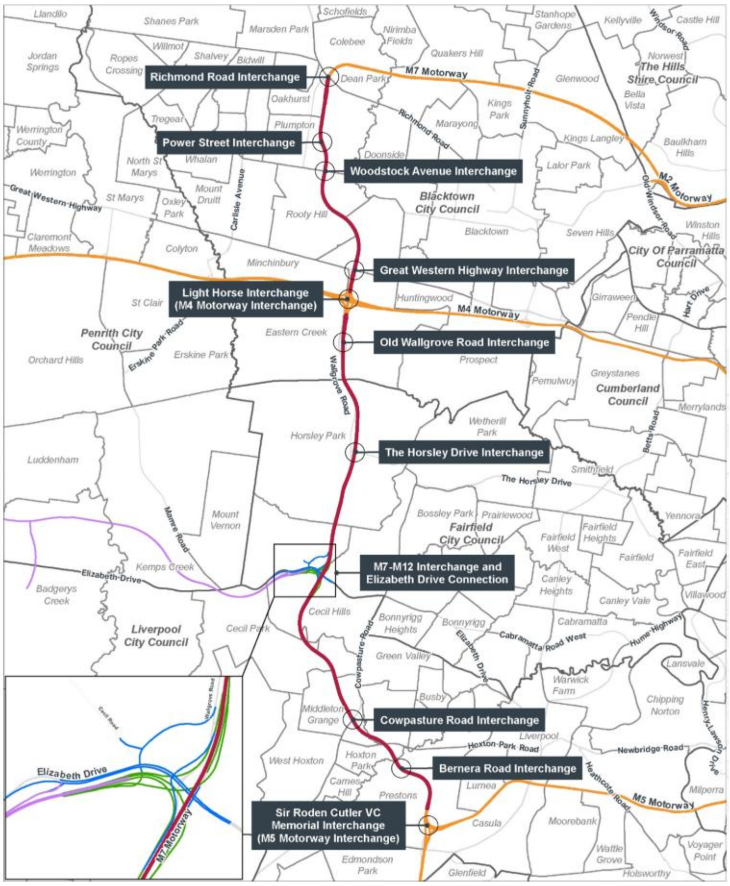

Figure 1. M7-M12 Integration Project extent

Jacobs and SMEC have formed a Design Joint Venture (JSJV) and has been engaged by JHG as the lead designer to provide detailed design services for the M7 widening, the road and civil works for the M7-M12 Interchange, and the completion of the detailed design for the EDC. JHG separately engaged other consultants for other scope items.

The project features the widening of 41 existing bridges in a very congested urban motorway environment. Twenty of these bridges are Super-T girder bridges as summarized in **Table 1**

Infra No.	Bridge name	Approx. bridge length (m)	No. of spans	Max. span length (m)
5.0	WM7 N/B over Maxwells Creek near Stn 1700	198.3	8	25.0
6.11	S/B Bridge over Bernera Road near Stn 2975	74.5	3	32.1
7.0 / 7.1	WM7 over Cabramatta Creek near Stn 3300	225.0	9	26.0
15.0 / 15.1	WM7 over Future Access Road near Stn 9630	46.0	3	20.0
19.10 / 19.11	WM7 over PAD 7	118.0	4	32.7
20.1 / 20.2	M7 over Saxony Road near Stn 13150	23.2	1	23.2
24.0 / 24.1	M7 over Austral Bricks Access Road near Ch 17030	42.1	3	20.1
25.10 / 25.11	WM7 over Waste Services Access near Stn 17760	35.4	2	21.2
27.0 / 27.1	WM7 over Great Western Highway near Stn 20610	79.0	3	35.0
30.0 / 30.1	Bridge over Angus Creek near Stn 22930	72.0	4	18.0
32.1 / 32.2	Bridge over Woodstock Avenue near Stn 24260	52.8	3	31.2

Table 1. Super-T Girder Bridges to be widened

2.0 Existing Design

2.1 Existing Superstructure

The existing bridge superstructure typically comprises simply-supported Super-T precast pretensioned girders acting compositely with a cast in-situ reinforced concrete deck slab with minimum thickness of 180 mm. The Super-T girders include 1000 mm, 1200 mm and 1500 mm depths, respectively and they are arranged in varying spacing between bridges, from 1670 mm to 2310 mm.

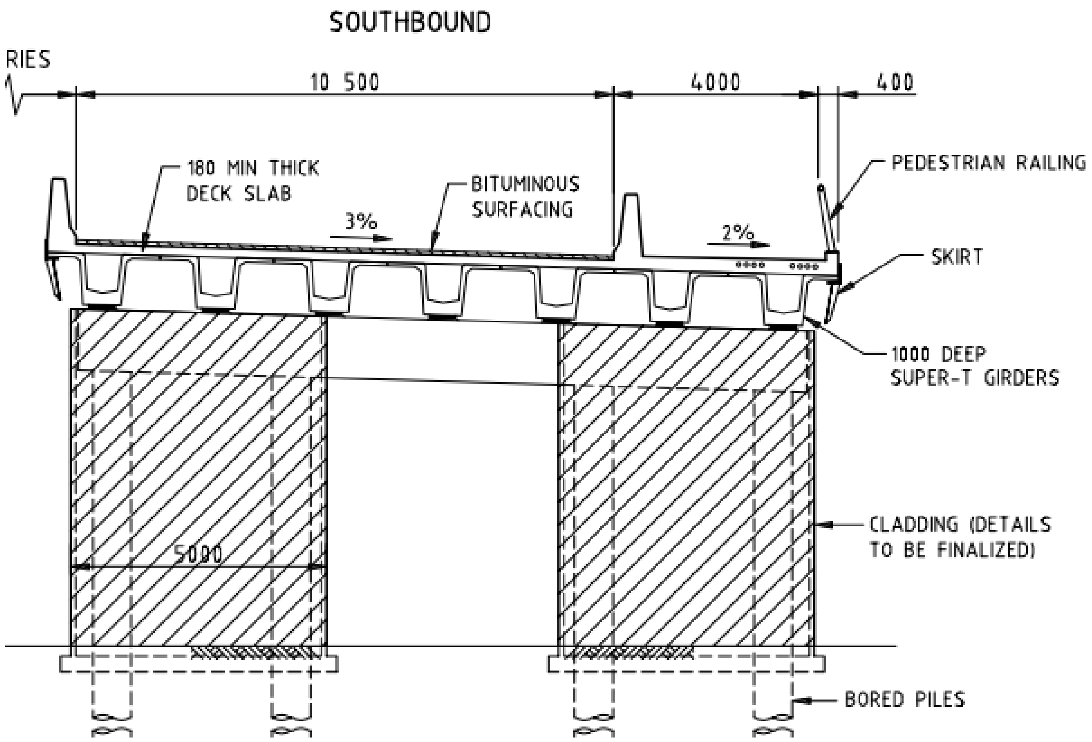

Figure 2. Typical Cross-Section at Pier – Super-T Bridges

2.2 Existing Substructure

With the exception of the single-span bridges Infra 20.1/20.2 over Saxony Road, the existing bridge substructure typically comprises piers with reinforced concrete headstocks supported on reinforced concrete columns. The columns vary in size from 750 mm to 1050 mm in diameter. Each column is supported on a cast-in-situ reinforced concrete bored pile having the same diameter as the column. Refer to Figure 2. Precast concrete cladding has been provided to the piers of bridges over local roads.

The existing abutment comprises of reinforced concrete headstock supported on concrete bored piles of either 750 mm or 900 mm in diameter. For all bridges spill through batters provided at the abutments with the exception of bridges 25.10/25.11 and Infra 27.0/27.1 where reinforced soil walls are provided at the abutment.

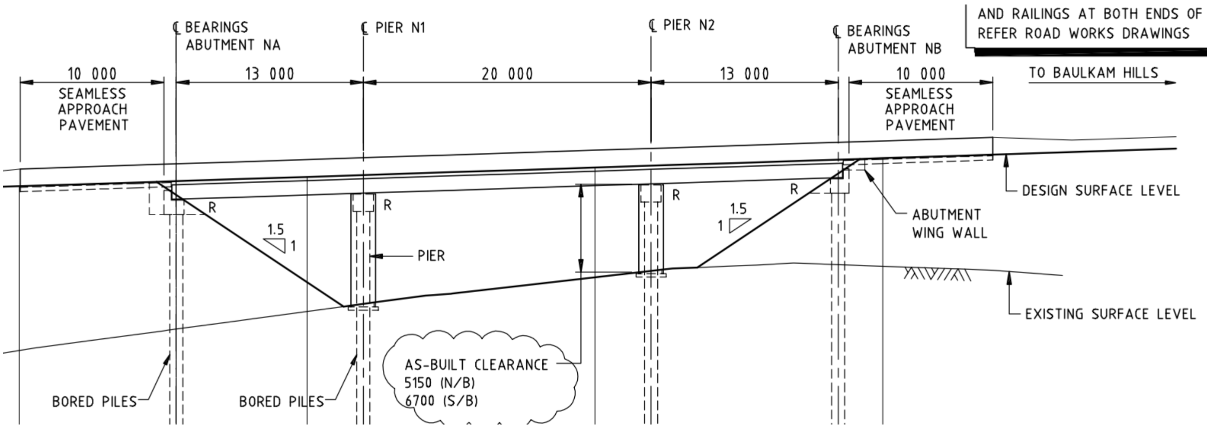

Figure 3. Typical Elevation – Existing Super-T Girder Bridges with Spill-Through abutments

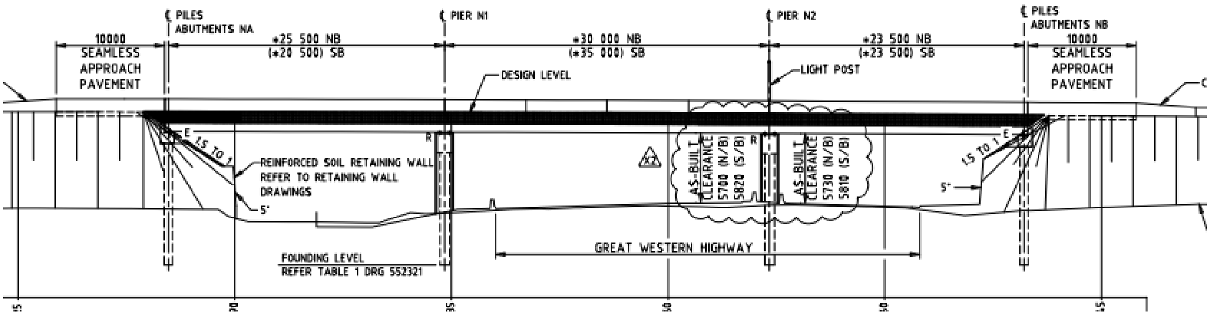

Figure 4. Elevation – Existing Super-T Girder Bridges with RSW abutments (shown for Infra 27.0)

2.3 Existing Bridge Articulation

All the existing Super-T girder bridge superstructures are supported on rectangular laminated elastomeric bearings over piers and abutments with the exception of bridges Infra 6.11 and Infra 30.0/30.1 where circular laminated elastomeric bearings were adopted due to the high skews.

2.4 Existing Bridge Barriers

Full-height concrete barriers were provided on the existing Super-T girder bridges with the exception that single steel rail with concrete parapet barriers were provided on bridges Infra 5.0 and Infra 7.0/7.1.

2.5 Key Constraints

The widening design of the Super-T bridges was subject to the following key constraints.

2.5.1 Site Constraints

The main site constraints that were critical for pier positions are existing services and utilities, existing creek and channel, existing road and shared paths, and future roads. The piers for the Super-T girder bridge widenings align with the existing bridges and were checked to ensure that they do not encroach the constraints.

Additional key constraints that influence the proposed bridge widening design are:

- Bridges over Waste Services Access near Stn 17760 (Infra 25.10 and 25.11)
  - Existing reinforced soil walls at the abutments
  - Existing switching station in close proximity to Abutment A
- Bridges over Great Western Highway near Stn 20610 (Infra 27.0 and 27.1)
  - Existing reinforced soil walls at the abutments
  - Existing reinforced concrete box culverts in close proximity to Pier 1
- Bridges over Woodstock Avenue near Stn 24260 (Infra 32.1 and 32.2)
  - Existing reinforced concrete box culverts and junction pits in close proximity to Piers 1 and 2.
  - Existing reinforced concrete box culverts in close proximity to Abutment B

Figure 5. Bridges over the Waste Services Access Road Infra 25.10/25.11 – Switching Station.

Courtesy: Google

2.5.2 Interaction with the Existing Bridges

The bridge widenings were made integral with the existing bridge via a longitudinal closure pour at the deck level as opposed to being an independent structure. The integral widening minimises the footprint of the widened structure and the associated bridge approach works. More importantly, it eliminated the need for a longitudinal joint, which would have been otherwise required to isolate the two bridges and all associated future maintenance works. In the final condition, the combined widened bridge superstructure will act together in response to traffic and other environmental loadings. The widening design carefully considered this interaction to avoid adversely impacting the existing structures. A detailed load rating assessment of the existing bridges in the final widened condition was undertaken to demonstrate that the widening can be accommodated by the existing bridges without strengthening.

For Earthquake (EQ) loading, the project Scope of Works and Technical Criteria (SWTC) requires that the M7 bridge widenings are to be designed to BEDC-4 Service Performance Level in accordance with AS 5100-2017 Series. Where seismic loading from the widening is transferred to the original structure, the original components of the combined widened structures are to have seismic design checks undertaken to assess concrete capacity in accordance with AS 5100.5-2004 and be strengthened if required to comply with AS 5100.2-2004 Clause 14, adopting the original EQ design parameters of the existing bridges. The highlighted SWTC requirement posed a design challenge in that it is very difficult to quantify the seismic load transfer from the widening to the original structure since they are integrated and will be acting as one combined structure. To demonstrate compliance with the SWTC, a two-tier EQ assessment of the integral widened bridge was adopted to assess the new components of the bridge widening and the original components of the existing bridges as described in Section 3.2.1.16.

In addition, in the longitudinal direction, the new widening superstructure is expected to undergo shortening due to the creep and shrinkage effects whilst the residual creep and shrinkage effects on the existing structure are negligible due to its age. Once the integral connection between the two superstructures is made via the longitudinal closure strip pour, the existing superstructure will restrain the new widening section from shortening, resulting in a compression and a tension effect in the existing superstructure and the widening, respectively. This interaction was carefully considered in the widening design.

2.5.3 Constructability In a Congested Urban Motorway Environment

The construction of the bridge widenings was undertaken in a very congested site next to live traffic on the M7 Motorway. The widening design was required to facilitate speedy construction with minimal lane closures and disruptions to the motorway operations. This was achieved by design optimisation, maximum use of precast elements and staged construction via the implementation of longitudinal closure pours, which connect the existing bridges and the bridge widenings.

2.6 Seamless Pavement

Seamless pavement is a unique feature of the M7 Motorway, which refers to the continuity between the bridge deck slab and the CRCP via a transition pavement/slab. This feature removes the need for transverse joints at the ends of the bridge deck, where approach slabs are typically provided, and the terminal anchors for the CRCP. Seamless pavement is provided for all existing Super-T girder bridges, with the exception of three bridges Infra 5.0 and Infra 7.0/7.1,

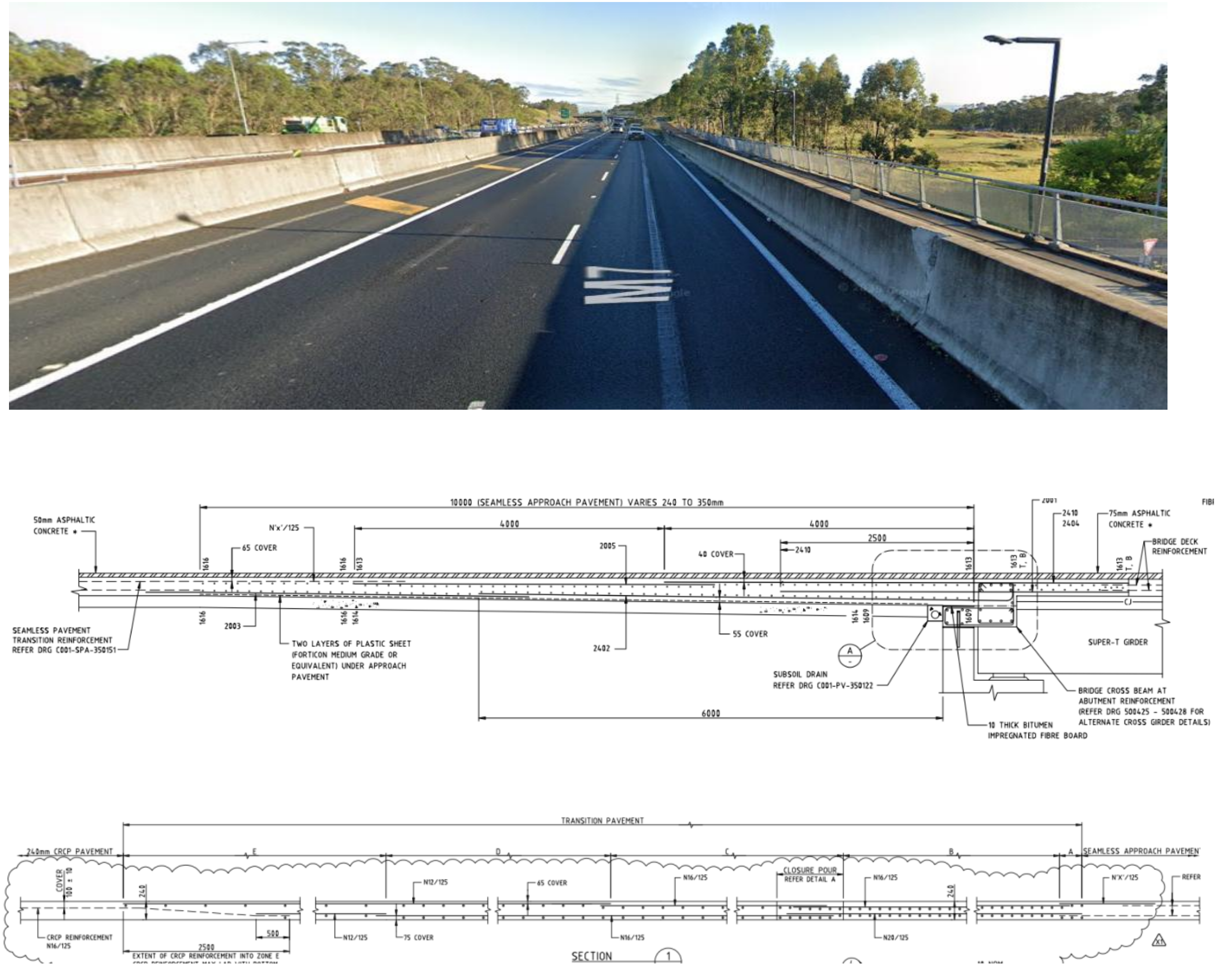

Figure 6. Typical Seamless Pavement Detail – Photo: Courtesy Google.

The seamless pavement contracts and expands in response to the fluctuation in temperatures, which are then restrained by the bridges. Depending on the temperature at its original construction, the restraint in thermal contraction and expansion of the seamless pavement will translate into an axial tension and compression applied on the bridge at deck level, respectively. This axial load will also affect the bending moment in the bridge girders due to an eccentricity between the line of load application and the girder centroid.

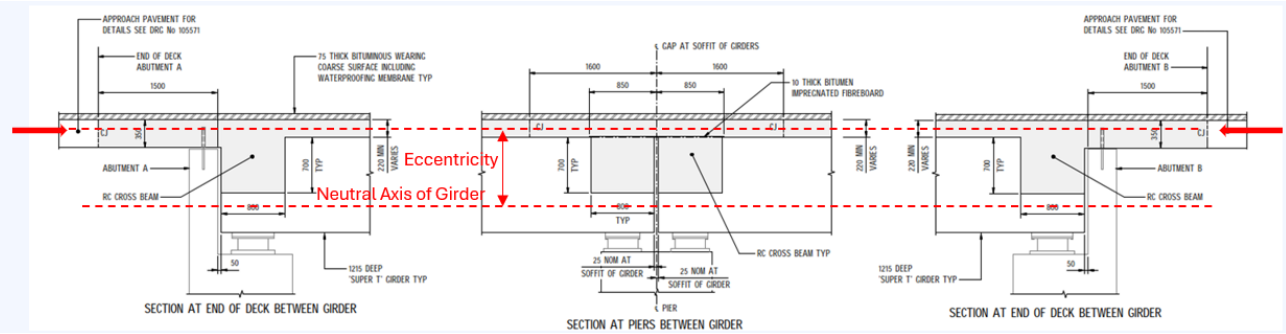

Figure 7. Eccentricity Effect Due to Seamless Pavement on Bridge Girders.

The widening design has taken the above seamless pavement/bridge interaction into consideration.

3.0 Widening Design

3.1 Widening Objective

The bridge widening was to provide additional one or two traffic lanes in each direction into the median between the carriageways. Based on an optimised road alignment design, the widening widths for the Super-T girder bridges are as summarized in **Table 2**.

Infra No.	Bridge name	Widening NB (m)	Widening SB (m)
5.0	WM7 N/B over Maxwells Creek near Stn 1700	3.7	N/A
6.11	S/B Bridge over Bernera Road near Stn 2975	N/A	3.7
7.0 / 7.1	WM7 over Cabramatta Creek near Stn 3300	3.5	3.5
15.0 / 15.1	WM7 over Future Access Road near Stn 9630	7.0	7.0
19.10 / 19.11	WM7 over PAD 7	7.0	7.0
20.1 / 20.2	M7 over Saxony Road near Stn 13150	3.5	3.5
24.0 / 24.1	M7 over Austral Bricks Access Road near Ch 17030	varies 2.0 max	3.7
25.10 / 25.11	WM7 over Waste Services Access near Stn 17760	3.5	3.5
27.0 / 27.1	WM7 over Great Western Highway near Stn 20610	varies 1.7 max	3.5
30.0 / 30.1	Bridge over Angus Creek near Stn 22930	2.8	3.5
32.1 / 32.2	Bridge over Woodstock Avenue near Stn 24260	3.5	3.5

Table 2. Widening Geometric requirements

3.2 Design Criteria

3.2.1 Design Loads

3.2.1.1 Dead Load

The unit weight of materials used to calculate the self-weight of the structural members are as follows:

- Reinforced concrete: 25.5 kN/m^3
- Prestressed concrete: 26.0 kN/m^3
- Steel: 77.5 kN/m^3

3.2.1.2 Superimposed Dead Load

The unit weight of materials used to calculate the superimposed loads were as follows:

- Asphalt: 22.0 kN/m^3
- Additional concrete to account for girder hog: 25.5 kN/m^3

3.2.1.3 Differential Settlement

Transverse differential settlement between the new and adjacent existing supports was considered in the design based on the outcome of the geotechnical assessment.

3.2.1.4 Earth Pressure

Earth pressure acting on the bridge structure was based on a soil material density of 22.0 kN/m3 and an effective angle of friction of 32°. Where present in the soil, hydrostatic groundwater pressure was based on a density of 10.0 kN/m3.

3.2.1.5 Creep & Shrinkage

Design shrinkage strain acting on a specific bridge member was calculated in accordance with Clause 3.1.7 of AS 5100.5-2017, based on the bridge site location, the member's concrete compressive strength and the member's hypothetical thickness. The effects of shrinkage on members were determined considering the proposed construction methodology and timing of work.

3.2.1.6 Construction Tolerances

Design of the substructure considered the potential of the piles and/or columns being out of position. For this, a 75-mm eccentricity (out of plane), was applied on the axial forces at the top of each pile / column. The resulting bending moment was added to the bending moment calculated under other actions.

3.2.1.7 Average Bridge Temperature

Variation in average bridge temperature was calculated in accordance with Clause 18.2 of AS 5100.2-2017 based on the bridge site location maximum and minimum shade air temperatures and the superstructure material composition.

3.2.1.8 Differential Temperature

Differential temperature profile across the superstructure was calculated in accordance with Clause 17.3 of AS 5100.2-2017 based on the bridge site location and superstructure type.

3.2.1.9 Live Loads

The vertical traffic loads were as follows:

- SM1600 loading in accordance with Clause 7.2 of AS 5100.2-2017.
- Fatigue Loading in accordance with Clause 7.9 of AS 5100.2-2017.
- Dynamic load allowance is applied to the traffic loads in accordance with Clause 7.7 of AS 5100.2-2017.

In addition, as per the requirement of the SWTC, integral bridge widenings which are 7m or wider are required to be designed for HLP400 loadings. Therefore, bridge widenings at four bridges Infra 15.0/15.1 and Infra 19.0/19.1 were required to accommodate HLP400 loadings.

3.2.1.10 Braking Loads

Braking forces were determined in accordance with Clause 7.8.2 of AS 5100.2-2017 based on the number of standard design lanes in the same direction and the length of the bridges.

3.2.1.11 Live Load During Construction

At early age of the closure strip pours, i.e. upon concrete reaching a compressive strength of 20 MPa, the closure strip between the widening and the existing bridges were assessed for B-Double 68t truck loading (as shown in **Figure 8**) placed on the existing bridge. The trucks were positioned within two temporary traffic lanes which are each 3.3 m wide. A dynamic load allowance of 0.4 is adopted based on provision of AS 5100.7 Clause 11.3.6. The accompanying lane factor is based on table 7.6 of AS 5100.2.

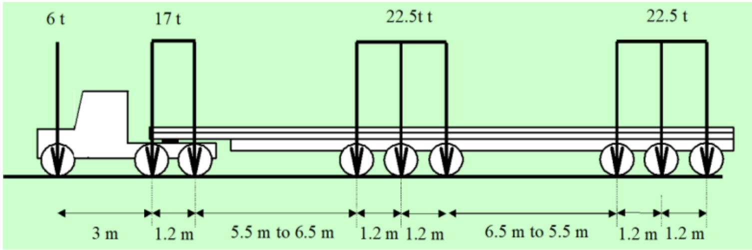

Figure 8. B-Double 68t.

3.2.1.12 Surcharge

The surcharge acting on the abutment walls resulting from traffic loads on the approaches was applied in accordance with Clause 14.2 of AS 5100.2-2017.

3.2.1.13 Traffic Barrier Loads

Forces acting on the traffic barriers were determined in accordance with Section 12 and Appendix A of AS 5100.2-2017 based on a medium performance barrier.

3.2.1.14 Minimum Lateral Restraint

Minimum restraint load was determined in accordance with Clause 10 of AS 5100.2-2017. The applied load was equal to 5% of the superstructure dead load at that support but not less than 500 kN.

3.2.1.15 Traffic Collision Load on Substructures

Collision loads acting on the substructure were determined in accordance with Clause 11.2 of AS 5100.2-2017. Collision loading applies to the piers of bridge widenings adjacent to existing roads of the following bridges.

- Infra 6.11: Southbound Bridge over Bernera Road.
- Infra 19.10/19.11: Bridges over PAD 7.
- Infra 24.0/24.1: Bridges over Austral Bricks Access Road.
- Infra 25.10/25.11: Bridges over Waste Services Access.
- Infra 27.1: Southbound Bridge over Great Western Highway.
- Infra 32.1/32.2: Bridges over Woodstock Avenue.

3.2.1.16 Earthquake Loads and Seismic Design Approach

The SWTC stipulates that the M7 bridge widenings are to be designed to BEDC-4 Service Performance Level in accordance with AS 5100-2017 Series. Where seismic loading from the widening is transferred to the original structure, the original components of the combined widened structures are to have seismic design checks undertaken to assess concrete capacity in accordance with AS 5100.5-2004 and be strengthened if required to comply with AS 5100.2-2004 Clause 14, adopting the original EQ design parameters.

The highlighted SWTC requirement posed a design challenge in that it was very difficult to quantify the seismic load transfer from the widening to the original structure since they are integrated and will be acting as one combined structure. To demonstrate compliance with the SWTC, a two-tier EQ assessment of the integral widened bridge is adopted to assess the new components of the bridge widening and the original components of the existing bridges as follows:

Earthquake Assessment 1 – AS5100:2017-BEDC4 Assessment:

In the first EQ assessment model, the combined bridge is analysed for an earthquake load corresponding to BEDC-4, Service Performance Level in accordance with AS 5100.2 -2017. Seismic design actions were obtained on the new components of the bridge widening and on the original components of the existing bridges.

The new components of bridge widening were then designed for the obtained seismic design actions.

The original components of the existing bridge were then assessed for the obtained seismic design actions. If the original components of the existing bridge were found to be adequate for these design actions, the SWTC requirement was then deemed to have been met.

If the original components of the existing bridge were found to be inadequate for these seismic design actions, Earthquake Assessment 2 was then undertaken.

Earthquake Assessment 2 – AS5100:2004 – Original design assessment:

In the second EQ assessment model, the combined bridge was assessed in accordance with AS 5100.2:2004 Clause 14 using parameters derived from the original M7 design criteria as follows:

- Bridge classification – Type II
- Acceleration coefficient a = 0.08
- Site factor S taken from Table 2.4(a) of AS 1170.4:1993

The bridge earthquake design category (BEDC) was taken as follows:

- BEDC-2 for 0.1 <= aS <= 0.2
- BEDC-1 for aS < 0.1

The original components of the existing bridge were then assessed for the corresponding earthquake loading acting on these components in accordance with AS 5100-2004.

If the original components were found to be inadequate under Earthquake Assessment 2, the components would require strengthening so that they are structurally adequate under this scenario.

The two-tier EQ assessment is illustrated by the flow chart in **Figure 9**

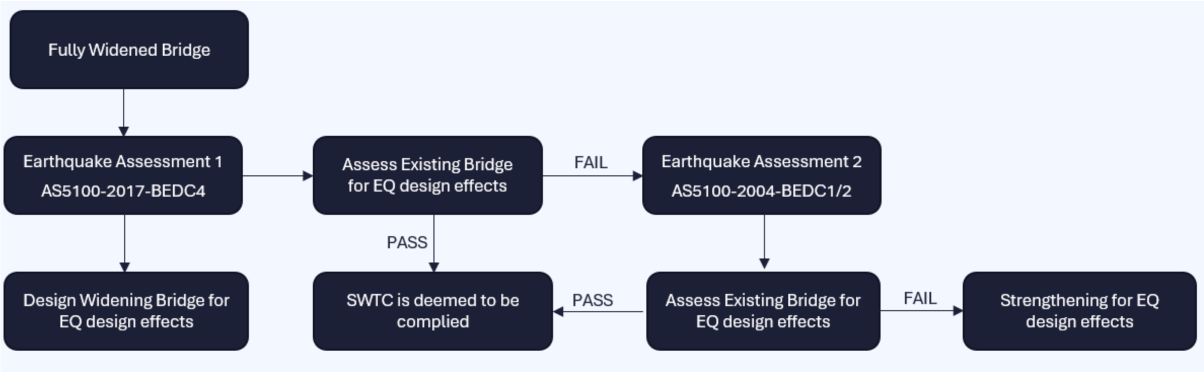

Figure 9. EQ Design Flow Chart

The above seismic assessment confirmed that strengthening of the existing structure for seismic design actions is not required for the proposed integral widening in accordance with the SWTC.

3.3 Construction Staging

To minimise disruptions to the motorway operations while enabling safe integration of the widening structure, the following construction sequence was broadly adopted:

1. Install cast-in-place piles at all piers and abutments.
2. Demolish existing abutment wingwall and prepare existing abutment surface as a construction joint.
3. Construct widening abutment connecting to the existing abutment.
4. Construct column extensions and pier headstocks.
5. Install bearings on pier and abutment headstocks and erect Super-T girder on the installed bearings.
6. Pour deck slab to nominally 600 mm from the existing bridge.
7. Pour link slabs over piers to nominally 600 mm from the existing bridge.
8. Install precast barrier on the new deck and pour barrier stitch.

9. Demolish existing bridge barrier and deck slab, exposing existing deck reinforcement for closure strip construction.
10. Implement temporary traffic restrictions and pour continuous longitudinal closure strip between ends of deck.
11. Remove traffic restrictions upon the closure strip concrete reaching the required minimum age and compressive strength.
12. Complete remaining bridge works including approach pavement, waterproofing and asphalt surfacing.

3.4 Widening Design Solution

3.4.1 Superstructure

The widening superstructure typical comprises simply supported Super-T girders, matching the depth of the existing girders. See **Figure 10**.

A 40 MPa cast-insitu concrete deck slab is provided to act compositely with the pre-tensioned Super-T girders. The deck slab thickness was proposed to be of 220 mm minimum and 200 mm minimum for bridge widenings with full-height precast barriers and with single steel rail with concrete parapet barriers, respectively. The deck min thickness was provided to accommodate the barrier impact load in a progressive failure mode in accordance with AS 5100.2-2017 Clause 12.3. Refer **Table 3**.

The design of the bridge widening Super-Ts complies with the requirements TfNSW BTD 2011/06 with two exceptions:

- The span length of the Super-T girders on Southbound Bridge over the Great Western Highway, Infra 27.1, exceeds the 33 m limit; and
- The skew of the Super-T girders on Southbound Bridge over Bernera Road, Infra 6.11, exceeds the 35-degree skew limit.

Detailed calculations to demonstrate the adequacy of the girders on the above two bridges were undertaken. On this basis, departures from the above requirements were approved by TfNSW.

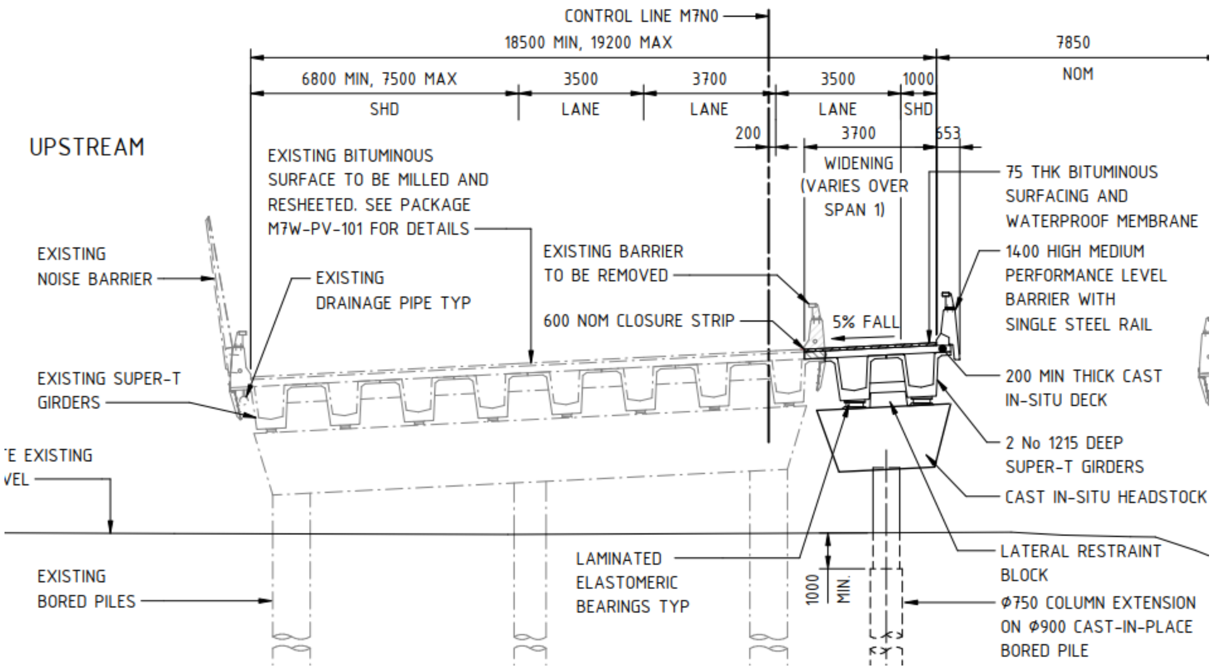

Figure 10. Typical bridge widening section over Piers– Super-T Bridges

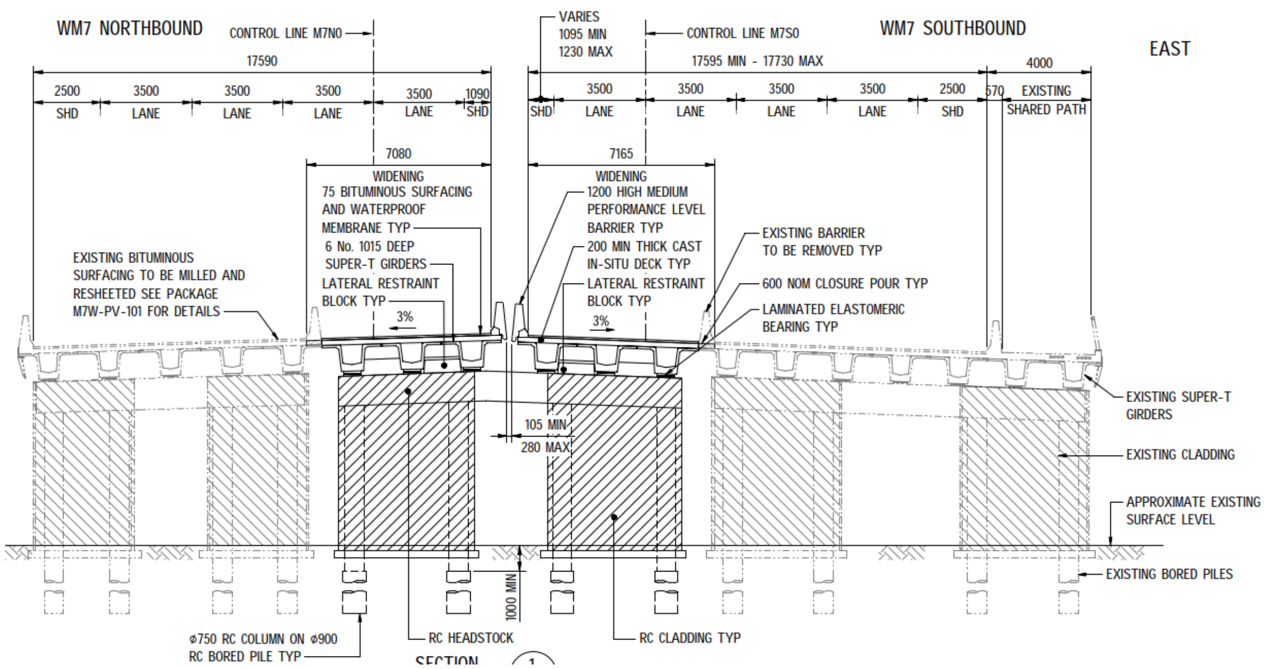

Figure 11. Full width widening section over Piers (shown for Infra 15.0/15.1)

Infra No.	Bridge name	Widening superstructure	No. Girders NB Widening	No. Girders SB Widening	Min. Deck Slab Thickness (mm)
5.0	WM7 N/B over Maxwells Creek near Stn 1700	Simply-supported 1215 deep Super-T	2	N/A	200
6.11	S/B Bridge over Bernera Road near Stn 2975	Simply-supported 1515 deep Super-T	N/A	2	220
7.0 / 7.1	WM7 over Cabramatta Creek near Stn 3300	Simply-supported 1215 deep Super-T	2	2	200
15.0 / 15.1	WM7 over Future Access Road near Stn 9630	Simply-supported 1015 deep Super-T	3	3	200
19.10 / 19.11	WM7 over PAD 7	Simply-supported 1515 deep Super-T	3	3	200
20.1 / 20.2	M7 over Saxony Road near Stn 13150	Simply-supported 1215 deep Super-T	2	2	220
24.0 / 24.1	M7 over Austral Bricks Access Road near Ch 17030	Simply-supported 1015 deep Super-T	1	2	220
25.10 / 25.11	WM7 over Waste Services Access near Stn 17760	Simply-supported 1215 deep Super-T	2	2	220
27.0 / 27.1	WM7 over Great Western Highway near Stn 20610	Simply-supported 1515 deep Super-T	1	2	220
30.0 / 30.1	Bridge over Angus Creek near Stn 22930	Simply-supported 1015 deep Super-T	2	1	220
32.1 / 32.2	Bridge over Woodstock Avenue near Stn 24260	Simply-supported 1515 deep Super-T	2	2	220

Table 3. Widening Superstructure Summary

In the proposed arrangement, the depth of the composite Super-T section under the widening is larger than the plank section under the existing bridge deck, resulting in a larger bending stiffness in the widening section than in the existing bridge deck. Under live loads, the widening section will therefore attract more loading, thus reducing the live load effects on the existing edge girders.

Where the widening comprises two or more Super-T girders, cross girders have been provided between the new girders to faciliate future jacking of the bridge for bearing replacement. Where the widening comprises one Super-T girder only, i.e. Infra 24.0, Infra 27.0 and Infra 30.1, cast in-situ corbels have been provided at the ends of girders to facilitate future jacking, see Figure 12. To avoid drilling large diameter reinforcement bars into the existing Super-T girder end blocks, which poses significant structural and constructability risks, no cross girder has been provided between the new and existing girders.

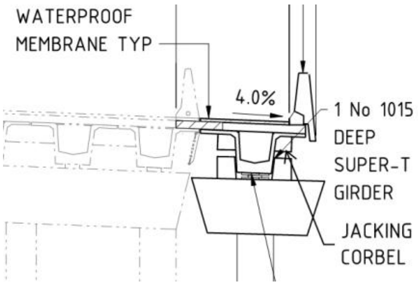

Figure 12. Jacking Corbel at Single Girder Widening (shown for Infra 30.1)

3.4.2 Typical Sub-structure

Except for the bespoke sub-structure solutions as described in Section 3.4.3, the bridge widening sub-structure typically comprises concrete piers that are independent from the existing piers. Each pier consists of a headstock supported on a single column/bored pile system. In the case of bridges Infra 15.0/15.1 and Infra 19.10/19.11 where full median widening was required, the pier comprises a headstock supported by two pairs of columns supported on bored piles. The size of the column and the supporting bored piles vary based on ground conditions, span loading and whether the pier is subject to the traffic collision load described in Section 3.2.1.15. Independent piers were proposed to avoid drilling large diameter reinforcement bars into the existing pier headstocks, which poses significant structural and constructability risks.

Each abutment typically comprises a headstock supported by a single bored pile. In the case of bridges Infra 15.0/15.1 and Infra 19.10/19.11 where full median widening was required, the abutment comprises a headstock supported by two pairs of bored piles. The new abutments are either integrally connected or dowelled to the existing abutments depending on the structural configuration adopted to accommodate the barrier impact load on the wing walls and the condition of the existing abutments identified on site. **Table 4** below summarises the adopted connection arrangements.

Infra No.	Bridge name	Abutment connection arrangement
5.0	WM7 N/B over Maxwells Creek near Stn 1700	Integrally connected to existing
6.11	S/B Bridge over Bernera Road near Stn 2975	Integrally connected to existing
7.0 / 7.1	WM7 over Cabramatta Creek near Stn 3300	Integrally connected to existing
15.0 / 15.1	WM7 over Future Access Road near Stn 9630	Dowelled to existing
19.10 / 19.11	WM7 over PAD 7	Dowelled to existing
20.1 / 20.2	M7 over Saxony Road near Stn 13150	Integrally connected to existing
24.0 / 24.1	M7 over Austral Bricks Access Road near Ch 17030	Dowelled to existing with cross beam provided between the new abutments
25.10 / 25.11	WM7 over Waste Services Access near Stn 17760	Integrally connected to existing
27.0 / 27.1	WM7 over Great Western Highway near Stn 20610	Integrally connected to existing
30.0 / 30.1	Bridge over Angus Creek near Stn 22930	Dowelled to existing with cross beam provided between the new abutments
32.1 / 32.2	Bridge over Woodstock Avenue near Stn 24260	Integrally connected to existing

Table 4. Summary of Abutment Connection Arrangements

In this system, the new pier and abutment columns are relatively stiffer than the existing columns and therefore will attract more load effects in the longitudinal direction. As the results, this will impact favorably on the edge columns and their associated foundations.

At the bridges over Saxony Road, Infra 20.1/20.2, two piled buttress retaining walls up to 7.5 m high, are required in front of the extended abutments in between the two existing Reinforced Soil Wall (RSW) abutments to support the embankment fill for the proposed widenings. Piled retaining walls were adopted to minimise the extent of excavation adjacent to the existing RSWs. The retaining wall consists of varying wall thickness from 450 mm top to 1050 mm base supported by 1200 mm deep and 1500 mm wide capping beam. The capping beam is supported by 4 No 1050 mm diameter front bored piles and 2 No 1200 mm diameter back piles. Feature grooves have been provided on the face of the new retaining walls to provide a seamless pattern across the new and existing retaining walls.

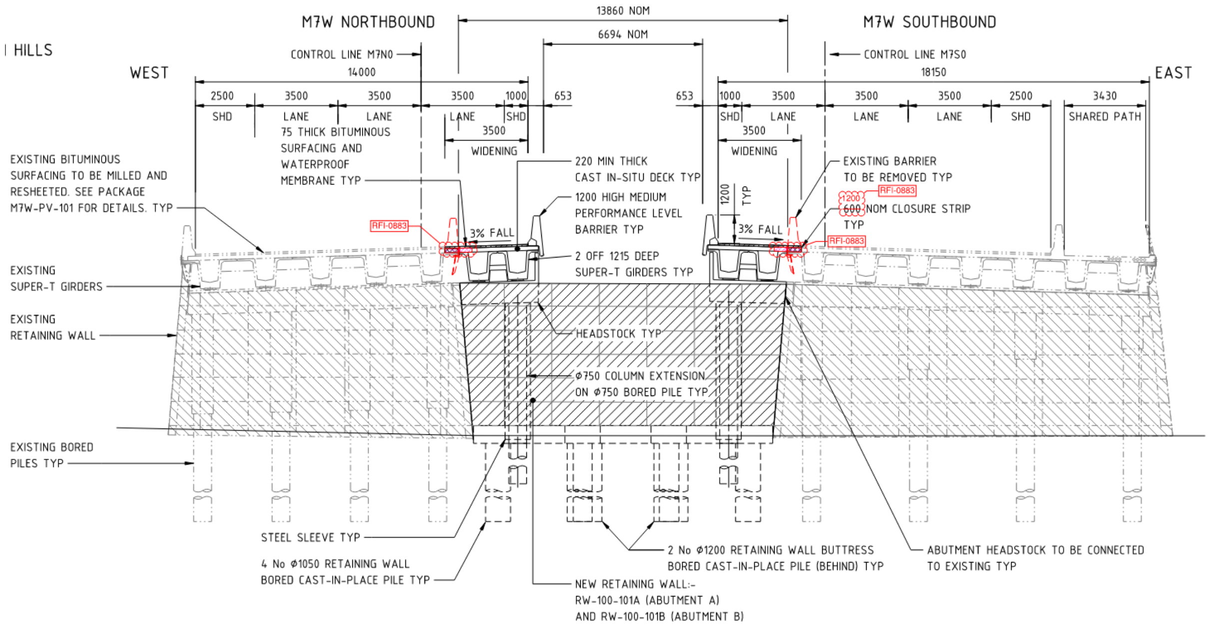

Figure 13. Abutment Front Elevation and Retaining Wall at Bridge Widenings Infra 20.1/20.2

3.4.3 Bespoke Sub-structure Solutions

Bespoke sub-structure solutions were required to overcome site constraints at bridge widenings Infra 25.10/25.11, Infra 27.0/27.1 and Infra 32.1/32.2.

3.4.3.1 Abutments of Bridge Widenings Infra 25.10/25.11

The bridge widenings Infra 25.10/25.11 was proposed to be supported by a combined abutment, comprising a headstock which is connected to and spans between the two existing abutment headstocks of the southbound and northbound bridges. A 900 mm dia pile is proposed to provide additional support to the widening abutment headstock.

The pile is positioned minimum 3 m away from the Endeavour Energy Switching Station to enable access for the installation of soil nails.

As the piling through the existing RSW is expected to damage the existing straps, soil nails were proposed locally adjacent to the pile location to stabilise the section of RSW impacted by the piling works. Precast facing panels were provided to facilitate speedy construction.

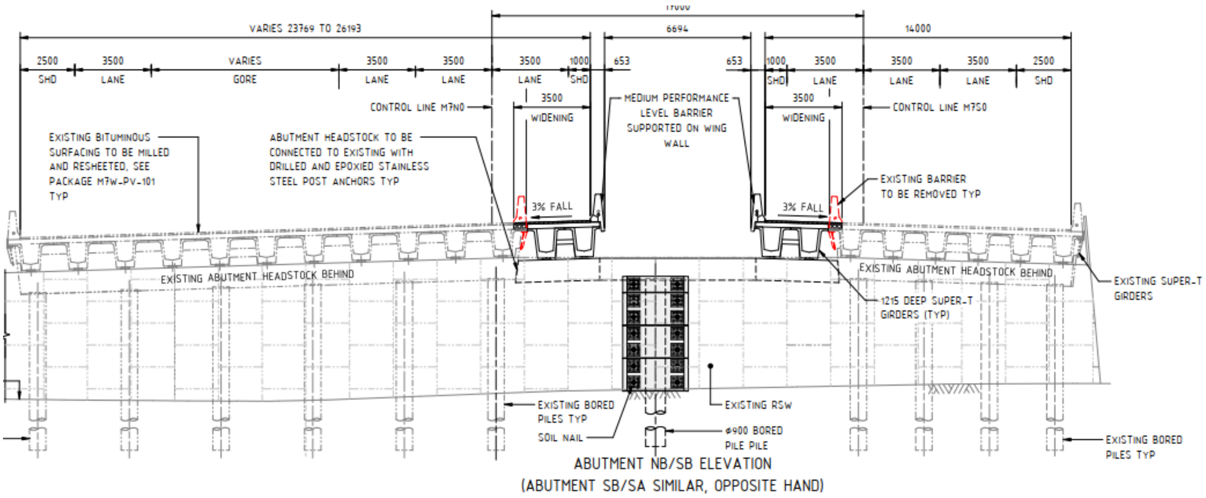

Figure 14. Abutment and soil nail strengthening at Bridge Widenings Infra 25.10/25.11

3.4.3.2 Abutments and Piers of Bridge Widenings Infra 27.0/27.1

The bridge widenings Infra 27.0/27.1 was proposed to be supported by a combined abutment, comprising a headstock which is connected to and spans between the two existing abutment headstocks of the southbound and northbound bridges. A 900 mm dia pile is proposed to provide additional support to the widening abutment headstock. As the piling through the existing RSW is expected to damage existing straps, soil nails were proposed locally adjacent to the pile location to strengthen the section of RSW impacted by the piling works. Precast facing panels were provided to facilitate speedy construction.

The pier design of the bridge widening over Great Western Highway Infra 27.0/27.1 was highly customized to reduce the construction footprint and to accommodate an existing major four-cell culvert. See **Figure 15**.

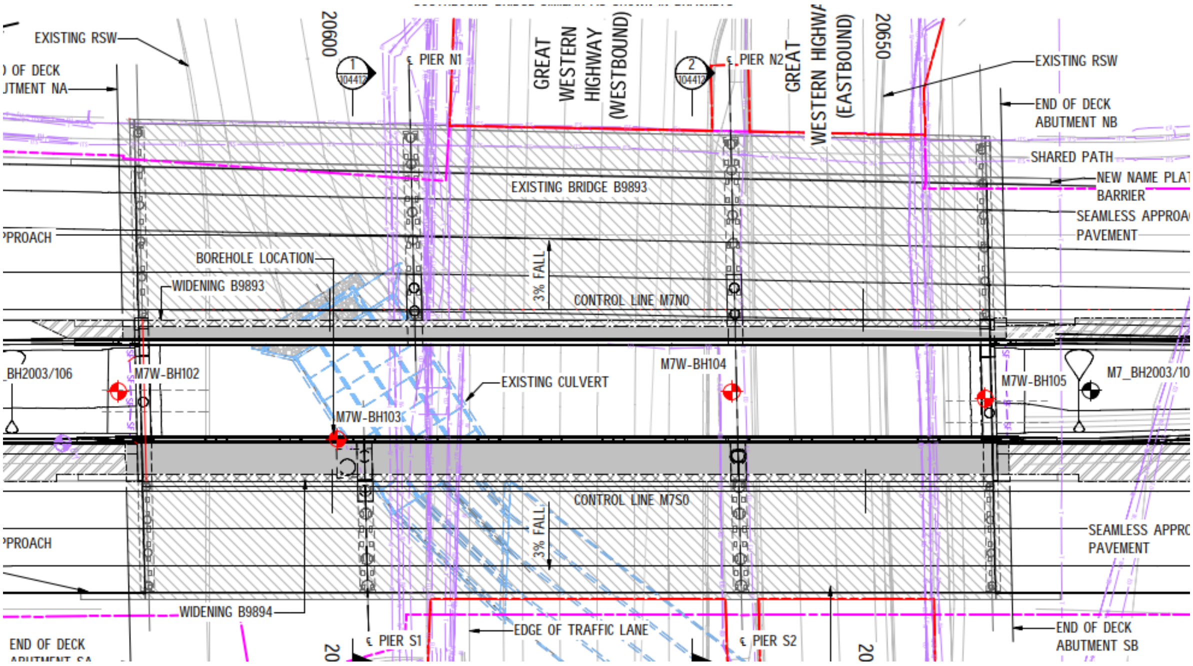

Figure 15. Site Constraint at Infra 27.0/27.1 – Existing Culvert

For the northbound bridge Infra 27.0, the existing piers were proposed to be strengthened by new blade walls constructed between the two innermost existing pier columns to support the widened superstructure. The blade wall was proposed to be constructed in multiple vertical pours to limit the vertical pressure that may be exerted on the existing box culvert.

For the southbound bridge Infra 27.1, Pier 2 comprises of a typical pier arrangement including a 1200 mm diameter column supported on a 1500 mm diameter reinforced concrete pile. At Pier 1, the pile has been offset from the 1050 mm diameter column with a cantilever pile cap in order to avoid clashing with the existing box culvert. The new pile cap at Pier 1 is connected to the existing columns via post installed reinforcement in order to limit the horizontal and vertical pier movement due to rotation of the foundation under eccentric load. To prevent load transfer to the existing culvert, a layer of compressible material is provided between the underside of the pile cap and top of the existing culvert and a galvanised, oversized steel sleeve with air gap between pile and sleeve has been provided for the top 2000 mm of the new pile. The soffit of the pile cap is isolated from the steel sleeve to avoid any load transfer to the sleeve and the existing culvert.

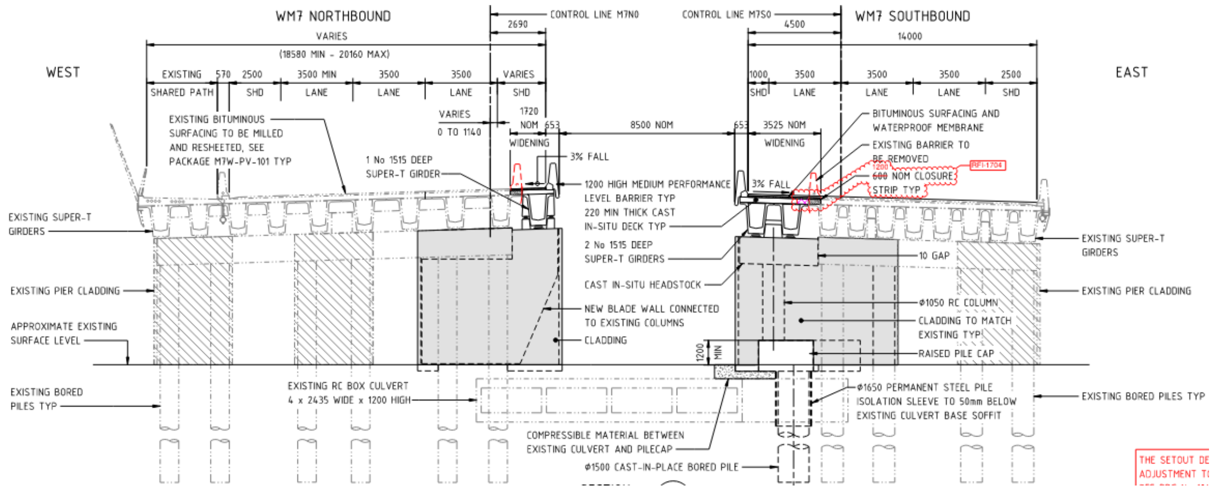

Figure 16. Pier 1 Arrangement at Bridge Widenings Infra 27.0/27.1

3.4.3.3 Abutments and Piers of Bridge Widenings Infra 32.1/32.2

The design of abutments and piers of bridge widenings Infra 32.1/32.2 was required to accommodate a major three-cell culvert. See **Figure 17**

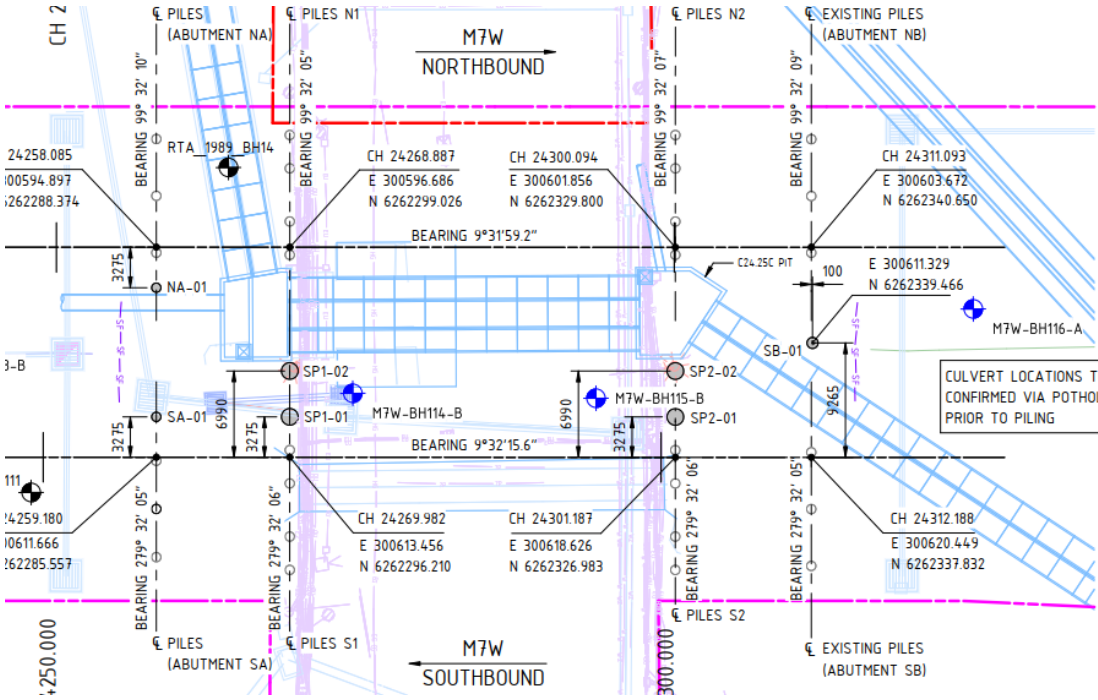

Figure 17. Site Constraint at Infra 32.1/32.2 – Existing Culvert

Bridge widenings Infra 32.1/32.2 were proposed to be supported by a combined abutment at each northern and southern end, respectively. The south abutment comprises a headstock, which is connected to and spans between the existing headstocks of the northbound and southbound bridges. Two 750 diameter bored piles are proposed to provide additional support to the headstock, each directly under the widening superstructure of Infra 32.1 and 32.2, respectively. The north abutment also comprises a headstock, which is connected to and spans between the existing headstocks of the northbound and southbound bridges. A single 900 diameter bored pile is provided to support the headstock. The pile was positioned away from the existing culvert.

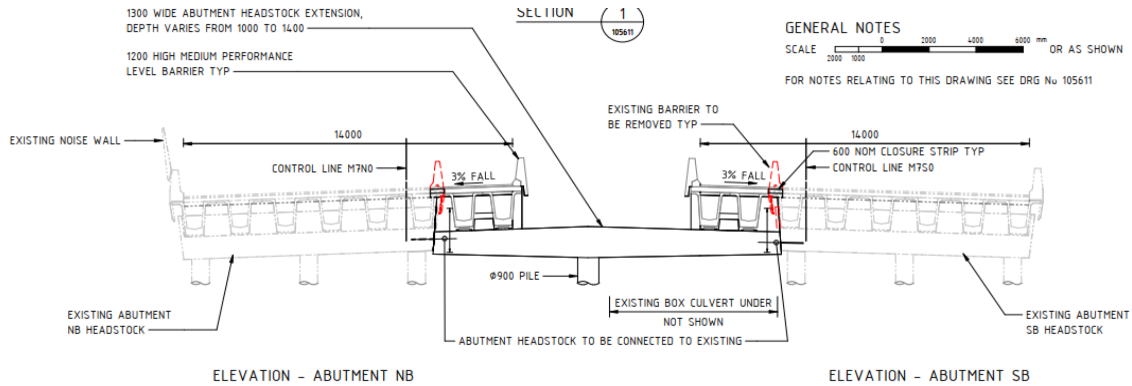

Figure 18. Combined Abutment – Northern End, Bridge widenings Infra 32.1/32.2

The widened bridge piers comprise a new headstock straddling the full width of the median to support both northbound and southbound widenings. Two 1050 mm diameter columns/1350mm diameter piles are provided to support the headstock and are positioned to avoid the existing culverts. The headstocks are integrally connected to the existing northbound pier headstocks for load transfer to support the northbound widening, but are isolated from the existing southbound pier headstocks. See **Figure 19**.

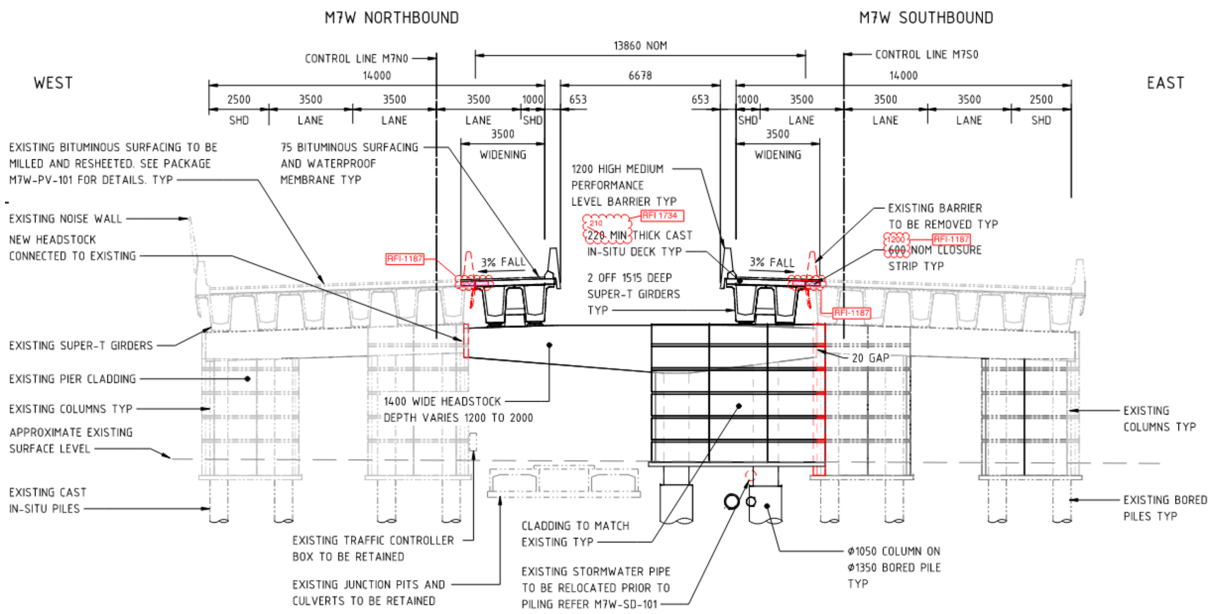

Figure 19. Combined Pier Arrangement- Bridge widenings Infra 32.1/32.2

3.4.4 Articulation

The bridge widening superstructures are supported by laminated elastomeric bearings at all piers and abutments.

In accordance with the SWTC requirements, jacking provision for the future bearing replacement for the bridge widenings was provided at abutments and piers. At the abutments, the seamless pavement approach slab/bridge deck system was designed to allow for a 10 mm vertical displacement during the jacking operations. The upward 10mm displacement of the seamless pavement during jacking is expected to induce vertical reactions onto the abutment headstocks. These reactions were considered in the design of the abutment headstocks and the associated foundations of bridge widenings with seamless pavement.

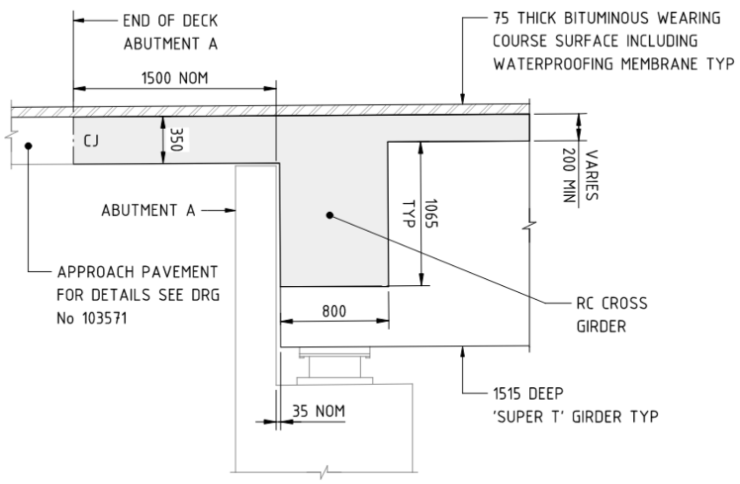

Figure 20. Typical Seamless pavement detail at the super-T bridge abutments

3.4.5 Longitudinal Closure Strip

Each widened section is proposed to be integrally connected with the existing bridge through an in-situ closure strip along the entire length of the bridge. For bridges required to carry traffic during construction, the SWTC requires that the distance between the closure strip and the nearest edge of traffic lane adjacent to the closure strip must not be reduced from the minimum distances set out in **Table 5** below until both:

A. the applicable minimum time after the completion of placement and finishing of all of the closure strip concrete ("Minimum Closure Strip Age") has elapsed; and
B. the minimum compressive strength of the closure strip concrete ("Minimum Closure Strip Strength") has been achieved.

Minimum Distance Between nearest edges of Traffic Lane and Closure Strip	Minimum Closure Strip Age	Minimum Closure Strip Strength
7 m	24 hrs	15 MPa
3.5 m	36 hrs	20 MPa

Table 5. SWTC required Minimum Traffic Clearances for Closure Strip at different Ages and Compressive Strengths

With the exception of bridges Infra 5.0, Infra 6.11, Infra 24.0 and Infra 30.0, which are wider than 14.1 m, strict adherence to the above SWTC requirements would have resulted in extended lane closures and significant disruption to motorway operations. To address this, an alternative traffic staging strategy was developed in consultation with WSO Co and TfNSW.

One critical aspect of maintaining the traffic clearance from the closure strip is to control the traffic-induced vibration on the immature concrete. The following Peak Particle Velocity (PPV) limits, as specified in Victoria DTP Technical Specification Section 610, are accepted as an indication of damage risk to immature concrete due to transmitted vibrations:

- Maximum instantaneous PPV: 55 mm/sec
- Average PPV: 5 mm/sec

To investigate the vibration response of the existing deck under the influence of live traffic, vibration monitoring has been undertaken on selected representative bridges under normal and controlled traffic conditions. The monitorings revealed that the maximum instantaneous and average PPVs at the edge of deck are less than the above limits, even when the monitoring station is located at about 1.0 m from the nearest traffic lane, therefore indicating the risk due to traffic-induced vibration is relatively low when the traffic clearance from the closure strip is reduced from that specified in the SWTC.

It is acknowledged that the vibration response of the existing deck could be different during construction of the closure strip when the existing bridge barrier is removed, hence the proposed strategy has aimed at maximising the traffic clearance as far as the existing bridge geometry permits.

Another critical aspect of maintaining the traffic clearance from the closure strip is to control the differential deflection between the new and existing decks at early age of the closure strip. This is particularly important for bridges with relatively long spans. It is understood that the SWTC requirements given in **Table 5** above have been developed for typical precast concrete plank and girder bridges with spans up to 33 m. As Infra 27.1

has a maximum span of 35 m, a higher level of deflection control is therefore deemed necessary.

To establish the deflection limit for Infra 27.1, the estimated deflection of Infra 19.10, which is a Super-T girder bridge with a span of 32.7 m, has been adopted as the benchmark. Edge of deck deflection of Infra 19.10 is estimated to be approximately 2 mm when subject to one lane of 68t B-double truck loading at a minimum traffic offset of 6.7 m from the edge of deck, whereas the edge of deck deflection of Infra 27.1 is estimated to be approximately 3 mm under the same loading condition. Temporary bracings have therefore been proposed to ensure that Infra 27.1 has a level of deflection control similar to that resulted from the minimum requirements as specified in the SWTC.

The temporary bracings comprise of a series of steel beams straddling across the closure strip and rigidly fixed to the new and existing decks at each end. The required flexural stiffness of the steel beams has been determined to ensure that the differential deflection between the new and existing decks is not more than 2 mm when subject to one lane of 68t B-double truck load at an offset of 6.7 m from the edge of the closure strip. The analysis model for the assessment of temporary bracings is shown in Figure 21. The temporary bracings are required to be installed prior to pouring of closure strip and can be removed upon the closure strip concrete reaching a minimum compressive strength of 20 MPa.

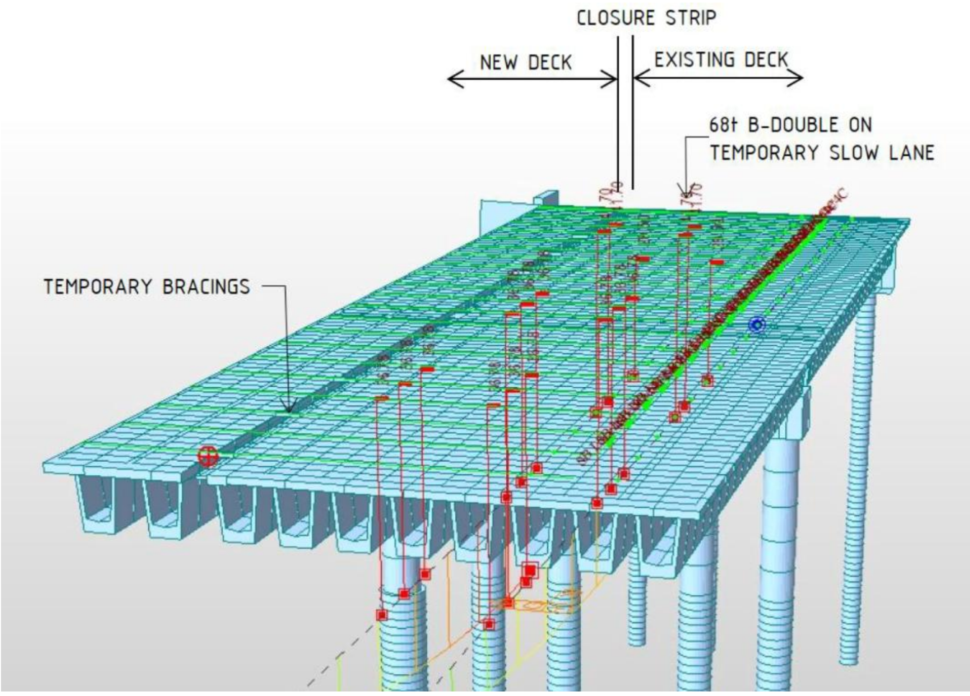

Figure 21. Analysis Model for Temporary Bracings at Infra 27.1

The traffic configurations and the corresponding speed restrictions, minimum traffic clearance to closure strip and the minimum strength of closure strips as shown in **Table 6** have been adopted.

	Infra 24.0 Infra 30.0 Infra 5.0 Infra 6.11	Infra 24.1 Infra 27.0 Infra 30.1 Infra 7.0	Infra 7.1 Infra 15.0/15.1 Infra 19.10/19.11 Infra 20.1/20.2 Infra 25.10/25.11 Infra 32.1/32.2	Infra 27.1
Traffic lane configuration	0.5 m shoulder + 2x3.3 m lanes	0.5 m shoulder + 1x3.3 m lane	0.5 m shoulder + 1x3.2 m lane	0.5 m shoulder + 1x3.3 m lane
Traffic speed limit	80 km/hr	Subject to Transport Management Centre (TMC) requirements		40 km/hr
Min. traffic clearance	7.0 m	7.0 m	6.8 m	6.7 m
Min. concrete strength	N/A	N/A	N/A	N/A
Traffic lane configuration	0.5 m shoulder + 2x3.3 m lanes	0.5 m shoulder + 2x3.3 m lanes	0.5 m shoulder + 2x3.3 m lanes	0.5 m shoulder + 1x3.3 m lane
Traffic speed limit	80 km/hr	80 km/hr	80 km/hr	60 km/hr
Min. traffic clearance	3.5 m	3.5 m	3.4 m	6.7 m
Min. concrete strength	15 MPa	15 MPa	15 MPa	20 MPa
Traffic lane configuration	-	-	-	0.5 m shoulder + 2x3.3 m lanes
Traffic speed limit	-	-	-	80 km/hr
Min. traffic clearance	-	-	-	3.4 m
Min. concrete strength	-	-	-	32 MPa

Table 6. Adopted Traffic Lane Configurations and associated Speed Limits, Minimum Traffic Clearances and Compressive Strengths for Closure Strip

For Infra 27.1, the vibration response of the existing deck nearest to the closure strip and the differential deflection between the longitudinal edges of the closure strip have been monitored during construction to validate the behaviour of the structures. The monitoring confirmed that the vibration and differential deflection limits have both been satisfied during construction.

Structural assessment has been undertaken to demonstrate that flexural cracking of the closure strip is adequately controlled as per the requirements of AS 5100.5 Clause 9.4.1 for the corresponding traffic lane configurations, based on two lanes of 68t B-double travelling on the temporary traffic lanes upon the closure strip concrete has attained a minimum compressive strength of 20 MPa.

The closure strips are nominally 1200 mm wide to accommodate double-lapped splices between the new and existing transverse deck reinforcement. This detailing allows installation of the new deck reinforcement prior to removal of the existing barrier, ensuring that traffic protection is maintained throughout construction staging. The transverse reinforcement are triple tied over the lapping region to minimise the risk of differential displacement. Longitudinal reinforcement of the closure strip is typically N16 at 100 mm centres each face to provide a suitable degree of crack control against restrained shrinkage from the new and existing decks.

The closure strip concrete is specified to have a minimum 28-day compressive strength of 50 MPa in accordance with TfNSW Specification D&C B80. Durability performance was also considered, including the effects of reduced cover to existing reinforcement within the interface zone. The adopted detailing and material specification ensures that the closure strip satisfies the project's 100-year design life requirements.

3.4.6 Seamless Pavement

Seamless pavement was proposed to be widened to accommodate the bridge widenings to emulate the same bridge/pavement interaction behaviour with the existing bridges. The seamless pavement design results in continuity between bridges and approach pavements; this continuity will restrain the bridge movements that normally occur in a conventional free-floating system. Strains due to temperature, concrete shrinkage and concrete creep are critical to the behaviour of the overall structure.

The design methodology adopted for the design of the seamless pavement for the widening is based on the original design from 2004. The main differences in this methodology are related to concrete properties adopted, which are in accordance with the current AS 5100.5:2017 standard, and other design provisions specific to the project, eg. settlement allowance and jacking provision for future bearing replacement.

A longitudinal analysis was undertaken for the two scenarios which produce maximum compression and tension, respectively in the seamless pavement slab/bridge deck system.

- **Scenario 1**: the seamless pavement is cast during summer which produces maximum tension force.
- **Scenario 2:** the seamless pavement is cast during winter which produces maximum compression force.

The longitudinal seamless pavement model adopted the same design parameters with the original design. This is a conservative design approach as the bridge widening and the seamless pavement widening are restrained by the existing elements and are not subject to the same movements due to thermal, creep and shrinkage. Tension stiffening is also considered in the calculation of crack widths. A friction coefficient of $\mu = 1.5$ was assumed between pavement and sub-base. Sensitivity of the results was tested with a range of friction co-efficient between 0.5 and 2.0. The axial force obtained from the longitudinal analysis of the seamless pavement was adopted in the design of the Super-Ts. Heavy longitudinal reinforcement was provided in the transition slab to control cracking.

A flexure analysis was undertaken for the seamless pavement to consider settlement and jacking provision for bearing replacement. Pavement subgrade stiffnesses were derived from modulus of subgrade reaction and interpretation of Young's modulus of soil. Sensitivity analysis has been undertaken by varying the subgrade stiffnesses by 50% and 200% to account for possible variations in the assumed stiffnesses. Allowance was made for lack of support immediately behind the bridge abutment, which is a function of the embankment settlement, bridge movement and loading condition. A long-term settlement of 30 mm was adopted in the design of the seamless approach pavement for the widenings based on the estimated post-construction settlement. An allowance of 10 mm of bridge jacking for future bearing replacement was considered as separate load case. In addition, SM1600 vehicular loads were also applied to the approach pavement to determine the maximum design action effects. Dynamic load allowance (DLA) of 0.3 has been allowed in the analysis except for the jacking case in which the DLA has been reduced to 0.1 in accordance with the requirement of TfNSW BTD 2018/01.

4.0 Conclusion

The M7-M12 Integration Project demonstrates an effective and adaptable approach to widening existing Super-T girder bridges within a highly constrained and operational motorway corridor. The outcomes of this work highlight how established bridge typologies can be extended and upgraded while maintaining structural performance, constructability and long-term durability.

Firstly, the integral widening strategy has proven to be both practical and robust. By adopting compatible Super-T girders, longitudinal closure strips and largely independent substructures, the widened bridges are able to act compositely with the existing structures while minimising intervention to the original elements. The elimination of longitudinal joints provides clear benefits in terms of improved ride quality, enhanced safety and reduced lifecycle maintenance requirements.

Secondly, the interaction between the bridges and the seamless pavement system is confirmed as a governing design consideration. The design appropriately accounts for axial forces induced by restrained thermal movements, creep and shrinkage within the structural system, including their secondary effects on girder behaviour. By extending the original seamless pavement philosophy to the widened structures, the design maintains continuity and achieves compliance with strength, serviceability and durability requirements.

Thirdly, the project highlights the importance of integrating constructability into the design of bridge widenings in brownfield environments. The use of staged construction, closure strip optimisation and targeted bespoke substructure solutions enabled delivery adjacent to live traffic while addressing significant constraints such as existing services, major drainage assets and reinforced soil walls. Durability considerations, including carbonation assessment for the reduced cover zone, confirmed that the closure strip can meet the required 100-year design life.

The two-tier seismic assessment provided a rational means of demonstrating compliance with the project-specific requirements for the combined widened bridges. The assessment confirmed that the proposed integral widening does not require strengthening of the existing structures for seismic design actions. Overall, the design approaches developed for the M7-M12 Integration Project provide a valuable reference for future bridge widening works on similar motorway networks. In particular, the integration of structural compatibility, seamless pavement interaction and construction staging offers a holistic framework for delivering efficient, safe and durable upgrades to existing bridge assets in congested urban environments.

5.0 Acknowledgements

The authors acknowledge John Holland Group, as the main works contractor, for their collaborative engagement and support during the development and delivery of the bridge widening design; the Western Sydney Orbital Company (WSO Co), as motorway owner and operator, for their leadership and stewardship of the M7–M12 Integration Project; and Transport for New South Wales (TfNSW) for their technical guidance, governance and input in establishing the project requirements and design framework.

6.0 Author Biographies

Kenny Luu is a Chartered Engineer (CPEng) and a Fellow of Engineers Australia (FIEAust) with over 23 years of extensive industry experience in the design and verification of bridges, earth retaining structures and other civil structures and 3 years research experience in various structural and geotechnical engineering topics. He possesses strong technical skills and an in-depth understanding of constructability requirements. These attributes together with a strong commitment to delivering the best possible engineering solutions to clients have enabled him to repeatedly achieve innovative and cost-effective design solutions for tenders and projects.

On the M7M12 Integration Project, Kenny was the Jacobs SMEC Design Joint Venture (JSJV) Bridges and Structures Discipline Lead during the tender design and detailed design stages.

TC Lee is a Chartered Engineer and member of Engineers Australia (MIEAust) and the Institution of Structural Engineers (MIStructE), with over 25 years of experience in the design and construction of bridges and civil infrastructures for major highway and railway infrastructure projects across Australia and Hong Kong. TC's extensive involvement in infrastructure projects ensures practical and technically sound solutions that address both construction and stakeholder requirements. His multidisciplinary knowledge in transportation projects supports the delivery of cohesive and efficient bridge designs.

On the M7M12 Integration Project, TC was the Jacobs SMEC Design Joint Venture (JSJV) Bridge Technical Lead during the detailed design stage and construction phase support.

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