An Overview of the Widening Design of the Plank 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.

Thirteen existing plank bridges are to be widened typically by a 3.5 m width to accommodate an additional lane into the median. The widening bridges are proposed to comprise 3 No. 450 mm deep side by side planks 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 plank design was required to account for the effects 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.

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 the 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 plank bridges.

Keywords: M7M12 IP, side-by-side planks, 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.

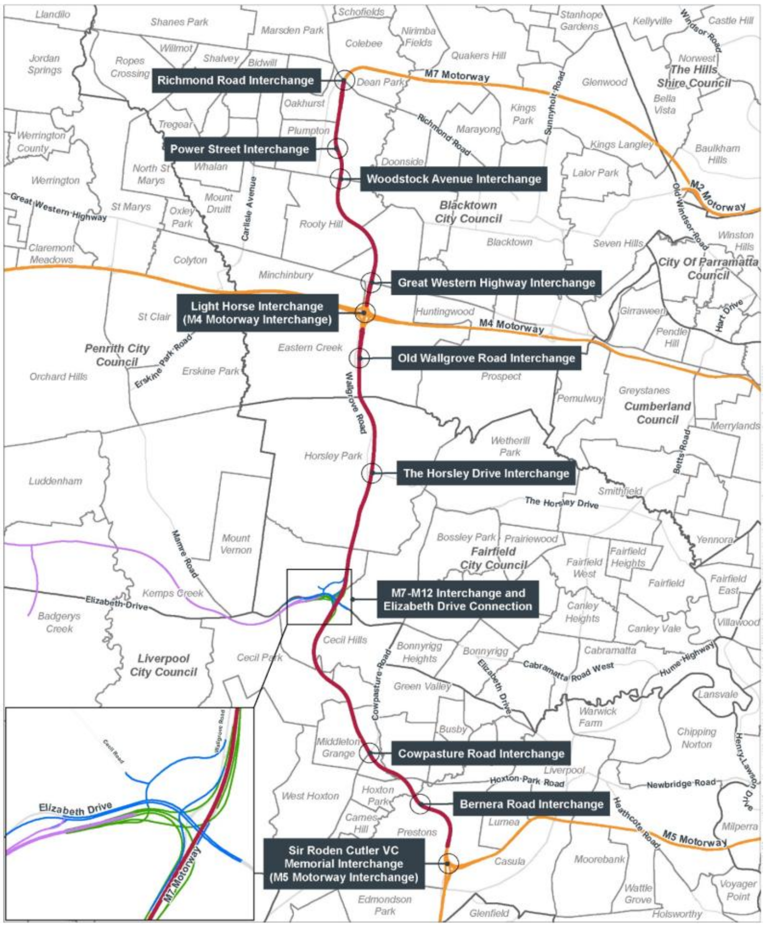

Figure 1. M7-M12 Integration Project extent

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. Thirteen of these bridges are plank bridges as summarized in **Table 1**

Infra No.	Bridge name	Approx. bridge length (m)	No. of spans	Max. span length (m)
5.4	WM7 N/B over Maxwells Creek Flood Plain near Stn 2140	55.5	4	14.0
12.0 / 12.1	WM7 over Shared Path & Waterway near Stn 6820	77.0	6	15.0
13.0 / 13.1	Bridges over Hinchinbrook Creek near Stn 8235	66.4	5	15.0
22.10 / 22.11	WM7 over Redmayne Road near Stn 15170	43.5	3	15.0
25.20 / 25.21	WM7 N/B & S/B over Reedy Creek near Stn 17940	80.5	6	15.0
25.92 / 25.93	WM7 over Reedy Creek Tributary near Stn 18380	35.0	3	14.0
35.1 / 35.2	WM7 over Shared Path at Florence Street near Stn 26420	12.0	1	12.0

Table 1. Plank Bridges to be widened

2.0 Existing Design

2.1 Existing Superstructure

The existing bridge superstructure typically comprises simply-supported 450mm deep side-by-side precast planks acting compositely with a cast in-situ reinforced concrete deck slab with minimum thickness of 160mm. Three types of plank widths, 1180mm, 1050mm and 600mm are used to accommodate the required deck widths and provide space provision for under deck drainage and utilities.

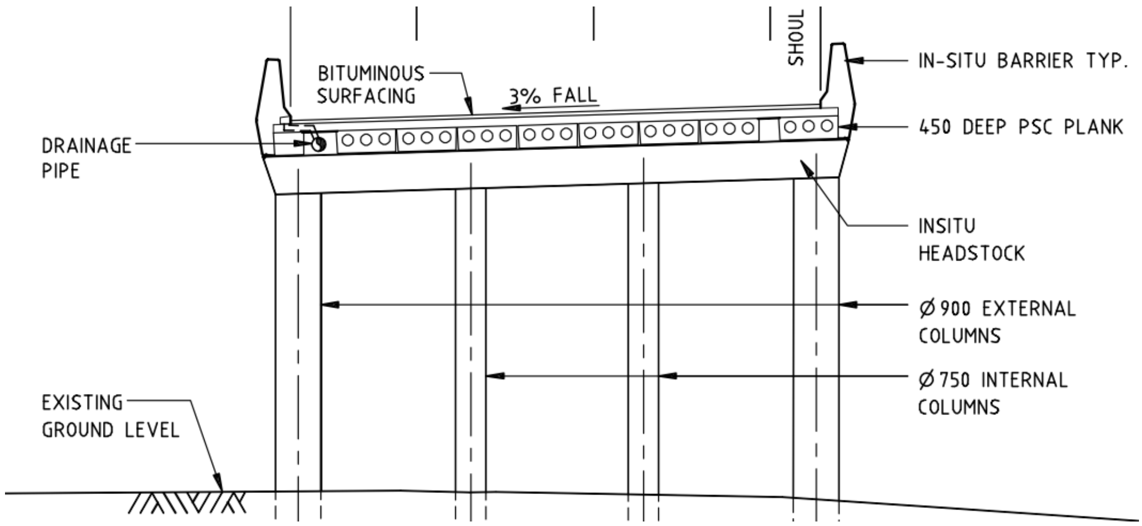

Figure 2. Typical Cross-Section at Pier – Existing Plank Bridges

2.2 Existing Substructure

With the exception of the single-span bridges Infra 35.1/35.2 over the shared path at Florence Street, the existing bridge substructure typically comprises piers with reinforced concrete headstocks supported on reinforced concrete columns. The outer columns are typically 900 mm in diameter, while the inner columns are of smaller 600mm and 750mm diameters. Each column is supported on a cast-in-situ reinforced concrete bored pile having the same diameter as the column. Refer to Figure 2.

The existing abutment comprises of reinforced concrete headstock supported on 750 dia concrete bored piles. For the bridges Infra 5.0, Infra 12.0/12.1, Infra 13.0/13.1, Infra 25.20/25.21, Infra 25.92/25.93 carrying the M7 Motorway over creeks or flood plains, spill through batters with scour protection are provided at the abutments. For bridges Infra 35.1/35.2 reinforced soil walls are provided at the abutments to retain the embankment from encroaching onto the Shared Path.

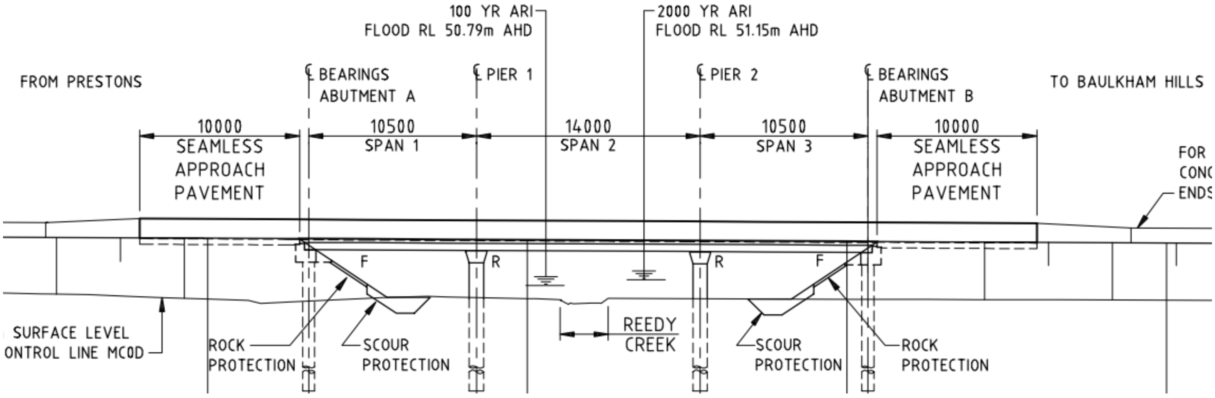

Figure 3. Typical Elevation – Existing Plank Bridges over Creeks/Flood Plains

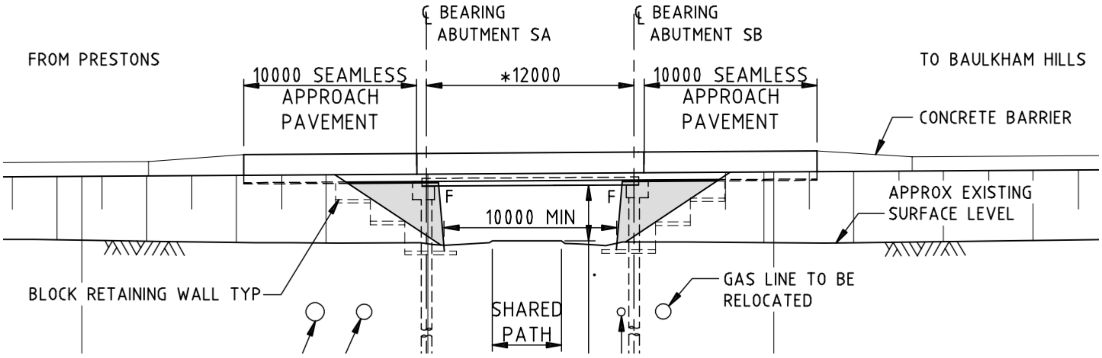

Figure 4. Elevation – Existing Plank Bridges Infra 35.1/35.2 over Shared Path at Florence Street

2.3 Existing Bridge Articulation

All the existing plank bridge superstructures are supported on unreinforced elastomeric strips over piers and abutments with the exception of bridges Infra 12.0/12.1, Infra 13.0/13.1 and Infra 25.20/25.21 where laminated elastomeric bearings were adopted at the piers and abutments.

2.4 Existing Bridge Barriers

Full-height concrete barriers were provided on the existing plank bridges with the exception that single steel rail with concrete parapet barriers were provided on bridges Infra 13.0/13.1.

2.5 Key Constraints

The widening design of the plank 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 plank bridge widenings align with the existing bridges and were checked to ensure that they do not encroach the constraints.

2.5.2 Interaction with the Existing Bridges

The bridge widenings were made integral with the existing bridge via a longitudinal closure strip 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 eliminates the need for a longitudinal joint, which would have been otherwise required to isolate the two bridges and the 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 parameter 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, maximising the use of precast elements and staged construction via the implementation of longitudinal closure strips, 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 plank bridges.

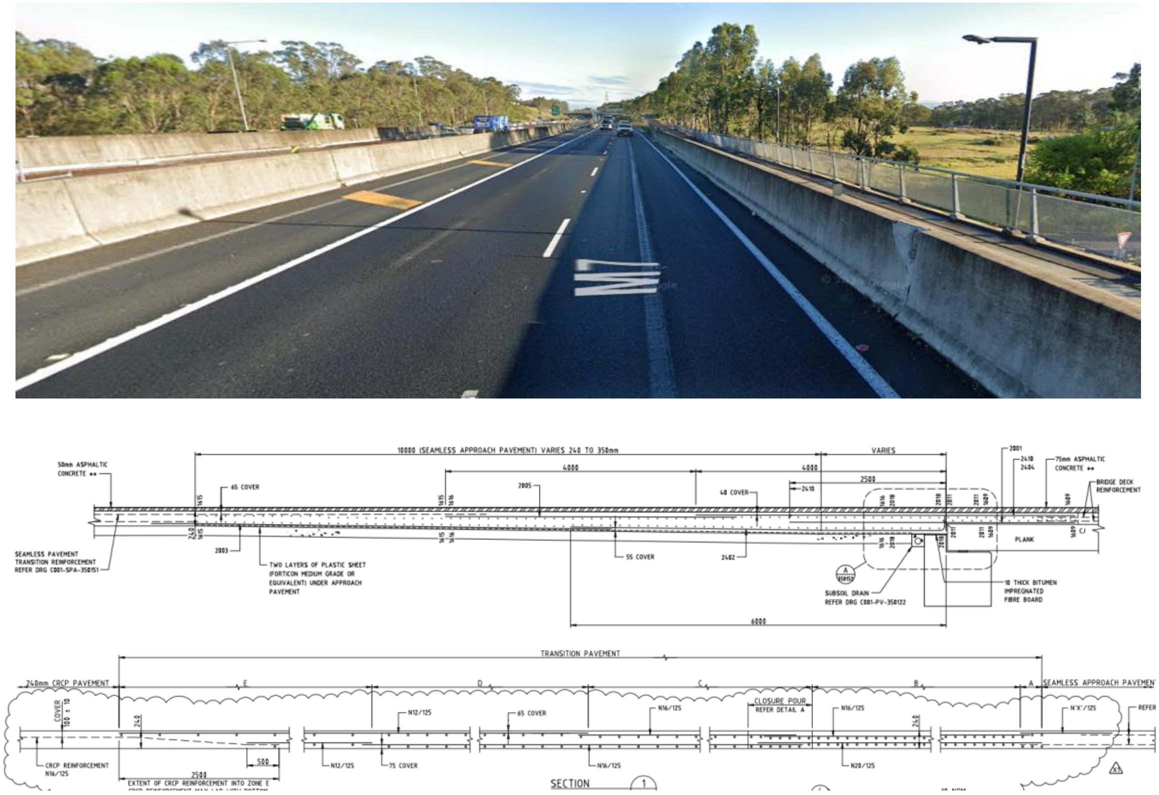

Figure 5. Typical Seamless Pavement Detail – Photo: Courtesy Google.

The seamless pavement contracts and expands in response to the fluctuation in temperatures, which are then restrained by the bridge. Depending on the temperature at the seamless pavement 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.

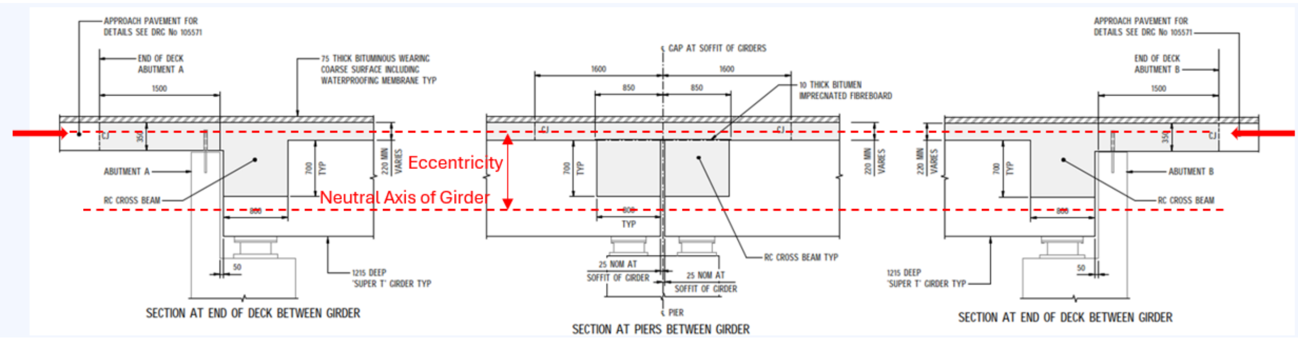

Figure 6. Eccentricity Effect Due to Seamless Pavement on Bridge Girders.

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 an additional 3.5 m lane in each direction into the median between the carriageways. The plank bridge widenings occur on straight alignment and have therefore been affected by the additional 3.5m lane width requirement, with the following exception:

The widening of Northbound Bridge over Maxwell Creek Flood Plain (Infra 5.4) and Northbound Bridge over Hinchinbrook Creek (Infra 13.0) occurs on a curve. This requires lane widening within the middle northbound lane of 300mm, making the required bridge widening 3.8m.

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 were 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/m^3 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/m^3.

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 effect, an 75 mm-eccentricity (out of plane) is 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.

HLP400 loadings have not been considered for integral plank bridge widenings less than 7m wide in accordance with the requirements of the SWTC.

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 20MPa, the closure strips between the widening and the existing bridges were assessed for B-Double 68t truck loading (as shown in **Figure 7**) positioned within two 3.3m wide temporary traffic lanes on the existing bridges. 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.

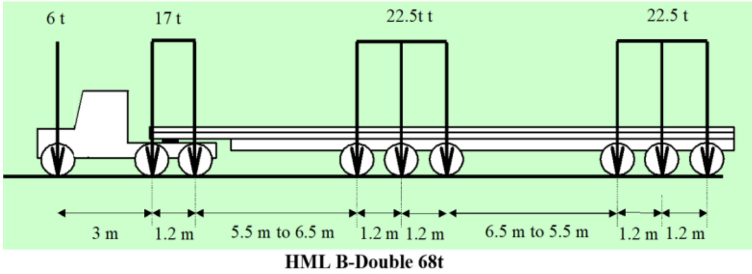

Figure 7. B-Double 68t.

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 is 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 only applies to the piers of bridge widenings Infra 22.10/22.11 which are adjacent to Redmayne Road.

3.2.1.16 Earthquake Loads and Seismic Design Approach

The SWTC stipulates that the M7 bridge widenings were 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 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 follows:

Earthquake Assessment 1 – AS5100:2017-BEDC4 Assessment:

In the first EQ assessment model, the combined bridge was 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) is 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 8

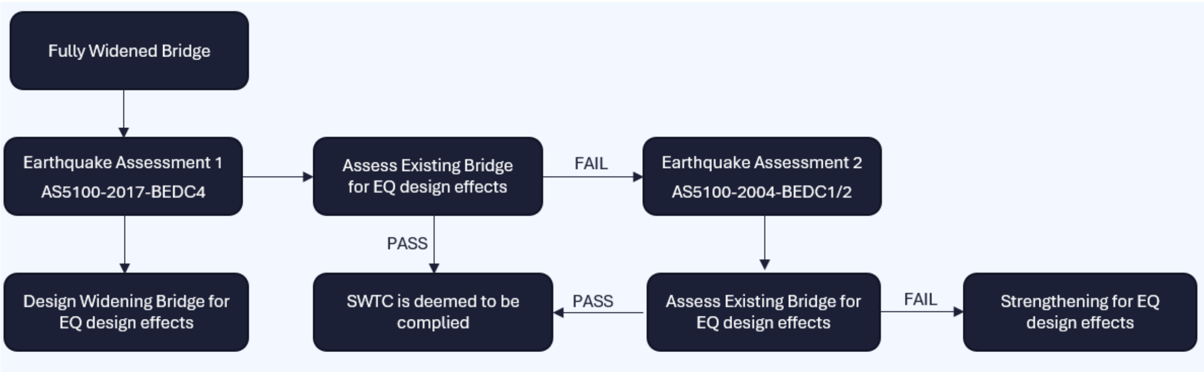

Figure 8. EQ Design Flow Chart

The above seismic assessment confirmed that strengthening of the existing structure for seismic design actions was 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 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 precast planks 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 comprises 3 No. of 450 mm deep side-by-side pre-tensioned precast planks, which have a typical standardised width of 1050 mm to simplify the fabrication. The gaps between the planks were varied between bridges to accommodate different widening widths, as required. See **Figure 9**.

A 40 MPa cast-insitu concrete deck slab was provided to act compositely with the pre-tensioned planks. The deck slab thickness was proposed to be of 220 mm minimum 200 mm minimum for bridge widenings with full-height precast barriers and with single steel rail with concrete parapet barriers, respectively. The minimum deck thickness adopted was designed to ensure that the design ultimate capacity of the bridge deck exceeds 1.1 times the design ultimate capacity of the barrier connection to the deck as required by AS 5100.2, Clause 12.3.

Infra. No.	Bridge Name	Minimum Deck Thickness
5.4	WM7 N/B over Maxwells Creek Flood Plain near Stn 2140	220 mm
12.0 / 12.1	WM7 over Shared Path & Waterway near Stn 6820	220 mm
13.0 / 13.1	Bridges over Hinchinbrook Creek near Stn 8235	200 mm
22.10 / 22.11	WM7 over Redmayne Road near Stn 15170	220 mm
25.20 / 25.21	WM7 N/B & S/B over Reedy Creek near Stn 17940	220 mm
25.92 / 25.93	WM7 over Reedy Creek Tributary near Stn 18380	220 mm
35.1 / 35.2	WM7 over Shared Path at Florence Street near Stn 26420	220 mm

Table 2. Widening of plank bridges minimum deck thickness

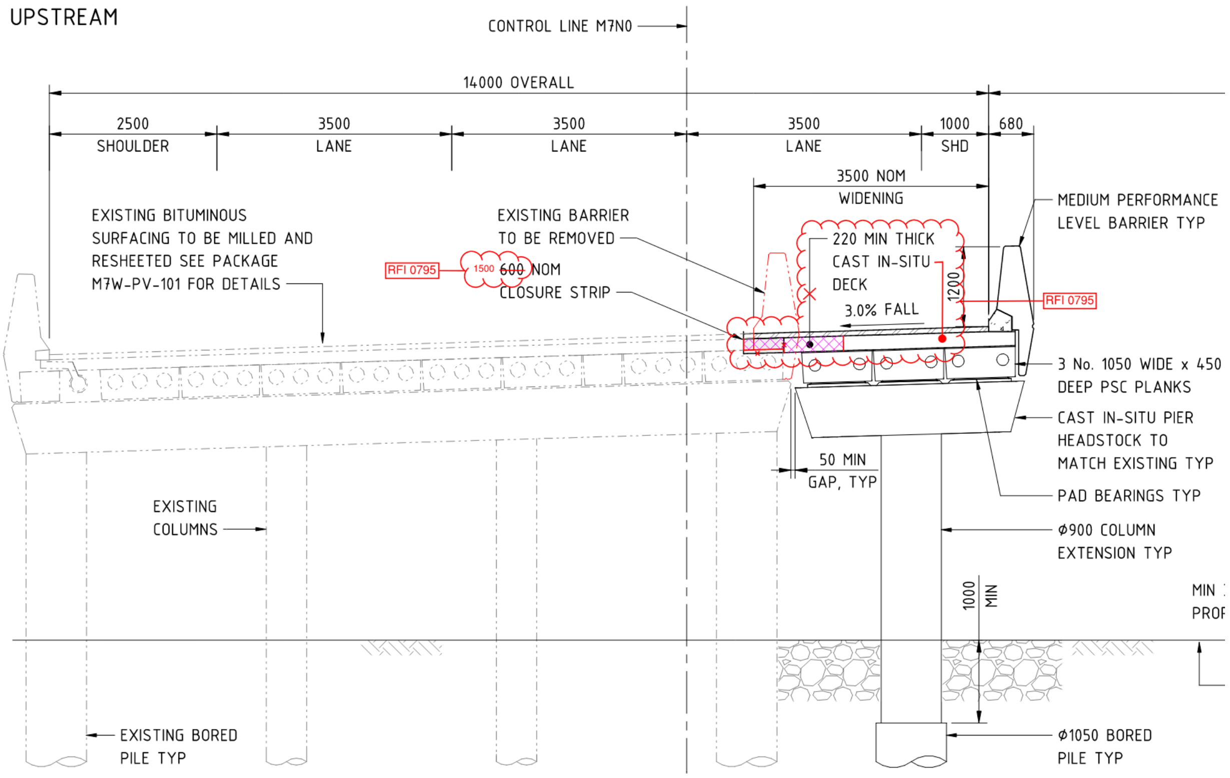

Figure 9. Typical bridge widening section over Piers– Plank Bridges

Localised debonding was provided over 50mm width at the edges of the planks to provide enhanced flexibility in the desk slab to mitigate longitudinal crack risks. Couplers were provided at the ends of the planks in the end spans to make connections with the seamless pavement transition slabs. See **Figure 10**.

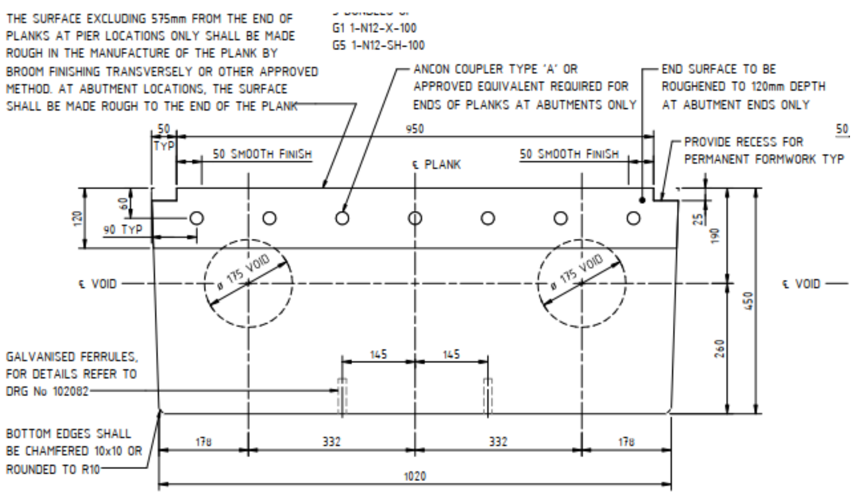

Figure 10. Typical Pre-tensioned 1050mm wide Planks Details

In the proposed arrangement, the depth of the composite plank 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 planks.

3.4.2 Sub-structure

The bridge widenings were proposed to be supported on concrete piers, which are independent from the existing piers. This aimed to avoid drilling into the existing pier headstocks which were not designed with widening provisions to facilitate constructability. Each pier typically comprises a headstock supported on a 900 mm diameter column which in turn is supported by a 1050 mm diameter bored pile. At bridges Infra 22.0/22.1, each pier is supported on a 1200 mm diameter column on a 1350 mm diameter bored pile to accommodate a traffic collision load in accordance with AS 5100.2.

Each abutment typically comprises a headstock supported by a single 750 mm diameter bored pile, except for Infra 35.1/35.2 of which 1050 mm diameter pile was used to reduce the connection requirement with the existing abutment. 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 3** below summarises the adopted connection arrangements.

Infra No.	Bridge name	Abutment connection arrangement
5.4	WM7 N/B over Maxwells Creek Flood Plain near Stn 2140	Integrally connected to existing
12.0 / 12.1	WM7 over Shared Path & Waterway near Stn 6820	Dowelled to existing with cross beam provided between the new abutments
13.0 / 13.1	Bridges over Hinchinbrook Creek near Stn 8235	Integrally connected to existing
22.10 / 22.11	WM7 over Redmayne Road near Stn 15170	Dowelled to existing with cross beam provided between the new abutments

25.20 / 25.21	WM7 N/B & S/B over Reedy Creek near Stn 17940	Dowelled to existing with cross beam provided between the new abutments
25.92 / 25.93	WM7 over Reedy Creek Tributary near Stn 18380	Dowelled to existing with cross beam provided between the new abutments
35.1 / 35.2	WM7 over Shared Path at Florence Street near Stn 26420	Dowelled to existing

Table 3. 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 bridges Infra 35.1/35.2, a reinforced concrete L-shaped retaining wall with a maximum retained height of approximately 3.5m was provided in between the Northbound and Southbound bridge abutments reinforced soil walls at each bridge end to support the abutment earthworks.

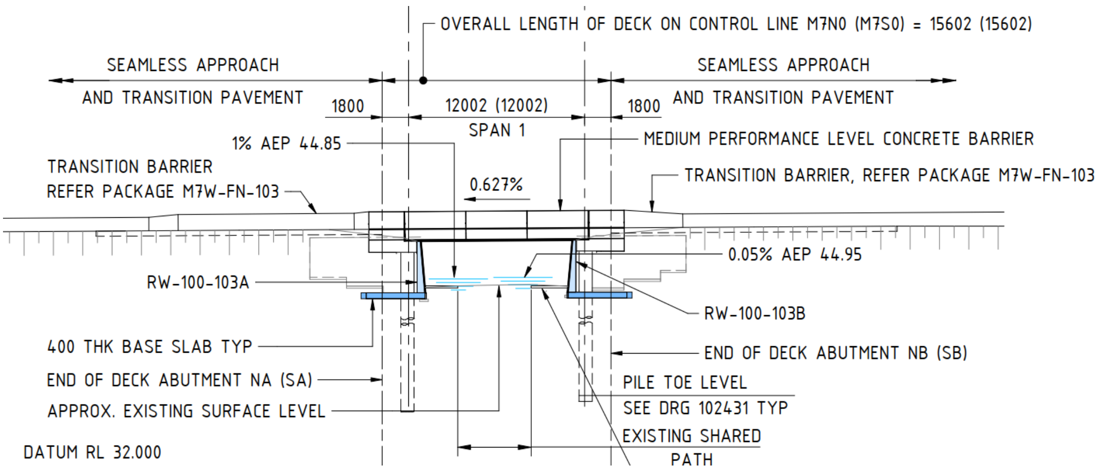

Figure 11. Abutment Elevation and Retaining Wall at Bridges Infra 35.1/35.2

3.4.3 Articulation

The proposed articulation for the bridge widening is compatible with the existing bridge in that unreinforced elastomeric strips are proposed at piers and abutments with the exceptions of bridges Infra 12.0/12.1, Infra 13.0/13.1 and Infra 25.20/25.21 where laminated elastomeric bearings were adopted at the piers and abutments. The bearing strips were checked for all design loadings including the provision of additional rotational allowance for construction tolerance in accordance with AS 5100.4.

In accordance with the SWTC requirements, jacking provision for the future bearing replacement for the bridge widenings was to match the existing conditions. 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. However, jacks were assumed not to be placed on the abutments or pier headstocks due to the limited available space.

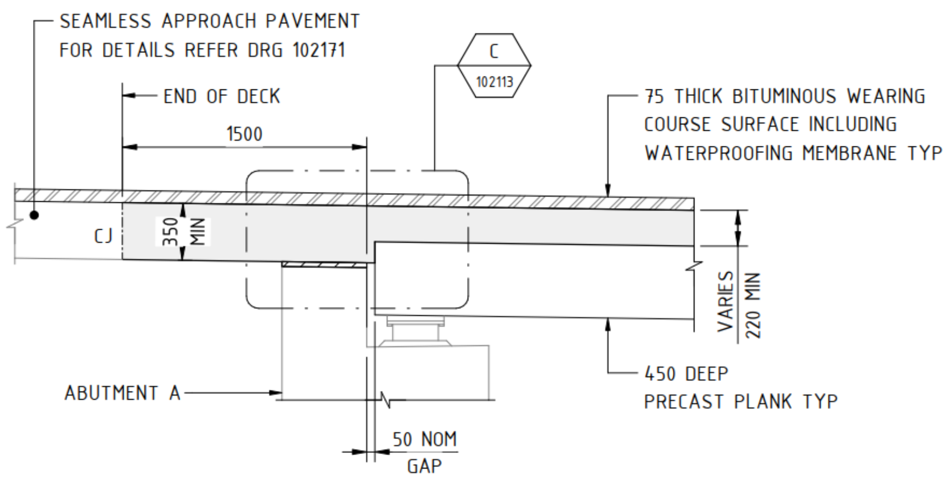

Figure 12. Abutment Elevation with Seamless pavement

3.4.4 Longitudinal Closure Strip

Each widened section was 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 4** 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 4. SWTC required Minimum Traffic Clearances for Closure Strip at different Ages and Compressive Strengths

With the exception of Infra 5.4, which is wider than 14.4 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, were 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 of Infra 12.1 has been undertaken under normal and controlled traffic conditions when the traffic lane is as close as 1.1 m from the proposed edge of closure strip. The monitoring revealed that the maximum instantaneous and average PPVs at the edge of deck were considerably less than the above limits, therefore indicating the risk due to traffic-induced vibration was relatively low when the traffic clearance from the closure strip is reduced from that specified in the SWTC.

It was 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. 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 5** have been adopted.

	Infra 5.4	Infra 13.0/13.1 Infra 25.93	Infra 25.92	Infra 12.0/12.1 Infra 22.10/22.11 Infra 25.20/25.21 Infra 35.1/35.2
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 + 1x3.2 m lane
Traffic speed limit	80 km/hr	Subject to Transport Management Centre (TMC) requirements		
Min. traffic clearance	7.0 m	7.0 m	6.8 m	6.5 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 + 2x3.3 m lanes
Traffic speed limit	80 km/hr	80 km/hr	80 km/hr	80 km/hr
Min. traffic clearance	3.5 m	3.5 m	3.4 m	3.1 m
Min. concrete strength	15 MPa	15 MPa	15 MPa	20 MPa

Table 5. Adopted Traffic Lane Configurations and associated Speed Limits, Minimum Traffic Clearances and Compressive Strengths for Closure Strip

Vibration monitoring undertaken during construction of the closure strip confirmed that the adopted vibration limits was not exceeded.

Structural assessment was 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 were nominally 1500 mm wide to accommodate double-lapped splices between the new and existing transverse deck reinforcement. This detailing allowed the 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 ais 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 was specified to have a minimum 28-day compressive strength of 50 MPa in accordance with TfNSW Specification D&C B80, and was subject to minimum 14 days of wet curing. Durability modelling was also undertaking, including the effects of reduced cover to existing reinforcement within the interface zone demonstrated that the closure strip satisfies the project’s 100-year design life requirements.

3.4.5 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 resulted in continuity between bridges and approach pavements; this continuity will restrain the bridge movements that would normally occur in a conventional free-floating system. The 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 was 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 was also considered in the calculation of crack widths. A friction coefficient of μ = 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 planks. 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 was 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 a 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 widening of the plank bridges on the M7-M12 Integration Project demonstrates a practical and robust approach to increasing motorway capacity while maintaining compatibility with the existing bridge and pavement systems. By adopting 450 mm deep side-by-side precast planks, integral longitudinal closure strips and independent widening piers, the design provides a structurally efficient solution that emulates the behaviour of the existing bridges while minimising impacts on existing substructures, services and live motorway operations.

A key design consideration was the interaction between the widened bridge, the existing structure and the seamless CRCP approach pavement. The design accounted for axial forces generated by restrained thermal movement, creep and shrinkage, as well as the associated eccentric effects on the plank girders. The adopted analysis and detailing approach enabled the widening to preserve the original seamless pavement concept while satisfying strength, serviceability, crack control and future jacking requirements.

The integral connection to the existing bridge via longitudinal closure strips also eliminated the need for a longitudinal movement joint, thereby improving road user safety and reducing future maintenance demands. The closure strip was detailed to support staged construction adjacent to live traffic, with checks undertaken at early-age and final concrete strengths. 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 widening design balances structural performance, constructability, durability and maintainability, providing a repeatable solution for widening existing plank bridges within a constrained and operational motorway corridor.

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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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