Design and Construct Bridge Structures on the Western Ring Road – Calder Freeway Interchange

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1 INTRODUCTION

The Western Ring Road provides a minimum two-way two-lane circumferential freeway link from the Princes Freeway near Laverton through the northern suburbs of Melbourne to the Greensborough Highway, a distance of approximately 40km. Along the route of the new Ring Road there are a number of major grade separation structures and intersections. Sinclair Knight Merz was responsible for the design and documentation of the Calder Freeway Interchange at Keilor. This section includes a total of 7 road bridge structures and 1 pedestrian bridge structure. The total capital cost for the Western Ring Road was in the order of $800 million.

This paper presents a brief summary of the different bridge types adopted and the factors influencing the choice of structure type in each instance.

2 CALDER FREEWAY INTERCHANGE AT KEILOR

VicRoads, Fletcher Construction Australia and Sinclair Knight Merz were responsible for the delivery of the $30 million first stage of the Calder Interchange. The interchange was designed to connect the Calder Freeway to the Western Ring Road and was constructed in two stages under separate contracts so that disruption to traffic on the Calder Freeway was minimised, refer to Figure 1. The first stage involved the widening of the existing pavements on the Calder Freeway over 2.5km, the construction of four road bridges, three bridges over rail lines and the extension of an existing pedestrian footbridge. The second stage, let under a separate contract to another contractor, involved the construction of a further six bridges and widening of two bridges over the railway lines. Both contracts were required to be completed within a 90 week contract period. Construction commenced in May 1994.

2.1 Purpose of Bridges

Fullarton Road Bridge

Fullarton Road formerly ran parallel to the Calder Freeway between Matthews Avenue to the east and Keilor Park Drive to the west, providing vehicular access to private housing on the northern side of the freeway. Construction of a grade separation structure over the proposed Western Ring Road was required to maintain this access.

The bridge carries two lanes of traffic (one in each direction) and has a 2m wide footpath located along the northern side of the bridge.

Ramp A Bridge
This bridge was provided to allow vehicles travelling north along the Western Ring Road to exit off the Ring Road and join the Calder Freeway, leading back into Melbourne. The bridge is constructed parallel to the Fullarton Road Bridge and spans over the Western Ring Road, Ramp C and Ramp D.

Ramp C Bridge
Ramp C provides access for traffic heading south along the Western Ring Road to exit north towards Bendigo along the Calder Freeway.

Ramp D Bridge
This bridge provides access for southbound traffic from the Calder Freeway to enter the westbound carriageway of the Western Ring Road. As well as being curved in plan, it has a high skew. (21° at the west abutment, 30° at the east abutment)

Fullarton Road over Rail Bridge, Ramp A Rail Bridge and Ramp B Rail Bridge
Ramp A and Ramp B Rail Bridges were provided to allow access on or off the Western Ring Road, and Fullarton Road over Rail Bridge was required to maintain access to the existing access road. All three bridges over the Albion to Broadmeadows Rail Line provide for two lanes of traffic. The Fullarton Road over Rail Bridge also included a pedestrian footpath. Each bridge comprises three simply supported spans varying in length from 11.4m to 15.2m.

Collinson Street Footbridge
The existing Collinson Street Footbridge over the Calder Freeway required extension to provide access over both Ramp C and E. The existing circular ramp at the southern end of the bridge was demolished and the bridge extended at the south end with 4 additional spans.

General features of these bridges are given in Table 1.

2.2 Choice of Bridge Type

2.2.1 Road over Road Bridges

The four road bridges were all to be constructed over the Western Ring Road (WRR) and adjoining entry and exit ramps. Due to the geometry of the interchange all the bridge structures were required to be curved in plan, of varying span length and, as they were to be clearly visible from the road, their appearance was important. In all cases the new bridges were constructed only 2m to 3m above the existing ground level with the Ring Road, entry and exit ramps constructed (as part of this contract) in cut under the bridges. Therefore the construction of the falsework required to support formwork for an insitu concrete superstructure was comparatively straightforward. Considerations including the centrifugal forces, spans up to 50m, large eccentric traffic loading and the need to provide torsional strength and stiffness favoured the adoption of enclosed box sections.

The use of precast elements such as super 'T' beams was not considered practical, economical or aesthetically acceptable. The span lengths required to achieve horizontal clearances from the Ring Road were outside the design limits for standard precast beams. Such beams are more suited for use on bridges of straight alignment and with spans less than 35m. They also generally have economical advantages when there is a requirement to construct over trafficked roads, rail or rivers where the cost of falsework is higher. Therefore there appeared to be no economic advantage in the use of precast beams for this part of the project (road over road bridges).

As the Western Ring Road did not exist, construction over trafficked roads was not required. Hence launched and segmental construction was clearly not justified.

Appearance was a significant consideration for these bridges, and was an important consideration in the decision to adopt box girders for the superstructure rather than a beam-slab construction. The box girder provides a smooth simpler shape with less dark pockets. The lines of the structure follow the road alignment rather than comprising a series of straight lines. Single cell and twin cell box girder structures were adopted, consistent with the concept details proposed in the tender documentation by VicRoads.

The substructures for these bridges consisted of insitu concrete wall piers on pad footings or bored piles.

2.2.2 Road over Rail Bridges

All three bridges over the Albion Broadmeadows Rail Line had been fully designed by VicRoads prior to calling tenders. Although the bridges were slightly curved in plan, their relatively short span (15.2m maximum span) favoured the use of precast beams, as the flange widths could be cast to accommodate minor changes in their width to create the curved plan shape. The only drawback with adopting short spans and the use of precast units was the requirement to construct piers within the rail cutting. However, since these new bridges were required to accommodate future tracks, the piers were generally located at the outside of the existing tracks and adjacent to future tracks. Thus, the area for the future tracks provided a relatively safe working area. Precast units using super 'T' beams offered the cheapest option as they could save time, provide good quality and maintain safety whilst work proceeded over the operating rail lines when compared to a cast insitu deck structure.

2.2.3 Footbridges

As a result of the construction of this interchange, the existing Collinson Street Footbridge over the Calder Freeway required extension to span over the new exit ramps from the Western Ring Road. The form of construction adopted for this structure was a concrete 'T' beam to match the existing. This was either reinforced or post tensioned depending on the span length. The 'T' beam shape for the new works was chosen to match the existing bridge spans that were to remain. Other cheaper structural forms could have been adopted, but were rejected on aesthetic grounds.

Figure 1 illustrates the relative locations of the various bridges.

2.3 Bridge Structures

2.3.1 Fullarton Road Bridge, Ramp A, Ramp C and Ramp D Bridges

Each bridge comprises spans of varying length with the exception of Ramp D Bridge which is simply supported. The main feature of the bridges is that they are each built with a tight radius horizontal curve on plan and a vertical curve. The location of the supporting reinforced concrete piers was dictated by the requirement to position the piers between the new road alignments.

The superstructures were typically designed as either 1.7m or 2.2m deep single or twin cell post tensioned concrete box girders. In all instances the central section of the deck were a minimum of 200mm thick, tapering up to 400mm thick at the intersection with the webs. To achieve the required deck width, cantilever outstands were adopted along the outside of the box girders. Where possible the soffit thickness was a minimum of 180mm. This tapered up to 380mm thick at the webs. Typically the webs were of constant thickness, although these were thickened locally, in regions of high shear at the piers and over the abutments. The box girder soffit was thickened in regions of high negative moment at the piers by tapering upwards within the box. Appropriate reinforcement detailing to accommodate the large torsions was required. (Refer '92 AUSTROADS Bridge Design Code Section 5)

Figures 2 to 5 show the typical box girder details.

The post tensioning tendons consisted of between 22 No. and 40 No. 15.2mm diameter strands. The large quantity of prestressing strand in Ramp D necessitated comparatively thick webs (550mm) to accommodate the ducts. The webs of all box girders were thickened at piers and abutments for shear and to accommodate tender anchorages. Horizontal tearing of the tendons from the horizontally curved webs was prevented by confining reinforcement. The requirement to limit the stress increment in reinforcement and tendons to 200MPa under HLP400 resulted, in some cases, in 100% of dead load being balanced by tendon curvature, so that reinforcement quantities were comparatively small. Transverse deck cantilevers are reinforced only, not prestressed.

With the exception of Ramp D Bridge, which had abutments founded directly on the underlying basalt, all abutments were the spill through type supported on 1200mm diameter bored pile foundations socketed into the underlying highly to moderately weathered basalt.

The piers were reinforced concrete blade wall type on pad foundations founded on the underlying basalt. All superstructures were supported on circular elastomeric bearings. These flexible bearings spread longitudinal braking loads to all piers and abutments. There is provision for jacking of box girders under the diaphragms, so that bearings can be replaced.

With the exception of Fullarton Road Bridge, which was not required to carry the HLP400 vehicle loading, all bridges have been designed for T44, L44 lane loading and HLP400 loadings. The HLP400 loading was considered to fully occupy one carriageway width and no other vehicles were assumed to be present on the bridge whilst the HLP400 vehicle was crossing the structure. Where appropriate, the piers have been designed to withstand road vehicle impact loadings of 1000kN (ultimate) applied at 1.2m above the road surface.

2.3.2 Fullarton Road over Rail Bridge, Ramp A Rail Bridge and Ramp B Rail Bridge

All three of the bridges over the Albion to Broadmeadows Rail Line comprise 750mm deep precast concrete super 'T' beam superstructures with a 140mm minimum composite insitu concrete deck, reinforced concrete piers and bored pile foundations. All piers have reinforced concrete crash walls cast around the base of the piers to provide protection against train impact. In each case the abutments are supported on bored pile foundations. The superstructures are supported on elastomeric bearings.

With the exception of Fullarton Road over Rail Bridge, which was not required to be designed to carry the HLP400 vehicle loading, all bridges have been designed for T44, L44 lane loading and HLP400 loadings. The piers have been designed to withstand train impact ultimate loadings of 2000kN parallel to the rails and 1000kN normal to the rails at 2m above rail level.

2.3.3 Collinson Street Pedestrian Bridge

The existing section of Collinson Street Pedestrian Bridge provided access over the Calder Freeway. The new extension provides adjoining access over Ramp C and Ramp E, thus providing pedestrian access over all roads. To minimise the length of the footbridge over Ramp C and Ramp E the new bridge was located perpendicular to the road alignment. However, this alignment differed from the existing bridge alignment and a short 'dog leg' section had to be introduced to link the existing bridge to the new bridge. The new extension comprises a 12.4m simply supported link span and a 12.4m, 28.5m and 7.1m continuous three span section over the new interchange ramps.

Since 3 of the 4 spans were relatively short, the 760mm deep concrete 'T' beam section was reinforced only. The remaining 28.5m span was post tensioned. The post tensioning consisted of 3 No. tendons of 11 No. 12.7mm diameter strands placed in 70mm diameter ducts.

To help reduce the prestress and limit the deflections at midspan, the 28.5m section was designed to be continuous under live loads. To provide continuity, a 450mm section of the superstructure over the piers was cast insitu. Continuity of the top reinforcement over the piers was provided by welding together reinforcement that was left projecting from the ends of adjoining beams. Due to the short back spans, tie down had to be provided at the adjoining pier and abutment.

The three new reinforced concrete piers and an abutment were supported on 750mm diameter bored piles founded in the underlying basalt. Elastomeric bearing pads were provided under the superstructure.

The design live loading was 5kPa in accordance with '92 AUSTROADS Bridge Design Code. The minimum lateral load of 500kN on the bridge superstructure necessitated the provision of upstand guide (keeper) walls on the piers.

2.4 Technical Issues

The project presented many technical challenges.

The bridge box girder superstructures required special consideration to be given to the following aspects:

- Tight horizontal plan curvatures;
- Large asymmetrically skewed ends;
- Complex vertical and horizontal geometry;
- High bearing loads and their proximity to the edge of the piers;
- Large eccentric traffic loads;
- High span to depth ratios (23.1 - 24.4);

- Uplift of Ramp D Bridge at highly skewed abutment;
- Varying barrier heights.

A major consideration in the decision to adopt single and twin box girder bridge superstructures was their higher torsional stiffness and strength. This enabled them to resist the torsional effects resulting from the horizontal curvature in plan and the large eccentric loads from vehicular traffic. Hold down of the ramp D bridge was necessary in some locations.

Three-dimensional plate finite element analysis of the structures was undertaken using "ACES" software. The analysis models were considered to simulate closely the behaviour of the bridges in service. The analysis enabled the accurate evaluation of the torsional effects and identification of local areas of high stress. Accurate distribution of shears between webs was calculated.

The finite element program used for deck analysis for this project was "ACES", which has been specifically developed for the design of bridge structures. This program has the facility to simulate moving traffic loads across the bridge superstructure. The Ramp A Bridge model consisted of 2047 nodes, 4112 elements and 68 load cases. Concentrated loadings at prestress anchorages and under bearings were analysed using STRAND6 finite element modelling.

The large volume of data generated by the model necessitated downloading onto customised spreadsheets. This enabled manipulation of the data and graphical presentation of the results thus providing an immediate sensibility check. Other Microsoft Excel spreadsheets were developed to analyse the in-service stresses, bending, shear and torsional actions in accordance with code requirements. All checking of the structure was carried out by experienced personnel using manual calculation methods, and simplified models in STRAND6 finite element software.

Although bridge barrier heights varied, the same form was used for each barrier by maintaining a constant external profile and adjusting the mounting height.

2.5 Method of Construction

2.5.1 Fullarton Road Bridge, Ramp A, Ramp C and Ramp D Box Girder Bridges

To help minimise the cost of formwork and falsework, the soffit width and web slopes of the box girders were standardised to enable maximum reuse of formwork. This also helped reduce construction times. Where possible, full excavation under the structures was not undertaken until after completion of the superstructure, therefore minimising the height of falsework. Excavations for piers were temporarily backfilled to allow deck formwork to be placed on the ground. Both Ramp C and Ramp D Bridges were virtually cast on the ground and excavation took place under them to form the underpass. This method of construction avoided the use of falsework and enabled faster and safer construction of these 2 bridges.

Generally, the casting sequence adopted for the box girder structures was to cast the soffit with a 75mm kicker along the webs first, followed by casting the webs and deck slab together. The typical pour length was 35m to 40m. Although this construction method proved satisfactory, it has a number of drawbacks:

- The construction joint along the base of the web is usually visible and difficult to disguise. It is virtually impossible to place the web formwork against the previously cast concrete section and get an adequately smooth surface.
- When casting the web and deck slab in a single pour the joint between the deck, cantilever and web is subject to high thermal gradients during hydration and therefore cracking can occur in this location. Base restraint from the previously poured soffit slab can cause vertical cracking of the (horizontally) lightly reinforced web.
- The preferred method to adopt when casting the box girders is to cast the soffit and webs in a single pour followed by casting the deck slab. The construction joint is then located under the deck cantilever and generally out of sight. The large quantity of longitudinal steel in the deck prevents shrinkage cracking due to base restraint.

2.5.2 Fullarton Road over Rail Bridge, Ramp A Rail Bridge and Ramp B Rail Bridge

The only departure from the conventional method of construction for these bridges was to replace the super 'T' beams, designed by VicRoads, with 'T' roff beams, which are modified super 'T' beams. The advantages of the 'T' roff beams are the reuse of the internal void formers, wall thickness is controlled and the beams are lighter than the equivalent super 'T' beams. Internal diaphragms are used to prevent spreading of the webs when the deck concrete is cast on site.

The total of 60 beams required for the three rail bridges were constructed at Fletcher Construction's precast yard at Rosedale.

2.5.3 Collinson Street Pedestrian Bridge

The 'T' beam shape required to match the existing bridge superstructure was not a standard precast beam shape. Thus, formwork had to be specially constructed. To save on transportation cost, the contractor chose to fabricate these units on site and lift them into position with cranes. The post tensioned span was prestressed prior to lifting.

The main span over the new road and the adjoining back spans were erected onto temporary supports supported off the side of the newly constructed piers until completion of the cast insitu joints.

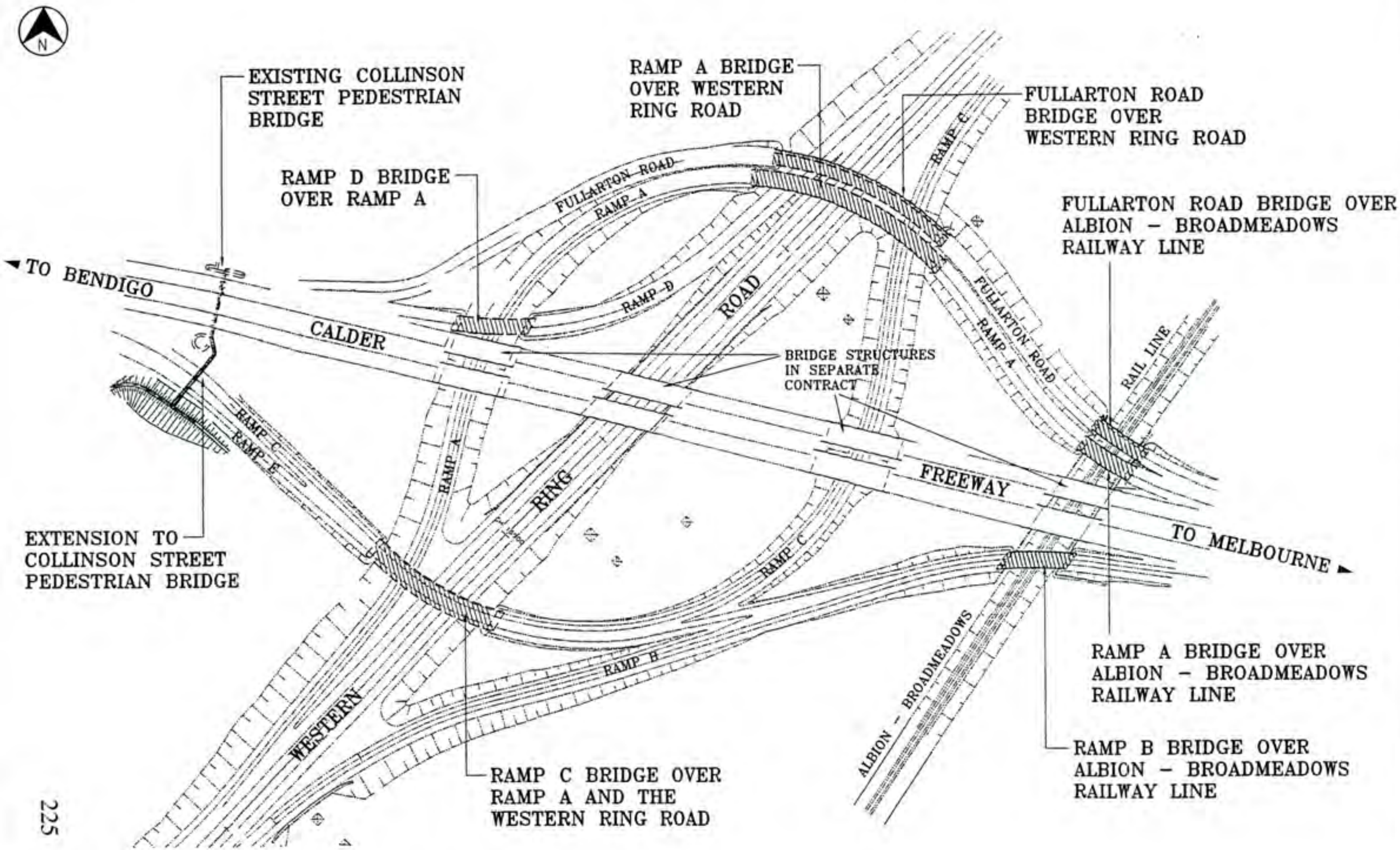
3 CONCLUSION

The bridges described in this paper represent a variety of superstructure types. They were predominantly designed under the value engineering process essential to a successful design and construct process. Generally precast deck unit elements were adopted for bridges over existing roads and rail lines. Where decks could be relatively easily formed, box girder decks were cast insitu.

For highly visible bridges, careful consideration was given to the appearance of the finished deck and substructure. It is noted that the achievement of visually appealing bridges does not necessarily lead to significant expense.

In the substructures, bored piles and pad footings were used since founding could be achieved at relatively shallow depth (less than 10m surface level).

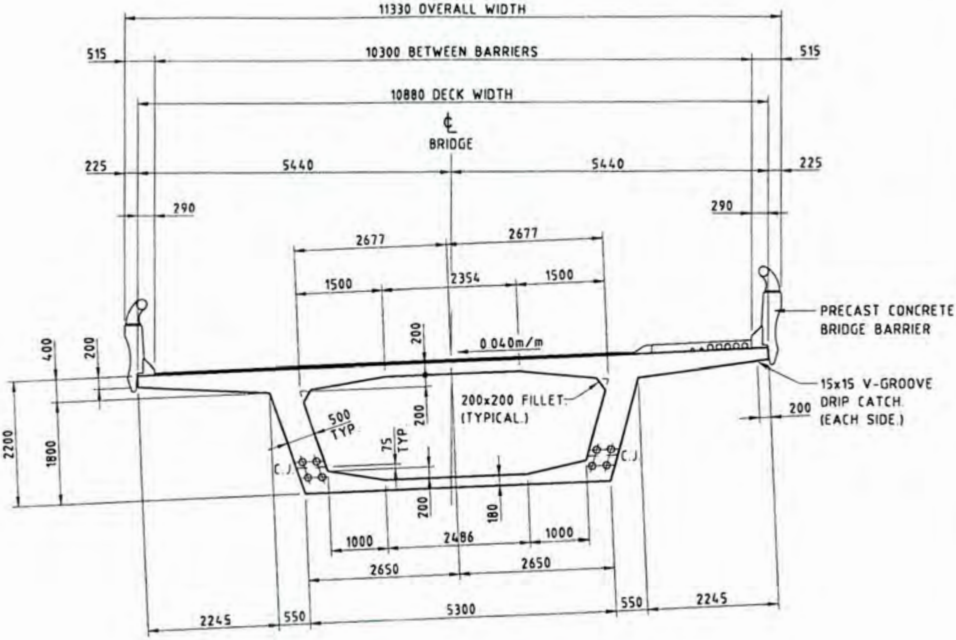
The bridge structures are good examples of appropriate concept design by the Principal, followed by detailed value engineering by the Designer / Contractor team to achieve the most economic arrangement that meets the Principal's requirements.



SINCLAIR KNIGHT MERZ	CALDER FREEWAY / WESTERN RING ROAD INTERCHANGE FIGURE 1

Table 1: General Bridge Features

Bridge	Length of Bridge	Number of Spans	Maximum Span Length	Depth and Superstructure Type	Width of Deck	Radius of Horizontal Curvature	Maximum Skew	No. of Lanes
Fullarton Road Bridge	139.7m	3 No.	53.7m	2.2m Single Cell Box Girder	11.3m	227.15m	Radial	2
Ramp A Bridge	153.8m	4 No.	45.0m	2.2m Single Cell Box Girder	12.3m	211.00m	Radial	2
Ramp C Bridge	84.4m	2 No.	49.9m	2.2m Twin Cell Box Girder	16.4m	227.90m	14^{o}	3
Ramp D Bridge	41.0m	1 No.	39.3m	1.7m Single Cell Box Girder	12.2m	249.00m	31^{o}	2
Fullarton Road Over Rail Bridge	36.8m	3 No.	12.5m	6 No. 750mm Super 'T' Beams	10.9m	284.00m	$\approx 5^{o}$	2
Ramp A Rail Bridge	36.8m	3 No.	12.6m	7 No. 750mm Super 'T' Beams	12.2m	224.00m	$\approx 5^{o}$	2
Ramp B Rail Bridge	44.7m	3 No.	15.2m	7 No. 750mm Super 'T' Beams	12.2m	349.00m	$\approx 37^{o}$	2
Collinson Street Pedestrian Bridge	60.8m	1 No.	39.3m	760mm 'T' Beam	2.1m	-	-	-



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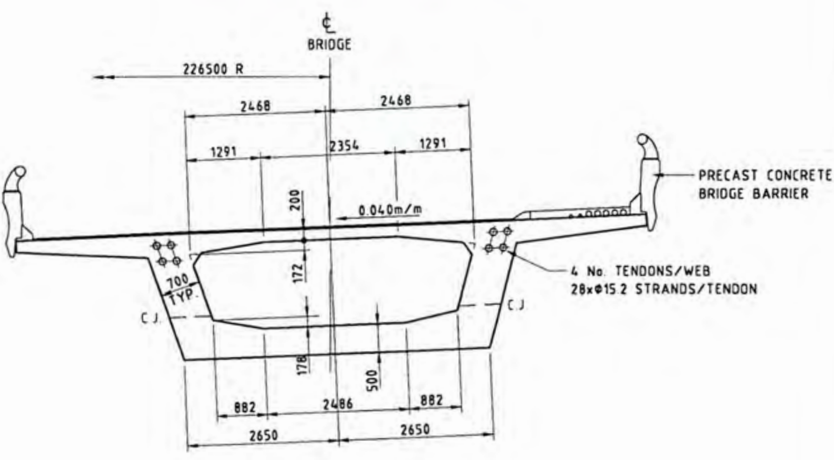
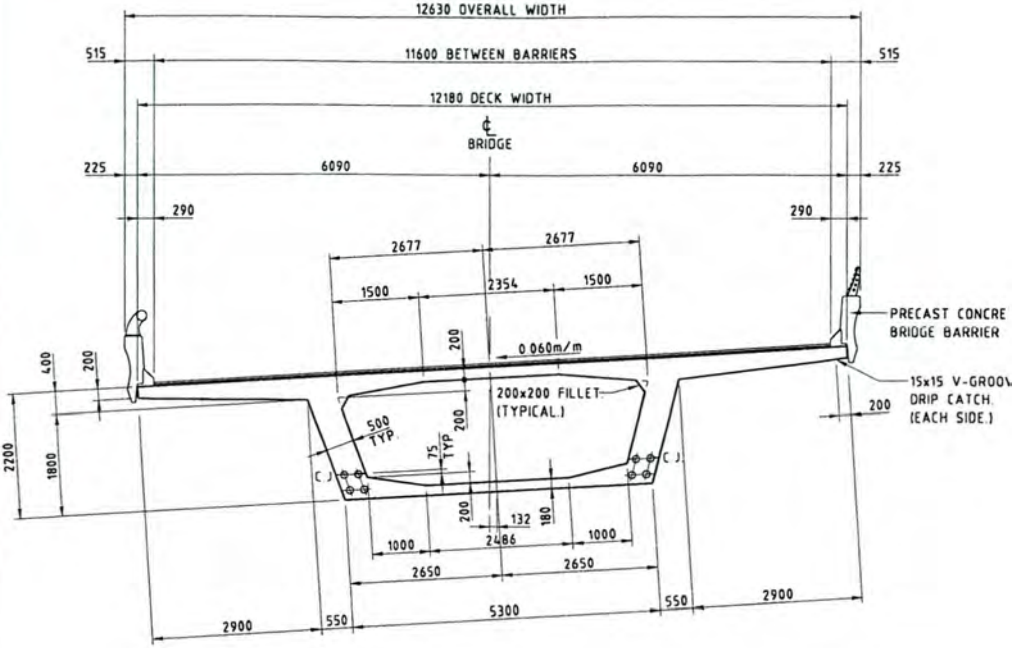


SECTION AT PIERS

TENDONS = 42 kg/m³
REINFORCEMENT = 185 kg/m³

SINCLAIR KNIGHT MERZ	CALDER FREEWAY INTERCHANGE FULLARTON ROAD BRIDGE BOX GIRDER	FIGURE 2



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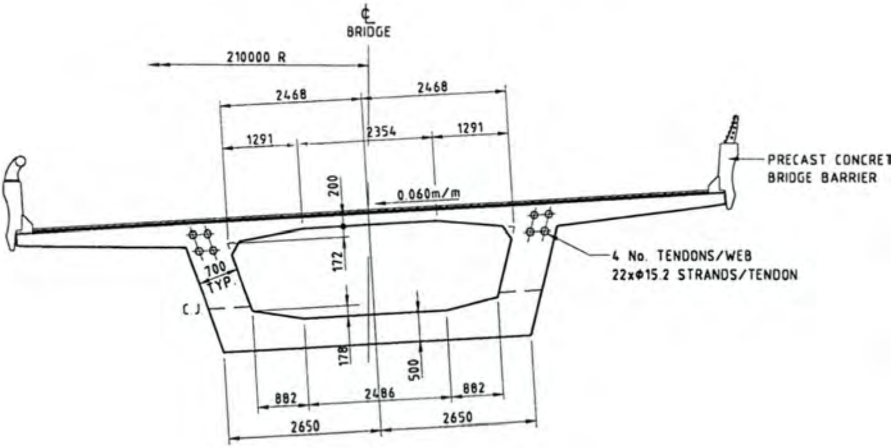

SECTION AT PIERS

TENDONS = 35 kg/m^3
REINFORCEMENT = 175 kg/m^3

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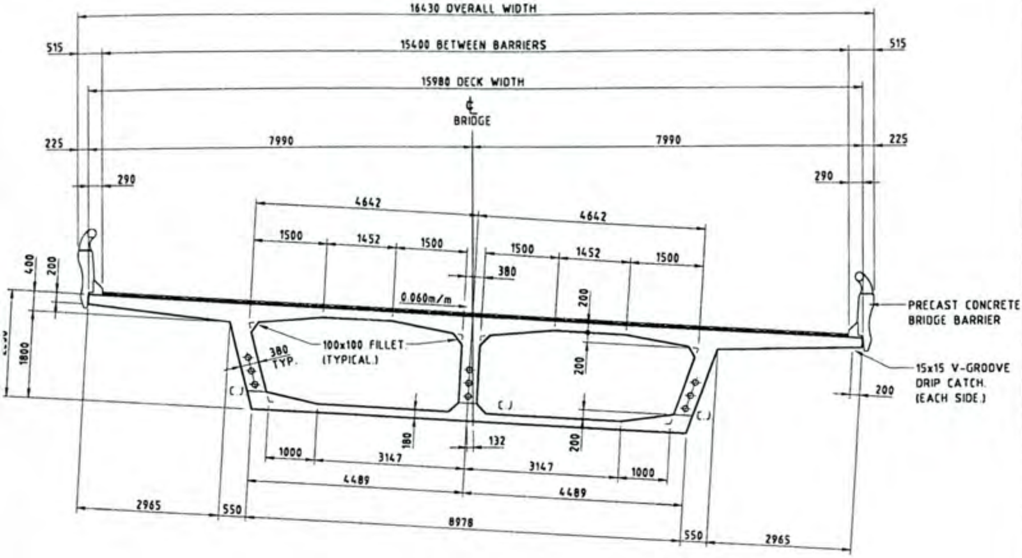
CALDER FREEWAY INTERCHANGE
RAMP A BRIDGE
BOX GIRDER

FIGURE :



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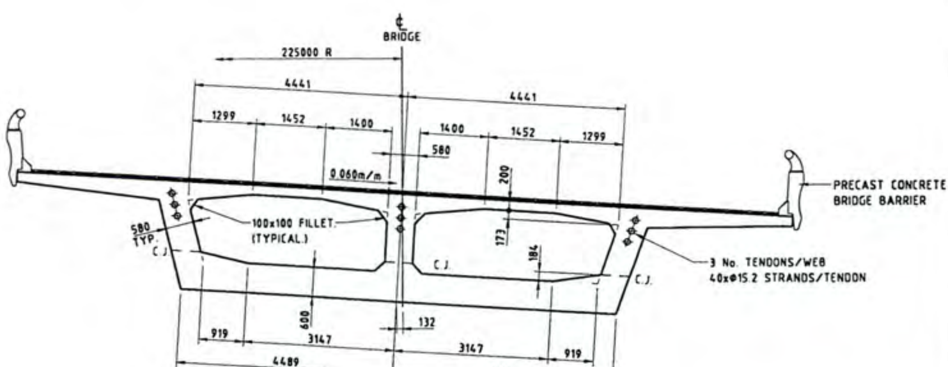

SECTION AT PIER

TENDONS = 48 kg/m^3
REINFORCEMENT = 180 kg/m^3

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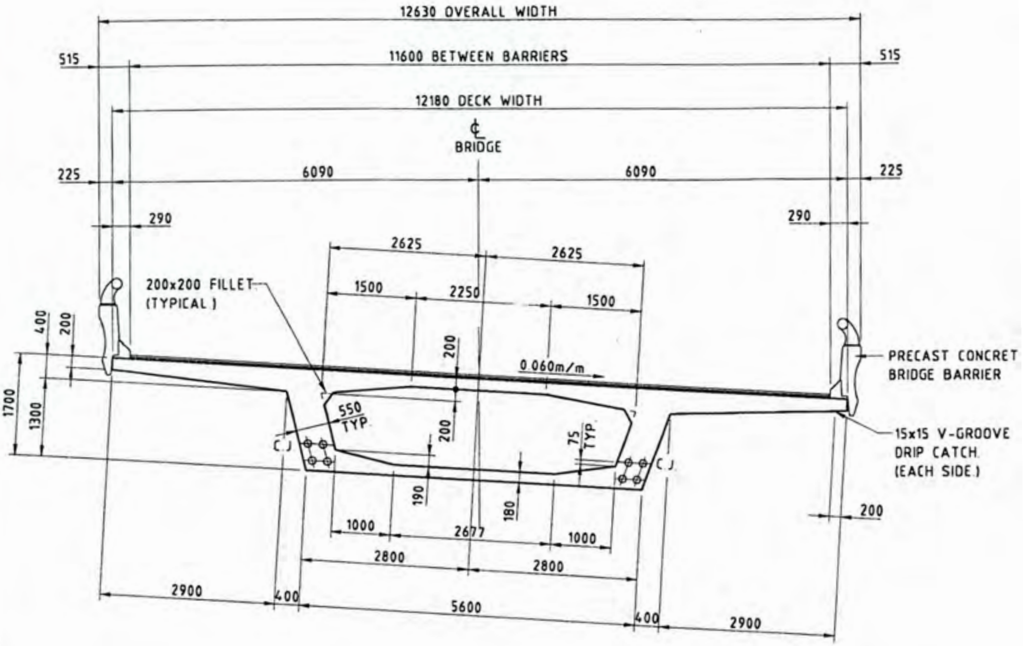
CALDER FREEWAY INTERCHANGE
RAMP C BRIDGE
BOX GIRDER

FIGURE 4



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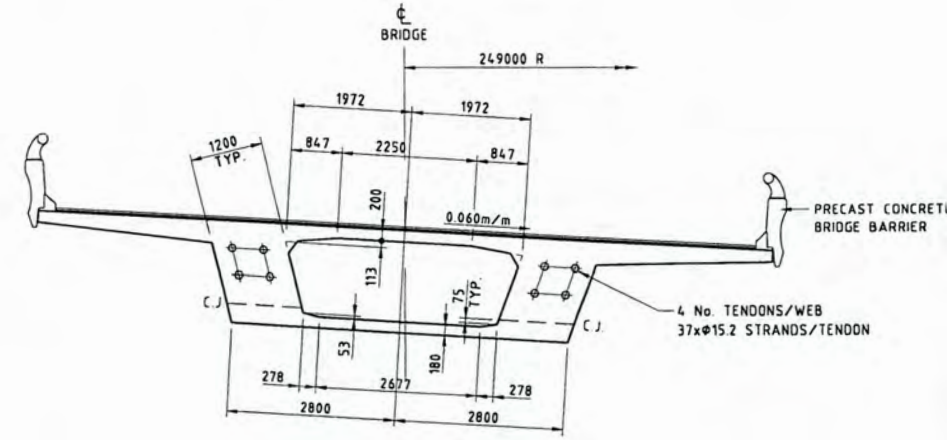

SECTION AT ABUTMENT

TENDONS = 55 kg/m^3
REINFORCEMENT = 185 kg/m^3

SINCLAIR KNIGHT MERZ	CALDER FREEWAY INTERCHANGE RAMP D BRIDGE BOX GIRDER	FIGURE 5