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THE BENEFIT OF THE NEW SUPER U-BEAM USED FOR SECTION 4 OF A WEST COAST EXPRESSWAY

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The West Coast Expressway is approximately 315.8 km in length and is separated into 15 sections of varying lengths. The concessionaire is West Coast Expressway Sdn. Bhd. Jacobs was involved in Section 4, totaling 5.59 km in length and including 7 directional ramps. These structures feature a new 'Super U-Beam' section whereas standard pre-tensioned precast beams such as the 'inverted T', 'I', 'M' and 'U' beams are typical options for span lengths ranging from 25 m to 40 m. The 'Super' U-beams are larger than standard U-beams and feature wide flanges. This arrangement results in a significant reduction in the number of beams necessary as well as a reduction in all the major material quantities. This paper will further discuss the technical details and advantages of the new 'Super U-Beam'.

Keywords: Pre-tensioned, Precast, Saving, Efficient, Quantity, U-beam.

1 INTRODUCTION

In 2012, Jacobs was appointed by West Coast Expressway Sdn. Bhd. to provide bridge and structural consultancy services and associated technical support during the construction stage for the Sg Rasau-NNKSB Viaduct in Section 4 of the West Coast Expressway (WCE). Section 4 – which runs from the Padang Jawa KTMB rail line to the New North Klang Straits Bypass Interchange – is approximately 5.59 km in length and features elevated structures over the majority of its length. In addition, there are 7nos of ramps which comprise elevated sections between RE Wall embankment approaches. The scale and characteristics of this project were such that the application of a new structural form could be made cost effective, the remit being, viaduct decks that would need predominantly off-site casting, could be as aesthetic as standard U-beam bridges while being cost competitive with post-tensioned T-beam bridges. This led to the development of the precast 'Super' U-beam section.

In order to standardize the design, multi-span viaducts with simply supported girders were proposed with spans ranging from 20 to 40 m, with most spans in the 28-32 m range. For spans up to 32 m, precast pre-tensioned Super U-beams with an in-situ concrete slab are used for the bridge decks. For longer spans, precast post-tensioned Super U-beams are used. The client's preference for off-site casting and lack of space along the alignment led to the preference for pre-tensioned precast beams rather than post-tensioned beams cast on or near the site.

A similar type of precast beam known as the "Super T" or "Teeroff" Girder is in widespread use in Australia. This new beam shape featuring a U with an extended top flange was introduced in the late 1980's and early 1990's. (Gray, Gaby, Grown, Kirkcaldie, Cato and Sweetman 2003) Super T girder's standard shapes have since been developed with depths ranging from 1.0 to 1.80 meter, for spans ranging from 18 to 35 meter. The Super T girder now dominates the precast beam market and is used nationwide in Australia for most bridge spans in the 22 to 35 meter range.

Based on our extensive experience in designing bridges using Super T girders in Australia we have further developed the Super 'T' Girder concept into the Super 'U' beam to be used as a first in Malaysia in Section 4 of the West Coast Expressway.

2 ADVANTAGES OF THE SUPER U-BEAM

2.1 Efficient Structural Form

The Super U-beam is markedly different from the standard U-beam. It has an outstand wing on each side of the webs, providing permanent participating formwork for the casting of the in-situ concrete deck slab. This wide top flange is part of the precast section and is typically 100mm thick on average. Between two adjacent girders, a gap not more than 1m is left between the edges of the top flanges. Permanent non-participating formwork, in the form of cement fiberboard, is provided in the gap between the edges of the top flanges as formwork to the in-situ slab casting. This lightweight permanent formwork allows hassle-free concrete casting without the need for erecting and removing formwork.

A wider top flange coupled with greater beam depth increases the lever arm between the precast section's centroid and the prestressing strands' centroid as well as creating a significantly larger second moment of area. This coupled with increased space in the bottom flange allows a greater amount of pre-tensioning to be applied in its most efficient location during precasting and leads to the possibility of using more widely spaced beams. This does not necessarily require thicker webs as the standard U-beam webs are sized for the practicalities of concreting rather than for strength. The Super U-beam, like the standard U-beam, has a closed box section when the slab is cast, which provides high torsional rigidity and shear resistance. With wider beam spacing, its web capacity in resisting shear and torsion can be fully utilized.

In terms of aesthetics, the Super U-beam provides an attractive box shape that can be used in a variety of situations and is comparable in this respect to the standard "U" beams. The wider beam spacing also facilitates bridge maintenance.

The overall system results in reduced concrete volume reduced prestressing and similar reinforcement quantities when compared with a standard U-beam deck.

2.2 Reduction in Beam Quantity

More widely spaced girders results in significant savings in the overall beam quantity, as elaborated in Table 1. Even though each beam will be more expensive due to greater concrete, prestress and reinforcement quantity, this is more than offset by the saving in construction time at casting yard, storage space, transportation and handling of girders.

With the reduction in beam quantity, the effort required for beam erection, storage and transportation reduces. Even though the Super U-beam requires heavier cranage due to its heavier weight, the deck construction cycle at site and the off-site precast beam production is significantly reduced as the quantity of beams to be lifted is reduced. The reduction of construction time also means reduced exposure to potentially hazardous site activities thereby minimizing construction risk.

3 BEAM PROPERTIES COMPARISON

The goal of the Super U-beam was specifically to improve the efficiency of the existing standard precast U-beam commonly used in Malaysia. The typical characteristics of the two types of beam are compared for a typical span length of 28 m. For this purpose, pre-tensioned standard U10 beam is selected as representative of the typical size chosen for this span length.

3.1 Beam Arrangement and Section Properties

First of all, comparison is made on the quantity of beams required for a range of deck widths, which is shown in Table 1. In general, the typical U-beam spacing is approximately 1.5 - 2.5 m while the optimum spacing for Super U-beams is approximately 3.5-4.5 m. From Table 1, it is evident that the number of Super U-beam required would be significantly less than for the standard U-beam. The optimum beam spacing mentioned dictates the quantity of beams required.

Table 1. Comparison of Beam Quantity Required for Super U-beam and “U10” U-beam.

Deck Width (mm)	Nos “U10” U-beam Required	Nos Super U-beam Required
7900	3	2
9700	4	2
11700	5	3

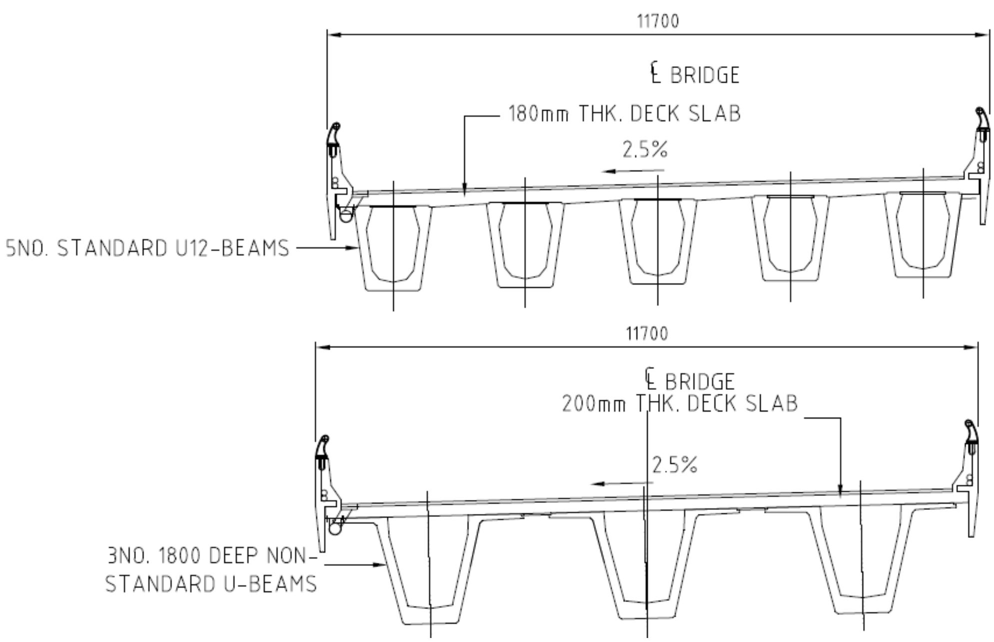

Figure 1. Typical cross sections of precast Super U-beam and “U10” U-beam.

Figure 1 shows the typical cross sections for an 11.7 m wide (twin traffic lanes + hard shoulder) Super U-beam deck which consists of three girders, and the equivalent “U10” U-beam deck which consists of five girders. Figure 2 and 3 show the concrete outline of the Super U-beam and “U10” standard U-beam respectively. The comparison of the detailed beam section properties for a specific deck width of 11.7 m is shown in Table 2.

From Table 2, it can be seen that the Super U-beam is about 48% heavier than a “U10” U-beam. The increased weight of Super U-beam is however, compensated by the reduced number of beams, especially for the wider decks where more than three U-beams are required. For instance, an 11.7 m wide deck requires three Super U-beams with total weight of 7.2 ton per meter length, while five "U10" U-beams with total weight of 8.2 ton per meter length are required.

The 48% increase in concrete volume is accompanied by a 48% increase in cross-sectional area and a 200% increase in section modulus. This means that for the same stress limit Super U-beams can sustain significantly higher bending moments.

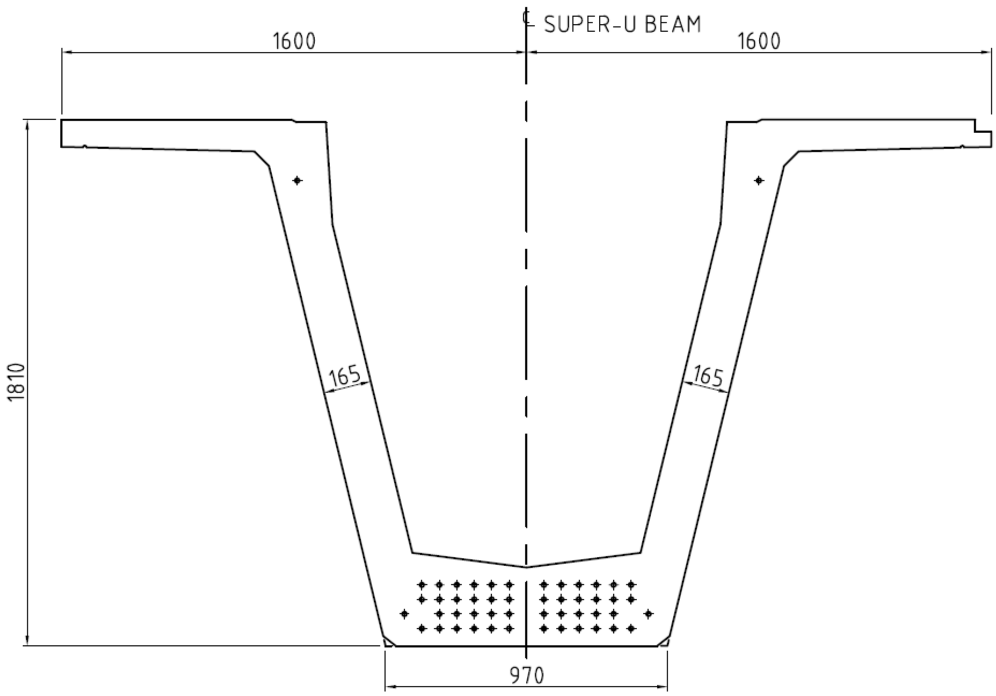

Figure 2. Concrete outline of precast Super U-beam.

Table 2. Comparison of Section Properties of Super U-beam and "U10" U-beam.

Section Properties	**Super U-beam**		**"U10" U-beam**	
	Precast	**Composite**	**Precast**	**Composite**
Beam depth (mm)	1810	2010	1400	1600
Web thickness (mm)	165		165	
Thickness of top flange (mm)	110 – 95 (tapered)		N/A	
Thickness of bottom flange (mm)	270		150	
Cross section area (mm^2)	984955.81	1762494	664755	1132341
Approximate beam weight (Ton)	69	123	47	79
Second moment of area, Ixx (mm^4)	4.02E+11	7.76E+11	1.41E+11	3.35E+11
Depth of centroid from soffit, Yb (mm)	888.64	1265.74	640	976.42
Section modulus about X-axis, Zxt (mm^3)	4.37E+8	1.04E+9	1.86E+8	3.43E+8
Section modulus about X-axis, Zxb (mm^3)	4.53E+8	6.13E+8	2.20E+8	5.37E+8

The top flange of Super U-beam consists of a pair of 110mm thick cantilever slabs at each side of the webs which then taper to 95 mm at the tip. The top flange is combined with a 200 mm thick in-situ RC slab topping to form the composite section. The resulting composite deck slab varies in thickness from 310 mm to 295 mm at the precast flange locations and is 200 mm thick elsewhere (over 1m between beam flanges and in between the webs of each Super 'U' Beam).

The thicker bottom flange coupled with a higher section modulus allow more prestressing strands to be provided without causing excessive tension in the beam's top fiber. This is beneficial during construction stage, where superimposed dead and live loads are not in place.

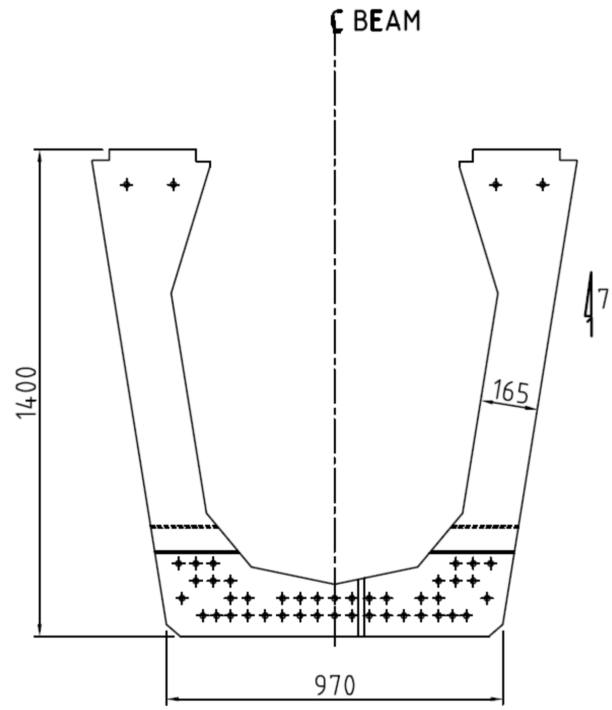

Figure 3. Concrete outline of "U10" standard U-beam.

4 BEAM STRESS COMPARISON

Consider an 11.7 m wide (10.8 m carriageway width), 28 m span simply supported deck for the comparison of SLS beam stress. For an 11.7 m wide deck, three number of Super U-beams at 3.82 m spacing or five number of "U10" U-beam at 2.34 m are required. Assume the deck is subject to gravity loads such as beam concrete self weight, deck surfacing and HA loading. The distributed load applied and the corresponding mid-span bending moment is shown in Table 3.

Table 3. Vertical loads applied on Super U-beam and "U10" U-beam.

Load	Super U-beam	"U10" U-beam
Beam selfweight (kN/m)	25*0.985 = 24.6	25*0.665 = 16.6
Deck in-situ concrete selfweight (kN/m)	25*0.2*3.82 = 19.1	25*0.2*2.34 = 11.7
Surfacing (kN/m)	2.2*3.82 = 8.4	2.2*2.34 = 5.1
HA (kN/m)	9.49*3.82 = 36.3	9.49*2.34 = 22.2
Total SLS load (kN/m)	97.3	61.1
SLS moment at midspan (kNm)	9539	5984

In this case study, the precast beams are designed as class 1 under load combination 1. Concrete grade 60 (strength at transfer of 50 N/mm^2) losses are assumed to total 10 % at transfer and 25% for long term. Based on optimized design, a total of 44nos and 39nos 15.7 mm diameter low relaxation bottom strands, with an initial force of 209 kN, are provided for the Super U-beam and “U10” beam respectively. The beam stress comparisons are summarized in Table 4.

For same deck area of 28 m span and 11.7 m width, the total prestressing strand required for Super U-beam and “U10” U-beam is 4.4 tons and 6.4 tons; the total concrete volume required for the precast Super U-beam and “U10” U-beam is 82.3 m^3 and 93.1 m^3. This leads to saving in 31% of steel strand and 12% of concrete. The saving becomes even more prominent with the increase in the deck width. The advantage of Super U-beam is clearly manifested through the increase in cross section area, second moment of inertia and concrete lever arm.

Table 4. SLS1 beam stress for Super U-beam and “U10” U-beam (Positive for compressive stress).

Load	**Midspan Beam Stress at transfer**	**Midspan Beam Stress at SLS1**
Super U-beam – Top fiber	0.62 N/mm^2	5.11 N/mm^2
Super U-beam – Bottom fiber	17.08 N/mm^2	0.5 N/mm^2
“U10” U-beam – Top fiber	0.89 N/mm^2	6.07 N/mm^2
“U10” U-beam – Bottom fiber	20.69 N/mm^2	0.39 N/mm^2

5 DECK CONTINUITY

For multispan bridges, the designer has the choice between isolated individual spans or a succession of continuous structures. In this project, reinforced concrete link slabs have been used to create continuity of the running surface between simply supported spans. Expansion joints are then placed 4 to 6 spans apart creating continuous “modules” between joints up to 160m long. The deck slab between the ends of the precast Super U beams transmits longitudinal loads through axial stiffness and local vertical loads in bending. The flexibility of the link slab is such that no longitudinal bending moment is generated from loads applied in the spans; however, the link slab must be designed to accommodate the imposed rotations occurring as a result of the deflections of the adjacent beams as well as the local bending moments from wheel loads (Benaim 2008).

6 CONCLUSION

This paper has described the characteristics of an innovative new Super U-beam used in the design of viaducts in Section 4 of the West coast Expressway Project. Comparisons have been drawn between this new beam and the commonly used standard precast U-beams and it can be concluded that significant material savings are achievable while maintaining the aesthetic advantages of the U-beam.

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