COST IMPLICATIONS OF ADOPTING EUROCODES

FOR

STEEL CONCRETE COMPOSITE BRIDGES

IN SRI LANKA

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168901H

Master of Science in Structural Engineering Design

Department of Civil Engineering

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Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in Structural Engineering Design

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Abstract

Keywords – Traffic loads, bridge deck types, composite bridges, deck cost, cost comparison

Construction of concrete bridges gained popularity after the introduction of pre-stressed concrete in 1950s, due to low cost of maintenance and locally available construction material. The concrete bridge industry was developed, so that reinforced and pre-stressed concrete bridges were designed and constructed in Sri Lanka.

Steel being imported material that require maintenance, steel bridge industry was not developed. Although with present high-grade steel, durable protective systems, steel composite bridges offer competitive designs for longer spans, locations with poor ground conditions, accessibility problems due to congested traffic and remote locations.

BS5400-2 (1978) and R.D.A Bridge design Manual remained as the main bridge design standards during past few decades up-to-date. Pre-tensioned beams used in the road network are still produced, and bridges are designed for these standards. BS design standard need to be replaced with Eurocode standard since BS standards will not be updated in future. This study selected UK National Annex for traffic loads (NA to BSEN 1991-2:2003) to compare with current BS 5400-2 loading adopted in Sri Lanka.

Standard simply supported bridge decks with two traffic lanes (carriageway 7.4m) and two footways on either side considered in this study. Standard pre-tensioned concrete beam deck spans 9.04m – 24.54m and composite designs made for this study for spans 31.5m – 50m considered in the comparison of traffic loads of BS5400-2 (1978 & 2006) and Eurocode UK National Annex. Culverts and existing bridge span up to 9.0m were not considered to maintain the simplicity of this study.

In order to compare deck costs, existing concrete decks were estimated based on Highway Schedule of Rates (HSR) and past construction data. Designs and estimates were prepared for recommended UKNA loading for steel composite bridges for spans 11.5m – 50m. The cost information provided from a steel fabricator and published data together with past construction data were considered in the estimation of composite decks.

This study recommends suitable UKNA loading, to replace current BS loading and identifies economical span range for steel composite bridges designed, when compared with existing concrete bridge types for prices prevailed in 2020. Identical costing process could be repeated with latest prices and HSR rates to for comparison of cost between concrete and steel concrete composite decks in future years.

I dedicate this thesis to my loving parents and family.

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Table of contents

CHAPTER 3 METHODOLOGY 54

List of Figures

List of Tables

List of Abbreviations

BS – British Standard

BCSA – British constructional steel work association

BOQ – Bill of Quantities

EC – Euro Code

ELS - Engineering & Laboratory Services (Pvt) Ltd, Sri Lanka

HSR – Highway schedule of Rates. Document published by Road Development Authority for each province that gives rates for construction of roads, bridges and highway structures

ICTAD – Institute for Construction Training and Development, Sri Lanka

KEL – Knife edge load BS 5400 part 2

RDA – Road Development Authoriry, Sri Lanka

SD&CC – State development and Construction Corporation, Sri Lanka

SEC – State Engineering Corporation, Sri Lanka

SLS – Serviceability Limit State

SOV – Special Order Vehicles

SV – Special Vehicles

TS – Tandem System

UDL, udl – Uniformely distributed load

UK – United Kingdom

UKNA – National Annex for United Kingdom

ULS – Ultimate Limit State

US $ - United States Doller

UB – Universal steel beam section

SLSEN – Eurocode National Annex for Sri Lanka

SCI – Steel Construction Institution, UK

Sqm – square meters

Rs – Sri Lankan rupees

“ +”   together with

Chapter – 01

Introduction

1.1 Background

Major Development of Country's Highway Network and the beginning of Rail Network took place during colonial rule. Bridges in these networks were masonry arch or metal bridges. Earliest metal bridges imported from United Kingdom were wrought iron truss bridges (Mahadewa, 1939). Exception is the wrought iron arch bridge at Peradeniya across "Mahaweli" river ("Of bridges" 1998, p.10). Later Steel was introduced, and most steel bridges in the highway network were fabricated in the Government factory. Steel bridges fabricated were mainly parallel chord truss bridges, Bow string girders, and plate girder bridges.

Most of these bridges now replaced with new concrete bridges due to inadequate width rather than strength requirements. The haunch plate girder bridge across Bolgoda Lake (Mahadewa, 1935) was an exceptional bridge designed and fabricated in this country, but unfortunately removed during rehabilitation of road. Recently many steel bridges were introduced to highway network under foreign aid packages, but all were imported structures. Completed structures have either steel concrete composite deck or steel plate deck.

Reinforced Concrete was introduced in 1920s and Prestressed concrete bridges were introduced in 1950s (Disanayaka, 1981/1982). New Kelani Bridge across Kelani Ganga in Colombo is a reinforced concrete bridge with suspended spans (Chandrasena and Rasaratnam, 1960) which is still in service. The longest girders (span 35m) pre-stressed by wires are in Warakathota Bridge at Ratnapura (Bridge No 64/3(miles) CRWB road revised drawing 518/2A, date unclear). Pre-stressing strands were introduced to local industry by the year 2000.

Pre-tensioned beam range comprise of spans 7m – 25m (Type Superstructure, 2005). Deck is completed as a slab with beams up to 19.0m. The span 25m is "M" beam (Drawing No

T/B/509, 2005). This deck is beam and slab type. Launching of this beams range is by crane.

Common post-tensioned beam span sizes are 32.5m (Drawing No SDCC/KTG/BRG/008, 2006), 30m, (post-tensioned beam 30m, 2018) and 35m (PC post-tensioned T Girders, 2013) The New Kallady Bridge with post tensioned box beams (2.05m x 1.04m, 9 Nos@1.49m c/c) has three spans of 48m (Construction of New Kallady Bridge, no date). Deck is formed as beam and slab type for both post-tensioned beam types above. Erection was by launching girder.

In addition, the box girder bridges were introduced by foreign contractors working under foreign aid. Push launch and incremental launching methods were used in construction of concrete box girder bridges.

During past the construction of bridges were as per British practices. The traffic load types HA and HB were introduced in British Standard (BS 153 (1973). The British Standard (BS 5400 part2, 1978) was introduced afterwards. Application of British Standard (BS 5400 part2, 2006) was limited. Now BS codes are not updated therefore changing to Eurocode has become compulsory. Sri Lanka's National Annex for bridge loading has still not been developed. Therefore, still Eurocode loading has not been introduced to Sri Lankan bridge design practice.

For Sri Lankan practice there were changes from BS 5400 part2. Since pre-stressing wires were used for a long time, the early design practice was to check BS loading HA and 30 units of HB loading separately for critical positions on deck i.e., for a heavy vehicle, closest position to curb line near mid span is critical for edge beam. Abnormal heavy vehicles (& HB30 units) were checked when it was travelling along centre line of the bridge without other traffic (Rowe, R.E. 1976). Bridge design manual (1996) of Road Development Authority (RDA) indicates deviations to BS 5400. Application of HB loading, reduction of tractive force, water current force, the log impact force on piers and deviations required to adopt local conditions. With the introduction of pre-stressing strands pre-tensioned beam range (except span 7.085m beam) was re-designed to BS 5400 part2 1978, as class 2 members.

At present concrete bridge decks in service do not show signs of over stressing. Therefore, adopting Eurocode loading to match with BS loading currently adapted has become a requirement. Therefore, UK National annex (which specify closer traffic load distribution to BS than Eurocode, as discussed in section 2.8)) ensure smooth transition from BS5400 and would be used as a starting point to develop Eurocode traffic loading for Sri Lanka.

However, some routes could demand higher load carrying capacity soon in future. Application of higher grades of concrete will increase both allowable compressive stress in service and allowable stress in tension during transfer of pre-stress. Pre-tensioned beam sections currently in use are large enough and therefore need to check ability to carry higher loads with higher grades of concrete. EN 1992-1-1 (2004) has enhanced allowable compressive stress of concrete for characteristic loads ($0.6f_{ck}$ vs $0.4f_{ck}$ cube) while allowable tension at transfer remains almost identical when compared to British Standard. In the presence of confinement, the maximum compressive stress limit is $0.66f_{ck}$ suggested by Broker, Jackson and Salim (2009, p76).

When a bridge is designed most economical solution between alternatives need to be found. Road Development Authority annually publish “Highway Schedule of Rates” (HSR) and its analysis for each province. Engineer’s estimate, price escalation calculation for bridge and road works are based on this document. Pre-tensioned beam prices are often quoted from producers.

Post-tensioned beams are produced at pre-cast yard generally located close to site. The launching cost depends on type of plant and volume of work available. Therefore, Post-tensioned beam prices are not quoted in HSR but could easily calculated for any year based on HSR rates if initial breakdown of costs are known.

1.2 Research Problem

Standard pre-tensioned beams for lengths 7.085m – 25m and post-tensioned beams up to 35m length has become the practice in local bridge industry today.

However, Steel concrete composite bridges offer cost advantage over existing concrete bridge types when spans become longer. With proposed changeover to Eurocode from BS 5400-2 loading, identification of structural forms and span range that is most economical to steel concrete composite bridges need to be identified.

Cost of inputs affect prices, thus the selection. Therefore, method of updating prices need to be addressed in finding economical solutions.

Therefore, this research “Cost implications of adopting steel concrete composite bridges under Eurocode loading” has become a timely requirement.

1.3 Aim and Objectives

The main aim of this research is to recommend most feasible structural forms and span range for composite bridge decks that are economical than existing concrete bridge decks under Euro code loading and prevailing market conditions.

Since Sri Lanka National Annex for Eurocode has not been developed, establishing suitable Eurocode loading for existing concrete decks and steel concrete composite decks has been the first objective of this research. It consists of following steps.

Compare traffic load distribution for BS 5400 -2 (2006 & 1978) loading with Eurocode UK National annex loading for

a) Most common existing pre-tensioned beam bridges (i.e., Slab bridge decks and 25m "M beam" with reinforced concrete deck).
b) Multi steel plate girder composite bridge designs developed in this research.
c) Ladder deck steel plate girder composite designs (two main girders with cross girders) developed in this research.

The second objective of this research is to develop new steel concrete composite bridge designs to Eurocode loading decided above, and compare deck costs with existing concrete decks for prevailing market conditions. This objective consists of following steps.

a) Develop simply supported steel concrete composite bridge designs for Eurocode loading for multi girder spans up to 32.5m (with rolled steel girders and plate girders) and ladder deck spans (40m – 50m) comparable to existing concrete bridge spans.
b) Estimate composite deck costs for the current year 2020 in following methods.
   - Based on rates submitted by a fabricator.
   - Recast rates of Kinniya bride and Kelanisiri Bridge, painting costs of the Narathupana Bridge using HSR.
   - Based on a published document in New Zealand for plate girder and ladder deck bridge deck designs.
c) Compare cost for existing pre-tensioned beam decks (lengths up to 25m) and post-tensioned beam deck lengths (32.5m - 48m recast to 2020 based on HSR) with steel concrete composite deck designs developed above.

1.4 Scope of the Research

As discussed in section 1.5 below, steel composite bridge decks considered in this study are simply supported, with most common deck configuration i.e., 10.4m wide deck consisting two traffic lanes of 3.7m width, and two footways of 1.5m width. Steel truss bridges are not considered.

The structural form of steel composite bridges, considering the economy, vary from rolled steel Universal beams (spans less than 20m), multi plate girders (spans 20m to 40m) and to ladder deck consisting two plate girders and cross girders (spans 40m to 50m). This structural configuration is considered in this study.

In the comparison of BS5400-2 and Eurocode for traffic loads, spans less than 9.0m are not considered to maintain simplicity of this research. Spans less than 9.0m include indeterminate reinforced concrete twin cell bridges, and flat pretension beam bridge (span 6.625m, Figure 2.8) with shear key connectivity in the deck that require different types of analysis. As highlighted in the section 2.2.4.2 the single axle load LM2 of Eurocode can be predominant for spans less than 7.0m.

The maximum span 50m is greater than most existing bridge lengths, and for steel composite plate girder bridges, is an economical structural form. Beyond 50m limit, steel truss form (two girder system) may become economically feasible solution. Therefore, in this study the span range was limited to 9.0m to 50m for traffic load comparison.

For cost comparison minimum span of 11.5m, that can economically be formed from rolled universal beam section of 12m long considered. As discussed in section 2.8, Eurocode UK National Annex for traffic loads is used for this research. Design parameters defined in Chapter 5 together with partial safety factors and design models discussed in sections 3.4.1 and 3.4.2 are applied.

1.5 Significance of the Research

Most bridges in this country are simply supported concrete bridges constructed during past few decades. Composite brides are “deck type” beam and slab bridges where reinforced concrete deck slab sits on top of steel I girders and acts compositely with them in bending. In a simply supported composite bridge steel I girder carries tension and concrete carries compression under flexure, utilizing both materials in most efficient way.

When the bridge is continuous, concrete over piers is under hogging moment and considered cracked. Therefore, sectional properties in hogging moment regions are determined by structural steel and reinforcing steel only. This offset the economy in continuous construction. Therefore, this study is limited to simply supported spans & two-lane bridges which are most common.

When compared with concrete bridges, steel concrete composite bridges offer economies with longer spans, complicated shapes, shallow foundations, and faster erection techniques with light machinery. Steel erection is convenient in congested areas where road closure is limited and remote locations where only light machinery could be mobilized.

However, steel need periodic maintenance, therefore by selecting proper protective system suit to environment steel concrete composite bridge could be made competitive alternative to concrete bridge.

Concrete is produced by locally available material. Standard pre-stressed beam designs are available; therefore, bridge industry has developed to produce concrete beams locally when required. Therefore, construction of concrete bridges has become a standard and straight forward work.

Steel is imported; therefore, prices fluctuate within a wide range due to fluctuating world steel prices and local currency. For steel composite bridges still maintenance requirement is considered as a backward issue.

Steel Fabrication, erection, painting require proper quality control in the factory and at site. Kinniya Bridge in Trinkomalee and Kelanisiriri Bridge across Kelani Ganga are two major Steel composite bridges designed for British Standard (BS 5400 parts 3 & 5) and fabricated in this country. However, neither standard designs were developed nor was an encouragement for local fabricators to come to bridge industry.

Steel composite bridges remain as an unfilled gap in the bridge industry and need to be researched and developed for competitive bidding with alternative concrete solutions. This research expected to produce information to fill the gap in bridge industry.

1.6 Presentation of Chapters

Chapter – 1. Introduction

Background about bridge industry from colonial era up to date, Changes to design practices, Highway schedule of rates, Estimation of costs of brides. Undeveloped local bridge industry for steel composite bridges. Research problem, Aim and Objectives, Scope of research, Significance of this research, Presentations of Chapters included.

Chapter - 2. Literature survey

Presents literature on highway loading of BS5400 part2 1978, 2006, Eurocode 1991-2:2003 and UK National annex to same. Existing bridge deck types and proposed common composite deck types are described. Bridge deck analysis and suitability of software Midas Civil for computer modelling described. Conclusions from literature survey included.

Chapter – 3. Methodology

Presents Methodology and research process, Bridge deck models for comparison of BS and Eurocode loading and models developed for steel concrete composite decks designed for cost comparison with concrete decks.

Chapter - 4 Comparison of BS loading, Eurocode (UK National Annex) loading. Distribution of maximum longitudinal bending moment across width of the deck at midspan, and maximum shear force on supports are presented for BS & Eurocode loading. Maximum longitudinal bending moment and shear force for different span lengths are presented for existing concrete bridge spans, and proposed steel composite spans. Comparisons of maximum bending and maximum shear force are presented for BS & Eurocode (UKNA) & final comparison derived.

Chapter – 5. Design of simply supported composite bridge decks to Eurocode (UK National Annex) using software Midas Civil.

Chapter – 6. Cost Calculations for existing concrete bridge structures for based on HSR. Cost Calculations for steel concrete composite structures designed in chapter 5. Comparison of concrete and steel composite deck costs.

Chapter - 7. Conclusions of chapters 4 and 6 with recommendations for future applications and future research.

Chapter – 02

Literature survey

2.1 Introduction

Investigation of loads in early bridges indicates that early structural forms of highway bridges during colonial era, i.e., masonry arches and steel/wrought iron bridges had standard type drawings. Design of arches and loads considered are not properly documented. Some drawings of steel bridges indicate loads carried by its members. Masonry arches are slow to respond to temperature effects due to its large size, but metal bridges respond to temperature effects quickly. Expansion joints and bearing were developed with the introduction of metal bridges.

Mahadewa, (1939) reports buckling of some members of "Katugasthota" bridge during its service. It gives the details of traffic count taken in June 1904. Elephants were prohibited on the bridge as preliminary step, and government decided to strengthen the bridge immediately. Mahadewa, (1935) & Chandrasena & Rasaratnam, (1960) describe loading considered for each design. Later in 1970s British Standard was introduced.

This research intends to provide comparison of BS5400 and Eurocode traffic loads as per UK National annex and cost comparison of concrete and steel composite bridges.

The section 2.2 of this chapter is devoted to explain Bridge loading of BS5400 and Eurocode. Different approaches of two types of loading, loading models and combinations are described. Section 2.3 gives details of most common pre-tension bridge decks of lengths 7.085m – 25m.

Steel composite bridges up to 50m were considered along with existing standard pre-tensioned beam decks up to 25m for comparison of traffic loading in BS5400 1978, 2006 and Eurocode. Section 2.4 describe types of steel composite structures, multi girder girder bridges (rolled steel, plate girders) and Ladder deck designs.

In addition, for the cost comparison post-tensioned concrete decks span 32.5m (Katugasthota Bridge 32.5m Beam, (2008)) and 48m Kallady Bridge (Kallady Bridge, 48m Beam, (2010)) were considered. For steel composite alternative, new multi girder and ladder decks (40m, 50m) designs were necessary.

The Software Midas Civil has the capability to analyse bridges for BS, Eurocode, & Eurocode (UKNA) loading and perform structural design to Eurocode considering stages of loading and associated time frames. It has capability to generate dynamic report in Microsoft Word and has excellent 3D graphical presentation. The structural design developed by software is sufficient for costing purpose. Midas Civil considered best for this research.

Suitability of Midas Civil software for 2D and 3D bridge deck modelling and special features of Midas Civil are presented under section 2.5. Previous research in to comparison of BS and Eurocode loading is presented in section 2.6.

Steel fabricators' responses are the best methods of estimating steel fabrication costs. Lack of response create a knowledge gap described in section 2.7. In addition to actual cost data of Kinniyai Bridge and Kalanisiri Bridge were converted to present day costs, by use of Highway Schedule of Rates (HSR). Kevin Cowie and Alistair Fussell (2011) developed "Preliminary Bridge Estimating tool" a similar document to HSR. It has been developed for costing of multi girder and ladder deck bridges in New Zealand. By replacing costs of steel and protective coating suit to local conditions this document provide accurate costing of structures designed.

Section 2.8 is presented with Conclusions from literature survey.

2.2 Bridge loading

Starting from bridge loads BS 153-3A 1972 (Specification for steel girder bridges) BS5400 part2 1978, and 2006, (specification for loads) standards were used for bridge design. Most bridges constructed during past fulfil BS5400 part2 1978 standard and pre-tensioned beam strands drawings were not changed to 2006 standard. BS5400 part2 2006 standard was adopted in special cases (Central Expressway). Therefore, defining local bridge loading in terms of Eurocode has become a necessity with changeover to Eurocode.

Road Development Authority (RDA) has supplementary bridge design manual for local conditions. It recommends changes and specify local values to BS5400-2. Application of live loads (HB loading), braking and traction, temperature, shrinkage, buoyancy, wind, water current force, loads due to floating debris and impact need to be specified as per RDA manual.

Development of local annex for Eurocode traffic loading and changes to RDA manual in terms of Eurocode loading has become a necessity today.

2.2.1 BS 5400 and Euro Code.

BS 5400 consider loads as external forces applied on the bridge structure and imposed deformations caused by restraint to movement. (Such as due to temperature, shrinkage) BS 5400-2 defines Dead loads as due to weight of structure, Super-imposed dead loads are due to weight of material which is not structural elements, and live loads as due to vehicle and pedestrian traffic on deck. Live loads are of two types. Primary live loads are due to mass of traffic considered as static and secondary live loads are due to changes in speed and direction, skidding, centrifugal, collision loads associated with traffic loads considered as secondary loads. Partial safety factors are assigned for each load to form combinations specified for different limit states as specified in Table 1 of BS 5400 part 2.

Eurocode classify forces, imposed displacements and accelerations are as actions and classify their variation in time as Permanent actions (G), (self-weight, shrinkage, settlements) Variable actions (Q), (imposed loads, wind load) and accidental actions (A), (explosions or impact from vehicles). Variable action has four representative values in decreasing order of magnitude as follows.

a) Characteristic value Q_k
b) Combination value $\psi_0 Q_k$
c) Frequent value $\psi_1 Q_k$
d) Quasi-permanent value $\psi_2 Q_k$

The reduction coefficient ψ applied to characteristic load taken account of the reduced probability of several independent variable actions (John Roberts, (2010)).

2.2.2 Application of Highway Bridge Loading

The concept loaded length forms the basis of applying highway bridge live loads. Loaded length is considered as base length of influence line considered as adverse area for the effect considered on structure (Clark, 1981).

Notional lanes are defined in every bridge code for the purpose of specifying highway bridge live loads and are different from actual traffic lanes. BS 5400 1978, 2006 & Eurocode has different lane widths. Designed loads need to be selected and applied in such a way that most adverse effect is caused in the element or the structure. (BS5400 part2 1978, cl 4.5.1). In EN 1991-2:2003 the lane giving most unfavorable effect is numbered as

Lane1, and the lane giving second most unfavorable effect is numbered as lane number 2 etc.

2.2.2.1 BS 5400 Part2 1978 Lane Information

Carriageway width w (m) and number of notional lanes are presented in Table 2.1 below.

Table 2.1 Number of notional lanes for carriage way BS5400 Part2 1978

Carriageway width w (m)	**Number of notional lanes**
4.6 < w < =7.6	2
7.6 < w < =11.4	3
11.4 < w < =15.2	4
15.2 < w < =19.0	5
19.0< w < =22.8	6

Number of notional lanes for carriageway width less than 4.6m is defined in Cl. 3.2.9.3.2 of BS 5400 part2 1978.

2.2.2.2 BS 5400 highway loads (live loads)

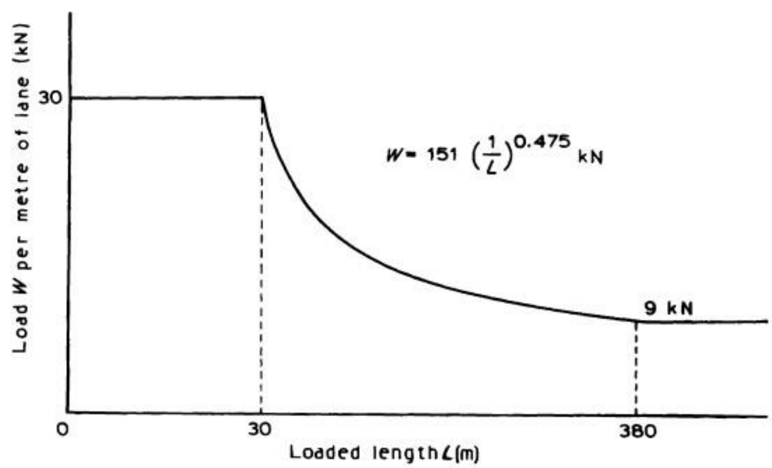
Defined as two types of HA and HB. (Both loading types include impact). HA loading represents normal traffic and HB loading represents abnormal loading such as vehicles carrying transformers, generators, machineries etc.

2.2.2.3 HA Loading

Consist of uniformly distributed load (UDL) and knife edge load (KEL). UDL is defined as 30kN/m per notional lane for loaded length up to 30m. For loaded lengths (L) in excess of 30m is derived from the equation.

$$w = 151 \left(\frac{1}{L}\right)^{0.475} \quad \text{but not less than 9}$$

Knife edge load is taken as 120 kN per notional lane. To determine local effects single nominal wheel load 100kN (cl. 6.2.5 of BS5400 part2) alternative to UDL and KEL could be considered. HA udl is illustrated in Figure 2.1 below.



Loading curve for HA UDL

Figure 2.1 HA udl distribution (BS5400 part2 1978)

Source – BS 5400 part2 1978

2.2.2.4 HB Loading

The HB vehicle model is illustrated in Figure 2.2 below. It represents abnormal heavy vehicle having four axles. Axle load is applied on deck as point loads spaced at 1m intervals. Single HB unit is considered as 10kN per axle.

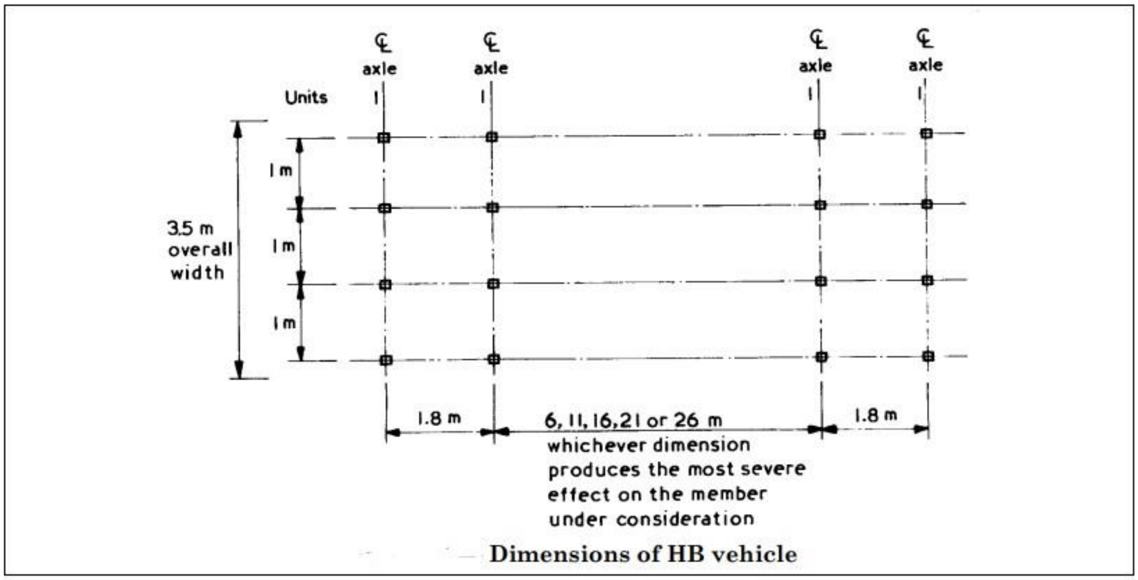


Figure 2.2 HB vehicle (Axle and wheel positions)

Source - BS 5400 part2 1978

HB vehicle could be applied on a single lane or can straddle between two lanes.

2.2.2.5 HA, HB loading combinations and RDA Bridge design manual

Bridge structure is designed for severe of HA or HA loading combined with HB loading. Application of HA and HB combination is described in Cl 6.4 of BS5400 part2 1978.

Bridge design manual (1996) requires local condition HB vehicle to straddle two notional lane widths. Pre-tensioned beams (former wire beams and new beams with strands) have been designed for most severe load effects of HA or HB (30 units) straddling two lanes. Rural bridges and imported steel panel bridges has been designed to HA loading only.

Although HA loading BS5400-2 ,1978 has been the standard, recent expressway design adopts HA BS5400-2, 2006 loading.

2.2.2.6 Load Combinations.

Table 1 of BS5400 Part2 1978 tabulates load factor (γ_{fL}) for Ultimate and Serviceability limit states, for five different load combinations given below.

(a) Combination 1 – Permanent loads together with appropriate primary live loads.
(b) Combination 2 - Loads in combination (1) together with wind and erection loads.
(c) Combination 3 - Loads in combinations (1) together and those arising from restraint due to temperature range and difference and erection loads.
(d) Combination 4 - Permanent loads and the secondary live loads, together with appropriate primary live loads.
(e) Combination 5 - Permanent loads together with friction due to bearings.

2.2.3 BS 5400 Part2 2006 Loading

Changes from BS 5400 part2 1978 include different notional lane width and udl component of HA load.

2.2.3.1 Lane Information

Carriageway width w (m) and number of notional lanes are tabulated below.

Table 2.2 Number of notional lanes for carriage way BS5400 Part2 2006

Carriageway width w (m)	Number of notional lanes
5 <= w < =7.5	2
7.5 < w < =10.95	3
10.95 < w < =14.6	4

14.6 < w < =18.25	5
18.25 < w < =21.9	6

Loading when carriageway width is less than 5.0m is specified in Cl 3.2.9.3.2 of BS5400 Part2 2006.

2.2.3.2 HA Loading (UDL)

For loaded length (L), the UDL expressed in kN per linear of notional lane is given by the equation and loading curve is illustrated in figure 2.3.

$$w = 336\left(\frac{1}{L}\right)^{0.67} \quad \text{when} \quad L <= 50 \text{ m}$$

$$w = 36\left(\frac{1}{L}\right)^{0.1} \quad 50\text{m} < L < 1600\text{m}$$

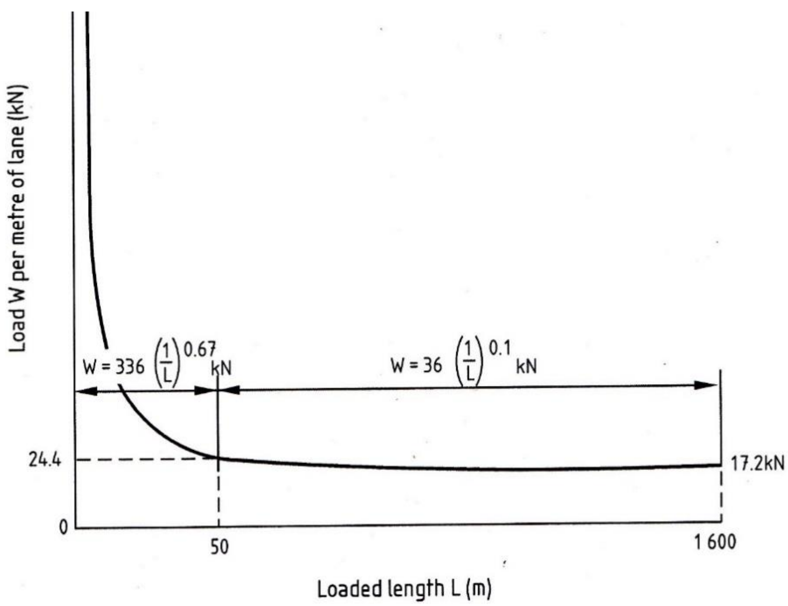


Figure 2.3 HA udl distribution (BS5400 part2 2006)

Source – BS 5400 part2 2006

2.2.4 Eurocode Loading & UK National Annex loading

2.2.4.1 Lane information

Notional lane width is 3m. When carriageway width is greater than 5.4m and less than 6m, the number of notional lanes is considered as two and notional lane width is less than 3m. In all other situations excess area allowing notional lanes is considered as remaining area. Sections 4.2.3, 4.2.4, and Table 4.1 of EN 1991-2-2003 give details of divisions of carriageway into notional lanes and their numbering.

2.2.4.2 Vertical loads

Characteristic values are intended for road traffic effects associated with ultimate limit state verifications and with particular serviceability verifications. (cl. 4.3.1 of EN 1991-2:2003)

Four load models represent traffic effects.

(a) Load Model 1 (LM1)

This model covers most effects of the traffic of Lorries and cars. Concentrated and uniformly distributed loads. This model should be used for global verifications. Application rules specify tire contact area as 0.4m x 0.4m and rules are given in cl 4.3.2 of EN 1991-2-2003.

LM1 consists of two components.

1) Tandem system (TS) – Double axle concentrated loads, each axle having the following weight $\alpha_Q Q_k$ where α_Q are adjustment factors.
2) Uniformly distributed loads (UDL system) having the following weight per square meter of notional lane. $\alpha_q q_k$ where α_q is adjustment factor.

Eurocode UK National Annex adjustment factors for LM1 are presented in Table 2.3 below.

Table 2.3 Load Model 1 (LM1) values for Eurocode and UK National Annex

Location	**Tandem system (TS) Axle Loads Eurocode & UK National annex**		**UDL system Eurocode & UK National annex**		
	UKNA α_{Qi} (Table NA.1)	Eurocode Q_{ik} (Table 4.2) & UKNA $\alpha_{Qi}Q_{ik}$ kN	Eurocode (Table 4.2) q_{ik} (kN/m^2)	UK National Annex	
				α_q (Table NA.1)	$\alpha_q q_{ik}$ (kN/m^2)
Lane 1	1.0	300	9	0.61	5.5
Lane 2	1.0	200	2.5	2.2	5.5
Lane 3	1.0	100	2.5	2.2	5.5
Other lanes		0	2.5	2.2	5.5
Remaining area		0	2.5	2.2	5.5

The load model 1 (LM1) of EN 1991-2 is illustrated in Figure 2.4 below.

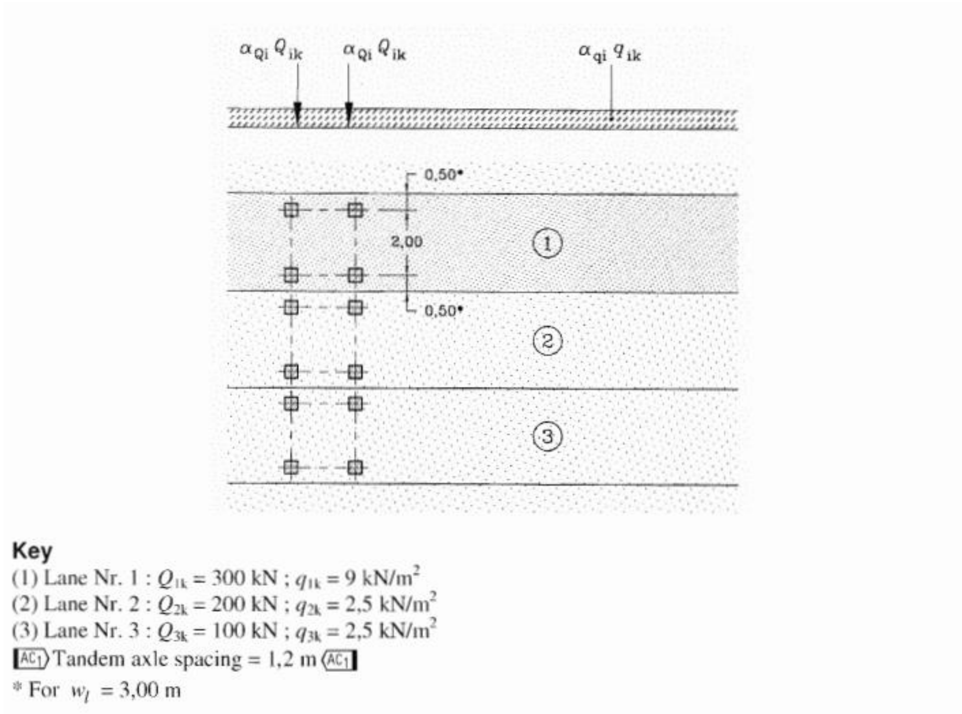


Figure 2.4 Application of load model 1 (LM1)

Source – EN 1991-2:2003

(b) Load Model 2 (LM2)

A single axle load of 400kN that covers the dynamic effects of normal traffic on short structural members. Eurocode specify 0.6m x 0.35m surface contact area. LM2 can be predominant for short spans i.e., for loaded lengths 3m-7m.

UK National annex specify surface contact area 0.4 x 0.4m for LM2. The load Model LM2 is illustrated in Figure 2.5 below.

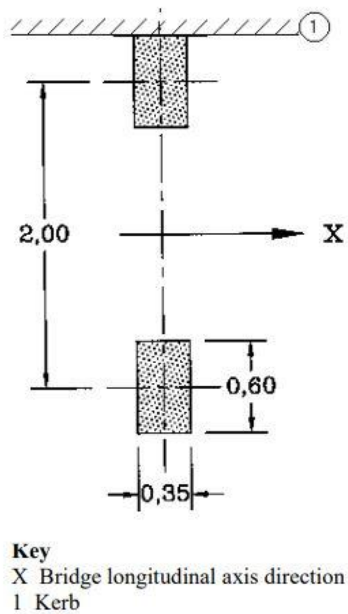


Figure 2.5 Load Model (LM2)

Source – EN 1991-2:2003

(c) Load Model 3 (LM3)

Assemblies of axle loads representing Special vehicles. Eurocode specify series of special vehicles and its use in Annex "A" of EN 1991-2:2003.

UK National annex specify different series of special vehicles that represent maximum effects that could be induced by vehicles in accordance with Special Types General Order (STGO) and Special Order (SO) regulations. Basic three Models SV80, SV100, SV196 simulate vertical effects of STGO vehicles, nominal axle load not exceeding Maximum 16.5 tonnes/axle. Dynamic amplification factors and application of special vehicle models on carriageway is given in Clauses NA.2.16.3 and NA.2.16.4.

Special vehicles SV80 (6 axles of 130kN) and SV100 (6 axles of 165kN) models has less weight than abnormal vehicle HB30 of BS 5400 (4 axles of 300kN) and expected to give similar loading effect with closer axle spacing. Therefore, SV80 and SV100 models were considered for this research. The two traffic models SV80 and SV100 specified in NA to BSEN 1991-2 are illustrated in Figures 2.6 and 2.7 below.

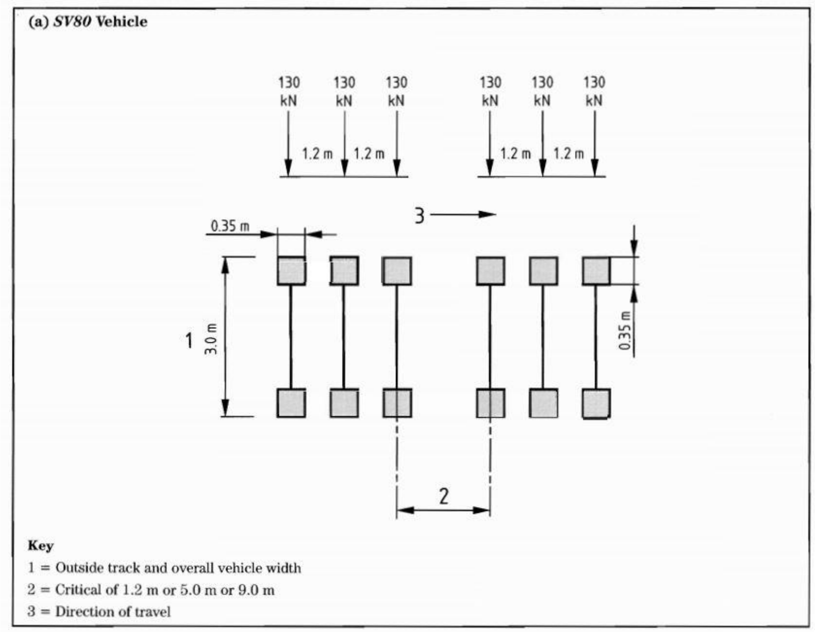


Figure 2.6 SV80 Model

Source – NA to BSEN 1991-2:2003

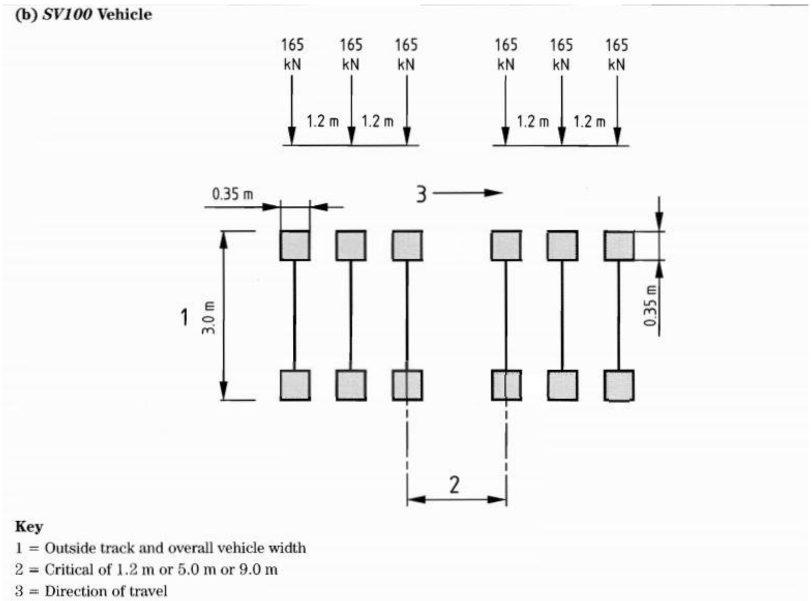


Figure 2.7 SV100 Model

Source – NA to BSEN 1991-2:2003

Load Model 4 (LM4)
Crowd loading of 5 kN/m2 of uniformly distributed load (includes dynamic amplification) intended for general verifications.

2.2.4.3 Horizontal forces –

EN 1991-2-2003 Clauses 4.4.1 and 4.4.2 specify Braking, acceleration forces and centrifugal forces. UK NAEN 1991-2 (2003) clauses NA.2.17, NA.2.18, NA.2.18.1, NA.2.18.2, NA.2.19, NA.2.20 specify Braking, acceleration forces and centrifugal forces. Groups of loads with vertical loads are described under section 2.2.4.4 below.

2.2.4.4 Groups of traffic loads.

EN 1991-2 Clause 4.5, and 4.5.1 specify groups of traffic loads and Characteristic values of multi component action. These groups of loads are mutually exclusive, therefore, should be considered as defining a characteristic action for combination with non-traffic load as tabulated in Table 2.4 below.

Table 2.4 Groups of traffic loads (EN 1991-2:2003, Table 4.4a)

		CARRIAGEWAY						FOOTWAYS AND CYCLE TRACKS
Load type		**Vertical forces**				**Horizontal forces**		**Vertical forces only**
Reference		4.3.2	4.3.3	4.3.4	4.3.5	4.4.1	4.4.2	5.3.2-(1)
Load system		LM1 (TS and UDL systems)	LM2 (Single axle)	LM3 (Special vehicles)	LM4 (Crowd loading)	Braking and acceleration forces	Centrifugal and transverse forces	Uniformly Distributed load
Groups of Loads	gr1a	Characteristic values				[a]	[a]	Combination value [b]
	gr1b		Characteristic value					
	gr2	Frequent values[b]				Characteristic value	Characteristic value	
	gr3 [d]							Characteristic value [c]
	Gr4				Characteristic value			Characteristic value [b]
	Gr5	See annex A		Characteristic value				
	Dominant component action (designated as component associated with the group)							

[a] May be defined in the National Annex.
[b] May be defined in the National Annex. The recommended value is 3 kN/m^2.
[c] See 5.3.2.1-(2). One footway only should be considered to be loaded if the effect is more unfavourable than the effect of two loaded footways.
[d] This group is irrelevant if gr4 is considered.

Table 4.4b of EN 1991-2 and Clause 4.5.2 specify groups of traffic loads (frequent values of the multi component action) and frequent action should consist only LM1 and LM2 that need to be considered without any accompanying component. Clause 4.5.3 specify groups of loads in transient design situations. BS EN 1990:2002+A1:2005 table A2.1 specify following ψ_1 factor, i.e., LM1 TS 0.75, LM1 UDL 0.4, (Pedestrian + cycle track loads) 0.4.

UK National Annex specify modified Groups 5 & 6 as tabulated below. LM3 combined with LM1 frequent values in group 5 for vertical load for superstructure design. NA to BS EN 1990:2002+A1:2005 table NA. A 2.1 specify following ψ_1 factor, i.e., LM1 TS 0.75, LM1 UDL 0.75, (Pedestrian + cycle track loads) 0.4. It further specifies frequent values of groups 4 and 5 need not be considered.

Group 6 specify horizontal load associated with vertical component for substructure and bearing design.

The groups of traffic loads specified in BS NA to EN 1991-2 Table NA.3 is reproduced in Table 2.5 below.

Table 2.5 Groups of traffic loads (UKNA to EN 1991-2:2003, Table NA.3)

Table NA.3 **Assessment of groups of traffic loads (characteristic values of the multi-component action)**

Load type		**Carriageway**						**Footways and cycletracks**
		Vertical forces				**Horizontal forces**		**Vertical forces only**
Reference		**4.3.2**	**4.3.3**	Annex A	**4.3.5**	**4.4.1**	**4.4.2**	**5.3.2.1** Equation (5.1)
Load system		LM1 (TS and UDL)	LM2 (Single axle)	LM3 (Special vehicles)	LM4 (Crowd loading)	Braking and acceleration forces	Centrifugal and transverse forces	Uniformly distributed load
Groups of loads	**gr1a**	Characteristic						0.6 times Characteristic
	gr1b		Characteristic					
	gr2	Frequent[4]				Characteristic	Characteristic	
	gr3[1]							Characteristic
	gr4				Characteristic			Characteristic
	gr5	Frequent[4]		Characteristic				
	gr6			Characteristic		Characteristic	Characteristic	
		Dominant component action (the group is sometimes designated by this component for convenience).						

(1) This group is irrelevant if gr4 is considered
(2) Characteristic value obtained from **5.3.2.1**
(3) This is a reduced value accompanying the characteristic value of LM1 and should not be factored by ψ_1. However, when gr1a is combined with leading non-traffic actions this value should be factored by ψ_0
(4) The ψ_1 factors should be taken from the UK National Annex to BS EN 1990

2.2.4.5 Application of special vehicle load models (LM3) and LM1.

EN 1991-2:2003, Annex A, A3 describe above application. UKNA to EN 1991-2:2003 describe above under NA.2.16.4 and dynamic amplification factors for SOV and SO vehicles are tabulated in Table NA.2

2.2.4.6 Pedestrian load

Values given in UKNA to EN 1991-2 in Table NA.3 and clause NA.2.36 When $0.6q_{fk}=3kN/m^2$ is applied reduction for longer loaded lengths not made. (ILES, 2014, SCI P354, p.12).

2.2.4.7 Groups of Highway loads

"A group of loads is treated as a single variable and thus may be considered as the leading action, $Q_{k,1}$ or as an accompanying action (in which case the factor ψ_0 is applied to the whole group, apart from gr1a, Table NA.3 where a separate factor is given for footway loading)" (ILES, 2014, Steel Construction Institute (SCI) P356, p.45).

2.2.4.8 Eurocode Combinations of Actions. Design Basis. (ILES P357, 2014)

Ultimate limit State (ULS) persistent or transient design situations is given by

$$E\left(\Sigma\, \gamma_{G,j}G_{k,j} + \gamma_P P + \gamma_{Q,1}Q_{k,1} + \Sigma_{i>1}\, \gamma_{Q,i}\, \psi_{0,i}Q_{k,i} \right) \qquad \text{EN1990 6.10}$$

The fatigue limit state is verified for the reference stress range due to the application of the simplified fatigue load model. Fatigue model 3 (FML3), defined in EN1991-2/4.6.4 is used as recommended by EN1993-2:2006

Stresses in structural steel, concrete, and reinforcement are verified at the serviceability limit state (SLS) for the characteristic combination of actions given by

$$E\left(\Sigma\, G_{k,j} + P + Q_{k,1} + \Sigma_{i>1}\, \psi_{0,i}Q_{k,i} \right) \qquad \text{EN1990 6.14b}$$

Crack widths in the deck slab are verified at the serviceability limit state for the quasi-permanent combination of actions given by

$E(\sum G_{k,j} + P + \sum_{i>1} \psi_{2,1} Q_{k,i})$ EN1990 6.16

Partial Factors

For persistent design situations, partial factors on actions at ULS (STR/GEO) are given in UKNA to BSEN 1990:2002+A1:2005 Table NA.A2.4(B) and combination values are tabulated in Table NA.A2.1 The partial factor on shrinkage γ_{Sh} is set at unity for both ULS and SLS (SLNA to EN1992-1-1, 2.4.2.1.(1))

2.3 Precast slab bridges.

A structure with a clear span of more than 3m is classified as a bridge. (ICTAD Publication SCA/5, 2009). Standard designs of single cell and twin cell reinforced concrete of clear span 4.175m (Type superstructure, 2005) offers economical solutions for weak ground conditions. These structures are insitu cast with grade 30 concrete.

Precast beam bridges (Type superstructure, 2005) constructed with beams made with grade 50 concrete and pre-stressed steel strands. Grade 40 insitu concrete is used for deck construction.

2.3.1 Precast solid slab bridges

Pre-tensioned beam range starts from flat beam of 7.085m (pre-tensioned wires). Standard flat beams are unable to be used for construction of skewed decks.

Beams produced using strands replaced early wire beams. Solid slab bridges 9.5m and 11.5m lengths are with pre-tensioned strands beams. 9.5m and 11.5m beams could be used for skewed decks.

Cross sections of smallest length 7.085m and largest length 11.5m bridge deck cross sections are shown in figures 2.8 and 2.9 below.

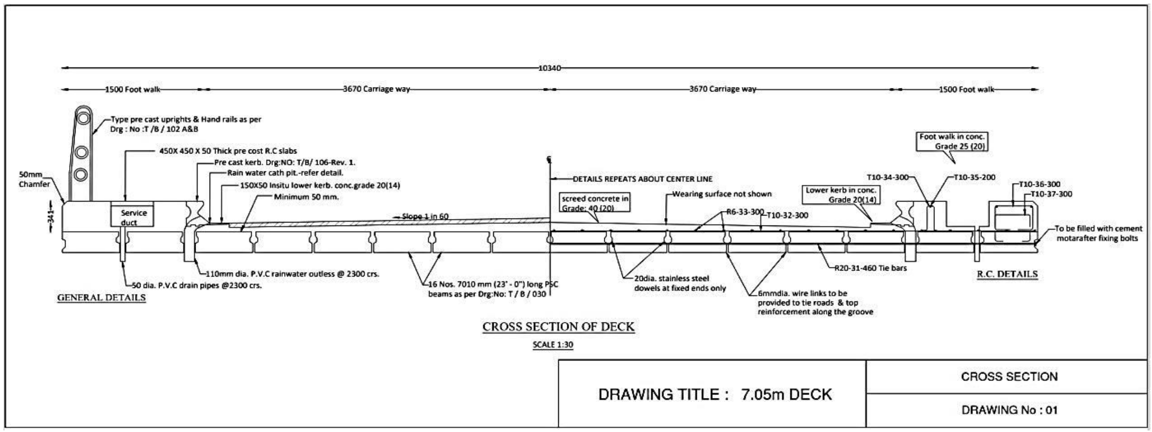


Figure 2.8 Two lane solid slab deck. 7.085m (smallest length) cross section

Source – Type drawing, Road Development Authority

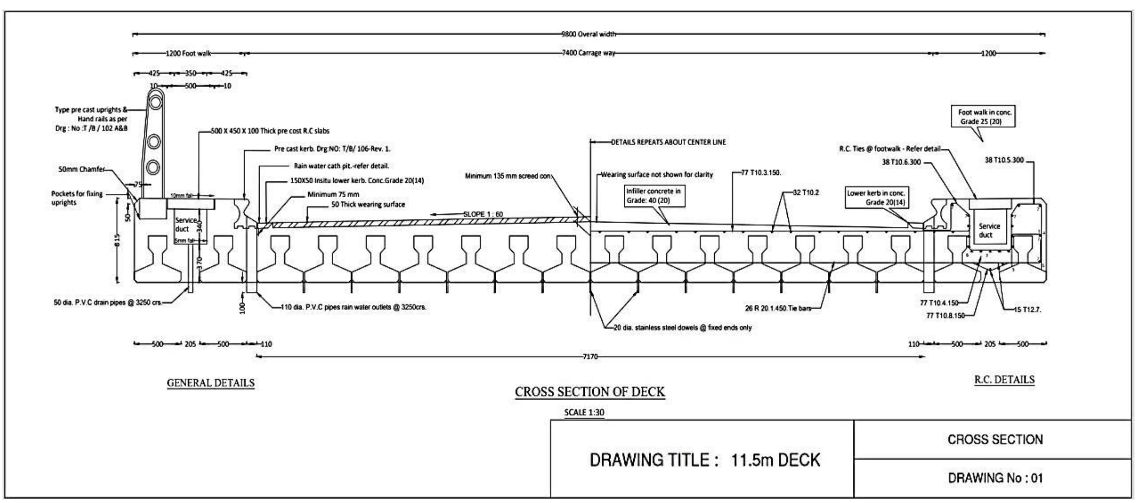


Figure 2.9 Two lane solid slab deck. 11.5m (largest length) cross section

Source – Type drawing, Road Development Authority

2.3.2 Precast solid bridges with void forms

Due to increase of beam height, (in longer spans) voids are formed with polythene displacers filled with saw dust reducing concrete material and dead weight without sacrificing deck stiffness. The smallest length 13.5m and largest length 19.0m deck cross sections are shown in Figures 2.10 and 2.11 below. This is an economical solution compared to a solid slab. Voided deck slabs are constructed with 13.5m, 14.5m, and 15.5m, 16.5, and 19m pre-tensioned (strands) beams.

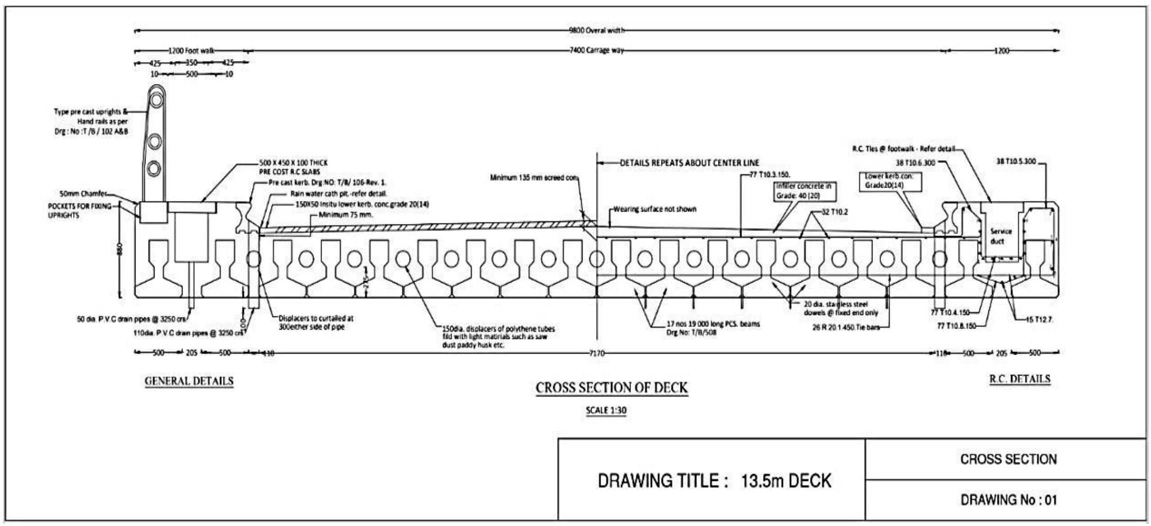


Figure 2.10 Two lane voided slab-deck 13.5m (smallest length) cross section

Source – Type drawing, Road Development Authority

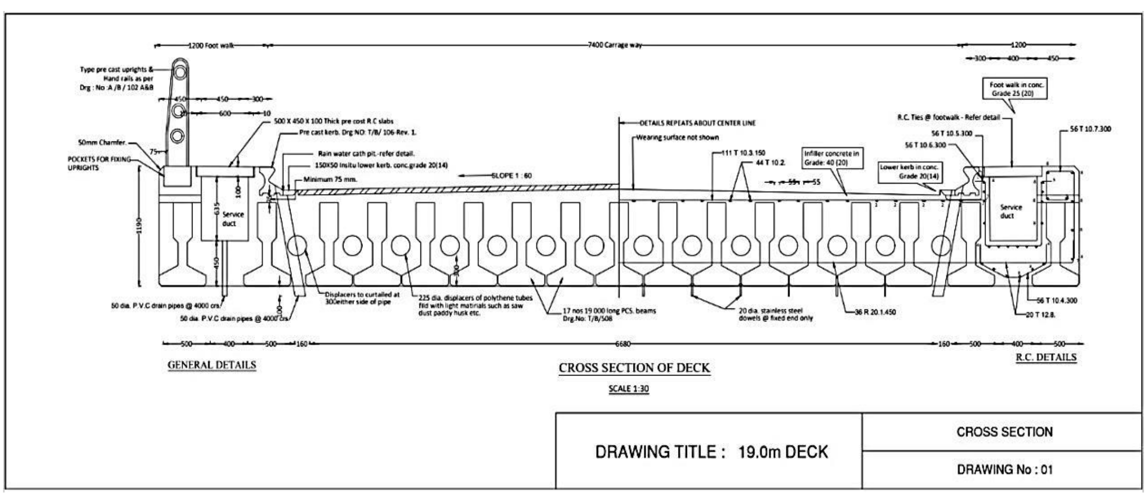


Figure 2.11 Two lane voided slab-deck 19.0m (largest length) cross section

Source – Type drawing, Road Development Authority

2.3.3 Precast M beam type bridges.

Only M-beam of 25m span is used in Sri Lankan highway network. Pre-tensioned beam with strands form beam and slab type deck construction. Permanent formwork is used for deck cast insitu. Diaphragms are provided for deck on abutments. The deck cross section is shown in Figure 2.12 below.

For erection positioning, and lifting capacity of crane is a deciding factor for 25M beam.

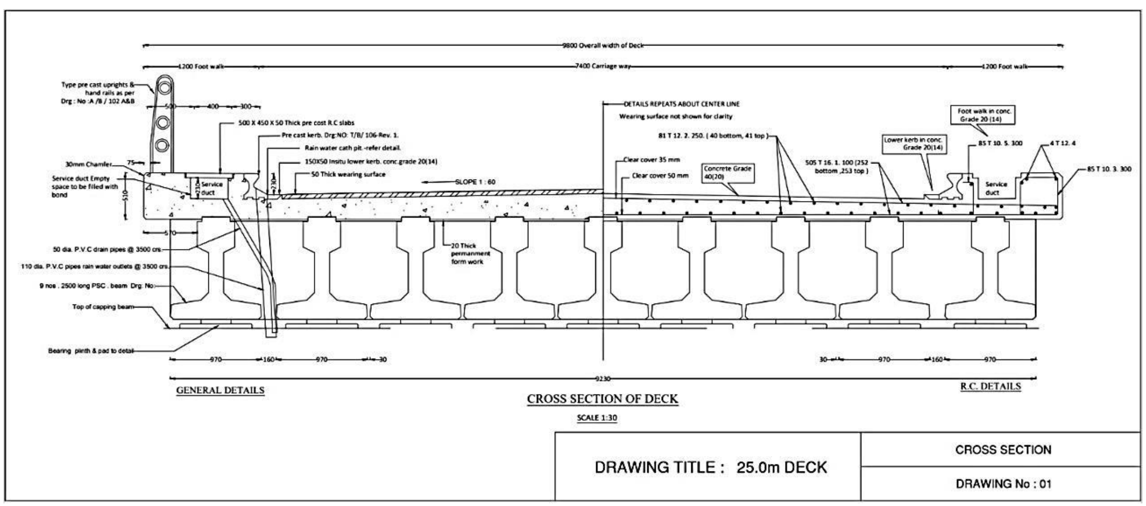


Figure 2.12 Two Lane beam and slab deck span 25.0m M Beam.

Source – Type drawing, Road Development Authority

2.4 Types of steel composite bridges.

Composite construction, in the form of reinforced concrete deck on top of a several steel girders (rolled beams, plate girders, trusses) is a widely used construction for highway bridges (ILES, 2014, SCI P356) is shown in Figure 2.13 below.

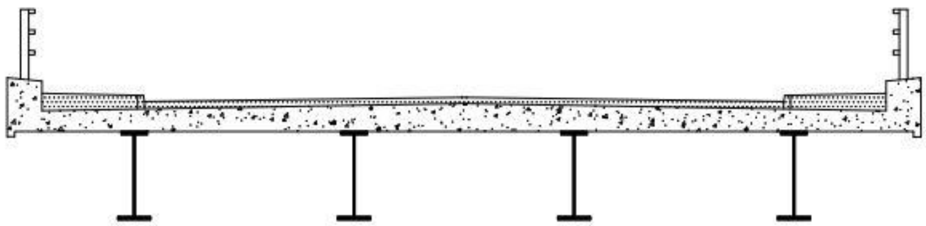


Figure 2.13 Steel concrete composite deck

Source – SCI publication P357

Concrete slab enhances moment of resistance of the girder. It distributes wheel loads to main girders and transfers some load from more highly loaded girders to adjacent girders. The larger the ratio span/width of deck, the better the load distribution between girders. Several girders carry major part of the load when deck becomes wider.

Composite construction is used within a wide range of configurations. In simply supported composite construction, concrete deck carries compression and steel girder carries tension (by the material below neutral axis) is the most efficient configuration. In this form, neutral axis lies within or just below concrete deck for a wide range of rolled universal beams. Compression of steel web above neutral axis in large sizes universal beams and plate girders need to be checked for buckling. Permanent bracings are provided on abutments for torsional restraint and as a load path to transfer lateral force on girders and deck to bearings.

In continuous construction, (ILES, 1993, SCI 065) section under hogging moment (over internal support) induces tension in concrete deck and compression in steel girder. Concrete deck is considered cracked within hogging moment region, therefore steel girder and steel reinforcement in the deck determine section properties and girder behavior. Saving in structural steel due to continuity is offset by additional hogging reinforcement provided in the deck. In hogging moment regions, steel web below neutral axis needs to be checked and permanent bracings to compression flange need to be provided.

During construction the weight of fresh concrete is carried by steel girders (unless propped). Beam should be guarded against lateral torsional buckling during this stage. For this purpose, temporary bracing needs to be provided as in Figure 2.14. In continuous construction concrete in sagging moment regions cast first, and hogging regions (over support) are cast later. Stud shear connectors (most common) are welded to top flange of steel girder to provide transfer of longitudinal shear between steel and concrete interface.

In deciding number of girders and spacing in-between, free board (space required under the girder) and economy of the structure need to be considered. For economy, concrete slab and girder webs need to be minimized cost in terms of material and fabrication. The deck with two main girders and cross girders that support concrete slab (cost optimized) which is known as ladder deck and is shown in Figure 2.15 is considered (ILES, 2014, SCI P356, P357,) as an economical solution for spans greater than 40m.

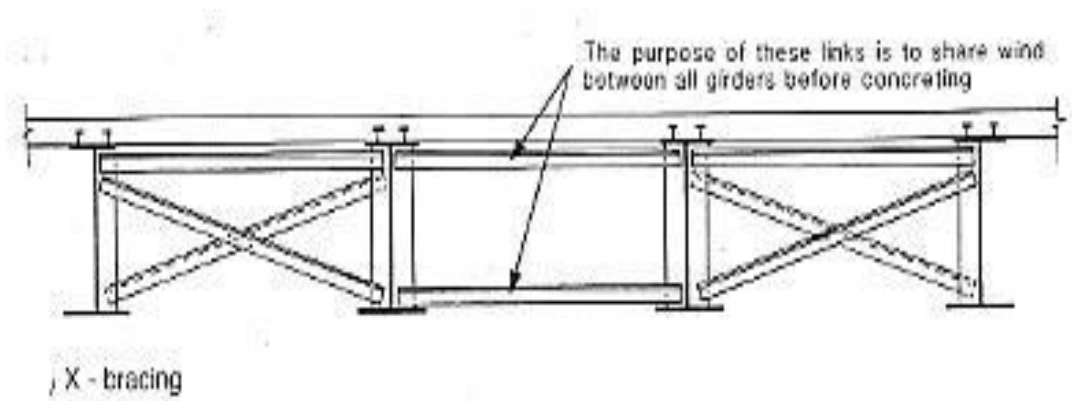


Figure 2.14 Intermediate temporary bracing (Source – SCI publication 066)

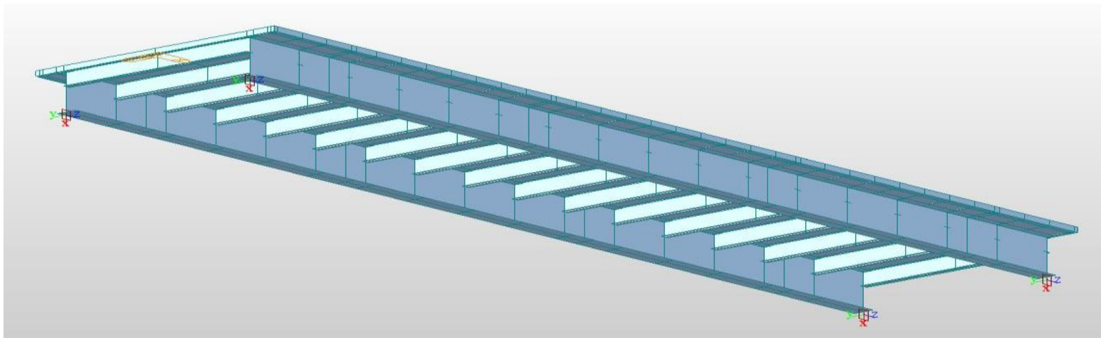


Figure 2.15 Ladder deck

2.4.1 multi-girder deck slab with rolled beams.

Composite concrete deck with Universal beams is a convenient construction with minimum steel fabrication cost. Spans up to 20m are common (ILES, 1993, SCI 065).

Girder spacing 1.5m for S275 steel (with deck slab 200mm thick) to 3.0m for S355 steel (with maximum deck slab 250mm thick) is common. Span/Depth ratio 16 for S275 and up to 22 for S355 steel is suitable for preliminary sizing of multi girder system.

Permanent bracings on supports, i.e., for abutments (and on piers for continuous construction) are provided as a frame using rolled channel sections as shown in Figure 2.16. Intermediate temporary triangulated bracings “X type” to stabilize both flanges (“L” angle or channel sections) are provided within the span to prevent torsional buckling of girders under fresh concrete.

Load bearing stiffeners and jacking stiffeners are provided on supports. Web thickness of Universal beams is generally sufficient for shear force requirement of simply supported beams and shear and bending moment interaction requirement on an internal support for continuous beam. Figure 2.16 illustrates permanent bracing provided for a deck with rolled universal beams.

A trimmer beam is cast with deck encasing abutment bracing to protect steel girders from water leaking through expansion joint.

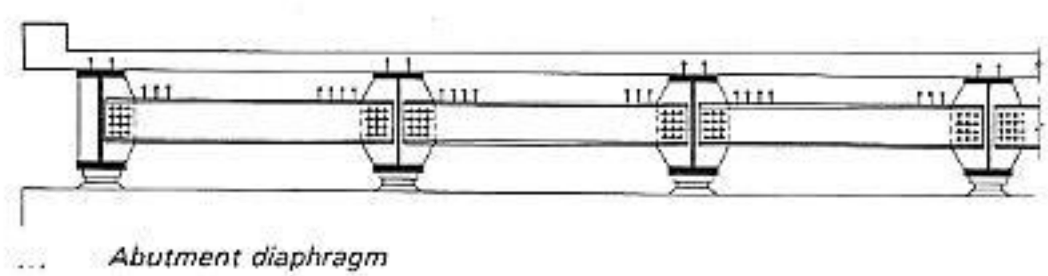


Figure 2.16 Universal beam multi girder deck abutment section connected with beam type bracing. (Source – SCI publication 065)

2.4.2 multi-girder deck slab with plate girders.

Plate girder designs become economical for spans 20m – 40m. There is freedom to select flange sizes and web size for girder spacing required. In simply supported construction the bottom flange size is governed by the tension force it carries. Top flange size is determined by erection conditions. i.e., lateral stability and usually taken as two third of bottom flange area. Web thickness is determined by the support shear that it need to carry (ILES, 1993, SCI 066, P084).

Span/Depth ratio 18 to 30 are possible with steel grade S355. Girder spacing 2.5m - 3.8 m with concrete deck slab up to 250mm are possible.

The permanent bracing on abutments generally is triangulated truss form “X” type, inverted “V” type shown in Figure 2.17 or “beam” type connecting all girders. Rolled channel sections are generally provided for truss and beam bracing. Intermediate permanent bracings when required is provided within the span as pairs shown in Figure 2.18. Continuity of bracing over whole length across deck result fatigue damage.

Plate girders are provided with stiffeners of different types on its web. Load bearing stiffeners, intermediate transverse stiffeners and end posts, to fulfil different functions in resisting shear force and shear force bending moment interaction.

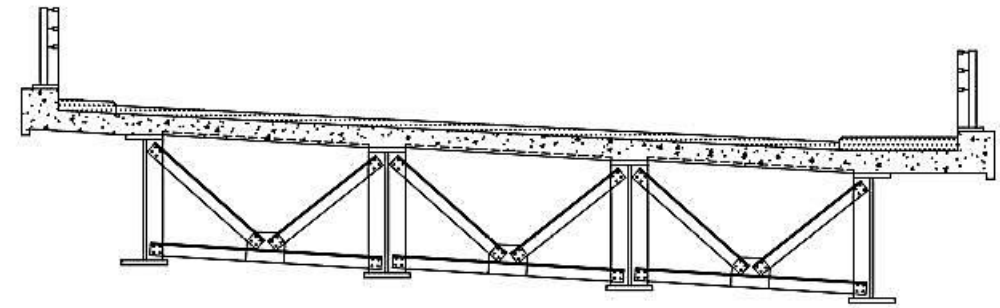


Figure 2.17 “V” type permanent bracing on abutment/intermediate support.

(Source – SCI publication P356)

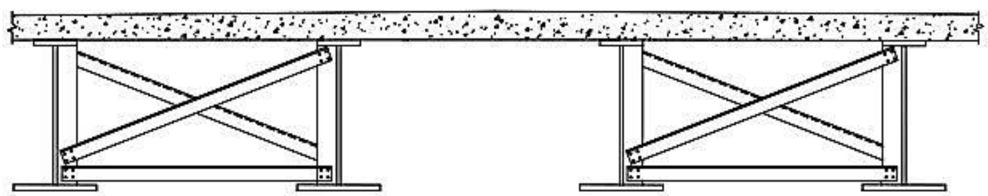


Figure 2.18 Paired permanent bracing.
(Source – SCI publication P356)

Multi girders could be lifted to position as braced pairs. Then the girders are more stable, and bracing connections are less hazardous at ground level than at height.

2.4.3 Ladder deck with composite concrete slab (ILES, 2014, SCI P356, P357).

Ladder deck comprise of two main steel plate girders and cross girders composite with concrete slab as shown in Figure 2.15. Deck spans greater than 40m offer economical solution. Continuous ladder deck can accommodate longer centre span with shorter side spans.

Overall depth (girder + slab) is (1/15) to (1/20) of the span for S355 steel. Spacing between main girders about 5.5m to 18m with side cantilevers 1.5m – 2.0m possible. Cross girder spacing 3.3m – 4.0m with deck slab thickness 250mm could be achieved with permanent formwork.

Cross girder is considered as simply supported between main girders. Cross girders are connected to intermediate transverse stiffeners that are designed to carry load transferred from deck or to bearing stiffeners.

The connection type between main and cross girders affect economy, thus different types are used to minimize cost. Intermediate plate cross girders are provided as lapped connections shown in Figure 2.19. For cross girders formed by universal beams or framed in to bearing stiffeners are connected using double covers as shown in Figure 2.20. Instead, use of stub flange with bolts in cover plates at maximum distance from the slab is more effective in transmitting moment due to splice eccentricity shown in Figure 2.21.

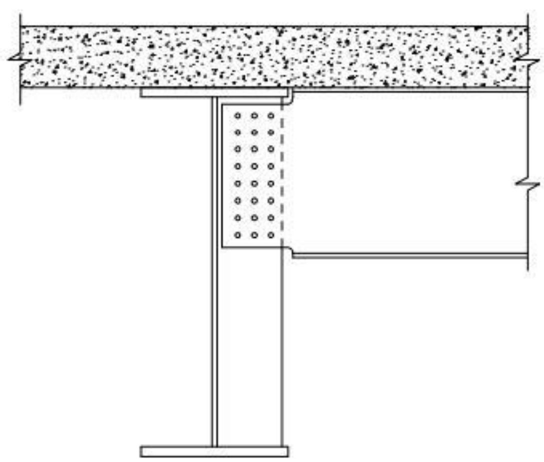


Figure 2.19 Lapped connection between cross girder and main girder

(Source – SCI publication P356)

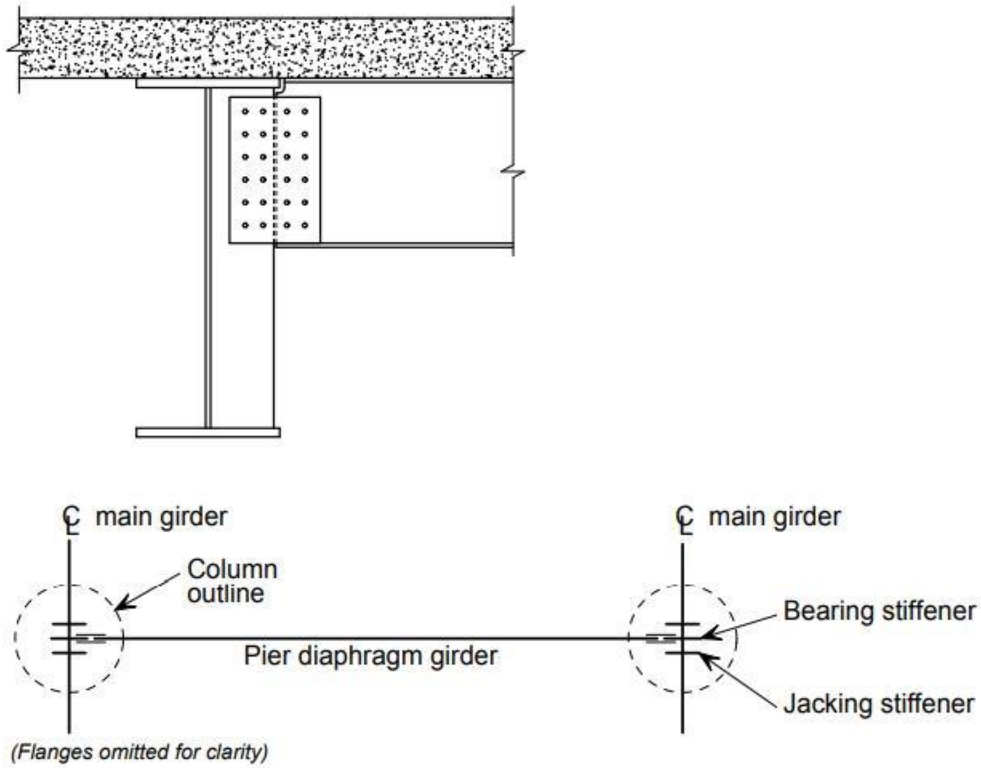


Figure 2.20 Spliced connection with double cover plates for diaphragm.

(Source – SCI publication P356)

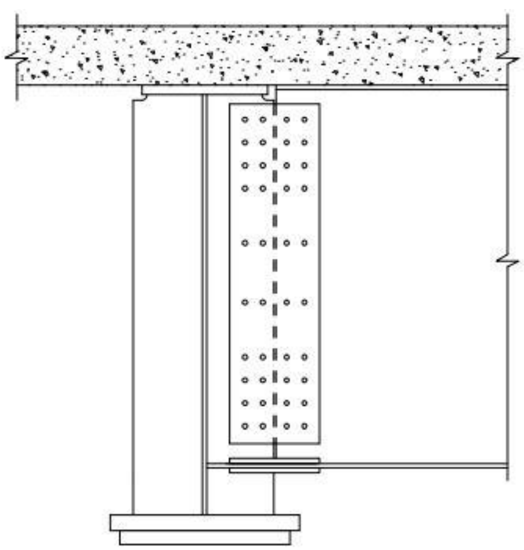


Figure 2.21 Spliced connection with stub flange.

(Source – SCI publication P356)

Ladder deck is too heavy to lift to position once pair of girders are assembled. If access by cranes is not possible from ground level, use of a launching girder (or a temporary panel bridge) is the best method to launch without stress reversals. Cross girders are connected after launching each girder to position. The stability of the single girder under its self-weight and possible wind needs to be checked for erection phase.

If the bridge has several spans cantilever launching of assembled bridge could be considered. A temporary nose as shown in Figure 2.22 needs to be attached to limit stress reversals. Stability of web with intermediate stiffeners for roller reaction need to be verified.

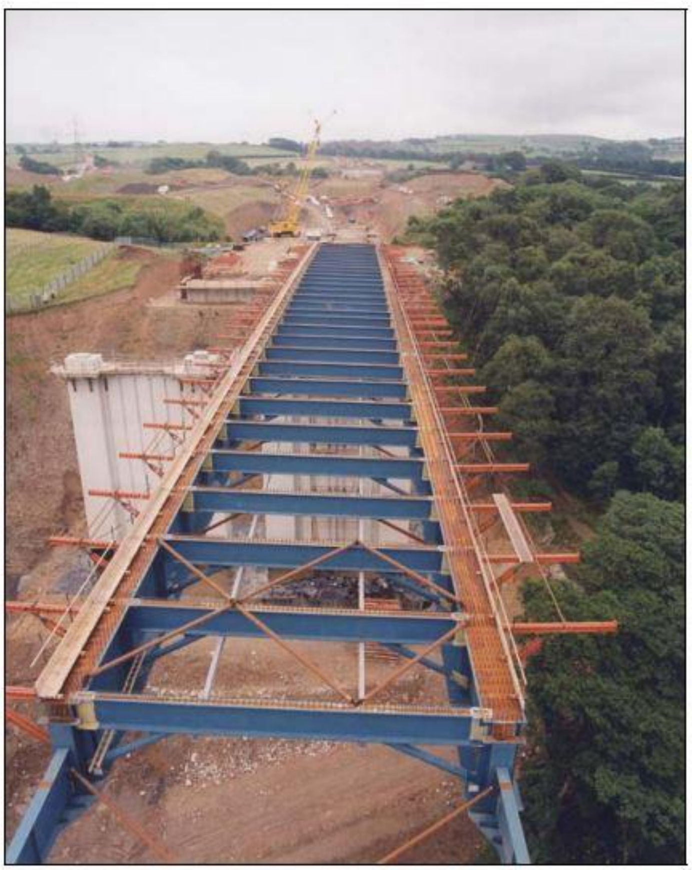


Figure 2.22 – Cantilever launching of ladder deck (with nose attached)
(Source – SCI publication P356)

2.4.4 Design details of plate girders.

Stiffeners, connections, bracing, butt welding, and ancillary items increase cost of fabrication. Cost effective detailing is an important aspect of design (ILES, 2014, SCI P356).

2.4.4.1 Stiffeners and end posts (Lee, (2014))

Stiffeners and end posts are provided to in the web to prevent buckling due to direct bending stress and stress due to shear as well as local failure under patch loads such as jacking. If the web is stocky shear buckling will not occur. Shear buckling strength depends on aspect ratio, plate thickness, imperfections, material properties and boundary conditions.

The Figure 2.23 below illustrates bending and shear stresses to which end post and intermediate stiffeners are subjected to.

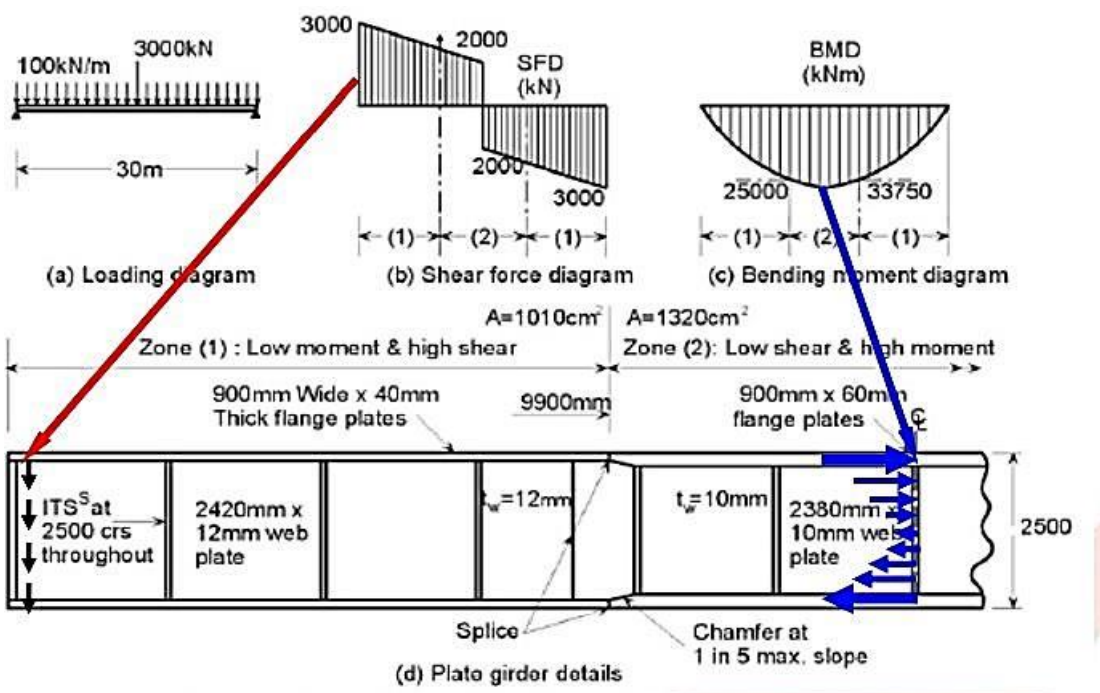


Figure 2.23 End post subjected to shear stress and intermediate stiffener subjected to direct bending stress. Source (Lee, 2014)

Shear buckling could be delayed if appropriate rigid transverse stiffeners are constructed to limit the extent and separate buckling regions.

2.4.4.2 Intermediate transverse stiffener

This is subjected to internal direct stress and shear stress. Intermediate stiffener creates compartments to increase web buckling resistance providing rigid support for tension field action and flange resistance (plastic hinge) for web buckling as illustrated in Figure 2.24.

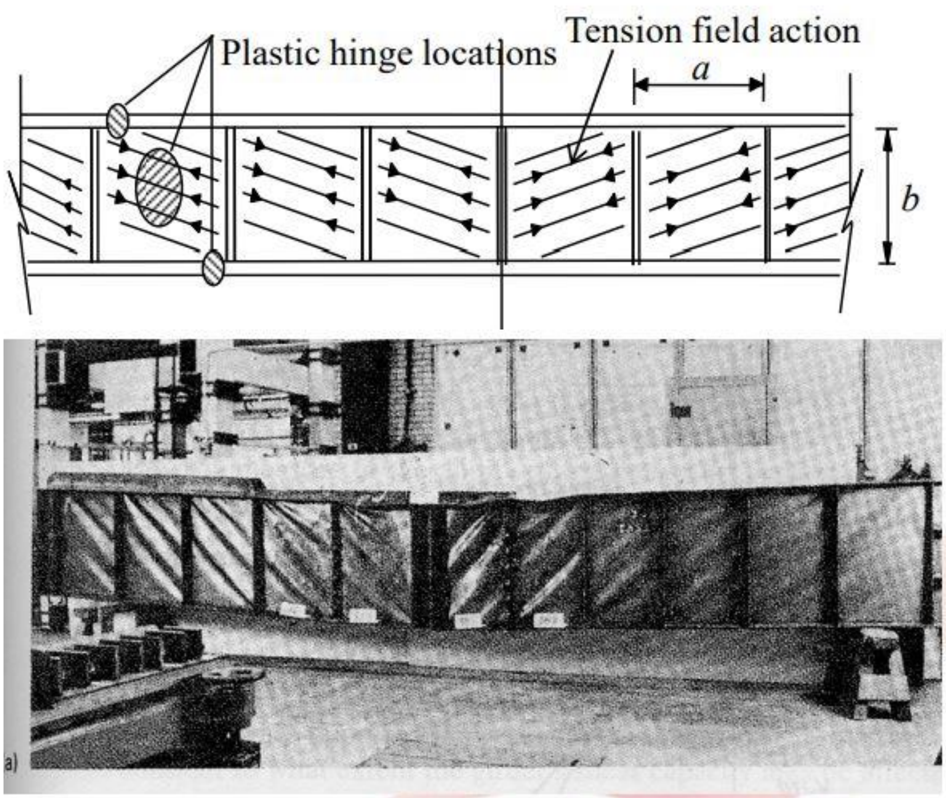


Figure 2.24 Tension field action and formation of plastic hinges. Source (Lee, 2014)

2.4.4.3 Load bearing stiffener

Prevent yielding, crushing, local and global failures where heavy patch loads are applied. (Lee, 2014)

2.4.4.4 End Post

This is a special form of load bearing stiffener that provides anchor supports for tension field action and flange resistance (plastic hinge) and reaction forces. Rigid and non-rigid posts are possible (Lee, 2014) and are illustrated in figure 2.25.

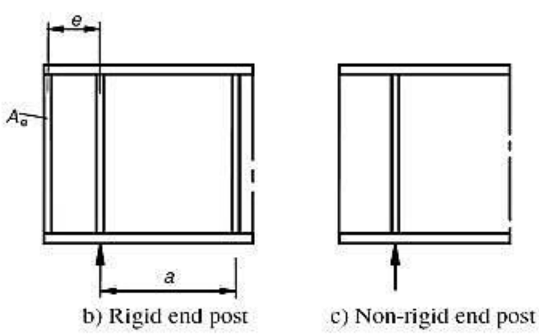


Figure 2.25 Rigid and non-rigid end post. Source (Lee, 2014)

2.5 Analysis of bridge decks.

2D line model is the first step and preliminary sizing and design could carry out based on an assumed load distribution across the width of deck. This model provides overall idea of forces and deformations, but not suitable for detailed design.

For detail analysis and hand calculations charts have been developed for load distribution. Charts by Putcher for isotropic slabs, and by Morris and Little for orthotropic slabs are widely used. In general, it is quicker and more reliable to carry out grillage analysis for the bridge deck (Hambly, 1991).

2D grillage is an in-plane horizontal mesh comprising members in longitudinal and transverse direction. Mesh element intersections form nodes. Elements represent properties of actual structure.

Grillage model is a widely used computer software for bridge deck analysis. Load input is often point loads, uniformly distributed loads (udl) and moments applied to nodes or on the element. Direct output of forces and moments are possible, therefore is suitable for global static analysis, and main girder design. Grillage does not capture local effects on deck; therefore, it is not suitable for local analysis of bridge decks.

Compared to 2D grillage, 3D space frame elements facilitate modelling in different levels of vertical plane. Vertical bracing, bearings and all elements in different levels could include in a 3D composite girder model. 3D frame (Space frame) computer models could be used to analyse plate girders and distortion of box girders (Hambly, 1991).

Finite element analysis is used for bridge decks analysis. Plate elements together with frame elements are included in bridge deck analysis software. “All plate” models or “plate and frame” element mixed models are supported in software. Plate elements could be used to model deck and girder web, to analyse stress distribution in each element. Frame elements could be used to model complete girder or girder flanges.

A full plate model could be used to check buckling of girders, and for stability analysis (during erection process), local effects and check stress distribution of all members including secondary elements such as cross beams, stiffeners (also when girder is jacked) and bearing plate.

2.5.1 Suitability of Midas Civil for Modelling.

Midas Civil has been used to model and design major bridges. Russky Bridge in Russia that has longest cable stayed centre span of 1104 m has been modelled using Midas Civil software. Severe climatic conditions, temperature, wind and snow has been considered during modelling. (Midas training, 2021). Bosak, (2020) describe modeling of service and push launch conditions and design of ladder deck bridge recently built in Europe. This bridge is 254m long with five continuous spans (58m – 46m). It has twin steel girders 3m deep, 13.5m apart with 3.1m side cantilevers.

Midas Civil supports Finite Element types of frame, plate, shell and solid. Loading types of static, moving, dynamic, construction stage, temperature and pre-stress. Boundary conditions support, spring types, link types, beam and plate end release types, linear constraints, panel zone effects. It supports linear, nonlinear, P-Delta, buckling, eigenvalue analysis. Pushover Analysis, and steel and concrete deck rating also included. Above features are essential to build a good computer model of a bridge.

Midas Civil provides wizards to form computer bridge models. It is always easier to start with the wizard and apply necessary changes to model generated thereby to represent the actual structure. Among many wizards "Steel composite Bridge Wizard" which can generate essential features of composite bridge having any horizontal and vertical geometry, splices and bracing types, different sections, construction stages, and traffic lanes and traffic loads to suit many codes including Euro, Euro (UK national annex) and BS codes.

Steel composite Bridge Wizard provides the following modelling options. (Bosak, 2020).

1. All frame (3D or 2D frame, grillage) model
   Construction stage analysis, Global static analysis, support reactions (bearing design) deformations, member design, and verification of main girders.

2. Deck as plate, girders as frame
   Verification of all structural steel during construction stage could be performed for Euro, BS and for many other codes.

3. Deck and web as plate, flanges as frame model
   Stability verification during construction, Transverse deck analysis and design (For ladder decks mixed method of modelling cross beams as frame elements could be adopted)

4. All plate
   All elements could be modelled as plates including cross beams and stiffeners to check lateral torsional buckling. Local verification of stiffener buckling, local web buckling, stress concentrations

General Design and model considerations (Bosak, 2020) and types supported in Midas Civil are summarized in Table 2.6 below.

Table 2.6 Summary of Model types supported in Midas Civil.

Model Type	**Purpose**	**Advantages**	**Limitations**
2D Line Beam Model	Preliminary Design	Fast, simple setup	Provides overall idea of forces and deformations, but not suitable for detailed design
Frame Model (2D/3D Grillage)	Global Static Analysis, Main Girder Design, Substructure Design	Fast setup and analysis, direct output of forces and moments for the design	Not suitable for transverse deck analysis

Mixed Model (Frame & Plate)	Global Static Analysis, Transverse Deck Analysis	Detailed stress distribution in main girder and deck; effects of transverse deck loading	Demanding on hardware, more complicated process to extract results (forces, moments) for composite girder design
Full Plate Model	Stability Analysis, Local Detail Analysis	Detailed stress distribution in all members including secondary elements (Cross beams, stiffeners, bearing plates, etc.)	Larger model size, more demanding on hardware, complicated to extract results for composite girder design

2.5.1.1 Frequently used Design features of Midas Civil

Midas Civil is capable of performing not only structural analysis but also designing for many codes including Eurocode. Important design features are listed below.

1. Defining erection phases of structure with time and ability to run software only up-to a pre -defined erection phase to check load effects during erection.
2. In built properties of concrete and steel including shrinkage, creep, and temperature effects.
3. In built application of Eurocode and BS traffic loading and Eurocode design of steel, composite and concrete components.
4. Application of dead and various types of transient loads.
5. Automatic generation of load combinations as per Eurocode and BS.
6. Display of maximum minimum (or envelope) load effects for static and traffic (moving) loads, and combinations defined
7. Moving load tracer – Display application of traffic load combination for a maximum/minimum load effect of a selected element.

8. Generation of design report – This is based on the most severe load combination for the appropriate for each load effect for the element selected for design. Midas Civil can generate dynamic report. Dynamic report automatically changes when analysis or design values are changed in the software input.

2.5.1.2 Design of Composite Plate Girder to EN1994 – 2 by Midas Civil

Composite Plate girder needs to be designed to satisfy following limit states and design checks are carried out (Eurocode Design Guide, 2021).

a) Ultimate Limit State
   1. Bending Resistance
      (Plastic resistance moment /Elastic resistance moment)
      2. Resistance to vertical shear (stiffened /unstiffened steel sections)
         (a) Plastic resistance to vertical shear
         (b) Shear buckling resistance
         (c) Interaction bending and vertical shear
   3. Resistance for lateral torsional buckling (steel I section)
   4. Resistance to Transverse forces
   5. Resistance to Longitudinal shear (for steel I section)
         (a) Design shear resistance of headed stud
         (b) Shear stress at the connection between girder and deck
   6. Resistance to Fatigue

   7. Serviceability Limit State
      1. Stress limitation for concrete
         For Quasi-permanent, Characteristic load combination
      2. Stress limitation for reinforcing steel
         For Quasi-permanent, Characteristic, Frequent load combination
      3. Stress limitation for structural steel

For Characteristic load combination

4. Resistance to Longitudinal shear

   For Quasi-permanent, Characteristic, Frequent Load Combination

The design report generated by Midas Civil is based on above checks.

2.6 Previous research in to review of highway loading

(Seyanthan & Jayasinghe, 2013) compared BS5400 loading (Combination HA – BS5400, 1978 and HB) with Eurocode (Combination LM1 and LM3) for span range 10m – 30m. Research also compared torsionless deck systems with full torsional (pseudo slab) systems (span range 10m-16m). It concluded that significant difference would not exist between two systems. Research recommends 85% of Eurocode combination value for "A" class roads and Expressways and 70% for B, C, D, E class roads.

2.7 Knowledge gaps.

BS5400 loading considered in RDA manual is given in section 2.2.2.5. It is lighter than BS5400 HA and HB30 load combination considered by (Seyanthan & Jayasinghe, 2013). Therefore, the Eurocode combinations recommended in 2.6 above has a larger margin than specified.

HA loading – BS5400 2006 not considered in the above research. Therefore, new expressway designs require comparison of Eurocode loading with HA – BS5400 2006 loading. Twin girder (ladder deck spans 40m, 50m) need separate detail consideration for BS5400 1978 and 2006 highway loading.

As stated in section 2.2.4.4 load group 1 of Eurocode and UKNA consist of LM1 with footway loading. Although footway loading is an associated load with LM1, for comparison of traffic models of two codes, comparison of LM1 with HA (BS5400 part2) as recommended in RDA manual is appropriate.

Finding the most feasible and economical solution requires accurate cost information from the industry. A similar document to HSR Analysis for steel fabrication and erection is presently unavailable. Cost information relies upon fabricators responses. Cost analysis of steel fabrication and erection remain as trade secrets. Often fabricators quote cost per tonne for identical work. This method does not capture the cost of complicated fabrication and value addition process.

The estimation tool developed by (Cowie and Fussell, 2011) is a similar document to HSR that can capture value addition. However, some costs given in the document are compounded, and could be assumed as an upper bound for Sri Lankan scenario. Therefore, estimation tool was used in addition to fabricators responses, and data of previous constructions that were considered to estimate different composite decks.

2.8 Conclusions from Literature Survey.

Changeover to Eurocode require study how traffic loads need to be specified for Sri Lanka. Study of differences in traffic loads specified in British Standards BS 5400 part 2: 1978, 2006, RDA Manual, and Eurocode EN 1991-2:2003 (UK NA) for Sri Lanka scenario is useful in this direction.

Maximum notional lane widths specified in above BS standards are 3.7m and 3.75m for two lane bridges. Eurocode UKNA notional lane width is 3.0m.

Sri Lankan highway standards specify maximum 3.7m lane width and 3.0m minimum lane width for four lanes with centre median. For two lanes a minimum of 3.1m specified when space is available. Bridge carriageway is fully occupied during peak hours in urban areas, therefore Eurocode approach notional lane width 3.0m with remaining area is more appropriate for Sri Lanka.

BS 5400 part 2 1978 & 2006 (notional lane widths 3.7m and 3.65m) specify constant load intensity for UDL & KEL across deck for two lane bridges up to 50m span. Eurocode LM1 udl and tandem axle system specify different loading to each lane, highest values being applied to lane 1. EN 1991-2:2003 (UK NA) specify constant udl across the deck. UKNA defines special vehicles that can closely represent HB vehicle defined in BS5400 part2. Therefore, traffic load distribution of UK National Annex represents former BS more closely than Eurocode. UK National annexes maintain compatibility in between, therefore able to provide guidance where local annexes have not been developed in areas of steel bridges, and steel concrete composite bridges.

Sri Lanka was adopting BS5400 for bridge designs. Due to reasons mentioned in above paragraph adapting UK National annexes are expected to avoid overdesign and provide smooth transition. Therefore, for traffic loads, comparative study with UK National annex to Eurocode 1991-2:2003 is most appropriate.

BS5400 part 2 1978 specify HA loading 30kN/lane udl up to 30m spans and Eurocode UKNA LM1 loading specify 5.5 kN/m^2 for notional lanes and remaining area. HA udl is more severe. BS HA KEL is less severe than Eurocode UKNA LM1 tandem axle load effect. Many bridges in Sri Lanka have been designed for BS5400 1978 standard modified by RDA manual. Comparison of HA loading with UKNA LM1 loading is essential for different spans and deck configurations.

BS5400 part2 2006 specify HA udl with a higher intensity compared to 1978 standard up to 50m span. Therefore HA & HB combinations need to be studied with Eurocode UKNA LM1 & LM3 combinations.

Special vehicles specified in BS and Eurocode UKNA has different axle arrangement and loads. 30 Units of HB has been specified in current Sri Lankan practice. Changeover to Eurocode requires identification of suitable STGO or SO vehicle types (SV and SOV in UKNA) that needed to be specified.

Considering most economical and feasible deck types, existing concrete bridge deck types of solid slab, voided slab, 25m M beam & slab deck, and plate girder (multi girder span 31.5m) composite deck slab, ladder decks (40m and 50m) were selected to study effects of loading types and to compare load models of BS5400 part2 and Eurocode UK National Annex.

Span lengths less than 9.0m, which include reinforced concrete bridges of single cell and twin cell (lengths 4.8m – 8.75m) and prestressed concrete flat beam deck of 7.0m length that would require the study of critical effects of Eurocode load model LM2, were not considered in this study to maintain simplicity. Therefore, this study considers bridge span lengths 9.04m – 50m.

Literature survey provides required information to complete comparative study of adopting UKNA loading and BS5400 loading for standard existing concrete bridge decks and proposed composite bridge decks. Different methods described in section 2.7 provide cost estimates that guide selection of most economical composite decks compared to concrete decks.

Chapter – 03

Methodology

3.1 Introduction

Literature review was conducted to gather information related to development of bridge industry in Sri Lanka, study application of Eurocode for steel concrete composite bridge systems, costing, and computer modelling and design of composite bridges by Midas Civil software.

As discussed in previous sections 1.4 and 1.5, new composite bridge designs prepared in this research are confined to simply support parallel chord girders, to make analysis simple and to represent actual existing concrete bridges more closely. The method of steel erection was assumed to be lifting from both ends either by single or dual mobile cranes. For long spans when structure is too heavy to lift it is assumed launching girder or a temporary panel bridge is used so that simply supported condition could be maintained.

Steel truss bridges are excluded since unavailability of accurate fabrication cost information for this research.

New composite bridge designs were based on steel grade S355, for better economy (ILES, D.C., P356, 2014). Deck concrete selected for environment condition EN1992-1-1:2004 Table 4.1 exposure classes XD1, XD2, XD3, and XS1. The deck concrete cylinder strength decided as 40 Nmm^2. Deck concrete C40/50, and 0.25m thick selected. Class C30/37 would be strong enough in most cases but does require slightly greater cover (ILES, D.C., P356, 2014)

3.2 Research Process

Since Sri Lanka National Annex for Eurocode has not been developed, establishing suitable loading for existing concrete decks and steel concrete composite decks has been the first objective of this research. It consists of the following steps.

- Compare traffic load distribution for BS 5400 -2 (1978 & 2006) loading with Eurocode UK National annex loading for

  a) Most common existing pre-tensioned beam bridges (Slab bridge decks and 25m "M beam" with reinforced concrete deck).
  b) Multi plate girder composite bridge designs developed in this research.
  c) Ladder deck plate girder designs (two main girders with cross girders) developed in this research.

The second objective of this research is to develop new steel concrete composite bridge designs to Eurocode loading decided above, and compare deck costs with existing concrete decks for prevailing market conditions. This objective consists of the following steps.

a) Develop simply supported steel concrete composite bridge designs for Eurocode loading for multi girder spans up to 32.5m (with rolled steel girders and plate girders) and ladder deck spans (40m – 50m) comparable to existing concrete bridge spans.

b) Estimate composite deck costs for the current year 2020 in following methods.
   - Based on rates submitted by a fabricator.
   - Recast rates of Kinniya bridge and Kelanisiri Bridge, painting costs of the Narathupana Bridge using HSR.
   - Based on a published document in New Zealand for plate girder and ladder deck bridge deck designs.

c) Compare cost for existing pre-tensioned beam decks (spans up to 25m) and post-tensioned beam deck (32.5m - 48m recast to 2020, based on HSR) with steel concrete composite deck designs developed above.

Cost information collected from SD&CC for pre-tensioned and post-tensioned beams. (Price list, 2020), (Katugasthota Bridge 32.5m beam, 2008) & (Kallady Bridge 48m beam, 2010) Road Development Development Authority allowed access to drawings, cost information of Kinniyai (Kinniyai bridge, 2005) and Kelanisiri composite plate girder bridges (Kelanisiri Bridge, 2001) and repainting of Naratupana bridge (Narathupana bridge, 2017). Colombo Dockyard Ltd provided cost information for fabrication, painting and erection (Cost information, 2020).

All computer modelling of existing concrete pre-tensioned beam slab bridges and steel concrete composite bridge decks for BS loading and Eurocode loading were carried out with Midas Civil software.

The above research process is summarized in a flow chart and presented in Figure 3.1.

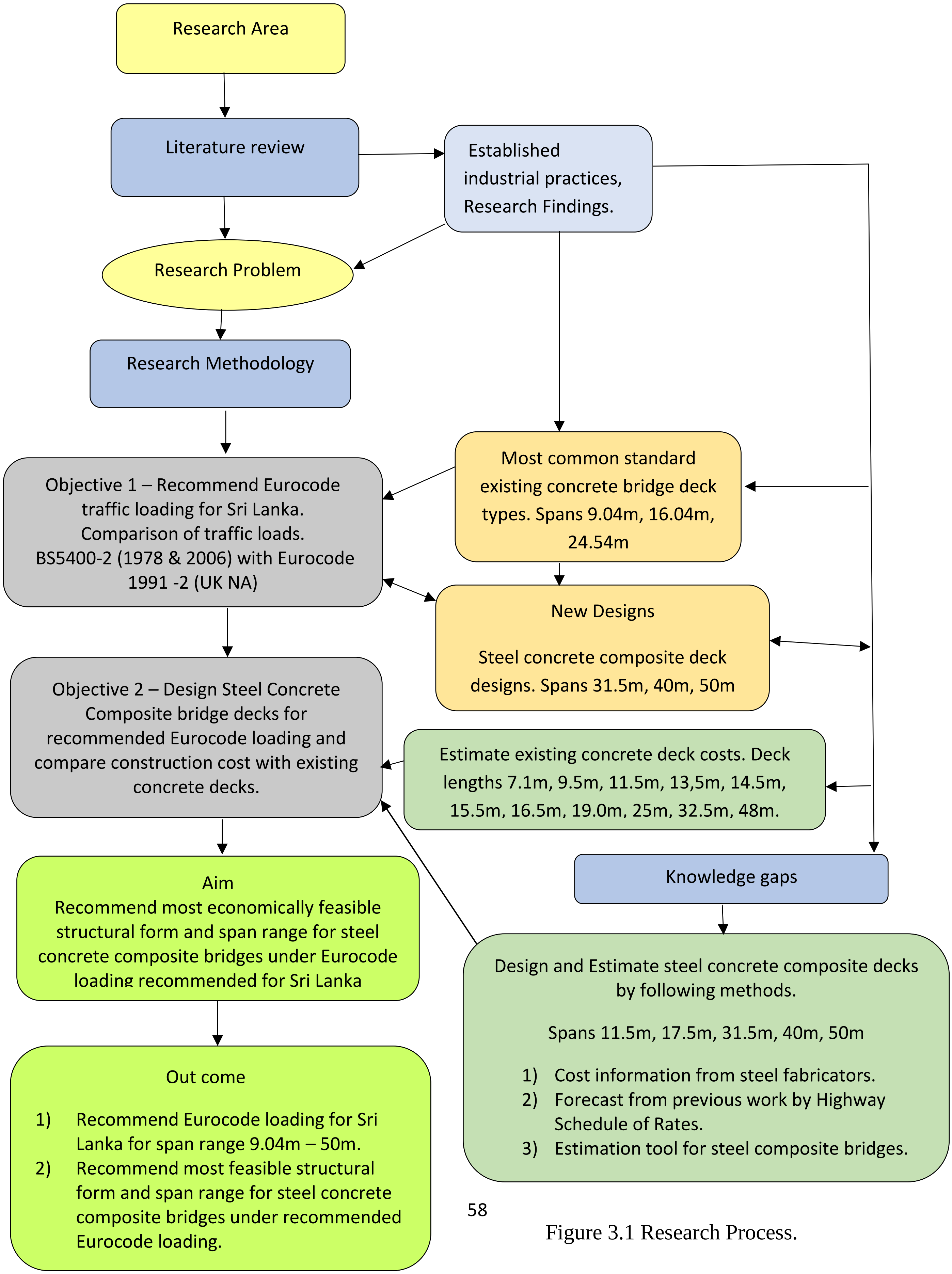


Figure 3.1 Research Process.

3.3 3D modelling and design of different types of bridge decks.

3.3.1 Modelling considerations

As previously discussed in section 2.8 span lengths less than 9.0m were not considered. Models for concrete slab bridges of lengths 9.5m, 16.5m, and 25m M beam and slab deck were created as 3D models, all members and bearings were connected through centroids of members like 2D grillage. Properties of beam concrete (grade50), infill concrete (grade40), and geometry, material properties were input to the software.

The model 31.5m composite plate girder maintains connectivity at centroid level. Models 40m, 50m ladder decks were created so that elements were connected for correct graphical presentation. In all three models, supports are modeled at a different level to the centroid of steel girder. For design of steel girders this is a requirement.

Notional lane details and loading details for BS and Eurocode were input to the model. Maximum moment may occur slightly outside centre-span for a set of point loads, but difference with mid-span moment is small enough to consider only mid span moments to keep analysis simple. Mid span moments across the deck and Shear on both supports across the deck were investigated for maximum values for all critical load cases considered.

Only the effect of traffic loads was specified for the comparative study.

3.3.2 Models of Midas Civil

Dead load is auto calculated by the program. User defined dummy material with zero weight could be specified in Midas Civil to avoid duplication of weight (i.e. when composite members are specified in longitudial beams, for composite cross beams and for transverse members of concrete cantilevers).

Midas Civil distribute loads to main girders during erection i.e. prior to the development of composite action. Therefore for models of ladder deck construction, intermediate dummy beams with small stiffness could be introduced between main girders, and cross girders without composite action under dummy beams. This approach capture correct load path through cross beams to main beams (Bosak, 2020). The design check on cross girder steel section is more conservative. However for the study of load distribution among main girders, the ladder deck model where deck slab is composite with main girders and cross girders considered most appropriate and conservative.

Composite sections were created by the facility “Composite General” which indicate properties before and after development of composite section. This was assigned to main members. This facility was used to develop composite sections with different grades of concrete, and steel and concrete.

Transverse members were assigned the same properties without weight density called dummy members. However, steel composite decks could be modelled by the wizard provided in Midas considering stages of loading.

Time effect shrinkage and creep of concrete not specified in software to avoid hogging moment created on support for comparison of traffic loads. However, in designs for costing these properties considered.

Software is capable of generating a physical view of concrete decks including service ducts and polythene displacers. Where possible bearings were modelled in the centroid of the beam level to avoid hogging moment created on support.

In a 3D composite girder model software (Midas Civil) introduces a rigid link between girder centroid and insertion point of the section. The section offset nodal points forming portal frame creates negative moment on support due to applied nodal loads (Midas Civil online manual, 2021) as illustrated in Figure 3.2. Therefore, support section end moment release for applied nodal loads should be specified (Vila, 2020) as illustrated in Figure 3.3. Midas Civil element-based loads such as beam loads and temperature loads are applied on the centroidal line of the element section.

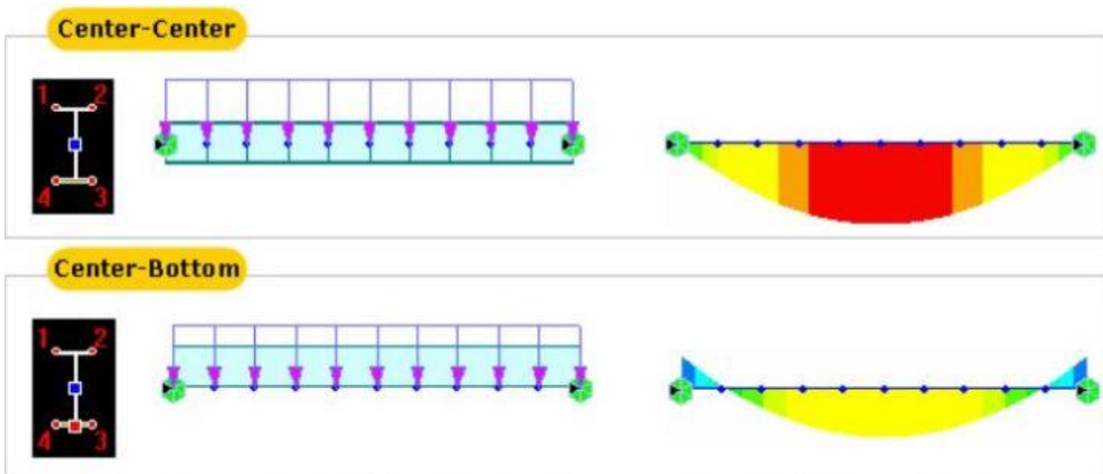


Figure 3.2 Application of element loads on centroidal line (top) and application of nodal loads on nodes created at an offset with insertion point (bottom).

Source - Midas Civil online manual

Similarly rigid link introduced on the support to model bearings at correct level introduce hogging moment on support. In such case end moment release need to be specified. (Vila, (2020)).

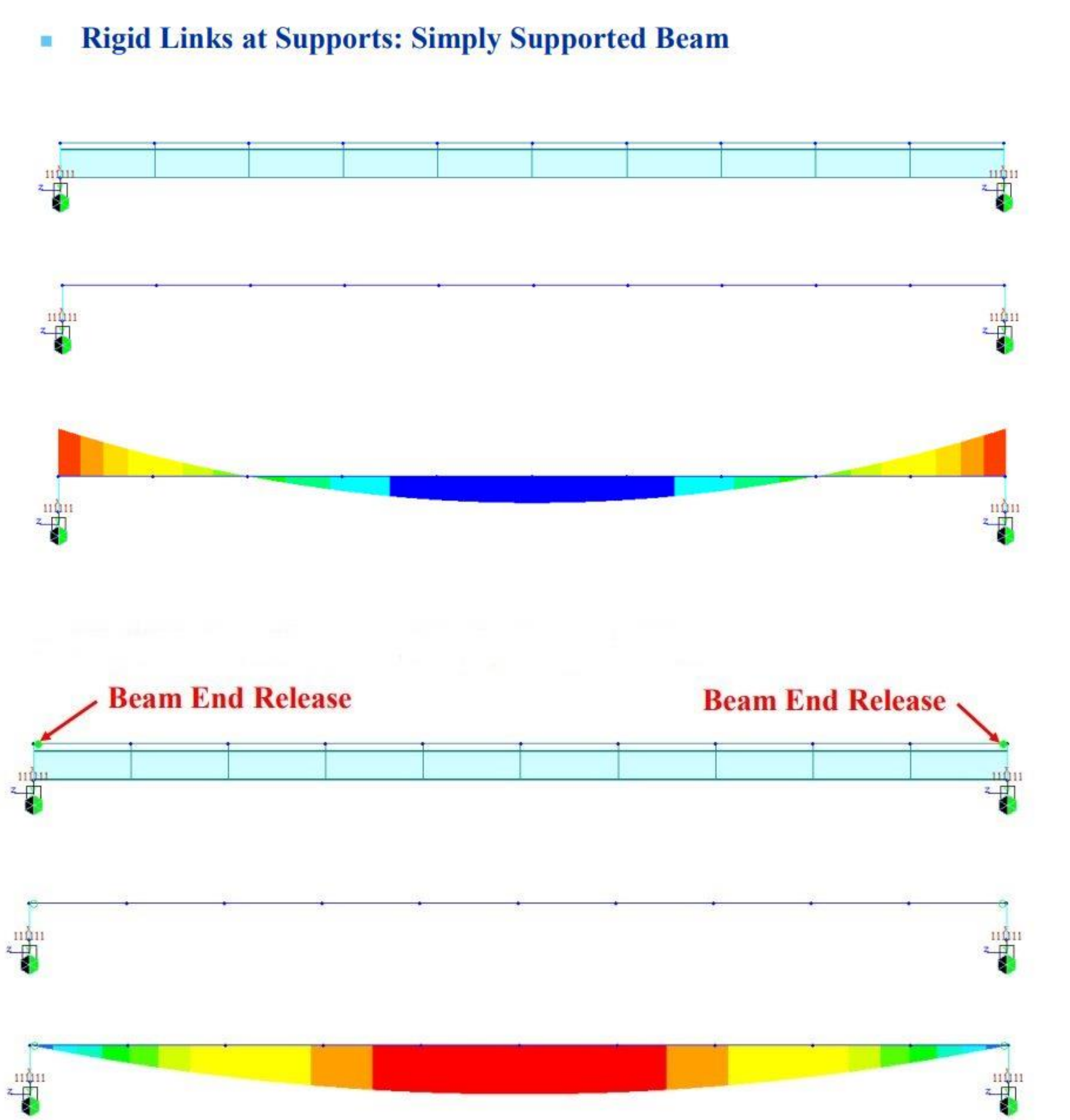


Figure 3.3 Application of rigid links on support to model bearings at correct level. Source – Document and video, Application of links in FE models, Lois J Vila.

Negative moment on support section for simply supported model also occurs due to

a) Torsional moment of transverse members induce hogging moment. (Hambly, 1991, pp 72,73)

b) Long term material properties of deck concrete specified with duration and construction sequence

3.3.3 Models for comparison of traffic loads.

Simply supported bridge decks were considered for comparison of traffic loads. This makes analysis simple and represent almost all bridges except few continuous ones in Sri Lanka.

Models of standard bridge decks 9.5m, 16.5m and 25m long considered with different moduli of elasticity for grade 50 beam concrete and grade 40 for infill /deck concrete. Post-tensioned decks are not standard type, therefore, beyond 25m, up to 50m span, steel concrete composite deck models were considered. Steel concrete composite decks up to 50m span are justified based on economy as concluded in sections 6.5 and 7.2. Following steel concrete composite models were considered. Multi girder steel composite deck span 31.5m, ladder deck plate girder spans 40m and 50m.

3.3.3.1 Model for 9.5m long (9.04m span) deck

Standard deck 9.5m long (span 9.04m) deck
(Type Superstructure, 2005, DRG NO MSL/B/201 dated 13th Dec 2005)

The computer model, longitudinal slab element, and transverse elements are shown in Figures 3.4, 3.5 and in 3.6. The slab bridge with 18 pre-tensioned concrete beams and service ducts on either side is shown in Figure 3.7. Traffic lanes for Eurocode and BS5400 are shown in Figures 3.4 and 3.7.

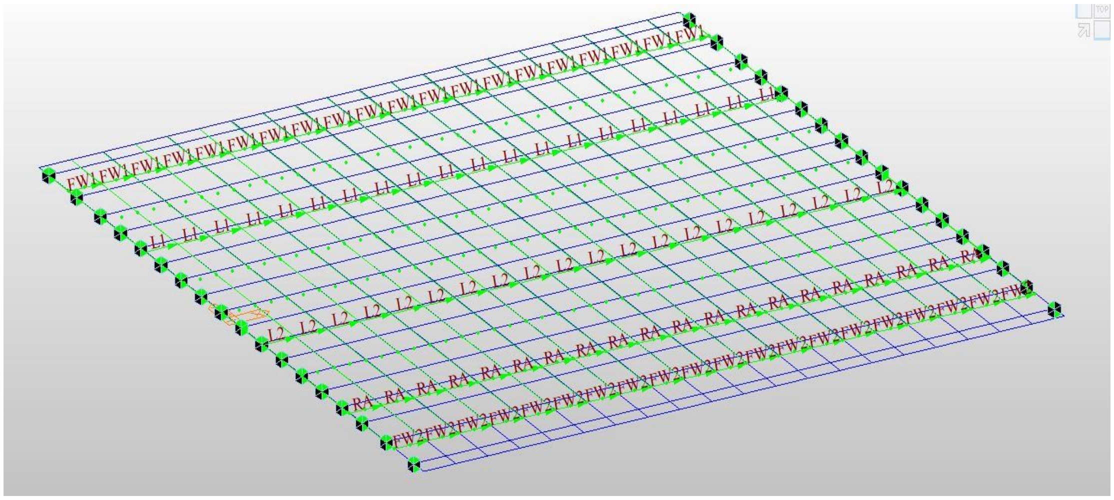


Figure 3.4 3D model 9.04m span

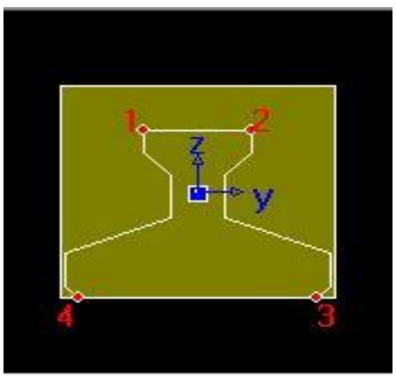


Figure 3.5 Composite deck slab element 9.04m span

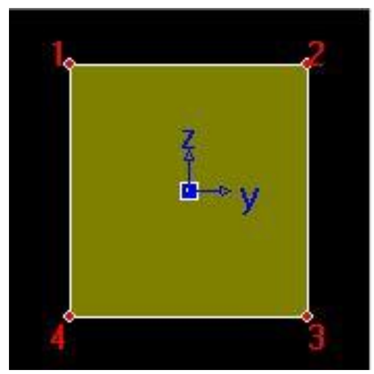


Figure 3.6 Transverse deck element 9.04m span

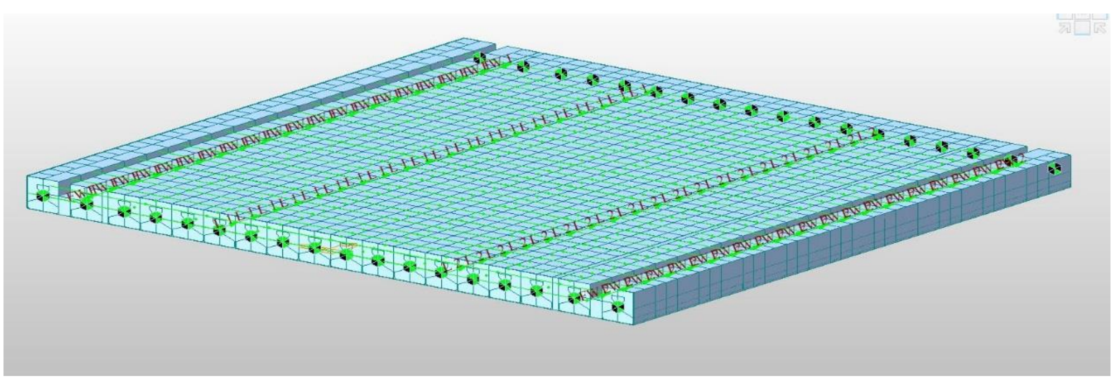


Figure 3.7 Composite deck slab 9.04m span

3.3.3.2 Model for 16.5m long (16.04m span) deck

Standard deck 16.5m long (span 16.04m) deck

(Type Superstructure, 2005 DRG NO MSL/B/203 dated 13th Dec 2005)

The computer model, longitudinal voided slab element, and transverse elements are shown in Figures 3.10, 3.8 and in 3.9. The slab bridge with 17 pre-tensioned concrete beams and service ducts on either side is shown in Figure 3.11. Traffic lanes for Eurocode and BS5400 are shown in Figures 3.10 and 3.11.

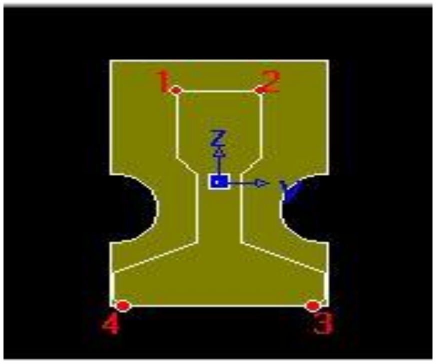


Figure 3.8 Composite deck section 16.04m span

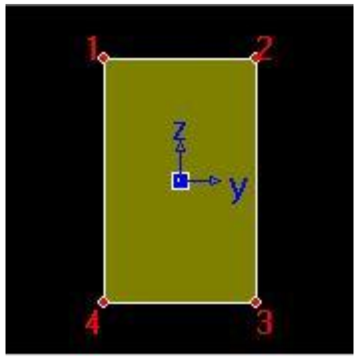


Figure 3.9 Transverse element 16.04m span

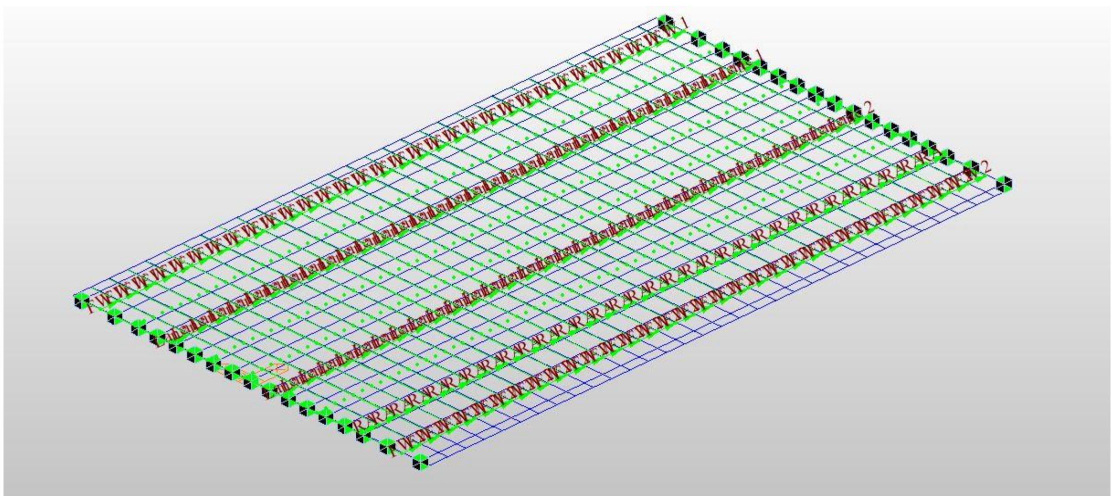


Figure 3.10 3D model 16.04m span

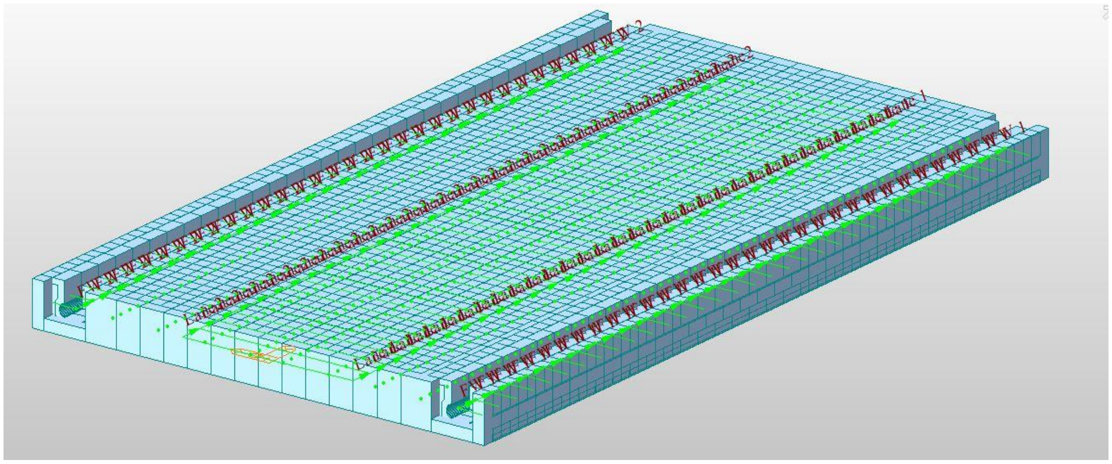


Figure3.11 Composite deck slab 16.04m span

3.3.3.3 Model for 25m long (24.54m span) deck

Standard deck 25m long (span 24.54m) deck.

(Type Superstructure, RDA DRG NO MSL/B/210)

The computer model, longitudinal voided slab element, and transverse elements are shown in Figures 3.12, 3.13 and in 3.14. The concrete multi girders 9 pre-tensioned beams with deck slab is shown in Figure 3.15. Supports are modelled at centroid level. All elements are connected through centroid level. Eurocode traffic lanes are shown in Figure 3.12.

If all elements are specified with section offset, for example, centre top of slab for correct graphical display, end moments on supports are introduced by applied nodal loads. Then moment releases on supports (pins) need to be specified for zero moment.

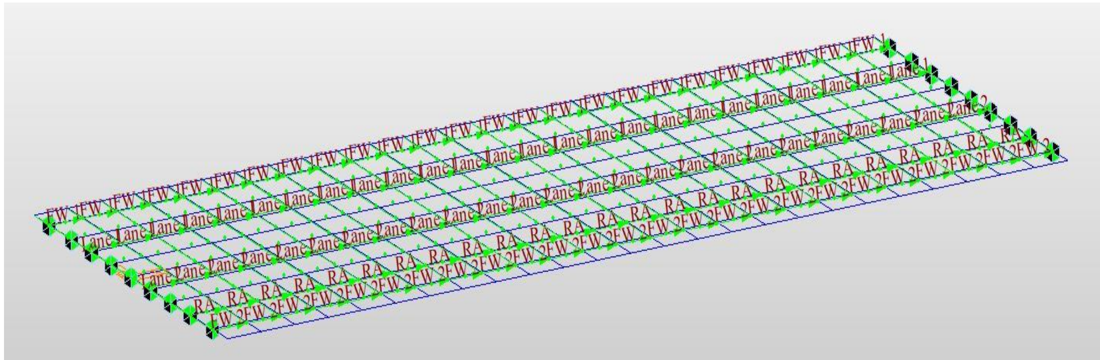
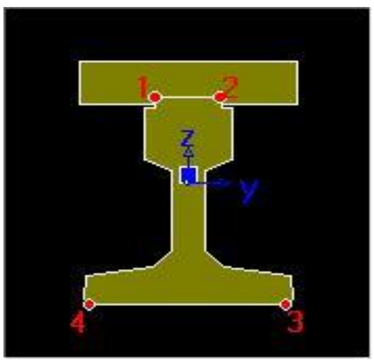


Figure 3.12 24.54m span model



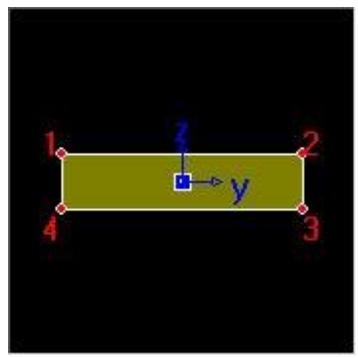


Figure 3.13

24.54m span M beam Composite deck section

Figure 3.14

24.54m Transverse slab Member

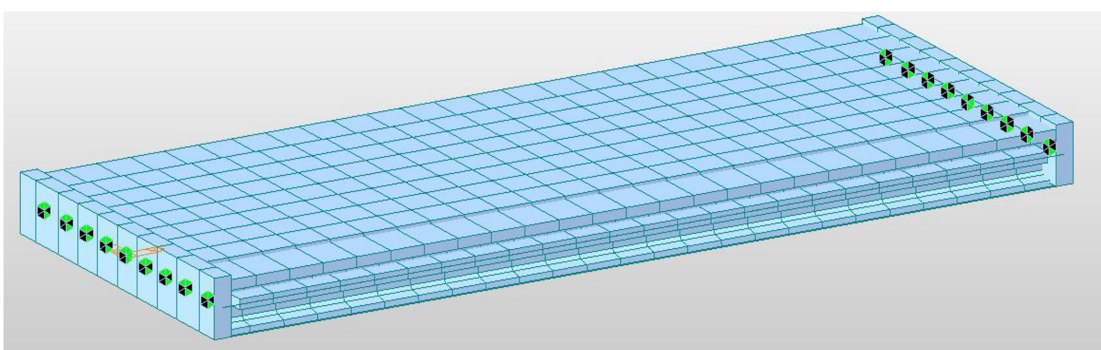


Figure 3.15 M beam and slab Bridge deck

3.3.3.4 Model for 31.5m span – Multi plate girder steel concrete composite deck

Steel plate girders (4 Nos@ 2.6m spacing) composite with concrete deck of 250mm thick is shown in Figure 3.16. A traffic lane marked for HB vehicle straddling along centre line, and elastomeric bearings introduced by the software are also shown in the Figure 3.16.

The computer model (with rigid links introduced by the software) is shown in Figure 3.17. Deck elements i.e., longitudinal composite deck section and transverse member element are shown in figures 3.18 and in 3.19 respectively.

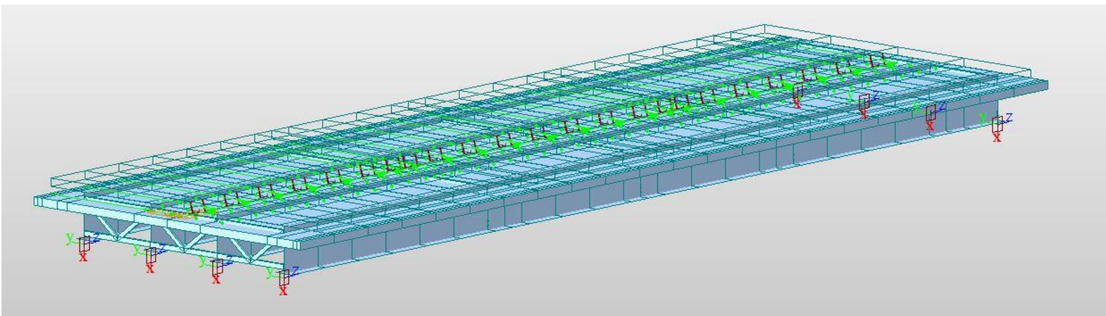


Figure 3.16 Composite plate girder deck 31.5m span

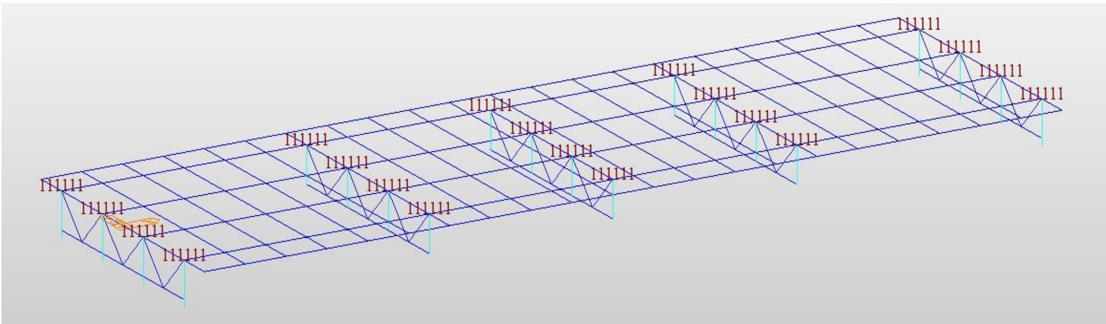
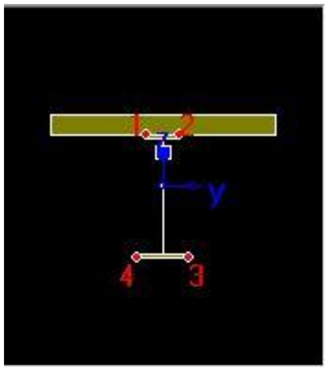


Figure 3.17 Model for span 31.5m composite plate girder



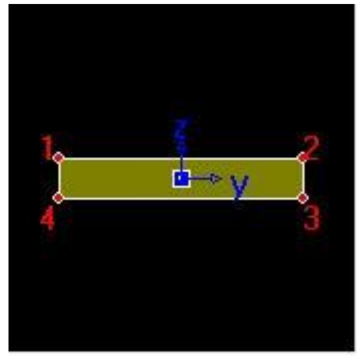


Figure 3.18 – 31.5m span

Composite deck section

Figure 3.19 – 31.5m span

Transverse member

3.3.3.5 Model for 40m span – Ladder deck plate girder

Steel plate girders (2 Nos@ 8m spacing) and cross girders composite with concrete deck 250mm thick. The ladder deck with bearings is shown in Figure 3.20 and the computer model (with rigid links) are shown in Figure 3.21.

All elements longitudinal and transverse have been assigned with section offsets (red colour) from centroids (blue colour). Two girder elements are shown in Figure 3.22. Transverse cantilever element is shown in figure 3.23. Transverse elements between main girders in the middle and on support section are shown in figure 3.24.

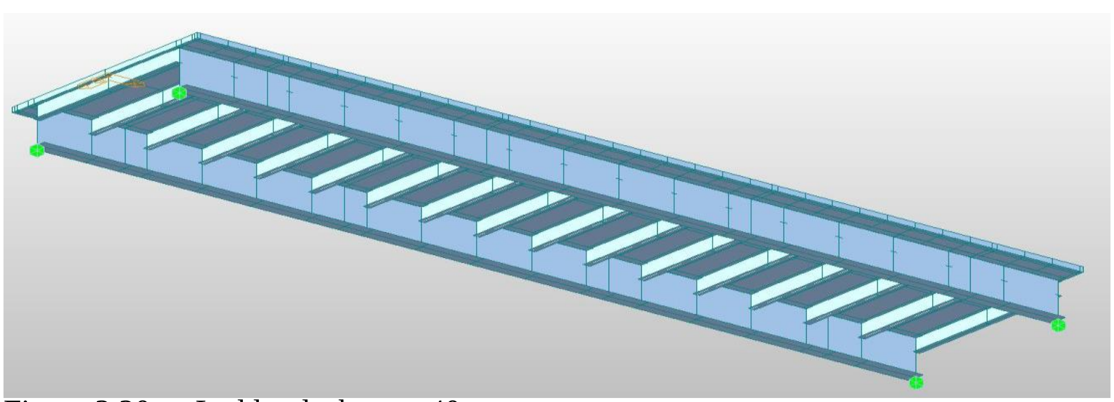


Figure 3.20 Ladder deck span 40m

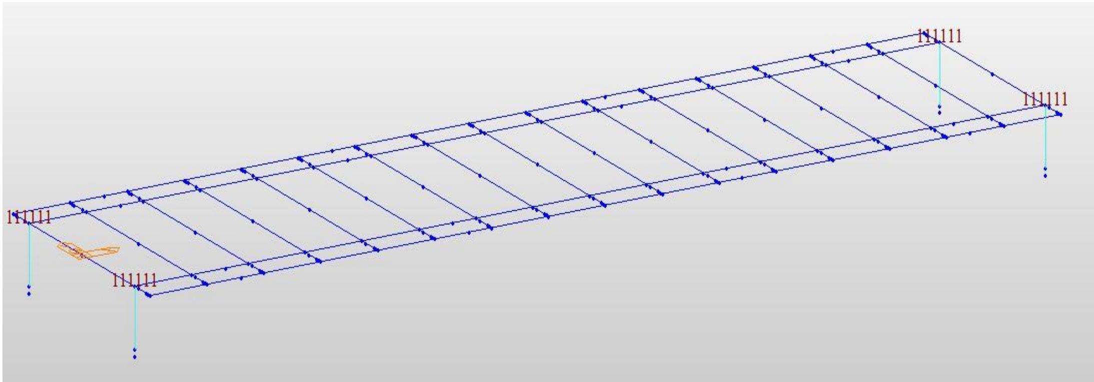
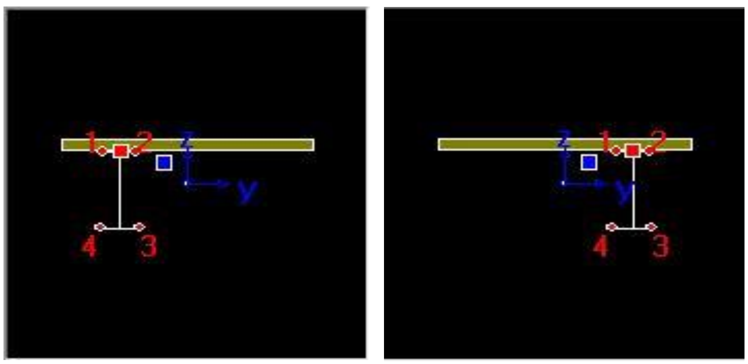


Figure 3.21 Model ladder deck span 40m



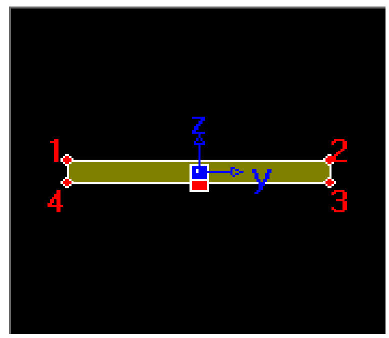
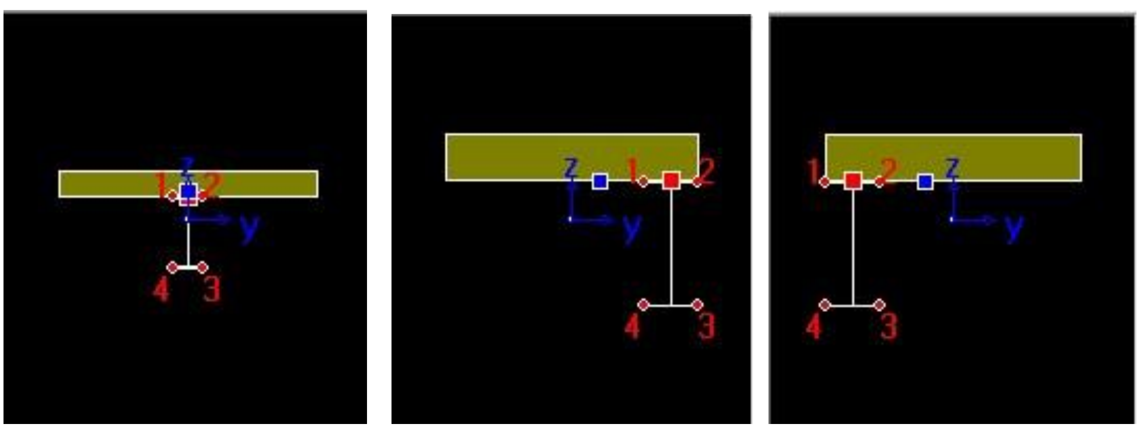


Figure 3.22

Composite deck section 40m span

Figure 3.23

Transverse cantilever element 40m span



Cross beam middle

Cross beam at each end

Figure 3.24 Transverse cross beam Elements between two main girders 40m span

3.3.3.6 Model for 50m span - Ladder deck plate girder

Steel plate girders (2 Nos@ 8m spacing) and cross girders composite with concrete deck 250mm thick. The ladder deck (with rigid links) is shown in Figure 3.25 and the computer model with elastomeric bearings are shown in Figure 3.26.

All elements longitudinal and transverse have been assigned with section offsets (red colour) from centroids (blue colour). Two girder elements are shown in Figure 3.27. Transverse cantilever element is shown in figure 3.28. Transverse elements between main girders in the middle and on support section are shown in figure 3.29.

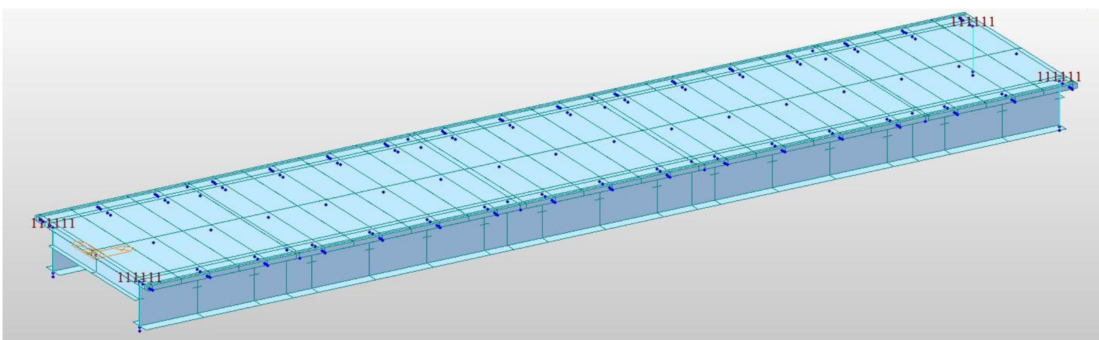


Figure 3.25 Ladder deck span 50m

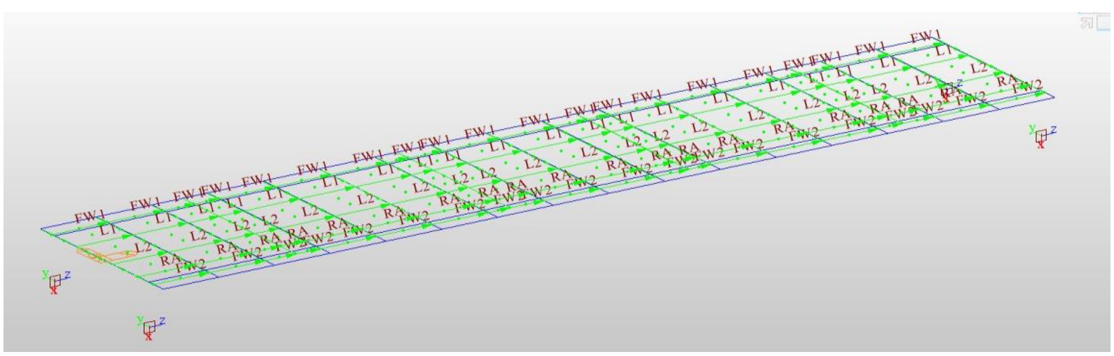
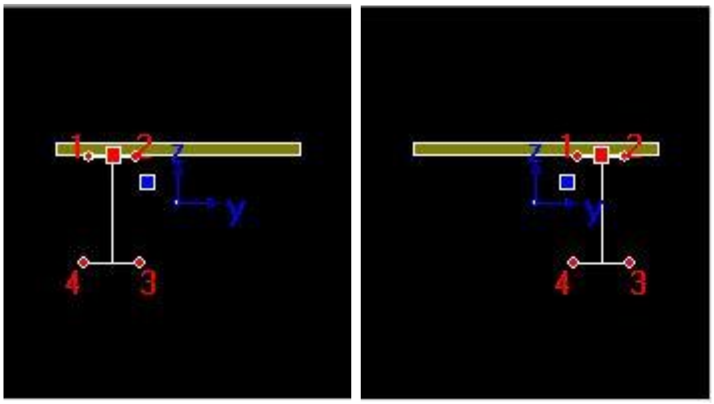


Figure 3.26 Model for ladder deck span 50m



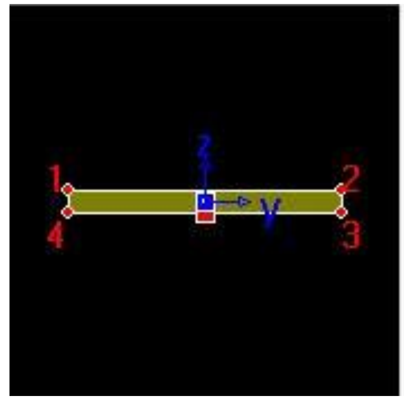
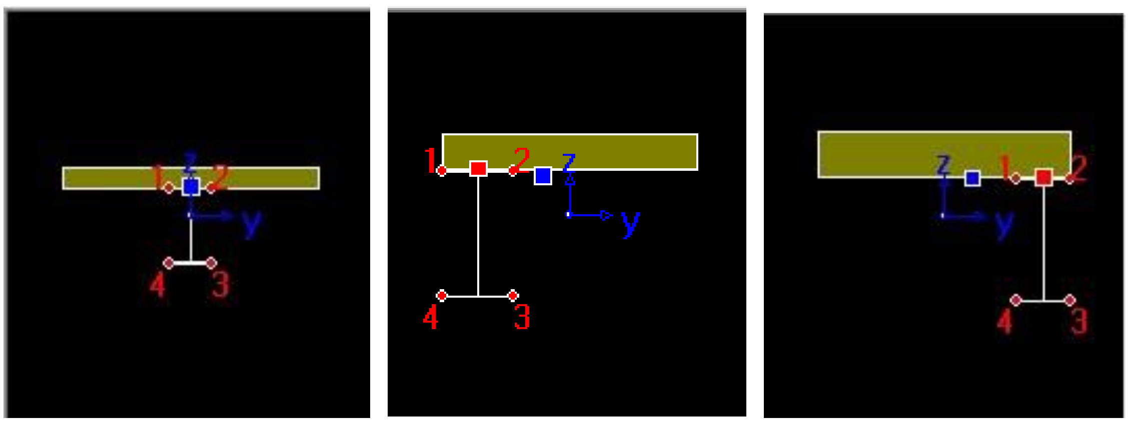


Figure 3.27

Figure 3.28

Composite girders 50m span

Transverse cantilever element 50m span



Cross beam middle.

Cross beams at each end.

Figure 3.29 – Transverse cross beam elements between two main girders 50m span

3.3.3.7 Ladder deck models 40m and 50m

The load distribution 40m and 50m ladder deck computer models were created without dummy beams for maximum loading effect on main girders.

Insertion point of main members in ladder deck models have small offset from centroids, but hogging moment on support created by nodal loads due to insertion point was not visible. Support section had very small sagging moment.

Models 40m, 50m, were changed to connect through centroids. Difference in support shear was small and mid-span bending moment was lesser for all load cases in new models. This is not possible due to the effect of insertion point offset; therefore, models are acceptable. (If there is a hogging moment on support created due to offset insertion point, release of same should increase bending moment at centre span.)

3.4 Design of steel concrete composite decks for cost calculations

3.4.1 Design Parameters

(a) Partial factors on strength

For steel bridges γ_M values are tabulated in EN 1993-2/6.1 (also specified in NA+A1:2012 to BSEN 1993-2). γ_v, $\gamma_{Ef,}$ and γ_{Mf} are given in EN1994-2, EN 1993-2/9.3 and in table 3.1 of EN 1993-1-9. Partial factors for concrete γ_c and reinforcement γ_s at ULS is given in EN1992-1-1 (also specified in SLNA to EN1992-1-1, 2.4.2.4.(1).)

Partial factors

Partial factors for strength of concrete and reinforcing steel, and for fatigue strength of shear studs are tabulated below in Table 3.1.

Table 3.1 Partial factors

γ_c for concrete	1.5	γ_v for headed stud	1.25
γ_s for reinforcing steel	1.15	γ_{Ff} for equivalent constant Amplitude stress range	1.00
γ_{Mo} for structural steel	1.0	γ_{Mf} for fatigue strength	1.00

γ_{M1} for structural steel	1.1	$\gamma_{Mf,s}$ for fatigue strength of studs in shear	1.00

(a) Material information

Structural steel f_{sk} = 355 MPa E_s = 210,000 MPa Table 3.1, EN 1993-1-1

Concrete f_{ck} = 40 MPa E_{cm} = 35000 MPa *(time effects considered)*

Table 3.1, EN 1992-1-1

Reinforcement f_{yk} = 500 MPa E_r = 210000 MPa Cl. 3.2.2.(3) EN1992-1-1

Shear connectors. Diameter 19mm, 100mm long, ultimate strength f_u = 495 MPa

3.4.2 Design Models of Steel concrete composite decks.

Steel concrete composite designs were developed for spans 11.5m, 17.5m, 31.5m, 40m, 50m for decks carring two traffic lanes of 3.7m wide and two footways of 1.5m wide for cost calculations presented in Chapter 6.0. Models of spans 31.5m, 40m, and a different 50m model were used to study traffic load distributions of Eurocode UK National Annex and BS 5400 part2, 1978 and 2006 discussed in Chapter 4.0. Details of all steel concrete composite model are presented in Table 3.2.

Table 3.2 Summary of model details – Steel concrete composite designs

Structure Details	Span (m)				
	11.5	17.5	31.5	40	50
Deck width 10.4m Slab thickness t_c = 250mm	Composte slab with universal beams	Composte slab with universal beams	Composte slab with plate girders	Composte slab with Ladder deck plate girders and cross beams	Composte slab with Ladder deck plate girders and cross beams

Girder Spacing	2.6m	2.6m	2.6m	8.0m	8.0m
Deck cantilever	1.3m	1.3m	1.3m	1.2m	1.2m
Steel girder type	Universal beam	Universal beam	Plate Girder	Plate Girder Ladder Deck	Plate Girder Ladder Deck
Overall Steel Girder height H	611.9mm	769.6mm	1430mm	1925mm	*2360mm 2375mm
Top flange dimensions $B_{f,top}$ x $t_{f,top}$	229mm x 19.6mm	268mm x 25.4mm	400mm x 40mm	700mm x 45mm	* 1000mm x 60mm 1000mm x 60mm
Web thickness t_w	11.9mm	15.6mm	15mm	18mm	*22mm 25mm
Bottom flange dimensions $B_{f,bot}$ x $t_{f,bot}$	229mm x 19.6mm	268mm x 25.4mm	600mm x 40mm	800mm x 55mm	*1200mm x 60mm 1000mm x75mm
Model Effective width of concrete flange B_c	2600mm	2600mm	2600mm	* 5200mm (40m, 50m, Models for traffic load comparison UKNA & BS5400, Sections 3.3.3.5 & 3.3.3.6) 2400mm (50m Ladder Deck Model with dummy beams 2800mm spacing for bridge deck design Section 3.4.2.5)	
Cross girder details – Ladder deck designs					
				2500mm	3125mm

Cross girder spacing / Effective width concrete flange				Cross girders are made not composite in 50m Ladder Deck Model with dummy beams (Section 3.4.2.5)	
Overall height				700mm	930mm
Flanges dimensions				300mm x 20mm	500mm x 15mm
Web thickness				15mm	15mm

***** Dimensions of 50m ladder deck model in section 3.3.3.6.

3.4.2.1 Span 11.5m

Model details are described in Table 3.2 and presented in figure 3.30 below. Temporary bracing during erection stages is also shown in figure 3.30.

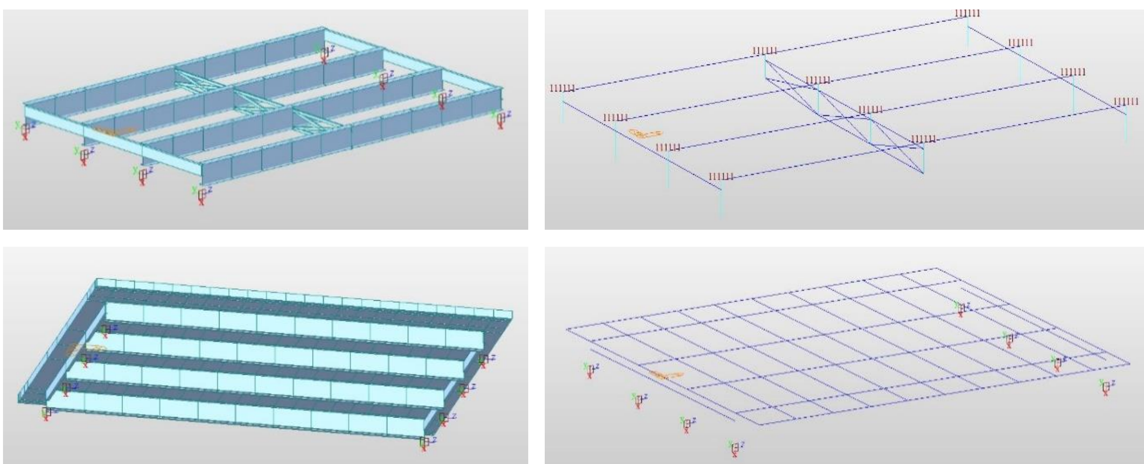


Figure 3.30 Span 11.5m during erection and completed structure.

Figures 3.31 and 3.32 present longitudinal composite girder and transverse element of the model.

Figure 3.31

Composite girder 11.5m span

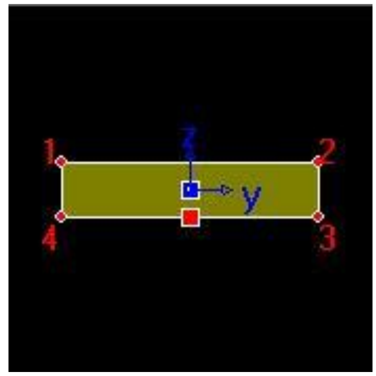


Figure 3.32

Transverse element 11.5m span

3.4.2.2 Span 17.5m

Model details are described in Table 3.2 and presented in figure 3.33 below. Temporary bracing during erection stages is also shown in figure 3.33.

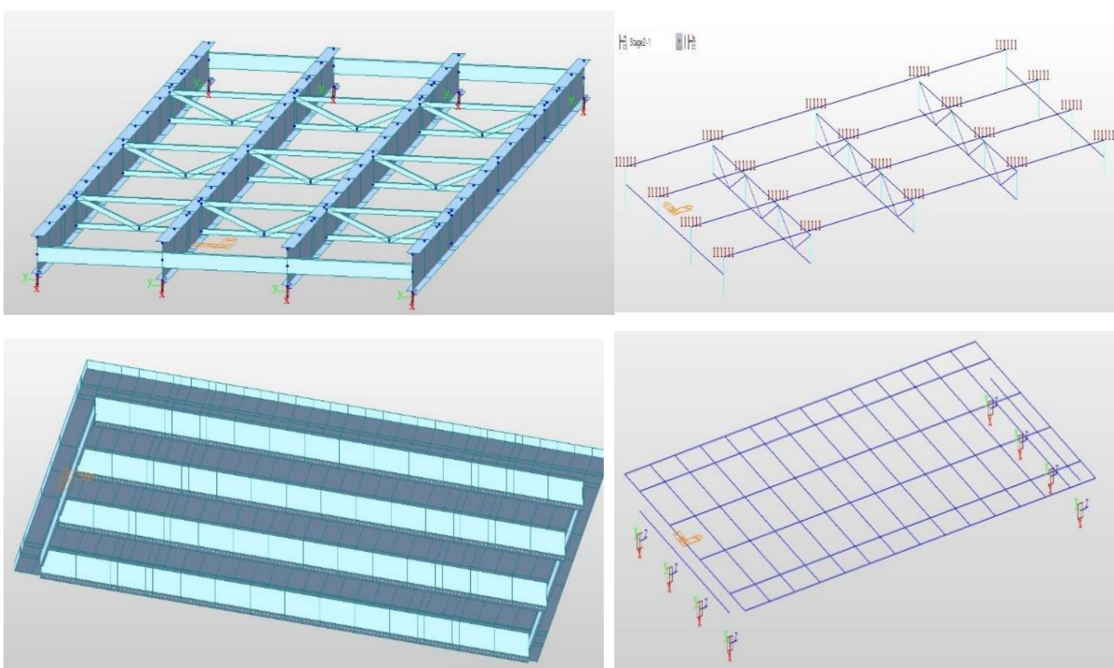


Figure 3.33 Span 17.5m during erection and completed structure.

Figures 3.34 and 3.35 present longitudinal composite girder and transverse element of the model.

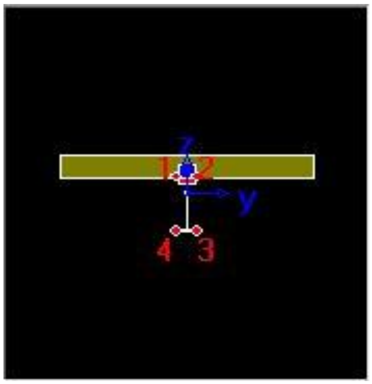


Figure 3.34
Composite girder 17.5m span

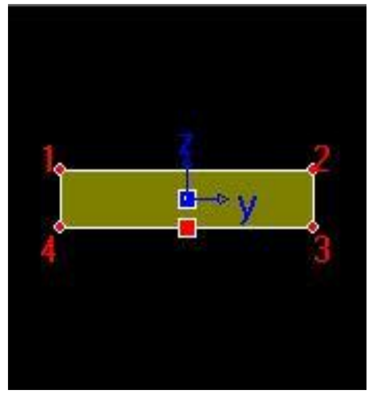


Figure 3.35
Transverse element 17.5m span

3.4.2.3 Span 31.5m

The deck model of section 3.3.3.4 was considered. Model details are given in Table 3.2

3.4.2.4 Span 40m

The deck model of section 3.3.3.5 was considered. Model details are given in Table 3.2

3.4.2.5 Span 50m (model with dummy beams)

This model shown in Figure 3.36 together with longitudinal and transverse section properties of elements in Figures 3.37, 3.38, 3.39 are considered for cost calculations.

The model considered in above section 3.3.3.6 has composite deck with main and cross giders. Midas Civil software distributes loads due to construction stages (fresh concrete) to main girders. Therefore traffic load distribution on composite deck is not affeted.

For design of structure, dummy beams of the model provide correct load path through cross beams. This model provides correct loading on cross girder but lower value for bending resistance of main girders due to smaller effective width of concrete flange. For the structure considered resistance at Ultimate limit of main girders are adequate. Steel code found adequate for cross girders. Model details are given in Table 3.2

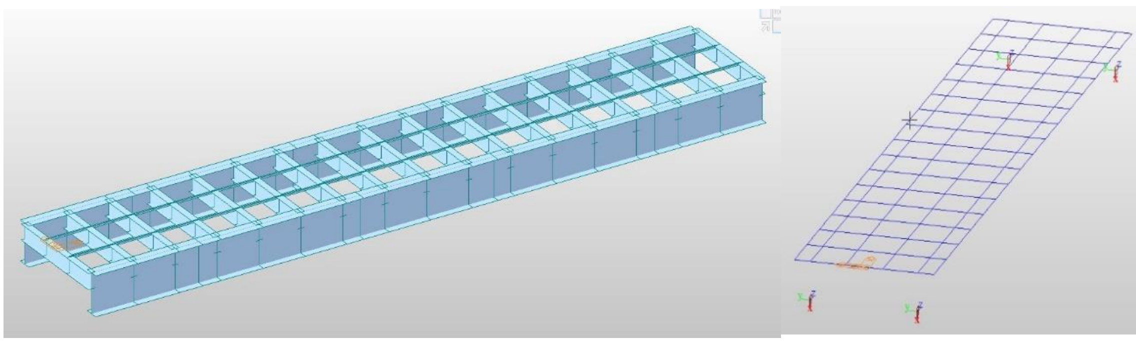
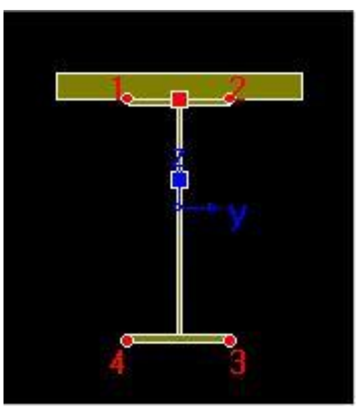
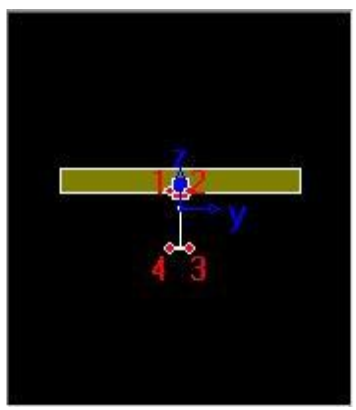


Figure 3.36 50m Deck model with dummy beams





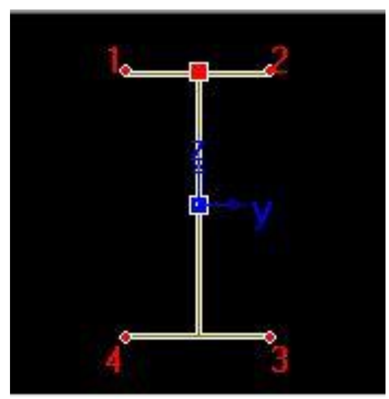


Figure 3.37

Composite girder 50m span

Figure 3.38

Dummy girder 50m span

Figure 3.39

Cross girder non composite.

3.5 Chapter summary

This chapter explains research process, followed with a flowchart (figure 3.1).

Application of 3D computer models are explained next. Effects due to eccentricities in application of loads and reactions in a bridge deck are considered. Causes of small negative moment on the support of simply supported deck is also explained.

Computer models considered for Eurocode (UKNA) and BS5400 traffic load comparison (9.5m, 16.5m, 25m, 31.5m, 40m, 50m,) are explained in sections 3.3.3.1 – 3.3.3.7.

Computer models of steel concrete composite deck designs developed for cost comparison (spans 11.5m, 17.5m, 31.5m, 40m, 50m,) with concrete decks are discussed next with appropriate design parameters of models in section 3.4.

Chapter – 04

Comparison of BS 5400 and Eurocode (UKNA) Loading

4.1 Introduction.

Bridge design was carried out during past few decades for guidelines and loads specified in BS 5400 Part2 1978. Although changes were introduced to BS 5400, part2 in 2006, these changes have not been adopted in Sri Lanka. Pre-stressed concrete beam (with strands) type drawings designed for BS5400 Part2 1978 loading were not changed to BS5400 part2 2006 loading.

Traffic loading specified for Sri Lankan roads remained unchanged during past few decades, therefor there is a need to review with the introduction of Eurocode loading. Eurocode still being introduced to Sri Lanka, and for bridges, Sri Lanka National Annexes still to be developed including bridge loads. The set of SV and SOV vehicles defined in UK National annex could be checked, since abnormal vehicle models to suit local scenario has still not been developed under Eurocode provisions. Therefore, as previously indicated in sections 1.1 and 2.8, UK National annex for bridge loading is used for comparison of BS 5400 loading with Euro Code loading.

Change to Euro Code requires, loading to be specified for existing bridge decks need to be compare with loading for new structures. More severe Euro code loading could be specified for a new bridge where required. As previously indicated in section 1.1, existing concrete beam sections could be redesigned to carry higher loads, while new beam sections also need to be introduced.

Upgrading or widening of existing bridge deck for a specified Euro code loading require comparison of lateral load distribution of Euro Code loading and BS 5400 loading.
BS 5400 and Euro code specifies load combinations consisting uniformly distributed and point loads on deck. Bridge decks are generally provided with service ducts. Lateral load distribution of each type of loading is required to determine most critical beam.

4.2 Main loading cases

Table 4.2.1 present basic comparison of traffic models between BS 5400 -2 and Eurocode UKNA to EN 1991-2. One model type represents effects of traffic lorries and cars and the other model type represent special vehicle with assembly of axle loads.

Groups of traffic loads NA to BSEN 1991-2 Table NA.3 are presented with comparable BS 5400 -2 traffic models in Table 4.2 for horizontal and vertical loads.

4.2.1 Comparison of traffic loads and combinations.

Table 4.1: Traffic loads comparison BS 5400 part2 1978 and UK NA to EN1991-2

BS 5400 part 2. (1978)	**Euro Code UK NA to EN1991-2**
HA loading (UDL + KEL) UDL – 30 kN/m/Notional Lane when span is less than 30m. KEL – 120kN/Notional Lane	LM 1 (Load model 1) (UDL + Tandem system: TS)
HB loading (Abnormal vehicle loads) 30, 37.5, 45 units One Unit = 10kN per axle	LM3 (Abnormal vehicle *axle* loads) Point loads. Types of SV (SV80, SV100, SV196) And SOV (SOV 250, SOV 450)

Table 4.2: Comparison of groups of traffic loads NA to BSEN 1991- 2 with BS5400-2

Group	EC UKNA Table NA.3 Characteristic values of Multi component action.	Comparable BS standard
gr 1a	LM1 (TS +UDL) + 0.6*FW (Characteristic load)	HA (KEL+UDL) +FW
gr 1b	LM2 (single axle, characteristic load)	
gr 2 combination with horizontal loads	LM1 (Frequent loads) +Braking load + Centrifugal and transverse loads	HA +Braking load + Centrifugal and transverse loads
gr 3 (a)*	FW (footway, characteristic)	FW (footway)
gr 4	LM4 (Crowd load) + FW (footway characteristic)	
gr 5	LM1(frequent value) + LM3 (special vehicle)	HA + HB combination
gr 6 combination with horizontal loads	LM3 (special vehicle) + Braking load + Centrifugal and transverse loads	HB + Braking load + Centrifugal and transverse loads

By inspection of Table 4.2 above for comparison of vertical loads, the following traffic load combinations are considered. For group 5 above, ψ_1 factor for BS EN 1990:2002+A1:2005 (with ψ_1 for LM1 udl 0.4 & TS 0.75) was used throughout Chapter 4, and results with maximum values are separately noted for NA to BS EN 1990:2002+A1:2005 (with ψ_1 for LM1 udl 0.75 & TS as 0.75) as specified in section 2.2.4.4 above. Design checks for chapter 5 were completed as per UKNA above.

For group 1a above $0.6q_{fk}$=3kN/m^2 is applied as specified in 2.2.4.6 above. The factor for frequent value ψ_1 to be used for LM1 in group 5 is specified in Eurocode and in UKNA. Load comparisons in sections 4.5.1 to 4.5.7 for maximum bending moment and in sections 4.7.1 to 4.8 for maximum shear were studied for load cases, load groups and load combinations below and as specified for software Midas Civil in Table 4.3.

1. LM1 (EC UKNA) and HA (BS 5400 part2, 2006 and 1978) comparison

2. LM1 + LM3 (EC UKNA)
   - 2a) LM3 SV80 lane1 + LM1 lane2
   - 2b) LM3 SV100 lane1 + LM1 lane2
   - 2c) LM3 SV80 straddling lanes 1&2 + LM1 (both lanes as applicable)
   - 2d) LM3 SV100 straddling lanes 1&2 + LM1 (both lanes as applicable)

     and

     HA (2006) + HB 30 (lane 1 and straddling lanes 1&2) ULS & SLS

3. a) LM3 SV100 lane 1, and 1&2, and HB 30 lane 1
   - b) LM3 SV80 lane 1, and 1&2, and HB30 30 lane1

4.2.2 Load cases of Midas Civil

Midas Civil software is capable of application of Eurocode and BS 5400 -2 traffic models and traffic model combinations on defined traffic lanes. Table 4.3 illustrate application of Midas Civil software for Eurocode and BS 5400 -2.

Table 4.3 Main loading cases as applied to Midas Civil software.

Combination number	Midas Civil BS NA EN 1991-2 Load case	Midas Civil BS5400 2006-2 Load case	Midas Civil BS5400 1978-2 Load case
1	LM1	HA	HA ULS, HA SLS (Include 1.5 & 1.2 partial safety factors)
2a	LM1 & LM3-SV80 Separate lanes (Note1)	HA HB30 Auto ULS HA HB30 Auto SLS (Note3)	
2b	LM1 & LM3-SV100 Separate lanes (Note 1)		
2c	LM1 & LM3-SV80 straddling lanes (Note2)		
2d	LM1 & LM3-SV100 straddling lanes (Note2)		
3a	LM3 SV100 single lane	HB30 single lane	HB30 straddling along centre line.
3b	LM3 SV 80 single lane		

		Pedestrian (FW)	
	LM1+ FW		
	LM2		
	LM4		

Note 1

Load cases 2a, 2b are considered in the load case “LM1&LM3 Multi” option in Midas Civil Eurocode tab. “LM1&LM3 Multi” consider application of the special vehicle load models described in A3 of EN 1991-2.

Note 2

Load cases 2c, 2d are considered in the load case “LM1&LM3 Multi straddling” option. “LM1&LM3 Multi straddling” considers application of the special vehicle load models described in figures NA.4 and NA.5 of NA to BSEN 1991-2.

Note3

Include 1.3 & 1.1 partial safety factors, for Ultimate and Serviceability limit states.

Auto refers to adverse of HB30 (applied on single lane) or (straddling lanes) with HA (BS5400 2006) loading.

4.3 Examples of loading effects

Section 4.5 below is devoted to study variation of maximum bending moment and maximum shear force on the cross section of the deck. The support shear and bending moment at centre span, and critical locations due to point loads in traffic models were studied. Bridge deck models previously described in section 3.3.3 together with BS NA EN 1991-2, BS5400 part2 (1978 with RDA manual) and BS5400 part2 (2006) loads previously described and compared in section 4.2 considered in deriving critical load effects.

Following examples 4.3.1 to 4.3.3 present several load cases of Maximum bending moment considered in section 4.5. Examples 4.4.1 to 4.4.3 present several load cases of Maximum shear force considered in section 4.6.

4.3.1 Maximum bending moment (BS NA EN 1991-2, LM1 & LM3 SV80)

Concrete deck 16.5m long (span 16.04m) voided slab applied with BS NA EN 1991-2 loading LM1&LM3. Special vehicle SV80 applied on a single lane and straddling between lanes. Midas Civil software "LM1&LM3 Multi straddling" tab applied loading (Table 4.3, Note 2).

BS NA EN 1991-2, Table NA.3 group5, ψ_1 factor for frequent loads (LM1 TS 0.75, LM1 UDL 0.75) are applied. The load distribution is shown in Figure 4.1.

The 2nd beam from edge of the deck gives critical bending moment and shown in Figure 4.2. The maximum moment for node 498i is 361.56 kNm. Mid span moment at node 497i is 361.0 kNm. The traffic load distribution corresponding to maximum moment occur when SV80 is straddling between lanes and is shown in Figure 4.3.

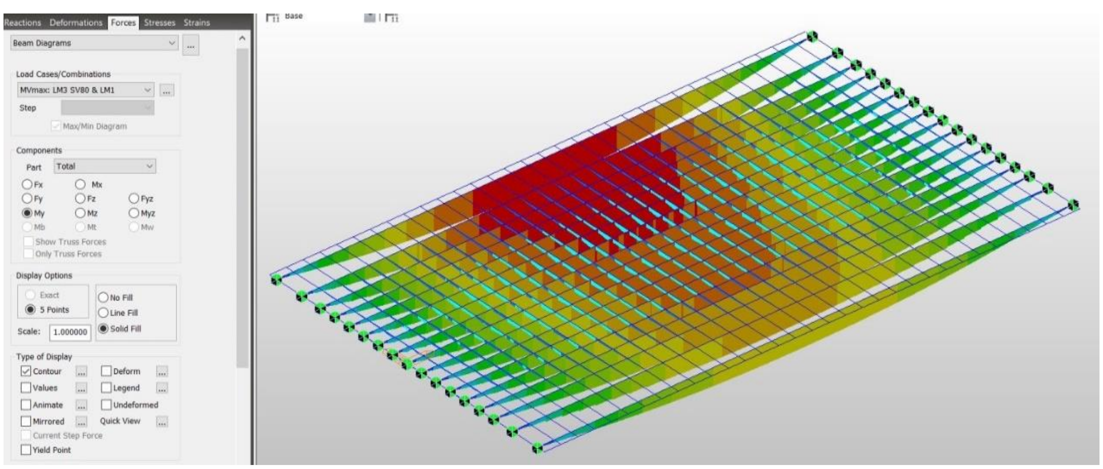


Figure 4.1 Distribution of maximum bending moment - 16.5m long deck

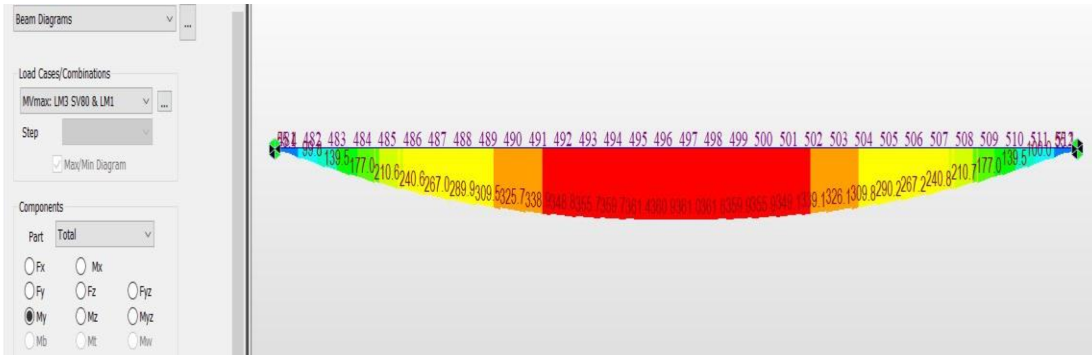


Figure 4.2 Bending moment distribution in 2nd beam from the edge of the deck

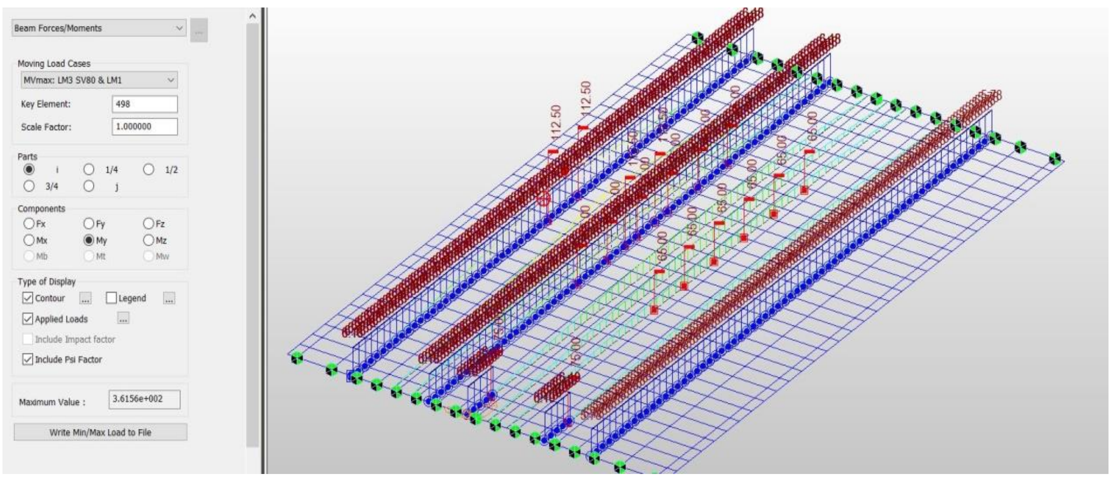


Figure 4.3 Traffic load distribution corresponding to maximum bending moment

4.3.2 Maximum bending moment (BS 5400 2006 -2, HA)

The 31.5m long composite plate girder deck applied with BS5400 2006 HA load on both lanes. The bending moment distribution is symmetric along centre line, middle pair of beams are subjected to maximum bending moments as shown Figure 4.4 and values are as shown in Figure 4.5. Maximum bending moment is 2506.9kNm, and occurs at nodes 150i and 152i, 0.75m from midspan as shown in Figures 4.5 and 4.6. Midspan node 151i has lesser bending moment 2476.3 kNm due to presence of midspan bracings.

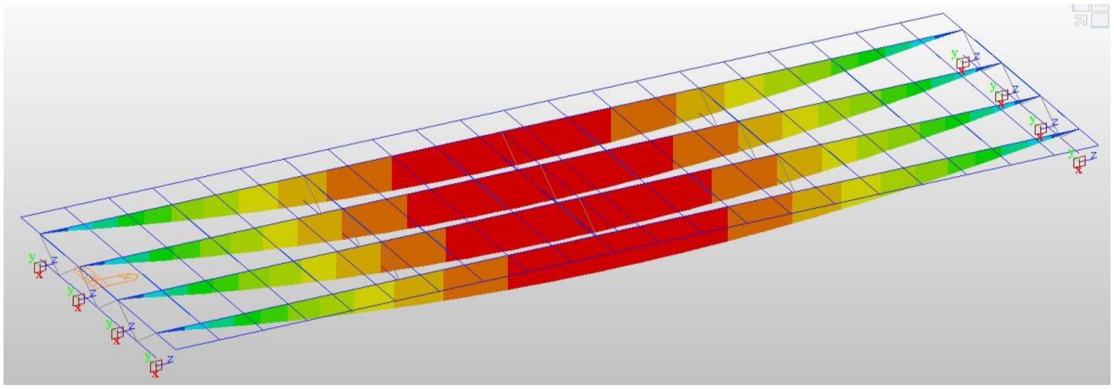


Figure 4.4 Distribution of maximum bending moment deck span 31.5m

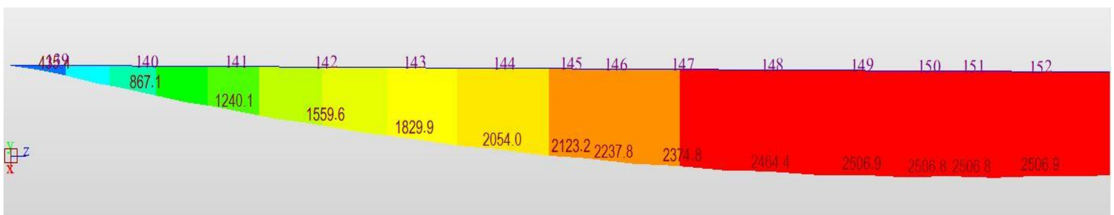


Figure 4.5 Maximum bending moment distribution 2nd beam from edge of the deck

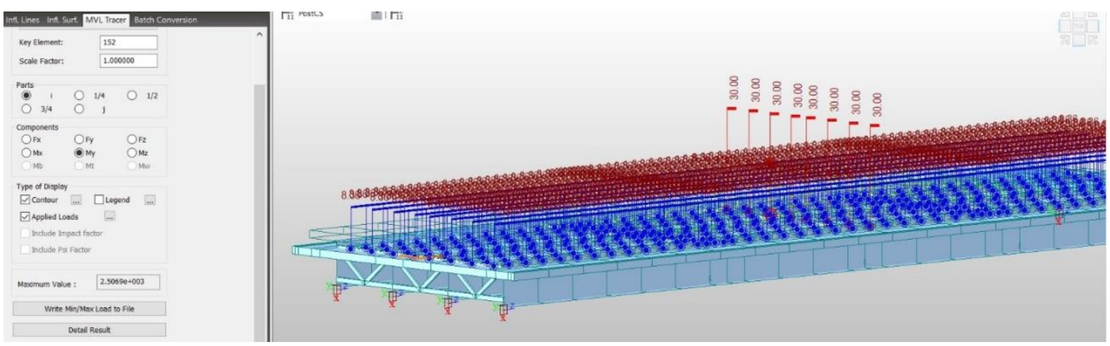


Figure 4.6 HA traffic load distribution corresponding to Maximum bending moment

4.3.3 Maximum bending moment (BS 5400-2, 1978 & 2006)

The 50m long composite ladder deck with HB30 applied symmetrically on centre line. Distribution of bending moment is equal among two beams as shown in Figure 4.7 and values are shown in Figure 4.8. Maximum bending moment at mid span (nodes 36i, 56i) is 6266.1kNm. HB30 position corresponding to maximum bending moment is shown in Figure 4.9.

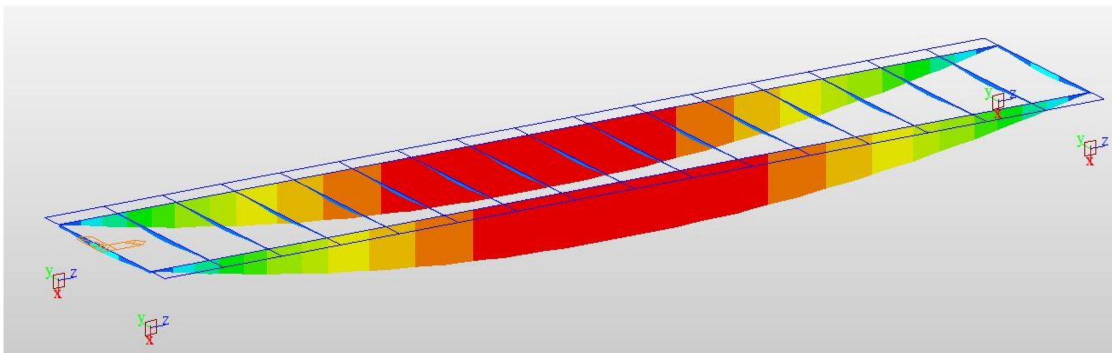


Figure 4.7 Distribution of maximum bending moment of ladder deck span 50m

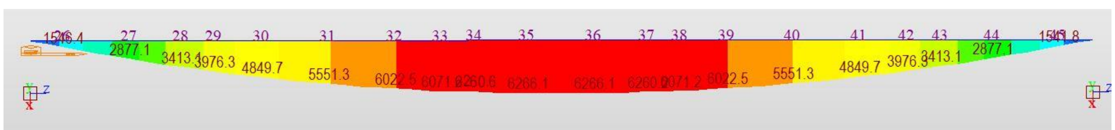


Figure 4.8 Moment distribution in a beam

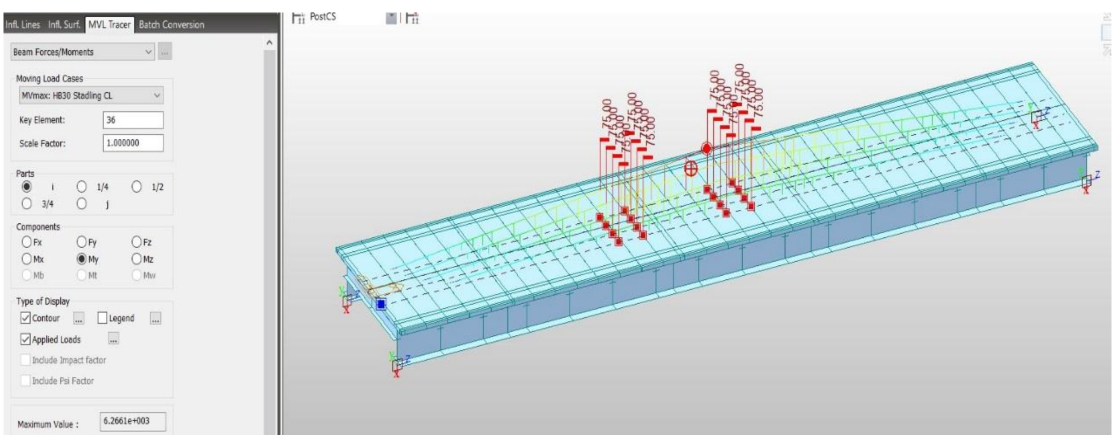


Figure 4.9 HB30 vehicle position corresponding to maximum bending moment

4.4 Examples of loading effects – Maximum Shear

4.4.1 Maximum Shear (BS 5400-2, 2006)

The 9.5m long solid concrete deck (span 9.04m) was applied with HA and HB30 loading according to BS 5400, 2006. Midas Civil software HA and HB Auto tab applied loading (Table 4.3, Note 3).

Maximum shear force distribution is shown in Figure 4.10. Maximum shear occurs at nodes 80j and 280j, with 84.469kN include partial safety factor γ_{fL}= 1.1 specified in BS5400 2006 for SLS for HA&HB loading combination. Application of HA and HB load corresponding to maximum shear is shown in Figure 4.11.

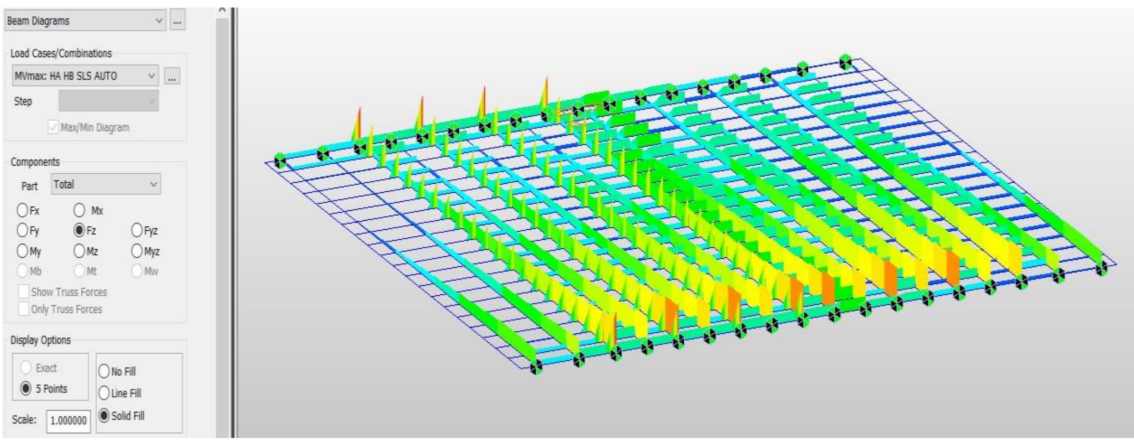


Figure 4.10 Maximum shear force distribution 9.5m long concrete deck

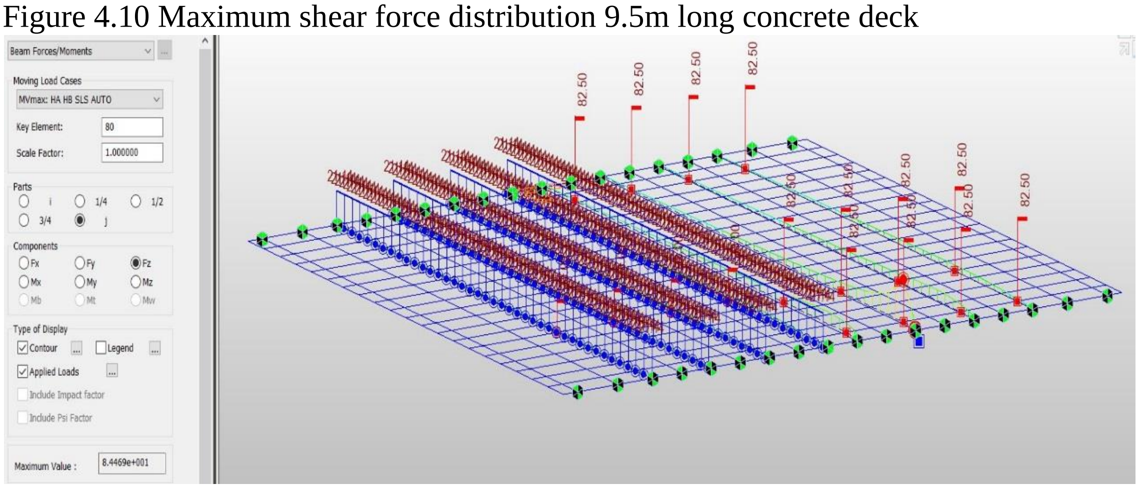


Figure 4.11 HA & HB30 positions for shear node 80j

4.4.2 Maximum Shear (BS NA EN 1991-2, LM1 & LM3 SV100)

The 25m M beam and slab deck applied with BS NA EN 1991-2 loading LM1&LM3. Special vehicle SV100 applied. Midas Civil software “LM1&LM3 Multi” tab applied loading (Table 4.3, Note 1).

BS NA EN 1991-2, Table NA.3 group5, ψ_1 factor for frequent loads (LM1 TS 0.75, LM1 UDL 0.75) are applied. The shear force distribution is shown in Figure 4.12.

The 2nd beam from edge of the deck has critical shear force and is shown in Figure 4.13. The maximum shear force at node 100j is 308.6kN. The traffic load distribution corresponding to maximum shear LM1 & LM3 SV100 (special vehicle models described in A3 of EN 1991-2) is shown in Figure 4.14.

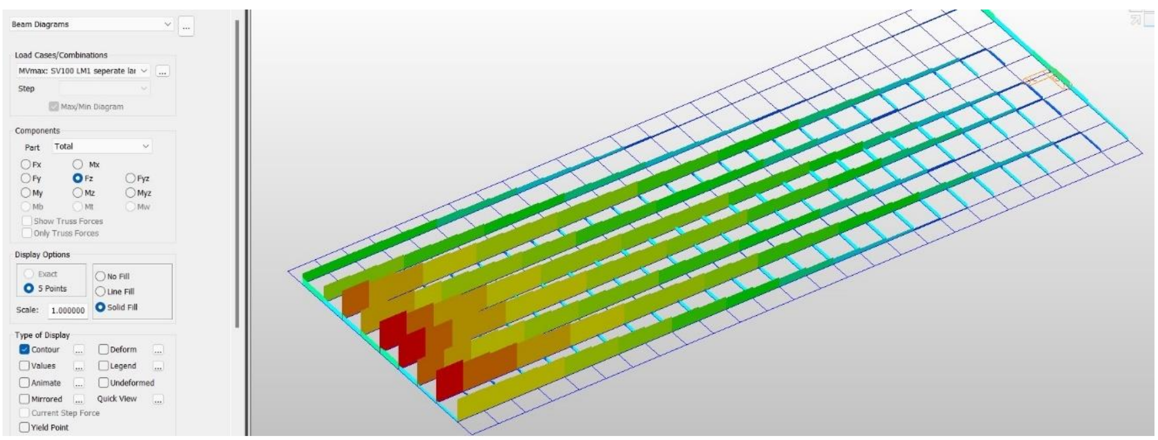


Figure 4.12 Maximum shear force distribution 25m concrete M beam and slab deck.

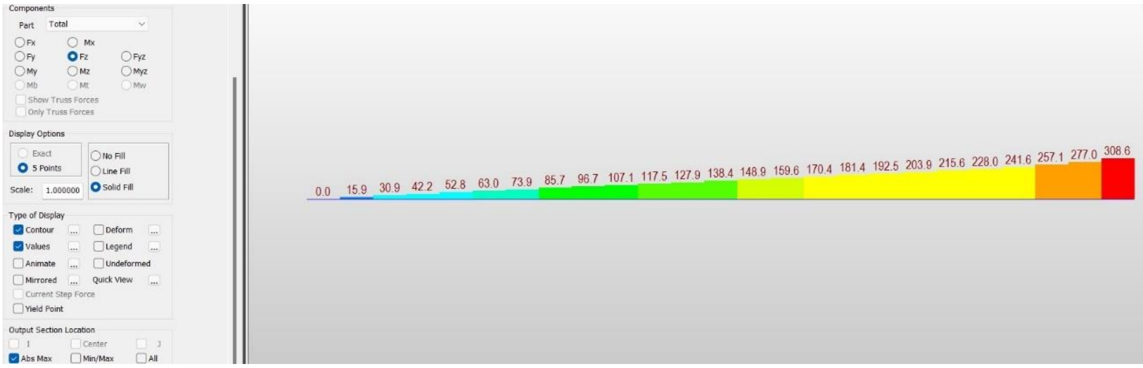


Figure 4.13 Maximum shear force distribution of the critical 2nd beam from edge

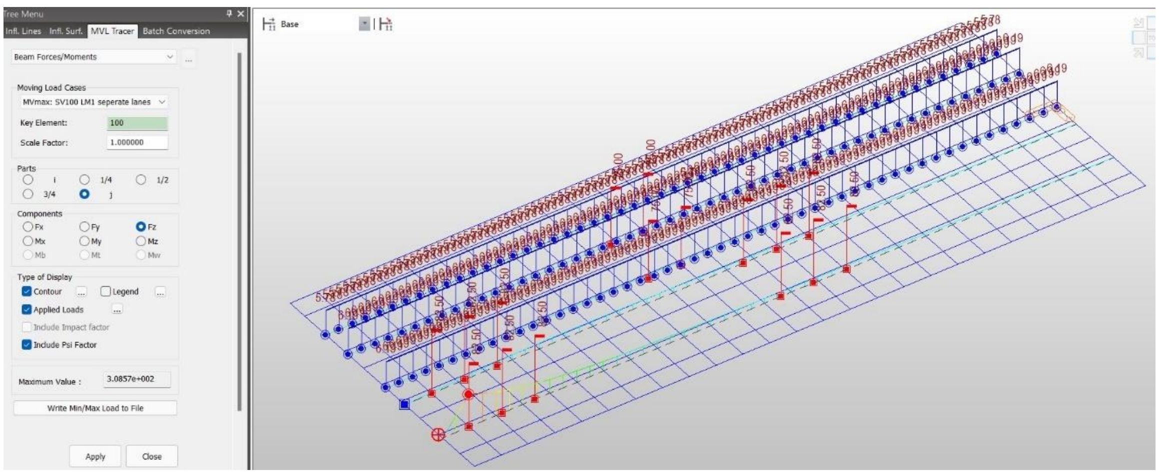


Figure 4.14 Application of traffic loads for LM1 & LM3 100

4.4.3 Maximum Shear (BS5400- 1978, HA)

The 40m ladder deck applied with HA BS5400-2 1978 loading on both lanes. Shear force distribution is shown in Figure 4.15. HA load corresponding to maximum shear force (elements 57j & 77j) is shown in Figure 4.16. Partial safety factor γ_{fL}= 1.2 for SLS is specified in BS5400 1978 is 724.49kN.

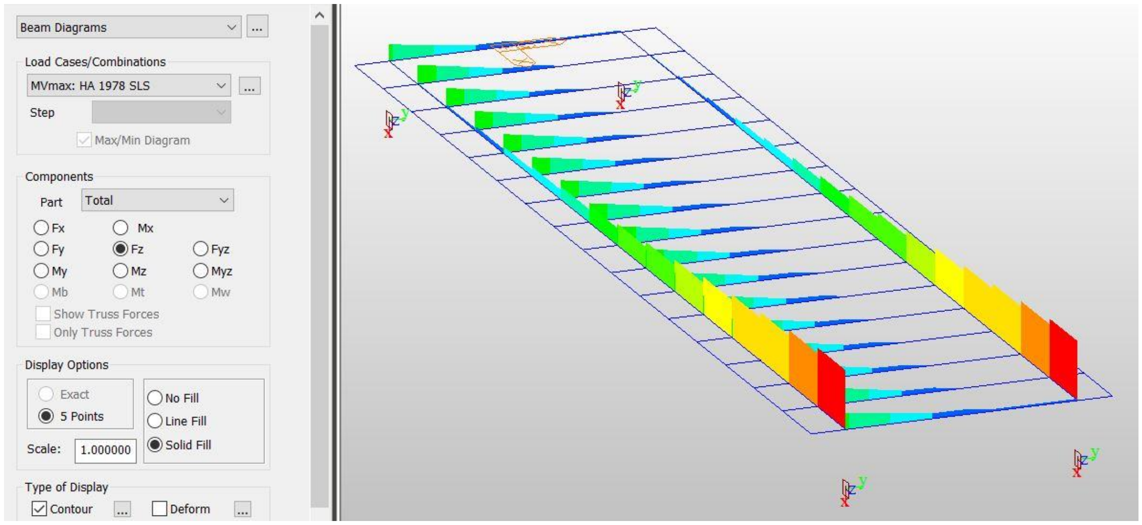


Figure 4.15 Distribution of maximum shear force (span 40m)

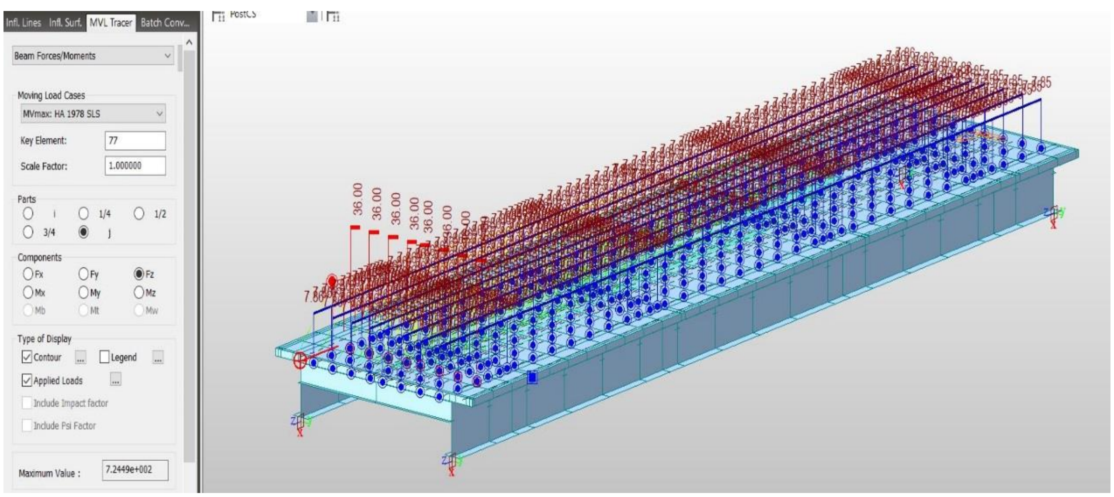


Figure 4.16 HA load corresponding to Maximum shear force at SLS

4.5 Maximum bending moment for different spans

Tables 4.4 – 4.9 tabulates maximum bending moments and mid span bending moments for models previously described in section 3.3.3 together with Eurocode UKNA BS5400 part2 (1978 with RDA manual) and BS5400 part2 (2006) loads previously described and load cases load groups and load combinations compared in section 4.2.

Bending moments due to Eurocode UKNA load groups LM1 & FW, LM2, LM1 together with LM3 (SV100 & SV80) straddling and on separate lanes, and LM4 are tabulated.

For comparison of load effects of traffic models, bending moments due to LM1 and HA loading of BS 5400 part2 (1978 & 2006) are tabulated. Load effects due to LM3 (SV100), LM3 (SV80) and HB30 on single lane are tabulated to compare special vehicles specified in both codes.

LM1 together with LM3 (SV100 & SV80) straddling and on separate lanes (application of ψ_1 factor as previously described in section 4.2 above) are compared with HA (BS5400 2006) & HB30 load combination tabulated as HA&HB (Auto). HB30 (BS5400) on centre line striding between lanes as per RDA design manual is also tabulated.

Figures 4.17 - 4.22 graphically present distribution of mid span bending moment across deck for tabulated load cases above. Figure 4.23 present maximum moment distribution with span (with UK NA ψ_1 factor LM1 TS 0.75, LM1 UDL 0.75).

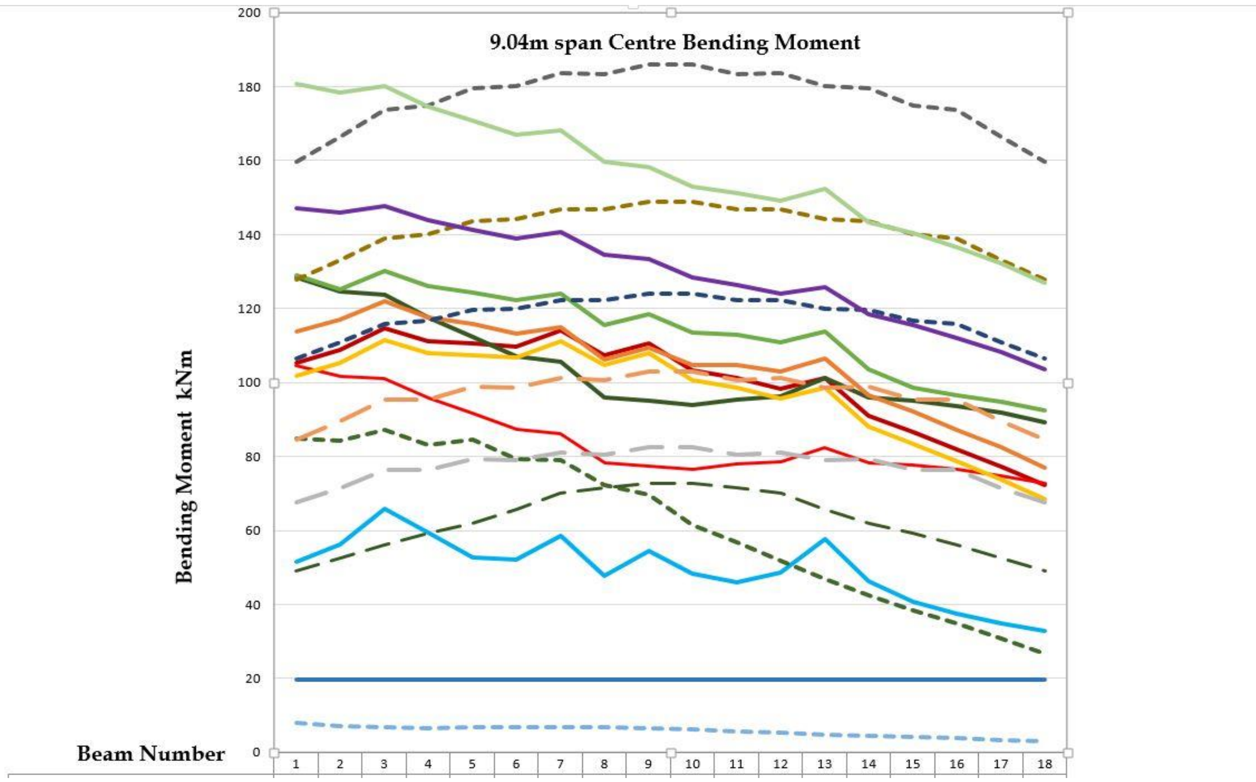
4.5.1 Maximum bending moment for span 9.04m

Table 4.4 Maximum bending moment for 9.5m deck (span 9.04m)

Element & node	**Load**	**Maximum Bending moment kNm**	**Max mid span Bending moment kNm**
Eurocode			
151i	LM1 & FW	114.7	114.7
151i	LM1	111.39	111.39
151i	LM2	65.83	65.83
70i	LM3(SV100) straddling with LM1	134.26	130.12
152i	LM3(SV80) straddling with LM1	123.87	121.91
191i	LM3(SV100) &LM1 separate lanes	180.78	180.78
191i	LM3 SV100 single lane	128.35	128.35
191i	LM3 SV80 single lane	104.74	104.74
152i	LM3(SV80) &LM1 separate lanes	148.01	147.18
31i	LM4	19.67	19.67
UK NA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			
70i	LM3(SV100) straddling with LM1	139.27	
152i	LM3(SV80) straddling with LM1	129.17	

191i	LM3(SV100) &LM1 separate lanes	183.41	
152i	LM3(SV80) &LM1 separate lanes	151.21	
BS 2006			
31i	HA & HB30 ULS Auto, HA alone (γ_{fL}= 1.5)	186.02	186.02
231i	HA & HB30 SLS Auto HA alone (γ_{fL}= 1.2)	148.82	148.82
31i	HA	124.01	124.01
152i	HB single lane	88.04	84.92
190i	Pedestrian	7.91	7.91
BS 1978			
31i	HA ULS γ_{fL}= 1.5)	103.05	103.05
31i	HA SLS (γ_{fL}= 1.2)	82.44	82.44
32i	HB30 on centre line	73.45	72.69

4.5.1.1 Lateral distribution of bending moment mid span 9.04m



Beam Number 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
LM 1 FW	105.45	108.89	114.7	111.25	110.48	109.73	113.95	107.35	110.57	103.31	101.32	98.4	101.36	91.1	86.62	81.93	77.15	72.23
LM 2	51.63	56.22	65.83	59.5	52.8	52.19	58.54	47.85	54.52	48.41	45.86	48.59	57.53	46.21	40.59	37.47	34.97	32.79
LM 3 SV100 only	128.35	124.55	123.88	117.57	112.46	107.15	105.58	96.09	95.02	93.87	95.45	96.28	101.09	95.84	95.16	93.71	91.78	89.26
LM 3 (SV100) LM 1 stradling	128.86	125.18	130.12	126.15	124.47	122.23	124.06	115.52	118.42	113.51	112.92	110.78	113.94	103.47	98.51	96.53	94.77	92.43
LM 4	19.55	19.58	19.6	19.62	19.63	19.64	19.65	19.66	19.67	19.67	19.67	19.67	19.66	19.65	19.64	19.61	19.58	19.53
LM 3 SV80 only	104.74	101.63	101.09	95.94	91.77	87.43	86.15	78.41	77.54	76.6	77.89	78.57	82.49	78.21	77.65	76.47	74.89	72.84
LM 3 (SV80) LM 1 stradling	113.66	117.13	121.91	117.68	115.75	113.31	115.04	106.34	109.36	104.77	104.6	102.9	106.54	96.56	92.09	87.27	82.46	76.9
LM 1 only	101.72	105.38	111.39	108.1	107.49	106.86	111.19	104.66	107.92	100.66	98.63	95.64	98.5	88.1	83.47	78.63	73.64	68.49
HA HB 2006 Auto ULS	159.83	166.33	173.73	175.03	179.55	180.08	183.53	183.4	186.02	186.02	183.4	183.53	180.08	179.55	175.01	173.71	166.31	159.83
HA HB Auto SLS 2006	127.86	133.06	138.98	140.02	143.64	144.06	146.83	146.72	148.82	148.82	146.72	146.83	144.06	143.64	140.01	138.97	133.05	127.86
HA 2006 both lanes	106.55	110.88	115.82	116.68	119.7	120.05	122.36	122.27	124.01	124.01	122.27	122.36	120.05	119.7	116.68	115.81	110.87	106.55
HB single lane	84.92	84.19	87.09	83.11	84.52	79.28	78.91	72.42	69.75	61.51	56.81	51.77	46.92	42.48	38.46	34.8	30.86	26.82
Pedestrian (BS)	7.91	6.96	6.71	6.65	6.71	6.81	6.82	6.7	6.46	6.12	5.73	5.32	4.91	4.51	4.13	3.77	3.37	2.96
HA ULS 1978	84.63	89.41	95.4	95.53	99	98.6	101.33	100.69	103.05	103.05	100.7	101.33	98.6	98.99	95.53	95.39	89.4	84.63
HA SLS 1978	67.7	71.53	76.32	76.43	79.2	78.88	81.06	80.56	82.44	82.44	80.56	81.06	78.88	79.19	76.42	76.31	71.52	67.7
LM3 SV100 & LM1 separate lanes	180.78	178.55	180.08	174.55	170.77	167.06	168.32	159.65	158.26	152.91	151.31	149.21	152.37	143.45	140.43	136.66	132.16	126.86
LM3 SV80 & LM1 seperate	147.18	145.95	147.65	143.77	141.33	139.02	140.69	134.51	133.39	128.34	126.33	124.01	125.91	118.37	115.52	112.13	108.14	103.5
HB30 stradling	48.98	52.62	56.1	59.19	61.93	65.79	69.98	71.55	72.69	72.69	71.56	69.98	65.79	61.93	59.18	56.09	52.61	48.99

Figure 4.17 Bending moment lateral distribution mid span of 9.04m.

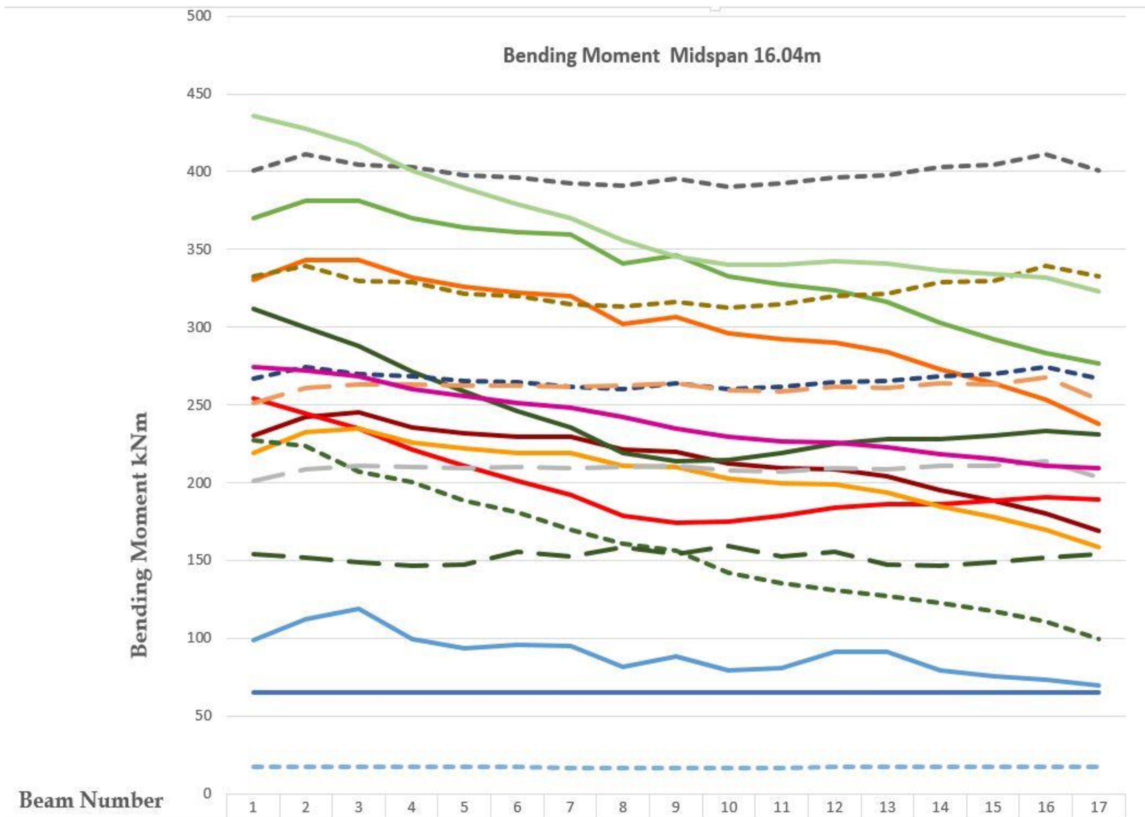
4.5.2 Maximum bending for 16.5m deck (span 16.04m)

Table 4.5 Maximum bending for 16.5m deck (span 16.04m)

Element & node	**Load**	**Maximum Bending moment kNm**	**Max mid span Bending moment kNm**
Eurocode			
209i	LM1 & FW	245.16	245.16
209i	LM1	234.91	234.91
209i	LM2	118.89	118.89
210i	LM3(SV100) straddling with LM1	381.62	381.41
498i	LM3(SV80) straddling with LM1	343.83	343.29
593i	LM3(SV100) &LM1 separate lanes	435.7	435.7
593i	LM3 SV100 single lane	311.58	311.58
593i	LM3 SV80 single lane	254.25	254.25
593i	LM3(SV80) &LM1 separate lanes	274.34	274.34
17i	LM4	65.28	65.28
UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			
210i	LM3(SV100) straddling with LM1	398.98	
498i	LM3(SV80) straddling with LM1	361.56	

593i	LM3(SV100) &LM1 separate lanes	445.75	
593i	LM3(SV80) &LM1 separate lanes	284.39	
BS 2006			
500i	HA & HB30 ULS Auto (γ_{fL}= 1.3)	414.63	411.28
500i	HA & HB30 SLS Auto (γ_{fL}= 1.1)	350.84	339.58
497i	HA	274.19	274.19
533i	HB single lane	240.1	227.1
561i	Pedestrian	17.48	17.48
BS 1978			
529i	HA ULS γ_{fL}= 1.5)	267.69	267.69
529i	HA SLS (γ_{fL}= 1.2)	214.15	214.15
302i	HB30 on centre line	168.84	159.26

4.5.2.1 Lateral distribution of bending moment mid span 16.04m



Beam Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LM1& FW	229.93	242.57	245.16	235.86	232.03	229.42	229.57	221.07	220.08	212.66	209.43	208.75	204.19	195.02	188.28	180.26	168.76
LM2	98.47	112.22	118.89	99.55	93.31	95.59	95.27	81.43	87.98	79.47	80.69	91.39	90.93	79.47	75.96	73.21	69.61
LM3 SV100 only	311.58	299.86	287.94	271.27	258.6	246.35	235.41	219.33	213.55	214.71	219.1	225.16	228.11	228.42	230.58	233.23	231.42
LM3SV100 LM1 stradling	370.16	381.01	381.41	370.24	364.15	361.23	359.63	340.91	345.82	332.81	327.21	323.71	315.88	303.12	292.66	283.45	276.74
LM4	65.27	65.24	65.25	65.26	65.27	65.27	65.28	65.28	65.28	65.28	65.28	65.28	65.27	65.26	65.26	65.25	65.28
LM3 SV80	254.25	244.69	234.96	221.36	211.02	201.03	192.1	178.98	174.26	175.21	178.79	183.74	186.14	186.39	188.16	190.32	188.84
LM3 SV80 LM1	330.46	343.28	343.29	331.92	325.62	322.04	319.97	302.21	306.87	296.1	292.06	290.11	283.82	272.65	263.77	253.14	237.83
LM1	219.46	232.27	234.91	225.66	221.86	219.28	219.44	210.95	209.96	202.54	199.3	198.6	194.02	184.81	178.04	169.96	158.27
HA HB 2006 AUTO ULS	400.57	411.28	404.41	402.85	397.92	396.47	392.14	390.8	395.4	390.45	392.12	396.46	397.91	402.83	404.37	411.24	400.51
HA HB 2006 AUTO SLS	332.96	339.58	329.76	328.81	321.55	320.33	314.59	313.01	316.53	312.36	314.5	320.35	321.55	328.8	329.74	339.55	332.92
HA 2006 both lanes	267.05	274.19	269.6	268.57	265.28	264.31	261.42	260.53	263.6	260.3	261.41	264.31	265.27	268.55	269.58	274.16	267.01
HB 2006 single lane	227.1	223.33	206.94	200.46	188.16	181.2	169.76	161.07	156.27	142.47	135.22	130.95	126.88	122.45	117.69	110.9	99.86
Pedestrian	17.38	17.16	17.07	17.01	16.96	16.92	16.89	16.87	16.87	16.87	16.89	16.92	16.96	17.01	17.08	17.17	17.48
HA 1978 ULS	251.31	261.06	263.26	262.91	262.16	262.64	261.45	262.78	263.9	259.55	259.05	261.5	260.99	263.93	263.49	267.69	253.8
HA 1978 SLS	201.05	208.85	210.61	210.33	209.73	210.11	209.16	210.23	211.12	207.64	207.24	209.2	208.79	211.15	210.79	214.15	203.04
SV100 & LM1 Separate lanes	435.7	427.26	417.44	400.87	389.45	378.95	370.37	356.22	345.05	340.41	340.02	342.12	340.78	336.45	334.55	332.01	322.79
SV80 & LM1 Separate lanes	274.34	271.96	268.32	260.38	255.53	251.36	248.46	242.63	234.46	229.21	226.55	225.51	222.64	218.15	215.13	211.22	209.26
HB30 stradling	154.38	151.92	148.84	146.7	147.25	155.44	152.38	158.53	154.14	159.26	152.46	155.43	147.24	146.7	148.85	151.93	154.34

Figure 4.18 Bending moment lateral distribution mid span of 16.04m

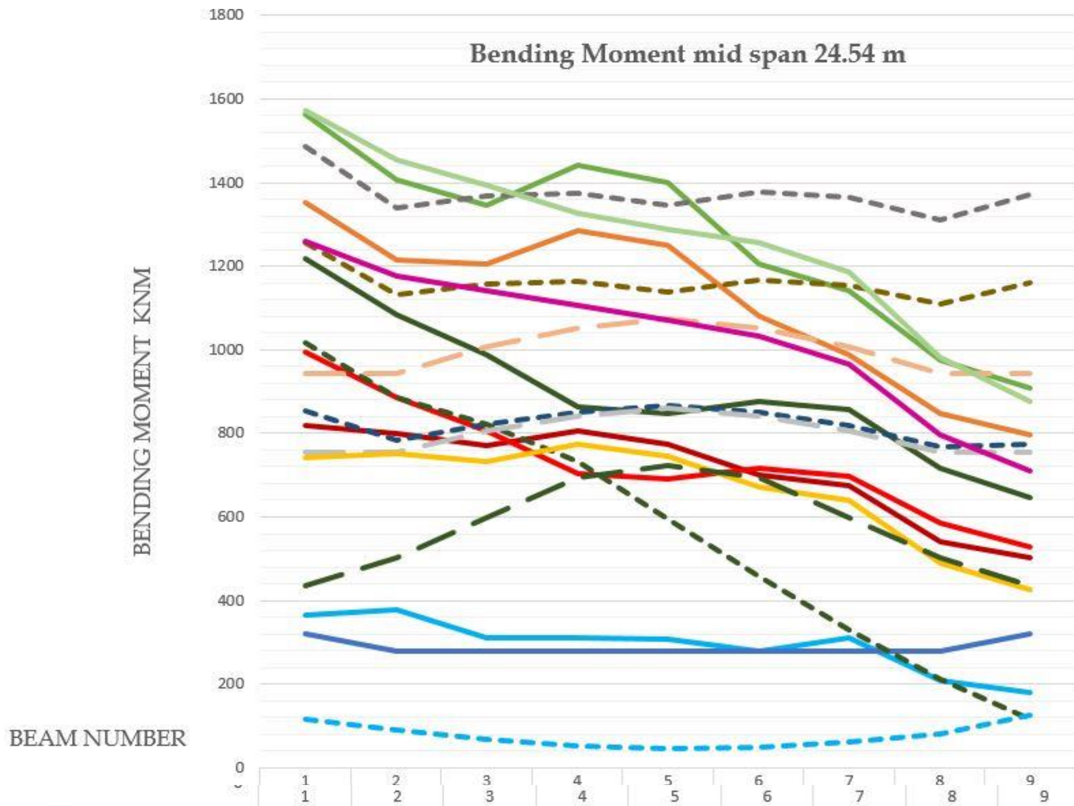
4.5.3 Maximum bending for 25m deck (span 24.54m)

Table 4.6 Maximum bending for 25m deck (span 24.54m)

Element & node	Load	Maximum Bending moment kNm	Max mid span Bending moment kNm
Eurocode			
113i	LM1 & FW	818.16	818.16
39i	LM1	775.4	774.82
89i	LM2	378.56	378.55
114i	LM3(SV100) straddling with LM1	1565.02	1564.37
114i	LM3(SV80) straddling with LM1	1351.13	1350.74
113i	LM3(SV100) &LM1 separate lanes	1571.16	1571.16
114i	LM3 SV100 single lane	1218.08	1218.01
114i	LM3 SV80 single lane	993.97	993.91
113i	LM3(SV80) &LM1 separate lanes	1259.53	1259.53
114i	LM4	321.86	321.83
UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			

114i	LM3(SV100) straddling with LM1	1602.71	
114i	LM3(SV80) straddling with LM1	1388.81	
113i	LM3(SV100) &LM1 separate lanes	1594.28	
113i	LM3(SV80) &LM1 separate lanes	1282.63	
BS 2006			
114i	HA & HB30 ULS Auto, (γ_{fL}= 1.3)	1486.82	1486.68
114i	HA & HB30 SLS Auto (γ_{fL}= 1.1)	1258.08	1257.96
14i	HA	867.07	867.04
114i	HB single lane	1015.88	1015.78
239i	Pedestrian	126.02	125.95
BS 1978			
238i	HA ULS γ_{fL}= 1.5)	1073.96	1073.93
238i	HA SLS (γ_{fL}= 1.2)	859.17	859.14
15i	HB30 on centre line	728.91	723.61

4.5.3.1 Lateral distribution of bending moment mid span 24.54m



	1	2	3	4	5	6	7	8	9
LM1& FW	818.16	800.82	771.04	804.9	774.33	701.1	676.56	539.86	502.91
LM2	363.75	378.55	310.39	311.71	308.67	279.13	309.59	209.81	181.34
LM3 SV100 only	1218.01	1085.09	987.45	864.27	848.28	876.78	856.28	716.39	647.22
LM3SV100 stradling & LM1	1564.37	1406.36	1345.39	1440.31	1399.23	1203.83	1142.09	974.95	908.89
LM4	321.83	279.44	279.15	279.12	279.34	279.79	280.23	280.4	321.59
LM3SV80	993.91	885.45	805.78	705.26	692.21	715.46	698.74	584.59	528.14
LM3SV80 & LM1	1350.74	1213.61	1206.37	1283.55	1250.19	1079.08	988.28	848.91	796.96
HA HB Auto ULS 2006	1486.68	1339.16	1368.01	1374.85	1345.55	1378.53	1364.03	1310.37	1370.79
HA HB Auto SLS 2006	1257.96	1133.13	1157.55	1163.34	1138.54	1166.45	1154.18	1108.77	1159.9
HA 2006 both lanes	852.61	783.59	820.8	850.23	867.04	851.15	818.38	768.06	775.52
HB 2006 single lane	1015.78	886.11	823.2	731.43	595.41	458.07	329.08	213.53	115.36
Pedestrian	117.51	91.98	67.88	51.53	44.87	48.25	60.56	81.6	125.95
HA 1978 ULS	944.46	943.83	1008.24	1051.12	1073.93	1051.12	1008.24	943.83	944.46
HA 1978 SLS	755.57	755.06	806.59	840.9	859.14	840.9	806.59	755.07	755.57
LM1	742.53	751.79	733.41	774.82	746.88	671.02	638.93	490.84	427.29
SV100 LM1 separate values	1571.16	1453.68	1394.88	1326.93	1287.43	1256.12	1185.48	981.06	874.94
SV80 LM1 lanes seperate	1259.53	1176.05	1142.23	1105.8	1070.39	1031.79	966.4	797.77	709.35
HB30 STRADLING	434.46	502.86	597.48	694.6	723.61	694.6	597.48	502.86	434.46

Figure 4.19 Bending moment lateral distribution mid span of 24.54m

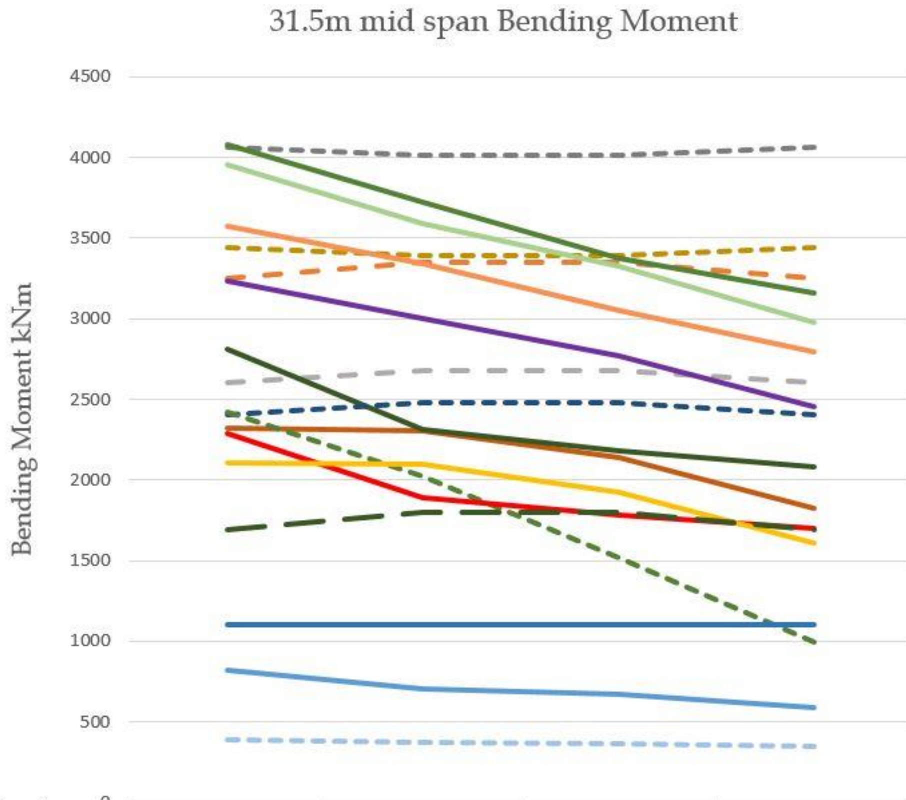
4.5.4 Maximum bending for composite plate girder deck span 31.5m

Table 4.7 Maximum bending for span 31.5m

Element & node	**Load**	**Maximum Bending moment kNm**	**Max mid span Bending moment kNm**
Eurocode			
152i	LM1 & FW	2340.14	2325.54
152i	LM1	2126.15	2107.63
127i	LM2	868.59	825.04
127i	LM3(SV100) straddling with LM1	4100.46	4077.41
127i	LM3(SV80) straddling with LM1	3600.66	3570.97
127i	LM3(SV100) &LM1 separate lanes	3966.61	3952.26
127i	LM3 SV100 single lane	2824.89	2809.96
127i	LM3 SV80 single lane	2305.16	2292.89
127i	LM3(SV80) &LM1 separate lanes	3246.39	3235.87
150i	LM4	1102.69	1102.66
UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			

127i	LM3(SV100) straddling with LM1	4407.38	
127i	LM3(SV80) straddling with LM1	3896.48	
127i	LM3(SV100) &LM1 separate lanes	4176.47	
127i	LM3(SV80) &LM1 separate lanes	3445.75	
BS 2006			
152i	HA & HB30 ULS Auto, (γ_{fL}= 1.3)	4097.93	4066.33
152i	HA & HB30 SLS Auto (γ_{fL}= 1.1)	3467.48	3440.74
152i	HA	2506.94	2476.26
127i	HB single lane	2435.51	2421.4
149i	Pedestrian	388.39	386.59
BS 1978			
152i	HA ULS γ_{fL}= 1.5)	3396.42	3350.6
150i	HA SLS (γ_{fL}= 1.2)	2717.05	2680.48
153i	HB30 on centre line	1856.31	1802.43

4.5.4.1 Lateral distribution of bending moment mid span 31.5m



Beam Number	1	2	3	4
LM1 & FW	2325.54	2308.68	2140.24	1827.28
HA HB 2006 Auto ULS	4066.33	4010.36	4010.36	4066.33
HA ULS BS5400 1978	3253.24	3350.6	3350.6	3253.24
LM2	825.04	702.35	669.43	591.23
HA HB 2006 Auto SLS	3440.74	3393.38	3393.38	3440.74
HA SLS BS5400 1978	2602.59	2680.48	2680.48	2602.59
LM3 SV100 only	2809.86	2317.37	2182.96	2083.69
HA 2006 both lanes	2406.47	2476.26	2476.26	2406.47
LM3 SV100 & LM1 stradling	4077.41	3722.7	3371.4	3162.75
HB 2006 single lane	2421.4	2027.23	1520.2	994.29
LM 4	1102.21	1102.62	1102.66	1102.11
Pedestrian 2006 BS	386.59	372.31	367.33	352.82
LM3 SV80 only	2292.89	1891.01	1781.33	1700.33
LM3 SV80 strad LM1	3570.97	3345.51	3050.4	2795.47
LM1 only	2107.63	2094.47	1926.03	1609.38
SV100 & LM1 separate lanes	3952.26	3590.6	3327.37	2979.79
SV 80 & LM1 separate lanes	3235.87	3001.14	2772.15	2450.98
HB30 stadling	1691.71	1802.43	1802.43	1691.71

Figure 4.20 Bending moment lateral distribution mid span of 31.5m

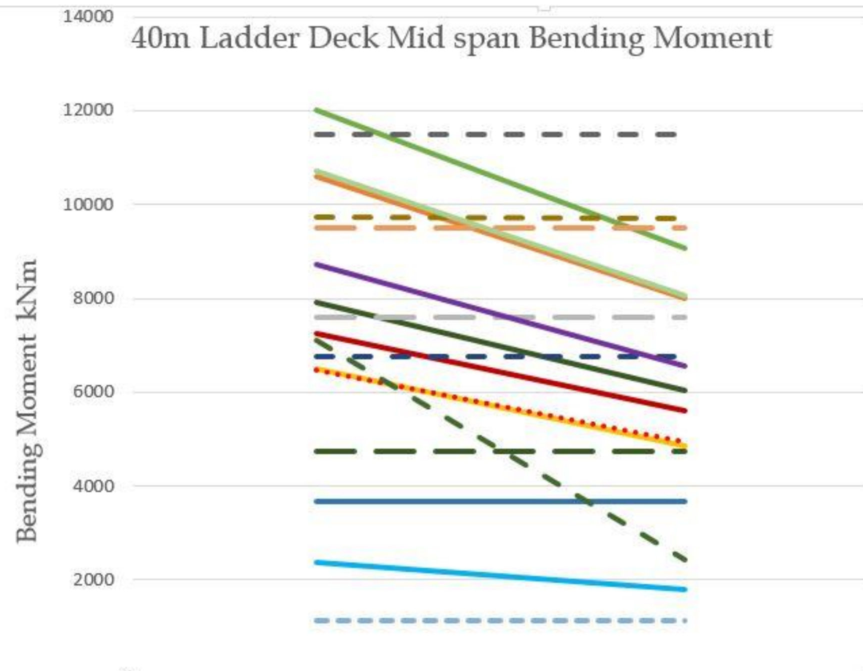
4.5.5 Maximum bending for composite plate girder deck span 40m

Table 4.8 Maximum bending for ladder deck span 40m

Element & node	Load	Maximum Bending moment kNm	Max mid span Bending moment kNm
Eurocode			
48i	LM1 & FW	7239.71	7239.71
48i	LM1	6490.06	6490.06
48i	LM2	2366.4	2366.37
48i	LM3(SV100) straddling with LM1	12008.04	12008.04
48i	LM3(SV80) straddling with LM1	10586.23	10586.23
48i	LM3(SV100) &LM1 separate lanes	10709.5	10709.5
48i	LM3 SV100 single lane	7912	7912
48i	LM3 SV80 single lane	6456.33	6456.33
48i	LM3(SV80) &LM1 separate lanes	8731.5	8731.5
48i	LM4	3665.76	3665.76
UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			
48i	LM3(SV100) straddling with LM1	12769.5	
48i	LM3(SV80) straddling with LM1	11755.42	
48i	LM3(SV100) &LM1 separate lanes	10940.58	

48i	LM3(SV80) &LM1 separate lanes	8962.58	
BS 2006			
48i	HA & HB30 ULS Auto, (γ_{fL}= 1.3)	11483.84	11485.1
48i	HA & HB30 SLS Auto (γ_{fL}= 1.1)	9717.1	9718.16
48i	HA	6763.5	6763.52
49i	HB single lane	7118.03	7092.43
48i	Pedestrian	1143.8	1143.8
BS 1978			
48i	HA ULS γ_{fL}= 1.5)	9497.8	9497.82
48i	HA SLS (γ_{fL}= 1.2)	7598.24	7598.26
47i	HB30 on centre line	4766.46	4749.6

4.5.5.1 Lateral distribution of bending moment mid span 40m Ladder deck



Beam Number (Ladder deck 40m)	1	2
LM1 FW	7239.71	5595.12
LM2	2366.37	1802.43
LM1 LM3 SV100 str	12008.04	9075.95
LM4	3665.76	3661.09
LM1 only	6490.06	4848.57
LM3 SV100	7912	6038.41
LM1 LM3 SV80 str	10586.23	7990.25
LM3 SV 80	6456.33	4927.44
HA HB AUTO 2006 ULS	11485.1	11479.4
HA HB 2006 Auto SLS	9718.16	9713.34
HA 2006 both lanes	6763.52	6761.22
HB 2006 SINGLE LANE	7092.43	2419.08
PEDESTRIAN 2006	1143.8	1143.6
HA (1.5) ULS BS5400 1978	9497.82	9494.58
HA (1.2) SLS BS5400 1978	7598.26	7595.66
LM3 SV100 & LM1 separate lanes	10709.5	8063.69
LM3 SV80 & LM1 separate lanes	8731.5	6554.09
HB30 Stradling	4749.6	4747.48

Figure 4.21 Bending moment lateral distribution mid span of 40m ladder deck

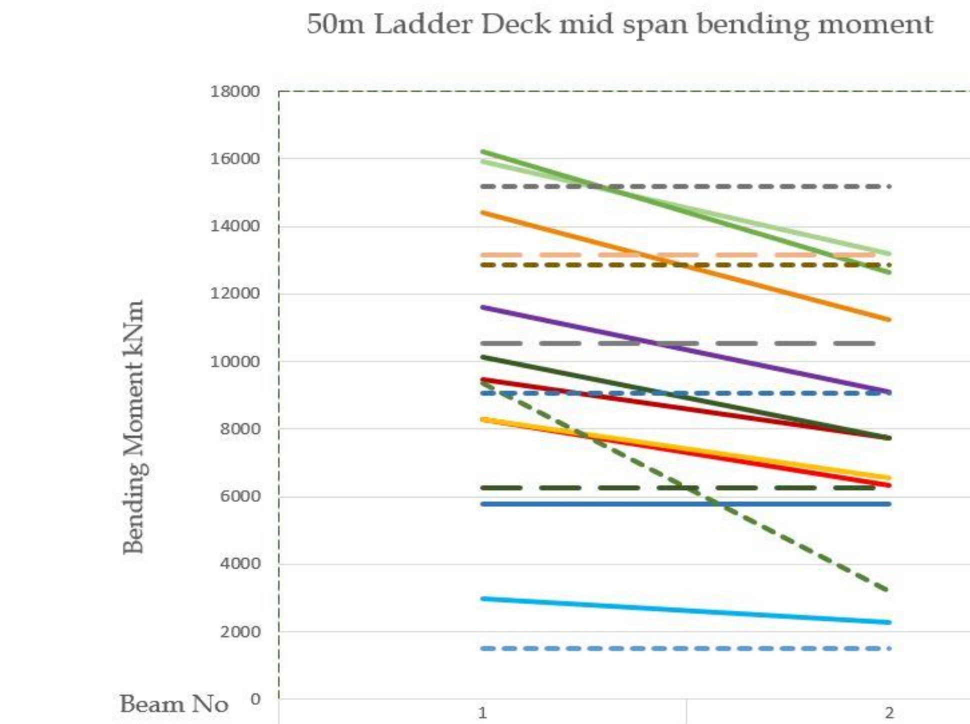
4.5.6 Maximum bending for composite plate girder deck span 50m

Table 4.9 Maximum bending for ladder deck span 50m

Element & node	**Load**	**Maximum Bending moment kNm**	**Max mid span Bending moment kNm**
Eurocode			
36i	LM1 & FW	9458.76	9458.76
36i	LM1	8273.36	8273.36
36i	LM2	2964.74	2964.74
36i	LM3(SV100) straddling with LM1	16226.77	16226.77
36i	LM3(SV80) straddling with LM1	14395.82	14395.82
36i	LM3(SV100) &LM1 separate lanes	15932.03	15932.03
36i	LM3 SV100 single lane	10134.75	10134.75
36i	LM3 SV80 single lane	8270.13	8270.13
36i	LM3(SV80) &LM1 separate lanes	11598.76	11598.76
36i	LM4	5776.33	5776.29
UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75)			
36i	LM3(SV100) straddling with LM1	17676.15	
36i	LM3(SV80) straddling with LM1	15845.19	
36i	LM3(SV100) &LM1 separate lanes	15932.03	

36i	LM3(SV80) &LM1 separate lanes	12394.62	
BS 2006			
36i	HA & HB30 ULS Auto, (γ_{fL}= 1.3)	15183.66	15183.66
36i	HA & HB30 SLS Auto (γ_{fL}= 1.1)	12847.71	12847.71
36i	HA	9050.01	9050.01
36i	HB single lane	9359.33	9359.33
56i	Pedestrian		1508.68
BS 1978			
36i	HA ULS γ_{fL}= 1.5)	13163.07	13163.07
36i	HA SLS (γ_{fL}= 1.2)	10530.46	10530.46
36i	HB30 on centre line	6266.05	6266.05

4.5.6.1 Lateral distribution of bending moment mid span 50m Ladder deck



Beam No	1	2
LM1 & FW	9458.76	7747.85
LM 2	2964.74	2261.6
LM3 SV100	10134.75	7740.7
LM4	5776.29	5776.33
LM3SV80 LM1str	14395.82	11251.33
LM3 SV80	8270.13	6316.55
LM1	8273.36	6562.45
LM3SV100 LM1 separate lanes	15932.03	13176.79
LM3SV80 LM1 Separate lanes	11598.76	9099.37
LM3 SV100 str	16226.77	12650.27
HA & HB 2006 Auto ULS	15183.66	15181.5
HA HB 2006 Auto SLS	12847.71	12845.88
HB single lane	9359.33	3182.11
HA 2006 Both lanes	9050.01	9050.01
Pedestrian 2006 Both sides	1508.68	1508.68
HA (1.5) BS5400 1978 ULS	13163.07	13163.07
HA (1.2) BS5400 1978 SLS	10530.46	10530.45
HB30 Stradling	6266.05	6266.05

Figure 4.22 Bending moment lateral distribution mid span of 50m ladder deck

4.5.7 Summary Maximum bending moments

Table 4.10 Summary - Maximum bending moments

Span (m)	**9.04**	**16.04**	**24.54**	**31.5**	**40**	**50**
Eurocode						
LM1 & FW	114.7	245.16	818.16	2340.14	7239.71	9458.76
LM1	111.39	234.91	775.4	2126.15	6490.06	8273.36
LM2	65.83	118.89	378.56	868.59	2366.4	2964.74
Euro Code ψ_1 LM1 TS 0.75, LM1 UDL 0.4						
LM3(SV100) straddling with LM1	134.26	381.62	1565.02	4100.46	12008.04	16226.77
LM3(SV80) straddling with LM1	123.87	343.83	1351.13	3600.66	10586.23	14395.82
LM3(SV100) &LM1 separate lanes	180.78	435.7	1571.16	3966.61	10709.5	15932.03
LM3(SV80) & LM1 separate lanes	148.01	274.34	1259.531	3246.39	8731.5	11598.76
UK National Annex ψ_1 LM1 TS 0.75, LM1 UDL 0.75						
LM3(SV100) straddling with LM1	139.27	398.98	1602.71	4407.38	12769.5	17676.15
LM3(SV80) straddling with LM1	129.17	361.56	1388.81	3896.48	11755.42	15845.19

LM3(SV100) &LM1 separate lanes	183.41	445.75	1594.28	4176.47	10940.58	14890.0
LM3(SV80) &LM1 separate lanes	151.21	284.39	1282.63	3445.75	8962.58	12394.62
LM3 SV100 single lane	128.35	311.58	1218.08	2824.89	7912	10134.75
LM3 SV80 single lane	104.74	254.25	993.97	2305.16	6456.33	8270.13
LM4	19.67	65.28	321.86	1102.69	3665.76	5776.33
BS 5400 part2 (2006)						
HA & HB30 ULS Auto HA alone (γ_{fL}= 1.3)	186.02	414.63	1486.82	4097.93	11483.84	15183.66
HA & HB30 SLS Auto HA alone (γ_{fL}= 1.1)	148.82	350.84	1258.08	3467.48	9717.1	12847.71
HA	124.01	274.19	867.07	2506.94	6763.5	9050.01
HB single lane	88.04	240.1	1015.88	2435.51	7118.03	9359.33
Pedestrian	7.91	17.48	126.02	388.39	1143.8	1508.68
BS 5400 part2 (1978)						
HA ULS (γ_{fL}= 1.5)	103.05	267.69	1073.96	3396.42	9497.8	13163.07
HA SLS (γ_{fL}= 1.2)	82.44	214.15	859.17	2717.05	7598.24	10530.46
HB30 on centre line	73.45	168.84	728.91	1856.31	4766.46	6266.05

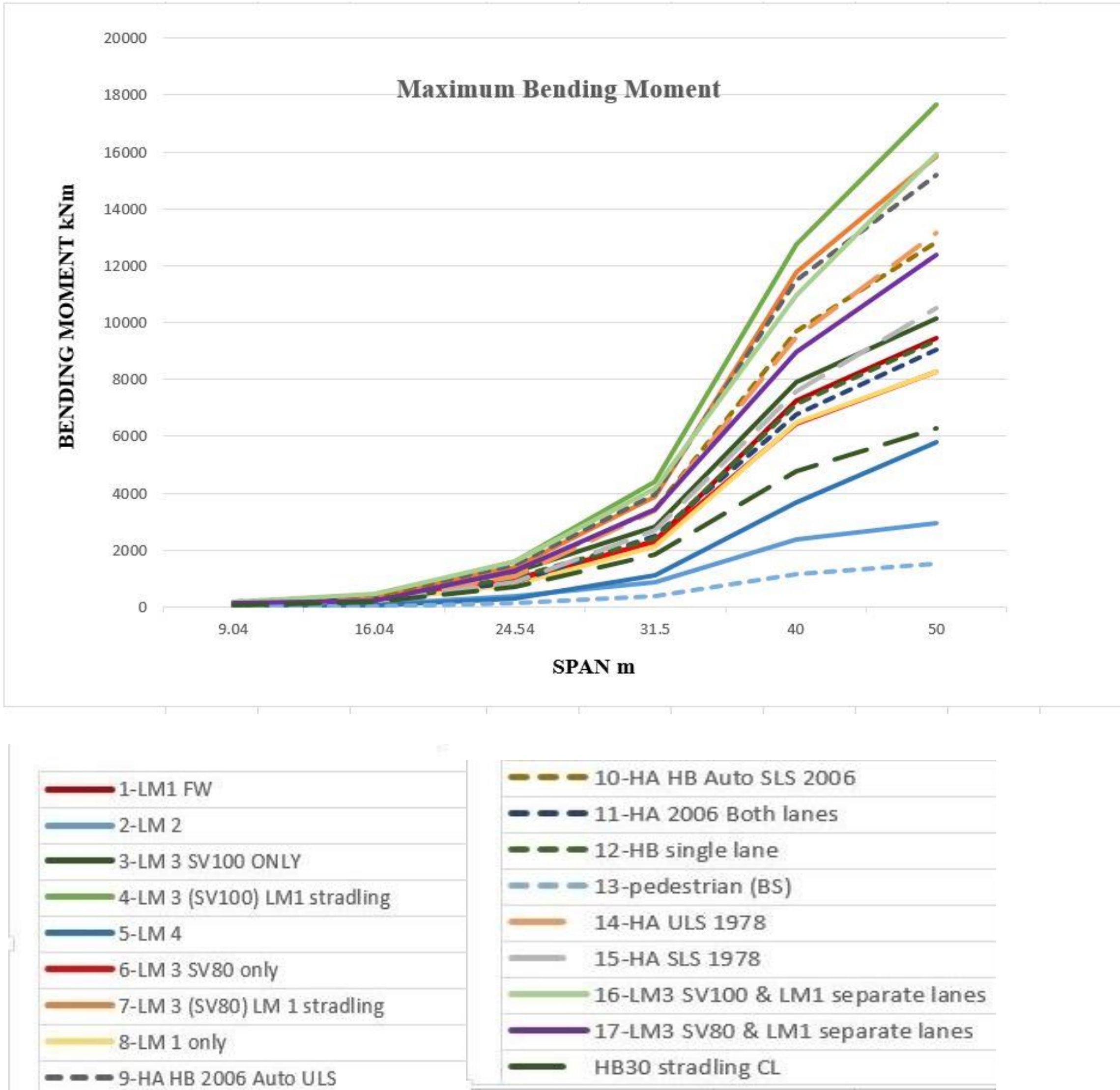


Figure 4.23 – Maximum bending moment diagram of traffic loads with span

4.6 Influence of different loadings on bending

The maximum bending moment of bridge decks could be varified by maximum mid span moment. The analysis of maximum bending moment and centre span maximum bending moment indicate small difference (tables 4.4 - 4.9). In span 31.5m presence of bracing effected mid span moments and maximum moment has occurred on adjacent node. Table 4.10 presents maximum bending moments considered for the analysis,

Bending moment distribution across deck depends on span, width and stiffness of members (Rowe, 1976). Figures 4.17 – 4.22 indicate distribution maximum midspan bending moments across deck for the types of loads considered. The ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.4) was considered for load groups consisting LM1 & LM3 in developing Figures 4.17 – 4.22. The Figure 4.13 indicates variation of maximum bending moment with span. For the Figure 4.23, the ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) was considered for load groups consisting LM1 & LM3.

If severe traffic loads are applied only on a single lane of a two lane deck (i.e HB30, LM3 SV80, SV100 on a single lane) edge beams carry higher bending stressess. Application of uniform loading over the deck (i.e. HA, LM1, LM4 on both lanes,) or application of loading symetric along centreline (HB30 stradling on centre line) induces higer bending stresses in beams close to centre line. For such loading better distribution of bending moment among beams within the cross section occur (figures 4.17 – 4.22).

4.6.1 Review of local RDA standard for maximum bending moment.

RDA manual considers most adverse effect due to HA BS5400 1978 on full deck and HB30 stradling on centre line for design.

Above RDA loading types show either almost equal distribution of centre span bending moment among girders or larger bending moments towards deck centre line. Analysis of maximum bending moment as per RDA manual is tabulated in Table 4.11a below.

Table 4.11a Comparison of Maximum Bending moments HA 1978 and HB30 stradling on centre line

Span m	**9.04**	**16.04**	**24.54**	**31.5**	**40**	**50**
A) HA SLS BS5400 1978 (γ_{fL}= 1.2) kNm	82.44	214.15	859.17	2717.05	7598.26	10530.5
B) HB30 on centre line kNm	73.95	168.84	728.51	1856.31	4766.46	6266.05
(B) /(A/1.2)	1.076	0.946	1.017	0.82	0.753	0.714
(B)*(SLS γ_{fL}= 1.1)/(A)	0.989	0.867	0.933	0.752	0.690	0.654

Without SLS factors, HA is more severe for deck spans larger than 24.54m (i.e. composite plate girder and ladder decks). HB stradling on centre line is severe than HA upto span 24.54m (i.e. 25m M beam and slab deck) and less.

With application of partial safty factors of BS5400 1978 for SLS, HA maximum bending moment is severe than HB30 (stradling on centre line) for spans 9.04m to 50m.

4.6.2 Analysis of Maximum Bending Moment

Comparison of bending moment between Eurocode(UKNA) and BS5400-2 for load cases, load groups, and load combinations previously discribed in section 4.2 is presented below in Table 4.11b. BS 5400-2 loads are taken as the basis for comparison.

Table 4.11b - Comparison of Eurocode (UKNA) with BS 5400 part2 maximum bending moments.

Span m	**9.04**	**16.04**	**24.54**	**31.5**	**40**	**50**
1) LM 1 /HA BS5400 1978	1.62	1.32	1.08	0.94	1.02	0.94
2) LM 1 /HA BS5400 2006	0.9	0.86	0.89	0.85	0.96	0.91
3) LM3SV100 single lane /HB30 single lane	1.46	1.30	1.20	1.16	1.11	1.08
4) LM3SV80 single lane /HB30 single lane	1.19	1.06	0.98	0.95	0.91	0.88
5) Max (LM1 & LM3 SV100 stradling and on separate lanes) * γ_{fL}= 1.1 / (Auto HA 2006 & HB30)SLS *EC ψ_1 (LM1 TS 0.75, LM1 UDL 0.4)*	1.34	1.37	1.37	1.31	1.35	1.39
UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)	1.36	1.40	1.40	1.40	1.45	1.51
6) Max (LM1 & LM3 SV80 stradling and on separate lanes) * γ_{fL}= 1.1 / (Auto HA 2006 & HB30)SLS	1.09	1.11	1.10	1.15	1.2	1.23

EC ψ_1 (LM1 TS 0.75, LM1 UDL 0.4)						
UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)	1.12	1.13	1.21	1.24	1.33	1.36

Comparison of Table 4.11b

1. Comparison of LM1 with HA BS 5400 1978 (current RDA standard)

   Considering HA loading of BS5400 1978 as the basis LM1(UKNA) maximum bending moment ratio varies from 1.62 to 1.08 within the span range 9.04m to 24.54m. Above ratio is 0.94 for spans 31.5m and 50m.

   Therefore, LM1(UKNA) loading for span range 9.04m to 24.54m and 107% of LM1(UKNA) loading for span range 24.54m to 50m is severe than maximum bending moment due to HA (1978) loading.

2. LM1 (UKNA) with HA BS5400 2006

   When HA BS5400 2006 is considered as the basis Minimum ratio is 0.85. Therefore, 118% of LM1(UKNA) loading is severe than maximum bending moment due to HA(2006) loading.

3. LM3 SV100 & SV80 with HB30

   Considering HB30 units as the basis minimum ratio for LM3 SV100 is 1.08 within span range 9.04m to 50m. Therefore, SV100 loading is severe than maximum bending moment due to HB30 loading.

LM3 SV80, the ratio varies from 1.19 to 0.98 within the span range 9.04m to 24.54m. The minimum ratio is 0.88 at 50m span. Therefore, SV80 loading for span range 9.04m to 24.54m, and 114% of SV80 loading for span range 24.54m – 50m is severe than maximum bending moment due to HB30 loading.

4. Maximum of LM1 & LM3 SV100 (UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75) stradling and on separate lanes with Maximum HA 2006 & HB30 combination

When HA 2006 & HB30 combination is considered as basis, the above ratio varies from 1.36 to 1.51 within the span range 9.04m – 50m.

Therefore, the loading LM1 with LM3 SV100 is severe than maximum bending moment due to HA2006 & HB30 loading combination. The group LM1 & LM3SV100 is very conservative (36% to 51%) than HA2006 & HB30 combination maximum bending moment.

5. Maximum of LM1 & LM3 SV80 (UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75) stradling and on separate lanes with Maximum HA 2006 & HB30 combination

When HA 2006 & HB30 combination is considered as basis, the above ratio varies from 1.12 to 1.36 within the span range 9.04m to 50m.

Therefore, the loading LM1 with LM3 SV80 is severe than for maximum bending moment due to HA2006 & HB30 loading combination. The group LM1 & LM3SV80 is conservative (12% to 36%) than HA2006 & HB30 combination maximum bending moment.

6. Eurocode ψ_1 factor for LM1 (TS 0.75, UDL 0.4) could be used to calculate maximum bending moment ratio of LM1 & LM3 loading to HA2006 & HB30 loading in (4) and (5) above with reduced margins of 31% and 10%.

4.7 Effect on maximum shear

Tables 4.12a to 4.12g and figures 4.24 to 4.29 present support shear distribution for models previously described in section 3.3.3 together with Eurocode UKNA BS5400 part2 (1978 with RDA manual) and BS5400 part2 (2006) loads previously described and load cases, load groups, and load combinations compared in section 4.2.

Due to moving load analysis, one support is shown with larger shear force. Small shear force is on support i and tabulated in table 4.12a. Larger shear force on support j are graphically presented with corresponding values.

Support shear force distribution due to Eurocode UKNA load groups LM1 & FW, LM2, LM1 together with LM3 (SV100 & SV80) straddling and on separate lanes, and LM4 are graphically presented.

For comparison of load effects of traffic models, shear force due to LM1 and HA loading of BS 5400 part2 (1978 & 2006) are graphically. Load effects due to LM3 (SV100), LM3 (SV80) and HB30 on single lane are graphically presented to compare special vehicles specified in both codes.

LM1 together with LM3 (SV100 & SV80) straddling and on separate lanes (application of ψ_1 factor as previously described in section 4.2 above) are compared with HA (BS5400 2006) & HB30 load combination graphically presented as HA&HB (Auto). HB30 (BS5400) on centre line straddling between lanes as per RDA design manual is also presented.

Maximum support shear force due LM1 together with LM3 (SV100 & SV80) straddling and on separate lanes for ψ_1 factors LM1 UDL 0.75, TS 0.75 are tabulated in Tables 4.12a – 4.12g.

Distribution of maximum shear force on both supports i and j considered. Shear force distribution of support i is tabulated below in Table 4.12a.

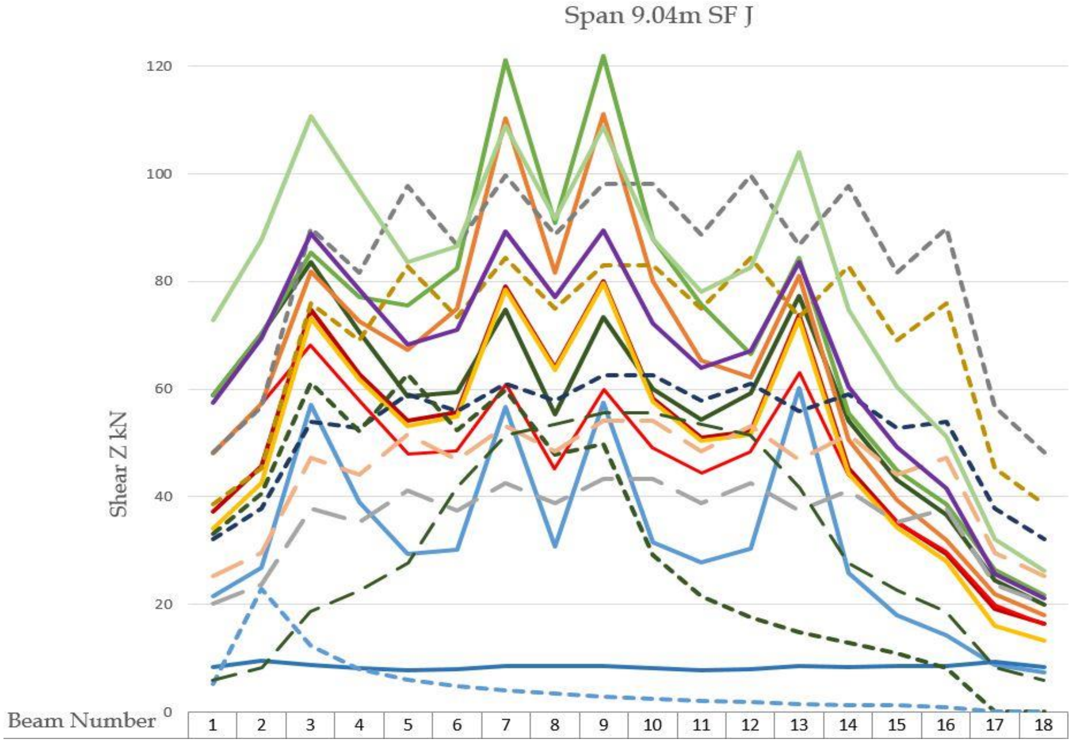
Table 4.12a Maximum shear force on support i due to traffic load.

Max Shear force on support i due to Traffic load (kN)	**span 9.04m**	**span 16.04m**	**Span 24.54m**	**Span 31.5m**	**Span 40m**	**Span 50m**
LM1 + FW	12.42	43.96	14.87	29.72	11.31	11.89
LM2	16.54	23.2	7.15	39.24	6.7	4.19
LM3SV100 single lane	10.19	78.53	25.36	24.17	4.13	2.58
LM3SV100 str + LM1	20.4	87.56	32.07	41.22	6.41	4.21
LM4	1.13	13.73	6.3	12.87	8.63	10.92
LM3SV80 single lane	8.31	64.09	20.69	19.72	3.37	2.1
LM3SV80 str + LM1	18.71	73.58	27.59	28.92	6.15	4.01
LM1	12.42	39.65	13.08	29.72	11.31	3.16
HA HB Auto BS 2006 ULS	20.26	87.78	24.94	44.44	7.99	5.02
HA HB Auto BS 2006 SLS	16.21	74.27	21.07	37.61	3.73	4.24

HA both lanes	13.5	74.27	13.25	17.42	2.61	1.62
HB30 single lane	6.31	67.37	19.16	34.07	6.15	3.86
HA BS 1978 ULS	18.87	48.77	15.97	21.39	3.73	2.33
HA BS 1978 SLS	15.09	39.02	12.78	17.11	6.76	1.87
LM1SV100 separate lanes	12.73	95.92	30.6	29.59	5.07	4.22
LM1SV80 separate lanes	12.42	61.73	24.11	28.92	4.94	3.16
HB30 stradling CL	2.4	1.27	59.3	23.96	1.54	1.38
Pedestrian	35.11	7.75	2.96	32.41	15.79	11.11

Span *UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)*	9.04m	16.04m	24.54m	31.5m	40m	50m
LM3SV100 stradling + LM1	20.41	87.84	32.5	41.29	6.31	4.21
LM3SV80 stradling + LM1	18.73	73.89	28.06	37.95	6.06	4.01
LM1 SV100 separate lanes	12.73	95.92	30.6	29.53	5.07	4.22
LM1 SV80 separate lanes	12.44	61.73	24.11	24.99	4.95	3.16

4.7.1 Span 9.04m (Solid slab deck)



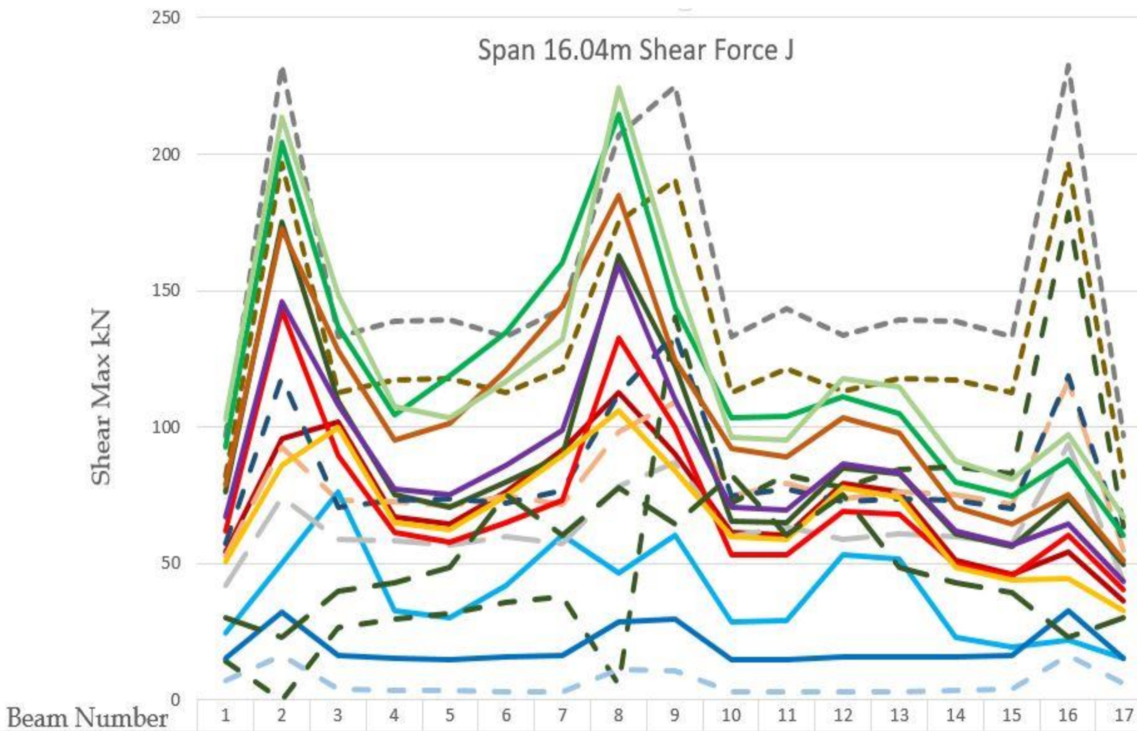
Beam Number 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
LM 1 FW	37.31	45.78	74.7	62.84	54.09	55.63	79.19	64.06	80.15	58.2	51.04	52.18	73.71	45.21	35.37	29.42	19.23	16.45
LM 2	21.52	26.74	57.19	39.06	29.38	30.19	56.7	30.77	57.5	31.59	27.75	30.4	60.2	25.79	17.91	14.16	8.78	7.29
LM 3 SV100 only	58.92	70.21	83.55	70.75	58.66	59.39	74.74	55.32	73.49	60.13	54.31	59.31	77.38	54.24	43.08	36.73	24.4	19.89
LM 3 (SV100) LM 1 str	58.92	70.21	85.45	77.08	75.47	82.49	121.08	90.99	121.93	88.03	75.74	66.53	84.5	55.6	44.86	38.57	26.41	21.63
LM 4	8.43	9.46	8.68	8.19	7.81	7.95	8.55	8.54	8.64	8.07	7.77	7.98	8.56	8.42	8.64	8.56	9.33	8.42
LM 3 SV80 only	48.08	57.29	68.18	57.73	47.87	48.46	60.99	45.14	59.97	49.07	44.32	48.4	63.14	44.26	35.16	29.97	19.91	16.23
LM 3 (SV80) LM 1 str	48.08	57.29	81.83	72.56	67.33	75.05	110.44	81.74	111.13	80.05	65.27	62.2	81.04	50.67	39.4	31.95	21.92	17.97
LM 1 only	34.16	42.54	73.19	61.78	53.26	54.93	78.59	63.52	79.63	57.68	50.5	51.58	73.01	44.37	34.3	27.91	15.98	13.3
HA HB 2006 ULS	48.34	56.65	89.84	81.6	97.87	86.72	99.83	88.7	98.08	98.08	88.7	99.83	86.72	97.87	81.6	89.84	56.65	48.34
HA HB 2006 SLS	38.67	45.32	76.02	69.05	82.81	73.38	84.47	75.05	82.99	82.99	75.05	84.47	73.38	82.81	69.05	76.02	45.32	38.67
HA 2006	32.23	37.77	53.95	52.71	58.98	55.89	61.06	57.86	62.55	62.55	57.86	61.06	55.89	58.98	52.71	53.94	37.76	32.23
HB single lane	33.07	40.58	61.13	52.1	62.88	52.37	59.93	47.85	49.82	29.13	21.57	17.54	14.83	12.82	10.98	8.24	0	0
Pedestrian	5.25	22.9	12.38	7.99	6.07	4.89	4.03	3.37	2.83	2.4	2.06	1.77	1.55	1.36	1.18	0.9	0.14	0.04
HA BS5400 1978 ULS	25.27	29.6	47.22	44.09	51.56	46.87	53.24	48.46	54.15	54.15	48.46	53.24	46.87	51.56	44.09	47.22	29.6	25.27
HA BS5400 1978 SLS	20.21	23.68	37.77	35.28	41.25	37.5	42.59	38.77	43.32	43.32	38.77	42.59	37.5	41.25	35.28	37.77	23.68	20.21
LM3SV100 & LM1 separate lanes	72.85	87.77	110.8	96.94	83.61	86.6	108.89	91.6	108.72	87.9	78.2	82.73	103.97	74.71	60.42	51.1	32.12	26.29
SV80 LM1 separate lanes	57.43	69.4	88.93	78.42	68.26	71.06	89.32	77.12	89.49	72.16	63.99	67.21	83.71	60.52	49.15	41.49	25.73	21.08
HB30 stradling BS5400	5.93	8.31	18.68	22.6	27.73	41.74	51.46	53.54	55.66	55.66	53.54	51.46	41.74	27.73	22.6	18.68	8.3	5.92

Figure 4.24 Shear force distribution support j span 9.04m

Table 4.12b Maximum shear force on support j due to LM1& LM3. Span 9.04m LM1 *UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	**Beam Number**	**Max Shear Force**
LM3 (SV100) LM1 straddling	9	124.54
LM3 (SV80) LM1 straddling	9	113.74
LM3 (SV100) LM1 separate lanes	3	110.63
LM3 (SV80) LM1 separate lanes	9	91.39

4.7.2 Span 16.04m (Voided slab deck 16.5m)



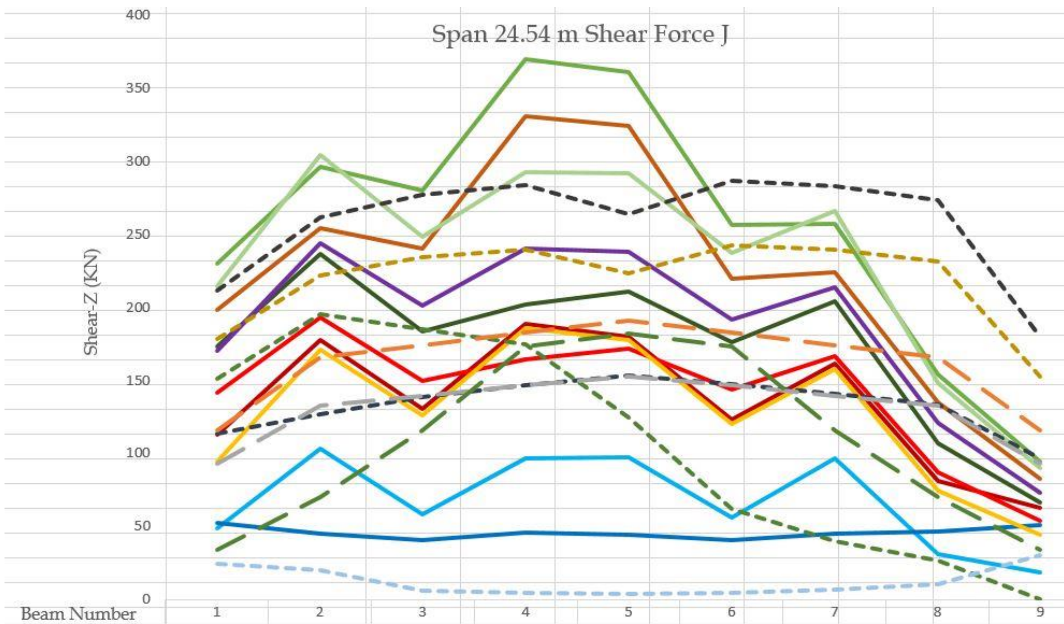
Beam Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LM1 & FW	54.24	95.9	101.93	66.9	64.21	76.32	91.5	112.52	90.06	61.32	60.55	79.45	76.14	50.9	46.06	54.24	36.23
HA & HB ULS 2006	96.95	232.47	133.01	138.71	139.41	133.27	143.58	207.12	225.03	133.27	143.19	133.54	139.41	138.77	132.96	232.55	96.94
HA ULS BS5400 1978	52.58	92.44	73.28	72.58	70.9	74.88	71.6	98.09	108.92	74.67	79.53	73.79	76.06	74.97	71.57	116.98	54.52
LM 2	24.5	49.9	76.44	32.53	30.37	41.89	60.46	46.71	60.49	28.69	28.92	52.98	51.48	22.94	19.4	21.86	15.47
HA HB SLS 2006	82.03	196.71	112.55	117.37	117.97	112.76	121.49	175.25	190.41	112.77	121.16	112.99	117.96	117.42	112.51	196.77	82.03
HA BS5400 SLS 1978	42.06	73.95	58.63	58.07	56.72	59.91	57.28	78.47	87.14	59.73	63.62	59.03	60.85	59.97	57.25	93.59	43.62
LM 3 SV100	76.02	174.9	109.72	74.97	70.73	79.82	89.52	162.81	122.53	65.46	65.08	84.81	83.15	60.91	56.04	73.67	49.5
HA 2006	57.23	118.51	70.37	73.17	73.7	72.37	76.86	111.96	134.18	74.72	77.05	72.44	73.67	73.17	70.34	118.55	57.22
LM 3 SV100 & LM1	92.85	204.1	136.85	104.37	118.58	134.44	160.37	214.85	144.02	103.4	103.92	111.06	104.82	79.93	74.59	88.14	60.28
HB 30 single lane	14.37	0	26.47	29.59	31.91	35.53	38.01	5.55	140.11	72.36	82.47	77.88	84.45	85.29	82.8	178.88	63.26
LM 4	15.31	31.98	16.45	15.14	14.97	15.57	16.14	28.47	29.47	14.96	14.94	15.78	15.98	15.75	16.5	32.62	15.13
Pedestrian 2006	7.18	16.22	3.9	3.48	3.23	3.06	2.95	10.97	10.5	2.88	2.94	3.05	3.22	3.45	3.87	16.24	6.13
LM 3 SV80	62.03	142.72	89.53	61.18	57.72	65.13	73.05	132.86	99.98	53.42	53.11	69.21	67.85	49.71	45.73	60.12	40.39
LM 3 SV80 & LM1	78.96	172.59	128.05	95.03	101.24	120.83	144.14	185.12	124.62	92.1	88.91	103.21	97.66	70.78	64.28	74.97	51.33
LM 1	50.56	86.18	99.61	64.83	62.29	74.5	89.73	105.95	83.77	59.6	58.79	77.62	74.21	48.83	43.74	44.49	32.55
SV100 LM1 Separate lanes	102.78	213.61	148.48	107.41	103.58	116.84	131.99	224.28	155.48	96.39	95.2	117.88	114.91	87.44	80.85	97.29	67.11
SV80 LM1 separate lanes	66.77	145.71	107.86	77.26	75.05	85.98	98.97	159.27	110.16	70.76	69.64	86.33	83.53	62.07	56.69	64.3	43.25
HB30 stradling	30.29	22.94	39.65	43.13	48.68	75.36	60.52	77.99	64.64	82.4	60.6	75.18	48.55	43.05	39.59	22.72	30.22

Figure 4.25 Shear force distribution support j span 16.04m

Table 4.12c Maximum shear force on support j due to LM1& LM3. Span 16.04m LM1 *UKNA* ψ_1 *(LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	Beam Number	Max Shear Force
LM3 (SV100) LM1 straddling	8	216.57
LM3 (SV80) LM1 straddling	8	186.84
LM3 (SV100) LM1 separate lanes	8	225.18
LM3 (SV80) LM1 separate lanes	8	160.17

4.7.3 Span 24.54m (M beam & slab deck 25m)



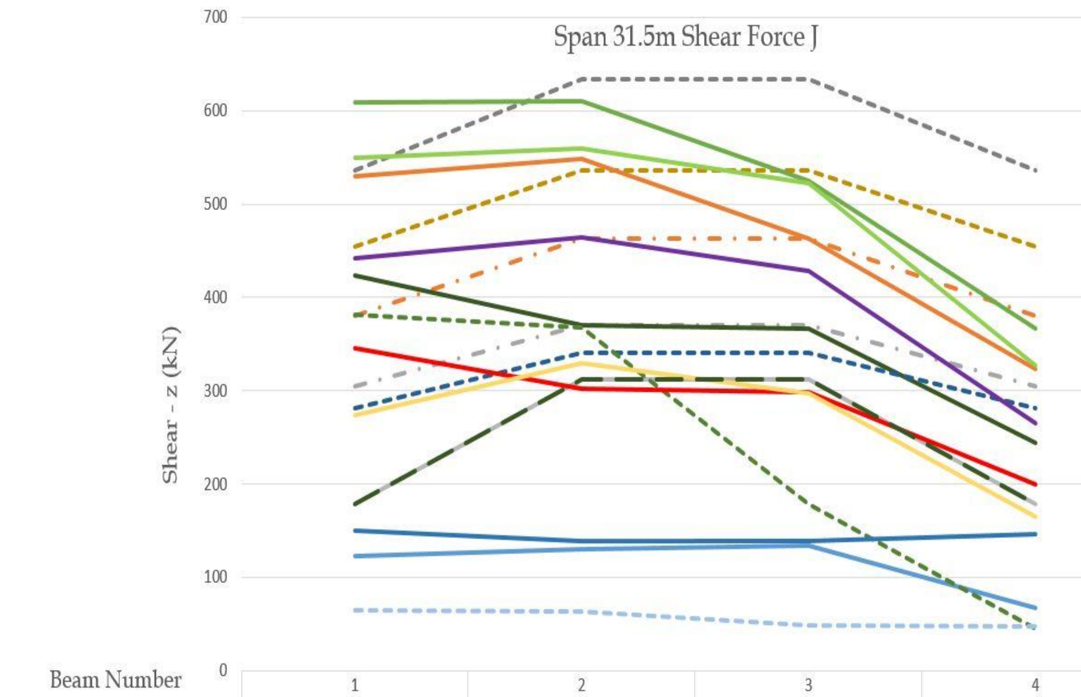
Beam Number	1	2	3	4	5	6	7	8	9
LM 1 & FW	112.75	177.7	130.4	188.66	180.16	122.77	161.75	81.32	62.55
LM2	48.96	103.35	58.16	96.51	97.38	56.26	96.78	31.01	18.66
LM3 SV100 only	173.53	236.42	183.36	201.87	210.76	175.87	204.34	106.69	66.27
LM3 SV100 & LM1	229.94	296.49	280.34	370.04	361.05	256.75	256.83	154.04	94.23
LM4	52.29	44.78	40.8	46.06	44.52	40.71	45.15	46.24	50.85
LM3 SV80 only	141.6	192.93	149.63	164.73	171.99	143.51	166.74	87.06	54.08
LM3 SV80 & LM1	198.44	254.53	240.45	331.12	324.33	219.94	224.06	134.66	82.48
LM 1 only	94.65	171.21	126.4	185.77	177.63	119.89	157.75	74.83	44.45
SV100 LM1 separate lanes	214.64	304.15	248.44	292.21	291.96	236.98	266.36	148.1	90.32
SV80 LM1 separate lanes	170.24	243.66	201.53	240.56	238.03	191.98	214.07	120.8	73.36
HA 2006 HB ULS	211.24	261.78	277.07	283.38	264	286.33	283.04	273.16	180
HA 2006 HB SLS	178.74	221.51	234.44	239.78	223.38	242.28	239.49	231.13	152.31
HA 2006	113.89	126.79	138.88	146.72	153.41	147.35	140.67	133.72	96.56
HB single lane	151.36	195.17	184.78	174.45	124.73	61.95	39.56	26.38	0.01
Pedestrian	24.15	20.27	5.92	4.21	3.75	4.4	6.37	10.75	30.51
BS 5400 HA 1978(ULS)	115.75	165.51	174.16	182.99	190.58	182.99	174.16	165.51	115.75
BS 5400 HA 1978(SLS)	92.6	132.41	139.33	146.39	152.46	146.39	139.33	132.41	92.6
HB30 Stradling lanes	34.11	70.25	115.76	173.41	182.34	173.41	115.76	70.25	34.11

Figure 4.26 Shear force distribution support j span 24.54m

Table 4.12d Maximum shear force on support j due to LM1& LM3. Span 24.54m LM1 *UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	**Beam Number**	**Max Shear Force**
LM3 (SV100) LM1 straddling	4	385.3
LM3 (SV80) LM1 straddling	4	346.4
LM3 (SV100) LM1 separate lanes	2	308.6
LM3 (SV80) LM1 separate lanes	4	250.52

4.7.4 Span 31.5m (Composite plate girder deck)



Beam Number	1	2	3	4
HB30 stradling	178.62	312.55	312.55	178.62
HA HB ULS 2006 BS	536.57	633.94	633.94	536.57
HA BS 5400 1978 ULS	380.21	462.52	462.52	380.21
LM2	123.4	130.22	134.07	67.6
HA HB SLS 2006 BS	454.02	536.41	536.41	454.02
HA BS5400 1978 SLS	304.17	370.01	370.01	304.17
LM3 SV100	423.91	370.07	365.96	244.08
HA only 2006 BS	281.65	340.61	340.61	281.65
LM3 SV100 & LM1	608.37	610.45	524.73	367.11
HB 2006 BS	380.87	367.24	178.67	44.64
LM 4	149.86	138.93	138.75	146.71
Pedestrian 2006 BS	65.16	63.82	49.04	47.44
LM3 SV80	345.92	301.98	298.63	199.17
LM3 SV80 LM1	530.38	548.6	463.13	323.24
LM1 only	273.46	329.52	297.69	165.2
LM3 SV100 LM1 separate lanes	549.29	559.29	522.91	327.12
LM3 SV80 LM1 separate lanes	442.58	464.34	428.76	265.13
HB30 stradling	178.62	312.55	312.55	178.62

Figure 4.27 Shear force distribution support j span 31.5m

Table 4.12e Maximum shear force on support j due to LM1& LM3. Span 31.5m LM1 *UKNA* ψ_1 *(LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	**Beam Number**	**Shear Force**
LM3 (SV100) LM1 straddling	2	662.41
LM3 (SV80) LM1 straddling	2	599.73
LM3 (SV100) LM1 separate lanes	2	586.87
LM3 (SV80) LM1 separate lanes	2	491.92

4.7.5 Span 40m (Lader deck)

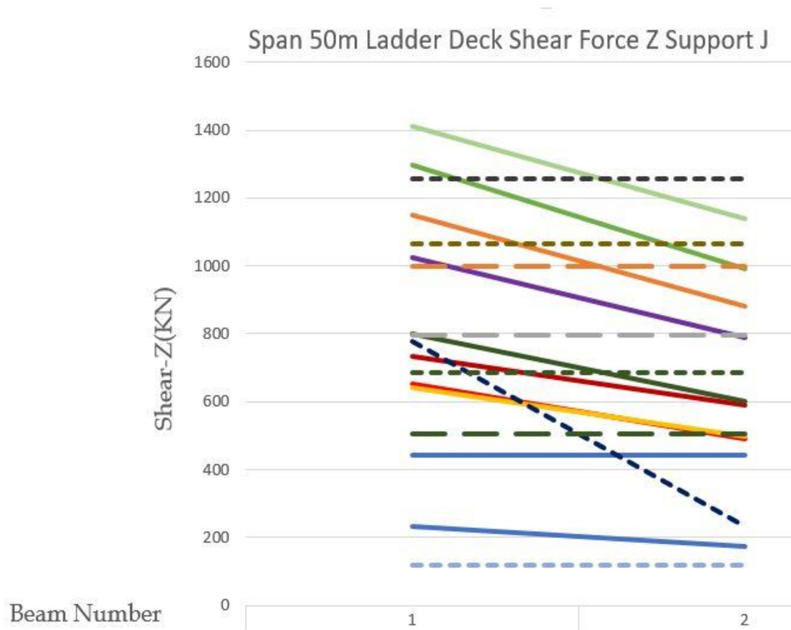
Beam Number 0	1	2
LM 1	712.12	537.53
HA HB Auto ULS 2006	1186.2	1186.07
HA (1.5) ULS BS5400 1978	905.55	905.62
LM 2	234.42	175.33
HA HB AUTO SLS 2006	1003.71	1003.6
HA (1.2) SLS BS5400 1978	724.44	724.5
LM1 & 3 SV100 Strad	1230.12	909.94
HA BOTH LANES COMBINED 2006	645.01	645.06
LM 4	353.23	352.31
HB LANE1 LOADED 2006	757.73	223.27
LM 1 only	637.65	463.83
PEDESTRIAN 2006	170.33	170.35
LM 3 SV 100 only	790.97	592.65
LM1 & 3(SV80) strad	1084.6	800.9
LM 3 SV 80 only	645.45	483.61
SV100 LM1 Separate lanes	1116.42	823.55
SV80 LM1 Separate Lanes	918.82	675.44
HB30 STR CL	490.51	490.49

Figure 4.28 Shear force distribution support j span 40m

Table 4.12f Maximum shear force on support j due to LM1& LM3. Span 40m LM1 *UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	**Beam Number**	**Shear Force**
LM3 (SV100) LM1 straddling	1	1316.67
LM3 (SV80) LM1 straddling	1	1171.26
LM3 (SV100) LM1 separate lanes	1	1141.27
LM3 (SV80) LM1 separate lanes	1	943.67

4.7.6 Span 50m (Ladder deck)



Beam Number	1	2
LM1 FW(max)	732.91	590.27
LM2(max)	232.07	174.17
LM3 SV 100(max)	799.48	600.71
LM3 LM1 SV100 str(max)	1296.55	991.98
LM4(max)	441.62	441.64
LM3 SV 80(max)	652.39	490.19
LM3 LM1 SV80 str(max)	1149.46	881.46
LM1 only(max)	639.79	497.15
LM3 Manual SV100 & LM1(max)	1412.1	1139.14
LM3 Manual SV80 & LM1(max)	1025.24	787.86
HA HB Auto ULS(max)	1257.19	1257.01
HA HB Auto SLS(max)	1063.78	1063.62
HB(max)	776.48	233.44
HA Both lanes loaded(max)	685.62	685.62
FW Both sides(max)	118.58	118.58
HA (1.5) ULS BS5400 1978	997.08	997.08
HA (1.2) SLS BS5400 1978	797.66	797.66
HB30 Stradling	504.96	504.96

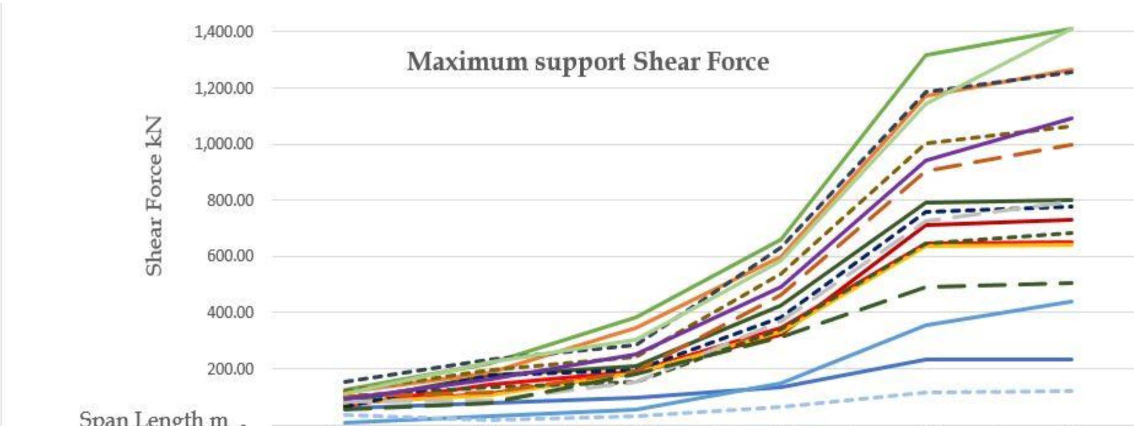
Figure 4.29 Shear force distribution support j span 50m

Table 4.12g Maximum shear force on support j due to LM1& LM3. Span 50m LM1 *UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)*

UK NA loading	Beam Number	Shear Force
LM3 (SV100) LM1 straddling	1	1413.51
LM3 (SV80) LM1 straddling	1	1266.41
LM3 (SV100) LM1 separate lanes	1	1412.10
LM3 (SV80) LM1 separate lanes	1	1094.22

4.8 Summary of Maximum Shear

A summary of maximum support shear is presented in Figure 4.30 below. It indicates the variation of maximum shear with spans of different deck types considered. For the Figure 4.30, the ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) as specified in NA to BSEN 1991-2 was considered for load groups consisting LM1 & LM3.



	9.04	16.04	24.54	31.5	40	50
LM 1 FW	80.15	112.52	186.66	320.29	712.12	732.91
LM 2	60.20	76.44	97.38	134.07	233.80	234.07
LM 3 SV100 only	83.55	174.90	210.76	423.91	790.97	799.48
LM 3 (SV100) LM 1 str	124.54	216.57	385.32	662.00	1,316.67	1,413.51
LM 4	9.46	32.62	52.29	149.86	353.23	441.64
LM 3 SV80 only	68.18	142.72	192.93	345.92	645.45	652.39
LM 3(SV80) LM 1 str	113.74	186.84	346.40	599.73	1,171.26	1,266.41
LM 1 only	79.63	105.95	185.77	329.52	637.65	639.79
HA HB 2006 ULS	152.04	232.55	286.33	633.94	1,186.20	1,257.19
HA HB 2006 SLS	121.63	196.77	242.28	536.41	1,003.71	1,063.78
HA 2006 BOTH LANES	101.36	134.18	153.41	340.61	645.06	685.62
HB single lane	62.88	178.88	195.17	380.87	757.73	776.48
Pedestrian 2006	35.11	16.24	30.51	65.16	113.50	118.58
HA 1978 ULS	102.66	116.98	190.58	462.52	905.62	997.08
HA 1978 SLS	82.13	87.14	152.46	370.01	724.50	797.66
LM1 SV100 separate lanes	110.63	225.18	302.17	586.87	1,141.27	1,412.10
LM1 SV80 separate lanes	91.39	160.27	250.52	491.92	943.67	1,094.22
HB30 stradling CL	55.66	77.99	182.34	312.55	490.51	504.96

Figure 4.30 Maximum Shear force diagram of traffic loads with span

4.9 Influence of different loadings on shear

As indicated in Figures 4.24 – 4.30, lesser the number of beams of the bridge deck, higher the maximum shear force that a beam would carry. The presence of point loads on a beam increase support shear. Eurocode traffic model LM3 consist of point loads at closer intervals (along bridge axis) than BS5400-2 HB vehicle model. Eurocode traffic model LM1 TS consists of point loads that induce high shear than BS 5400-2 HA KEL model.

Figures 4.24 – 4.29 indicate the maximum shear on a support for the types of loads considered. The ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.4) was considered for load groups consisting LM1 & LM3 in developing Figures 4.24 – 4.29. The longer span length and reduction of number of girders in the model has contributed to increase of shear force with span as shown in Figure 4.30.

4.9.1 Review of local RDA standard for maximum shear.

Analysis of maximum shear force as per RDA manual is tabulated in Table 4.13 below.

Table 4.13 Comparison of Maximum Shear force HA 1978 and HB30 stradling on centre line

Span m	9.04	16.04	24.54	31.5	40	50
A) HA SLS BS5400 1978 (γ_{fL}= 1.2) kN	82.13	87.14	152.46	370.01	724.5	797.66
B) HB30 on centre line kN	55.66	77.99	182.34	312.55	490.51	504.96
(B) /(A/1.2)	0.81	1.07	1.44	1.01	0.81	0.76
(B)*(SLS γ_{fL}= 1.1)/(A)	0.75	0.98	1.32	0.93	0.74	0.7

HB30 shear force (without SLS factors), is more severe for deck spans 16.04m- 31.5m (i.e. composite plate girder). For decks of 9.04m, and for ladder decks 40m and 50m support shear force due HA is critical.

With application of partial safty factors of BS5400 1978 for SLS, HA maximum support shear force is severe than HB30 (stradling on centre line) except for 24.54m span (i.e. M beam and slab deck).

4.9.2 Analysis of Maximum shear force

Comparison of support shear force between Eurocode(UKNA) and BS5400-2 for load cases, load groups, and load combinations previously discribed in section 4.2 is presented below in Table 4.14. BS 5400-2 loads are taken as the basis for comparison.

Table 4.14 - Comparison of Eurocode (UKNA) with BS 5400 part2 maximum shear force on support.

Span m	9.04	16.04	24.54	31.5	40	50
1) LM 1 /HA BS5400 1978	1.16	1.46	1.46	1.07	1.06	0.96
2) LM 1 /HA BS5400 2006	0.79	0.79	1.21	0.97	0.99	0.93
3) LM3SV100 single lane /HB30 single lane	1.33	0.98	1.08	1.11	1.04	1.03
4) LM3SV80 single lane /HB30 single lane	1.08	0.80	0.99	0.91	0.85	0.84
5) Max (LM1 & LM3 SV100 stradling and on separate lanes) * γ_{fL}= 1.1 /	1.0	1.25	1.68	1.15	1.35	1.46

(Auto HA 2006 & HB30)SLS						
UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)	1.13	1.26	1.75	1.36	1.44	1.46
Max (LM1 & LM3 SV80 stradling and on separate lanes) * γ_{fL}= 1.1 / (Auto HA 2006 & HB30)SLS	1.01	1.03	1.50	0.95	1.19	1.19
UKNA ψ_1 (LM1 TS 0.75, LM1 UDL 0.75)	1.03	1.04	1.57	1.23	1.28	1.31

Comparison of Table 4.14 on maximum shear

1. LM1 (UKNA) with HA BS5400 1978 (current RDA standard)

   Considering HA BS5400 1978 as basis, the ratio varies from 1.16 to 1.06 for span 40m. At span 50m the rato is 0.96.

   Therefore, shear force due to LM1(UKNA) within span range 9.04m to 40m, and 105% of LM1(UKNA) within span range 40m to 50m is severe than shear force due HA 1978.

2. LM1 (UKNA) with HA BS5400 2006

   Considering HA loading of BS5400 2006 as the basis, minimum ratios are 0.79 for spans less than 24.54m and 0.93 for spans greater than 24.54m.

   Therefore 127% of LM1 (UKNA) is severe than shear due to HA BS5400 2006 loading.

3. LM3 SV100 & SV80 with HB30

Considering HB30 units as basis ratio varies 0.98 to 1.33 for span range 9.04m to 50m. Therefore SV100 is severe or equal to shear due to HB30 within above span range.

For SV80 minimum above ratio is 0.8. Therefore 125% of SV80 is severe than maximum shear due to HB30 units within span range of 9.04m – 50m.

4. Maximum of LM1 & LM3 SV100 UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) straddling and on separate lanes with Max HA (BS5400 2006) & HB30 combination.

   When HA2006 & HB30 is considered as basis, the ratio varies from 1.13 to 1.75 within the span range 9.04m to 50m. Therefore LM1 & LM3SV100 group is severe than maximum shear force due to HA2006 & HB30 combination.

5. Maximum of LM1 & LM3 SV80 UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) stradling and on separate lanes with Max HA2006 & HB30 combination

   When HA2006 & HB30 is considered as basis, the ratio varies from 1.03 to 1.57 within the span range 9.04m to 50m. Therefore LM1 & LM3 SV80 group is severe than maximum shear force due to HA2006 & HB30 combination.

4.10 Summary of findings

(Comparison of tables 4.11b for maximum bending moment and 4.14 for maximum shear)

1. Comparison of LM1(UKNA) with HA BS 5400 1978 (current RDA standard)

Considering HA loading of BS5400 1978 as the basis, based on sections 4.6.2 – 1, and 4.9.2 - 1, LM1(UKNA) loading within span range 9.04m to 24.54m and 107% of LM1(UKNA) loading within span range 24.54m to 50m has severe load effects than HA BS 5400 1978 maximum bending moment and maximum shear force.

2. Comparison of LM1(UKNA) with HA BS5400 2006

Considering HA loading of BS5400 2006 as the basis, based on sections 4.6.2 – 2, and 4.9.2 - 2, 127% of LM1(UKNA) loading within span range 9.04m to 50m has severe load effects than HA BS 5400 2006 maximum bending moment and maximum shear force.

3. Comparison of LM3SV100 and SV80 (UKNA)with HB 30units

Considering HB30 units as basis, based on sections 4.6.2– 3, and 4.9.2 – 3, for minimum ratio with LM3 SV100 is 0.98 for span range 9.04m to 50m. Therefore SV100 has severe (or equal) load effeccts than HB30 maximum bending moment and maximum shear force.

Considering HB30 units as basis, based on sections 4.6.2-3, and 4.9.2-3, minimum ratio with LM3 SV80 is 0.8. for span range 9.04m – 50m. Therefore 125% of SV80 has severe load effects than HB30 maximum bending moment and maximum shear force.

4. Comparison of Maximum of LM1 & SV100 UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) group with Maximum HA (BS5400 2006) HB30 combination.

Considering HA&HB30 combination for BS5400 as basis, minimum ratios with LM1&SV100 UKNA group are 1.13 (span 9.04m, shear force) and 1.36 (span

9.04m, bending moment). Therefore application of LM1&SV100 has severe load effects than HA(2006) & HB30 combination maximum bending moment and maximum shear force.

5. Comparison of Maximum of LM1 & SV80 UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) combination with Maximum HA (BS5400 2006) HB30 combination.

   Considering HA&HB30 combination for BS5400 as basis, minimum ratios with LM1&SV80 UKNA group are 1.03 (span 9.04m, shear force) and 1.12 (span 9.04m, bending moment). Therefore application of LM1&SV80 has severe load effects than HA(2006) & HB30 combination maximum bending moment and maximum shear force.

Chapter - 05

Design of Steel composite bridges to Euro code (UK National annex) for cost estimates.

5.1 Introduction

The design life of a bridge is defined as 120 years both in BS5400 part 1 and in Table NA.2.1, UKNA to EN1990. Prediction of traffic loading during this life span is not accurate. Generally traffic volume predictions are for a period 15 – 25 years for road pavements after which designes are reviewed and pavement is rehabilitated.

Most bridges in the local road network has been designed for HA loading of BS 5400 part2 (1978) with load effects due to HB30 stradling on centre line of the bridge. In recent expressways BS5400 part2 (2006) has been adopted.

As shown in section 4.9 above LM1(UKNA) loading within span range 9.04m – 24.54m and 107% of LM1(UKNA) loading within span range 24.54m – 50m has severe load effects than HA BS 5400 1978 maximum bending moment and maximum shear force.

UKNA SV100 vehicle has severe load effects than BS5400 HB30 vehicle. BS5400 HB30 has severe load effects than UKNA SV80 within span range 9.04m – 50m.

Group5 LM1(UKNA) with LM3SV80 has severe load effects than BS5400 HA2006 and HB30 combination within span range 9.04m – 50m.

The additional cost of a bridge due upgrade in design standard LM3 from SV80 to SV100 for spans range 9.04m - 50m is small when compared to total project cost. Upgrade result stronger and robust briges than existing structures.

Therefore steel composite bridge deck designs made for cost comparison is based on load combination LM1 (UKNA) with LM3 SV100.

5.2 Design information

5.2.1 Composite deck types

5.2.1.1 Multi girder bridges

Simply supported steel girder composite with concrete deck shown in Figure 2.13.

Rolled steel (steel grade S355) beams (spans 11.5m, 17.5m) and plate girder (span 31.5m) at 2.6m spacing were considered. Concrete grade C40/50 with deck slab 250mm thick, and 1.3m side cantilevers, Two lane carriageway 7.4m, footways 1.5m wide inclusive 0.3m width for uprights were considered.

5.2.1.2 Simply supported plate girder ladder deck.

Two plate girders (steel grade S355) at 8m spacing considered with cross girders 2.5m to 3.5m spacing shown in Figure 2.15.

Concrete grade C40/50 with deck slab 250mm thick, and 1.2m side cantilevers. Two lane carriageway 7.4m, footways 1.5m wide inclusive 0.3m for uprights were considered.

5.2.2 Design

As suggested above designs were completed accordance with Eurocodes, as modified by the UK national Annexes. Where relevant reference to Sri Lanka National Annex to EN 1992-1-1 (2004) and EN 1991-1-4 (2005) is made.

5.2.2.1 Actions on deck

(a) Permanent Actions on deck

Self weight of steel, wet concrete, formwork, barrier (hand rail), footway dead load (additional load), wearing surface load, utility loads considered. Long term effects creep and shrinkage, and development of compressive strength of concrete considered.

(b) Transient Actions on deck

Moving loads, wind loads, braking load, differential temperature positive difference, and negative difference considered. Moving traffic loads and combinations are considered as described under section 2.2.4

LM1 (TS and UDL), LM2 (Single axle), LM3 (Special vehicles), LM4 (Crowd loadig), footway loading, braking and accelaration forces of UKNA to EN 1991-2:2003 considered with traffic groups specified in Table NA.3 (Assessment of groups of traffic loads). UKNA ψ_1 factor (LM1 TS 0.75, LM1 UDL 0.75) and footway loading 3kN/sqm specified for Table NA.3 loading were considered. For LM3, SV80 and SV 100 vehicles were considered.

5.2.2.2 Loads considered for designs

5.2.2.2.1 Horizontal loads

(a) Wind Loading – EN 1991-1-4 Section 8 wind action on bridges

SLS EN 1991-1-4: 2016 Table NA.1

$V_b = 38.34\ ms^{-1}$, F_w= 2.55 KN/m (for 50m span girder)

(b) Braking and Accelaration forces EN 1991-2:2003, Cl 4.4.1, UKNA 2.18.1

5.2.2.2.2 Vertical loads - Permanent loads for construction stages & traffic loading to UKNA to EN 1991-2:2003

5.2.2.2.3 Temperature gradiant EN 1991-1-5 (2003), Figure 6.2b simplified procedure.

5.2.2.3 Other design considerations

5.2.2.3.1 Shear lag effect – Effective width of flanges EN 1994-2-2005, 5.4.1.2 (5)

For the models considered effective width is not affected by shear lag. Detail calculation are given in appendix A1.

5.2.2.3.2 Fatigue

Fatigue loading –

Simplified fatigue load model for road bridges up to 80m span was considered. (EN 1993-2 cl 9.2.2, cl 9.5) Fatigue load model 3 (single vehicle model) in conjunction with traffic data specified for the bridge location in accordance with EN 1991-2 applied.

Fatigue assessment –

EN 1993-1-9 cl 3 presents two methods of assessment. i.e., damage tolerant method and safe life method. UKNA to EN 1993-1-9 NA.2.5.1 specifies safe life method of assessment.

Shear connector details.

Diameter 19mm, 100mm long, ultimate strength f_u = 495 MPa

Damage equivalent factors (EN 1993-2-cl 9.5.2) considered for Fatigue assessment of shear connectors are as follows. Detail calculation is given in Appendix A2.

$\lambda_{v1} = 1.550$ $\lambda_{v2} = 0.591$ $\lambda_{v3} = 1.023$ (design life 120 years)

$\lambda_{v4} = 1.080$ $\lambda_v = \lambda_{v1}\lambda_{v2}\lambda_{v3}\lambda_{v4} = 1.012$

5.3 Design Reports and Drawings of composite decks

The preliminary sizing of simply supported steel composite girder depends on mid span moment, moment resistace of composite section, support shear and shear resistance of steel section. British constructional steelwork association (BCSA) website https://steelconstruction.org provides free Excel sheets and steel area graphs for preliminary calculations of composite steel bridge girders under Eurocode (UKNA) loading . For steel connections, commercial software is available. The wesite https://BIMware.com provide free software for steel connection design adequate for cost calculation.

The computer models has been discussed under section 3.4.2. Table 3.2 present summary of deck model details for spans 11.5m, 17.5m, 31.5m, and ladder deck spans 40m & 50m. Appropriate load combinations, support shear and Mid span bending moments and corresponding traffic loads are presented in Appendix B. Design checks discussed in section 2.5.1.2 are presented for above decks in report tables 5.1, 5.2, 5.3, 5.4, 5.5 below.

The effective width of compression flange of concrete deck was governed by girder spacing for all cases considered above. As shown in Appendix A1 shear lag effect did not govern the effective width of examples considered.

Maximum bending moment at mid span, maximum support shear, longitudinal shear and negative moment on support section are verified with checks for lateral torsional buckling, fatigue, and serviceability stresses of the composite section and are presented in table 5.1 to table 5.5. Negative moments on support section were discussed in above section 3.3.2.

Midas Civil software verify lateral torsional buckling as an inverted U frame as outlined in EN 1993-1-1 (6.3) and EN 1993-2 table D3. The fatigue check presented in tables is discussed in sections 5.2.2.3.2 and Appendix A2.

Tender drawings Figures 5.1 to 5.11 and Figures in Annex J, J1.1, J1.2, J2.1, J2.2 are prepared for spans 11.5m, 17.5m, 31.5m, 40m and 50m for cost calculation of Chapter 6 presented in Table 6.4.

5.3.1 Span 11.5m - Universal beam deck

The model is discussed under section 3.4.2.1. The details of bridge deck is shown in Figure 5.1. Universal beam 611.9mm x 229mm x 125kg/m section 12m long are considered for girders. Temporary bracing during construction under weight of fresh concrete is provided to prevent torsional buckling of main girders. Rolled steel Universal Beam sections needs minimum fabrication therefore, is an economical choice for short spans.

Design results presented in Table 5.1 indicate that second beam from the edge is most critical for support shear and midspan bending moment for traffic loading considered. Design checks at critical sections are tabulated in table 5.1 below.

Figures B1.1 to B1.3 of Appendix B1 present critical load combination for shear, shear force diagram and traffic load combination corresponding to critical load shear. Figures B2.1 to B2.3 of Appendix B2 present critical load combination for maximum bending moment, bending moment diagram and traffic load combination corresponding to maximum bending moment.

Figure 5.1 indicate configuration details of the deck used for cost calculations in Table 6.4.

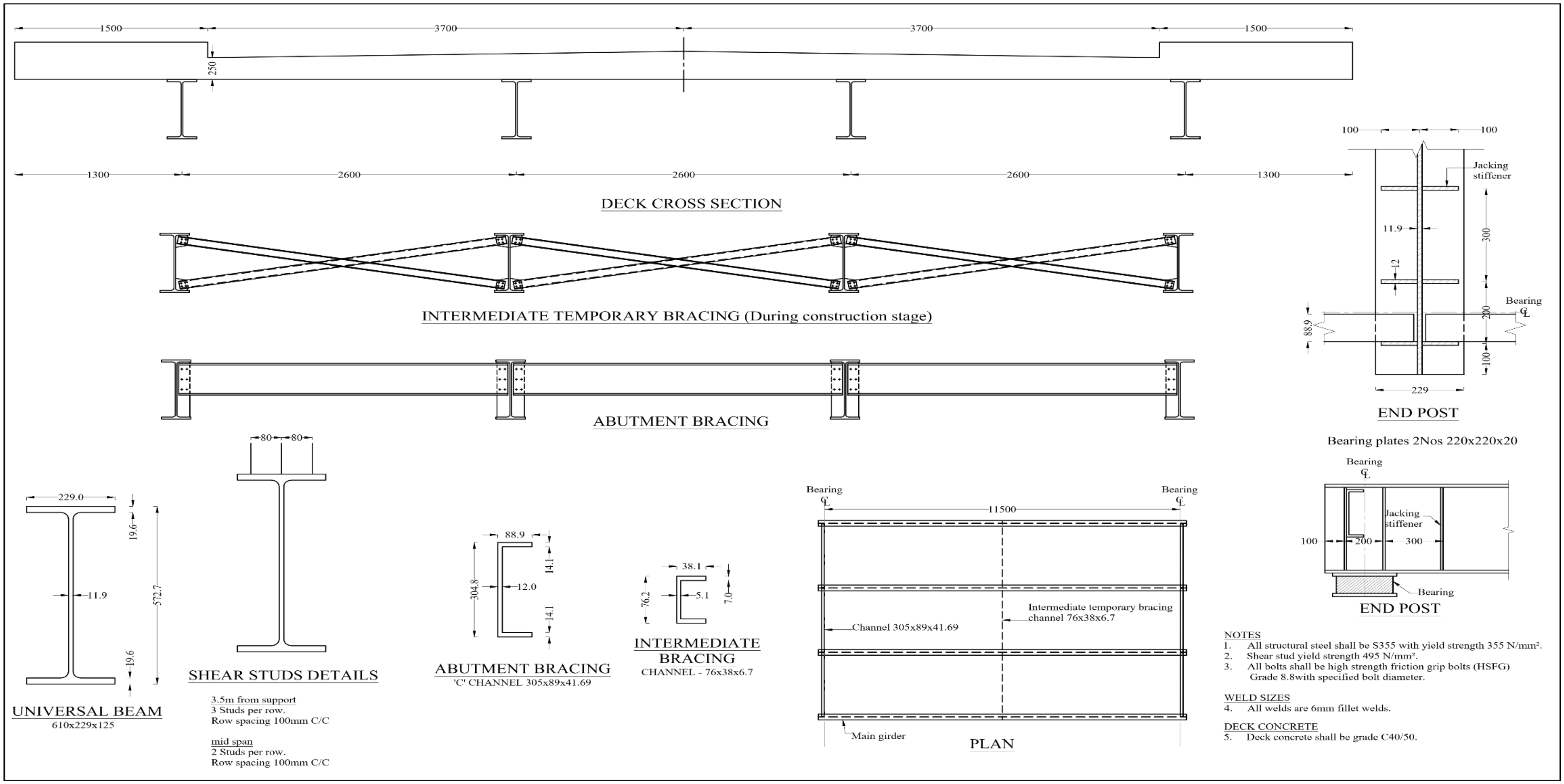


Figure 5. 1 STEEL CONCRETE COMPOSITE BRIDGE DECK.SPAN 11.5m

(CROSS SECTION,BRACING AND BEARING DETAILS)

Design Checks of Section 2.4.3 11.5m span deck	**Support Section (Elements 39i, 48j) 2nd beam from edge is most critical**	**Mid span section (43j, 44i) 2nd beam from edge is most critical**
Positive Moment (ULS)		M_{ed} = 1977.66 KNm < M_{Rd} = 2850.1 KNm (Load comb sLCB9)
Negative Moment (ULS)	M_{ed} = -282.98 KNm < M_{Rd} = 1290.1KNm (Load comb sLCB9)	
Shear resistance (ULS)	V_{edi} = 834.67KN (Load comb sLCB5) $V_{bw,\ RD}$ = 1523.8 KN $V_{bf,\ RD}$ = 0 KN V_{edi} / ($V_{bw,\ RD}$ + $V_{bw,\ RD}$) = 0.548 OK	V_{edi} = 333.781KN (Load comb sLCB5) $V_{bw,\ RD}$ = 1523.8 KN $V_{bf,\ RD}$ = 0 KN V_{edi} / (Vbw, RD + $V_{bw,\ RD}$) = 0.224 OK
Lateral torsional Buckling (ULS)	(Load comb sLCB16) (N_{ed} / $N_{b,\ Rd}$) + (Med / $M_{b,\ Rd}$) = 0.29< 1 OK	(Load comb sLCB9) (Ned / $N_{b,\ Rd}$) + (Med / $M_{b,\ Rd}$) = 0.71<1 OK

Longitudinal shear Resistance (ULS)	(Load comb sLCB 5) Shear connector spacing 100mm, 3Nos Single connector resistance = 89.82KN $V_{L,ED}$ = 1000.0KN/m < $V_{L,RD}$ = 2694.657 KN/m	Load comb sLCB 5) Shear connector spacing 100mm, 2Nos Single connector resistance = 89.82KN $V_{L,ED}$ = 485.84KN/m < $V_{L,RD}$ = 1796.438 KN/m
Resistance to fatigue	(Load comb sLCB 15) Shear stress range for the connector $\Delta\tau$ = 87.103 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 88.16 MPa verification $\gamma_{Ef.} \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf, s}) = 0.98 < 1$ OK. Provide shear connectors (3Nos) at 100mm spacing to satisfy fatigue check	(Load comb sLCB 15) Shear stress range for the connector $\Delta\tau$ = 63.469 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 64.24 MPa verification $\gamma_{Ef\,.} \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf, s}) = 0.714 < 1$ OK. Provide shear connectors (2Nos) at 100mm spacing to satisfy fatigue check

Stress limitation (SLS)	(Characteristic Load comb sLCB21) Structural steel $\sigma_{Ed, ser}$ = 25.5 MPa < $f_y / \gamma_{M, ser}$ =355MPa (Bottom right fibre in the flange) $\tau_{Ed, ser}$ = 18.442 MPa < f_y / $(3)^{0.5}$.$\gamma_{M, ser}$ = 204.96MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 40.878 < $f_y / \gamma_{M, ser}$ =355MPa Concrete slab sLCB39 $\gamma_c < k_2 f_{ck}$ = 2.922 MPa < 18 MPa	(Characteristic Load comb sLCB21) Structural steel $\sigma_{Ed, ser}$ = -33.42 MPa < $f_y / \gamma_{M, ser}$ =355MPa (Bot left fibre in the flange) $\tau_{Ed, ser}$ = 0.458 MPa < f_y / $(3)^{0.5}$.$\gamma_{M, ser}$ = 204.959MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 33.42 < $f_y / \gamma_{M, ser}$ =355MPa Concrete slab Quasi Permanent load combination sLCB21 $\gamma_c < k_2 f_{ck}$ = 3.445 MPa < 18 MPa
Longitudinal shear Resistance (SLS)	Single connector resistance K_s=0.75, = 89.82*0.75 = 67.366 KN $V_{L,ED}$ = 27.153 KN/m < $V_{L,RD}$ = 2020.993 KN/m (SLCB21)	Single connector resistance K_s=0.75, = 89.82*0.75 = 67.366 KN $V_{L,ED}$ = 1.915KN/m < $V_{L,RD}$ = 1347.329 KN/m (SLCB22)
Load Combinations	sLCB 9,5,16,15,21	sLCB 9,5,15,21,22

Steel code check of axial force resistance, moment of resistance, combined axial and moment resistance and shear resistance of the steel girder and bracing for erection phase (under wet deck concrete) found satisfactory.

Table 5.1 Design Summary 11.5m deck

5.3.2 Span 17.5m - Universal beam deck

The model is discussed under section 3.4.2.2. Universal beam 769.6mm x 268mm x 197kg/m section considered with two splices in the main girders.

Temporary bracing during construction under weight of fresh concrete were provided at mid span and quarter span positions to prvent torsional buckling of main girders. Splices increse cost. Therefore, single splice capable of transmitting incresed bending moment for each girder was considered for cost calculation (Annex I, table I4).

Results show second beam from the edge is most critical for support shear and end beam is most critical for midspan bending moments for traffic loading considered. Design checks at critical sections are tabulated in table 5.2 below.

Figures B1.4 to B1.6 of Appendix B1 present critical load combination for shear, shear force diagram and traffic load combination corresponding to critical load shear. Figures B2.4 to B2.6 of Appendix B2 present critical load combination for maximum bending moment, bending moment diagram and traffic load combination corresponding to maximum bending moment.

Figure 5.2 and 5.3 indicate configuration details of the deck used for cost calculations in Table 6.4.

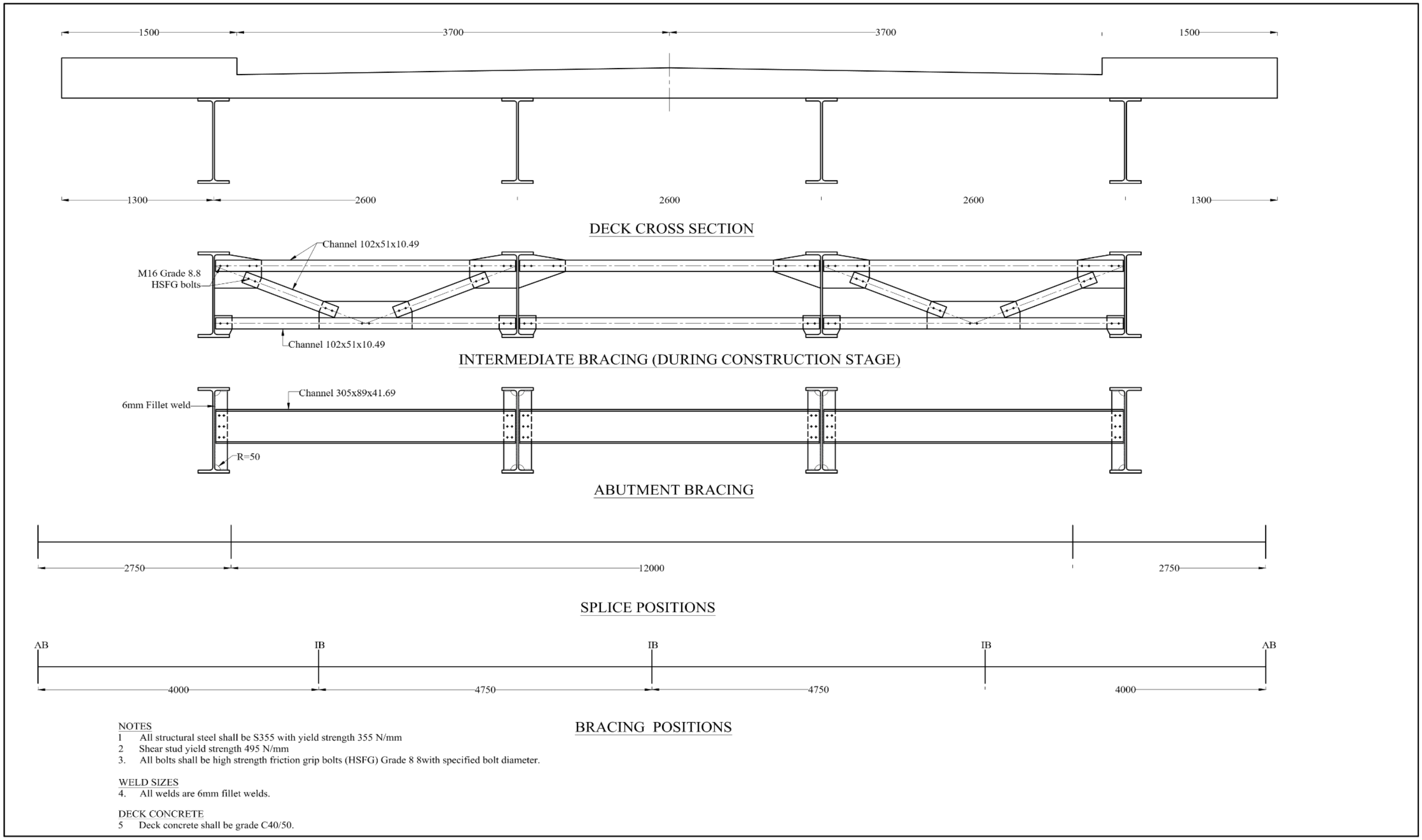


Figure 5.2 STEEL CONCRETE COMPOSITE BRIDGE DECK SPAN 17.5m

(CROSS SECTION AND BRACING DETAILS)

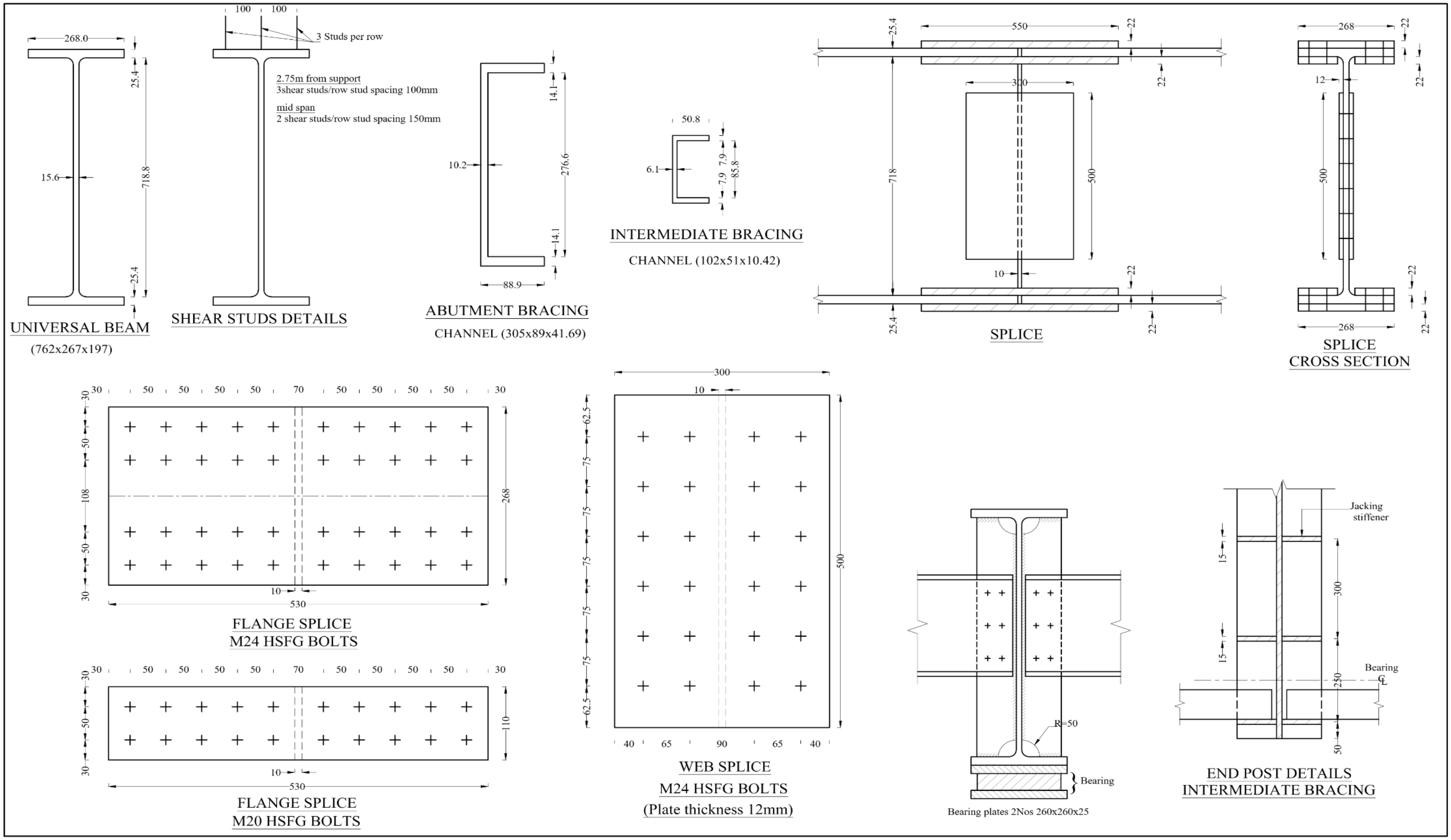


Figure 5.3 STEEL CONCRETE COMPOSITE BRIDGE DECK SPAN 17.5M

(SHEAR STUD ,BEARING AND SPLICE DETAILS)

Design Checks of Section 2.4.3 17.5m span deck	Support Section 86i, 103j (2nd beam from edge most critical)	Mid span section 76j, 77i (End beam most critical)
Positive Moment (ULS)	M_{ed} = -32.72 KNm < M_{Rd} = 4935.937 KNm (Load comb sLCB 3)	M_{ed} = 3991.25 KNm < M_{Rd} = 4935.937 KNm (Load comb sLCB 11)
Negative Moment (ULS)	M_{ed} = -73.468 < M_{Rd} = 2513.735 KNm (Load comb sLCB1)	
Shear resistance (ULS)	V_{edi} = 1042.5 KN (Load comb sLCB 5) $V_{bw, RD}$ = 2507.2 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bf, RD}$) = 0.427 OK	V_{edi} = 259.2 KN (Load comb sLCB 11) $V_{bw, RD}$ = 2507.2 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bf, RD}$) = 0.103 OK
Lateral torsional Buckling (ULS)	(Load comb sLCB 2) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.0772 < 1 OK	(Load comb sLCB 11) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.8177 <1 OK
Longitudinal shear Resistance (ULS)	(Load comb sLCB 5) Shear connector spacing 150mm 3Nos Single connector resistance = 89.822 KN $V_{L,ED}$ = 1090.49 KN/m < $V_{L,RD}$ = 2694.657 KN/m	Load comb sLCB 11) Shear connector spacing 150 mm 2Nos Single connector resistance = 89.822 KN $V_{L,ED}$ = 1154.315 KN/m < $V_{L,RD}$ = 1197.625 KN/m
Resistance to fatigue	(Load comb sLCB 17) Shear stress range for the connector $\Delta\tau$ = 94.984 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles	(Load comb sLCB 24) Shear stress range for the connector $\Delta\tau$ = 63.82 MPa Equivalent constant amplitude range of shear

	$\Delta\tau_{E2} = \lambda_v\ \Delta\tau$ = 96.137 MPa verification $\gamma_{Ef}\ .\ \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf,s})$ = 1.068 > 1 Marginally fails. Provide shear connectors (3Nos) at 100mm spacing to satisfy fatigue check	stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v\ \Delta\tau$ = 64.595 MPa verification $\gamma_{Ef}\ .\ \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf,s})$ = 0.718 < 1
Stress limitation (SLS)	(Load comb sLCB 37) Structural steel = $\sigma_{Ed,ser}$ = -207MPa < $f_y /\gamma_{M,ser}$ =355MPa (Top left fibre in the flange) $\tau_{Ed,ser}$ = 16.814 MPa < $f_y /(3)^{0.5} .\gamma_{M,ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed,ser}^2 + 3\ \tau_{Ed,ser}^2)^{0.5}$ = 209 MPa < $f_y /\gamma_{M,ser}$ =355MPa Concrete slab sLCB49 $\gamma_c < k_2 f_{ck}$ = 0.108 MPa < 18 MPa	(Load comb sLCB 26) Structural steel $\sigma_{Ed,ser}$ = 136.662 MPa < $f_y /\gamma_{M,ser}$ =355MPa (Top right fibre in the flange) $\tau_{Ed,ser}$ = 0.257 MPa < $f_y /(3)^{0.5} .\gamma_{M,ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed,ser}^2 + 3\ \tau_{Ed,ser}^2)^{0.5}$ = 136.663 < $f_y /\gamma_{M,ser}$ =355MPa Concrete slab Quasi Permanent load combination sLCB 49 $\gamma_c < k_2 f_{ck}$ = 0.665 MPa < 18 MPa
Longitudinal shear Resistance (SLS)	Single connector resistance K_s=0.75, $P_{RD}Ks$ = 67.366 KN $V_{L,ED}$ = 46.239 KN/m < $V_{L,RD}$ = 2020.993 KN/m (SLCB 25)	Single connector resistance K_s=0.75, $P_{RD}Ks$ = 67.366 KN $V_{L,ED}$ = 3.263 KN/m < $V_{L,RD}$ = 898.219 KN/m (SLCB 26)
Combinations	SLCB 1, 2, 3, 5, 17, 25, 37, 49	SLCB 11, 24, 26,

Steel code check of axial force resistance, moment of resistance, combined axial and moment resistance and shear resistance of the steel girder and bracing for erection phase (under wet deck concrete) found satisfactory.

Table 5.2 Design Summary 17.5m deck

5.3.3 Span 31.5m – Steel multi plate girder deck

The model is discussed under section 3.4.2.3. Basic configuration during erection and completed structure is shown in Figure 5.4. Plate girder details are summarized in table 3.2.

Main girders with two splices considered. Temporary bracing during construction under weight of fresh concrete were provided at mid span and quarter span positions to prvent torsional buckling of main girders. Results show edge beam is most critical for support shear and midspan bending moments for traffic loading considered. Design checks at critical sections are tabulated in table 5.3 below.

Figures B1.7 to B1.9 of Appendix B1 present critical load combination for shear, shear force diagram and traffic load combination corresponding to critical load shear. Figures B2.7 and B2.8 of Appendix B2 present bending moment diagram and traffic load combination corresponding to maximum bending moment.

Figures 5.5 and 5.6 indicate configuration details of the deck used for cost calculations in Table 6.4.

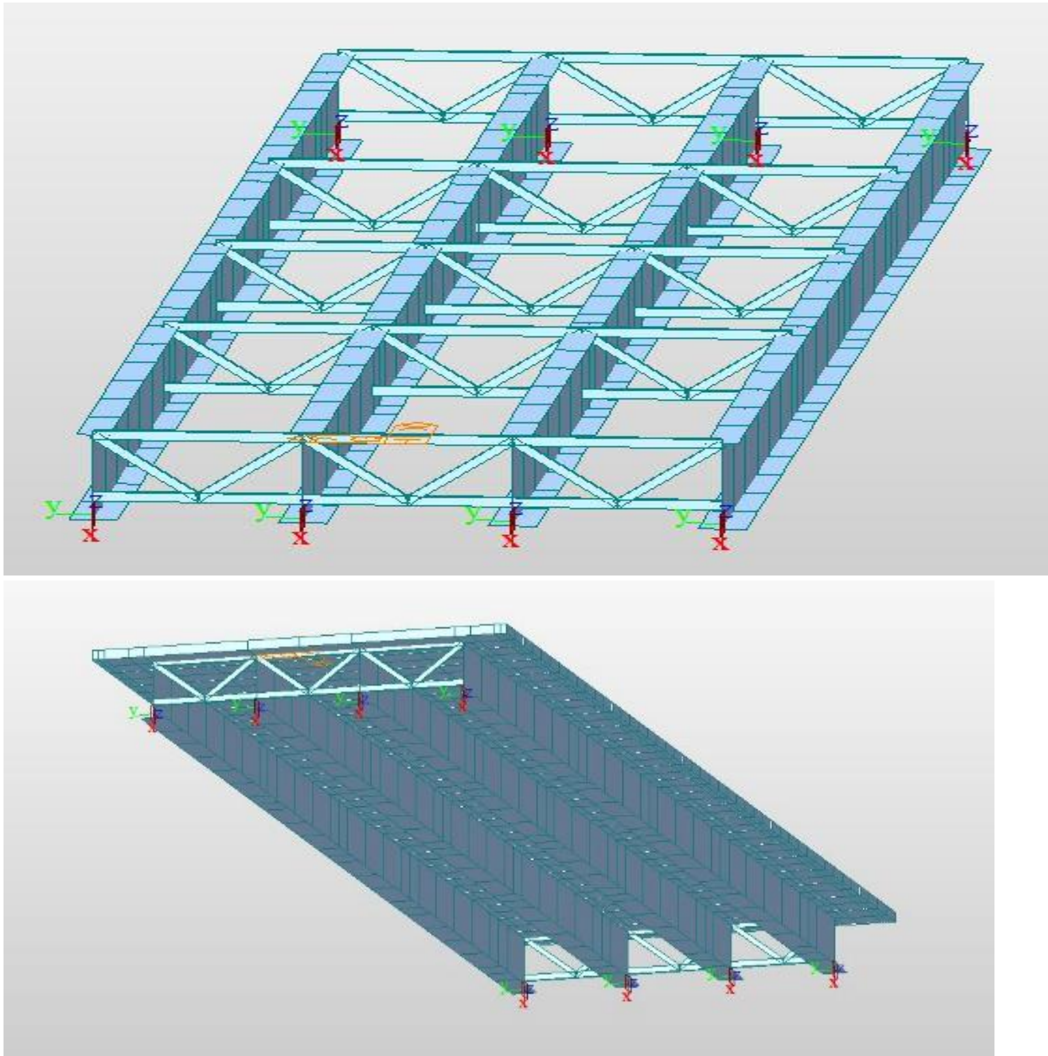


Figure 5.4 Deck span 31.5m with plate girders.

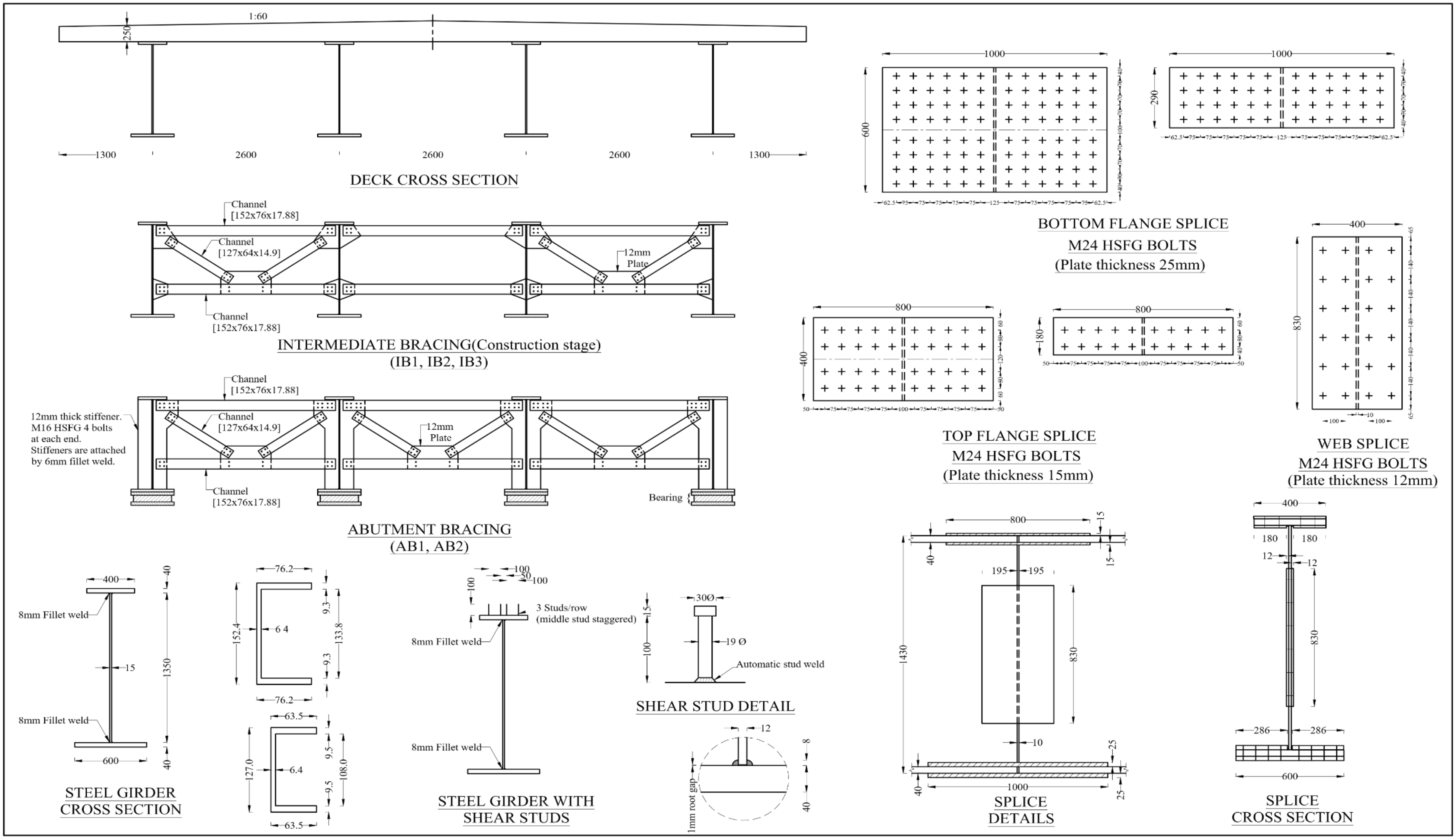


Figure 5. 5 STEEL CONCRETE COMPOSITE DECK SPAN 31.5m.
(DECK CROSS SECTION, PLATE GIRDER, BRACING, SHEAR CONNECTION, SPLICE DETAILS)

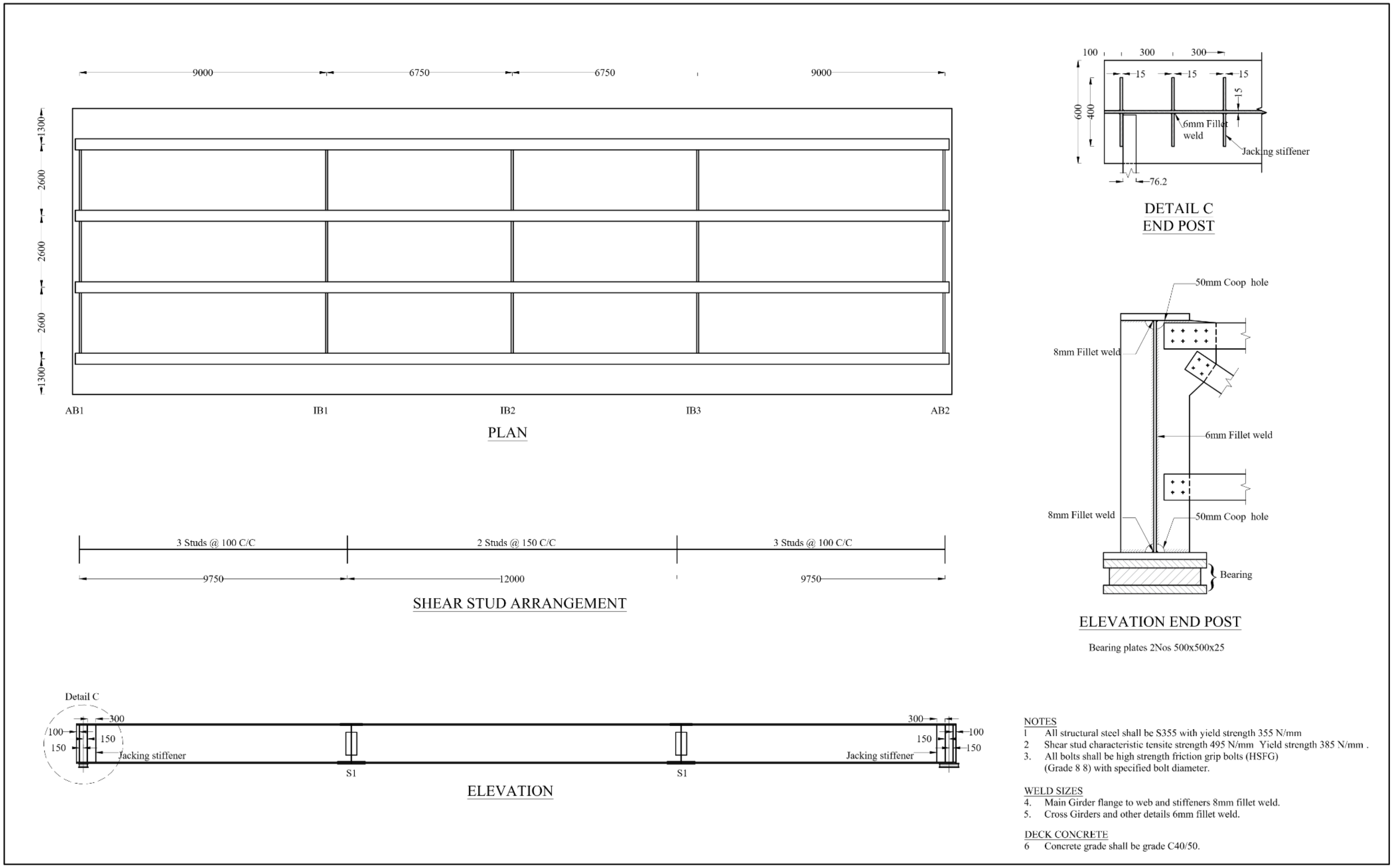


Figure 5. 6 STEEL CONCRETE COMPOSITE DECK SPAN 31.5m.

(SPLICES, SHEAR STUD ARRANGEMENT AND BEARING DETAILS)

Table 5.3 Design Summary of 31.5m plate girder

Design Checks of Section 2.4.3 31.5 m span deck	**Support Section 114i, 138j Edge beam critical for support shear**	**Mid span section 126i, Edge beam critical for centre BM**
Positive Moment (ULS)	M_{ed} = -71.29 KNm < M_{Rd} = 19030.44 KNm (Load comb sLCB 1)	M_{ed} = 10309.2 KNm < M_{Rd} = 19030.44 KNm (Load comb sLCB 5)
Negative Moment (ULS)	M_{ed} = -432.5 < M_{Rd} = 11916.536 KNm (Load comb sLCB5)	
Shear resistance (ULS)	V_{edi} = -1439.379 KN (Load comb sLCB 5) $V_{bw, RD}$ = 2610.3 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bf, RD}$) = 0.551 < 1.0 OK MV interaction OK	V_{edi} = -315.5 KN (Load comb sLCB11) $V_{bw, RD}$ = 2610.3 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bf, RD}$) = 0.121 < 1 OK η'_3 = V_{edi} / $V_{bw, RD}$ = 0.121< 0.5 MV interaction OK
Lateral torsional Buckling (ULS)	(Load comb sLCB 5) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.0476 < 1 OK	(Load comb sLCB 5) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.545 <1 OK
Longitudinal shear Resistance (ULS)	(Load comb sLCB 5) Shear connector spacing 100 mm, 2Nos	(Load comb sLCB 11) Shear connector spacing 200 mm, 2Nos

	Single connector resistance = 89.826 KN $V_{L,ED}$ = 630.559 KN/m < $V_{L,RD}$ = 1796.438 KN/m	Single connector resistance = 89.822 KN $V_{L,ED}$ = 200.782 KN/m < $V_{L,RD}$ = 898.219 KN/m
Resistance to fatigue	(Load comb sLCB 20) Shear stress range for the connector $\Delta\tau$ = 82.381 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 81.502 MPa Verification $\gamma_{Ef} . \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf, s})$ = 0.906 < 1 OK Provide shear connectors (2Nos) at 100mm spacing to satisfy fatigue check.	(Load comb sLCB 26) Shear stress range for the connector $\Delta\tau$ = 52.862 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 52.299 MPa Verification $\gamma_{Ef} . \Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf, s})$ = 0.581 < 1 OK
Stress limitation (SLS)	(Characteristic Load comb SLCB30) Structural steel $\sigma_{Ed, ser}$ = 19.986 MPa < $f_y /\gamma_{M, ser}$ =355MPa (Top left fibre in the flange) $\tau_{Ed, ser}$ = 20.235 MPa < $f_y /(3)^{0.5} .\gamma_{M, ser}$ = 204.959 MPa	(Characteristic Load comb sLCB30) Structural steel $\sigma_{Ed, ser}$ = 123.4 MPa < $f_y /\gamma_{M, ser}$ =355MPa (Top right fibre in the flange) $\tau_{Ed, ser}$ = 0 MPa < $f_y /(3)^{0.5} .\gamma_{M, ser}$ = 204.959 MPa

	(Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 40.346 MPa < $f_y / \gamma_{M, ser}$ =355MPa Concrete slab Characteristic load combination sLCB 20 $\gamma_c < k_1 f_{ck}$ = 0 MPa < 24 MPa	(Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 123.4 MPa < $f_y / \gamma_{M, ser}$ =355MPa Concrete slab Characteristic load combination sLCB30 $\gamma_c < k_1 f_{ck}$ = 0.128 MPa < 24 MPa
Longitudinal shear Resistance (SLS)	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN $V_{L,ED}$ = 47.035 KN/m < $V_{L,RD}$ = 1347.329 KN/m (SLCB 30)	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN $V_{L,ED}$ = 0.337 KN/m < $V_{L,RD}$ = 673.664 KN/m (SLCB 30)
Combinations	sLCB 1, 5, 20, 30, Steel code check for erection condition (wet concrete) is OK	sLCB 5, 11, 26, 30 Steel code check for erection condition (wet concrete) is OK

Steel code check of axial force resistance, moment of resistance, combined axial and moment resistance and shear resistance of the steel girder and bracing for erection phase (under wet deck concrete) found satisfactory.

5.3.4 Span 40m plate girder ladder deck

The model is discussed under section 3.4.2.4. Basic configuration during erection and completed structure is shown in Figure 5.7. Plate girder details are summarized in table 3.2. Four splices are provided in the main girder. Model provides composite main girders and cross girders.

Cross girders provide adequate torsional resistance to main girders. It is assumed that assembled girdrs are lifted and positioned from both ends. Results show that beam under lane1 is most critical for support shear and midspan bending moments for traffic loading considered. Design checks of critical sections are tabulated in table 5.4 below.

Figures B1.10 to B1.12 of Appendix B1 present critical load combination for shear, shear force diagram and traffic load combination corresponding to critical load shear. Figures B2.9 to B2.10 of Appendix B2 present bending moment diagram and traffic load combination corresponding to maximum bending moment.

Figures 5.8, 5.9, and Figures in Annex J, J1.1 and J1.2 indicate configuration details of the deck used for cost calculations in Table 6.4.

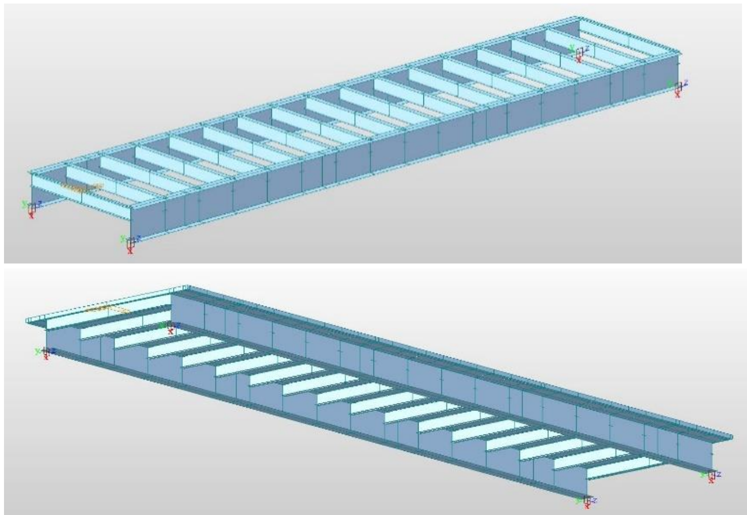


Figure 5.7 Ladder deck 40m bare steel section during construction and completed composite structure.

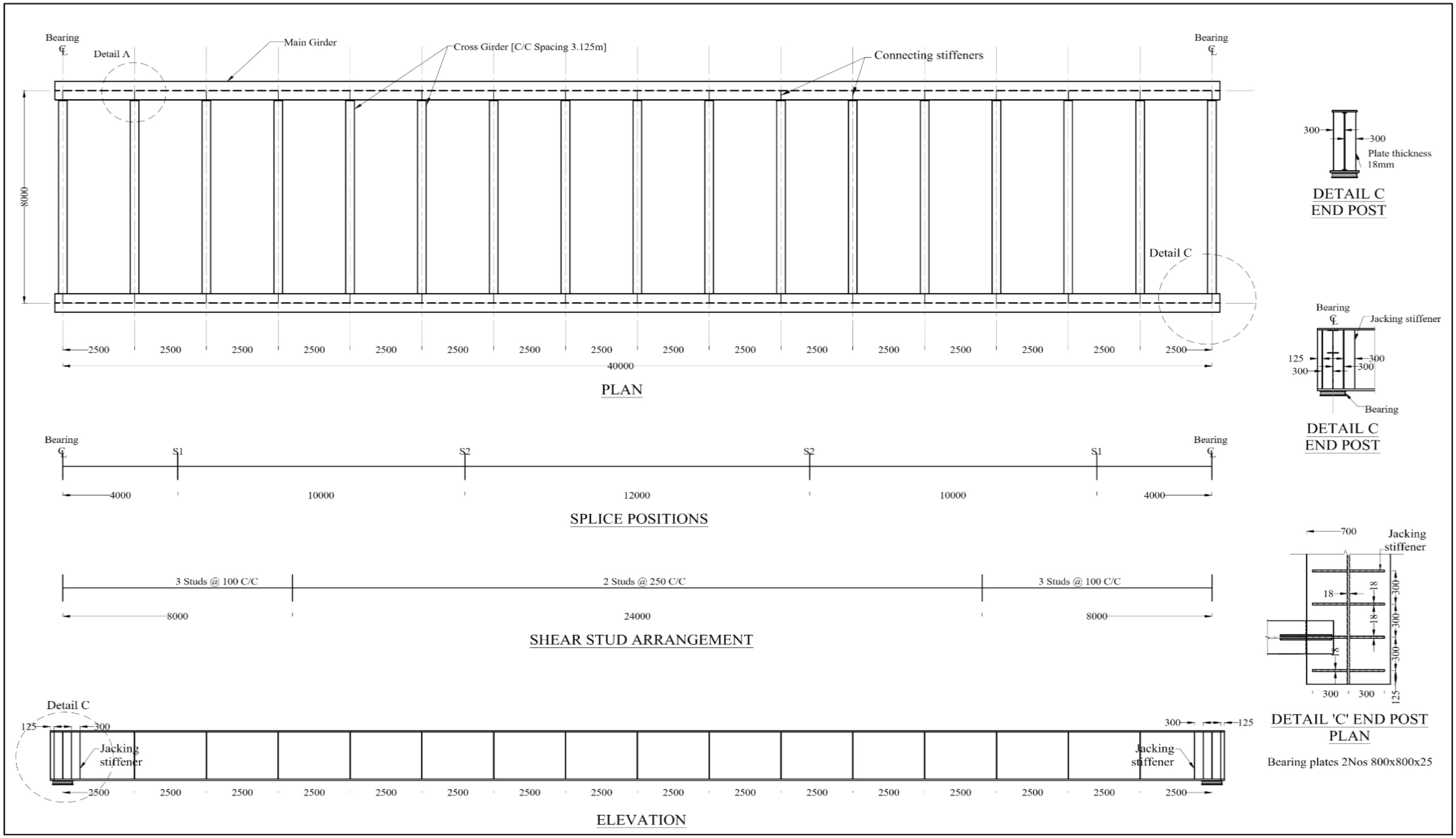


Figure 5. 8 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 40m

(STEEL GIRDER PLAN AND ELEVATION)

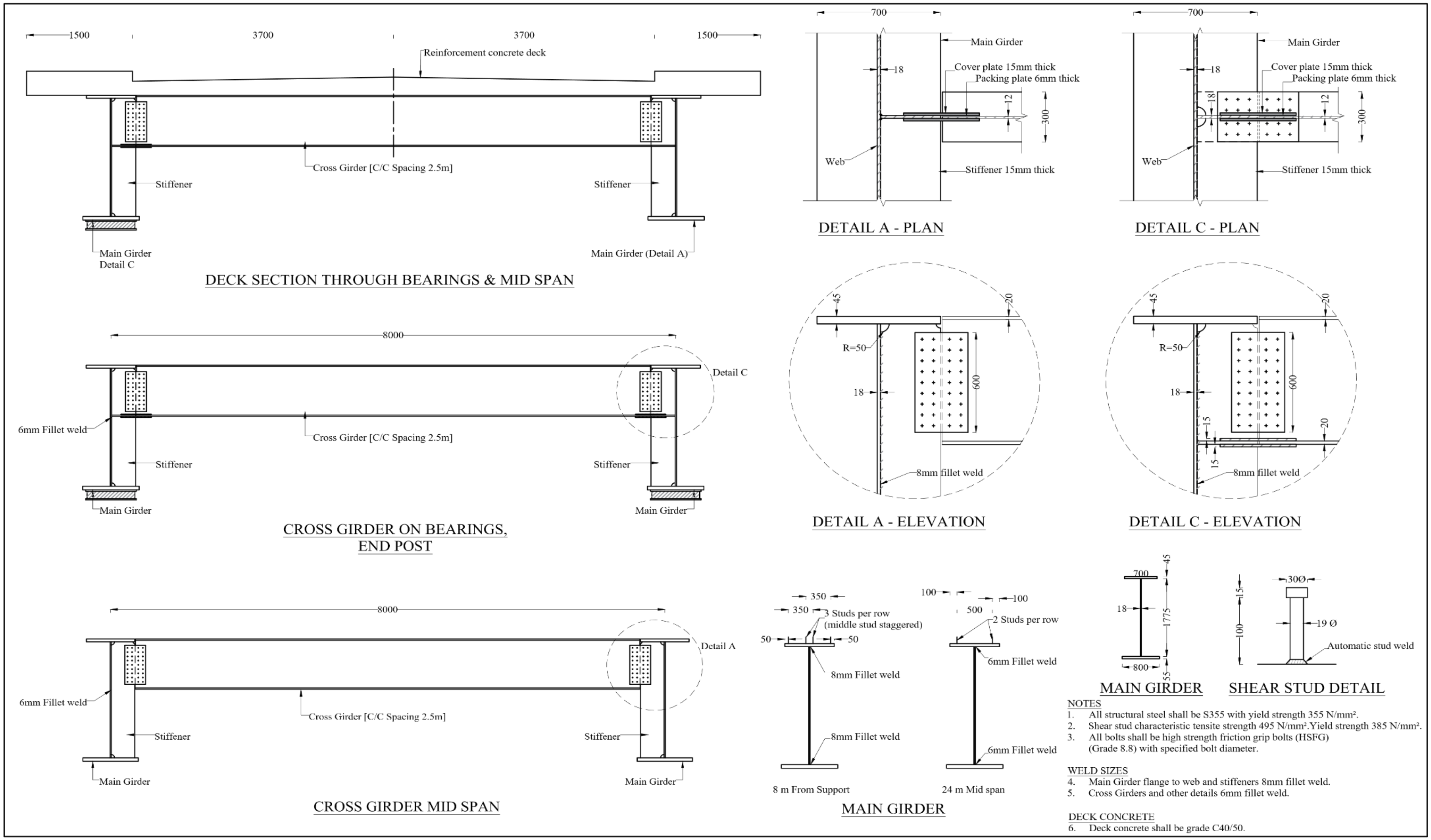


Figure 5. 9 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 40m

(CROSS SECTION ,CROSS FRAME,SHEAR STUD DETAILS)

Design Checks of Section 2.4.3 40m span Ladder deck	Support Section 57j	Mid span section 48i
Positive Moment (ULS)	M_{ed} = 229.596 KNm < M_{Rd} = 41129.744 KNm (Load comb sLCB 5)	M_{ed} = 31754.5 KNm < M_{Rd} = 41912.916 KNm (Load comb sLCB 5)
Negative Moment (ULS)	M_{ed} = 0 < M_{Rd} = -395.866 KNm (Load comb sLCB11) Due to properties of concrete. Hogging reinforcement need to be provided.	
Shear resistance (ULS)	V_{edi} = 3093.991 KN (Load comb sLCB 5) $V_{bw, RD}$ = 4369.8 KN $\eta'_3 = 0.735$, $\eta_1 = 0.693$ Interaction M, V $\eta_1+(1-M_{f,Rd}/M_{pl,Rd}) \cdot (2 \cdot \eta'_3-1)^2$ = 0.761 <1 OK	V_{edi} = 785.003 KN (Load comb sLCB5) $V_{bw, RD}$ = 4369.818 KN $\eta'_3 = V_{edi} / V_{bw, RD} = 0.18 < 0.5$ Interaction M, V OK
Lateral torsional Buckling (ULS)	OK. Cross girders provided at close intervals to compression flange.	OK. Cross girders provided at close intervals to compression flange.
Longitudinal shear		(Load comb sLCB 5)

Resistance (ULS)	(Load comb sLCB 5) Shear connector spacing 100 mm Single connector resistance = 89.822 KN (3 connectors /row) $V_{L,ED}$ = 122.994 KN/m > $V_{L,RD}$ = 2020.993 KN/m Provide shear connectors (3Nos/row) at 100mm c/c to satisfy fatigue check.	Shear connector spacing 250 mm Single connector resistance = 89.822 KN (2 connectors /row) $V_{L,ED}$ = 420.522 KN/m < $V_{L,RD}$ = 718.575 KN/m Provide shear connectors (2Nos/row) at 200mm c/c to satisfy fatigue check.
Stress limitation (SLS)	(Characteristic Load comb 25) Structural steel $\sigma_{Ed, ser}$ = 28.732 MPa < $f_y / \gamma_{M, ser}$ =355MPa (Top left fibre in the flange) $\tau_{Ed, ser}$ = 32.426 MPa < $f_y /(3)^{0.5} .\gamma_{M, ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2\ )^{0.5}$ = 63.087 MPa < $f_y / \gamma_{M, ser}$ =355MPa Concrete slab Quasi Permanent load sLCB 45 $\gamma_c < k_2 f_{ck}$ = 2.481 MPa < 18 MPa	(Characteristic Load comb 26) Structural steel $\sigma_{Ed, ser}$ = 184.727 MPa < $f_y / \gamma_{M, ser}$ =355MPa (Top right fibre in the flange) $\tau_{Ed, ser}$ = 0.494 MPa < $f_y /(3)^{0.5} .\gamma_{M, ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2\ )^{0.5}$ = 184.729 < $f_y / \gamma_{M, ser}$ = 355MPa Concrete slab Characteristic load combination sLCB 25 $\gamma_c < k_1 f_{ck}$ = 0.0 MPa < 24 MPa

Longitudinal shear Resistance (SLS)	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN Spacing 250mm $V_{L,ED}$ = 122.994 KN/m < $V_{L,RD}$ = 2020.993 KN/m OK (SLCB 25)	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN Spacing 250mm $V_{L,ED}$ = 7.081 KN/m < $V_{L,RD}$ = 538.931 KN/m OK (SLCB 25)
Combinations	sLCB 5, 11, 25	SLCB 5, 25, 26

Steel code check of axial force resistance, moment of resistance, combined axial and moment resistance and shear resistance of the main steel girders and cross girders for erection phase (under wet deck concrete) found satisfactory.

Table 5.4 Design summary 40m Ladder Deck

5.3.5 Span 50m plate girder ladder deck

The model is discussed under section 3.4.2.5. Plate girder details are summarized in table 3.2. Four splices are provided in the main girder. Cross girders provide adequate torsional resistance to main girders. It is assumed that assembled girdrs are lifted and positioned from both ends.

Single beam restrained at support section was checked and found to satisfactory for lateral torsional buckling resistance. The model consist of dummy longitudinal composite girders and cross girders which are not composite and running under dummy beams. Therefore model captures weight of fresh concrete on cross girder. The steel code check on cross girder is conservative. The cross girder section found adequate.

Results show beam under lane1 is most critical for support shear and midspan bending moments for traffic loading considered. Design of critical sections are tabulated in table 5.5 below. Ultimate limit state of main girders based on reduced effective width of concrete flange was found adequate.

Figures B1.13 to B1.15 of Appendix B1 present critical load combination for shear, shear force diagram and traffic load combination corresponding to critical load shear. Figures B2.11 and B2.12 of Appendix B2 present bending moment diagram and traffic load combination corresponding to maximum bending moment.

Figures 5.10 , 5.11 and Figures in Annex J, J2.1, J2.2 indicate configuration details of the deck used for cost calculations in Table 6.4.

Span 50m Ladder Deck

(Deck model with dummy beams considered in section 3.4.2.5).

Design Checks of Section 2.4.3 50m span deck	**Support Section 91j**	**Mid span section 82i**
Positive Moment (ULS)	M_{ed} = 165.07 kNm < M_{Rd} = 79006.7 KNm (Load comb sLCB 2)	M_{ed} = 46098.34 KNm < M_{Rd} = 79006.702 KNm (Load comb sLCB 5)
Negative Moment (ULS)	M_{ed} = -251.16Nm M_{Rd} = 0 KNm (Load comb sLCB 5) Hogging reinforcement required.	
Shear resistance (ULS)	V_{edi} = 3840.319 (Load comb sLCB 5) $V_{bw, RD}$ = 8018.353 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bf, RD}$) = 0.417 OK Interaction MV η'_3 = 0.48 < 0.5 OK	V_{edi} = 822.91 KN (Load comb sLCB5) $V_{bw, RD}$ = 8018.353 KN $V_{bf, RD}$ = 0 KN V_{edi} /($V_{bw, RD}$ + $V_{bw, RD}$) = 0.103 OK Interaction MV η'_3 = 0.103 < 0.5 OK
Lateral torsional Buckling (ULS)	(Load comb sLCB 5) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.01235 < 1 OK	(Load comb sLCB 5) (Ned / $N_{b, Rd}$) + (Med / $M_{b, Rd}$) = 0.606 <1 OK

Longitudinal shear Resistance (ULS)	(Load comb sLCB 5) Shear connector spacing 150 mm Single connector resistance = 89.822 KN (3 connectors/row) $V_{L,ED}$ = 599.737 KN/m < $V_{L,RD}$ = 1796.438 KN/m	Load comb sLCB 5) Shear connector spacing 250 mm Single connector resistance = 89.822 KN (2 connectors/row) $V_{L,ED}$ = 218.5 KN/m < $V_{L,RD}$ = 718.575 KN/m
Resistance to fatigue	(Load comb sLCB 19) Shear stress range for the connector $\Delta\tau$ = 78.418 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 79.37 MPa verification $\gamma_{Ef} . \Delta\tau_{E2} / (\Delta\tau_c / \gamma_{Mf, s})$ = 0.882 < 1 OK	(Load comb sLCB 20) Shear stress range for the connector $\Delta\tau$ = 70.535 MPa Equivalent constant amplitude range of shear stress related to 2 million cycles $\Delta\tau_{E2} = \lambda_v \Delta\tau$ = 71.391 MPa verification $\gamma_{Ef} . \Delta\tau_{E2} / (\Delta\tau_c / \gamma_{Mf, s})$ = 0.793 < 1 OK
Stress limitation (SLS)	(Characteristic Load comb 29) Structural steel $\sigma_{Ed, ser}$ = 18.382 MPa < $f_y / \gamma_{M, ser}$ =355MPa	(Characteristic Load comb 30) Structural steel $\sigma_{Ed, ser}$ = 143.583 MPa < $f_y / \gamma_{M, ser}$ =355MPa (Top right fibre in the flange)

	(Top right fibre in the flange) $\tau_{Ed, ser}$ = 27.375 MPa < $f_y/(3)^{0.5} . \gamma_{M, ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 50.855 < $f_y/\gamma_{M, ser}$ =355MPa Concrete slab sLCB 29 Characteristic combination $\gamma_c < k_1 f_{ck}$ = 0 MPa < 24 MPa	$\tau_{Ed, ser}$ = 0.939 MPa < $f_y/(3)^{0.5} . \gamma_{M, ser}$ = 204.959 MPa (Neutral axis in the web) $(\sigma_{Ed, ser}^2 + 3\ \tau_{Ed, ser}^2)^{0.5}$ = 143.593 < $f_y/\gamma_{M, ser}$ =355MPa Concrete slab SLCB 29 Characteristic combination $\gamma_c < k_1 f_{ck}$ = 0 MPa < 24 MPa
Longitudinal Shear for SLS	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN Spacing 250mm $V_{L,ED}$ = 81.414 KN/m < $V_{L,RD}$ = 1347.329 KN/m OK (SLCB 29)	Single connector resistance K_s=0.75, $P_{Rd,ser}$ = 67.366 KN Spacing 250mm $V_{L,ED}$ = 5.87 KN/m < $V_{L,RD}$ = 538.931 KN/m OK (SLCB 30)
Combinations	sLCB 2,5,19,29	sLCB 5,20,30

Steel code check of axial force resistance, moment of resistance, combined axial and moment resistance and shear resistance of the main steel girders and cross girders for erection phase (under wet deck concrete) found satisfactory.

Table 5.5 Design Summary 50m Ladder Deck

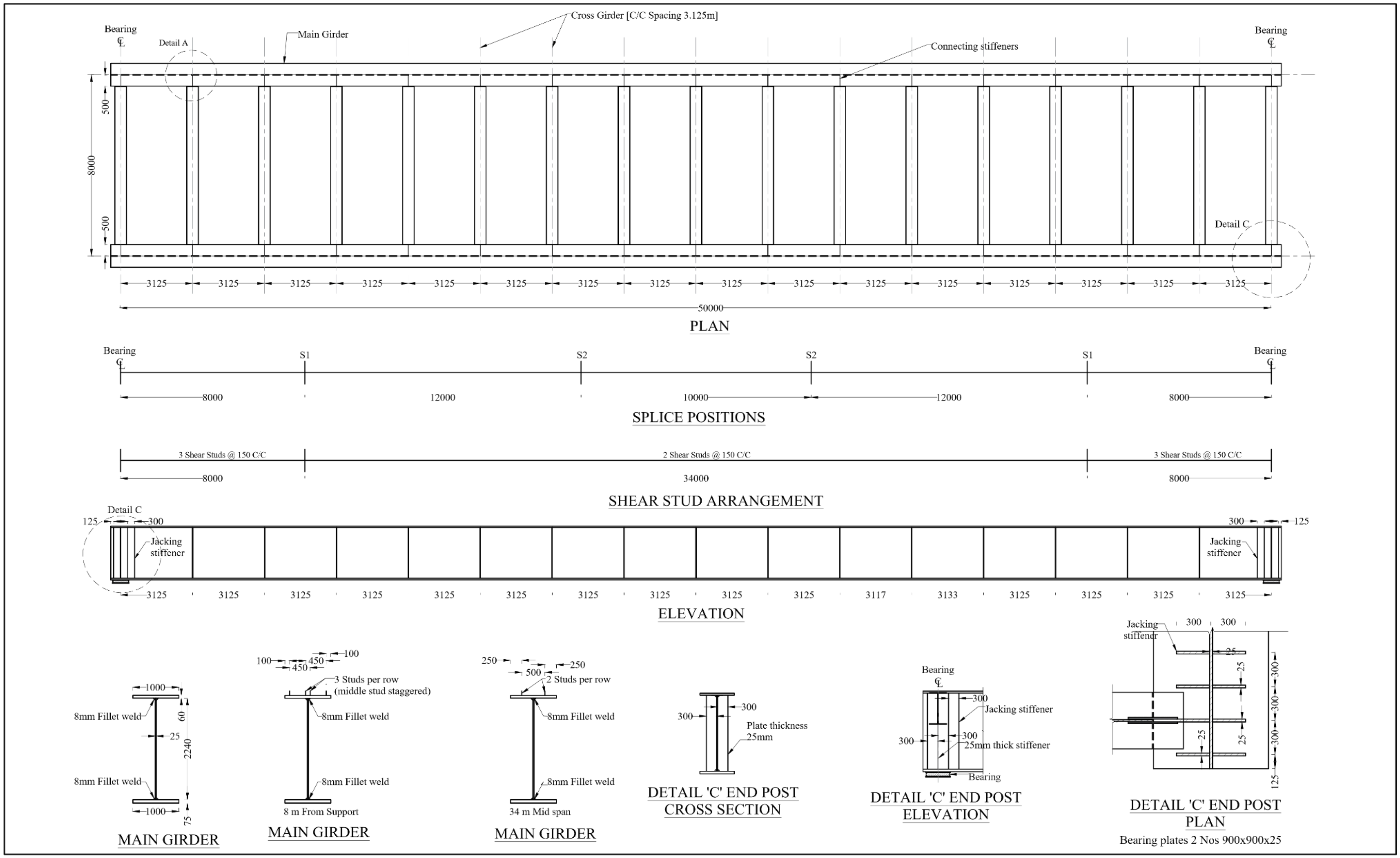


Figure 5.10 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 50m

(MAIN GIRDER PLAN, ELEVATION, END POST, SHEAR STUD DETAILS)

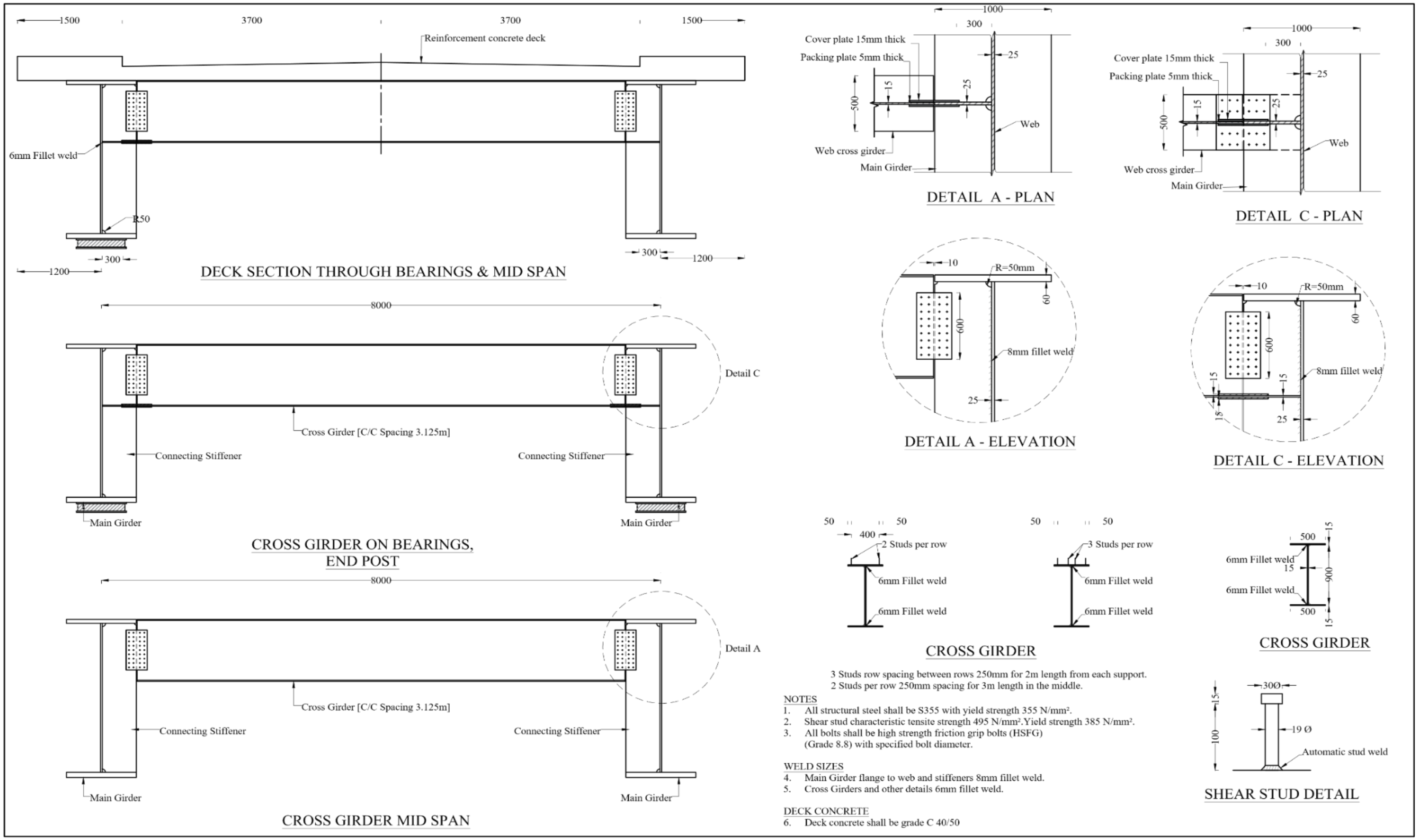


Figure 5. 11 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 50m

(DECK CROSS SECTION, CROSS FRAME DETAILS, SHEAR STUD DETAILS)

Chapter – 06

Costing of Bridge Decks

6.1 Introduction

In Road Development Authority, preparation of estimates for bridges are based on Highway Schedule of Rates (HSR) published annually for each province. These rates could easily be used to revise an estimate for the current year. HSR tabulates rates for items necessary for construction of concrete structures, but not for steel structures.

The current prices of highway bridge beams up to 25m length could be obtained from manufactures (SD&CC, SEC, ICC, & ELS) when estimations are prepared. However so far only SD&CC and foreign contractors has produced posttensioned beams.

If the cost breakdown is known in terms of material, labour, and plant, price of a precast beam, concrete deck or steel composite deck could easily be revised based on HSR. This method is practiced in costing of structures in this thesis.

In case of steel composite structures, consideration of price variation of steel (obtained from internet) together with price fluctuation of hiring rate of a representative plant, labour types, and other minor items tabulated in HSR could easily be used to calculate current cost of structure.

Launching of 25m concrete beams are possible by a single 50 tonne crane or with the assistance of another small crane depending on the situation. Concrete beams are heavy; therefore, erection of longer spans require launching girder and are costly than steel girders.

Erection of steel plate girders up to 30m span could be handled by two mobile cranes, and grater spans require launching girders or temporary structures. Assembling the structure on ground is easier than assembling at a height. Therefore, pairing of girders before erection should be considered for stability, and faster erection although heavy cranes may be required.

Heavy cranes are required for a short period during erection to handle major components of a bridge. Mobilizing heavy cranes are costly and contribute to a major part of the erection cost. Concrete super structures require heavy cranes or erection girders for a longer duration when compared to steel structures.

HSR tabulates transport, stacking and erection costs of pre-tensioned beams up to 16m length therefore could directly be used in estimations. Revising plant costs and labour rates of an actual cost breakdown of an erection scheme as per HSR could be used to estimate current cost.

6.2 Methodology

Comparison was made between newly designed composite decks with existing concrete decks. HSR 2020 rates were used.

For existing structures given in type drawings, cost of beams, deck with infill concrete, deck without asphalt surfacing, total deck cost is highlighted separately. Bridge furniture i.e., bearings, expansion joints are separately shown when available.

6.3 Costing of concrete decks

6.3.1 Pre-tensioned beam concrete decks

Based on HSR 2020 rates of following existing concrete decks were estimated. A summary of costs for beam lengths 7.01m – 25m are tabulated in table 6.1 below. Figure 6.1 illustrates the variation of Pretension concrete beam deck cost per square meter with span length. Estimates for lengths 7.085m, 9.5m, 13.5m, 19m, 25m, are presented in appendix C.

Table 6.1 Cost breakdown of pre-tensioned beam decks 2020 HSR rates

Span	**Cost of beams Rs/sqm**	**Cost of deck slab without furniture Rs/sqm**	**Cost of deck excluding wearing surface Rs/sqm**	**Completed deck Rs/sqm**
7.085 m	18719.80	19748.78	29434.99	30420.70
9.5 m	21285.55	26711.69	38216.09	39203.34
11.5 m	19101.02	25283.89	36422.31	37409.32
13.5 m	21699.26	27976.09	38729.25	39716.87
14.5m	20791.15	28054.54	38888.94	39876.07
15.5m	23933.92	31686.66	42427.15	43414.54
16.5m	23639.85	31853.17	42675.62	43663.23
19.0m	24891.30	34487.31	44212.78	45200.02
25.0m	27035.95	32429.84	53472.06	54459.40

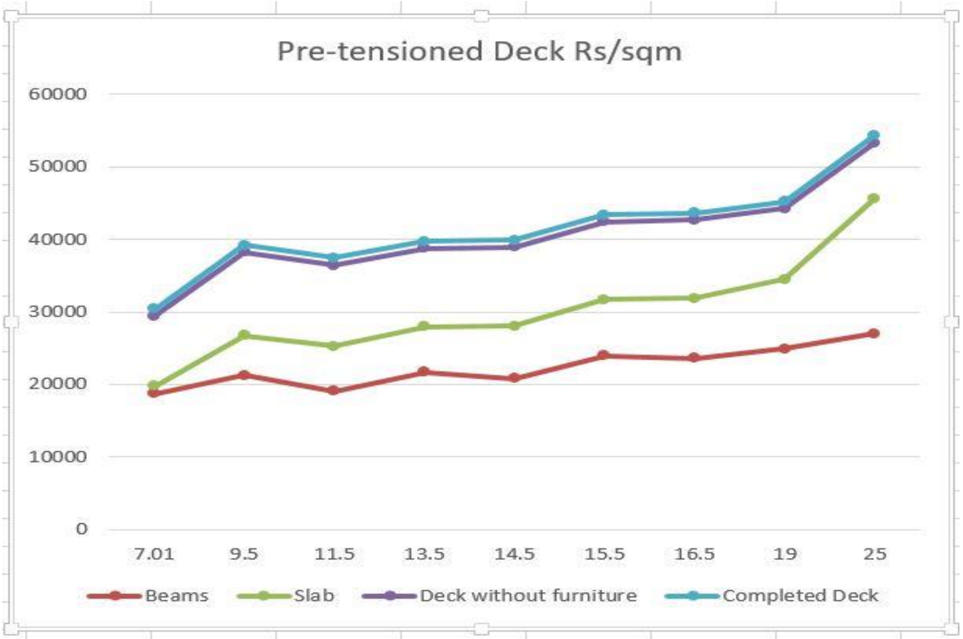


Figure 6.1 – Pretension concrete beam deck cost /sqm

6.3.2 Post-tensioned beam concrete decks

Three cost breakdowns submitted by SD&CC (Katugasthota bridge 32.5m beam, (2008)), (Kallady bridge 48m beam, (2010)), (post-tensioned beam 30m, (2018)) was recast to 2020 based on HSR rates and are presented in Appendix D.

Erection was based on quoted BOQ rates converted to 2020 rates assuming 75% of cost due to plant & equipment and 25% of cost due to semi-skilled labour. The cost of a deck slab (grade 40 concrete) of average thickness 250mm thick was added separately to calculate deck costs.

Kallady bridge (Appendix E) consists of nine box beams in the deck cross section. Twelve (12) box beams post-tensioned by SD&CC. Construction was completed by another foreign contractor, at a high price for stressing of balance 42 beams and launching of all beams (weight 163 tonnes each).

Cost analysis of above post-tensioned decks (as per 2020 rates) in appendix D are summarized in table 6.2 below. Figure 6.2 illustrates the variation of deck costs of pretensioned and post-tensioned beams with span length.

Table 6.2 Cost breakdown of post-tensioned beam decks 2020 HSR rates.

Span	**Cost of beams Rs/sqm**	**Cost of beams + erection Rs/sqm**	**Cost of erected beams + slab Rs/sqm**
30m SD&CC-Post tensioned beam	48486.58 Deck with 5 beams	71238.51 Katugasthota rate	87004.75 Total
32.5m SD&CC Katugasthota bridge	46,848.39 Deck with 5 beams	67,850.18	Total 83,616.42
48m SD&CC Kallady bridge	93733.11 Deck with 9 beams	126857.81 (SD&CC BOQ Rate) 297113.27 (Actual)	Total 142624.05 (SD&CC BOQ Rate) 312879.51 (Actual)

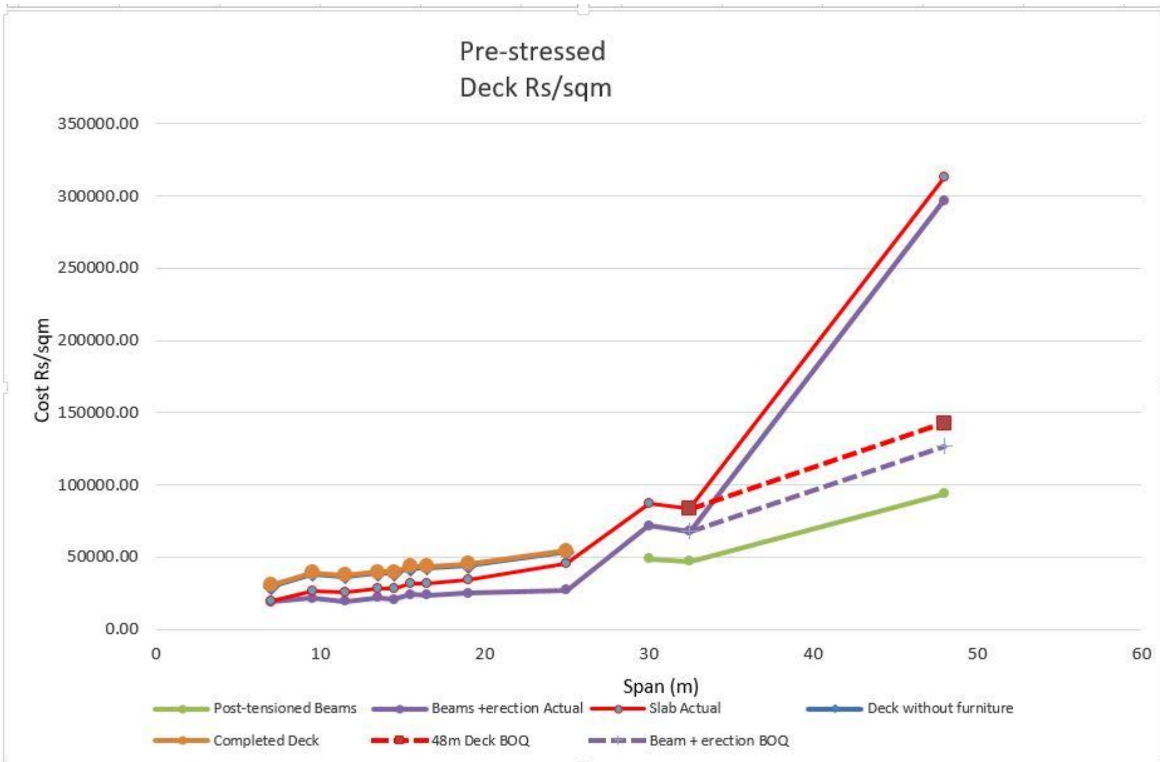


Figure 6.2 Cost (basic rates) of pre-stressed concrete bridge decks Rs/sqm
(The rates of 32.5m and 48m spans are based on actual costs recast to 2020, for 48m beam BOQ rates are also shown in dotted lines.)

6.4 Costing of steel concrete composite decks

The cost of a steel bridge depends on cost of steel and cost of fabrication. Steel being an imported material world prices govern its cost. Current prices of fabrication and protective treatment contain about 50% labour input as per fabrication details given by Colombo General Engineering Services.

Fabrication cost depends on steel design and detailing. Moment transfer connections are expensive than a connection that transfer shear. Welded splices could be cheaper than bolted splices. For site connections bolted splices are preferred. Types of stiffeners and attachments affect cost.

For imported fabricated steel, Chinese and Indian products are low cost when compared to European products (i.e., Marbey Bridges and French Bridges) due low cost of labour. Labour cost and overheads determine fabrication cost of domestic contractors. Therefore, small and medium size contractors also are capable to construct bridges formed from rolled sections with minimum fabrication cost.

Rate i.e., cost of steel work per ton for type of steel structure is often quoted for comparison of different designs. This is not accurate, because only a small percentage of the overall cost of the steel work can be related to tonnage.

When cost elements are considered separately (as in reference 32) estimation is more accurate. This method consistently tracks the value-added process in production of steel work.

6.4.1 Methods of Costing of steel bridges (designed to Eurocode in chapter 5).

1) Actual cost data from fabricators for designs.
2) Recast cost information of past projects based on HSR for new designs.
3) Preliminary Bridge estimating tool (Cowie and Fussell, 2011).

Costing carried out as per all three methods above.

Three domestic contractors were requested to quote steel fabrication, painting and erection costs of steel girders (cost item/tonne) designed in chapter 6. Only Colombo Dock Yard General Engineering services responded. Rates submitted were based on tonnage and square meters.

Steel fabrication cost breakdowns submitted by Chinese Contractor for Kinniyai Ferry Bridge (Kinniyai Bridge, 2005), and by State Engineering Corporation for Kelanisiri Bridge (Kalanisiri Bridge, 2001), costs/tonne for each item was recast for steel designs in

Chapter 5 with 2020 HSR rates and current world steel price at US$ 950/ton (US$ 1150/ton with profit).

6.4.1.1 Preliminary bridge estimating tool (Cowie and Fussell, 2011)

Above document is similar to HSR. It tabulate cost factors of fabrication as listed below, i.e., rates in NewZealand for the year 2011 (includes contractor's margin).
Prices for steel plates and sections

(a) Three pate girder fabrication rates with 8mm continuous fillet welds (CFW)
(b) Rates for complete penetration Butt weld (CPBW) for joining flange and web plates
(c) Girder stiffeners connection for different types of stiffeners (6mm CFW 16mm stiffener plate)
(d) Connection rates for girder splice connections, cross frame - I sections end connections and bracing angle connections
(e) Rates for shop drawings
(f) Transportation rates
(g) Coating rates.

New Zealand dollar to US dollar exchange rates in February 2011 to January 2021 remains without a significant change at 1NZ$ = 0.75 – 0.72 US $. Labour rates are higher in New Zealand when compared to Sri Lanka's rates therefore estimation as per this document provides an upper bound to Sri Lankan cost estimate. A set of estimates were prepared as per this document for the Eurocode designs of Chapter 5.

6.4.1.2.

SCI lecture notes Cost/tonne for steel girder bridges for UK practice by Evans, J. (1995) compared with Preliminary bridge estimating tool (Cowie and Fussell, 2011) are as given in table 6.3 below.

Table 6.3 Cost breakdown of steel girder bridge

Steel basis	**Preliminary bridge estimating tool, (2011) Steel construction, New Zealand**	**SCI lecture notes by J Evans (1995) Flient & Niel Partnership, UK**		
		Cheap *	Typical **	Expensive - **
Material	37%	53%	38.3%	25.5%
Fabrication	41%	20%	22.3%	26.6%
Surface coatings	18%	11.5%	16%	18.1%
Transportation	4%	4%	5.3%	6.4%
Erection	Without erection	11.5%	18.1%	23.4%

* The margin 4% distributed. ** The margin 6% distributed.

6.4.2 Estimates from actual cost data

Steel composite deck designs presented in Chapter 5 were estimated. Current cost data (Cost information, 2020) from Dock Yard, recast costs of Chinese contractor (Kinniyai bridge, 2005), and recast costs of State Engineering Corporation (Kelanisisi Bridge, 2001), and preliminary bridge estimating tool (Cowie and Fussell, 2011) were used in preparation of cost estimates for composite bridge decks, and are presented in Appendices F, G, H, and I. A summary from appendices is tabulated in table 6.4 below.

Table 6.4 Steel Deck Cost & cost breakdown Cost Rs/sqm

Span m	**50**	**40**	**31.5**	**17.5**	**11.5**
Dock Yard (Appendix F)	288,856.83	185,600.35	155,170.06	61,287.39	39,689.93
Chinese contractor (Appendix G)	187,083.32	122,833.15	103,600.73	46,383.78	30,126.88
State Engineering Corporation (Appendix H)	205,743.25	140,723.67	112,284.35	53,059.28	35,791.16
Estimating tool, NZ (Appendix I)	214,841.60	163343.33	92,300.43	61,185.95	61,035.01

Cost/ Tone US $

Estimating tool (Appendix I)	2729.36	3214.42	3665.03	4173.72	4307.15
Dock Yard (Appendix F)	4009.48	4181.61	4204.38	3785.9	3808.69
Chinese contractor (Appendix G)	2097.58	2767.45	2807.09	2645.98	2891.01
State Engineering Corporation (Appendix H)	2824.15	3149.87	2954.08	2956.71	3059.36

Break down Percentages.

Estimating tool (Appendix I)

Material	50.14	42.28	37.97	30.31	29.37
Fabrication	32.39	38.71	43.25	48.00	49.63
Protective Coatings	17.47	19.01	18.79	18.66	18.06

Dock Yard (Appendix F)

Material	25.48	25.14	25.75	28.60	29.08
Fabrication	41.85	41.83	42.73	40.89	38.03
Protective Coatings	8.9	11.46	12.31	11.31	15.54
Erection	23.77	21.57	19.21	19.21	17.36

Chinese Contractor (Appendix G)

Material	48.01	45.30	49.71	47.19	43.52
Fabrication	32.02	30.21	29.82	31.47	29.02
Protective Coatings	19.98	24.49	25.47	21.33	27.46

State Engineering Corporation (Appendix H)

Material	41.58	37.50	39.03	39.23	34.58
Fabrication	46.16	48.13	45.09	47.53	48.90
Protective Coatings	12.26	14.41	15.88	13.24	16.52

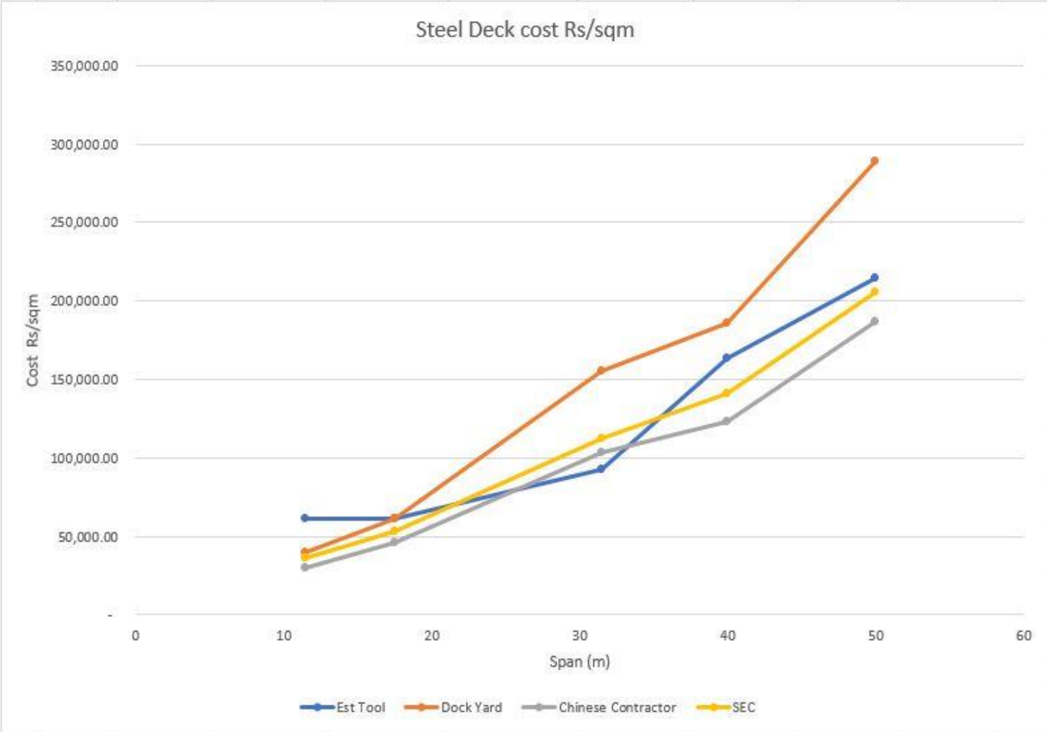


Figure 6.3 Steel structure cost Rs/sqm (with profit)

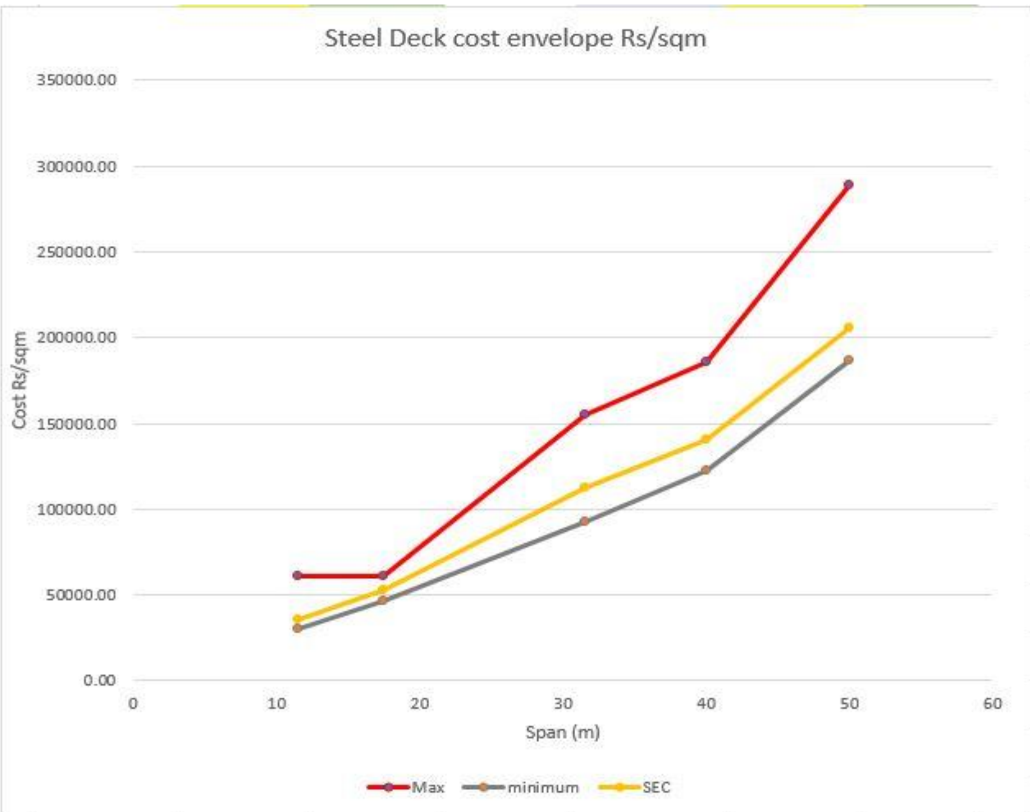


Figure 6.4 Steel structure cost envelope Rs/sqm (with profit)

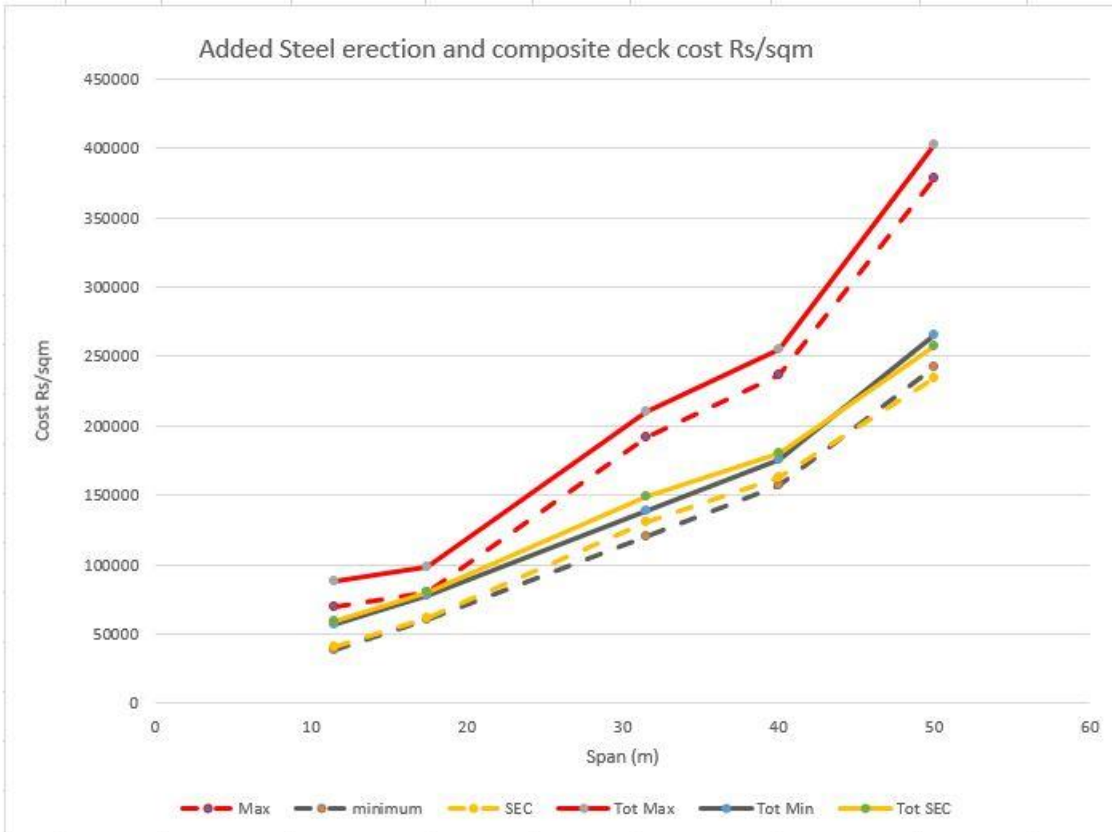


Figure 6.5 Cost envelope with erection (with profit) and composite deck

Figure 6.3 illustrates variation of composite deck cost of different contractors and estimation tool calculated for different deck types and span lengths. Figure 6.4 shows the cost envelope based on maximum and minimum values of Figure 6.3. Calculated values of local contractor SEC are superimposed on this figure.

The Figure 6.5 shows erection cost added to values of Figure 6.4 (dotted lines) and added cost of concrete deck cost (full lines). The erection cost is based on interpolated values of range \$800 - \$ 1250/ton by Dock Yard at upper limit and \$250/ton by Chinese contractor at lower limit as tabulated in Table 6.5.

Table 6.5 Cost breakdown of estimates to Euro code.

(SEC provided erection cost. Composite deck cost/sqm estimated and added.)

Span	Deck Cost Rs/sqm						(2), (3), (4) Cost of erection Rs/sqm			Total			Composite Deck Rs/sqm	Total with deck cost Rs/sqm		
	1. Estimation tool	2. Dock Yard	3. Chinese contractor	4. State Engineering Corporation	MAX	MIN	max DY	min ChC	SEC	Max	Min	SEC		Max	Min	SEC
11.5	61,035.01	39689.93	30126.88	35791.16	61035.01	30126.88	8336.71	8008.64	5079.47	69371.72	38135.52	40870.63	18300.95	87672.67	56436.47	59171.58
17.5	61,185.95	61287.39	46383.78	53059.28	61287.39	46383.78	18485.47	13472.06	8544.64	79772.86	59855.84	61603.92	18300.95	98073.81	78156.79	79904.87
31.5	92,300.43	155170.06	103600.73	112284.35	155170.06	92300.43	36906.79	28363.53	17989.54	192076.85	120663.96	130273.89	18300.95	210377.8	138964.91	148574.84
40	163,343.33	185,600.35	122833.15	140723.67	185600.35	122833.15	51042.66	34110.62	21634.62	236643.01	156943.77	162358.29	18300.95	254943.96	175244.72	180659.24
50	214,841.60	288,856.83	187083.32	205743.25	288856.83	187083.32	90054.31	55366.68	28846.16	378911.14	242450	234589.41	23345.27	402256.41	265795.27	257934.68

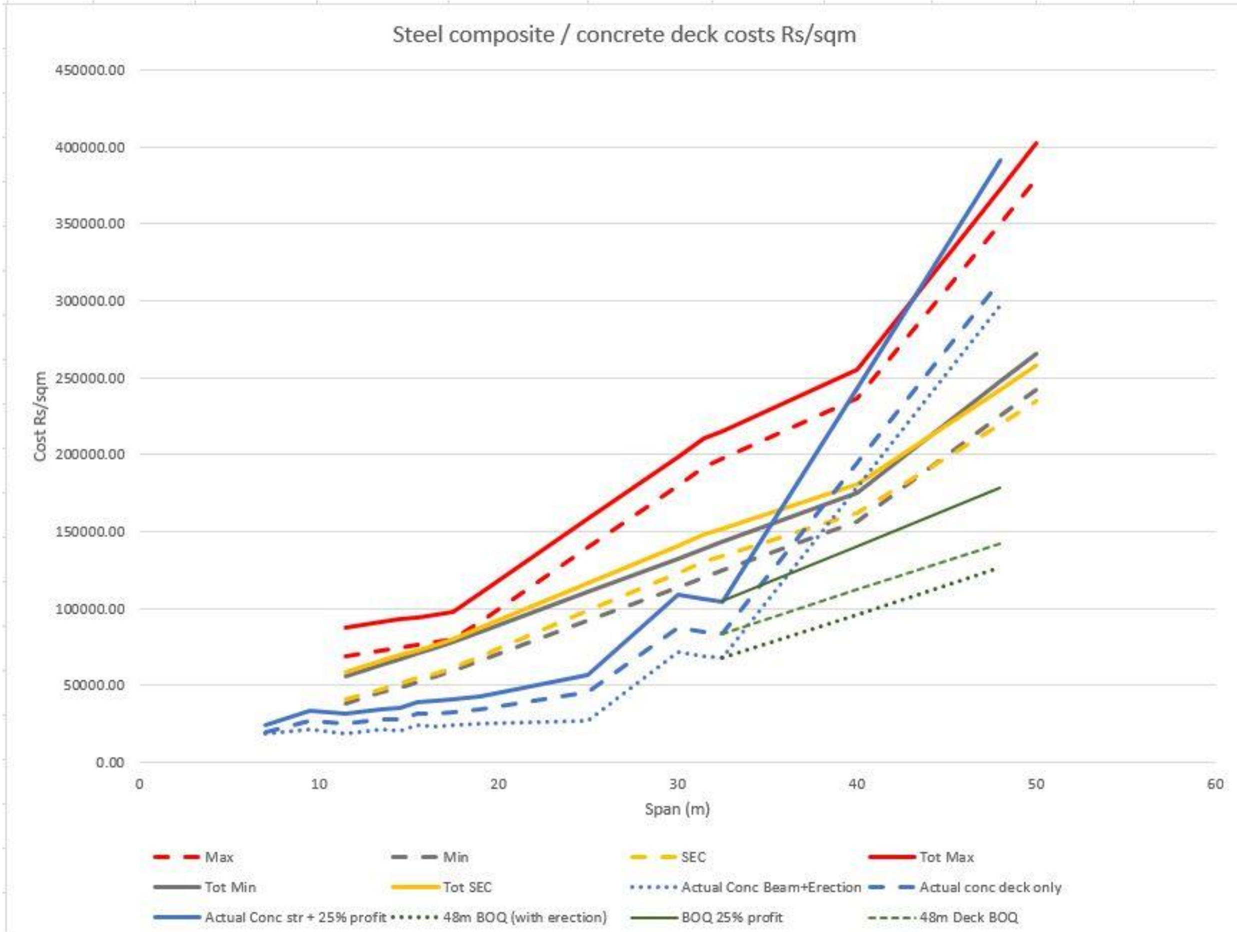


Figure 6.6 Cost envelopes of steel composite decks and concrete decks.

Figure 6.6 shows superimposed graphs developed for concrete decks shown in Figure 6.2 and for composite decks shown in Figure 6.5.

The costing of concrete structures for HSR basic rates are added with 25% of profit for comparison. The values of span 32.5m and 48m are based on actual cost and recast to 2020 using HSR rates. Span 48m original BOQ value is also shown in dotted line extension.

The cost of imported steel bridges is tabulated in Table 6.6 for comparison with composite deck costs of Sri Lanka.

6.4.3 Imported Structures (Marbey UK steel bridges with steel deck plates erected in Ratnapura division, (cost information, 2013))

Table 6.6 Cost of imported galvanized bridges imported from UK within last seven years.

Bridge Location	Bride Type	Super structure Cost Pounds sterling	Erection cost SLRs	Total cost Rs (Sterling pound = SLR 250/-)	Dimensions	Cost/sqm
21/3 TA	ATLAS (Girder Bridge)	308270.00	4,661,742.68	81729242.68	28.296m x 8.523m	338,890.93
33/2 TA	ATLAS (Girder Bridge)	353355.00	2,999,062.33	91337812.33	28.296m x 9.462m	341,147.83
14/1 TA	DELTA TRUSS	769781.00	2,692,553.29	195137803.3	54m x 8.96m	403,310.61
17/9 RPK	C200 Panel Bridge	310,422.00	3,798,832.06	81404332.06	35.528m x 9.69m	236,457.44

4/3 MK	ATLAS (Girder Bridge)	219,089.00	5,967,885.00	60740135.00	17.44m x 10.5m	331,695.80
9/11 MK	ATLAS (Girder Bridge)	621131.00	14,390,391.00	169673141.00	36.576m x 9.683m	479,078.81
Kurugammodara	C200 Panel Bridge	562,279.00	8,064,928.00	148634678.00	(8+14+5) panels 85.46m X 4.953m	351,146.97

6.5 Cost comparison – Conclusions

1 Highway Schedule of rates provides most reliable method of estimation since it captures each element of value addition. Therefore, this document was used to estimate current cost of concrete bridge decks and recast estimate cost of post-tensioned beams of 30m, 32.5m, and 48m and steel concrete composite bridge decks constructed by State Engineering Corporation and Chinese contractor.

2 Post-tensioned beams require launching girder for erection. Use of a panel bridge is the most common practice in Sri Lanka. However, 48m long (162.5 tonnes in weight) beams impose 34.375 KN/m load exceeding HA udl/lane 24.4 KNm (BS5400 part2 2006) limit, therefore require launching girder designed for this purpose. Therefore, the erection cost of this beam was exceptionally high exceeded BOQ value. Therefore, erection cost of concrete beams longer than 35.0m is critical when compared with steel concrete composite as an alternative option.

3 Analysis of costs of steel composite bridges indicate upper bound by Dock Yard General Engineering Services and lower bound is by State Engineering Corporation (SEC), Chinese contractor and estimation tool (figure 6.3). These limits could be updated with current rates at any time. Concrete bridge decks of spans less than 35.0m long indicates cheaper solution when compared with steel concrete alternatives (figure 6.6).

4 Estimation tool has captured difference in fabrication process, shows clear change when deck type is changed from composite I girder to ladder deck designs spanning between lower and upper bounds (figure 6.3).

5 The price differences of decks due to rates of Dock Yard, SEC, and Chinese contractor are smallest for spans less than 17.5m (figure 6.3). This is due to low cost of simple fabrication required within this span range. Therefore medium-

sized contractors can make this market segment (spans less than 17.5m) competitive.

6 Composite bridge decks designed for Eurocode with spans greater than 35m fabricated in Sri Lanka are more economical than comparable concrete bridge decks (figure 6.6).

7 Imported bridges are costlier than locally fabricated steel bridges. UK ATLAS modular bridges are costlier, and DELTA truss and C200 truss panel bridges are equal or just above the cost upper bound of locally fabricated composite bridges (spans greater than 36m).

Chapter – 07

Conclusions.

7.1 Summary

This chapter presents brief description of the research, followed by main findings with recommended future applications. Finally, chapter recommends future research based on limitations to this research.

This research was carried out to find economical span range of steel concrete composite bridges for Sri Lanka under Eurocode loading.

Eurocode loading will replace current BS 5400 loading with the changeover to Eurocode from British Standard. Eurocode UK National annex traffic loading was checked for most common present concrete deck types with precast pre-tensioned beams up to 25m and proposed steel concrete composite decks within span range of (25m -50m) post tensioned beam range of Sri Lanka. Application method of UK National annex traffic loading recommended.

Steel concrete composite decks were designed (to cover both pre-tensioned and post-tensioned beam range up to 50m) for UK National annex loading recommended above. Costing of decks were based on three different methods, i.e., present cost data from a fabricator, recast past cost data to suit present scenario, and a published document.

The comparison of Eurocode UK National Annex loading with BS 5400 loading for bridge decks specified in paragraph 2 above is given in Chapter 4. Computer models developed are described in Chapter 3.

Current RDA application of BS 5400 (1978) loading and BS 5400 (2006) loading specified in recent expressway designs were considered. In Chapter 4 comparisons were made between UKNA LM1 loading and HA (1978) loading, UKNA LM3 SV100 & SV80 with HB30 loading, UKNA load group LM3 (SV100, SV80) & LM1 with BS5400 load combination HA (2006) & HB30.

Current practice of RDA, i.e., application of HA (1978) loading on the deck, and HB30 vehicle straddling on the centre line also reviewed to decide most critical load effects and is presented in Chapter 4.

Composite steel concrete deck designs for the span range (11.5m – 50m) for recommended UKNA loading is presented in Chapter 5. In Chapter 6, Cost comparison is presented. Comparison made between steel composite decks with pretension and post-tensioned concrete decks.

Based on the outcome of costing several recommendations have been made including economical span range for steel composite bridge decks under recommended Eurocode UK National Annex loading.

7.2 Main findings.

1. Due to unavailability of Sri Lankan National Annex for Eurocode traffic loading (including fatigue considerations for composite structures), UK national annex for Eurocode traffic loading considered most appropriate. As indicated reasons in of sections 1.1, 2.8, Euro Code UK National annex bridge loading is considered for comparison with BS 5400 loading.

2. A comparison of traffic loads as per UK National Annex with BS 5400 is given in chapter 4. Pre-tensioned concrete bridge deck configuration spans 9.04m up to 24.54m and composite deck I plate girder design span of 31.5m and Ladder deck designs 40m, 50m considered.

   Comparison of traffic loading Eurocode (UKNA) and BS 5400 part 2 (2006 & 1978).

   Specified severe load effect below is recommended to replace BS5400 load effect. Specified loads are marginal for one or several bridge decks considered. Therefore change to Eurocode (UKNA) would not result severe over design.

a) Considering HA loading of BS5400 1978 as the basis, comparison of LM1(UKNA) with HA5400 1978 (current RDA standard) indicate LM1(UKNA) load effects are severe within span range 9.04m – 24.54m. For 24.54m – 50 span range, 7% increse of LM1(UKNA) load effect would be required for severe effect.

b) Comparison of LM1(UKNA) with HA BS5400 2006
Considering HA loading of BS5400 2006 as the basis, comparison of LM1(UKNA) with HA BS5400 2006 indicate 27% increse of LM1(UKNA) load effect would be required for severe effect for span range 9.04m – 50m.

c) Comparison of LM3 (SV100 and SV80)with HB 30 units.
Considering HB30 units as the basis, LM3 SV100 or 125% of LM3 SV80 load effect is severe than load effect due to HB30 units.

e) Comparison of Maximum of load group LM1 & LM3SV100 (UKNA) and load group LM1 & LM3SV80 (*UKNA* ψ_1 *(LM1 TS 0.75, LM1 UDL 0.75)* with combination maximum HA & HB30 (BS5400, 2006).

Considering HA & HB30 (BS5400, 2006), as the basis, load group LM1 & LM3SV80 (UKNA)load effect is severe than load effect due to HA & HB30.

3. Cost Comparison of composite bridge designs to Eurocode (traffic loading LM1 (UKNA) & LM3SV100) & with existing concrete decks.

The cost of steel composite bridges was calculated (per/ton or item), (cost information, 2020) as provided by Dock Yard General Engineering Services, recasting of actual costs (Kinniyai Bridge, 2005) of a Chinese contractor and State Engineering Corporation (Kelanisiri Bridge, 2001) and by a published Estimating document (Cowie and Fussell, 2011). This establishes upper and lower bounds for steel fabrication and erection in this country.

Concrete bridge decks are shown cheaper than steel composite bridge decks up to spans of 35m. Beyond this point, erection governs the competitiveness of concrete bridge when compared with steel concrete composite design.

4. At current rates steel composite decks are cheaper than concrete alternative for spans greater than 35.0m.

7.3 Recommended future applications.

Pre-tensioned beam bridges of spans less than 25m built during past few decades followed BS5400 1978 HA standard. All bridges in A & B class roads were checked when HB30 vehicle is stradling along centre line.

Bending moment due to HB30 is severe than HA within spans are less than 25m, and HA is severe within 25m-50m span range (section 4.6.1). Shear force due to HB30 is severe than HA within span range 16.04m to 31.5m (section 4.9.1).

Applications

1. Application of LM1(UKNA) loading for design result stronger bridges than bridges design for BS5400 1978 HA for spans less than 25m.

2. Bridges could be designed for severe load effect due to LM1(UKNA) or LM3SV100 stradling on centre line of the bridge for spans less than 25m. For spans 25m to 50m severe load effect due to 107% of LM1(UKNA) or LM3SV100 should be considered for design. Such bridges are stronger than present designed for HA or HB30 stradling on centre line.

3. Following Eurocode loading result severe load effects than for load combination HA(2006) and HB30 adopted in recent express way designs.

a) 127% of LM1(UKNA) has severe load effects than HA(2006) within span range 9.04m to 50m.

b) UKNA LM1&SV80 (with *UKNA* ψ_1 *(LM1 TS 0.75, LM1 UDL 0.75)* load result severe load effect than for the combination HA2006 with HB30 within span range 9.04m to 50m.

4. The structural configuration of steel composite bridge decks heighlighted under above section 1.4 and considered for this study is recommended for future applications.

5. Steel concrete composite decks need to be checked for spans greater than 35.0m as an economically viable solution.

6. Construction of steel composite steel bridges decks of spans less than 17.5m (18m long) could be made competitive among medium sized contractors.

7. Latest HSR rates and market prices could be used with costing methods described in this thesis to compare cost of concrete decks with steel composite decks.

8. Imported steel bridges (Galvanized permanent bridge types ATLAS & DELTA) are more expensive (Cost information, 2013) than locally fabricated composite bridges. Therefore, local industry needs to be encouraged to come in to steel bridge construction.

Implications of adopting recommended Eurocode loading

As recommended in this section, bridges designed for LM1(UKNA) loading result stronger bridges than bridges designed for BS5400 - 2– 1978 HA loading for span range 9.04m – 25m. For 25m – 50m span range LM1(UKNA) loading need to be incresed by 107% to be inline with BS5400 -2 HA loading. Therfore, bridges are not overdesigned by adopting recommended UK National Annex loading.

Although BS5400 -2 (2006) standard was limited for recent expressway design, adoption of HA loading result stronger bridges than 1978 standard. Recommended 127% LM1(UKNA) has load effect with minimum over design with respect to BS5400 -2 (2006) standard.

As in current practice design to HA loading and check on HB vehicle straddling along centre line is to continue, LM1(UKNA) loading as recommended above and SV100 model could be adopted.

The load group UKNA LM1&SV80 (with *UKNA* ψ_1 *(LM1 TS 0.75, LM1 UDL 0.75)* induce severe load effects than for loading combination HA & 30 units of HB as per BS 5400 - 2 (2006). Therefore, adopting this standard as discussed in 7.3 – (3b), will result stronger bridges than bridges currently being designed for expressways.

7.4 Recommendation for Future Research.

1. Comparison of UK National Annex loading with BS 5400 -2 loading for bridge spans 3m – 9m and culverts.

2. Eurocode National annexes for Sri Lanka including National annex for traffic load need to be developed.

3. The standard for fabrication of steel for bridge construction (similar document to HSR) should be developed for Sri Lankan Conditions. Such document is capable of value addition process and is more accurate than SLRs/ton method.

4. Research into costing of small steel composite bridges by medium size contractors of Sri Lanka.

5. Research in to erection costs of concrete & steel composite bridge spans larger than 30m in Sri Lanka.

6. Standardization of steel concrete composite decks for Sri Lanka.

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Appendix A

A1 Effective flange width of design models

The effective flange width is given by (EN 1994-2-2005, 5.4.1.2 (5)).

$$b_{eff} = b_0 + \Sigma\, b_{ei}$$

where b_0 = is the distance between the centres of the outstand shear connectors.

b_{ei} = is the value of the effective width of concrete flange on each side of web and taken as Le /8 for simply supported spans. L_e is the distance between points of zero bending moments.

Table A.1 Effective width of concrete flanges in computer models

Span (m)	**b_0 (m)**	**Σ b_{ei} (m)**		**b_{eff} (m) minimum**	**Effective width (actual)**
		Internal beam	**Edge beam**		
11.5	0.1	2.875	2.7375	2.838	> 2.6
17.5	0.15	4.375	3.4875	3.638	> 2.6
31.5	0.25	7.875	5.2375	5.488	>2.6
40	0.3		6.2	6.5	>5.2
50	0.4		7.45	7.85	>5.2

A2 Fatigue assessment of shear stud connections

Damage equivalent factors (EN 1993-2-cl 9.5.2) considered for are as follows.

Design value of range shear stress

$\Delta\tau_{E2} = \lambda_v \, \Delta\tau$ BSEN 1994-2, cl 6.8.6.2

$\Delta\tau$ – range of shear stress in the stud cross-section

$\lambda_v = \lambda_{v1}\lambda_{v2}\,\lambda_{v3}\,\lambda_{v4}$

$\lambda_{v1} = 1.550$ (BSEN 1994-2, cl 6.8.6.2 (4), span is less than 100m)

$\lambda_{v2} = (Q_{ml}/ Q_0)*(N_{obs} / N_0)^{0.125}$

$= 0.591 = (260/480) \times (1.0/0.5)^{0.125}$

$Q_0 = 480kN$, $N_0=0.5x10^6$, $N_{obs}= 1x10^6$, EN 1993-2 cl 9.5.2 Table 9.1

$Q_{ml} = 260kN$, 1993-2 NA.2.39 EN 1994-2, cl 6.8.6.2 (4)

$\lambda_{v3} = (t_{LD} /100)^{0.125} = 1.023$ EN 1993-2 NA.2.40 t_{LD} design life 120 years

(BSEN 1993-2 cl 9.5.2 (5) & BSEN 1994-2, cl 6.8.6.2 (4))

λ_{v4} depends on relative magnitude of the stress range due to the passage of model FML3 in the second lane and is taken as 0.85.

$\lambda_{v4} = (1+0.85)^{0.125} = 1.080$

(BSEN 1993-2 cl 9.5.2 (6) & BSEN 1994-2, cl 6.8.6.2 (4))

$\lambda_v = \lambda_{v1}\lambda_{v2}\,\lambda_{v3}\,\lambda_{v4} = 1.012$

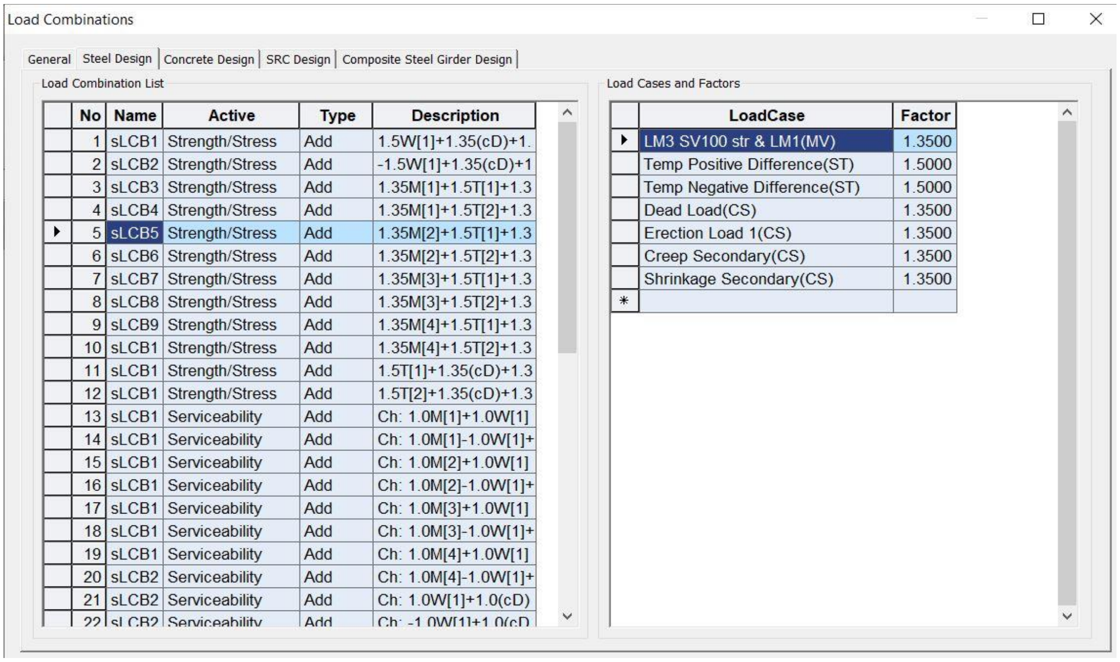
verification

$\gamma_{Ef}\,\Delta\tau_{E2} /(\Delta\tau_c /\gamma_{Mf,\,s}) < 1.0$ BSEN 1994-2, cl 6.8.7.2 (2)

Appendix B Critical load combinations in designs.

B1 Critical support shear load combinations.

B1.1 Span 11.5m



No	Name	Active	Type	Description
1	sLCB1	Strength/Stress	Add	1.5W[1]+1.35(cD)+1.
2	sLCB2	Strength/Stress	Add	-1.5W[1]+1.35(cD)+1
3	sLCB3	Strength/Stress	Add	1.35M[1]+1.5T[1]+1.3
4	sLCB4	Strength/Stress	Add	1.35M[1]+1.5T[2]+1.3
5	sLCB5	Strength/Stress	Add	1.35M[2]+1.5T[1]+1.3
6	sLCB6	Strength/Stress	Add	1.35M[2]+1.5T[2]+1.3
7	sLCB7	Strength/Stress	Add	1.35M[3]+1.5T[1]+1.3
8	sLCB8	Strength/Stress	Add	1.35M[3]+1.5T[2]+1.3
9	sLCB9	Strength/Stress	Add	1.35M[4]+1.5T[1]+1.3
10	sLCB1	Strength/Stress	Add	1.35M[4]+1.5T[2]+1.3
11	sLCB1	Strength/Stress	Add	1.5T[1]+1.35(cD)+1.3
12	sLCB1	Strength/Stress	Add	1.5T[2]+1.35(cD)+1.3
13	sLCB1	Serviceability	Add	Ch: 1.0M[1]+1.0W[1]
14	sLCB1	Serviceability	Add	Ch: 1.0M[1]-1.0W[1]+
15	sLCB1	Serviceability	Add	Ch: 1.0M[2]+1.0W[1]
16	sLCB1	Serviceability	Add	Ch: 1.0M[2]-1.0W[1]+
17	sLCB1	Serviceability	Add	Ch: 1.0M[3]+1.0W[1]
18	sLCB1	Serviceability	Add	Ch: 1.0M[3]-1.0W[1]+
19	sLCB1	Serviceability	Add	Ch: 1.0M[4]+1.0W[1]
20	sLCB2	Serviceability	Add	Ch: 1.0M[4]-1.0W[1]+
21	sLCB2	Serviceability	Add	Ch: 1.0W[1]+1.0(cD)
22	sLCB2	Serviceability	Add	Ch: -1.0W[1]+1.0(cD

LoadCase	Factor
LM3 SV100 str & LM1(MV)	1.3500
Temp Positive Difference(ST)	1.5000
Temp Negative Difference(ST)	1.5000
Dead Load(CS)	1.3500
Erection Load 1(CS)	1.3500
Creep Secondary(CS)	1.3500
Shrinkage Secondary(CS)	1.3500

Figure B1.1 Load combination 5 for maximum shear on support. (39i, 48j)

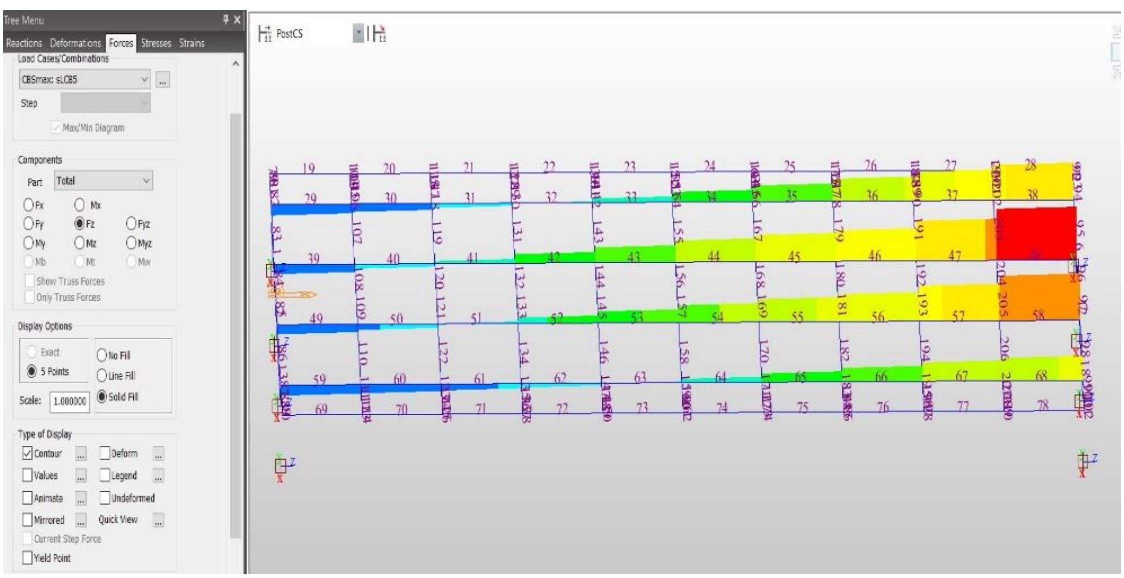


Figure B1.2 Shear force diagram LC5 (maximum moving load shear shown on 48j) span 11.5m

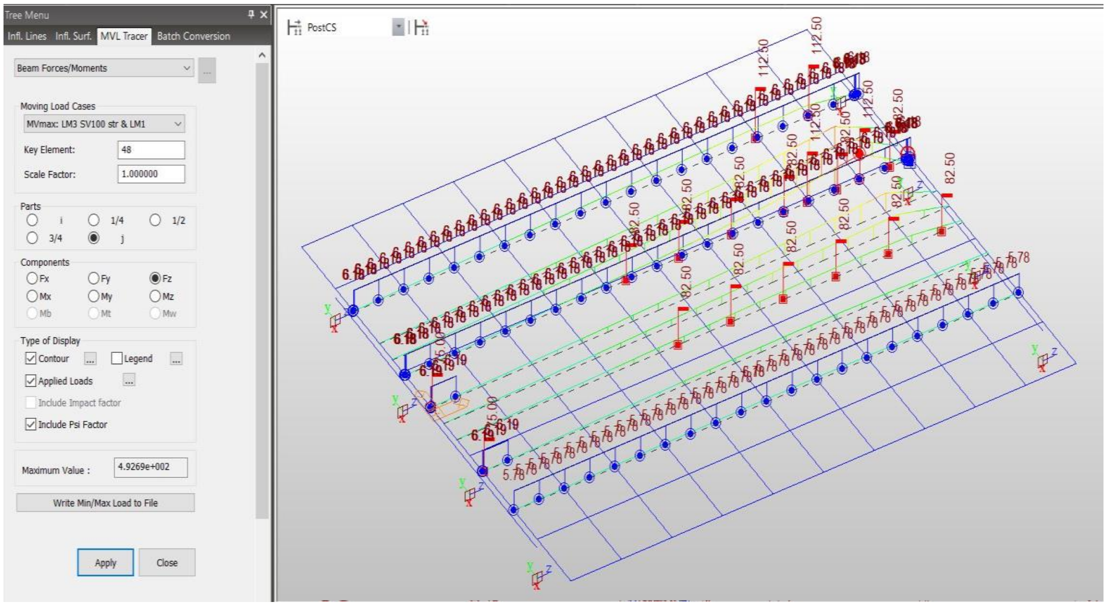
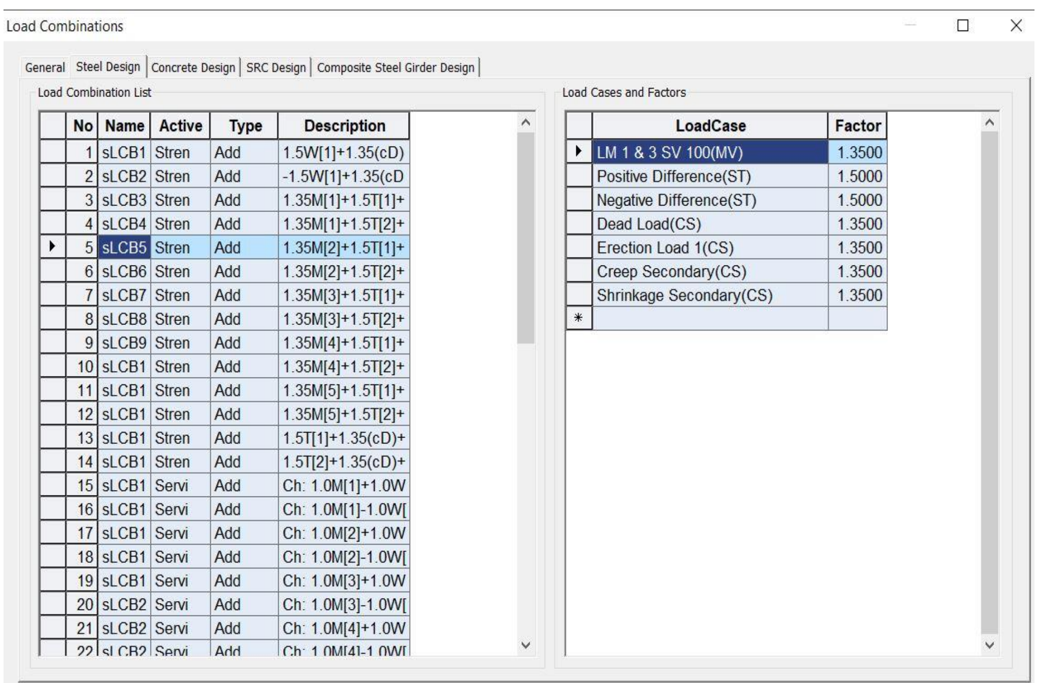


Figure B.1.3 Traffic loading (Load Case 5) LM1 & LM3SV100 on stradling lanes span 11.5m (B.1.3a Maximum support shear 492.6kN. (node 48j))

B.1.2 Span 17.5m


Load Combinations

General | Steel Design | Concrete Design | SRC Design | Composite Steel Girder Design

Load Combination List

No	Name	Active	Type	Description
1	sLCB1	Stren	Add	1.5W[1]+1.35(cD)
2	sLCB2	Stren	Add	-1.5W[1]+1.35(cD
3	sLCB3	Stren	Add	1.35M[1]+1.5T[1]+
4	sLCB4	Stren	Add	1.35M[1]+1.5T[2]+
5	sLCB5	Stren	Add	1.35M[2]+1.5T[1]+
6	sLCB6	Stren	Add	1.35M[2]+1.5T[2]+
7	sLCB7	Stren	Add	1.35M[3]+1.5T[1]+
8	sLCB8	Stren	Add	1.35M[3]+1.5T[2]+
9	sLCB9	Stren	Add	1.35M[4]+1.5T[1]+
10	sLCB1	Stren	Add	1.35M[4]+1.5T[2]+
11	sLCB1	Stren	Add	1.35M[5]+1.5T[1]+
12	sLCB1	Stren	Add	1.35M[5]+1.5T[2]+
13	sLCB1	Stren	Add	1.5T[1]+1.35(cD)+
14	sLCB1	Stren	Add	1.5T[2]+1.35(cD)+
15	sLCB1	Servi	Add	Ch: 1.0M[1]+1.0W
16	sLCB1	Servi	Add	Ch: 1.0M[1]-1.0W[
17	sLCB1	Servi	Add	Ch: 1.0M[2]+1.0W
18	sLCB1	Servi	Add	Ch: 1.0M[2]-1.0W[
19	sLCB1	Servi	Add	Ch: 1.0M[3]+1.0W
20	sLCB2	Servi	Add	Ch: 1.0M[3]-1.0W[
21	sLCB2	Servi	Add	Ch: 1.0M[4]+1.0W
22	sLCB2	Servi	Add	Ch: 1.0M[4]-1.0W[

Load Cases and Factors

LoadCase	Factor
LM 1 & 3 SV 100(MV)	1.3500
Positive Difference(ST)	1.5000
Negative Difference(ST)	1.5000
Dead Load(CS)	1.3500
Erection Load 1(CS)	1.3500
Creep Secondary(CS)	1.3500
Shrinkage Secondary(CS)	1.3500

Figure B1.4 Load combination 5 for maximum shear on support. (86i, 103j). span 17.5m

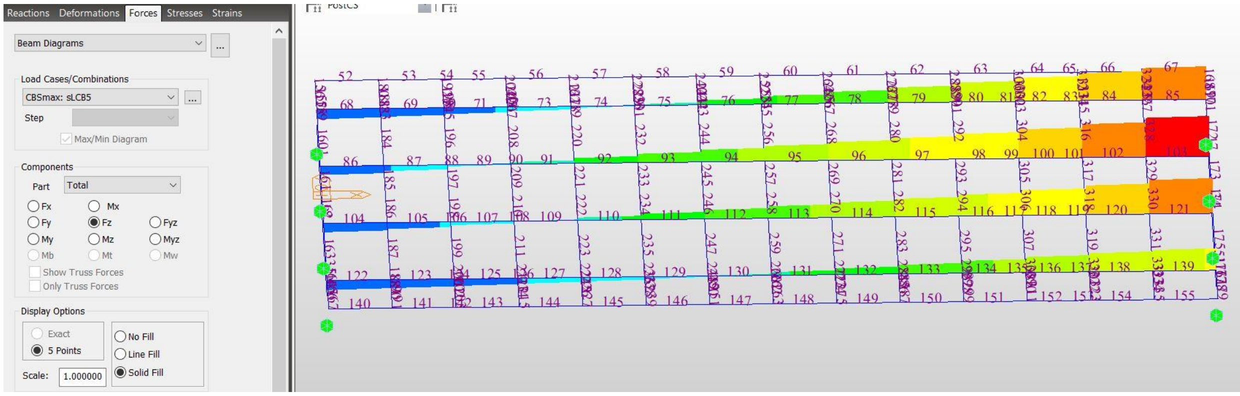


Figure B1.5 Shear force diagram LC5 (maximum moving load shear shown on 86i, 103j). span 17.5m

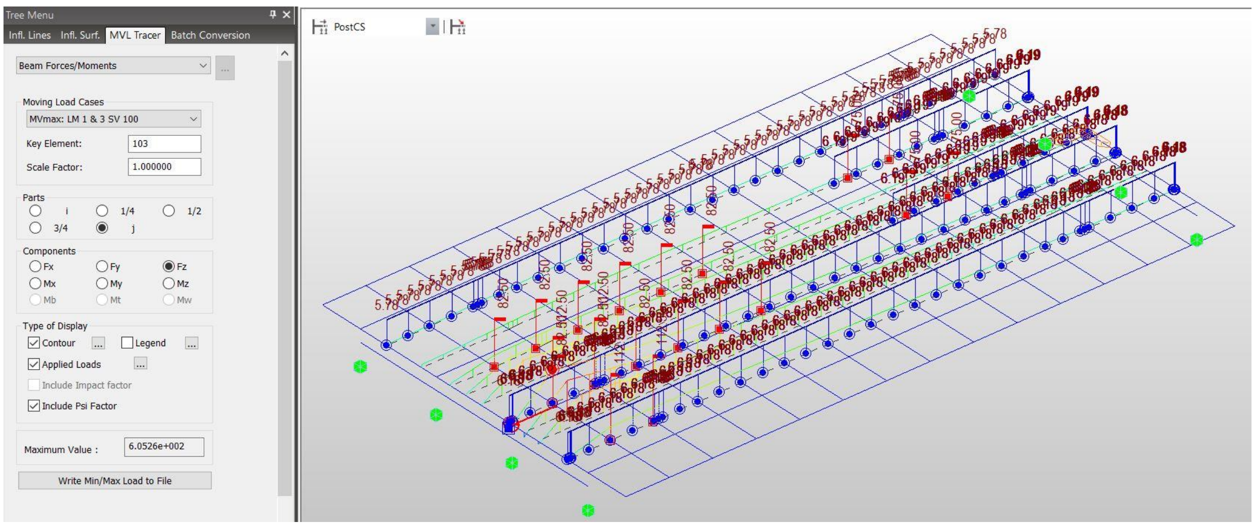


Figure B.1.6 Traffic loading (Load Case 5) LM1 & LM3SV100 on stradling lanes. Span 17.5m

(B.1.6a Maximum support shear 605.26kN. (node 103j))

B.1.3 Span 31.5m

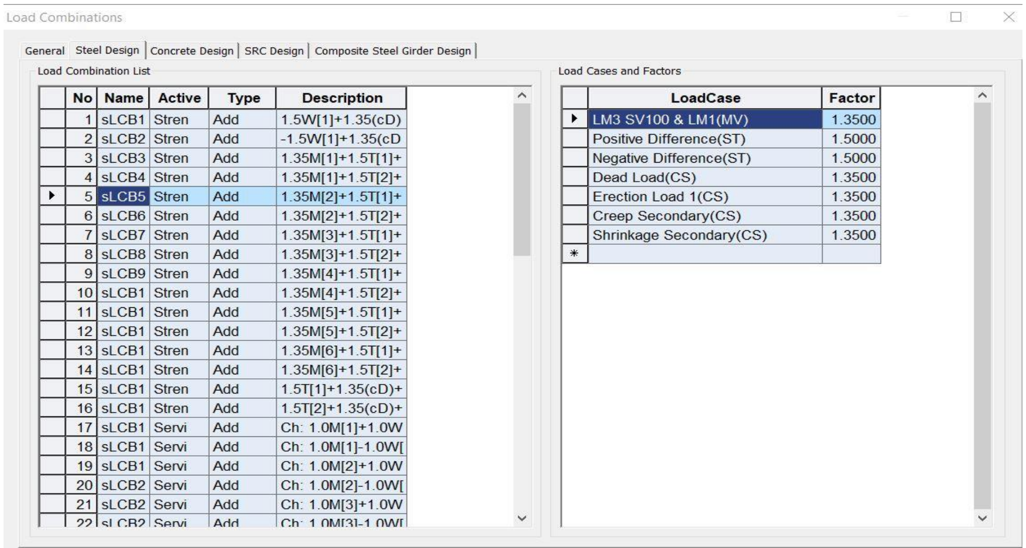


Figure B1.7 Load combination 5 for maximum shear on support (114i, 138j). span 31.5m

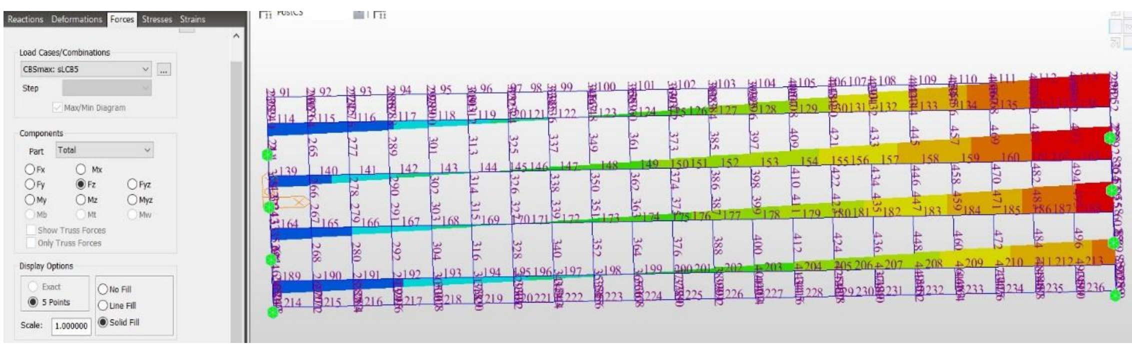


Figure B1.8 Shear force diagram LC5 (maximum moving load shear shown on 138j) span 31.5m

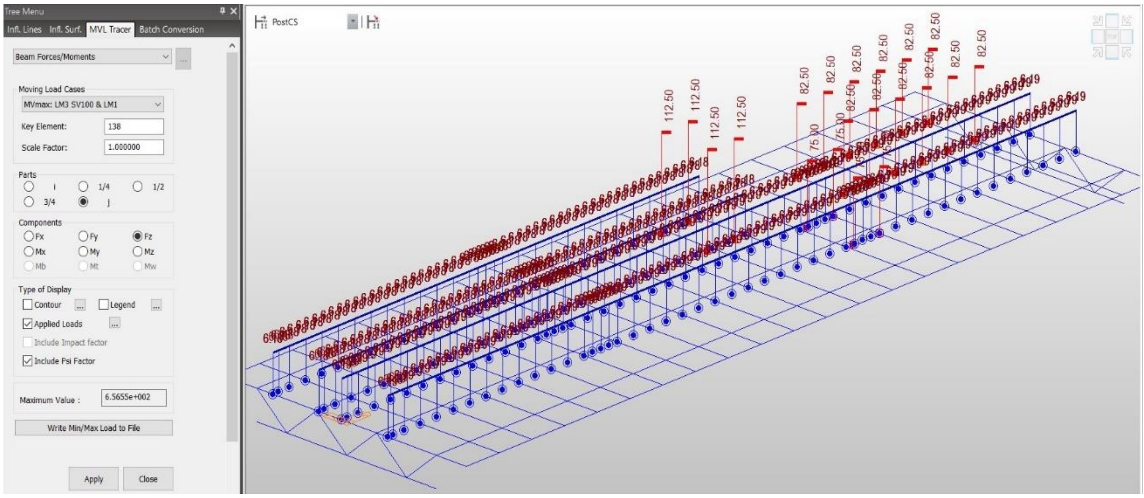
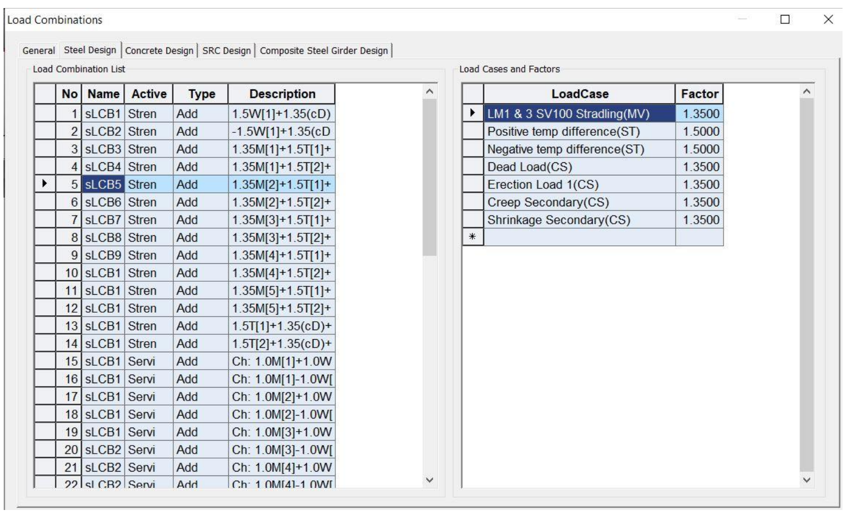


Figure B.1.9 Traffic loading (Load Case 5) LM1 & LM3SV100 on stradling lanes. Span 31.5m.

(B.1.9a Maximum support shear 656.55kN. (node 138j)).

B.1.4   Span 40m Ladder deck


Load Combinations

General | Steel Design | Concrete Design | SRC Design | Composite Steel Girder Design

Load Combination List

No	Name	Active	Type	Description
1	sLCB1	Stren	Add	1.5W[1]+1.35(cD)
2	sLCB2	Stren	Add	-1.5W[1]+1.35(cD
3	sLCB3	Stren	Add	1.35M[1]+1.5T[1]+
4	sLCB4	Stren	Add	1.35M[1]+1.5T[2]+
5	sLCB5	Stren	Add	1.35M[2]+1.5T[1]+
6	sLCB6	Stren	Add	1.35M[2]+1.5T[2]+
7	sLCB7	Stren	Add	1.35M[3]+1.5T[1]+
8	sLCB8	Stren	Add	1.35M[3]+1.5T[2]+
9	sLCB9	Stren	Add	1.35M[4]+1.5T[1]+
10	sLCB1	Stren	Add	1.35M[4]+1.5T[2]+
11	sLCB1	Stren	Add	1.35M[5]+1.5T[1]+
12	sLCB1	Stren	Add	1.35M[5]+1.5T[2]+
13	sLCB1	Stren	Add	1.5T[1]+1.35(cD)+
14	sLCB1	Stren	Add	1.5T[2]+1.35(cD)+
15	sLCB1	Servi	Add	Ch: 1.0M[1]+1.0W
16	sLCB1	Servi	Add	Ch: 1.0M[1]-1.0W[
17	sLCB1	Servi	Add	Ch: 1.0M[2]+1.0W
18	sLCB1	Servi	Add	Ch: 1.0M[2]-1.0W[
19	sLCB1	Servi	Add	Ch: 1.0M[3]+1.0W
20	sLCB2	Servi	Add	Ch: 1.0M[3]-1.0W[
21	sLCB2	Servi	Add	Ch: 1.0M[4]+1.0W
22	sLCB2	Servi	Add	Ch: 1.0M[4]-1.0W[

Load Cases and Factors

LoadCase	Factor
LM1 & 3 SV100 Stradling(MV)	1.3500
Positive temp difference(ST)	1.5000
Negative temp difference(ST)	1.5000
Dead Load(CS)	1.3500
Erection Load 1(CS)	1.3500
Creep Secondary(CS)	1.3500
Shrinkage Secondary(CS)	1.3500

Figure B1.10   Load combination 5 for maximum shear on support (57j). Span 40m Ladder deck.

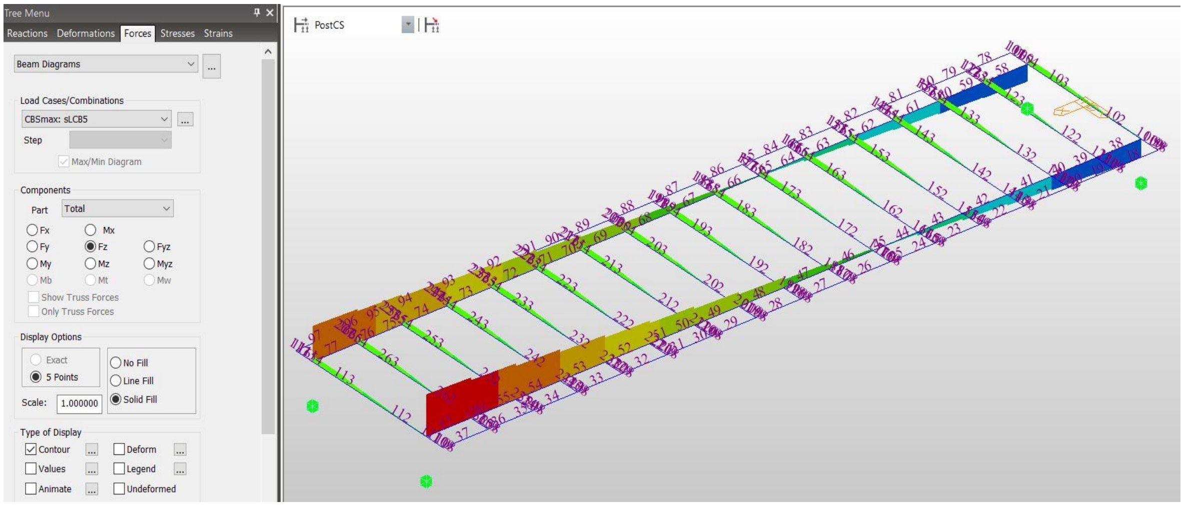


Figure B1.11 Shear force diagram LC5 (maximum moving load shear shown on 57j). Span 40m Ladder deck

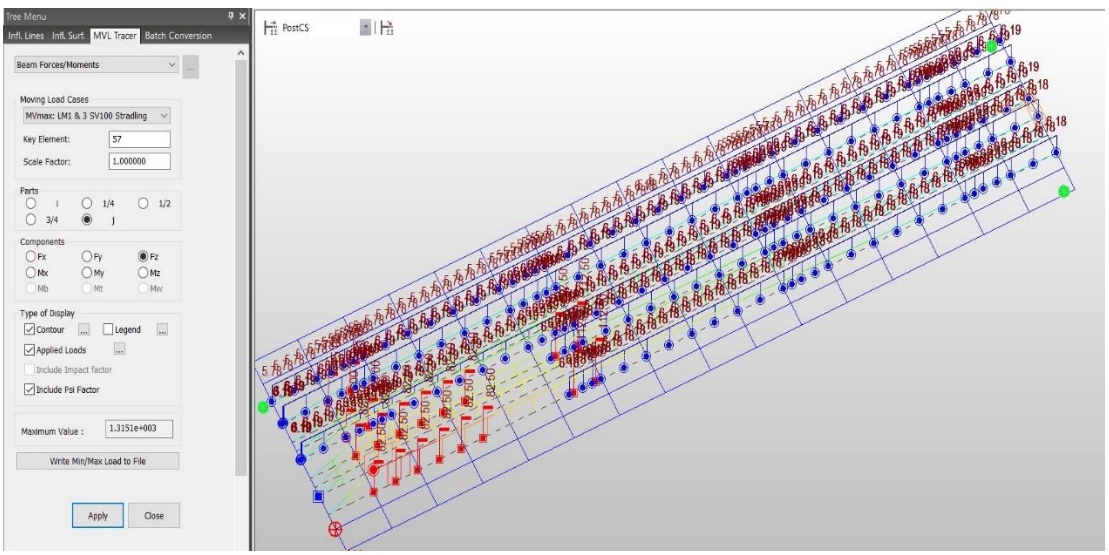


Figure B.1.12 Traffic loading (Load Case 5) LM1 & LM3SV100 on stradling lanes. Ladder deck 40m.

(B.1.12a Maximum support shear 1315.1kN. (node 57j)).

B.1.5 Span 50m Ladder deck

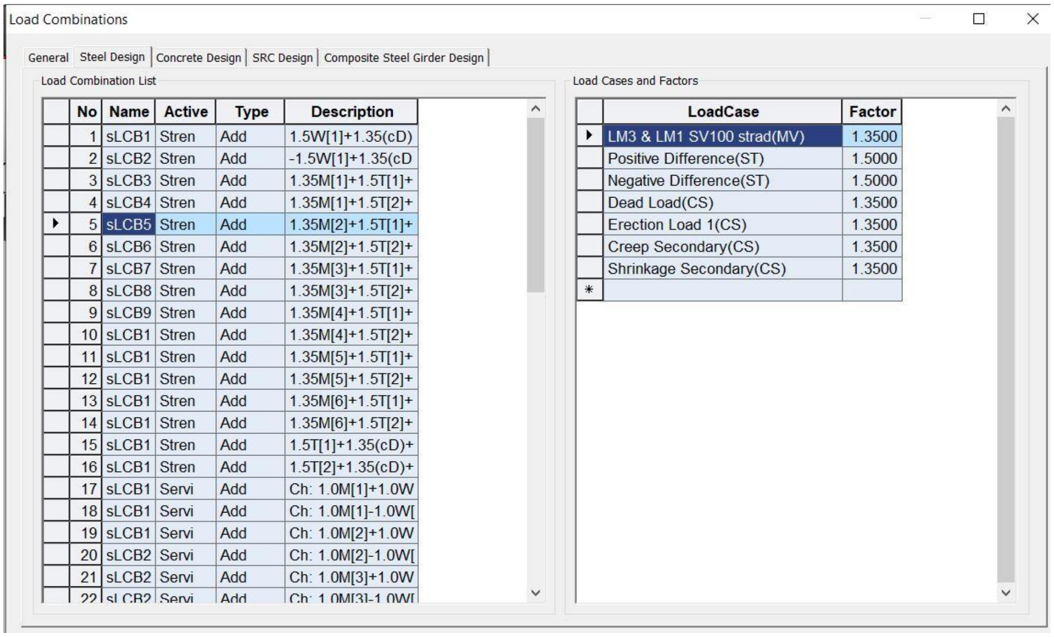


Figure B1.13 Load combination 5 for maximum shear on support (91j). Span 50m Ladder deck

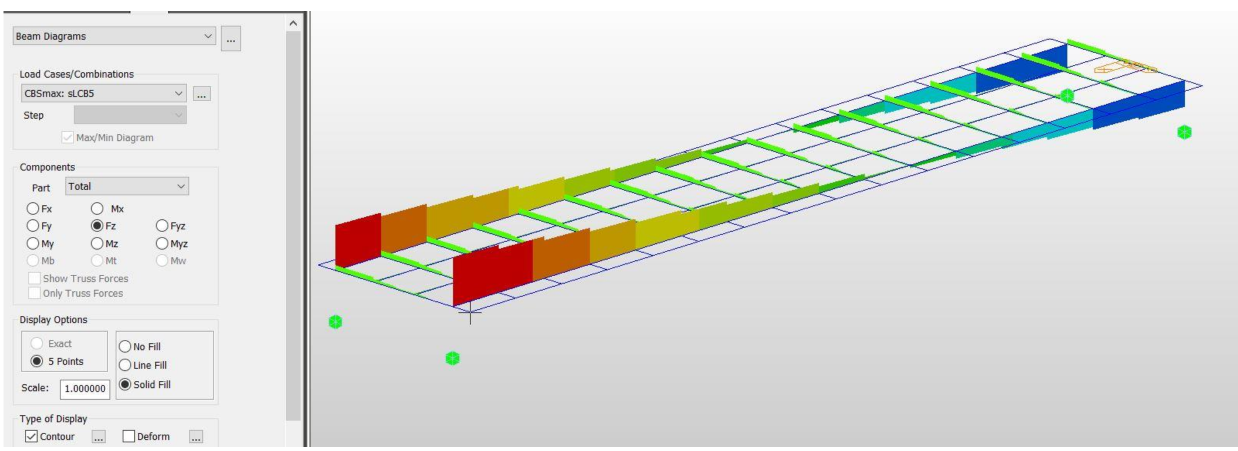


Figure B1.14 Shear force diagram LC5 (maximum moving load shear shown on 91j). Span 50m Ladder deck

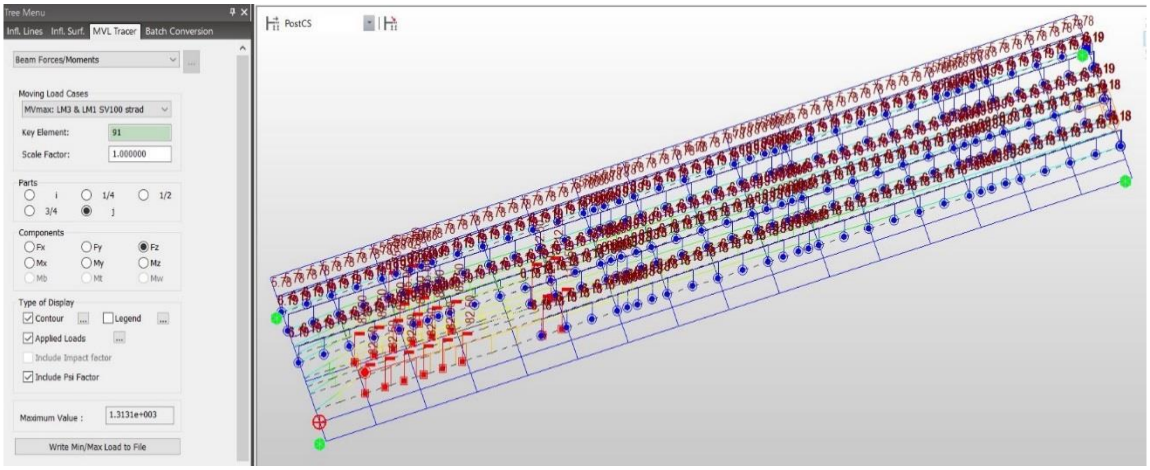
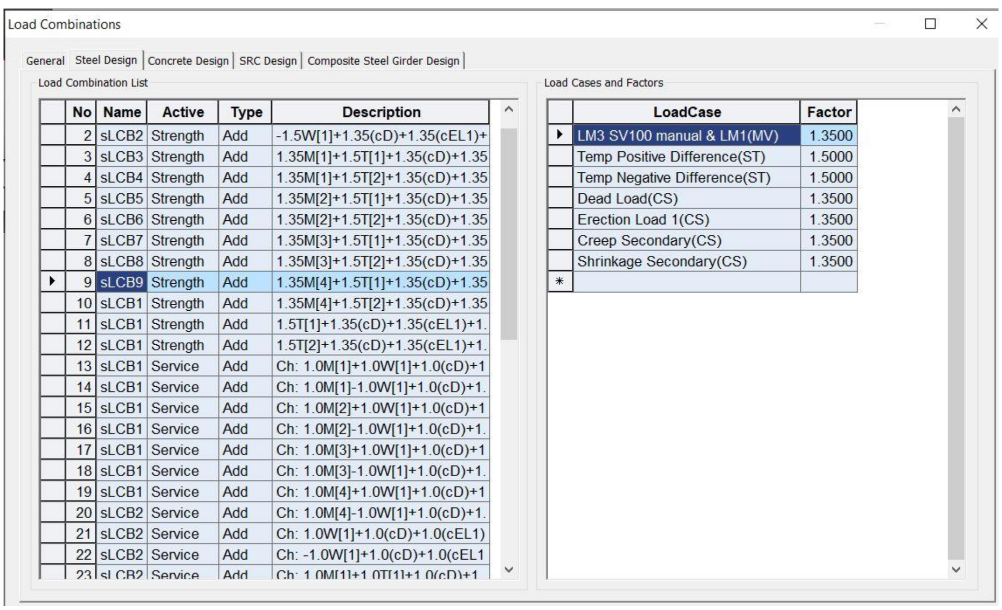


Figure B.1.15 Traffic loading (Load Case 5) LM1 & LM3SV100 on stradling lanes. Ladder deck span 50m. (B.1.15 Maximum support shear 1313.1kN. (node 91j))

B2 Critical mid span bending moment load combinations

B2.1 Span 11.5m



Load Combinations

General | Steel Design | Concrete Design | SRC Design | Composite Steel Girder Design

Load Combination List

No	Name	Active	Type	Description
2	sLCB2	Strength	Add	-1.5W[1]+1.35(cD)+1.35(cEL1)+
3	sLCB3	Strength	Add	1.35M[1]+1.5T[1]+1.35(cD)+1.35
4	sLCB4	Strength	Add	1.35M[1]+1.5T[2]+1.35(cD)+1.35
5	sLCB5	Strength	Add	1.35M[2]+1.5T[1]+1.35(cD)+1.35
6	sLCB6	Strength	Add	1.35M[2]+1.5T[2]+1.35(cD)+1.35
7	sLCB7	Strength	Add	1.35M[3]+1.5T[1]+1.35(cD)+1.35
8	sLCB8	Strength	Add	1.35M[3]+1.5T[2]+1.35(cD)+1.35
9	sLCB9	Strength	Add	1.35M[4]+1.5T[1]+1.35(cD)+1.35
10	sLCB1	Strength	Add	1.35M[4]+1.5T[2]+1.35(cD)+1.35
11	sLCB1	Strength	Add	1.5T[1]+1.35(cD)+1.35(cEL1)+1.
12	sLCB1	Strength	Add	1.5T[2]+1.35(cD)+1.35(cEL1)+1.
13	sLCB1	Service	Add	Ch: 1.0M[1]+1.0W[1]+1.0(cD)+1
14	sLCB1	Service	Add	Ch: 1.0M[1]-1.0W[1]+1.0(cD)+1.
15	sLCB1	Service	Add	Ch: 1.0M[2]+1.0W[1]+1.0(cD)+1
16	sLCB1	Service	Add	Ch: 1.0M[2]-1.0W[1]+1.0(cD)+1.
17	sLCB1	Service	Add	Ch: 1.0M[3]+1.0W[1]+1.0(cD)+1
18	sLCB1	Service	Add	Ch: 1.0M[3]-1.0W[1]+1.0(cD)+1.
19	sLCB1	Service	Add	Ch: 1.0M[4]+1.0W[1]+1.0(cD)+1
20	sLCB2	Service	Add	Ch: 1.0M[4]-1.0W[1]+1.0(cD)+1.
21	sLCB2	Service	Add	Ch: 1.0W[1]+1.0(cD)+1.0(cEL1)
22	sLCB2	Service	Add	Ch: -1.0W[1]+1.0(cD)+1.0(cEL1
23	sLCB2	Service	Add	Ch: 1.0M[1]+1.0T[1]+1.0(cD)+1

Load Cases and Factors

LoadCase	Factor
LM3 SV100 manual & LM1(MV)	1.3500
Temp Positive Difference(ST)	1.5000
Temp Negative Difference(ST)	1.5000
Dead Load(CS)	1.3500
Erection Load 1(CS)	1.3500
Creep Secondary(CS)	1.3500
Shrinkage Secondary(CS)	1.3500

Figure B2.1 Load combination 9 for maximum midspan bending moment (43j, 44i) span 11.5m

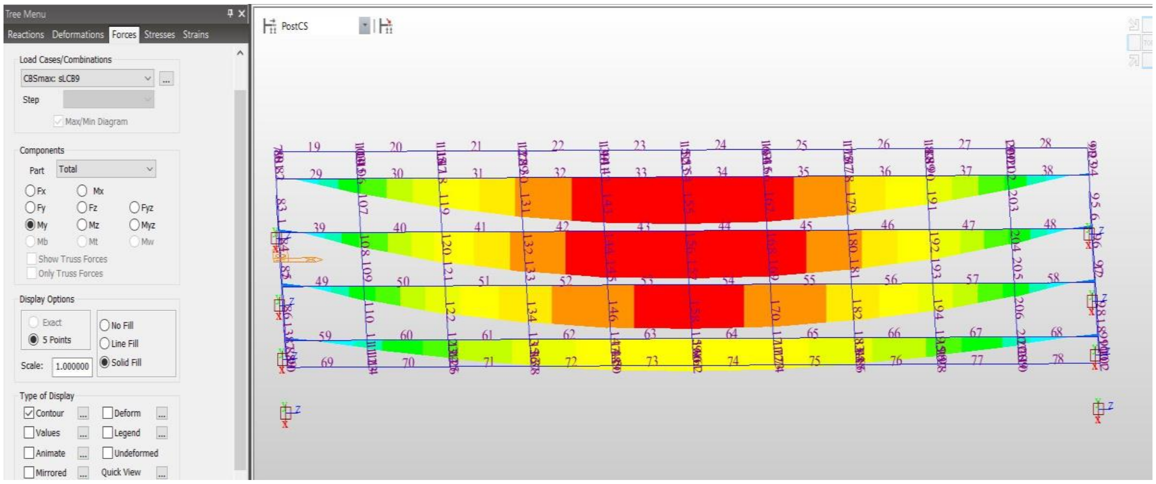


Figure B2.2 Bending Moment diagram Load Case 9. Span 11.5m.

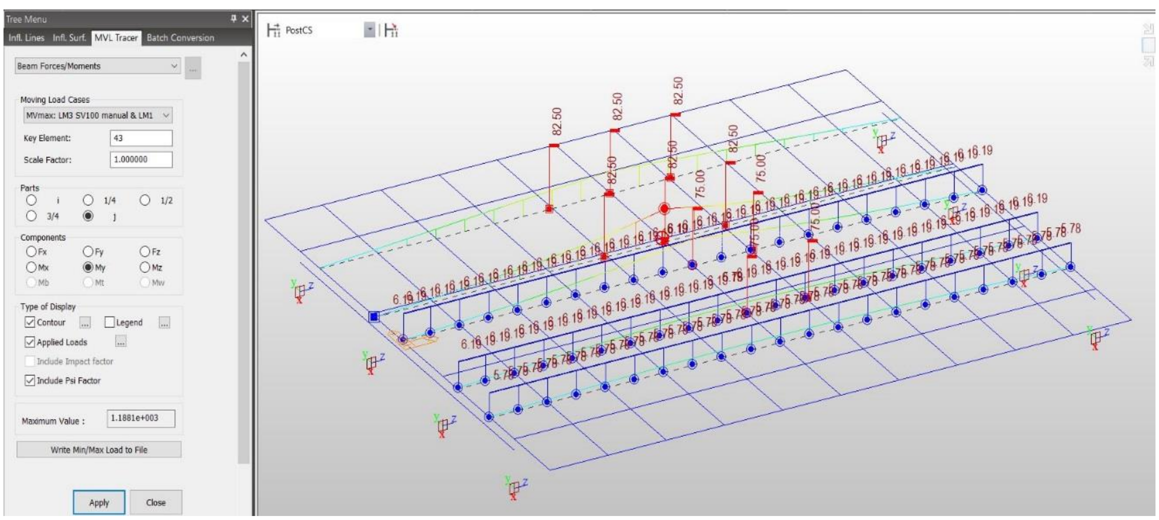


Figure B2.3 Traffic loading (Load Case 9) LM1 & LM3SV100 on separate lanes applied span 11.5m (B2.3a Maximum bending moment 1188.1kNm. (nodes 43j, 44i)).

B2.2 Span 17.5m

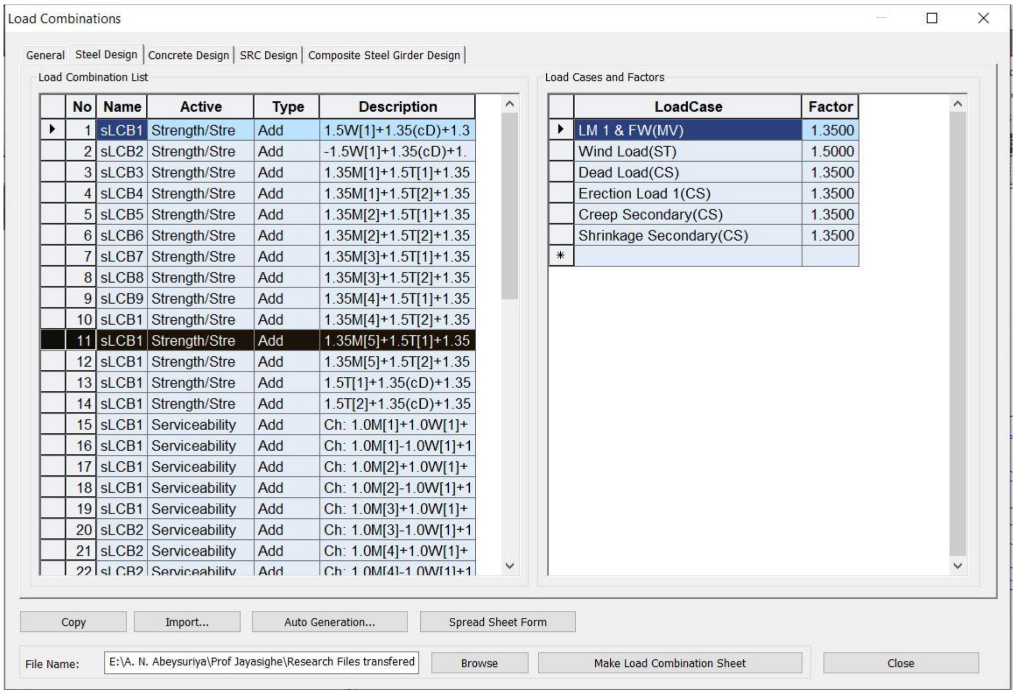


Figure B2.4 Load combination 11 for maximum midspan bending moment (76j, 77i) Span 17.5m

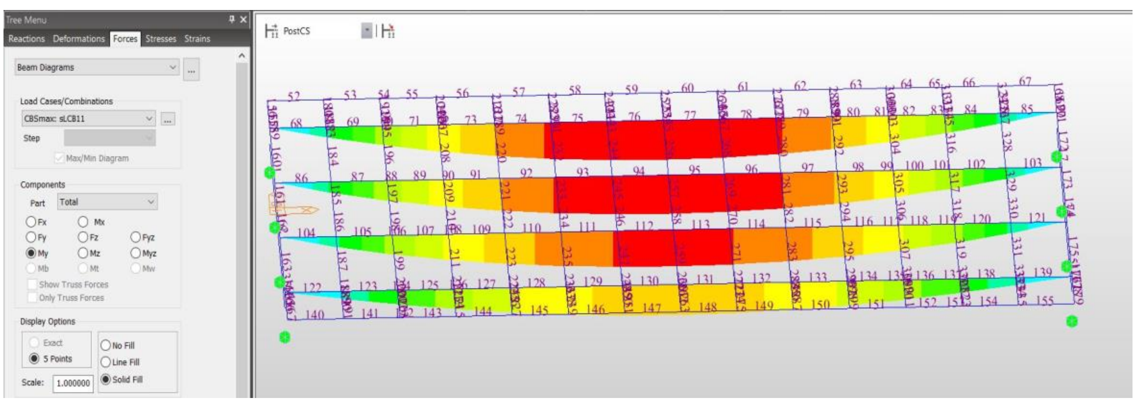


Figure B2.5 Bending Moment diagram Load Case 11. Span 17.5m

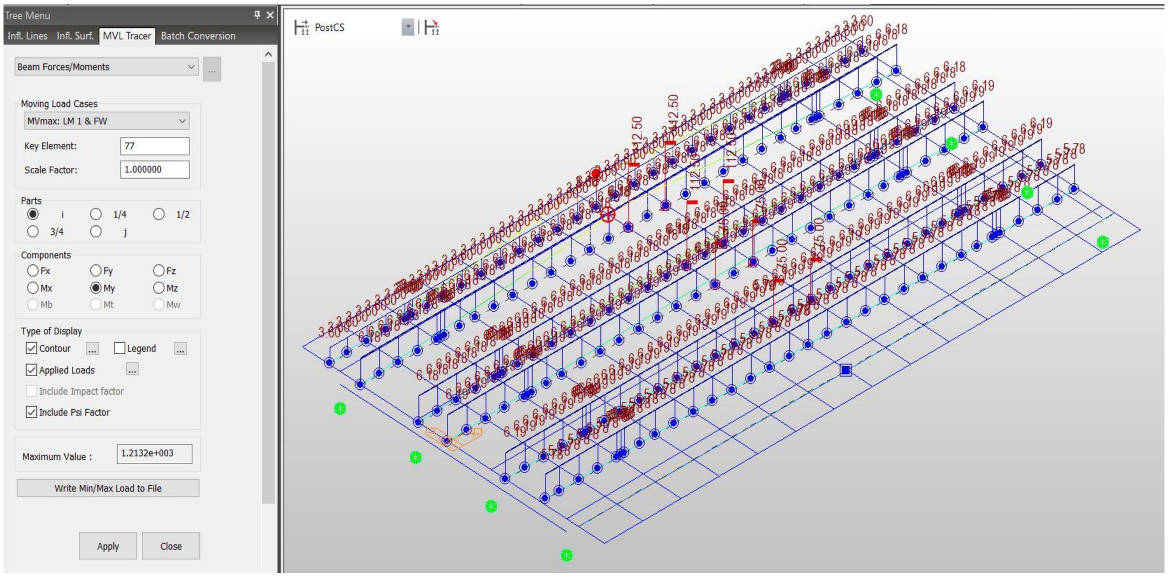


Figure B2.6 Traffic loading (Load Case 11) LM1 & FW applied span 17.5m.

(B2.6a Maximum bending moment 1213.2kNm. (nodes 76j, 77i) of edge beam).

B2.3 Span 31.5m

Load combination 5 applies to maximum shear (138j) and maximum bending moment (126i)

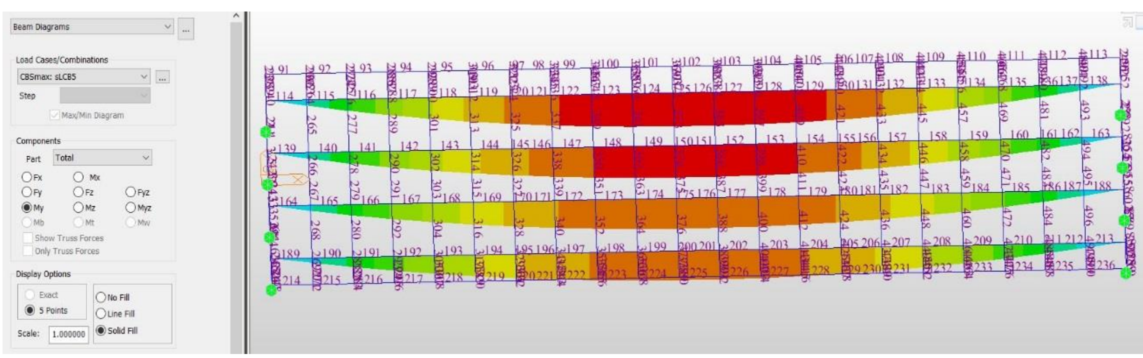


Figure B2.7 Bending Moment diagram Load Combination 5. Span 31.5m

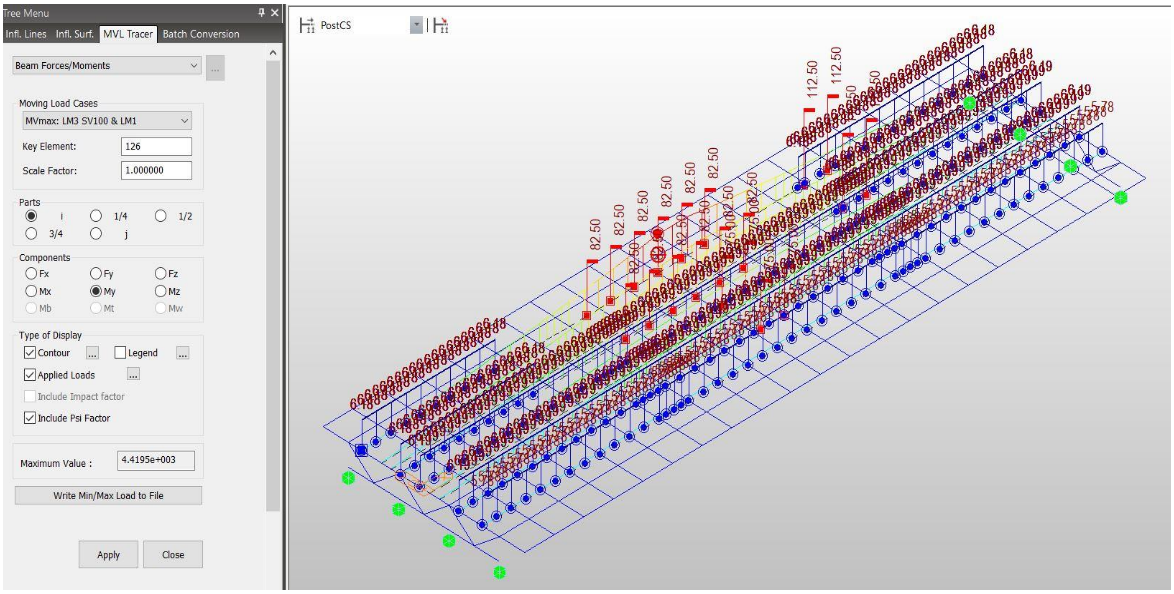


Figure B2.8 Traffic loading (Load combination 5) LM1 & LM3SV100 strading applied span 31.5m (B2.8a Maximum bending moment 4419.5kNm. (nodes 126i) of edge beam).

B2.4 Span 40m Ladder deck

Load combination 5 for maximum shear under section H1.4, at (57j) applies to maximum bending moment at (48i).

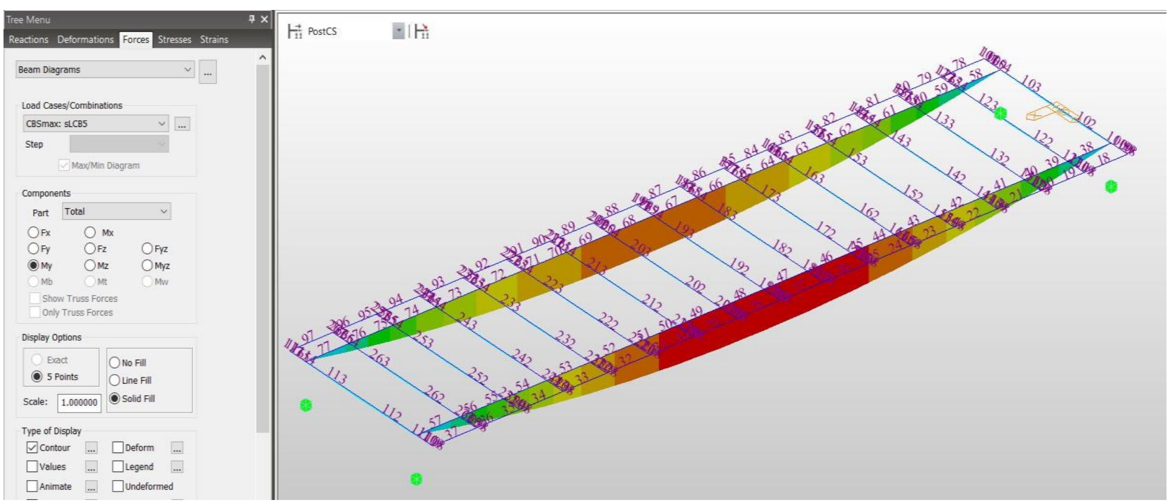


Figure B2.9 Bending Moment diagram Load Combination 5. Span 40m Ladder deck

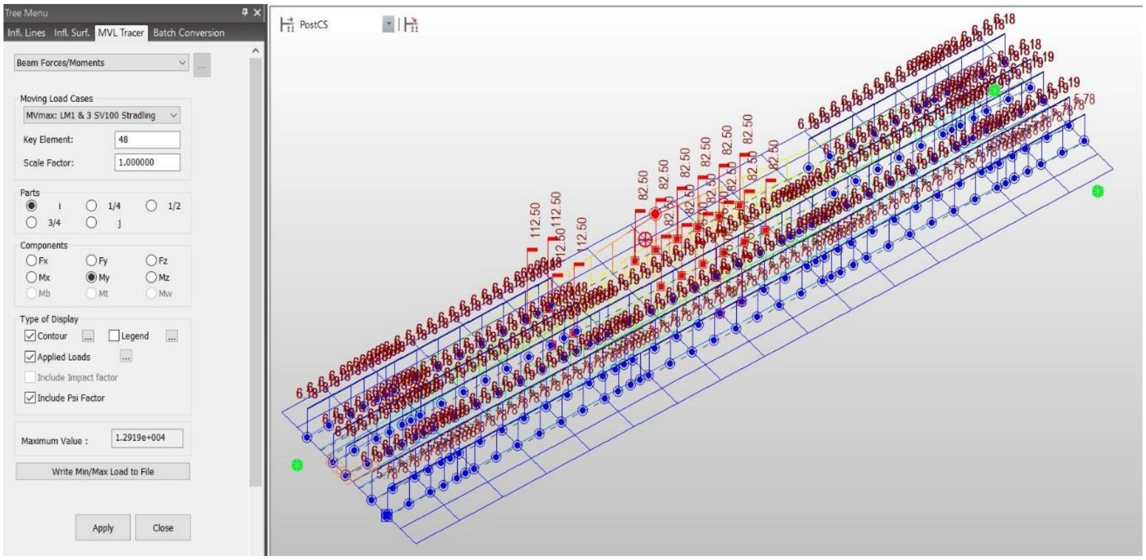


Figure B2.10 Traffic loading (Load combination 5) LM1 & LM3SV100 strading applied 40m Ladder deck (B2.10a Maximum bending moment 12919kNm (nodes 48i)).

B2.5 Span 50m Ladder deck

Load combination 5 for maximum shear under section H1.5, at (91j) applies to maximum bending moment at (82i).

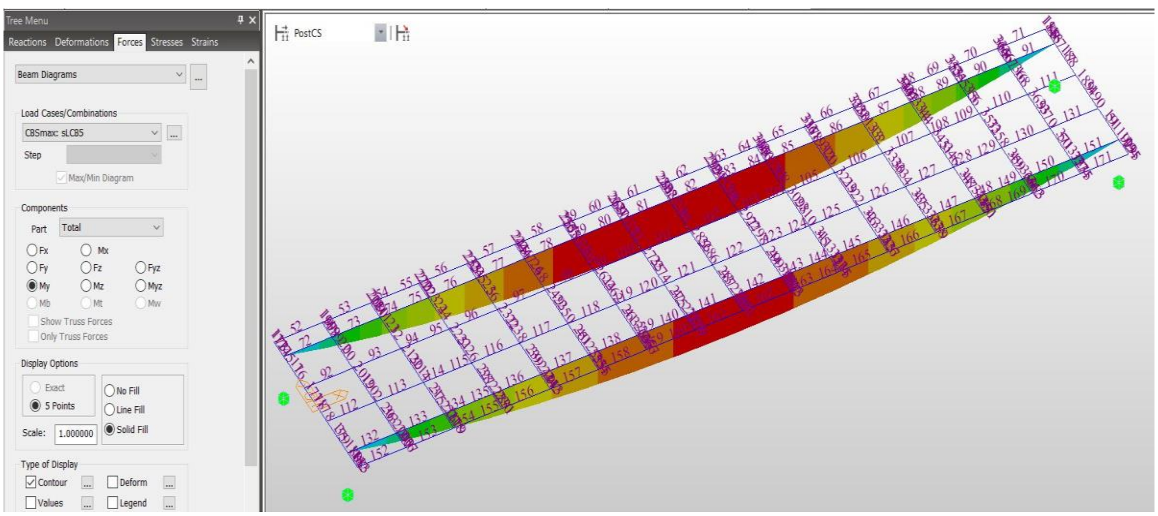


Figure B2.11 Bending Moment diagram Load Combination 5. 50m Ladder deck

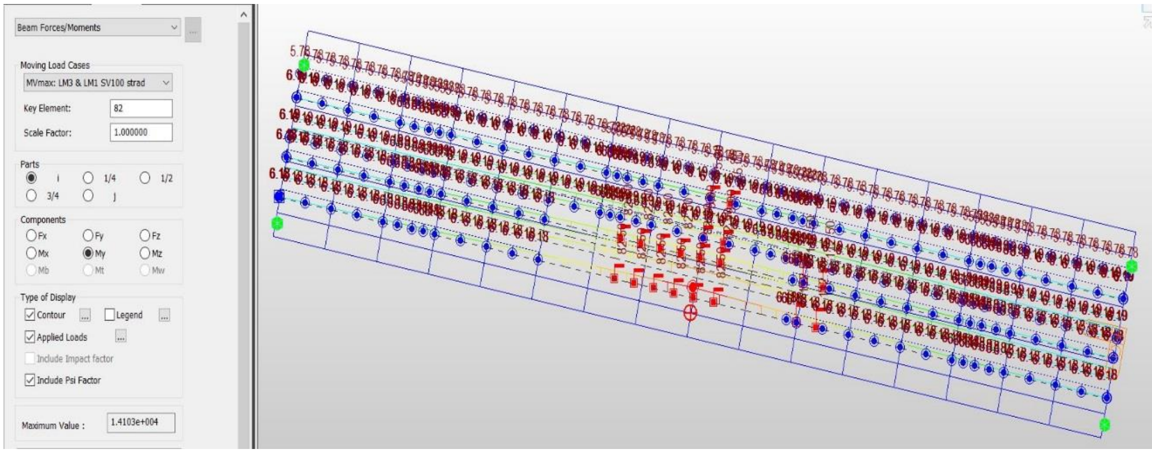


Figure B2.12 Traffic loading (Load combination 5) LM1 & LM3SV100 strading applied. span 50m Ladder deck (Maximum bending moment 14103kNm (nodes 82i)).

Appendix C

Cost analysis of pre-tensioned beams

C1 -Bridge deck construction - 7.1 in length Flat beam

Table C1 Estimate 7.1m deck

Item	Pay Item	Description	Quantity	Unit	Rate	Amount	Cost Rs/sqm
		SUPER STRUCTURE					
2.21	P(005)	Supply & Launching PSC Beams 7.01m Long	16.00	Nos.	83,246.35	1,331,941.60	18719.7965
2.22	1001(1)	Infiller concrete of Class A Grade 40(20mm) between beams in bridge deck inclusive of end make up, screed and camber	4.00	Cu.m	18,303.39	73,213.56	19748.7777
2.23	1011(1)	Concrete hand rail base	2.00	Cu.m	15,728.39	31,456.78	
2.24	1001(1)	Cold worked deformed high yield steel bars of Grade 460 in deck & footwalks	0.42	MT	248,000.00	104,160.00	
2.25	1002(1b)	Hot Rolled mild steel bars of Grade 250 in deck & footwalks	0.22	MT	248,050.00	54,571.00	
2.26	1008(1)	Formwork (smooth finish).	4.78	Sq.m	2,775.75	13,268.09	

2.27	1012(1)	Supply & fix 20mm dia 200mm long mild steel dowels	16.00	Nos.	189.61	3,033.76
2.28	1009(1)	Expansion joints with M.S angle iron and hard rubber	20.30	L.m.	7,770.10	157,733.03
2.29	1011(1)	Construction of Hand rail	14.02	L.m.	8,527.75	119,559.02
		Bridge Bearings				
2.30	1010(2)	75x12mm. hard rubber bearing pads supplied & laid over capping beam as per drawing.	20.30	L.m.	1,436.35	29,157.91
2.31	808(5)	Concrete guard stones supplied and fixed as per Drawing.	8.00	Nos	3,452.53	27,620.24
2.32	807(1)	Pre cast kerb in class B Grade 25(20) concrete with light reinforcement & mould as per drawings No T/B/106 Rev,11	14.02	lm	2,359.90	33,085.80
2.33	807(3)	lower kerbs in class B Grade 20 concrete cast insitu as per drawings	14.02	lm	1,443.90	20,243.48
2.34	1016(1a)	Service duct of size 450x450mm formed in deck as per drawings	7.85	lm	1,247.05	9,790.84
2.35	1017(1)	450x450x50mm thick cover slabs for service ducts in class B grade 25(20) concrete inclusice light reinforcement and smooth shuttering provided as per drawing	32.00	Nos	1,804.86	57,755.42

2.36	1016(1b)	Filling service ducts with sand at 1st stage construction	Item	PS		25,000.00	
2.37	1020(1)	Supplying & fixing 110mm dia PVC rain water outlets and 50mm dia PVC drain pipes as per drawings	1.97	lm	775.85	1,528.42	
2.37	1020(1)	Supplying & fixing 50mm dia PVC drain pipes as per drawings	2.64	lm	464.00	1,224.96	29434.9929
2.38	502(2)	MC cutback bituman (10-20%) or emulsiified bitumen grade CSS-1 or CSS 1h tack coat applied at the rate of 0.5 l/sq.m over the existing surface before applying bitumen bound base regulating course	53.63	sq.m	47.80	2,563.51	
2.39	506(2)	Asphaltic Concrete Surfacing compacted to a minimum thickness of 50mm in position	6.57	MT	10,284.80	67,571.14	
		TOTAL				**2,164,478.55**	30420.7016

C2. Bridge deck construction - 9.5m in length deck with infil concrete

Table C2 Estimate 9.5m deck

Item	Pay Item	Description	Quantity	Unit	Rate	Amount	Rs/sqm
		SUPER STRUCTURE					
2.21	P(005)	Supply & Launching PSC Beams 9.5 m Long	18.00	Nos.	110,093.60	1,981,684.80	21285.55
2.22	1001(1)	Infiller concrete of Class A Grade 40(20mm) between beams in bridge deck inclusive of end make up, screed and camber	27.60	Cu.m	18,303.39	505,173.56	26711.69
2.23	1011(1)	Concrete hand rail base	3.00	Cu.m	15,728.39	47,185.17	
2.24	1001(1)	Cold worked deformed high yield steel bars of Grade 460 in deck & footwalks	0.74	MT	248,000.00	183,520.00	
2.25	1002(1b)	Hot Rolled mild steel bars of Grade 250 in deck & footwalks	0.84	MT	248,050.00	208,362.00	
2.26	1008(1)	Formwork (smooth finish).	14.16	Sq.m	2,775.75	39,304.62	
2.27	1012(1)	Supply & fix 20mm dia 200mm long mild steel dowels	18.00	Nos.	189.61	3,412.98	
2.28	1009(1)	Expansion joints with M.S angle iron and hard rubber	19.60	L.m.	7,770.10	152,293.96	
2.29	1011(1)	Construction of Hand rail	19.00	L.m.	8,527.75	162,027.20	

		<u>Bridge Bearings</u>				
2.30	1010(2)	75x12mm. hard rubber bearing pads supplied & laid over capping beam as per drawing.	19.60	L.m.	1,436.35	28,152.46
2.31	808(5)	Concrete guard stones supplied and fixed as per Drawing.	8.00	Nos	3,452.53	27,620.24
2.32	807(1)	Pre cast kerb in class B Grade 25(20) concrete with light reinforcement & mould as per drawings No T/B/106 Rev,11	19.00	lm	2,359.90	44,838.10
2.33	807(3)	lower kerbs in class B Grade 20 concrete cast insitu as per drawings	19.00	lm	1,443.90	27,434.10
2.34	1016(1a)	Service duct of size 450x450mm formed in deck as per drawings	16.72	lm	1,247.05	20,850.68
2.35	1017(1)	500x450x100mm thick cover slabs for service ducts in class B grade 25(20) concrete inclusice light reinforcement and smooth shuttering provided as per drawing	42.00	Nos	2,305.01	96,810.22
2.36	1016(1b)	Filling service ducts with sand at 1st stage construction	Item	PS		25,000.00

2.37	1020(1)	Supplying & fixing 110mm dia PVC rain water outlets and 50mm dia PVC drain pipes as per drawings	4.04	lm	775.85	3,134.43	
2.37	1020(1)	Supplying & fixing 50mm dia PVC drain pipes as per drawings	2.40	lm	464.00	1,113.60	38216.09
2.38	502(2)	MC cutback bituman (10-20%) or emulsiified bitumen grade CSS-1 or CSS 1h tack coat applied at the rate of 0.5 l/sq.m over the existing surface before applying bitumen bound base regulating course	70.30	sq.m	47.80	3,360.34	
2.39	506(2)	Asphaltic Concrete Surfacing compacted to a minimum thickness of 50mm in position	8.61	MT	10,284.80	88,552.13	
		Total				**3,649,830.60**	39203.34

C3 - Bridge deck construction - 13.5m in length voided slab

Table C3 Estimate 13.5m deck

Item	Pay Item	Description	Quantity	Unit	Rate / Rs.	Amount /Rs.	**Cost/sqm**
		SUPER STRUCTURE					
2.21	P(005)	Supply & Launching PSC Beams 13.5 m Long	18.00	Nos.	159,489.55	2,870,811.90	21699.26
2.22	1001(1)	Infiller concrete of Class A Grade 40(20mm) between beams in bridge deck inclusive of end make up, screed and camber	45.37	Cu.m	18,303.39	830,424.80	27976.09
2.23	1011(1)	Concrete hand rail base	4.00	Cu.m	15,728.39	62,913.56	
2.24	1001(1)	Cold worked deformed high yield steel bars of Grade 460 in deck & footwalks	0.75	MT	248,000.00	186,000.00	
2.25	1002(1b)	Hot Rolled mild steel bars of Grade 250 in deck & footwalks	1.48	MT	248,050.00	367,114.00	
2.26	1008(1)	Formwork (smooth finish).	24.03	Sq.m	2,775.75	66,701.27	

2.27	1012(1)	Supply & fix 20mm dia 200mm long mild steel dowels	18.00	Nos.	189.61	3,412.98
2.28	1009(1)	Expansion joints with M.S angle iron and hard rubber	19.60	L.m.	7,770.10	152,293.96
2.29	1011(1)	Construction of Hand rail	27.00	L.m.	8,527.75	230,249.18
		Supply & lay polythene displacers of 150 mm dia	232.20	L.m.	63.44	14,731.52
		Bridge Bearings				
2.30	1010(2)	75x12mm. hard rubber bearing pads supplied & laid over capping beam as per drawing.	19.60	L.m.	1,436.35	28,152.46
2.31	808(5)	Concrete guard stones supplied and fixed as per Drawing.	8.00	Nos	3,452.53	27,620.24
2.32	807(1)	Pre cast kerb in class B Grade 25(20) concrete with light reinforcement & mould as per drawings No T/B/106 Rev,11	27.00	lm	2,359.90	63,717.30
2.33	807(3)	lower kerbs in class B Grade 20 concrete cast insitu as per drawings	27.00	lm	1,443.90	38,985.30

2.34	1016(1a)	Service duct of size 450x450mm formed in deck as per drawings	29.70	lm	1,247.05	37,037.39	
2.35	1017(1)	500x450x100mm thick cover slabs for service ducts in class B grade 25(20) concrete inclusice light reinforcement and smooth shuttering provided as per drawing	60.00	Nos	1,868.75	112,124.72	
2.36	1016(1b)	Filling service ducts with sand at 1st stage construction	Item	PS		25,000.00	
2.37	1020(1)	Supplying & fixing 110mm dia PVC rain water outlets and 50mm dia PVC drain pipes as per drawings	6.46	lm	775.85	5,011.99	
2.37	1020(1)	Supplying & fixing 50mm dia PVC drain pipes as per drawings	3.40	lm	464.00	1,577.60	38729.25
2.38	502(2)	MC cutback bituman (10-20%) or emulsiified bitumen grade CSS-1 or CSS 1h tack coat	99.90	sq.m	47.80	4,775.22	

		applied at the rate of 0.5 l/sq.m over the existing surface before applying bitumen bound base regulating course					
2.39	506(2)	Asphaltic Concrete Surfacing compacted to a minimum thickness of 50mm in position	12.24	MT	10,284.80	125,885.95	
		TOTAL				**5,254,541.35**	39716.87

C4. Bridge deck construction - 19.0 in length voided slab with infil concrete

Table C4 Estimate 19.0m deck

Item	Pay Item	Description	Quantity	Unit	Rate	Amount	Rs/sqm
		SUPER STRUCTURE					
2.21	P(005)	Supply & Launching PSC Beams 19.0 m Long	17.00	Nos.	272,632.93	4,634,759.85	24891.30
2.22	1001(1)	Infiller concrete of Class A Grade 40(20mm) between beams in bridge deck inclusive of end make up, screed and camber	97.62	Cu.m	18,303.39	1,786,776.93	34487.31
2.23	1011(1)	Concrete hand rail base	4.92	Cu.m	15,728.39	77,383.68	
2.24	1001(1)	Cold worked deformed high yield steel bars of Grade 460 in deck & footwalks	0.90	MT	248,000.00	223,200.00	

2.25	1002(1b)	Hot Rolled mild steel bars of Grade 250 in deck & footwalks	1.77	MT	248,050.00	439,048.50
2.26	1008(1)	Formwork (smooth finish).	40.47	Sq.m	2,775.75	112,334.60
2.27	1012(1)	Supply & fix 20mm dia 200mm long mild steel dowels	17.00	Nos.	189.61	3,223.37
2.28	1009(1)	Expansion joints with M.S angle iron and hard rubber	19.60	L.m.	7,770.10	152,293.96
2.29	1011(1)	Construction of Hand rail	38.00	L.m.	8,527.75	324,054.41
		Supply & lay polythene displacers of 225 mm dia	312.80	L.m.	51.63	16,150.49
		<u>Bridge Bearings</u>				
2.30	1010(2)	75x12mm. hard rubber bearing pads supplied & laid over capping beam as per drawing.	19.60	L.m.	1,436.35	28,152.46
2.31	808(5)	Concrete guard stones supplied and fixed as per Drawing.	8.00	Nos	3,452.53	27,620.24
2.32	807(1)	Pre cast kerb in class B Grade 25(20) concrete with light reinforcement & mould as per drawings No T/B/106 Rev,11	38.00	lm	2,359.90	89,676.20
2.33	807(3)	lower kerbs in class B Grade 20 concrete cast insitu as per drawings	38.00	lm	1,443.90	54,868.20
2.34	1016(1a)	Service duct of size 450x450mm formed in deck as per drawings	55.86	lm	1,247.05	69,660.21

2.35	1017(1)	500x450x100mm thick cover slabs for service ducts in class B grade 25(20) concrete inclusice light reinforcement and smooth shuttering provided as per drawing	84.00	Nos	1,868.75	156,974.61	
2.36	1016(1b)	Filling service ducts with sand at 1st stage construction	Item	PS		25,000.00	
2.37	1020(1)	Supplying & fixing 110mm dia PVC rain water outlets as per drawings	11.20	lm	775.85	8,689.52	
2.37	1020(1)	Supplying & fixing 50mm dia PVC drain pipes as per drawings	5.50	lm	464.00	2,552.00	44212.78
2.38	502(2)	MC cutback bituman (10-20%) or emulsiified bitumen grade CSS-1 or CSS 1h tack coat applied at the rate of 0.5 l/sq.m over the existing surface before applying bitumen bound base regulating course	140.60	sq.m	47.80	6,720.68	
2.39	506(2)	Asphaltic Concrete Surfacing compacted to a minimum thickness of 50mm in position	17.22	MT	10,284.80	177,104.26	
		TOTAL				**8,416,244.17**	45200.02

C5. Bridge deck construction - 25.0 in length Beam and Slab

Table C5 Estimate 25m deck

Item	Pay Item	Description	Quantity	Unit	Rate / Rs.	Amount / Rs.	Rs/sqm
		SUPER STRUCTURE					
2.21	P(005)	Supply & Launching PSC Beams 25.0 m Long	9.00	Nos.	735,978.52	6,623,806.65	27035.95
2.22	1001(1)	Class A Grade 40(20mm) between beams in bridge deck inclusive of end make up, screed and camber	61.90	Cu.m	18,303.39	1,132,979.84	45598.97
2.23	1011(1)	Concrete hand rail base	8.00	Cu.m	15,728.39	125,827.12	
2.24	1001(1)	Cold worked deformed high yield steel bars of Grade 460 in deck & footwalks	13.77	MT	248,000.00	3,414,960.00	45598.97
2.25	1002(1b)	Hot Rolled mild steel bars of Grade 250 in deck & footwalks	0.00	MT	248,050.00	0.00	
2.26	1008(1)	Formwork (smooth finish).	210.80	Sq.m	2,775.75	585,128.10	
2.27	1012(1)	Supply & fix 20mm dia 200mm long mild steel dowels		Nos.	189.61	0.00	
2.28	1009(1)	Expansion joints with M.S angle iron and hard rubber	19.60	L.m.	7,770.10	152,293.96	

2.29	1011(1)	Construction of Hand rail	50.00	L.m.	8,527.75	426,387.38
		Bridge Bearings				
2.30	1010(2)	75x12mm. hard rubber bearing pads supplied & laid over capping beam as per drawing.	19.60	L.m.	1,436.35	28,152.46
2.31	808(5)	Concrete guard stones supplied and fixed as per Drawing.	8.00	Nos	3,452.53	27,620.24
2.32	807(1)	Pre cast kerb in class B Grade 25(20) concrete with light reinforcement & mould as per drawings No T/B/106 Rev,11	50.00	lm	2,359.90	117,995.00
2.33	807(3)	lower kerbs in class B Grade 20 concrete cast insitu as per drawings	50.00	lm	1,443.90	72,195.00
2.34	1016(1a)	Service duct of size 400x230mm formed in deck as per drawings	50.00	lm	1,247.05	62,352.50
2.35	1017(1)	500x450x50mm thick cover slabs for service ducts in class B grade 25(20) concrete inclusice light reinforcement and smooth shuttering provided as per drawing	112.00	Nos	1,493.58	167,281.25

2.36	1016(1b)	Filling service ducts with sand at 1st stage construction	Item	PS		25,000.00	
2.37	1020(1)	Supplying & fixing 110mm dia PVC rain water outlets as per drawings	22.65	lm	775.85	17,573.00	
2.37	1020(1)	Supplying & fixing 50mm dia PVC drain pipes as per drawings	185.00	lm	464.00	85,840.00	53328.13
2.38	502(2)	MC cutback bituman (10-20%) or emulsiified bitumen grade CSS-1 or CSS 1h tack coat applied at the rate of 0.5 l/sq.m over the existing surface before applying bitumen bound base regulating course	185.00	sq.m	47.80	8,843.00	
2.39	506(2)	Asphaltic Concrete Surfacing compacted to a minimum thickness of 50mm in position	22.66	MT	10,284.80	233,053.57	
		TOTAL				**13,307,289.07**	54315.4656

Appendix D – Cost Analysis of Post-tensioned Beams and Decks

D1 recast estimate of 30m post tensioned beam deck analysis

Table D1 Post-tensioned beam 30m (estimated for 2020 HSR rates)

30 m post tension Beam Analysis - SD & CC

	A	B	C	D	E	F	G	H	I	J	K	L	M
3	Material	Unit	HSR Code	Quantity	2018 Rates			2020 Rates					
4					Rate /Rs.	Amount / Rs.	Total / Rs.	Rate /Rs.	Amount / Rs.	Total / Rs.			
5	Concrete (G50)	m^3	B0-385	25.27	20,000.00	505,400.00		22,000.00	555,940.00			B0-385	1.09
6	Cement	bags	B0-401	10.00	800.00	8,000.00		939.85	9,398.50				
7	15.7 mm strand wire	kg	B0-432	1,215.00	160.00	194,400.00		178.24	216,561.27		Tor Steel	B0-411A	1.11
8	Steel	kg	B0-411	4,800.00	120.00	576,000.00		133.68	641,663.03		Barbending	ST054	1.03
9	Binding wire	kg	B0-431	20.00	150.00	3,000.00		200.90	4,018.00				
10	Gunnies 50 %	m3	B0-632	35.00	105.00	1,837.50		105.00	3,675.00			B0-632	0.96
11	Grease	kg	B0-616	15.00	450.00	6,750.00		711.95	10,679.25				
12	Diesel	l	B0-612	15.00	122.00	1,830.00		104.00	1,560.00				
13	Cotton waste	kg	B0-633	5.00	30.00	150.00		40.00	200.00				
14	End block		B0-411A	2.00	200,000.00	400,000.00		220,000.00	440,000.00			B0-411A	1.11
15	Cover block	Item	B0-385			500.00			550.00				
16	Grinding wheel	Item	10% increase/year			1,000.00			1,200.00				
17	Timber support & wedges	Item	10% increase/year			1,500.00			1,800.00				steel products
18	Nuts & bolts	kg		15.00	300.00	4,500.00		330.00	4,950.00			B0-411A	1.11
19	Distribution plates	Nos		6.00	1,200.00	7,200.00		1,320.00	7,920.00			B0-411A	
20	Duct tube	m		210.00	300.00	63,000.00		330.00	69,300.00			B0-411A	
21	Spacer grills	Nos		140.00	50.00	7,000.00		55.00	7,700.00			B0-411A	
22	Barrels	Nos		56.00	60.00	3,360.00		66.00	3,696.00			B0-411A	
23	Wedges	Nos		56.00	85.71	4,799.76	1,790,227.26	94.28	5,279.74	1,986,090.79		B0-411A	
24									-				
25	**Labour**								-				
26	Bending	kg	B0-003	4,800.00	8.00	38,400.00		8.80	42,240.00			B0-003	1.06
27									-				
28	Tying								-				
29	Mould fixing & concreting	kg		4,800.00	14.00	67,200.00		15.40	73,920.00				
30	Grouting	skilled	B0-002	15.00	1,547.00	23,205.00		2,200.00	33,000.00				
31		unskilled	B0-003			12,000.00		1,650.00	12,732.63				
32		unskilled	B0-004	6.00	1,424.00	8,544.00		1,527.34	9,164.04				
33	Staking	unskilled	B0-004	6.00	1,424.00	8,544.00		1,527.34	9,164.04				
34		skilled	B0-002	4.00	1,547.00	6,188.00		2,200.00	8,800.00				
35	Neat finishing & preparing	skilled	B0-002	2.00	1,547.00	3,094.00		2,200.00	4,400.00				
36	Crane operator	skilled	B0-001	1.00	1,547.00	1,547.00		2,500.00	2,500.00				

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
37	Welder	skilled	B0-001	1.00	1,547.00	1,547.00		2,500.00	2,500.00					
38	Loading	unskilled	B0-004	12.00	1,424.00	17,088.00		1,527.34	18,328.08					
39	Curing	unskilled	B0-004	1.00	1,424.00	1,424.00	188,781.00	1,527.34	1,527.34	218,276.13				
40	Land & Bed cost 10000/3	Item					3,333.33		-	3,633.62		B0-385		
41	Mould cost 2500000/30	Item					83,333.33		-	92,833.19		B0-411A		
42	Crane (02 nos)	Item					60,000.00		-	66,000.00		B0-146A	1.07	
43	Concrete mixer	Item					3,000.00		-	3,300.00		B0-102	1.08	
44	Dumpers	Item					2,000.00		-	2,200.00		B0-132, B0-002	1.09	
45	New St.Jack 11000000/40 nos x (50%)	Item					137,500.00		-	152,625.00		B0-411A		
46							**477,947.66**		-	**538,867.94**				
47	Add 10% from material						179,022.73		-	198,609.08				
48	for/machinery/electricity/ water								-					
49	Add 5% from labour cost for tools						23,897.38		-	26,943.40				
50	Sub total						2,471,095.03		-	2,750,511.21				
51									-					
52	Add 10% Overhead						247,109.50		-	275,051.12				
53	Add 30% profit						741,328.51		-	825,153.36		**Cost Rs/sqm**		**Cost Rs/sqm**
54							**3,459,533.04**			**2,750,511.21**				**without profit 30%**
55														
56	**TOTAL**						**3,459,533.04**			**3,850,715.69**				
57								5 Beams		19,253,578.45		61710.19		**48486.58**
58	For Deck 10.4m wide							**Slab (As for Katugasthota Bridge, with 40% OH&profit)**				20,066.13		**15,766.25**
59	No of beams 2m C/C, 1.2m cantilever							Total (Beam+slab)				**81,776.32**		**64,252.82**
60														
61								**Launching**	Plant	510,000.00	1.50	765,000.00		
62									Labour B0-003	170,000.00	3.092088	525,654.96		**22,751.93**
63									Cost of a beam including launching			**4,041,166.17**		
64									OH&Profit 40%			1,616,466.47		
65									Total (Beam+launching)			**5,657,632.64**		
66											**Cost Rs/sqm**	**90667.19**		**71238.51**
67								**Beam&slab**	Cost of a beams including launching			20,205,830.85		
68									Slab (As for Katugasthota Bridge)			4,471,880.40		
69									Total Cost			24,677,711.25		
70			**Cost calculation for the slab**						OH & Profit 40%			9,871,084.50		
71									Total (Beam+launching+slab)			34,548,795.75		
72		Slab unit length / m		1							**Cost Rs/sqm**	**110733.32**		**87004.75**
73		Slab unit width / m		1										

Deck Slab

Item	Description	Code	Unit	Quantity	Rate / Rs.	Amount / Rs.
1	Supply and fixi	ST1-061	m^2	1	2,713.90	2,713.90
2	Grade 40 (19)	B0- 380 , T1-007A , ST1-053 , B0-003 & B0-106	m^3	0.25	18,303.39	4,575.85
3	Reinforcement	ST1-055	kg	28.4	248.00	7,043.20
						14,332.95

D2 Recast estimate 32.5m post-tensioned beam deck analysis

Table D2 Katugasthota bridge post-tensioned girders 32.5m long (estimated with 2020 rates).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1			Katugasthota Bridge 32.5 m beam										
2													
3	Material	Unit	HSR Code	Quantity	2008 Rates		2020 Rates						
4					Rate /Rs.	Amount / Rs.	Rate /Rs.	Amount / Rs.					
5	Moulds	Item				30,000.00		36,000.00		B0-411A	1.24		
6	NO of bolts	Item				10,000.00		15,418.27		B0-432	1.541827		
7	Bed Preperation	Item				27,500.00		41,473.77		B0-382	1.508137	Gr25 Conc	
8	Laying base plates	SK labour day	B0-001	5.00	1,000.00	5,000.00	4,000.00	20,000.00		B0-001	4		
9	Timber 2" x 5"	ft	B0-391	62.50	100.00	6,250.00	221.11	13,819.44		B0-391	2.211111		
10	Rubber Pads	ft		8.34	75.00	625.50	167.89	1,400.20		ST-122	2.238526		
11	Reinforcements	Ton	ST1-055	3.30	150,000.00	495,000.00	248,000.00	818,400.00		ST1-055	1.642384		
12	Binding wires	kg	B0-431	25.00	180.00	4,500.00	275.31	6,882.76		B0-431	1.529501		
13	Barbending & bonding	kg		66.00	1,000.00	66,000.00	3,092.09	204,077.81		B0-003	3.092088		
14	Welder	Days	B0-001	1.00	1,000.00	1,000.00	2,500.00	2,500.00					
15	Hts stands cutting	USK labour day	B0-004	7.00	1,000.00	7,000.00	1,527.34	10,691.38					
16	Hts stands fixing	USK labour day	B0-004	8.00	1,000.00	8,000.00	1,527.34	12,218.72					
17	Hts stands fixing	USK labour day	B0-004	3.00	1,000.00	3,000.00	1,527.34	4,582.02					
18	Duct 50mm dia	m		20.00	350.00	7,000.00	375.00	7,500.00					
19	Duct 70mm dia	m		240.00	500.00	120,000.00	525.00	126,000.00					
20						**790,875.50**		**1,320,964.37**					
21													
22	Anchors	Nos		12.00	2,000.00	24,000.00	3,284.77	39,417.22		ST1-055	1.642384		
23	Cable HTS	m		1,500.00	130.00	195,000.00	168.41	252,617.04		B0-432	1.295472		
24	Concrete (G50)	m3	B0-385 , T-007A	27.00	14,900.00	402,300.00	22,337.86	603,122.27		B0-385	1.499185	Gr 40 Conc	
25	Air compressor	hrs	B0-156	4.00	800.00	3,200.00	1,251.50	5,005.98		B0-156	1.56437		
26	Labour	Nos	B0-002	7.50	1,000.00	7,500.00	3,892.15	29,191.14		B0-002	3.892152		
27	Shutter vibrator	hrs		24.00	400.00	9,600.00	625.75	15,017.95		B0-156	1.56437		
28	Electrician	Days	B0-001	1.00	1,000.00	1,000.00	2,500.00	2,500.00					
29	Mould ifxing	Days	B0-002	30.00	1,000.00	30,000.00	2,200.00	66,000.00					
30	Crane	hrs	B0-146A	16.00	2,500.00	40,000.00	4,424.12	70,785.94		B0-146A	1.769649		
31	Mould removing	Days	B0-002	10.00	1,000.00	10,000.00	3,892.15	38,921.52		B0-002	3.892152		
32	Crane	hrs	B0-146A	8.00	2,500.00	20,000.00	4,424.12	35,392.97					
33	Stressing , Electrcian & Mechanic	Nos		2.00	1,000.00	2,000.00	2,500.00	5,000.00		B0-001			
34	Bearing plates	Nos		12.00	4,000.00	48,000.00	4,986.87	59,842.40		B0-411	1.246717		
35	Jack	Days		2.00	25,000.00	50,000.00	31,167.92	62,335.83		B0-411			
36	Vedges sets	Nos		85.00	500.00	42,500.00	623.36	52,985.46		B0-411			
37	Labour	Days	B0-002	14.00	1,000.00	14,000.00	2,200.00	30,800.00					
38	End concrete cement	bags	B0-401	2.00	700.00	1,400.00	939.85	1,879.70					
39	*Labour*	Days	B0-002	6.00	1,000.00	6,000.00	2,200.00	13,200.00					
40	*Forms*	Item	1.5			2,000.00		3,000.00					

	A	B	C	D	E	F	G	H	I	J	K	L
41	*CM/PV*	Item	1.5			1,500.00		2,250.00				
42						**910,000.00**		**1,389,265.42**				
43												
44	Grouting	days	B0-002	10.00	1,000.00	10,000.00	2,200.00	22,000.00				
45	Pumps	Item				2,500.00		3,912.67		B0-104	1.56507	
46	Cement	bags	B0-401	14.00	650.00	9,100.00	939.85	13,157.90				
47	Air compressor	days	B0-156	1.00	7,500.00	7,500.00	11,732.77	11,732.77		B0-156	1.56437	
48	Labour Elec / Mecha 1 day	days	B0-001	1.00	2,000.00	2,000.00	2,500.00	2,500.00				
49								-				
50	Finishing labour	days	B0-002	2.00	1,000.00	2,000.00	2,200.00	4,400.00				
51	Cement	bags	B0-401	1.00	650.00	650.00	939.85	939.85				
52												
53	Base plate removal	days	B0-002	10.00	1,000.00	10,000.00	2,200.00	22,000.00				
54	Jacks	nos	1.5	6.00	500.00	3,000.00	750.00	4,500.00				
55	Curing	days	B0-004	3.50	1,000.00	3,500.00	1,527.34	5,345.69				
56												
57	Horizontal movement	days	B0-004	12.00	1,000.00	12,000.00	1,527.34	18,328.08				
58						**62,250.00**		**108,816.96**				
59	Additional labour					-						
60	Welder	days	B0-001	3.00	1,000.00	3,000.00	2,500.00	7,500.00				
61	Electrician	days	B0-001	4.00	1,000.00	4,000.00	2,500.00	10,000.00				
62	Mechanical	days	B0-001	5.00	1,000.00	5,000.00	2,500.00	12,500.00				
63	Crane	hrs	B0-001	12.00	2,500.00	30,000.00	2,500.00	30,000.00				
64						**42,000.00**		**60,000.00**				
65						**1,805,125.50**		**2,879,046.75**				
66	ADD 10% OH							287,904.68				
67	ADD 30% Profit							863,714.03				
68	TOTAL								**4,030,665.45**			
69							5 beams		20,153,327.27		59625.23	
70	BOQ Launching Rs 680,000/beam	Plant	510,000.00	1.50	765,000.00		Slab (As for Katugasthota Bridge)				14332.95	
71		Labour B0-003	170,000.00	3.092088003	525,654.96			TOTAL			**73958.18**	
72		Total			**4,169,701.71**							
73		OH&Profit 40%			1,667,880.69							
74		Total			**5,837,582.40**							
75					**Cumulative Cost /sqm**							
76		Beam	Erection	Slab/sqm	**5 Beams**	**Erection**	**Slab**					
77		2,879,046.75	1,290,654.96	14,332.95	42,589.45	61,681.98	76,014.93					
78	ADD 10% OH	3,166,951.43	1,419,720.46	15,766.25	**46,848.39**	**67,850.18**	**83,616.42**					
79	ADD 30% Profit	3,742,760.78	1,677,851.45	18,632.84	55,366.28	80,186.57	98,819.41					
80	TOTAL with 40%	4,030,665.45	1,806,916.94	20,066.13	59,625.23	86,354.77	106,420.90					
81												

D3. Recast estimate post tensioned beam deck 48m

Table D3 Kallady Bridge Post-tensioned Box girders 48m long (estimated to 2020 HSR rates)

Kallady Bridge - Cost analysis of casting of a box beam (48m)

2010

No	Item	Qty	HSR code	Unit	2008 Rates Rate / Rs.	2008 Rates Amount / Rs.	2020 Rates Rate / Rs.	2020 Rates Amount / Rs.	K	L	M
1.0	**Cost for beam bed**	1/5		no	1,117,650.00	223,530.00	1,651,180.83	330,236.17	B0-382	1.47736843	Gr25 Conc
2.0	**Cost for inner mould**	1/18		no	2,538,510.00	141,028.33	3,594,757.37	199,708.74	B0-411A	1.42	
3.0	**Cost for outer mould**	1/18		no	2,462,891.00	136,827.28	3,487,674.10	193,759.67	B0-411A	1.42	
4.0	**End mould**	1/27		no	61,525.00	2,278.70	87,124.91	3,226.85	B0-411A	1.42	
5.0	**Cost for Reinforcement work**							-			
5.1	Labour cost for bar bending & Binding	6,300.00		kg	13.00	81,900.00	33.63	211,880.09	B0-003	2.587058436	
5.2	Cost for bar bending machine	1.00		no	750.00	750.00	1,500.00	1,500.00		2	
5.3	Steel reinforcement.	6,300.00	B0-411	kg	107.00	674,100.00	132.90	837,270.00			
5.4	Binding wire	100.00	B0-431	kg	125.00	12,500.00	200.90	20,090.00			
5.5	Labour cost for bar binding										
5.6	cost for plant and machinery	1.00		sum	3,000.00	3,000.00	4,500.00	4,500.00		1.5	
6.0	**Fixing of inner mould**										
6.1	Labour cost	30.00	B0-003	day	850.00	25,500.00	2,199.00	65,969.99	B0-003	2.587058436	
6.2	Machine cost										
6.3	Crane	8.00	B0-146A	hour	3,000.00	24,000.00	4,619.38	36,955.06	B0-146A	1.539793999	
6,4	lorry	1.00	B0-125	day	5,000.00	5,000.00	6,324.44	6,324.44	B0-125	1.264887064	
6.6	Mould oil	10.00	B0-602	liter	184.00	1,840.00	490.67	4,906.67	B0-602	2.666666667	
6.7	Sponge sheets	20.00		no	350.00	7,000.00	525.00	10,500.00		1.5	
6.8	Nut and bolts	180.00	B0-432	kg	350.00	63,000.00	447.24	80,502.65	B0-432	1.277819833	
6.9	Tools	3.00		no	400.00	1,200.00	511.13	1,533.38	B0-432	1.277819833	
7.0	**Fixing of duct**										
7.1	Ductsheaths	500.00		m	584.00	292,000.00	700.80	350,400.00		1.2	
7.2	Duct collars	100.00		no	127.00	12,700.00	152.40	15,240.00		1.2	
7.3	welding plant	1.00	B0-105	hr	800.00	800.00	1,272.44	1,272.44	B0-105	1.590551375	
7.4	Welding rod	20.00		kg	210.00	4,200.00	252.00	5,040.00		1.2	
7.5	Labour cost	16.00	B0-003	day	850.00	13,600.00	2,199.00	35,183.99	B0-003	2.587058436	
8,0	**Strand wire**							-			
8.1	Strand	5,148.00		kg	130.00	669,240.00	170.00	875,160.00	SD&CC estimate		
8.2	Labour cost	15.00	B0-003	day	850.00	12,750.00	2,199.00	32,985.00	B0-003	2.587058436	
8.3	Machinerry(grinder)	1.00		sum	1,500.00	1,500.00	3,000.00	3,000.00		2	
9	**Anchor cones**	20.00		no	1,445.00	28,900.00	2,046.25	40,924.99	B0-411A	1.416089505	

	A	B	C	D	E	F	G	H	I	J	K	L	M
34	8.3	Machinerry(grinder)	1.00		sum	1,500.00	1,500.00	3,000.00	3,000.00			2	
35	9	**Anchor cones**	20.00		no	1,445.00	28,900.00	2,046.25	40,924.99		B0-411A	1.416089505	
36	10.0	**Fixing of outer mould**							-				
37	10.1	Labour cost	36.00	B0-003	day	850.00	30,600.00	2,199.00	79,163.99		B0-003	2.587058436	
38	10.2	Machine cost							-				
39	10.21	Crane	24.00	B0-146A	hour	3,000.00	72,000.00	4,619.38	110,865.17		B0-146A	1.539793999	
40	10.22	Lorry	1.00	B0-125	day	5,000.00	5,000.00	6,324.44	6,324.44		B0-125	1.264887064	
41	10.30	Tie rods	20.00		no	763.00	15,260.00	1,080.48	21,609.53		B0-411A	1.416089505	
42	10.4	Mould oil	10.00	B0-602	liter	184.00	1,840.00	490.67	4,906.67		B0-602	2.67	
43	10.5	Sponge sheets	30.00		no	350.00	10,500.00	525.00	15,750.00			1.5	
44	10.6	Nut and bolts	70.00	B0-432	kg	350.00	24,500.00	447.24	31,306.59		B0-432	1.277819833	
45	10.7	2"*2" Timber	40.00	B0-391	ft	60.00	2,400.00	119.51	4,780.35		B0-391	1.991810737	
46	10.8	Tools	3.00		no	400.00	1,200.00	566.44	1,699.31		B0-411A	1.416089505	
47	11.0	**Alling of the mould/ flat form work**						-	-				
48	11.1	Acrow jacks	240.00		no	42.00	10,080.00	59.48	14,274.18		B0-411A	1.416089505	
49	11.2	screw jacks	240.00		no	21.00	5,040.00	29.74	7,137.09		B0-411A	1.416089505	
50	11.3	Labour cost	30.00	B0-004	day	850.00	25,500.00	2,199.00	65,969.99		B0-003	2.587058436	
51									-				
52	12.0	**Concreting**							-				
53	12.1	Redy mix Concrete	62.00	B0-385 , T1007A	m3	23,100.00	1,432,200.00	33,219.61	2,059,615.57		B0-385	1.43807818	Gr 40 Conc
54	12.2	Truck mixture							-				
55	12.3	Pump car							-				
56	12.4	Labour	40.00	B0-003	no	850.00	34,000.00	2,199.00	87,959.99		B0-003	2.587058436	
57	12.5	Poker vibrator	2.00	B0-106	no	700.00	1,400.00	1,129.08	2,258.16		B0-106	1.612967894	
58	12.6	Shutter vibrator	6.00		no	1,200.00	7,200.00	1,500.00	9,000.00			1.25	
59	12.7	Expenditure for foods	1.00		no	400.00	400.00	600.00	600.00			1.5	
60	13.0	**Demoulding(Inner and end mould)**							-				
61	13.1	Labour cost	16.00	B0-003	no	850.00	13,600.00	2,199.00	35,183.99		B0-003	2.587058436	
62	13.2	Tools	2.00		no	400.00	800.00	566.44	1,132.87		B0-411A	1.416089505	
63	14.0	**Demoulding(Outer mould)**							-				
64	14.1	Labour cost	10.00	B0-003	no	850.00	8,500.00	2,199.00	21,990.00		B0-003	2.587058436	
65	14.2	Machine cost							-				
66	14.21	Crane	8.00	B0-146A	hour	3,000.00	24,000.00	4,619.38	36,955.06		B0-146A	1.539793999	
67	14.22	lorry or tractor	1.00	B0-117	day	5,000.00	5,000.00	7,906.52	7,906.52		B0-117	1.581303935	

	A	B	C	D	E	F	G	H	I	J	K	L	M
68	14.3	Tools	2.00		no	800.00	1,600.00	1,132.87	2,265.74		B0-411A	1.416089505	
69	15.0	**Cleaning of the mould**							-				
70	15.1	Labour cost	16.00	B0-003	day	850.00	13,600.00	2,199.00	35,183.99		B0-003	2.587058436	
71	16.0	**Cleaning of the nut and bolts**							-				
72	16.1	Labour	6.00	B0-003	day	850.00	5,100.00	2,199.00	13,194.00		B0-003	2.587058436	
73	16.2	Tools			sum	1,500.00	1,500.00	2,124.13	2,000.00		B0-411A	1.416089505	
74	13.0	**Electricity**	1.00		sum	20,000.00	20,000.00	28,493.15	28,493.15		B0-612	1.424657534	
75	14.0	**Curing**							-				
76	14.1	Labour	7.00	B0-003	day	850.00	5,950.00	2,199.00	15,393.00		B0-003	2.587058436	
77	14.2	water pump	7.00	B0-133A	day	350.00	2,450.00	501.87	3,513.11		B0-133A	1.433921057	
78	14.3	kerosine	21.00	B0-601	liter	110.00	2,310.00	216.07	4,537.50		B0-601	1.964285714	
79	14.4	Guny bags	210.00	B0-632	no	50.00	10,500.00	64.80	13,607.62		B0-632	1.295964126	
80	14.5	water pipe line			sum	400.00	400.00	800.00	800.00			2	
81	15.0	**Preparing cover blocks**											
82	15.1	concrete(G 50)	0.25	B0-385 , T1007A	m3	12,950.00	3,237.50	18,623.11	4,655.78		B0-385	1.43807818	Gr 40 Conc
83	15.2	Labour	6.00	B0-003	day	850.00	5,100.00	2,199.00	13,194.00		B0-003	2.587058436	
84	16.0	Beam lifting							-				
85	16.1	Labour	12.00	B0-004	day	850.00	10,200.00	2,199.00	26,388.00		B0-003	2.587058436	
86	16.2	Jack	2.00		no	1,000.00	2,000.00	1,500.00	3,000.00			1.5	
87	17.0	beam shifing							-				
88	17.1	Labour	36.00	B0-004	day	850.00	30,600.00	2,199.00	79,163.99		B0-003	2.587058436	
89	17.2	Equipments	1.00		sum	1,000.00	1,000.00	1,500.00	1,500.00			1.5	
90	18.0	other expenditure(labour)							-				
91	18.1	water supply for labour (for bouser)	3.50		day	5,000.00	17,500.00	2,987.94	10,457.80		B0-128	0.59758861	
92	18.2	Accomadation facilities			sum	9,000.00	9,000.00	18,000.00	10,000.00			2	
93	18.3	other expenditure(site staff)			sum	31,500.00	31,500.00	63,000.00	35,000.00			2	
94			Sub total				4,343,711.81		6,296,807.28				
95			over head(10%)				434,371.18		629,680.73				
96			Vat 12 %				573,369.96		831,178.56				
97			Total				**5,351,452.95**		**7,757,666.57**				
98													
99		Sub Total					4,343,711.81		6,296,807.28				
100		Stresssing, grouting,finishing					43,788.19		65,682.29			1.5	
101		TOTAL A					**4387500.00**		**6,362,489.57**				

102														
103	BOQ	Launching - Plant	0.75			877500			1491750.00			1.7		
104		Launching - Labour	0.25			292500			756714.59		B0-003	2.587058436		
105		TOTAL B (LAUNCHING)				1170000.00			2248464.59					
106														
107		TOTAL A+B					**5557500.00**		**8610954.16**					
108														
109	**Actual launching cost - sub contractor**						Labour	Plant						
110		US $	51681			5546404.92								
111		SLR	2116295.67			2116295.67								
112						**7662700.59**	1915675.15	5747025.44	**13805198.84**					
113														
114														
115														
116														
117														
118					**Cumulative Cost /sqm**					**Cumulative Cost /sqm (Actual)**				
119		Beam	Erection	Slab/sqm	**9 Beams**	**Erection**	**Slab**		Beam	Erection	Slab/sqm	**9 Beams**	**Erection**	**Slab**
120		6362489.57	2248464.59	14332.95	85211.91	115325.28	129658.23		6362489.57	13805198.84	13819531.79	85211.91	270102.97	284435.92
121	ADD 10% OH	6998738.52	2473311.05	15766.25	**93733.11**	**126857.81**	**142624.05**		6998738.52	15185718.72	15200051.67	**93733.11**	**297113.27**	**312879.51**
122	ADD 30% Profit	8271236.43	2923003.97	18632.84	110775.49	149922.86	168555.70		8271236.43	17946758.49	17961091.44	110775.49	351133.86	369766.70
123	TOTAL with 40%	8907485.39	3147850.43	20066.13	119296.68	161455.39	181521.52		8907485.39	19327278.37	19341611.32	119296.68	378144.16	398210.29

Deck Slab

Item	Description	Code	Unit	Quantity	Rate / Rs.	Amount / Rs.
1	Supply and fixing of smooth finish formw	ST1-061	m^2	1	2,713.90	2,713.90
2	Grade 40 (19) concrete	B0- 380 , T1-007A , ST1-053 , B0-003 & B0-106	m^3	0.25	18,303.39	4,575.85
3	Reinforcement tor steel	ST1-055	kg	28.4	248.00	7,043.20
						14,332.95

Appendix E- Kallady Bridge Drawings Figure E 1.1 Kallady Bridge – Plan, Elevation and Cross section

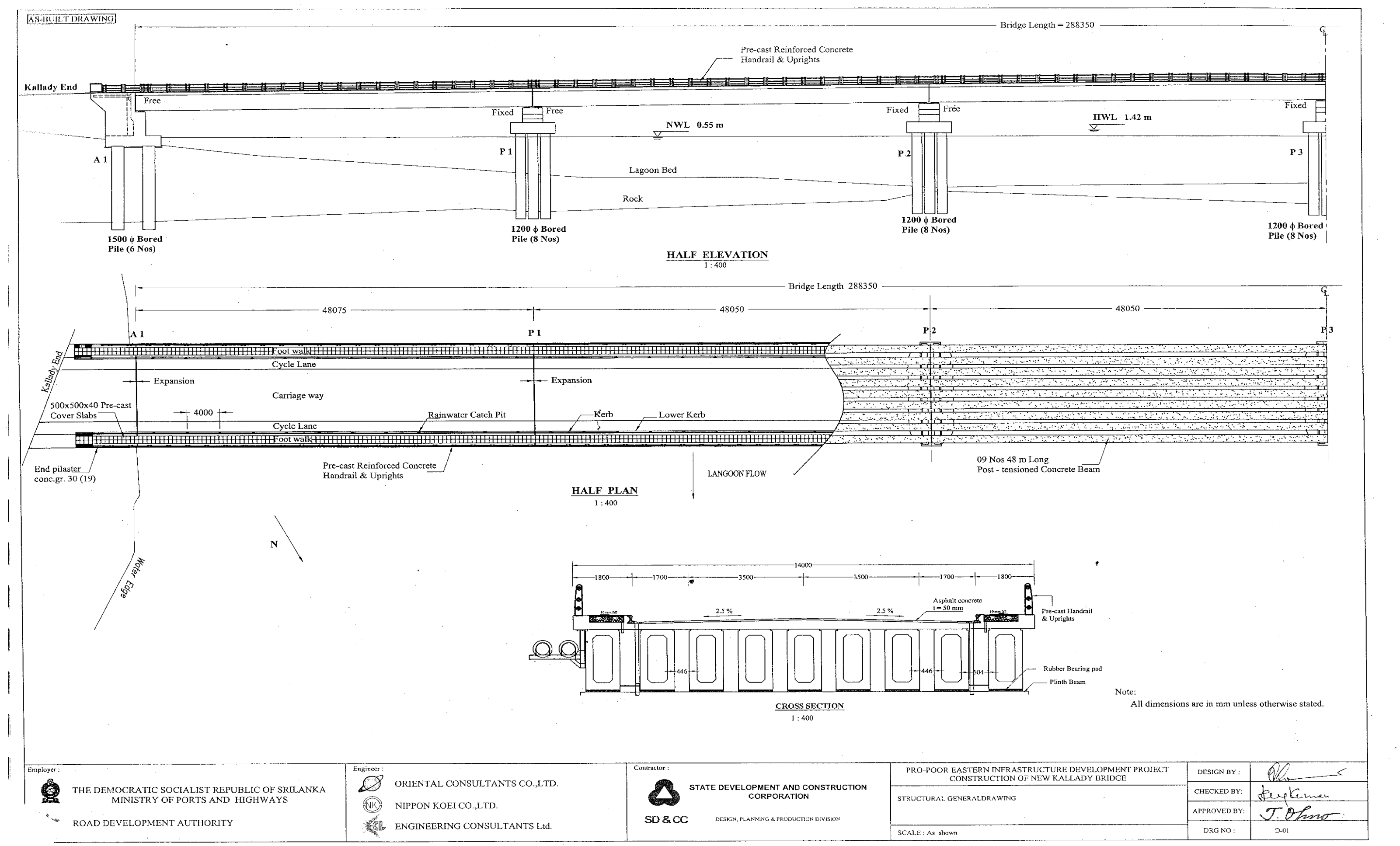
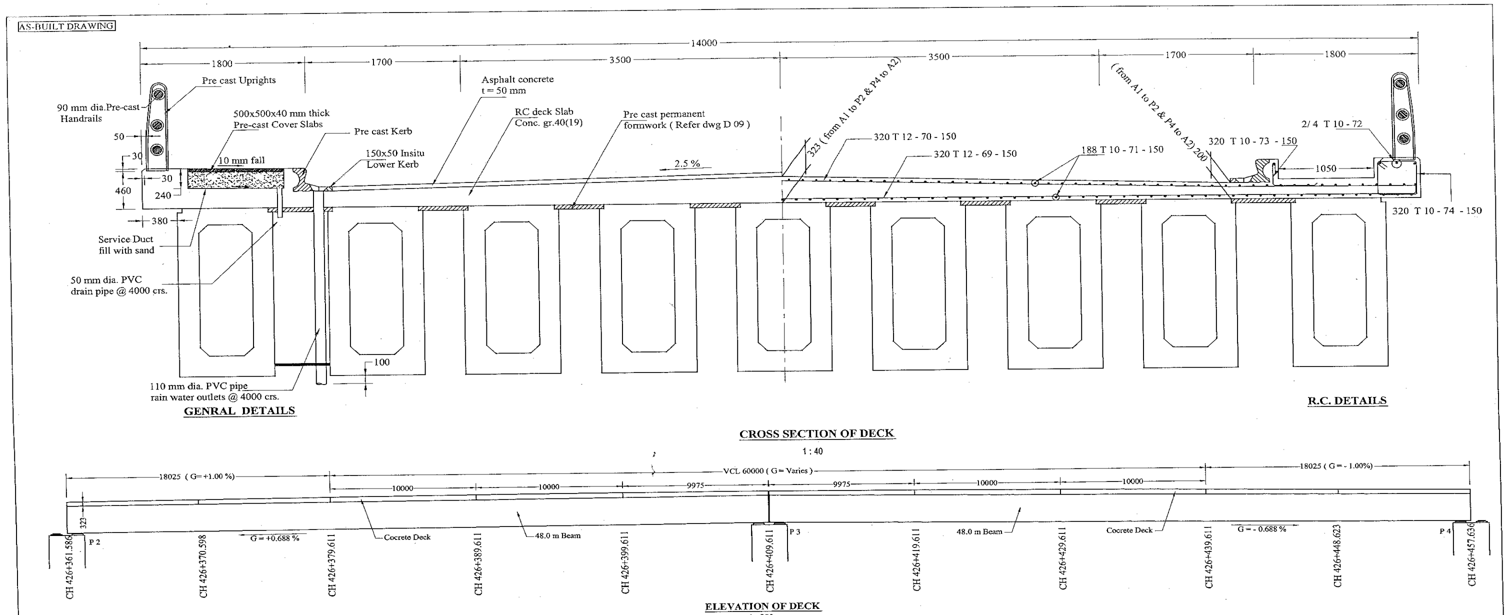


Figure E1.2 Kallady Bridge – Deck Details



CHAINAGE	DECK THICKNESS BETWEEN P2 & P4 (mm)	
	At the Centre Line	At the Lower Kerb
426 +361.586	323	200
426 +370.598	351	228
426 +379.611	379	256
426 +389.611	394	271
426 +399.611	375	252
426 +409.611	323	200
426 +419.611	375	252
426 +429.611	394	271
426 +439.611	379	256
426 +448.623	351	228
426 +457.636	323	200

SCHEDULE OF REINFORCEMENT

Member	Bar Mark	Type & Size	No of Members	No of Bars in Each	Total No of Bars	Length of Each Bar in mm	Total Length in m	Total Weight kg
Deck	69	T 12	06	320	1920	14160	27,187.2	24,142.2
	70	T 12	06	320	1920	14160	27,187.2	24,142.2
	71	T 10	06	188	1128	48090	52,245.5	33,415.2
	72	T 10	06	08	48	48090	2,308.3	1,421.9
	73	T 10	06	320	1920	800	1,536.0	946,2
	74	T 10	06	320	1920	1820	3,494.4	2,152.5
								86,220.2

Note:
All dimensions are in mm unless otherwise stated.

Employer :
THE DEMOCRATIC SOCIALIST REPUBLIC OF SRILANKA
MINISTRY OF PORTS AND HIGHWAYS
ROAD DEVELOPMENT AUTHORITY

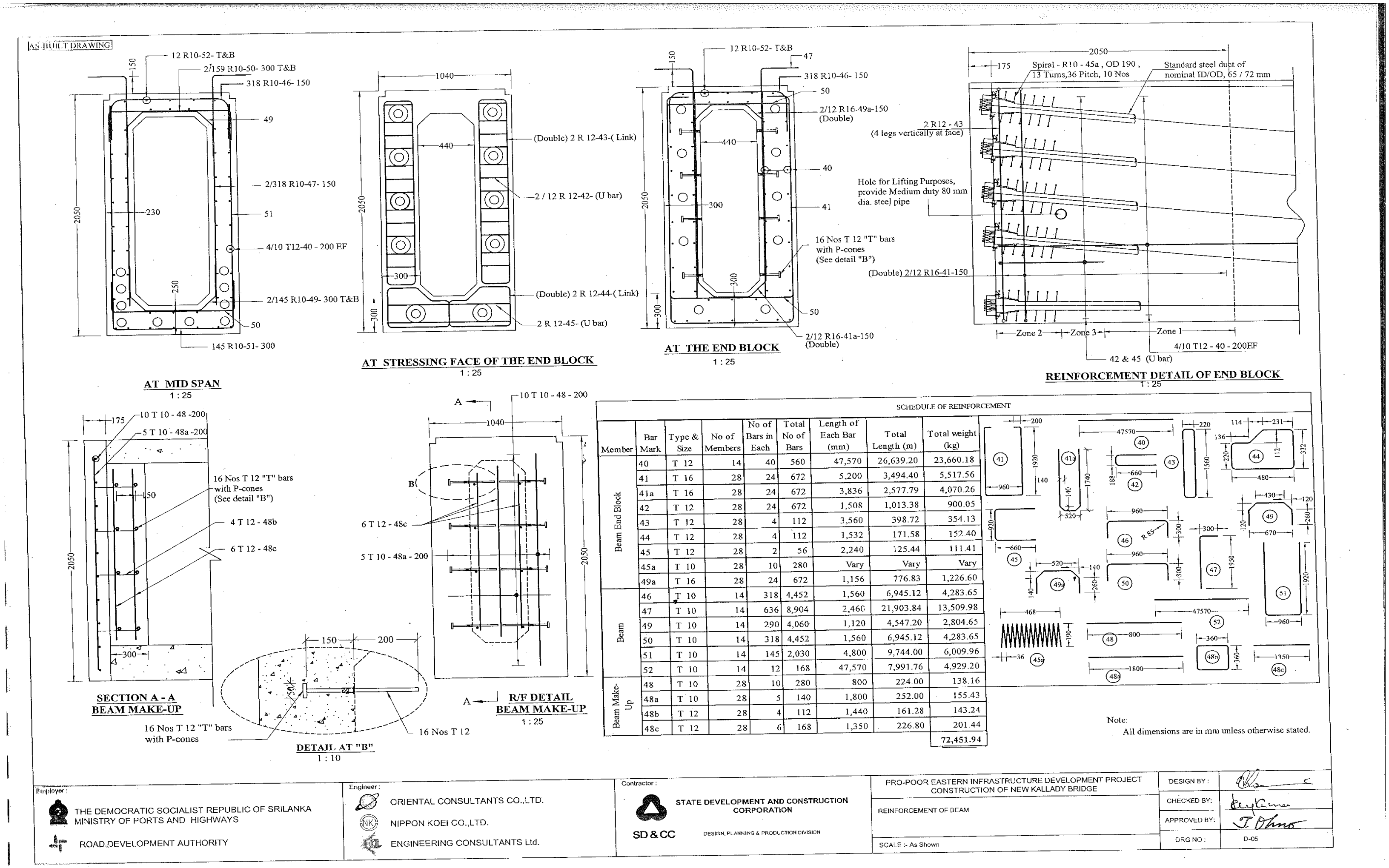
Engineer :
ORIENTAL CONSULTANTS CO.,LTD.
NIPPON KOEI CO.,LTD.
ENGINEERING CONSULTANTS Ltd.

Contractor :
STATE DEVELOPMENT AND CONSTRUCTION CORPORATION
SD&CC
DESIGN, PLANNING & PRODUCTION DIVISION

PRO-POOR EASTERN INFRASTRUCTURE DEVELOPMENT PROJECT
CONSTRUCTION OF NEW KALLADY BRIDGE
DECK SLAB
SCALE :- As Shown

DESIGN BY :
CHECKED BY:
APPROVED BY: J. Ohmo
DRG NO : D-08

Figure E1.3 Details of the Box Beam



SCHEDULE OF REINFORCEMENT

Member	Bar Mark	Type & Size	No of Members	No of Bars in Each	Total No of Bars	Length of Each Bar (mm)	Total Length (m)	Total weight (kg)
Beam End Block	40	T 12	14	40	560	47,570	26,639.20	23,660.18
	41	T 16	28	24	672	5,200	3,494.40	5,517.56
	41a	T 16	28	24	672	3,836	2,577.79	4,070.26
	42	T 12	28	24	672	1,508	1,013.38	900.05
	43	T 12	28	4	112	3,560	398.72	354.13
	44	T 12	28	4	112	1,532	171.58	152.40
	45	T 12	28	2	56	2,240	125.44	111.41
	45a	T 10	28	10	280	Vary	Vary	Vary
	49a	T 16	28	24	672	1,156	776.83	1,226.60
Beam	46	T 10	14	318	4,452	1,560	6,945.12	4,283.65
	47	T 10	14	636	8,904	2,460	21,903.84	13,509.98
	49	T 10	14	290	4,060	1,120	4,547.20	2,804.65
	50	T 10	14	318	4,452	1,560	6,945.12	4,283.65
	51	T 10	14	145	2,030	4,800	9,744.00	6,009.96
	52	T 10	14	12	168	47,570	7,991.76	4,929.20
Beam Make-Up	48	T 10	28	10	280	800	224.00	138.16
	48a	T 10	28	5	140	1,800	252.00	155.43
	48b	T 12	28	4	112	1,440	161.28	143.24
	48c	T 12	28	6	168	1,350	226.80	201.44
								72,451.94

Appendix F – Estimation of composite decks as per rates submitted by Dock Yard General Engineering services.

Rates of Dock Yard General Engineering Services.

a) Material steel grade S355@ 950 US$ per tonne (with profit 1150 US$ per tonne)
Material wastage assumed as 20%
Following rates include profit.
b) Welding consumables - 150 US$/tonne
c) Nuts & bolts - 4500 US$/tonne
d) Fabrication – 2000 US$/tonne (includes 180 manhrs @ 6$/hr)
e) Blast cleaning (SA 2.5quality) & painting (total 300microns DFT)
- 57 US$/sqm (includes 5 manhrs @ 4$/hour), or 600US$/tonne
Total Cost – US$ 3800 – 4250 per tonne
f) Erection – US$ 800 – 1250 /tonne
Chinese contractor

g) Blast cleaning (SA 3 quality) with hot aluminium spray (given in the document) specified for Kinniyai bridge.

State Engineering Corporation (SEC) cost data for Kelanisiri bridge protective treatment was modified by recent data available from re-painting of bridge at Narathupana.

h) Cost data of Narathupana Bridge, (2017). - SEC paint coating rates were replaced.

Blast cleaning to SA2.5 quality – 1968.21 Rs/sqm

Application of paint (320 microns DFT) 3126.74 Rs/sqm (15 years for first maintenance)

Table F. 1 Estimate of cost of Ladder Deck and Plate I girder decks as per rates of Dock Yard General Engineering Services

		Estimation of steel Decks as per rates submitted by Dock Yard General Engineering Services. Ladder Decks & I plate girder											
						50m Ladder Deck			**40m Ladder Deck**			**31.5m plate girder Deck**	
		Rate		Unit	Quantity	Cost		Quantity	Cost		Quantity	Cost	
		US $	SLR			US $	SLR		US $	SLR		US $	SLR
Steel tonnage		1150.00		ton	208.13	239344.35		102.58	117965.28		67.17	77245.90	
wastage 20%		950.00		ton	41.63	39543.85		20.52	19489.92		13.43	12762.37	
welding consumables		150.00		ton	208.13	31218.83		102.58	15386.78		67.17	10075.55	
Fabrication material		1000.00		ton	208.13	208125.52		102.58	102578.50		67.17	67170.35	
Fabrication Labour $1000			180000	ton	208.13		37462593.17	102.58		18464130.25	67.17		12090662.64
Nuts & Bolts		4500.00		ton	2.37	10647.23		1.83	8244.05		1.10	4950.00	
Blast Cleaning & painting													
Material		37.00		sqm	1710.00	63270.00		1100.00	40700.00		755.00	27935.00	
Labour+consumables $20			3600	sqm	1710.00		6156000.00	1100.00		3960000.00	755.00		2718000.00
Total						592149.77			304364.52			200139.17	
Cost US$ /tonne						4009.48			4181.61			4204.38	
Cost SLR/sqm							288856.83			185600.35			155170.06
Erection (50m) $1250 /ton		1250		ton	208.13	260156.90		102.58	117965.28		67.17	67170.35	
Erection (40m) $1150/ton		1150											
Erection (31.5m) $1050/ton		1000											
Cost US$ /tonne						5259.48			5331.61			5204.38	
Cost SLR /sqm							378911.14			236643.01			192076.85
Material cost %						25.48			25.13			25.75	
Fabrication cost %						41.85			41.83			42.73	
Protective tratment %						8.90			11.46			12.31	
Erection						23.77			21.57			19.21	
						100.00			100.00			100.00	
Deck concrete Rs/sqm							23,345.27			18,300.95			18,300.95
Total cost	Steel structure US$/ton					5259.48			5331.61			5204.38	
	Steel structure + Deck						402,256.41			254,943.96			210,377.80

Estimation of steel Decks as per rates submitted by Dock Yard General Engineering Services. Rolled steel section girders

Table F2. Estimate of cost of rolled beam decks as per rates of Dock Yard General Engineering Services.

					17.5m Ladder Deck			11.5m Ladder Deck		
		Rate		Unit	Quantity	Cost		Quantity	Cost	
		US $	SLR			US $	SLR		US $	SLR
Steel tonnage		1150.00		ton	17.21	19795.17		6.92	7962.72	
wastage 20%		950.00		ton	3.44	3270.51		1.38	1315.58	
welding consumables (80%)		150.00		ton	13.77	2065.58		5.54	830.89	
Fabrication material (80%)		1000.00		ton	13.77	13770.55		5.54	5539.28	
Fabrication Labour $1000 (80%)			180000	ton	13.77		2478699.16	5.54		997070.67
Nuts & Bolts		4500.00		ton	0.75	3375.00		0.05	225.00	
Blast Cleaning & painting										
Material		37.00		sqm	160.00	5920.00		87.00	3219.00	
Labour+consumables $20			3600	sqm	160.00		576000.00	87.00		313200.00
Total						48196.81			19092.47	
Cost US$ /tonne						3785.90			3808.69	
Cost SLR/sqm							61287.39			39689.93
Erection (50m) $900 /ton		900		ton	17.21	15491.87		6.92	5539.28	
Erection (40m) $800/ton		800								
Cost US$ /tonne						4685.90			4608.69	
Cost SLR /sqm							79772.86			48026.64
Material cost %						28.60			29.08	
Fabrication cost %						40.89			38.03	
Protective tratment %						11.31			15.54	
Erection						19.21			17.36	
						100.00			100.00	
Deck concrete Rs/sqm							18,300.95			18,300.95
Total cost	Steel structure US$/ton					4685.90			4608.69	
	Steel structure + Deck						98,073.81			66,327.59

Appendix G Recasting of Estimates -Steel composite bridges

Based on rates of Chinese contractor for Kinniya Bridge

Rates of 2005 recast to 2020 HSR rates

Chinese contractor 2005 Kinniya bridge fabrication data

Fabrication Man hrs /ton		25.35
Storage + transport	US $/ton	46.86
Labour	US $/ton	24.65
Consumables	US $/ton	90
Plant	US $/ton	80
Rents	US $/ton	55
Wastage 6%		

Protective Treatment Hot Aluminium spray rates per sqm

Labour	US $	5.5
Machinary	US $	4.3
Material	US $	6.15
OH&profit	US $	9.05
	Total	25

Labor rate US$/hr	0.9724
Steel rate US$/ton	950
Launching / ton $	200
Overhead & profit	20.26%
Protective treatment	
Overhead & profit	36.00%

G2

40m ladder deck

Weight			102.58	tonnes	Adjastment Factor 2005 - 2020	
Area			1094.27	sqm		
Cost		$	US $	SLR		
Steel			97449.58			
Fabrication cost/ton						
Labour Rs 900/hr	25.35			2340317.54		
Plant $	80.00		21522.17		2.62	(B0-105) - (B0-001)
Rent $	55.00		11283.64		2.00	
Wastage 6%			5846.97			
Consumables	90.00		23080.16		2.50	
Fab total			55885.97	2340317.54		
Protective treatment per sqm						
Labour hrs/sqm	5.66			5570440.37		
Plant	4.30		11774.36		2.50	B0144
Material	6.00		13131.27		2.00	>STEEL PRICE
	Total		184088.14	7910757.91		
Cost $/ton			2223.05			
Cost RS/sqm				98669.77		
Profit						
Fabrication	25%					
Protective coating	36%					

Cost $/ton		2767.45			
Cost RS/sqm			122833.15		
With Profit	25%				
Transport $/ton	58.575			2.45015912	B0-131A
Launching $/ton	250			2.5	
Cost $/ton		3535.97			
Cost RS/sqm			156943.77		

G3
31.5m I
girder
deck

				Adjastment Factor 2005 - 2020	
Weight		67.170	tonnes		
Area		754.908	sqm		
Cost	$	US $	SLR		
Steel		63811.83			
Fabrication cost/ton					
Labour @ Rs900/hr	25.35		1532484.31		(B0-105) -
Plant $	80.00	14093.13		2.62	(B0-001)
Rent $	55.00	7388.74		2.00	
Wastage 6%		3828.71			
Consumables	90.00	15113.33		2.50	

Fab total		36595.19	1532484.31		
Protective treatment per sqm					
Labour hrs/sqm	5.66		3842892.46		
Plant	4.30	8122.80		2.50	B0144
					>STEEL
Material	6.00	9058.90		2.00	PRICE
	Total	121417.43	5375376.76		
Cost $/ton		2252.19			
Cost RS/sqm			83121.23		
Profit					
Fabrication	0.25				
Protective coating	0.36				
Cost $/ton		2807.09			
Cost RS/sqm			103600.73		
With Profit	0.25				
Transport $/ton	58.58			2.45	B0-131A
Launching $/ton	250.00			2.50	
Cost $/ton		3575.61			
Cost RS/sqm			131964.26		

G4

17.5m I girder deck

Weight		17.72	tonnes	Adjastment Factor 2005 - 2020

Area		158.06	sqm		
Cost	$	US $	SLR		
Steel		16,838.47			
Fabrication cost/ton					
Labour @ Rs 900/hr	25.35		404,387.20		
Plant $	80.00	3,718.85		2.62	(B0-105) - (B0-001)
Rent $	55.00	1,949.72		2.00	
Wastage 6%		1,010.31			
Consumables	90.00	3,988.06		2.50	
Fab total		9,656.63	404,387.20		
Protective treatment per sqm					
Labour hrs/sqm	5.66		804,628.30		
Plant	4.30	1,700.76		2.50	B0144
Material	6.00	1,896.76		2.00	>STEEL PRICE
	Total	31,102.92	1,209,015.50		
Cost $/ton		2,133.73			
Cost RS/sqm			37,404.07		
Profit					
Fabrication	25.00%				
Protective coating	36.00%				
Cost $/ton		2,645.98			
Cost RS/sqm			46,383.78		

With Profit	25.00%				
Transport $/ton	58.58			2.45	B0-131A
Launching $/ton	250.00			2.50	

Cost $/ton		3,414.49	
Cost RS/sqm			59,855.84

G5

11.5m I girder deck

				Adjastment Factor 2005 - 2020	
Weight		6.924	tonnes		
Area		86.189	sqm		
Cost	$	US $	SLR		
Steel		6577.90			
Fabrication cost/ton					
Labour @ Rs900/hr	25.35		157972.64		
					(B0-105) -
Plant $	80.00	1452.76		2.62	(B0-001)
Rent $	55.00	761.65		2.00	
Wastage 6%		394.67			
Consumables	90.00	1557.92		2.50	
Fab total		3772.33	157972.64		
Protective treatment per sqm					
Labour hrs/sqm	5.66		438746.77		

Plant	4.30	927.39		2.50	B0144
					>STEEL
Material	6.00	1034.26		2.00	PRICE
	Total	12706.55	596719.41		
Cost $/ton		2313.90			
Cost RS/sqm			24112.87		
Profit					
Fabrication	25%				
Protective coating	36%				
Cost $/ton		2891.01			
Cost RS/sqm			30126.88		
With Profit	25%				
Transport $/ton	58.58			2.45	B0-131A
Launching $/ton	250.00			2.50	
Cost $/ton		3659.53			
Cost RS/sqm			38135.52		

Apendix H

Recasting of Estimates – Steel composite bridges

Based on Rates of Kalanisiri Bridge 2001 (submitted by State Engineering Corporation) recast to 2020 HSR rates
Mid Span (50m) - Kelani Rajamaha Vihara end

Table H1

Details of Kalanisiri Bridge submitted by State Engineering Corporation

Item	**Unit**	**Quantity**	**Year 2001**
			Price
Material - Cost for steel	Mt	149.38	8,012,160.62
M.S.shear studs	Nos	984.00	309,960.00
Bolts nuts & washers	Nos	1,472.00	958,272.00
Zink coatings	LS		70,656.00
Machinery works	LS		265,600.00
Gas cutting materials	LS		606,243.00
Welding rods	kg	2,110.00	438,669.00
Grinding wheel	LS		15,120.00
Labour charges for fabricating steel items	Mt	147.88	2,957,600.00
Plant hire for fabrication	LS		591,520.00
Sand blasting	sq.m.	1,400.00	672,000.00
Painting - Material	sq.m.	1,400.00	729,572.55
- Labour	sq.m.	5,600.00	184,800.00
Erection works	LS		3,000,000.00

Sub total			18,812,173.17
Hand rail - M.S.Steel hollow squre bars			446,476.80
Material			100,560.00
Labour			4,800.00
Concreting handrail post pockets			
Painting with 3 coats			
sand blasting	sqm	203.04	97,459.00
material			95,207.70
labour			24,116.00
Sub total			768,619.50
Total			**19,580,792.67**

H1

50m Ladder deck

Table H2 Cost Estimate 50m Ladder Deck, Rates of State Engineering Corporation.

Sand blasting and cost of protective treatment was modified as per cost data of Narathupana Bridge.

Factors 2020-2001

Item	Unit	Quantity		Year 2020					
			Rate US $	Rate RS	Amount US$	Amount Rs			
Material cost for steel	Mt	208.13	950.00		197,719.24				
M.S.shear studs	Nos	2,193.00		945.00		2,072,385.00	3		
Bolts nuts & washers	Tons	2.37	4,500.00		10,647.23				
Zinc coatings	LS					211,968.00	3	3.18	Steel price
Machinery works	LS					1,062,400.00	4	3.81	(B0-105) - (B0-001)
Gas cutting materials	LS					2,424,972.00	4		
Welding rods	kg	846.11		623.70		527,716.44	3		
Grinding wheel	LS					60,480.00	4		

Labour charges for fabricating steel items	Mt	208.13		140,000.00		29,137,572.46	7	6.68		B0-001
Plant hire for fabrication	LS					2,366,080.00	4			
Sand blasting	sq.m.	1,708.59		1,968.21		3,362,859.61	4.1	4.10		B0-156
Painting - Material	sq.m.	1,708.59		3,126.74		5,342, 317.09	6			
- Labour	sq.m.	6,834.36		231.00		1,578,737.53	7			
Erection	LS					12,000,000.00	4	3.65	3.17	B0 154
Total				Cost without erection	208,366.47	48,083,228.14				
				Cost/ton	2,284.66					
				Cost/sqm		164,594.60				

Material %		41.58				
Fabrication %		46.16		Cost with profit 25%		
Protective treatment %		12.16		Cost/ton	2,855.82	
				Cost/sqm		205,743.25
				Cost with erection		
				Cost/ton	2,604.98	
				Cost/sqm		187671.53
				Cost with erection & profit 25%		
				Cost/ton	3,256.22	
				Cost/sqm		**234,589.41**

H2

40m Ladder

Deck

Item	Unit	Quantity		Year 2020			Factors 2020-2001		
			Rate US $	Rate RS	Amount US$	Amount Rs			
Material cost for steel	Mt	102.58	950.00		97,449.58				
M.S.shear studs	Nos	1,979.00		945.00		1,870,155.00	3		
Bolts nuts & washers	Tons	1.83	4,500.00		8244.05				
Zinc coatings	LS					163,584.00	3	3.18	Steel price
Machinery works	LS					859,200.00	4	3.81	(B0-105) - (B0-001)
Gas cutting materials	LS					1,919,768.00	4		
Welding rods	kg	698.94		623.70		435,927.40	3		

Grinding wheel	LS					50,400.00	4				
Labour charges for fabricating steel items	Mt	102.58		140,000.00		14,360,990.20	7	6.68		B0-001	
Plant hire for fabrication	LS					1,574,880.00	4				
Sand blasting	sq.m.	1,094.27		1968.21		2,153,754.02	4.1	4.10		B0-156	
Painting - Material	sq.m.	1,094.27		3126.69		3,421,449.63	6				
- Labour	sq.m.	4,377.09		231.00		1,011,107.42	7				
Erection	LS					7,200,000.00	4	3.65	3.17	B0 154	B0 155
Total				Cost without erection	105,693.63	27,807,985.67					
				Cost/ton	2,536.42						

				Cost/sqm		112,578.94
Material %		37.45				
Fabrication %		48.13		Cost with profit 25%		
Protective treatment %		14.41		Cost/ton	3,170.53	
				Cost/sqm		140,723.67
				Cost with erection		
				Cost/ton	2,926.37	
				Cost/sqm		129,886.63
				Cost with erection & profit 25%	3657.96	162358.29
				Cost/ton	3,657.96	
				Cost/sqm		**162,358.29**

Table H3 Cost Estimate 40m Ladder Deck, Rates of State Engineering Corporation

Sand blasting and cost of protective treatment was modified as per cost data of Narathupana Bridge.

H3 31.5m I Plate Girder Deck

Item	Unit	Quantity	Rate US $	Year 2020 Rate RS	Amount US$	Amount Rs	Factor for span / tonnage	Factors 2020-2001		
Material cost for steel	Mt	67.17	950.00		63,811.83					
M.S.shear studs	Nos	1,064.00		945.00		1,005,480.00		3		
Bolts nuts & washers	Tons	1.09	4,500.00		4,885.64					
Zink coatings	LS					128,822.40	0.7875	3	3.18	Steel price
Machinery works	LS					676,620.00	0.7875	4	3.81	(B0-105) - (B0-001)
Gas cutting materials	LS					1,511,817.30	0.7875	4		
Welding rods	kg	818.03		623.70		510,203.34	0.7875	3		
Grinding wheel	LS					39,690.00	0.7875	4		
Labour charges for fabricating steel items	Mt	52.90		140,000.00		7,405,530.87	0.7875	7	6.68	B0-001

Plant hire for fabrication	LS					1,240,218.00	0.7875	4				
Sand blasting	sq.m.	754.91		1968.00		1,485,658.94		4.1	4.10		B0-156	
Painting - Material	sq.m.	754.91		3126.69		2,360,363.29		6				
- Labour	sq.m.	3,019.63		231.00		697,534.99		7				
Erection Factor	LS					4,714,696.54	0.6548	4	3.65	3.17	B0 154	B0 155
Total				Cost without erection	68,697.47	17,061,939.14						
				Cost/ton	2,433.90							
				Cost/sqm		89,827.48						
Material %		39.03										
Fabrication %		45.09		Cost with profit 25%								
Protective treatment %		15.88		Cost/ton	2,954.08							

				Cost/sqm		109,025.57
				Cost with erection		
				Cost/ton	2,823.85	
				Cost/sqm		104,219.11
				Cost with erection & profit 25%		
				Cost/ton	3,529.81	
				Cost/sqm		**130,273.89**

Table H4 Cost Estimate 31.5m Plate girder Deck, Rates of State Engineering Corporation

Sand blasting and cost of protective treatment was modified as per cost data of Narathupana Bridge.

H4

17.5m I multi girder (rolled sections) deck

Table H5 Cost Estimate 17.5 m UB composite Deck, Rates of State Engineering Corporation

Sand blasting and cost of protective treatment was modified as per cost data of Narathupana Bridge.

Item	Unit	Quantity		Year 2020				Factors 2020-2001		
			Rate US $	Rate RS	Amount US$	Amount Rs	Factor for span / tonnage			
Material - Cost for steel	Mt	17.72	950.00		16,838.47					
M.S.shear studs	Nos	720.00		945.00		680,400.00		3		
Bolts nuts & washers	Tons	0.74	4,500.00		3,309.65					
Zink coatings	LS					71,568.00	0.4375	3	3.18	Steel price
Machinery works	LS					171,840.00	0.2	4	3.81	(B0-105) - (B0-001)
Gas cutting materials	LS					383,953.60	0.2	4		
Welding rods	kg	68.85		623.70		42,943.46		3		
Grinding wheel	LS					22,050.00	0.4375	4		

Labour charges for fabricating steel items	Mt	7.75		140,000.00		1,085,638.04	0.4375	7	6.68		B0-001	
Plant hire for fabrication	LS					689,010.00	0.4375	4				
Sand blasting	sq.m.	158.06		1,968.00		311,101.34		4.1	4.10		B0-156	
Painting - Material	sq.m.	158.06		3,126.69		494,215.00		6				
- Labour	sq.m.	632.25		231.00		146,050.51		7				
Erection Factor	LS					1,244,099.48	0.1728	4	3.65	3.17	B0 154	155
Total				Cost without erection	20,148.12	4,098,769.95						
				Cost/ton	2,421.43							
				Cost/sqm		42,447.43						
Material %		39.23										
Fabrication %		47.53		Cost with profit 25%								

Protective treatment %		13.24		Cost/ton	2,956.71	
				Cost/sqm		51,830.87
				Cost with erection		
				Cost/ton	2,811.37	
				Cost/sqm		49,283.14
				Cost with erection & profit 25%		
				Cost/ton	3,514.21	
				Cost/sqm		**61,603.92**

H5

11.5m I multi girder (rolled sections) deck

Table H6 Cost Estimate 11.5 m UB composite Deck, Rates of State Engineering Corporation
Sand blasting and cost of protective treatment was modified as per cost data of Narathupana Bridge.

Item	Unit	Quantity		Year 2020				Factors 2020-2001		
			Rate US $	Rate RS	Amount US$	Amount Rs	Factor for span / tonnage			
Material cost for steel	Mt	6.92	950.00		6,577.90					
M.S.shear studs	Nos	488.00		945.00		461,160.00		3		
Bolts nuts & washers	Tons	0.04	4,500.00		165.99					
Zink coatings	LS					47,030.40	0.2875	3	3.18	Steel price (B0-105) - (B0-001)
Machinery works	LS					123,510.00	0.1438	4	3.81	
Gas cutting materials	LS					275,966.65	0.1438	4		
Welding rods	kg	61.29		623.70		38,226.98		3		
Grinding wheel	LS					14,490.00	0.2875	4		
Labour charges for fabricating steel items	Mt	1.99		140,000.00		278,695.10	0.2875	7	6.68	B0-001
Plant hire for fabrication	LS					452,778.00	0.2875	4		

Sand blasting	sq.m.	86.19		1968.00		169,619.13		4.1	4.10		B0-156	
Painting - Material	sq.m.	86.19		3126.69		269,484.97		6				
- Labour	sq.m.	344.75		231.00		79,638.25		7				
Erection Factor	LS					486,003.72	0.0675	4	3.65	3.17	B0 154	B0 155
Total				Cost without erection	6,743.88	2,210,599.47						
				Cost/ton	2,747.65							
				Cost/sqm		28,632.93						
Material %		34.58										
Fabrication %		48.90		Cost with profit 25%								
Protective treatment %		16.52		Cost/ton								

					3,434.56	
				Cost/sqm		35,791.16
				Cost with erection		
				Cost/ton	3,137.59	
				Cost/sqm		32,696.51
				Cost with erection & profit 25%		
				Cost/ton	3,921.99	
				Cost/sqm		**40,870.63**

Appendix I Cost Estimates of Steel composite bridges -Preliminary bridge estimating tool

I.1 50m Ladder deck

Table I1 Cost Estimate 50m Ladder Deck, Preliminary Estimating tool (Steel ton = US$950 + 20% profit = US$ 1150)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1								**50m DECK**						
2														
3	**Item**	**Description**					**Quantity**	**Units**	**Rate(Nz dollars)**	**Sub total (NZ $)**	**Total NZ$**	**Rate (Rs.)**	**Sub total (Rs.)**	**Total (Rs.)**
4	**1**	**Material supply**												
5	**1.1**	**Girders**	Width/Dep	Thickness	Length									
6		Span girders	m	m	m	kg/m3								
7	**1.1.1**	Top flange	1.00	0.060	50.00	7,700.00	23,100.00	kg	1.61	37,191.00		209.30	4,834,830.00	
8	**1.1.2**	Bottom flange	1.00	0.075	50.00	7,700.00	28,875.00	kg	1.61	46,488.75		209.30	6,043,537.50	
9	**1.1.3**	Web	2.240	0.025	50.00	7,700.00	21,560.00	kg	1.61	34,711.60		209.30	4,512,508.00	
10	**1.1.4**	wastage	10%				7,353.50	kg	1.61	11,839.14		209.30	1,539,087.55	
11	**1.1.5**	total for 2 girders	2.00				2.00	No			**260,460.97**			**33,859,926.10**
12	**1.2**	**Cross girder**												
13	**1.2.1**	Top flange	0.50	0.015	8.00	7,700.00	462.00	kg	1.61	743.82		209.30	96,696.60	
14	**1.2.2**	Bottom flange	0.50	0.015	8.00	7,700.00	462.00	kg	1.61	743.82		209.30	96,696.60	
15	**1.2.3**	Web	0.90	0.015	8.00	7,700.00	831.60	kg	1.61	1,338.88		209.30	174,053.88	
16	**1.2.4**	wastage	10%				175.56	kg	1.61	282.65		209.30	36,744.71	
17	**1.2.5**	total for 17 girders	17.00				17.00	No			**52,855.85**			**6,871,260.40**
18														
30														
31	**2**	**Fabrication & Connections**												
32	**2.1**	**Girders**												
33	**2.1.1**	**Two plate girder fabrication**					100.00	m	610.00	61,000.00		79,300.00	7,930,000.00	
34														
35	**2.1.2**	**Bolted Girder Splices S1**	1300 - 1600kg				4.00	Nos	6,000.00	24,000.00		780,000.00	3,120,000.00	
36														
37	**2.1.3**	**Bolted Girder Splices S2**	1300 - 1600kg				4.00	Nos	6,000.00	24,000.00		780,000.00	3,120,000.00	
38														
39	**2.1.4**	**Cross girder - Main girder splices**					30.00	Nos	500.00	15,000.00		65,000.00	1,950,000.00	
40							4.00	Nos	1,000.00	4,000.00		130,000.00	520,000.00	
41											**128,000.00**			**16,120,000.00**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
42	**2.1.5**	intermidiate stiffeners - fitted stiffner fillet welded					30.00	no	640.00	19,200.00		83,200.00	2,496,000.00	
43	**2.1.6**	abutment stiffener -fitted stiffner Butt welded ends					8.00	no	1,000.00	8,000.00		130,000.00	1,040,000.00	
44		abutment stiffener -fitted stiffner fillet welded ends					8.00	no	640.00	5,120.00		83,200.00	665,600.00	
45		**Cross Girders - provide camber mid span**									**32,320.00**			**4,201,600.00**
46	**2.1.7**	top flange	CPBW Splice at the m		34.00	0.50	17.00	m	234.00	3,978.00		30,420.00	517,140.00	
47	**2.1.8**	bottom flange	CPBW Splice at the m		34.00	0.50	17.00	m	234.00	3,978.00		30,420.00	517,140.00	
48	**2.1.9**	Web	CPBW Splice at the m		34.00	0.90	30.60	m	234.00	7,160.40		30,420.00	930,852.00	
49											**15,116.40**			**22,806,732.00**
50	**3**	**Shop Drawings**												
51	**3.1**	main Girder					147.07	tonnes	150.00	22,060.50		19,500.00	2,867,865.00	
52	**3.2**	Cross girder					32.83	tonnes	150.00	4,924.46		19,500.00	640,179.54	
53	**5**	**Coatings**									**26,984.96**			**3,508,044.54**
54	**5.1**	Protective treatment DFT 300 microns @ 57 US$/sqm												
55	**5.1.1**	Girders & cross beams					1,364.80	sqm	80.00	109,184.00	**109,184.00**	10,400.00	14,193,920.00	
56														**14,193,920.00**
57		sub total									**624,922.18**			**101,561,483.04**
58	**6**	**Contigency**				10%					62,492.22			**10,156,148.30**
59	**7**	TOTAL STEEL WORK									**687,414.39**			**111,717,631.34**
60														
61														
62			current new zeland dollar rate =			130.00				**Cost/tonne**	**3,821.10**	NZ $	**Cost Rs /sqm**	**214841.60**
63											**2,729.36**	US $		
64			US $ 1 =	NZ $ 1.4	Current rate									
65			US $ 1 =	NZ $ 1.288	2011 rate						Material %	**50.14**		
66			NZ $1 =	SLR	132.725						Fabrication %	**32.39**		
67											Coatings %	**17.47**		
68			Steel ton	US$	1150									
69				NZ $	1610									
70														
71			1470.7	section kg/m		1.086957	NZ current/2011 rate							

I.2 40m Ladder deck

Table I2 Cost Estimate 40m Ladder Deck. Preliminary Estimating tool (Steel ton = US$950 + 20% profit = US$ 1150)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1								40m DECK						
2														
3	**Item**	**Description**					**Quantity**	**Units**	**Rate(Nz dollars)**	**Sub total (NZ $)**	**Total NZ$**	**Rate (Rs.)**	**Sub total (Rs.)**	**Total (Rs.)**
4	**1**	**Material supply**												
5	**1.1**	**Girders**	Width/Depth	Thickness	Length									
6		Span girders	m	m	m	kg/m3								
7	**1.1.1**	Top flange	0.70	0.045	40.00	7,700.00	9,702.00	kg	1.61	15,620.22		209.30	2,030,628.60	
8	**1.1.2**	Bottom flange	0.80	0.055	40.00	7,700.00	13,552.00	kg	1.61	21,818.72		209.30	2,836,433.60	
9	**1.1.3**	Web	1.775	0.018	40.00	7,700.00	9,840.60	kg	1.61	15,843.37		209.30	2,059,637.58	
10	**1.1.4**	wastage	10%				3,309.46	kg	1.61	5,328.23		209.30	692,669.98	
11	**1.1.5**	total for 2 girders	2.00				2.00	No			**117,221.07**			**15,238,739.52**
12	**1.2**	**Cross girder**												
13	**1.2.1**	Top flange	0.30	0.02	8.00	7,700.00	369.60	kg	1.61	595.06		209.30	77,357.28	
14	**1.2.2**	Bottom flange	0.30	0.02	8.00	7,700.00	369.60	kg	1.61	595.06		209.30	77,357.28	
15	**1.2.3**	Web	0.66	0.012	8.00	7,700.00	487.87	kg	1.61	785.47		209.30	102,111.61	
16	**1.2.4**	wastage	10%				122.71	kg	1.61	197.56		209.30	25,682.62	
17	**1.2.5**	total for 17 girders	17.00				17.00	No			**36,943.46**			**4,802,649.37**
18														
31	**2**	**Fabrication & Connections**												
32	**2.1**	**Girders**												
33	**2.1.1**	**Two plate girder fabrication**					80.00	m	490.00	39,200.00		63,700.00	5,096,000.00	
34														
35	**2.1.2**	**Bolted Girder Splices S1**	700.1 - 1000kg				4.00	Nos	4,000.00	16,000.00		520,000.00	2,080,000.00	
36														
37	**2.1.3**	**Bolted Girder Splices S2**	700.1 - 1000kg				4.00	Nos	4,000.00	16,000.00		520,000.00	2,080,000.00	
38														
39	**2.1.4**	**Cross girder - Main girder splices**					30.00	Nos	500.00	15,000.00		65,000.00	1,950,000.00	
40							4.00	Nos	1,000.00	4,000.00		130,000.00	520,000.00	
41											**90,200.00**			**11,206,000.00**
42														

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
42														
43	**2.1.5**	intermidiate stiffeners - fitted stiffner fillet welded					30.00	no	480.00	14,400.00		62,400.00	1,872,000.00	
44	**2.1.6**	abutment stiffener -fitted stiffner Butt welded ends					8.00	no	760.00	6,080.00		98,800.00	790,400.00	
45		abutment stiffener -fitted stiffner fillet welded ends					8.00	no	480.00	3,840.00		62,400.00	499,200.00	
46		**Cross Girders - provide camber mid span**									**24,320.00**			**3,161,600.00**
47	**2.1.7**	top flange	CPBW Splice at the middle		34.00	0.30	10.20	m	393.00	4,008.60		51,090.00	521,118.00	
48	**2.1.8**	bottom flange	CPBW Splice at the middle		34.00	0.30	10.20	m	393.00	4,008.60		51,090.00	521,118.00	
49	**2.1.9**	Web	CPBW Splice at the middle		34.00	0.66	22.44	m	234.00	5,250.96		30,420.00	682,624.80	
50											**13,268.16**			**16,612,460.80**
51	**3**	**Shop Drawings**												
52	**3.1**	main Girder					66.19	tonnes	150.00	9,928.38		19,500.00	1,290,689.40	
53	**3.2**	Cross girder					22.95	tonnes	150.00	3,441.94		19,500.00	447,451.80	
54	**5**	**Coatings**									**13,370.32**			**1,738,141.20**
55	**5.1**	Protective treatment DFT 300 microns @ 57 US$/sqm												
56	**5.1.1**	Girders & cross beams					866.72	sqm	80.00	69,337.60	**69,337.60**	10,400.00	9,013,888.00	
57														**9,013,888.00**
58		sub total									**364,660.61**			**61,773,478.89**
59	**6**	**Contigency**				10%					36,466.06			**6,177,347.89**
60	**7**	TOTAL STEEL WORK									**401,126.67**			**67,950,826.78**
61			current new zeland dollar rate =			130.00								
62														
63			US $ 1 =	NZ $ 1.4	Current rate		1.0869565	NZ current/2011 rate		**Cost/tonne**	**4,500.19**	NZ $	**Cost Rs/sqm**	**163343.33**
64			US $ 1 =	NZ $ 1.288	2011 rate						**3,214.42**	US $		
65			NZ $1 =	SLR	132.725									
66											Material %	**42.28**		
67			Steel ton	US$	1150						Fabrication %	**38.71**		
68				NZ $	1610						Coatings %	**19.01**		
69														
70														
71			827.365	Section kg/m										

I.3 31.5m I plate girder deck

Table I3 Cost Estimate 31.5m Plate Girder Bridge. Preliminary Estimating tool (Steel ton = US$950 + 20% profit = US$ 1150)

						31.5m DECK							
Item	Description					Quantity	Units	Rate(NZ $)	Sub Total(NZ $)	Total(NZ $)	Rate (Rs.)	Sub total(Rs.)	Total (Rs.)
1	**Material supply**												
1.1	**Girders**	Width/Depth	Thickness	Length									
	Span girders	m	m	m	kg/m3								
1.1.1	Top flange	0.40	0.04	31.50	7,700.00	3,880.80	kg	1.61	6,248.09		209.30	812,251.44	
1.1.2	Bottom flange	0.60	0.04	31.50	7,700.00	5,821.20	kg	1.61	9,372.13		209.30	1,218,377.16	
1.1.3	Web	1.35	0.015	31.50	7,700.00	4,911.64	kg	1.61	7,907.74		209.30	1,028,005.73	
1.1.4	wastage	10%				1,461.36	kg	1.61	2,352.80		209.30	305,863.43	
1.1.5	total for 4 girders	4.00					No			103,523.01			**13,457,991.05**
1.2	**Abutment bracing**		kg/m	no	length(m)								
1.2.1	Top Chord		17.88	6.00	2.50	268.20	kg	1.61	431.80		209.30	56,134.26	
1.2.2	Bottom chord		17.88	6.00	2.50	268.20	kg	1.61	431.80		209.30	56,134.26	
1.2.3	Bracing		14.90	12.00	1.06	189.53	kg	1.61	305.14		209.30	39,668.21	
1.2.4	Waste	10%				72.59	kg	1.61	116.87		209.30	15,193.67	
										1,285.62			**668,521.61**
1.3	**Intermidiate bracing**		kg/m	no	length(m)								
1.3.1	Top Chord		17.88	9.00	2.50	402.30	kg	1.61	647.70		209.30	84,201.39	
1.3.2	Bottom chord		17.88	9.00	2.50	402.30	kg	1.61	647.70		209.30	84,201.39	
1.3.3	Bracing		14.90	18.00	1.06	284.29	kg	1.61	457.71		209.30	59,502.32	
1.3.4	Waste	10%				108.89	kg	1.61	175.31		209.30	22,790.51	
										1,928.43			**250,695.61**
2	**Fabrication & Connections**												
2.1	**Girders**												
2.1.1	three plate girder fabrication					126.00	m	430.00	54,180.00	54,180.00	55,900.00	7,043,400.00	**7,043,400.00**
2.1.2	Bolted Splice					8.00	Nos	2,000.00	16,000.00	16,000.00	260,000.00	2,080,000.00	**2,080,000.00**
2.1.5	intermidiate stiffeners -fitted stiffener- fillet weld					18.00	Nos	400.00	7,200.00		52,000.00	936,000.00	
2.1.6	abutment stiffeners -fitted stiffener- fillet weld					16.00	Nos	400.00	6,400.00		52,000.00	832,000.00	
	abutment stiffeners -fitted stiffener- Butt welded ends					32.00	Nos	640.00	20,480.00		83,200.00	2,662,400.00	**4,430,400.00**
										34,080.00			
2.2	**Abutment crossframe**												
2.2.1	top chord	bolted to girder stiffener				12.00	no	75.00	900.00		9,750.00	117,000.00	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
34	**2.2.2**	bottom chord	bolted to girder stiffener				12.00	no	75.00	900.00		9,750.00	117,000.00		
35	**2.2.3**	bracing	bolted to girder stiffener				6.00	no	75.00	450.00		9,750.00	58,500.00		
36		bracing	bolted to gusset				6.00	no	135.00	810.00		17,550.00	105,300.00		
37											3,060.00			**397,800.00**	
38	**2.3**	**Intermidiate crossframe bracing**													
39	**2.3.1**	top chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00		
40	**2.3.2**	bottom chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00		
41	**2.3.3**	bracing	bolted to girder stiffener				12.00	no	75.00	900.00		9,750.00	117,000.00		
42	**2.3.4**	bracing	bolted to gusset				12.00	no	135.00	1,620.00		17,550.00	210,600.00		
43											5,220.00			**678,600.00**	
44	**3**	**Shop Drawings**													
45	**3.1**	Girder					58.45	tonnes	150.00	8,768.18		19,500.00	1,139,863.73		
46	**3.2**	Abutment cross frames					0.73	tonnes	150.00	108.89		19,500.00	14,155.60		
47	**3.3**	intermidiate crossframes					1.09	tonnes	150.00	163.33		19,500.00	21,233.39		
48											9,040.41			**1,175,252.72**	
49	**5**	**Coatings**													
50	**5.1**	Protective treatment DFT 300 microns @ 57 US$/sqm													
51	**5.1.1**	Girders					601.60	sqm	80.00	48,128.00		10,400.00	6,256,640.00		
52	**5.1.2**	Abutment cross frames					24.73	sqm	80.00	1,978.18		10,400.00	257,162.88		
53	**5.1.3**	intermidiate cross frames					33.85	sqm	80.00	2,707.78		10,400.00	352,010.88		
54											52,813.95			**6,865,813.76**	
55		sub total									281,131.41			**27,925,074.74**	
56	**6**	**Contigency**				10%					28,113.14			**2,792,507.47**	
57	**7**	TOTAL STEEL WORK									309,244.55			**30,717,582.21**	
58			current new zeland dollar rate =			130.00									
59															
60			US $ 1 =	NZ $ 1.4	Current rate		1.086957	NZ current/2011 rate		Cost NZ $/ton	5,131.04		Cost Rs/sqm	**92,300.43**	
61			US $ 1 =	NZ $ 1.288	2011 rate					Cost US $/ton	3,665.03				
62			NZ $1 =	SLR	132.725					%					
63										Material	37.97				
64			Steel ton	US$	1150					Fabrication	43.25				
65				NZ $	1610		463.925	Section kg/m		Coatings	18.79				

I.4 17.5m rolled I girder deck

Table I4 Cost Estimate 17.5m UB Deck. Preliminary Estimating tool (Steel ton = US$950 + 20% profit = US$ 1150)

17.5m DECK

Item	Description					Quantity	Units	Rate(NZ $)	Sub total NZ$	Total NZ$	Rate (Rs.)	Sub total(Rs.)	Total (Rs.)
1	**Material supply**												
1.1	**Girders**	Width/De	Thickness	Length									
	Span girders	m	m	m	kg/m3								
1.1.1	Top flange	0.268	0.03	17.50	7,700.00	917.27	kg	1.61	1,476.81		209.30	191,984.65	
1.1.2	Bottom flange	0.268	0.03	17.50	7,700.00	917.27	kg	1.61	1,476.81		209.30	191,984.65	
1.1.3	Web	0.718	0.02	17.50	7,700.00	1,509.31	kg	1.61	2,429.99		209.30	315,898.12	
1.1.4	wastage	10%				334.38	kg	1.61	538.36		209.30	69,986.74	
1.1.5	total for 4 girders	4.00					Nos			**23,687.82**			**3,079,416.68**
1.2	**Abutment crossframes**		kg/m	no	length(m)								
1.2.1	Top Chord		41.69	6.00	2.56	640.36	kg	1.61	1,030.98		209.30	134,027.01	
1.2.4	Waste	10%				64.04	kg	1.61	103.10	**1,134.07**	209.30	13,402.70	
													147,429.71
1.3	**Intermidiate bracing**		kg/m	no	length(m)								
1.3.1	Top Chord		10.49	9.00	2.56	241.69	kg	1.61	389.12		209.30	50,585.63	
1.3.2	Bottom chord		10.49	9.00	2.56	241.69	kg	1.61	389.12		209.30	50,585.63	
1.3.3	Bracing		10.49	18.00	0.85	160.67	kg	1.61	258.67		209.30	33,627.59	
1.3.4	Waste	10%				64.40	kg	1.61	103.69		209.30	13,479.89	
										1,140.61			**148,278.74**
2	**Fabrication & Connections**												
2.1	**Girders**												
2.1.1	Splices (12+5.5)					4.00	no	2,000.00	8,000.00		260,000.00	1,040,000.00	
2.1.2	Abutment stiffener -Butt welded ends					-	no	510.00	-		66,300.00	-	
2.1.2	Abutment stiffener -fillet weld all around					48.00	no	320.00	15,360.00		41,600.00	1,996,800.00	
2.1.3	Intermediate stiffener -curtailed stiffner single end					18.00	no	270.00	4,860.00	**28,220.00**	35,100.00	631,800.00	**3,668,600.00**
2.2	**Abutment crossframes end connections**												
2.2.1	top chord	bolted to girder stiffener				12.00	no	145.00	1,740.00	**1,740.00**	18,850.00	226,200.00	
													226,200.00
2.3	**Intermidiate crossframes end connection**												

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
32	**2.3**	**Intermidiate crossframes end connection**												
33	**2.3.1**	top chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00	
34	**2.3.2**	bottom chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00	
35	**2.3.3**	bracing	bolted to girder stiffener				12.00	no	75.00	900.00		9,750.00	117,000.00	
36	**2.3.4**		bolted to gusset on bottom chord				12.00	no	135.00	1,620.00		17,550.00	210,600.00	
37											**5,220.00**			**678,600.00**
38	**4**	**Shop Drawings**												
39	**4.1**	Girder					13.38	tonnes	150.00	2,006.31		19,500.00	260,820.16	
40	**4.2**	Abutment cross frames					0.64	tonnes	150.00	96.05		19,500.00	12,486.99	
41	**4.3**	intermidiate crossframes					0.64	tonnes	150.00	96.61	**2,198.97**	19,500.00	12,558.90	
42														**285,866.05**
43	**5**	**Coatings**												
44	**5.1**	Protective treatment DFT 300 microns @ 57 US$/sqm												
45	**5.1.1**	Girders					155.68	sqm	80.00	12,454.40		10,400.00	1,619,072.00	
46	**5.1.2**	Abutment cross frames					15.13	sqm	80.00	1,210.56		10,400.00	157,372.80	
47	**5.1.3**	intermidiate cross frames					10.83	sqm	80.00	866.59	**14,531.55**	10,400.00	112,656.96	
48														**1,889,101.76**
49		sub total									**77,873.02**			**10,123,492.95**
50	**6**	**Contigency**				10%					**7,787.30**			**1,012,349.29**
51	**7**	TOTAL STEEL WORK									**85,660.32**			**11,135,842.24**
52			current new zeland dollar rate =			130.00								
53										Cost NZ$/ton	5,843.21		Cost Rs/sqm	61,185.95
54			US $ 1 =	NZ $ 1.4	Current rate		1.086957	NZ current/2011 rate		Cost US$/ton	4,173.72			
55			US $ 1 =	NZ $ 1.288	2011 rate									
56			NZ $1 =	SLR	132.725					material %	30.31			
57										Fabrication %	48.00			
58			Steel ton	US$	1150	($950+20%margin)				Coatings %	18.66			
59				NZ $	1610									
60			191.077	Section kg/m										
61														
62			Steel tonnage		14.66									

I.5 11.5m rolled I girder deck

Table I5 Cost Estimate 11.5m Deck. Preliminary Estimating tool (Steel ton = US$950 + 20% profit = US$ 1150)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1								**11.5m DECK**							
2															
3	**Item**	**Description**					**Quantity**	**Units**	**Rate(NZ $)**	**Sub total NZ$**	**Total NZ$**	**Rate (Rs.)**	**Sub total(Rs.)**	**Total (Rs.)**	
4	**1**	**Material supply**													
5	**1.1**	**Girders**	Width/De	Thickness	Length										
6		Span girders	m	m	m	kg/m3									
7	**1.1.1**	Top flange	0.229	0.020	17.50	7,700.00	604.81	kg	1.61	973.75		209.30	126,587.13		
8	**1.1.2**	Bottom flange	0.229	0.020	17.50	7,700.00	604.81	kg	1.61	973.75		209.30	126,587.13		
9	**1.1.3**	Web	0.534	0.012	17.50	7,700.00	855.48	kg	1.61	1,377.32		209.30	179,052.09		
10	**1.1.4**	wastage	10%				206.51	kg	1.61	332.48		209.30	43,222.63		
11	**1.1.5**	total for 4 girders	4.00					Nos			**14,629.20**			**1,901,795.93**	
12															
13	**1.2**	**Abutment crossframes**		kg/m	no	length(m)									
14	**1.2.1**	Top Chord		41.69	6.00	2.56	640.36	kg	1.61	1,030.98		209.30	134,027.01		
15	**1.2.4**	Waste	10%				64.04	kg	1.61	103.10	**1,134.07**	209.30	13,402.70		
16														**147,429.71**	
17	**1.3**	**Intermidiate bracing**		kg/m	no	length(m)									
18	**1.3.1**	Top Chord		6.70	9.00	2.56	154.37	kg	1.61	248.53		209.30	32,309.22		
19	**1.3.2**	Bottom chord		6.70	9.00	2.56	154.37	kg	1.61	248.53		209.30	32,309.22		
20	**1.3.3**	Bracing		6.70	18.00	0.85	102.62	kg	1.61	165.22		209.30	21,478.06		
21	**1.3.4**	Waste	10%				41.14	kg	1.61	66.23		209.30	8,609.65		
22											**728.51**			**94,706.16**	
23	**2**	**Fabrication & Connections**													
24	**2.1**	**Girders**													
25	**2.1.1**	Splices					-	no	2,000.00	-		260,000.00	-		
26	**2.1.2**	Abutment stiffener -Butt welded ends					-	no	510.00	-		66,300.00	-		
27	**2.1.2**	Abutment stiffener -fillet weld all around					48.00	no	320.00	15,360.00		41,600.00	1,996,800.00		
28	**2.1.3**	Intermediate stiffener -curtailed stiffner single end					6.00	no	270.00	1,620.00	**16,980.00**	35,100.00	210,600.00	**2,207,400.00**	
29	**2.2**	**Abutment crossframes end connections**													
30	**2.2.1**	top chord	bolted to girder stiffener				12.00	no	145.00	1,740.00	**1,740.00**	18,850.00	226,200.00	-	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
31														**226,200.00**	
32	**2.3**	**Intermidiate crossframes end connection**													
33	**2.3.1**	top chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00		
34	**2.3.2**	bottom chord	bolted to girder stiffener				18.00	no	75.00	1,350.00		9,750.00	175,500.00		
35	**2.3.3**	bracing	bolted to girder stiffener				12.00	no	75.00	900.00		9,750.00	117,000.00		
36	**2.3.4**		bolted to gusset on bottom chord				12.00	no	135.00	1,620.00		17,550.00	210,600.00		
37											**5,220.00**			**678,600.00**	
38	**4**	**Shop Drawings**													
39	**4.1**	Girder					8.26	tonnes	150.00	1,239.06		19,500.00	161,078.14		
40	**4.2**	Abutment cross frames					0.64	tonnes	150.00	96.05		19,500.00	12,486.99		
41	**4.3**	intermidiate crossframes					0.41	tonnes	150.00	61.70	**1,396.82**	19,500.00	8,021.41		
42														**181,586.54**	
43	**5**	**Coatings**													
44	**5.1**	Protective treatment DFT 300 microns @ 57 US$/sqm													
45	**5.1.1**	Girders					99.80	sqm	80.00	7,983.92		10,400.00	1,037,909.60		
46	**5.1.2**	Abutment cross frames					15.13	sqm	80.00	1,210.56		10,400.00	157,372.80		
47	**5.1.3**	intermidiate cross frames					0.30	sqm	80.00	24.38	**9,218.86**	10,400.00	3,169.92		
48														**1,198,452.32**	
49		sub total									**51,047.47**			**6,636,170.67**	
50	**6**	**Contigency**				10%					**5,104.75**			**663,617.07**	
51	**7**	TOTAL STEEL WORK									**56,152.21**			**7,299,787.73**	
52			current new zeland dollar rate =			130.00									
53			US $ 1 =	NZ $ 1.4	Current rate		1.086957	NZ current/2011 rate		Cost NZ$/ton	6,030.01		Cost Rs/sqm	61,035.01	
54			US $ 1 =	NZ $ 1.288	2011 rate					Cost US$/ton	4,307.15				
55			NZ $1 =	SLR	132.725										
56										material %	29.37				
57			Steel ton	US$	1150	($950+20%margin)				Fabrication %	49.63				
58				NZ $	1610					Coatings %	18.06				
59			118.006	Section kg/m											
60			Steel tonnage		9.31										

Appendix J Connection details of Ladder Decks.

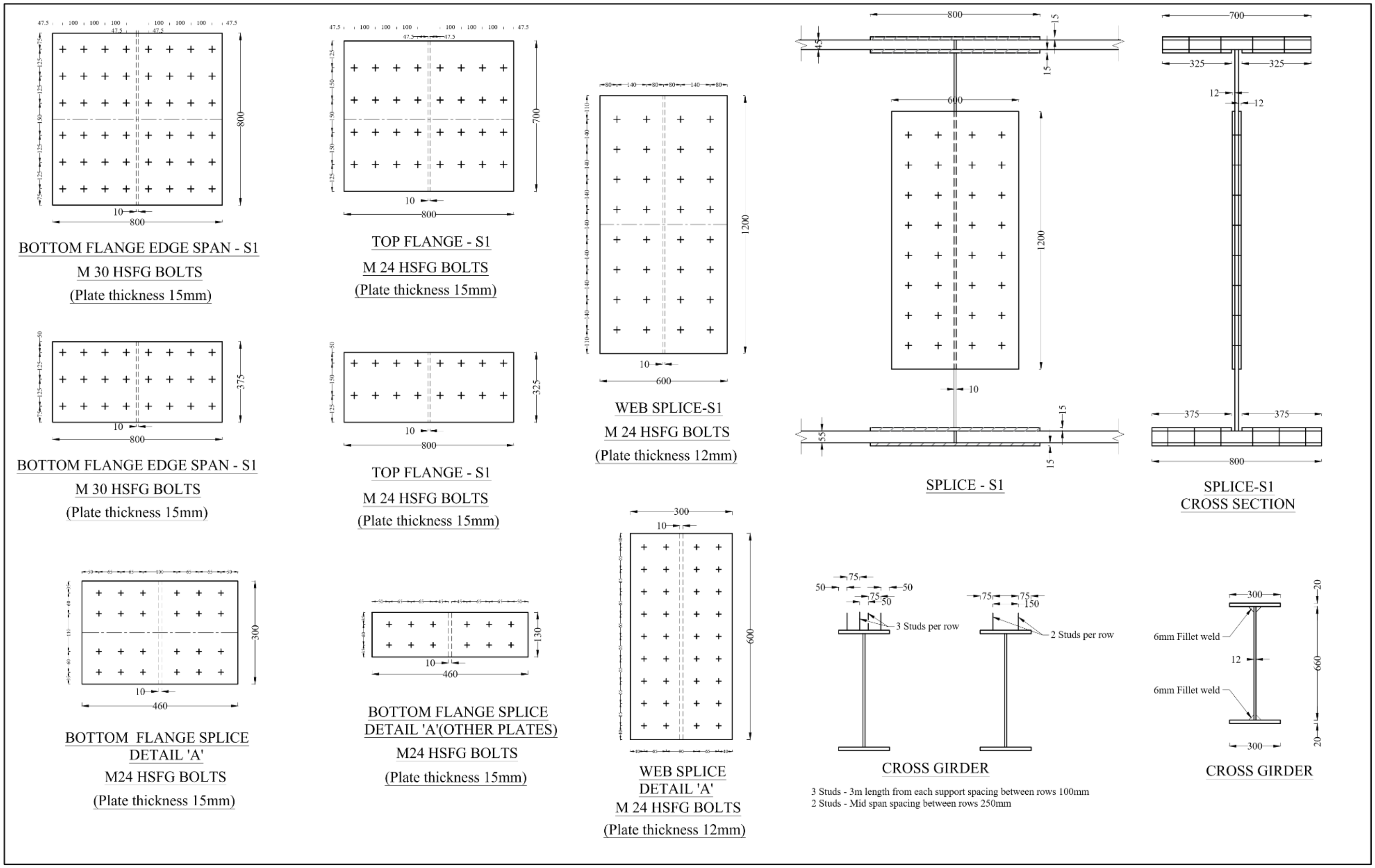


Figure J1.1 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 40m
(SPLICE - SI AND AT A, CROSS GIRDER DETAILS)

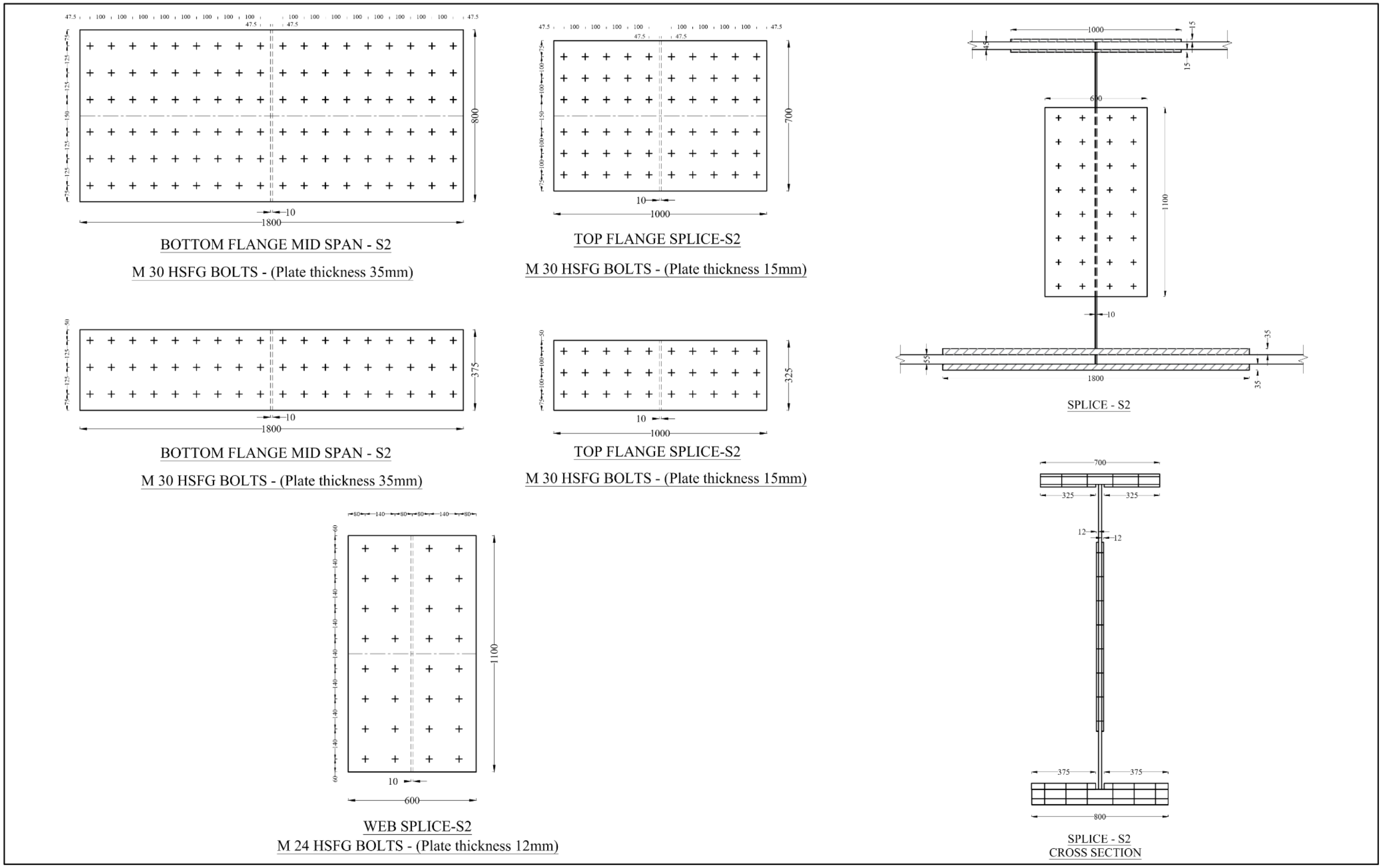


Figure J1.2 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 40m
(SPLICE S2)

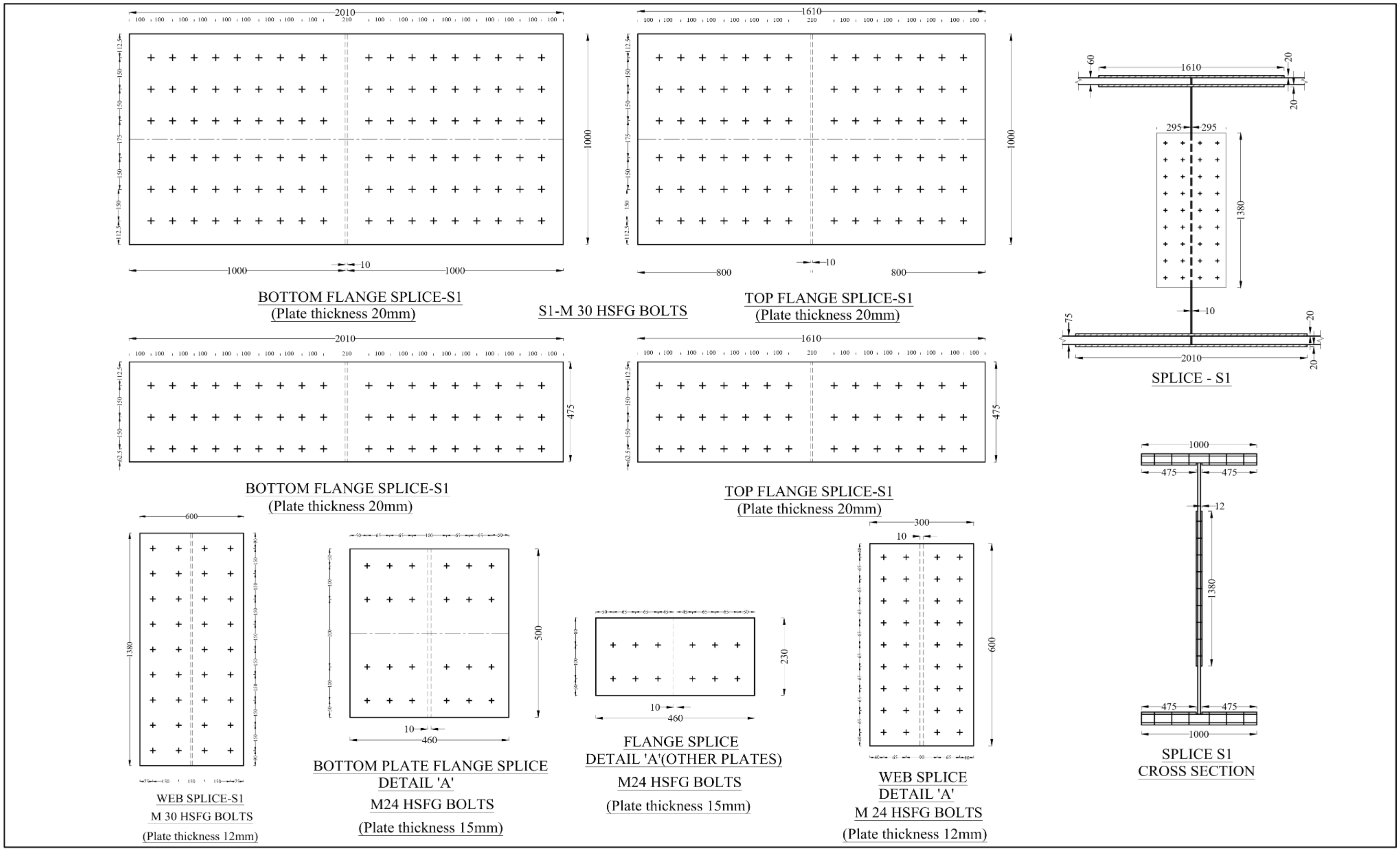


Figure J2.1 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 50m
(SPLICE S1 AND SPLICE A)

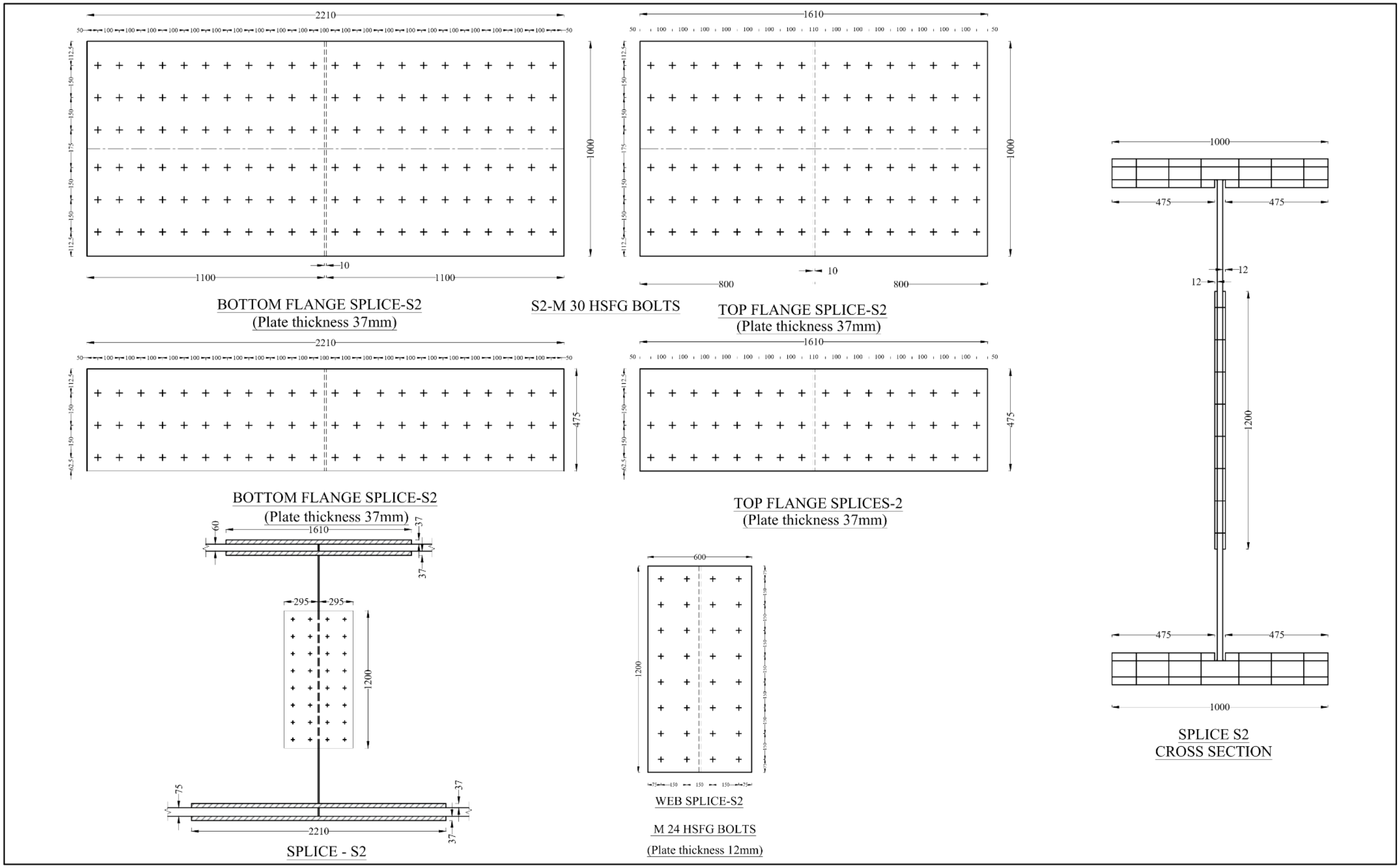


Figure . J2.2 STEEL CONCRETE COMPOSITE LADDER DECK SPAN 50m (SPLICE S2)