Parametric Studies on Composite Bridges: Bending Moment Analysis

By

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15134

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme

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Approved by,

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(Dr. Narayana Sambu Potty/ Professor Dr. Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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CHAN KENG CHUN

Abstract

The research is about parametric studies on composite bridge and integral composite bridge that are designed by using Eurocodes. Besides, the research will also show the comparison between BS and Eurocodes by using composite bridge as example. In Malaysia today, most engineering firms are still using British Standards as their code of practice whereas worldwide firm may have shifted to Eurocodes. On the other hand, bridges in Malaysia are mostly purely composite types which needed much maintenance cost if compared to integral composite bridge. The research will show all the methods used to design both types of bridges with two different codes. Specific graphs, diagrams and flow charts are used to help readers get better understanding when reading through. Design calculation is done by using manual calculation, working example and also spreadsheet. For software modeling, CSI Bridge 2014 and Oasys GSA have been used. These software helps on designing of composite bridges on Eurocodes which were used for comparison. Results of the research show the live loading of Eurocodes bridge design is lesser than the British Standard bridge design. Results also show that with different parameters used on the bridge, different value of stresses will acting on the bridge structures. Future recommendations have also been show in the later part of this report.

Acknowledgement

I would like to express the deepest appreciation to those who helped me to complete this report and as well as my Final Year Project (FYP). It would not be done even I have my own effort which is not sufficient enough. Thus, I would like to extend my sincere thanks to all of them.

First of all, I would like to thank my Final Year Project Supervisor, Dr. Narayanan Sambu Potty for his guidance and constant supervision during my research. He has helped me in all kind of direction and providing necessary information on my daily job scope. Unfortunately, he has gone back to his native country to join another University as the Head of Department. Thus, I would like to say all the best to Dr. Narayanan and wish we can meet again in near future. Besides, I would also like to give appreciation to my new supervisor Professor Dr. Nasir Shafiq for his helpful guidance at the near end of the research after taking over from previous supervisor.

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Chapter 1: INTRODUCTION

1.1 General Background

Nowadays, most of the engineering firms in Malaysia are still using British Standards (BS) as their code of practice for structure designing. However in recent period, many worldwide firms are already converted to use Eurocodes as their design's reference due to several factors. In Malaysia, most of the institutes are following the trend which they have started converting by teaching some related courses in Eurocodes. Thus, this research paper is focus on what are the differences in comparison if design a same structure but using different codes. To minimize the research scope, bridge structure has been chosen as the design topic. Besides, the research is also focus on comparison between two types of bridges which are composite bridge and integral bridge. Hence, the overall research is consisting two types of comparison as shown below:

- British Standards design versus Eurocodes design on composite bridge
- Composite bridge design versus integral bridge design on specific parametric studies

1.2 Problem Statement

In Malaysia, almost all the engineering firms are yet ready to use the Eurocodes as their code of practice. Even the latest project, the KVMRT (railway transportation) is still using BS code as their design reference. They still stick to the original BS code as their reference because converting of code of practice required lot of time and efforts. They are unwilling to spend the time and effort due to the heavy workload that already existing. However, in recent Engineering Conference held in 2011, it highlighted that industry, authority and lawmakers must work together and try to enforce the Eurocodes as code of practice. It is just a matter of time before industry starting to convert the codes. Hence, this research would help to clarifier some of the converting issue on bridge.

On the other hand, some studies have found out that majority bridges in Malaysia were design as composite bridge meanwhile rarely design as integral bridge. An issue has been found out that most of the bridges in Malaysia needed frequent maintenance on their joints and bearings. According to Dr. Ng See King (n.d.) in an article called Bridge Problem in Malaysia, broken of joints and bearings are the common issues to bridge which its occur when the loads are not uniformly distributed. Many methods had been used to overcome the problem but they largely involve provision of restraint to the existing bearings. These have increased the cost for the bridge where maintenance must be done on time to time. For integral bridge, it doesn't have the same issue as the composite design because it doesn't contained bearing. However, industrial engineers still favor on designing composite bridge than integral bridge. Therefore, parametric studies on composite bridge and integral bridge are required so that to understand its characteristics and behaviors differences. These understanding could be useful for industrial engineers to get a general concept about differences on both designs and allowed them more freedom of choice on types of bridge.

1.3 Objectives

There are several objectives that set on this research. The objectives are:

1. Design and model composite bridges by using BS and Eurocodes and compare both bridge designs
2. Parametric studies on composite bridge
3. Comparative parametric studies on composite bridge and integral bridge

CHAPTER 2: LITERATURE REVIEW AND BRIDGE THEORY

2.1 Research Background

Bridge is a unique structure that has been used by mankind for centuries. It was started from a very simple long wooden bridge that puts across a river, to a very complex bridge such as the current world's longest bridge Danyang-Kunshan Grand Bridge which stands at 164.8 Km long. A bridge is a structure which built as passage for a subject to cross over an obstacle such as body of water, valley or road. There are many different types of bridges which using for different purposes. Its design is depending on four main conditions which are the function of the bridge, the nature of terrain where bridge is constructed, material used for construction and the budget for the whole construction. On the other hand, the classifications of bridges are varying depending on how the forces of tension, compression, bending, torsion and shear are distributed. These classifications have separated various types of bridges which will be discussed in this document.

2.2 Loadings

All structures shall be designed to withstand the loadings that will be shown below. These loadings will form together to act as the combination load which consider as most critical loading. The very first two critical loadings that will be acted on the structures are the dead load and superimposed dead load. These loads are consists of weight of structural members or any other permanent load that will act on the bridge before and after it is completed. Imposed load is the next critical loading to be concerned. Basically, it is the move loading which is not constant all the time. For examples traffic loads, there are two types of loading in this case which are normal loading (HN) and overload loading (HO). These loadings will be formed as combination loadings as well which it will consider in the worst effect on the member. A reduction factors will apply on this case which the BS and Eurocodes are differ from each other.

Besides vertical forces, the loadings are also can be inverted from horizontally. Braking and traction are one of the horizontal forces to be acted on the bridge. For local effects, a horizontal force, equal to 70% of an HN axle load shall be applied at any point of deck surface as skidding axle. For effects on the bridge as a whole, a horizontal force shall be applied at deck surface level in each section of superstructure between expansion joints.

Furthermore, there will be loadings came from natural resources. These loadings are likes wind loads, thermal effects, earthquake and others will all affected the stability of bridge as well. Some of these loadings must be taken into account to the design but not all of them. Heavy earthquake is a very rare scene happen in Malaysia. Slight earthquake may be added up as the vibration loads that check for the effects from traffic loadings. Allowance should also be given to construction loads and water effects. Weight false work may happen during the construction required allowance for these loading. For water effects, groundwater pressure is the concern for bridge's piers. It may push the piers upwards and caused the bridge loses its stability.

In this research, fatigue effects on bridge design are yet to be confirmed. Time length is the problem which is the main causes of this unconfirmed issue. Understanding of fatigue effects required times due to the complexity of its characteristics.

2.3 Types of Bridges

As mentioned, only two types of bridges will be focused on this research paper which is composite bridge and integral composite bridge. However, there are many types of composite bridge as well which plate girder bridge has been chosen. Thus, understanding characteristics of plate girder and composite bridge are also required for this research. Each types of bridge will be explained in detail as following:

Composite Bridge

The simplest way to define a composite bridge is that the bridge having joint or bearing in between its column and slab. In most cases, slab is made of concrete and beam is made of steel. For all kind of spans, Composite Bridge can provided a cost-effective solution by utilizing all the tensile strength of the steel in the main girder and the compressive strength of concrete in the slab. However, the cost of construction may be raised in later part due to the maintenance needed on the joint or bearings. There are many types of Composite Bridge, but mainly on 2 categories which are multi-girder bridge and ladder Deck Bridge.

Plate Girder Bridge

Plate Girder Bridge is a type of bridge that supported by two or more plate girders which are typically I-beams steel made up from separate structural steel plates. The use of plate girders rather than the rolled beam sections for the two main girders allowed the cost of the bridge can be cut short by choosing the most economical girder for the structure. The plates are either welded or bolted together to form as a vertical web and horizontal flanges of the beam.

Integral Bridge

An Integral Bridge can be defined as a bridge that without any joint or bearings which are opposite to Composite Bridge. They span from one abutment and cross over an intermediate support to the other abutment without any movement joint in the deck. There are four basic ways that categorize the bridge as integral which by depending on its abutment details. The four forms of abutment are frame abutments (fully integral bridges), bank pad abutments, flexible support abutments and semi-integral end screen abutments.

2.4 Design Standard

The bridge designs are varying on British Standard and Eurocodes as below.

BS 5400

"Set up standards of quality for goods and services, and prepare and promote the general adoption of British Standards and schedules in connection therewith and from time to time to revise, alter and amend such standards and schedules as experience and circumstances require", these are the objective set by the BSI Royal Charter, Faller and Graham (2003) for the British standards. For bridges, the British standard BS 5400 Steel, concrete and composite bridges consist of 10 parts, which were published and revised from 1978 through to 2010. In March 2010, BS 5400 was formally superseded by the

Eurocodes and withdrawn. Although the Bridge manual no longer references BS 5400, this standard still remains useful as a reference document.

Eurocodes

The Eurocodes are a set of structural design standards that have been developed by CEN, the European standards body, and adopted throughout Europe. The Eurocodes are published in a total of 58 separate parts, each are dealing with either general, material-specific or structure type-specific matters. Each part contains principles and application rules that are common in all the adopting countries, apart from certain aspects that have been left for national choice, as determined by the individual national standards body. The Eurocodes are published unchanged by each national standards body, together with a national annex that implements the Eurocode in the country and gives the national choices for that country.

The Eurocode parts that are relevant to the determination of global analysis on steel-concrete composite bridges are shows as follow:

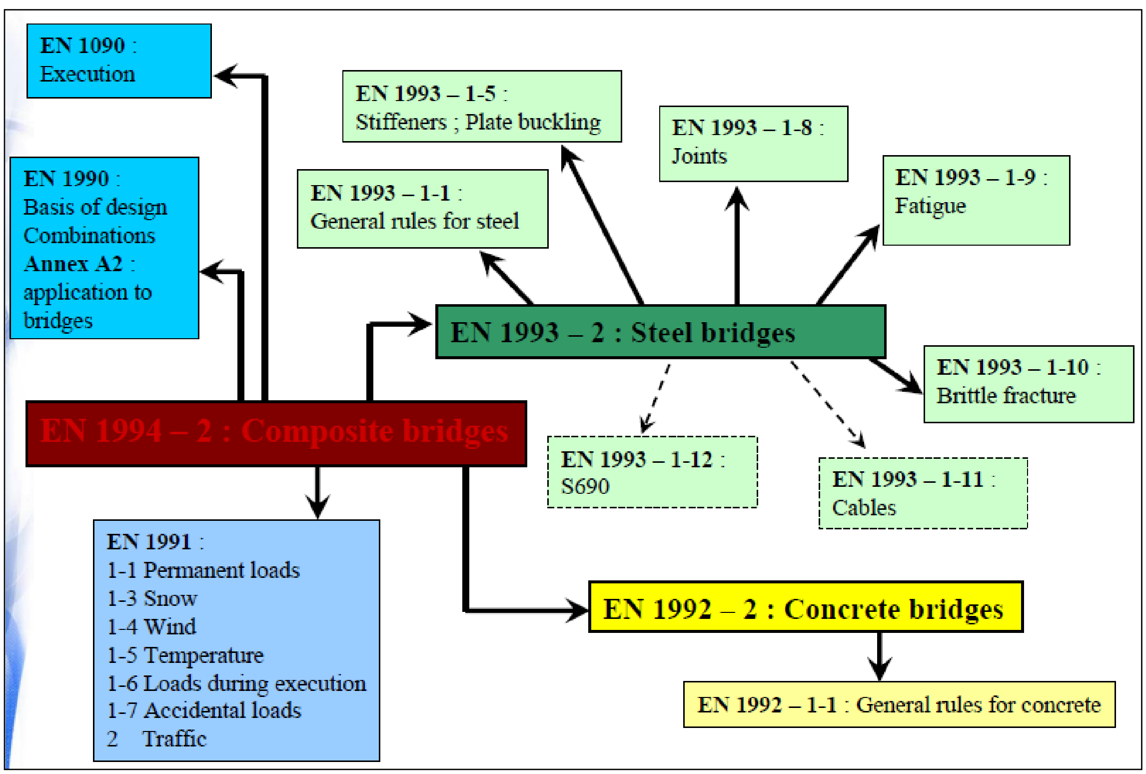


Figure 2.1: EN 1994-2 Composite Bridge flow diagram

CHAPTER 3: Methodology

3.1 Introduction

The methodology used in this research is designed to follow the suitability of the listed objectives. The objectives are:

1. Design and model composite bridges by using BS and Eurocodes and compare both bridge designs
2. Parametric studies on composite bridge
3. Comparative studies on composite bridge and integral bridge

3.2 Set Up of Sign Convention and Loadings

Constant sign convention use for all beams and slab is important. If sign convention is using differently from time to time, the moment of inertia will not be accurate. In this research, the axes are differs from the traditional UK convention but many software analysis packages are compatible with these signs. The sign are as follows:

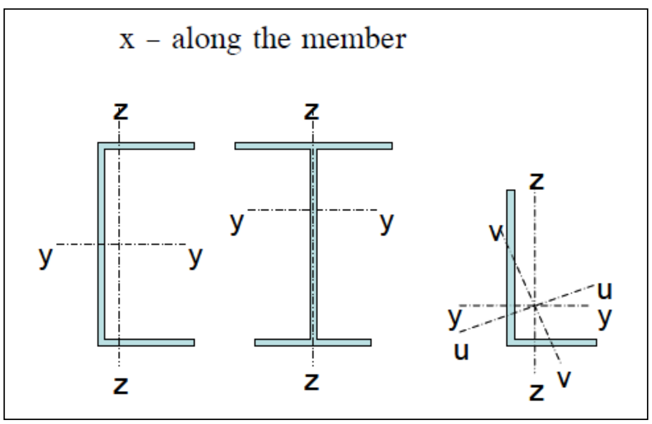


Figure 3.1: Sign conventional for structures

The next important element needed to be identified in early stage is the loadings on the bridge. All loading modal can be found in both BS 5400 Part 1 and EN part 2. Let say taking the traffic loads from Eurocodes as the example of the loading modal as shown below:

In EN 1991-2, there are several traffic loads models are given but only one model, Load Model 1 which representing as normal traffic will be discussed here. Uniformly distributed load over the full width of traffic lane and a pair of axles are the two components that Load Model 1 comprises. For the Uniform Distribution Load (UDL), the length of lane loaded should be those parts of the influence line that lead to adverse load effects. Therefore, in a continuous three-span bridge, the central span should be under sagging moments at the mid span and two adjacent spans should be under hogging moment at the intermediate support between spans. In each lane, a pair of axles which referred as a Tandem System (TS) should be positioned centrally in the lane at the position along the lane that causes maximum adverse effect. Thus, the TS sagging moments would be at mid span and hogging moment would be part way into central span for the three spans. The characteristic values of the two components of LM1 are:

UDL	qk	=	5.5 KN/m^3
TS	Qk	=	300 KN (on each axle)

The arrangement of LM1 is shown below:

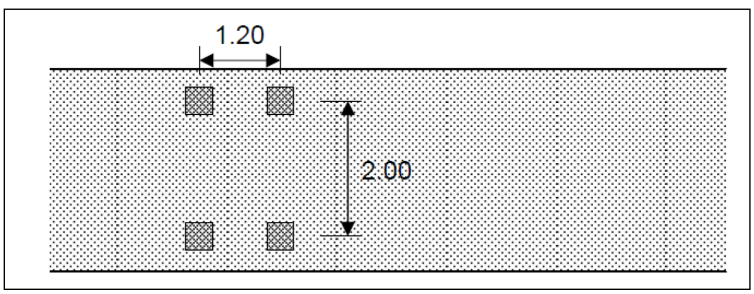


Figure 3.2: Load modal 1

This is the only example I given in this section. I do not hope this section contains too much and caused the whole chapter lengthy.

3.3 Design Analysis

After setting up important components, design analysis is the next step which can be obtained from both codes. First thing first, all bridges design must follow the minimum requirement of Ultimate Limit State (ULS) and Serviceability Limit State (SLS) standards. Thus, all the beams should be designed to provide sufficient strength to resist the action effects from all kinds of loadings. It can be done by following the guidance as shown below. During the analysis, there are some partial factors that must apply to the ULS and SLS where both codes having different values for partial factors. It can be found in both codes which will not further discuss in Methodology. For ULS, the following are needed to be considered:

1) Material strength
2) Limitations on shape on account of local buckling of individual elements (i.e. webs and flanges)
3) Moment resistance of cross section
4) Effective sections (reductions for compression buckling and holes)
5) Lateral torsional buckling
6) Web buckling (governed by depth to thickness ratio of web and panel size)
7) Combined bending and shear effects
8) Resistance to coexistent axial forces

As for SLS, the beams should also be designed to ensure that no yielding or permanent deformation on the lower design effects (i.e. minimum stress). However, for some cases SLS can be automatically satisfied with no further checks are needed. It's all depends on what are the classes the beam is designed under ULS. The following are the four classification of cross section:

a) Class 1, where the full plastic moment of the cross section can be developed and there is sufficient rotation capacity to form a plastic hinge
b) Class 2, where the full plastic moment if the cross section can be developed but there is insufficient rotation capacity to form a plastic hinge

c) Class 3, where the stress at the extreme fibre assuming a linear elastic distribution of stress can reach the yield strength but local buckling would prevent the development of the plastic resistance of the cross section

d) Class 4, where the local buckling occurs before the attainment of yield stress at the extreme fibre and thus the resistance of the cross section is less than that if it were a class 3 section.

By following the classification above, if designed beam's ULS is designed under class 3 or class 4, SLS are automatically satisfied. Oppositely, if ULS is designed under class 1 or class 2, by utilizing the plastic moment capacity, it is possible that yielding on the beam may occur due to the extreme fibres under SLS characteristic loading. Therefore, in these cases SLS must take into account.

Lastly, besides ULS and SLS, thermal effect must also be considered. Expansion and contraction are the nature effects for every steels due to temperature change can be calculated by using the thermal coefficient given in the codes. It must add up to the design because it may cause cracking or buckling on the structure.

3.4 Design Spreadsheet and Software Modeling

Research continues by focusing on design calculation and software modeling. Parts of the BS composite design calculation are done on manual calculation. For examples, the bridge loading, due to the calculation needed drawing sketching as part of the calculation. It will be harder if it is done by using software to sketch the drawings. However, completing all the design calculation manually will require lots of time. This would drag the research which is totally ineffective for the whole research. Thus, to avoid unnecessary time wasting on calculation, spreadsheet will be designed for all the required calculation components. Structures calculation like beams, slab, and columns will be included where all the calculation will be done by the spreadsheet.

As for software modelling, CSI Bridge 2014 is used. The software is powerful enough to design composite bridge on Eurocodes. Unfortunately, this software is US based software which does not include BS in the software. Nevertheless, as mentioned, manual calculations and spreadsheet are the method used to design the BS composite bridge which is sufficient enough. Besides, due to the CSI Bridge 2014 evaluation expiry date, it only allowed 30 days of evaluation period. Thus, for parametric studies on composite bridge, Oasys GSA is used. The software served the same function as CSI Bridge 2014 but with different approach. Overall, the parametric studies on composite bridge are fully done on software modelling using Oasys GSA.

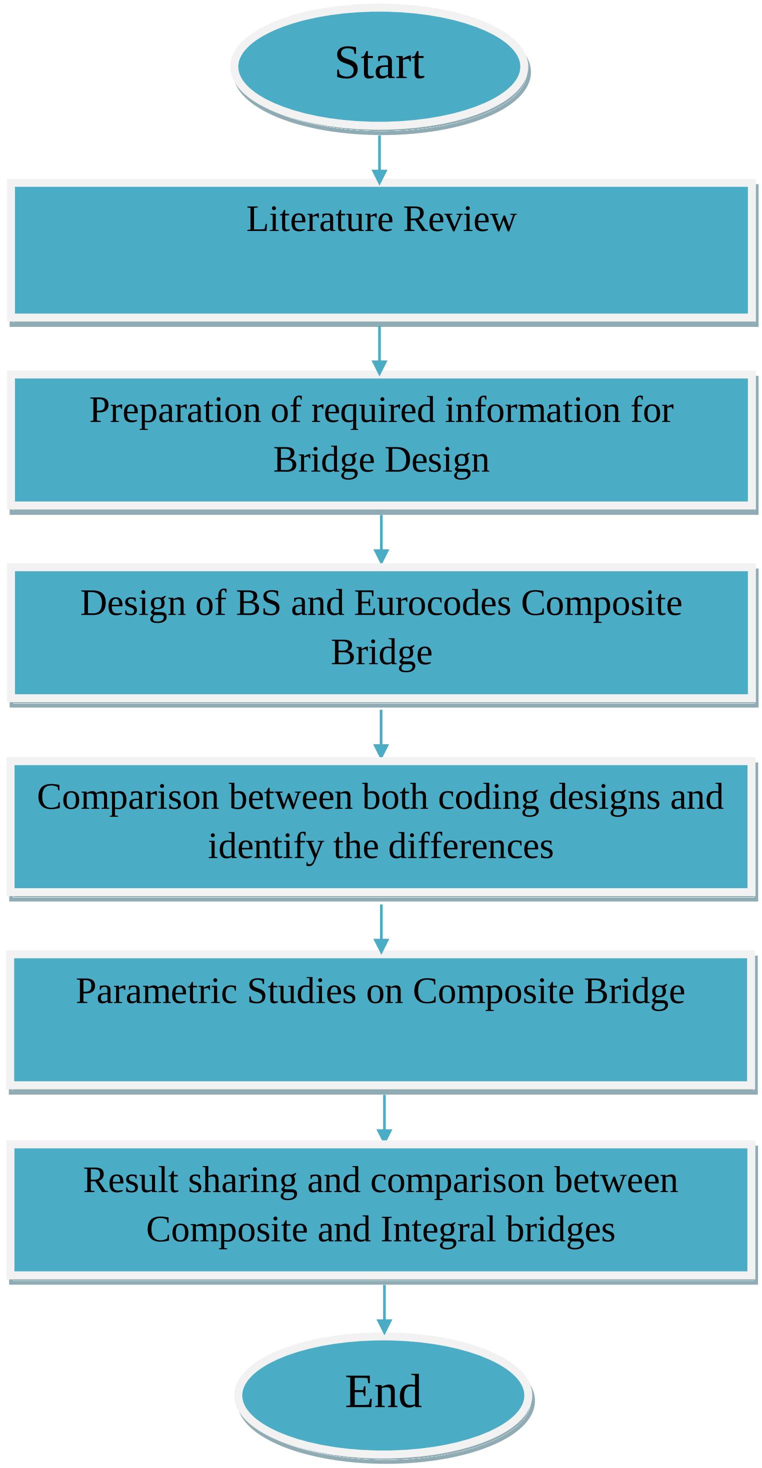
3.5 Parametric Studies

The parameter to be studies are included the design factor of complexity, strength of structures, effective's area and etc. The studies are done by using software modelling. For example, changing the types of beam support used on the spans and identify what are the differences before and after. On the other hand, there is another research is completed where the research is on parametric studies on integral bridges. Thus, comparison on different types of bridge can be done by sharing the parametric studies. Both types of bridges will be examined and made comparison.

3.6 Comparative Studies

Once designs analysis has been completed through design spreadsheet and software modeling, comparative studies among code of practices and types of bridges will be done. For code of practices comparison, it will focus on the comparison on live load distribution and reinforcement design. For types of bridges comparison, it will focus on the comparison of bending moment diagram of specific parameters with different changes. Once all the comparisons have been done, further discussion will be written on result and discussion section.

3.7 Flow Chart



3.8 Gantt Chart and Key Milestone

FYP 1

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defense														
5	Project Work Continues														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Key Milestone

Process

FYP 2

No.	Detail / Week	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Progress Work Continues														
2	Submission of Progress Report														
3	Further Progress														
4	Pre-SEDEX														
5	Submission of Draft Dissertation														
6	Submission of Dissertation														
7	VIVA														

Key Milestone

Process

CHAPTER 4: Results and Discussion

4.1 Introduction

The research begins with all the research objectives are being undergone at the same time. The objectives are:

1. Design and model composite bridges by using BS and Eurocodes and compare both bridge designs
2. Parametric studies on composite bridge
3. Comparative studies on composite bridge and integral bridge

The first objective of the research is mainly to identify what are the differences between BS and Eurocodes on bridge design. The research begins with designing and modeling a composite bridge with two different code of practice which are the BS and Eurocodes. Even though the bridges are designs with different codes, but they share the same characteristics such as dimensions, span size and width, number of spans and others.

To further understand the behavior of stresses acting on composite bridge, parametric studies on a new design composite bridge is required which as the second objective. Researcher decided to use the composite bridge designed by Eurocodes as the main object for parametric studies because the design was done by software modelling. Basically, comparative studies on composite bridge and integral bridge will be done on comparing some critical parameters such as maximum bending moment from combination loading and others by changing some parameters like girders type, concrete classes used and others.

Parameters to be studied are as:

1) Changing the types of beam structure
2) Curved Bridge behavior
3) Different configuration of bridge
4) Distribution Factor

4.2 Results and Discussion

4.2.1 Objectives 1: Design and model composite bridges by using BS and Eurocodes and compare both bridge designs

The following are the basic design data for the composite bridge.

Design Data:

Number of Spans	: 4
Number of girders	: 4
Spans Length	: 14.0, 20.3, 20.3, 14.0 m
Skew	: 33˚
Carriageway	: 7.3 m wide, 2 lanes
Surfacing	: 125 mm thick (including waterproofing)
Footways	: 1.5 m wide, each side
Overall deck's width	: 11.4 m
Slab thickness	: 0.235 m
Girder Properties	: Top Flange = 300 x 25 mm
	Web = 20 x 730 mm
	Bottom Flange = 300 x 25 mm

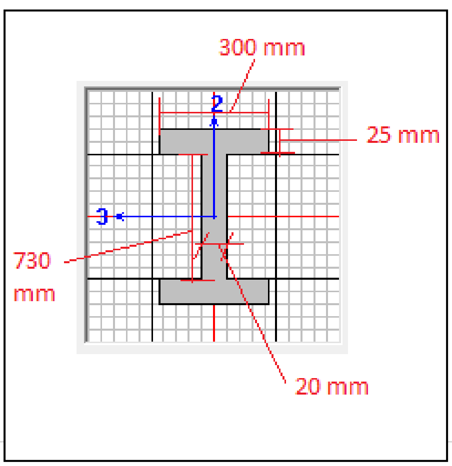


Figure 4.1: Section Properties

The BS composite bridge design was done by using manual calculation and spreadsheet. A worked example published by D.C. Iles in 2002 was used to help the researcher design the BS' composite bridge. On the other hand, CSI Bridge 2014 was used to design the Eurocodes' composite bridge.

As mentioned, BS's design is done by manual calculation and Eurocodes' design is done by using software modelling. Figures below show few different views of the composite bridges that have been designed. To further understand the full design of BS composite bridge, please refer to the appendices section where all the spreadsheet and manual calculation procedures can be found.

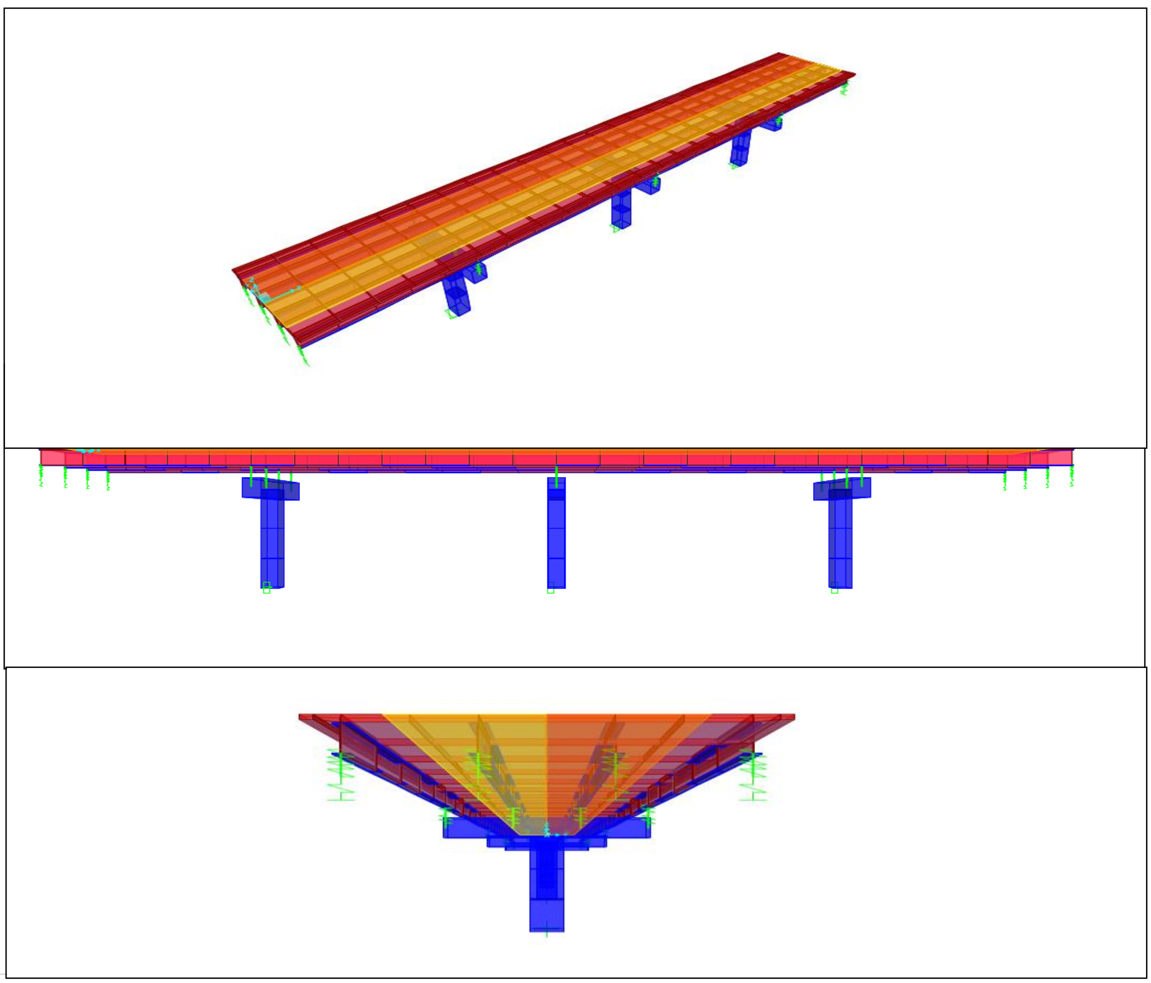


Figure 4.2: 3-D, elevation & cross-section view of the composite bridge (software model)

From the software drawings, it’s have clearly show the important parameter with different colors. Orange and yellow are represent as lane 1 and lane 2 respectively; blue represents the bridge piers and red represents the bridge girder and slab.

The results of comparison on between BS and Eurocodes designs showed that the major differences are came from different approaches when coming to design of live loading distribution on the support structure. Table 4.1 below has been provided to summarize the general ideas of live loading distribution for both codes.

Code of Practice	British Standard (BS)	Eurocodes
Loading Classification	The loading representing normal traffic is not varied. The axle loads in the nominal four axle abnormal unite (used for design) may vary between 250KN and 450KN. The loads applied to a structure are regarded as either permanent or transient. a) Permanent loads. For the purposes of this standard, dead loads, superimposed dead loads and loads due to filing material shall be regarded as permanent loads. b) Transient loads. For the purposes of this standard all loads other than permanent ones shall be considered transient.	1) The actual loads on road bridges result from various categories of vehicles and from pedestrians. 2) Vehicle traffic may differ between bridges depending on its composition (e.g. percentages of lorries), its density (average number of vehicles per year), its conditions (jam frequency), the extreme likely weights of vehicle and their axle loads, and, if relevant, the influence of road signs restricting carrying capacity. 3) Loads due to the road traffic, consisting of cars, lorries and special vehicle (e.g. for industrial transport, give rise to vertical and horizontal, static and dynamic forces.
Division of the Carriageway	For design purposes, the carriageway shall be divided into notional traffic lanes, the width of which shall be not less than 2.3m or more than 3.8m.	The number of notional lanes depends on the width: - $w < 5.4$ m => n1 = notional lane; - 5.4 m $\leqslant w < 6$ m => n1 = 2 notional lanes; - $w \geqslant 6$ m => n1 = Int (w/3) notional lanes. Accordingly, their width is: - $w < 5.4$ m => 3 m; - 5.4 m $\leqslant w < 6$ m => w/2; - $w \geqslant 6$ m => 3 m.

		For what regards the width of the remaining area: - w < 5.4 m => w – 3 m; - 5.4 m ⩽ w < 6 m => 0; - w ⩾ 6 m => w – 3 x n1.
Vehicle/Vertical Loads	There are two types of loadings: a) Type HA loading (normal traffic). Formula design loading for bridges is consist of a uniformly distributed lane loading, together with one knife-edge load. Two carriageway lanes shall always be considered as occupied by full HA loading (100 percent). All other lanes shall be considered as occupied by one-third of the full lane loading (33 1/3 percent). b) Type HB loading (abnormal vehicle). Exceptional design loading for bridges where a bridge is calculated for the type HA loading and checked for HB loading, which represents abnormal heavy vehicles. When considering the effects of the loading a reduced partial load factor is applied to the HB load and the coexistent HA loading. The HB load may be in any position, occupying one lane or straddling two. No other loading shall be considered in the 25m length at each end of the vehicle. HA loading shall also be applied to two lanes; either the remainder of the lane occupied by the HB vehicle plus an adjacent lane, or the remainder of the two lanes straddled by the HB vehicle, or the remainder of one straddled lane plus an adjacent	a) Load Model 1 comprises two components: a uniformly distributed load over the full width of a traffic lane and a pair of axles. For the UDL, the length of lane loaded should be those parts of the influence line that lead to adverse load effects. In each lane (up to a maximum of three lanes) a pair of axles (referred to as a Tandem System, TS) should be positioned centrally in the lane at the position along the lane that causes maximum adverse effect. b) Load Model 2 comprises single axle model load where dynamic application is included that should be applied at any location on the carriageway. Unless it is specified to adopt for the wheels the same contact surface as for load model 1, the contact surface of each wheel is a rectangle of sides 0.35m and 0.60m. c) Load model 3 comprises set of models of special vehicles. When one or more of the standardized models of this set is required by the client to be taken into account, the load values and dimensions should be as described in Annex A of Eurocode I.

	lane. All other lanes shall be loaded to 1/3 HA load.	d) Load model 4 comprises crowd loading. If relevant, it is represented by a nominal load. Unless otherwise specified, it should be applied on the relevant parts of the length and width of the road bridge deck, the central reservation being included where relevant. This loading system, intended for general verifications, is associated solely with a transient situation.
Load Combination	Combination 1: For highway and foot/cycle track bridges, the loads to be considered are the permanent loads, together with the appropriate primary live loads, and, for railway bridges, the permanent loads, together with the appropriate primary and secondary live loads. Combination 2: For all bridges, the loads to be considered are the loads in combination 1, together with those due to wind, and, where erection is being considered, temporary erection loads. Combination 3: For all bridges, the loads to be considered are the loads in combination 1, together with those arising from restraint due to the effects of temperature range and difference, and, where erection is being considered, temporary erection loads. Combination 4: This does not apply to railway bridges except for vehicle collision loading on bridge supports. For highway bridges, the loads to be considered are the permanent loads and the secondary live loads, together with the appropriate primary live loads associated with them.	Not specified.

	Secondary live loads shall be considered separately and are not required to be combined. Each shall be taken with its appropriate associated primary live load. For foot/cycle track bridges, the only secondary live load to be considered is the vehicle collision load with bridge supports. Combination 5: For all bridges, the loads to be considered are the permanent loads, together with the loads due to friction at bearings.	
Other forces	Not specified.	Along with vehicle loads, other loads and forces are acting in combinations as specified by various codes. It was decided to use the symbols of Eurocode I as the main symbols and where variations in symbol exist, they should be identified. The other forces are braking and accelerating forces, centrifugal forces, accidental and collision forces, wind, water and earthquake forces, forces due to temperature effects, earth pressure and forces due to erection.

Table 4.1: Loads & load distribution of BS and Eurocodes

The differences approach of the live loadings distribution has resulted different maximum stresses acting on the support structure for both coding design. It can be identified by taking an example from the mid-span bending moment acting on a 20.3m span

Mid-span Bending Moment of 20.3m span

Table 4.2: Bending Moment (KNm) of 20.3m mid-span of BS design

Loading	Nominal	ULS			SLS		
		γ_{fL}	BM	Shear	γ_{fL}	BM	Shear
HB (Max BM)	+737	1.3	+958		1.1	+811	
HA	+318	1.3	+413		1.1	+350	
FW	+48	1.3	+62		1.0	+48	
			+1433			1209	

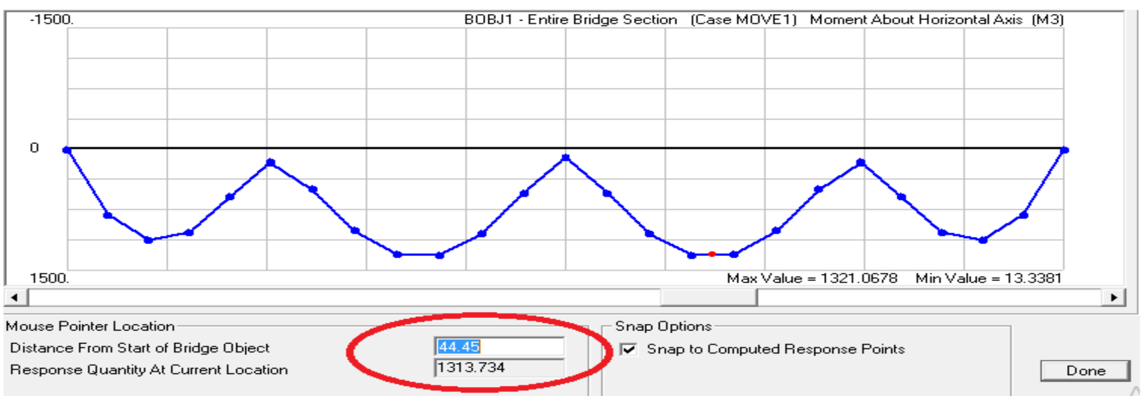


Figure 4.3: Bending Moment (KNm) of 20.3m mid-span of Eurocodes design

Comparing the results from the table and figure above, the bending moment of 20.3m mid-span for BS design is **1433 KNm** which has decreased to **1314 KNm** compared to Eurocodes design. The difference margin between both bending moments is about 8.31 %. which proved that the different manner adopted by both codes to determine the design live loads as well as the different approach taken in evaluating the worst load case for design loading as shown in Table 4.1 has attributed to this result.

4.2.2 Objective 2: Parametric studies on composite bridge

A new composite bridge design by using Oasys GSA in Eurocodes is required so that to standardize with another research on parametric studies on integral bridge. Figure 4.4 shared the overview look of the new composite bridge. Both bridges share the same characteristics as below:

Number of Spans	: 2		
Number of girders	: 3		
Spans Length	: 25.0, 25.0 m		
Carriageway	: 6 m wide, 2 lanes		
Footways	: 1.0 m wide, each side		
Overall deck's width	: 9 m		
Slab thickness	: 0.300 m		
Concrete T-Beam Properties	: Top Flange	= 3000 x 300 mm	
	Web	= 500 x 970 mm	

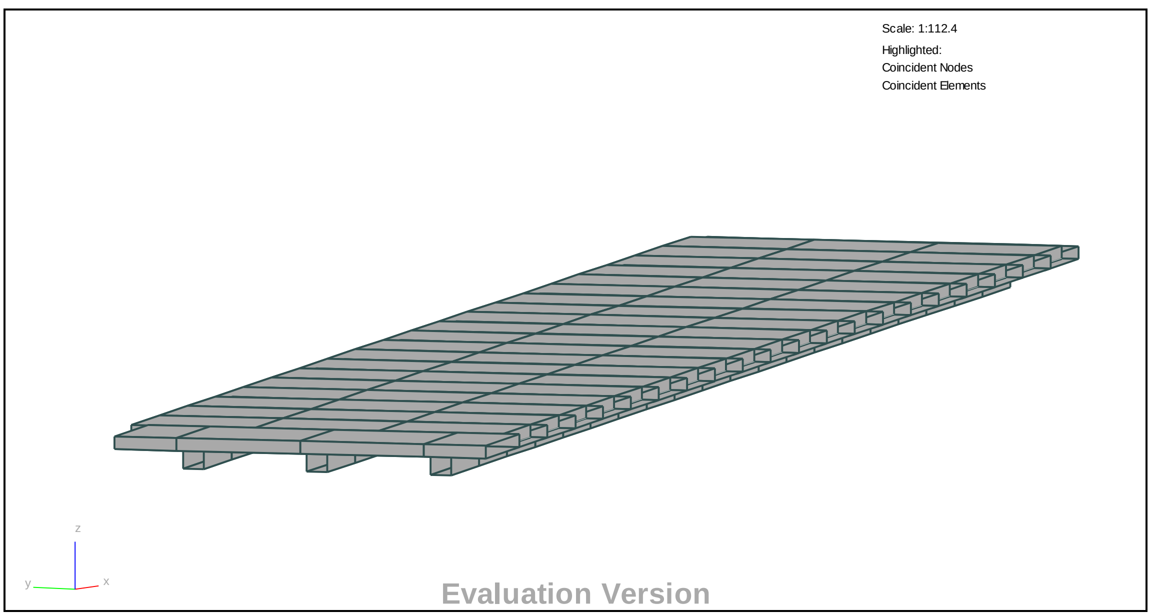


Figure 4.4: Overview of new composite bridge

(1) Changing the types of beam structure

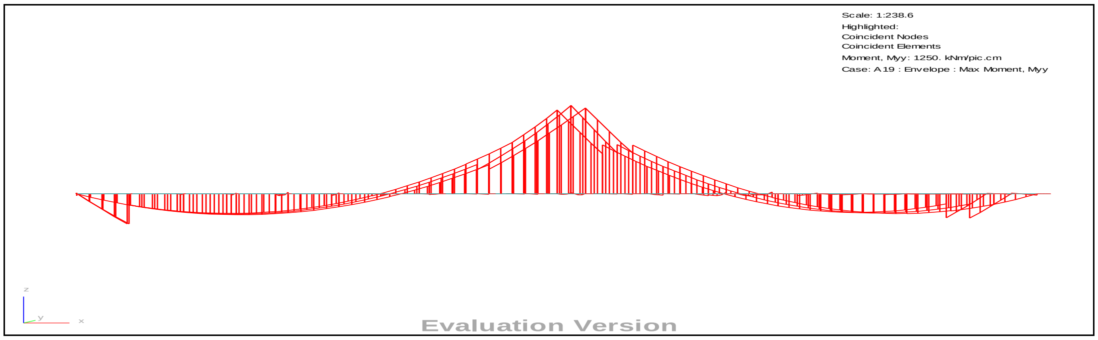


Figure 4.5(a): Bending moment of entire bridge section with T-beam

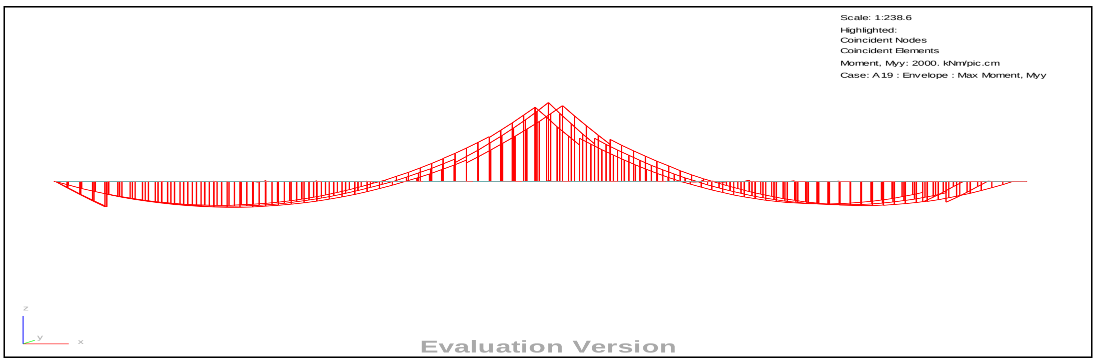


Figure 4.5(b): Bending moment on entire bridge section with I-beam

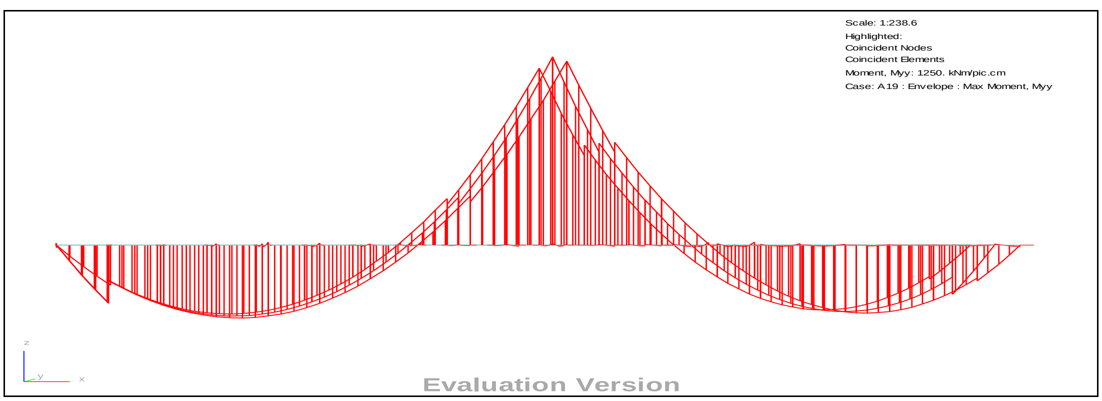


Figure 4.5(c): Bending moment on entire bridge section with Rectangular beam

Three types of beam structure have been chosen for this study which is T-beam, I-beam and Solid Rectangular Beam. They shared the same width and depth, 3000 x 300 m. The bending moment showing in the figures 4.5 (a), (b), (c) were calculated with the combination of all loadings acting on the entire bridge. The figures clearly show (c) has a higher maximum bending moment compared to (a) and (b). Table 4.2 below will give a better view on bending moment differences between the 3 figures. From the table, rectangular beam bridge has the highest maximum bending moment which is 7667 KNm. It was due to the extra self-weight added on the bridge structure as rectangular beam is a lot heavier compared to T and I beam. However, for deflection of the beam, T-beam deflects the most among the three beams. I-beam and rectangular beam deflected about the same. Thus, it is safe to say that I-beam is the most suitable beam used on this bridge.

Table 4.3: Maximum Bending Moment of different beam structures

Elements	T beam (KNm)	I Beam (KNm)	Rectangular Beam (KNm)
1	4.42E-05	6.20E-06	-1.30E-06
1	4.42E-05	6.20E-06	-1.30E-06
97	4255	5683	7701
7	-1206	-1590	4106
8	4218	5654	7674
1	4.42E-05	6.20E-06	-1.30E-06

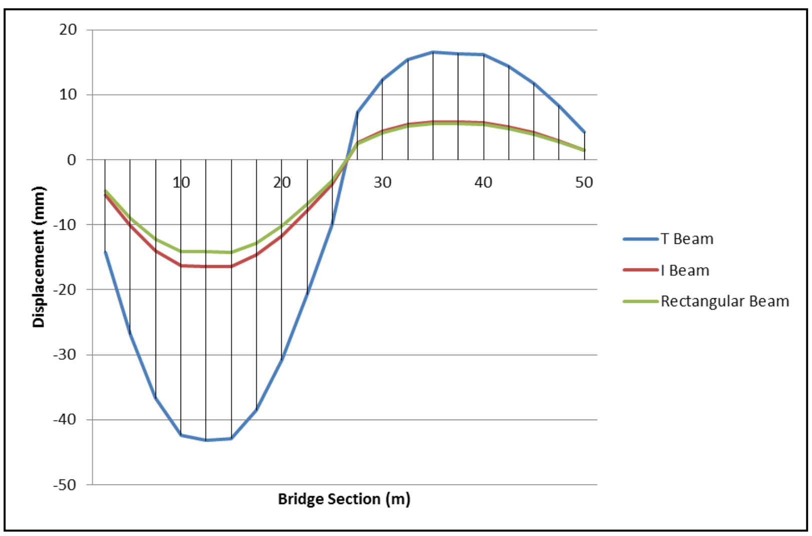


Figure 4.6: Displacement curve for all beams

(2) Curve Bridge Behavior

The curve road or bridge is designed with a right-turn curve of 50 degree from start of the deck to the end deck. It shared the same physical properties as the main design in figure 4.4.

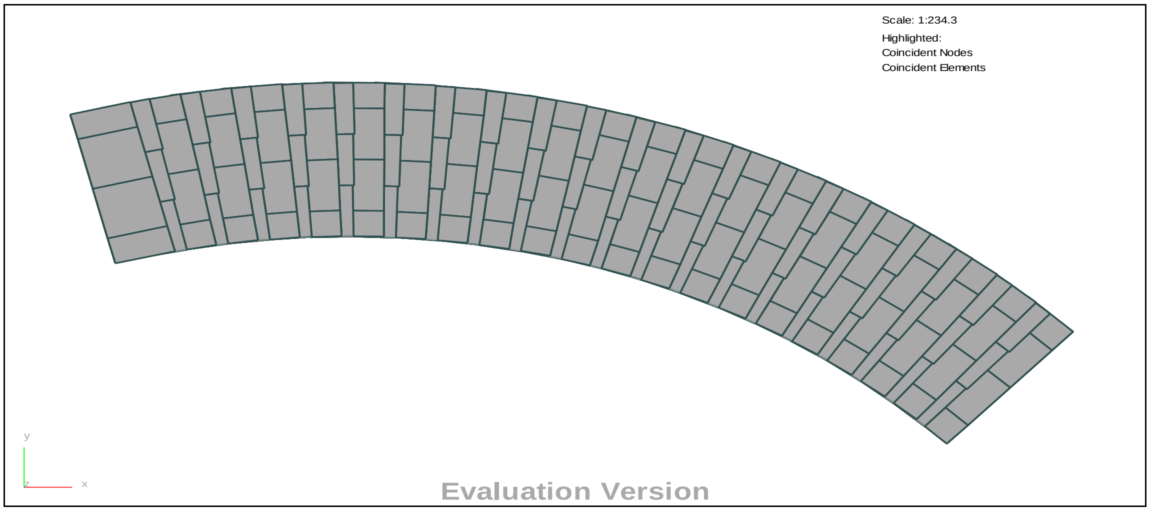


Figure 4.7 (a): Overview of Curve Bridge

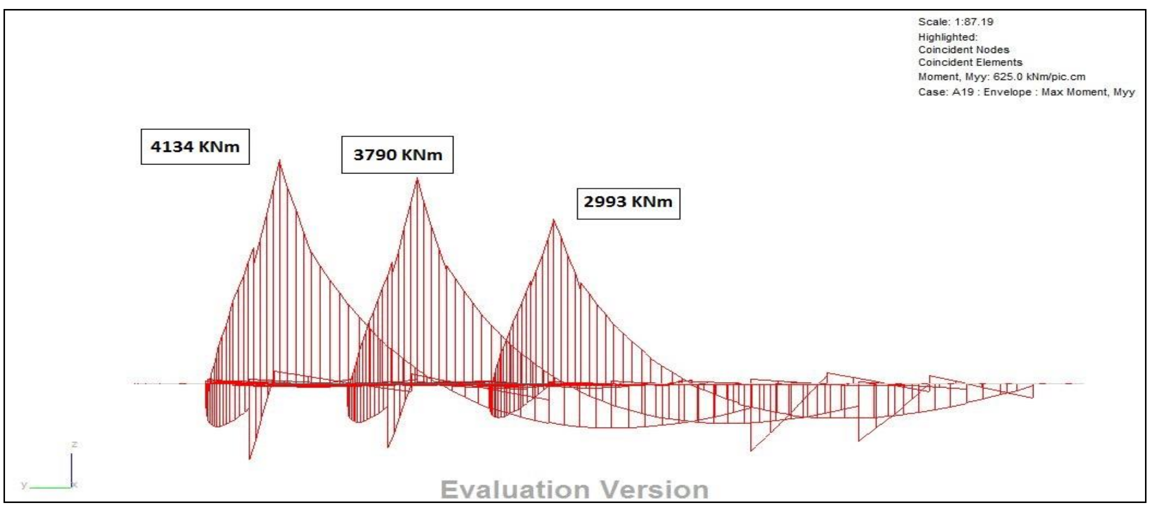


Figure 4.7 (b): Bending moment on the entire bridge section

From the figure 4.6 (b) above, it shows 3 different maximum bending moments acting on the mid-span of the bridge. The right turn curve has resulted the least bending moment (2993 KNm) is acting on right exterior T-beam and the highest bending moment (4134 KNm) is acting on left exterior T-beam with about 27.6 % margin. This phenomenon was happened because the carriageway is located towards to the left of the bridge.

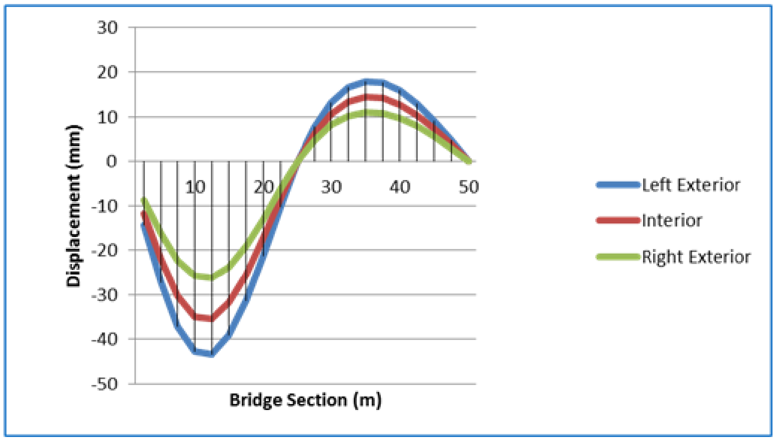


Figure 4.7 (c): Displacement curve of the girders

(3) Different Configuration of Bridge

Three spans composite bridge with 2 interior piers located at 15m and 35m from the starting deck is designed and used for the study. Comparing the figure 4.7 below to figure 4.5 (a) as they share the same physical properties, the shape of the bending moment diagram is different. Figure 4.7 shows the three span bridge having two maximum bending moment on mid-span while Figure 4.5 (a) having only one at the mid-span. Table 4.3 also shows the differences of the maximum bending moment between two bridges is about half. The table also shows the maximum stresses acting on the bridge are at different elements or beam section.

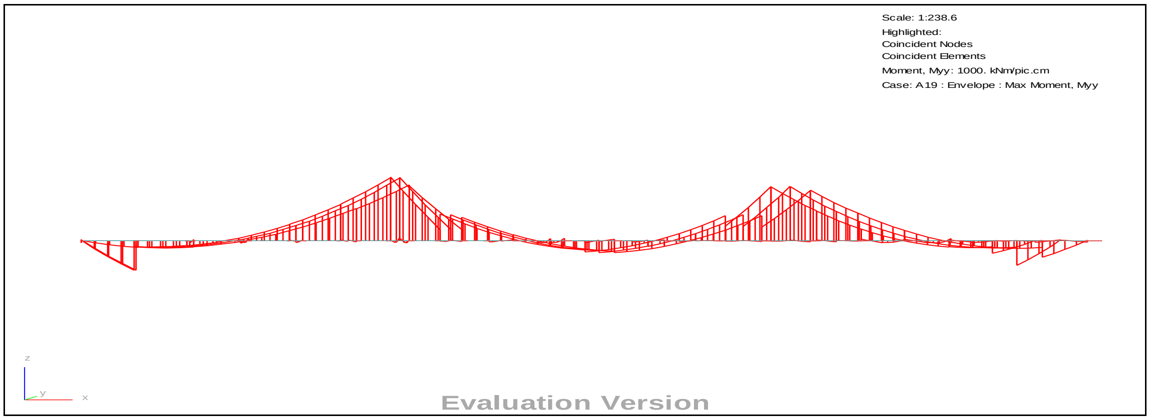


Figure 4.8: Maximum bending moment on entire bridge section

Table 4.4: Maximum bending moment for three and two spans bridges

Elements	Two Spans (KNm)	Three Spans (KNm)
60	517.9	1600
61	545.4	1903
62	576.7	1964
87	3977	-308.3
88	4255	-301.9
89	4107	-288.6

However, the results didn't mean that constructing a three spans bridge will be more cost effective than constructing a two spans bridge. Added span will also adding another pier structure to the bridge. Therefore, even reducing the sizes of the beam structure wills not necessary give a more cost effective structure. A further study on the costing of the bridge structures needed to carry out in order to identify such statement.

4) Distribution Factor

Distribution factor is used to identify which beam structure among three is having the highest stress when one of the load case is acting on the bridge. The formula used to determine the DF is:

$$DF = \frac{M_i}{\sum_{i=1}^{n} M_i}$$

where M_i is the maximum moment acting on the beam. From the figure 4.9, it shows that the interior beam is always receiving the highest load distribution with percentage of 85%. For the exterior beam, it has equally shared the load distribution with about 8% of the total load distribution.

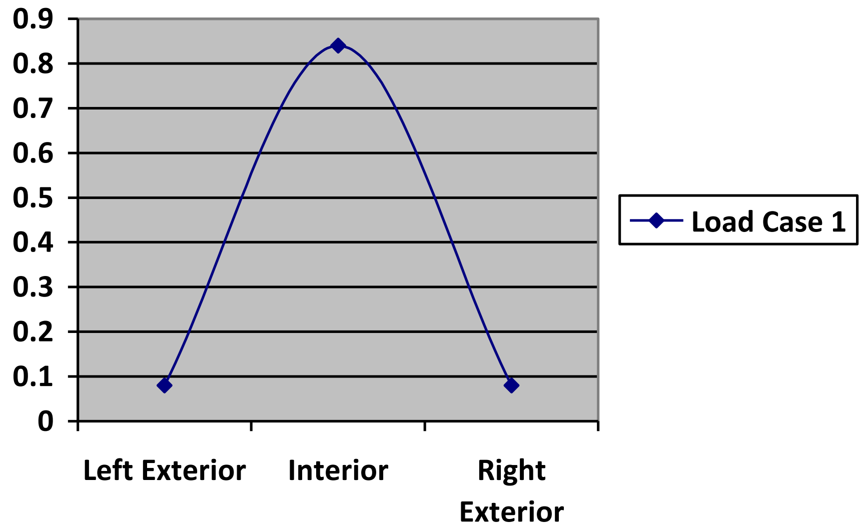


Figure 4.9: Distribution factor of the girders

4.2.3 Objective 3: Comparative studies on composite bridge and integral bridge

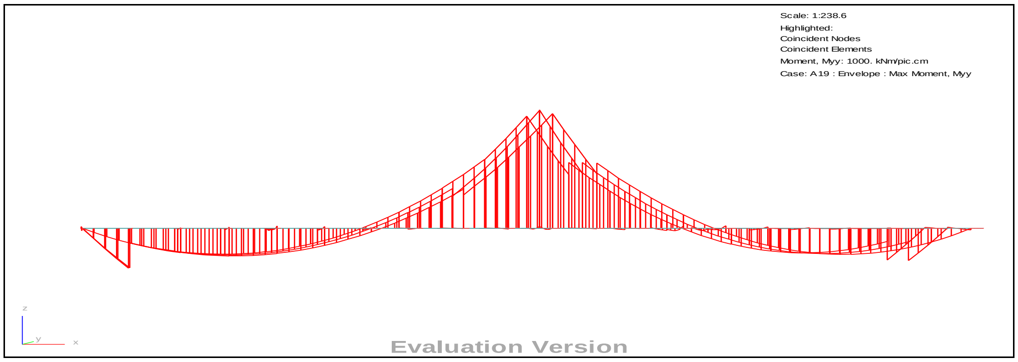


Figure 4.10 (a): Bending moment diagram of composite bridge

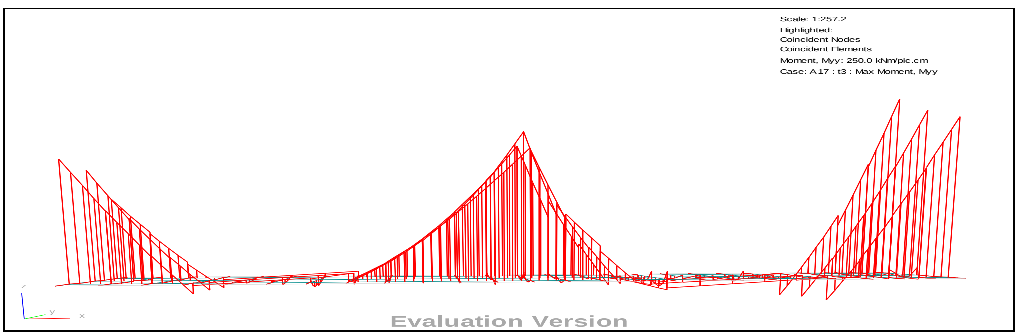


Figure 4.10 (b): Bending moment diagram of integral bridge

The research continues to its final objective by sharing all the accumulated results with another research. The final study is comparing the behavior and reaction of the composite and integral bridges when both having same physical properties and undergone the same stresses. From figures 4.8 (a) and (b), it can tell that the bending moment behave differently on both bridges. For composite bridge, the start and end abutment having little stresses while for integral bridge the abutments are having about the same maximum bending moment on the mid-span of the bridge. As for maximum shear force, the results show the same behavior as the bending moment as shown in figure 4.8 (c).

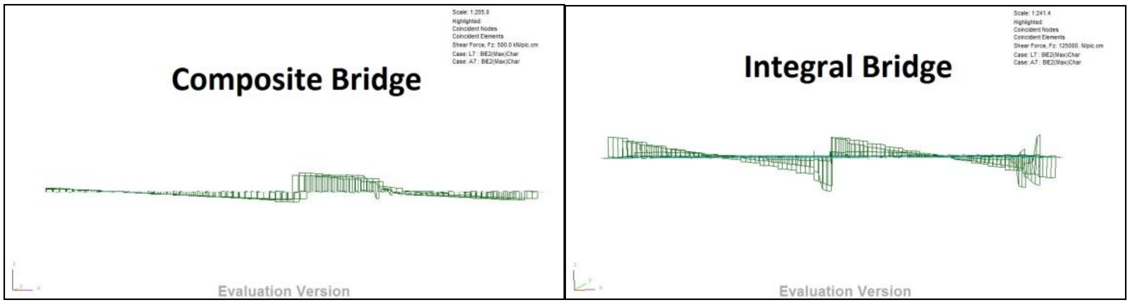


Figure 4.10 (c): Maximum vertical shear force on entire bridge section

These phenomenon occurred because due to the integral abutment was designed as fixed support while composite abutment was designed as pin support. The vertical and horizontal loadings effects on the section will cause the bridge structure to be moved. Normally, bridge bearing was used to absorb the movement however for integral bridge case, the beam structure and the abutment are attached and merged with each other. Thus, movement load will entirely absorb by the structure its own.

This reason could be probably is the main reason that Malaysia Bridge does not favor to integral bridge because the huge amount of stresses acting on the abutment and pier will make engineer harder to design the bridge structure. However, this result has opened up a future studies regarding the economic differences between composite and integral bridge.

Chapter 5: Conclusion and Future Recommendation

In a nutshell, the research has completed and served two types of comparison:

- British Standards design versus Eurocodes design on composite bridge
- Composite bridge design versus integral bridge design on specific parametric studies

For comparison on BS and Eurocodes designs, it has shown that the different way on approaches the live loadings distributions are the main differences among the both design. These have resulted different maximum stresses values acting on each bridge. The final result is the live loads acting on the Eurocodes composite bridge is lesser than the live loads acting on the BS composite bridge by a margin of 8.31%. The result will leads to further changes like Eurocodes design will needed lesser reinforcement on slab compared to BS design thus the design is more cost effective.

The parametric studies on composite bridge have also identified few important statements. The changing the types of beam structures will affect the stresses values on the bridge. In this case, rectangular beam structure will create the highest stresses on the bridge compared to T-beam and I-beam structure. Therefore, it is recommended that T-beam and I-beam will be more ideal design as beam structure for bridge. For the curved bridge studies, it has been understood that the beam structure on the most left has more stresses than beam structure on the most right with 27.6 % margin. The final parametric studies are on what will different configuration of bridges resulted. The result showed with three Spans Bridge, the stresses will dissipated more and the piers and abutments will receive lesser stresses when compared to the two spans bridge.

The comparative studies on composite bridge and integral bridge has also found out that integral bridge structures is harder to design compared to the composite bridge due to the extra stresses on abutments.

However, it is recommended that further studies are needed to be done on identifying the economical differences between composite bridge and integral bridge. This will allowed the industrial parties to have a clearer picture on what types of bridge should use as the design standard. Also, more parametric studies should also done on other types of bridges such as arch bridge, Cable Bridge and other to allow Malaysian industrial parties understand more on bridge types. Another study should also be done on what are the difficulties that Malaysia industrial is facing to change their structure code of practice from British Standard to Eurocodes. The study again could be crucial to the industrial so that they can tackle the difficulties that they are facing and adopted Eurocodes as design code of practice as soon as possible.

All in all, the research has managed to achieve all the objectives that have been set up. It also enables to share the research results with another researcher which has benefited for both researches.

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Appendices