IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Bridge loading in Malaysia : past, present and the future

To cite this article: Atikah Bt Zakaria@Ya *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **512** 012034

IOP Conf. Series: Materials Science and Engineering **512** (2019) 012034 doi:10.1088/1757-899X/512/1/012034

Bridge loading in Malaysia : past, present and the future

Atikah Bt Zakaria@Ya, Fairul Zahri Mohamad Abas, Mohd Yunos Ali and Nadia Azmi

Bridge Design Division, PWD Malaysia.

Email: fairul.jkr@1govuc.gov.my

Abstract. A rapid growth of development in our country has demanded our road network to be expanded over the last few decades. To cope with rapid development, the transport industry has deployed larger vehicles with heavier axle loads. In many instances, the level of services of our road network governed by the bridge load capacity. Since pre-independence era, our bridges have been designed based on the British Code. Begin with British developed code of DSIR at early 20s to British Code (BS) and eventually to Eurocode, our bridge loadings have been evolved substantially. In the midst of foreign code, our National Axle Load study conducted in mid 80s has also marked a significant finding to our local bridge capacity in which three major groups of load carrying capacity have emerged from namely STAL, MTAL and LTAL. This paper presents the journey of our local bridge loading code of practice and the corresponding impact to the structural design and construction. Comparisons are made as early as in 20s at the time where the code was based on British Department of Scientific and Industrial Research (DSIR) to the early age of British Code and to the migration of Eurocode. A typical concrete bridge deck spanning of 20m to 60m are modeled and analyzed with respective live loading derived from these established code of practice. Discussion on the way forward of implementing the Eurocode into our local design practices are also included.

1. Introduction

Bridge structures as part of a road network has evolved since pre-historical time. The main function of the bridge has remained unaltered in defying the gravity force from the beginning of human civilization. Similarly in Malaysia, bridge structures as part of the road network played a significant roles particularly in promoting economic growth by connecting cities, allowing goods transportation and so on.

The understanding of the bridge mechanism evolved as the science and technology advanced. The foremost importance of the bridge structures is that it must be able to sustain the intended design load at that particular point of time. The locality, economy and geographical aspect of the country typically dictate the mode of transport thence the bridge capcity that need to be designed. As such, bridge and transport engineers have work hand to hand to ensure that the functionality of the bridge during service is not compromised.

The objective of this paper is to comprehend the evolution of the bridge loading in Malaysia and how is the intensity of load affects the bridge capacity in carrying the load.

2. From the past

Bridge design in Malaysia has always been influenced by the British Standard due to the colonization links between these two countries. The period between 1914 and 1918 marked a new era in the evolution of the highway bridge loading in United Kingdom. Malaysia has first adopted bridge design standard as early as 1922 from *British Standard Loading Train* as shown in Figure 1. This standard loading train consisted of a 20 tons tractor plus three trailer of 13 tonnes each respectively [1]. This configuration of loading was actually a direct representation of traction engine plus three trailer used on the road at that time as shown in Figure 2. This type of loading prevailed until late 1931 when British Ministry of Transport (MOT) adopted a new approach to design loading known as *MOT loading curve*. It consisted of a uniformly distributed load (UDL) plus with an invariable single transverse line load known as knife-edge load (KEL). The concept of loaded length was also introduced at this stage as part of the improvement from previous application of Standard Loading Train which has only specific dimensions. A reproduction of the curve of uniformly distributed load (UDL) against loaded length is as shown in Figure 3.

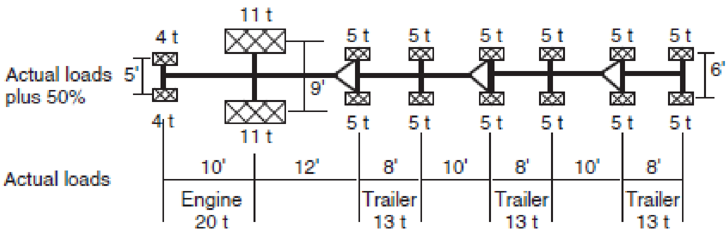


Figure 1: Standard Loading Train adopted in 1922 [1].

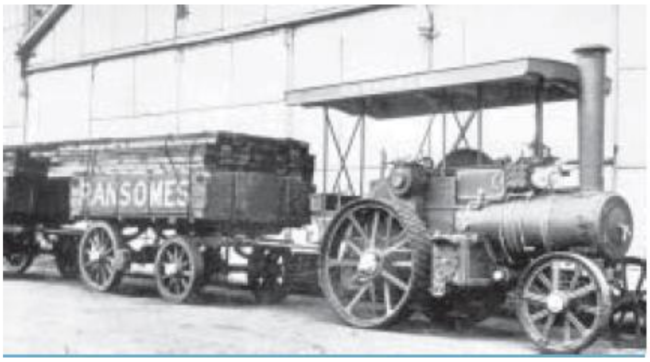


Figure 2: Traction engine plus three trailer c. 1910 (after ICE Manual)

At this point of time, the British Government through the MOT has also introduced the Construction and Use (C&U) Regulation for Lorries and Truck which indicated the legally allowed loads and dimensions for various types of vehicles.

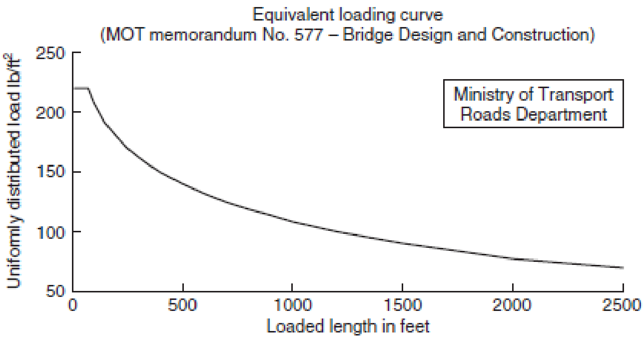


Figure 3: Original *MOT loading curve* of UDL against loaded length

In 1954, Henderson presented a paper suggesting reconsidering the load pattern of *British Standard Loading Train* and the *MOT Loading Curve* [2]. Henderson (1954) observed that in reality the loads in used were differed from the standard loading train or standard loading curve. It was found that there were those that could be describe as legal load that conform to C&U regulation while certain vehicle carrying abnormal indivisible heavy load, which were outside the regulation where special permission was required for transportation. Thus, his observations lead to the categorization of normal and *abnormal* indivisible load due to the fact that both ordinary traffic load and abnormal vehicle are dissimilar in weight and arrangement of wheels to those represented by the former loading trains. As a result, the MOT in conjunction with British Standard Institution (BSI) had come up with two kind of loading for design purpose, namely normal (HA) and abnormal (HB) loadings with the philosophy that the design should be made on the basis of normal loading and checked for abnormal traffic loading. This was embodied by the standard code document of BS 153. Several revisions have been made along the way as more precise information about traffic volumes and weight has been gathered and in 1978 the standard code of BS 153 was replaced by BS 5400.

Malaysia however did not completely adopt this type of loadings. Only normal HA loading was adopted for design purpose of major road while 2/3 of HA load intensity was used for designing minor roads up until year 1972 [3]. From late 1972 to 1990, our local bridge design practice has adopted to include HB in combination of HA type of loading. The HB loading vehicle load however was applied at the centreline of the bridge deck and was in coherent as per BS 5400.

In 1985, the Government of Malaysia has commissioned a National Axle Load Study for bridges in Peninsular Malaysia [3]. The study was completed in the late 1987. The details of the study are not presented in this paper. As the result, one of the major outcomes of the study lead to the formulation of Malaysian Design Bridge loads called Standard JKR Specification for Bridge Loading. The specification was read and applied in conjunction with BS5400 however. The only part that the specification covered was only the live load by replacing HA and HB loadings to LTAL and SV loadings respectively. The specification nevertheless valid for highway bridges with loaded not exceeding 50m.

3. At present

The LTAL load used as the specification of Bridge Design in Malaysia was not prolonged when it was found that the load effect of LTAL were higher than the load effect caused by the design load in UK, Canada and USA. In 2001, the British Standard Institution and Department of Transport has come to agreement that BD 37/01 will be used as the current code for Bridge Design in UK. BD 37/01 which is based on BS 5400 part 2 (BSI, 1978) was also adopted in Malaysia to replace the JKR Bridge Design Specification. Similar to BS 5400 part 2 (1978), the two most prominent load applications are defined as normal load (HA) only and HA in combination of abnormal loading (HB). The normal load consists of a uniformly distributed load (UDL) occupied on a designated notional lane plus a lane KEL. The intensity of UDL load curve is given as in Figure 4. It showed two-part curve in which each load curve W in kN/m is defined by equation (1) for one up to 50m loaded and equation (2) for the remainder up to 1600m respectively [4].

$$W=336(1/L)^{0.67} \quad (1)$$

$$W=36(1/L)^{0.1} \quad (2)$$

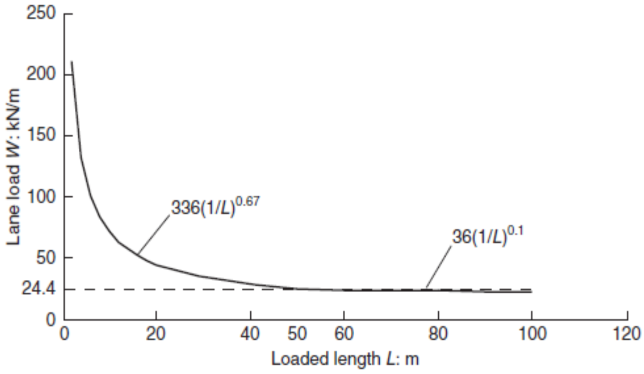


Figure 4: British Standard (BD37/01) normal loading curve for UDL HA type of loading

The application and intensity of normal load (HA-UDL) depends upon the carriageway width, the loaded length and the number of loaded lanes. The carriageway width will dictate how many numbers of notional lanes on a particular bridge deck. Notional lane in fact is not necessarily the same as the actual traffic lanes defined by the lane marking. It is given by:

$$\text{Int}\,[(b/3.65)+1] \tag{3}$$

where *b* is the total width of the bridge deck measured between kerbs on the deck.

The loading for abnormal vehicle in BD37/01 has a similar configuration as in BS 5400 part 2 (1978). It can be called as HB type of loading. This abnormal vehicle load is distributed on 16 wheels arranged on four axles as shown in Figure 5.The weight is measured by multiplying the unit per axle to the maximum number of 45. 1 unit of axle is taken as 10kN and produced up to 450kN per axle load for 45 unit of HB loading. It can be seen from Figure 5 that the configuration of HB vehicle can be adjusted to suit the influence line of the deck analysis interest. The inner axle spacing can vary to give the worst effect ranging from 6m to 25m in an increment of 5m.

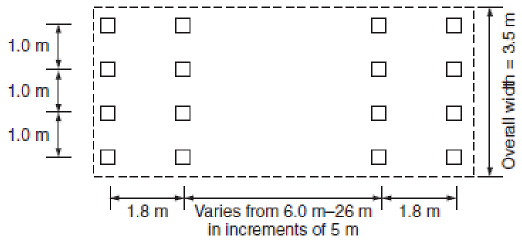


Figure 5: Abnormal HB vehicle configuration

BD 37/01 called that all road bridges shall be designed to carry HA loading. In addition to that, 30 unit of HB type of loading shall be taken in combination of HA loading for all road bridges except for accommodation bridge which allowed HA type of loading only. However, depending on the class of road carried by the structures, the number of unit of HB type of loading can be increased. For instance, 45 unit of HB type of loading for motorway and trunk road while 37.5 unit of HB loading for principal road. Other public road shall be taken as 30 of HB loading.

Similar to HA-UDL load application, the abnormal vehicle load of HB type is also applied onto the notional lane. However, there is an opportunity that the HB vehicle can be applied straddling onto two notional lane depending on the width of notional lane itself. HA-UDL type of loading is also applied on the remaining notional lane in the case of combination of HA and HB type of load application.

4. In the future

All the while Malaysia has adopted British Standard as its design code for civil works design and construction. In March 2010, British Standard Institute (BSI) withdrew 57 related and conflicting structural codes and had published 58 documents as the replacements. In view of this change, Top Management of JKR Malaysia in 2015 has given 00a directive to embark on the use of Eurocode for the design purpose including the bridge design loading and structural code. Initial point was raised on what loading shall be taken for the application of abnormal type of vehicle loading.

Eurocode for bridge loading compendium published in volume EN 1991-2. The load model for vehicle representation have been explicitly elucidate as to compared with previous BS code into 4 major type as listed in Table 1[5].

Table 1: Load model definitions in EN 1991-2 for bridge loading

Load Model	Definition
LM 1	Normal loading due to lorries plus cars
LM 2	A single axle for local effects
LM 3	Special vehicles for the transportation of exceptional loads
LM 4	Crowd loading

The normal loading represented by load model 1 (LM1) has a similar configuration as to British standard whereby it comprises of uniformly distributed load plus a double-axle tandem applied onto the respective notional lane [6]. The notional lane width is generally taken as 3m, and the number of notional lanes as *Int(w/3)* where *w* is the carriageway width. Instead of deriving from load curve, the UDL normal load of EN1991-2 together the tandem load are given by the characteristic values with respect to notional lane number as listed in Table 2.

Table 2: Characteristic value of normal load in EN 1991-2

Location (Not.lane)	Tandem System load TS	UDL System load
	Axle load (kN)	Q (kN/m2)
Lane Number 1	300	9
Lane Number 2	200	2.5
Lane Number 3	100	2.5
Other lanes	0	2.5
Remaining area	0	2.5

Abnormal loads are considered in a similar manner to the British Code, with a special abnormal load (model LM3) placed in one lane (or straddling two lanes) with a 25m clear space front and back and normal LM1loading placed in the other lanes. The vehicle may be specified by the particular load authority involved, or alternatively it may be as defined in EC1 which specifies eight load configurations with varying numbers of axles, and loads from 600kN to 3600 kN. Wheel areas are assumed to merge to form long areas of 1.2m x 0.15 m. Axle lines are spaced at 1.5m and may consist of two or three merged areas. A typical configuration for an 1800kN vehicle is shown in Figure 6.

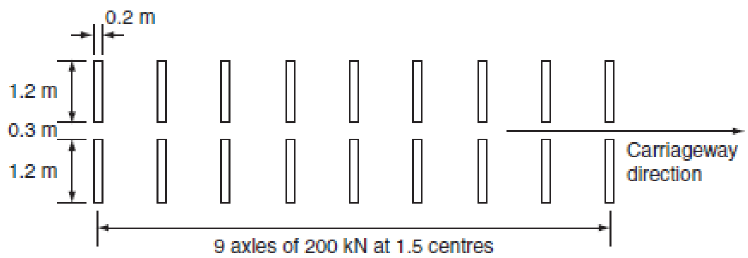
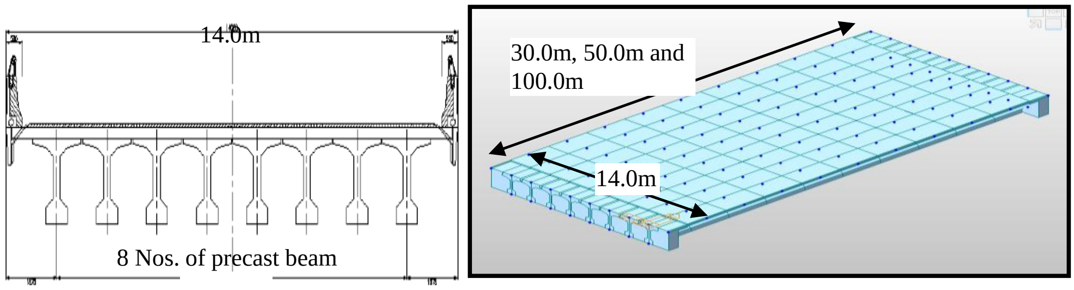


Figure 6: Typical LM 3 vehicle

5. BS and EC load comparison

To depict the advance of bridge live loading from British Standard to Eurocode, a simple comparison in term of bending moments for a single and multiple span bridges are carried out. A single span bridge of 30m, 50m and 100m length as shown in Figure 7 and 8 respectively have been modelled by using computer modelling package MIDAS. Similarly, a comparison on two-span simple beam bridge is modelled and the structures responses of bending moment are also compared [7].

Primary type of UDL loading which was derived from BS loading (HA –Type) and EN l (Load Model 1 (LM 1)) were first compared in term of their load carrying capacity represented by value positive bending moment.The prerequisite data in term of number of notional lane, loaded length, partial factors that are required in deriving the UDL type of load in British Standard and Eurocode are the same for the purpose of comparison.



(a) **(b)**

Figure 7: (a) Simple beam bridge deck of 14.0m wide and (b) the grillage model of the bridge deck

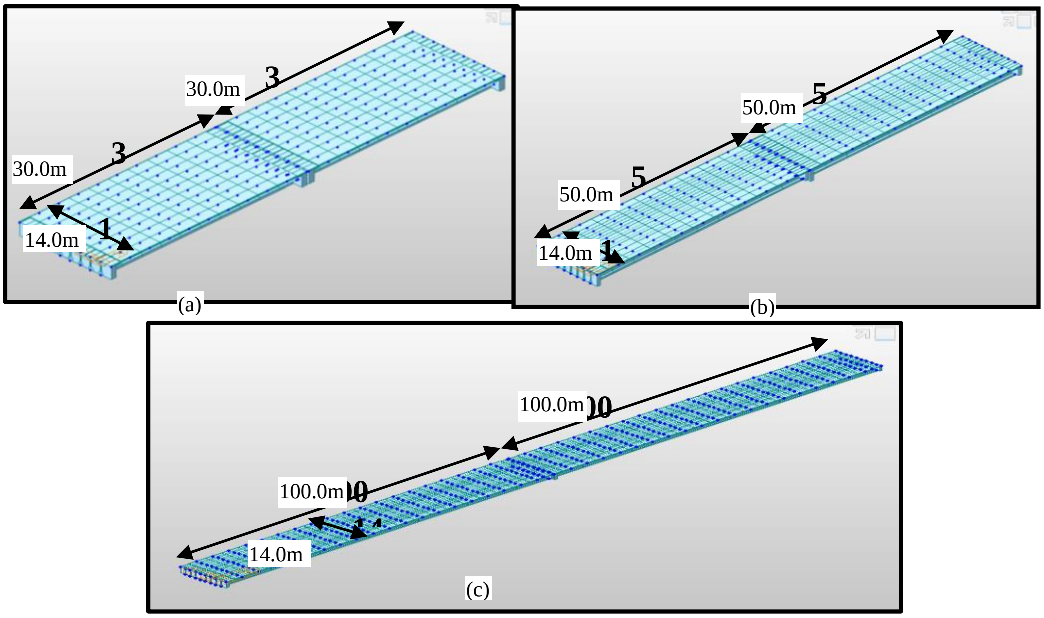


Figure 8: Simple two-span beam bridge deck of 14.0m wide and the grillage model of the bridge deck for (a) 30m each (b) 50m each and (c) 100m each span respectively

The positive bending moment values for the single span model with the span length of 30m, 50m and 100m respectively are shown in Table 3 while the results for two span span length are given in Table 4. In the case of simply-supported bridge model, the span length can be considered as the loaded length at which the traffic loading acted upon it. In this investigation the loaded length were made equal length of 30m, 50m and 100m each.

In order to see clear comparisons and relationships between the bending moment and its respective loaded length of two difference codes, the graph in Figure 9 and Figure 10 are plotted. From Figure 9, it can be seen that the positive bending moment values obtained by using the UDL type of traffic loading from BS code and EN code are almost identical. This demonstrates that the EN code can be replaceable to the BS code without any substantial deprivation of the existing load designed by using BS code. This is applicable when it deals with UDL type of bridge loading for a single span bridge. Similar pattern can also be seen when the UDL type of loadings of both codes were applied to two-span continuous bridge as shown in Figure 10. Agreements between these codes are prominent for a short loaded length whereas slight difference can be seen for a loaded length greater than 200m.

Although the EN code has omitted the influence of loaded length to the intensity of UDL loading it can be deduced that a characteristic values given for the LM 2 which consist of tandem (TS) and UDL systems respectively has produced a similar load effect as per BS. The main difference come from the substantial reduction in load applied to the location of traffic lane on the deck.

Table 3: Comparison of Positive Bending Moment Values for 30m, 50m and 100m Single-Span Bridge Model

Type	Loaded Length (m)								
	30			50			100		
	Unfactored	FOS	Factored	Unfactored	FOS	Factored	Unfactored	FOS	Factored
British Code (kNm)	2,342.59	1.50	3,513.89	4,647.81	1.50	6,971.72	12,711.11	1.50	19,066.67
Eurocode (kNm)	2,377.86	1.35	3,210.11	4,824.83	1.35	6,513.52	12,735.90	1.35	17,913.47

Table 4: Comparison of Positive Bending Moment Value for Continuous Two-Span Bridge Model of Equal Span of 30m, 50m and 100m respectively.

Type	Loaded Length (m)								
	2 Span @ 30m each			2 Span @ 50m each			2 Span @ 100m each		
	Unfactored	FOS	Factored	Unfactored	FOS	Factored	Unfactored	FOS	Factored
British Code (kNm)	1,365.28	1.50	2,047.92	2,879.42	1.50	4,319.13	7,543.06	1.50	11,314.59
Eurocode (kNm)	1,650.86	1.35	2,228.66	3,297.07	1.35	4,451.04	8,115.20	1.35	11,360.52

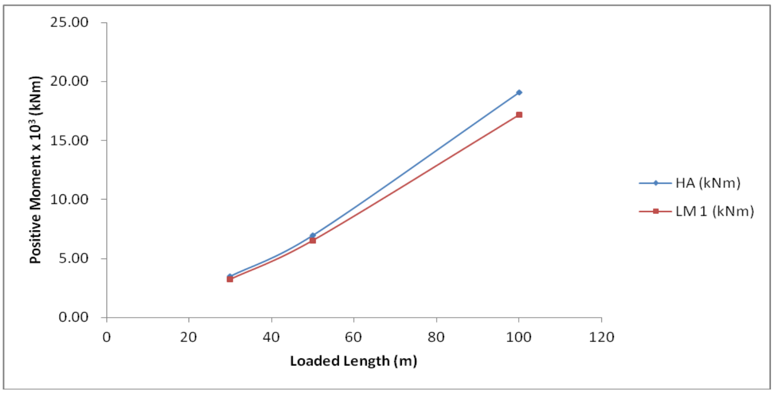


Figure 9: Comparison of Positive Bending Moment of UDL loading from British code BS (HA-UDL) and Eurocode EN (LM 1) for 30m, 50m and 100m Single Span

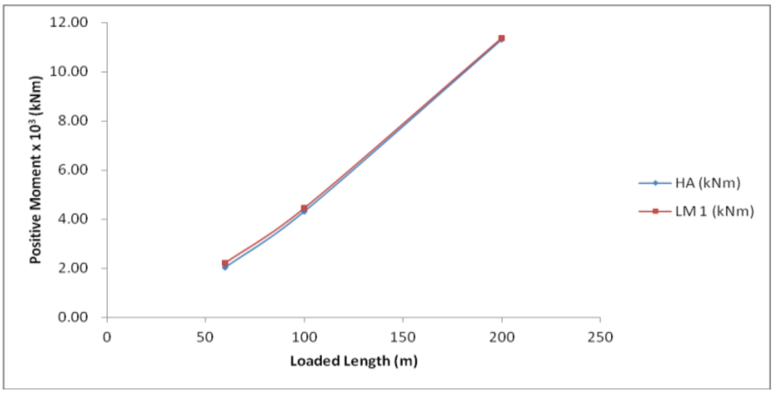


Figure 10: Comparison of Positive Bending Moment of UDL Loading from British code BS (HA-UDL) and Eurocode EN (LM 1) for Two Span Bridge Model.

The abnormal load between both BS and EC code were also compared. Comparison of current practice of British Code of abnormal load (HB 30) was made against Eurocode EN load of special vehicle (SV 100) while the abnormal loading of HB 45 in BS was compared against SV196 of EC code. These two sets are the common abnormal vehicle used for design loading for majority of principle road. The HB 30 and HB 45 were derived from the nature of exceptional industrial load with the total weight of 1200 kN and 1800kN respectively while SV 100 and SV 196 represent the effect of special type general order vehicle with the overall weight of 1000 kN and 1960kN respectively. Similar grillage models and span configurations as the primary UDL load was used to analyse these two type of loadings.

The positive bending moment values for the single span model with the span length of 30m, 50m and 100m respectively are given in Table 5 and 6 while the results for two span of varying span length are given in Table 7 and 8 respectively.

Table 5: Comparison of Positive Bending Moment Values for 30m, 50m and 100m Single-Span Bridge Model for HB 30 and SV 100 Loadings.

Type	Loaded Length (m)								
	30			50			100		
	Unfactored	FOS	Factored	Unfactored	FOS	Factored	Unfactored	FOS	Factored
British Code (kNm)	2,320.64	1.30	3,016.83	4,130.46	1.30	5,369.60	6,599.58	1.30	8,579.45
Eurocode (kNm)	2,691.07	1.35	3,632.94	4,416.05	1.35	5,961.67	6,702.12	1.35	9,047.86

Table 6: Comparison of Positive Bending Moment Values for 30m, 50m and 100m Single-Span Bridge Model for HB 45 and SV 196 loadings

Type	Length (m)								
	30			50			100		
	Unfactor	FOS	Factor	Unfactor	FOS	Factor	Unfactor	FOS	Factor
British Code (kNm)	3,480.96	1.30	4,525.25	6,195.69	1.30	8,054.40	9,899.36	1.30	12,869.17
Eurocode (kNm)	4,096.73	1.35	5,530.59	7,380.49	1.35	9,963.66	11,889.56	1.35	16,050.91

Table 7: Comparison of Positive Bending Moment for HB 30 and SV 100 Values for Continuous Two-Span Bridge Model of Equal Span of 30m, 50m and 100m Respectively

Type	Length (m)								
	2 Span @ 30m each			2 Span @ 50m each			2 Span @ 100m each		
	Unfactor	FOS	Factor	Unfactor	FOS	Factor	Unfactor	FOS	Factor
British Code (kNm)	1,748.60	1.30	2,273.18	3,185.63	1.30	4,141.32	5,504.20	1.30	7,155.46
Eurocode (kNm)	2,108.28	1.35	2,846.18	3,514.11	1.35	4,744.05	6,702.12	1.35	9,047.86

Table 8: Comparison of Positive Bending Moment for HB 45 and SV 196 Values for Continuous Two-Span Bridge Model of Equal Span of 30m, 50m and 100m Respectively

Type	Length (m)								
	2 Span @ 30m each			2 Span @ 50m each			2 Span @ 100m each		
	Unfactor	FOS	Factor	Unfactor	FOS	Factor	Unfactor	FOS	Factor
British Code (kNm)	2,622.90	1.30	3,409.77	4,778.44	1.30	6,211.97	7,997.56	1.30	10,396.83
Eurocode (kNm)	3,051.22	1.35	4,119.15	5,668.78	1.35	7,652.85	9,559.47	1.35	12,905.28

The comparison of HB 30 against SV 100 and HB45 against SV196 were also made by plotting the bending moment values against the loaded length under consideration as shown in Figures 11,12,13 and 14 respectively. From Figure 11, it can be seen that the maximum positive moment from HB 30 load is relatively in good agreement to the Eurocode load of SV 100 loading despite of the difference in overall weight of the application vehicles. A slight difference between these two load types is also worth mentioning at the loaded length of 30m. At this point, SV 100 produced a positive maximum bending moment of 20% higher than the HB 30 load which has the unfactored total load of 120kN. By referring to the methodology of this study, it can be deduced that the difference of the positive bending moment values is due the vehicle axle configuration at which the point loads acted upon. SV 100 has closer axle configuration as to compare with HB 30 axles configuration. Therefore, the intensity of the loading is higher, while HB 30 has the load that spreads apart within the span.

The argument of vehicle axle configuration is more prominent when it deals with two-span continuous bridge deck. At loaded length of 200m by which the vehicle is loaded at one span of 100m only, the difference in positive moment between BS code and EN code is as high as 26%. This is not so obvious in the case of short to medium span length. Let alone the effect of lateral bunching that may significantly affects to the short and medium span bridge.

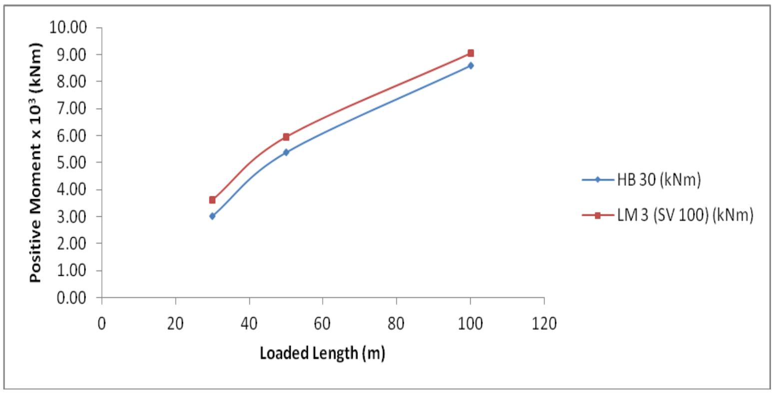


Figure 11: Comparison of Positive Bending Moment from British Code BS (HB 30) and Eurocode EN (SV 100) for 30m, 50m and 100m Single Span Models

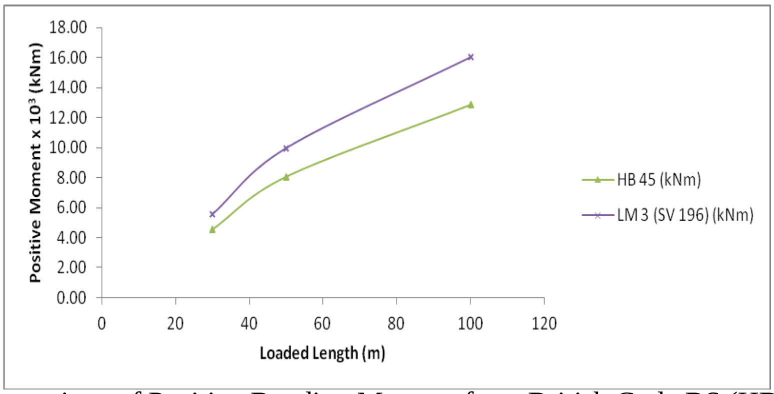


Figure 12: Comparison of Positive Bending Moment from British Code BS (HB 45) and Eurocode EN (SV 196) for 30m, 50m and 100m Single Span Model

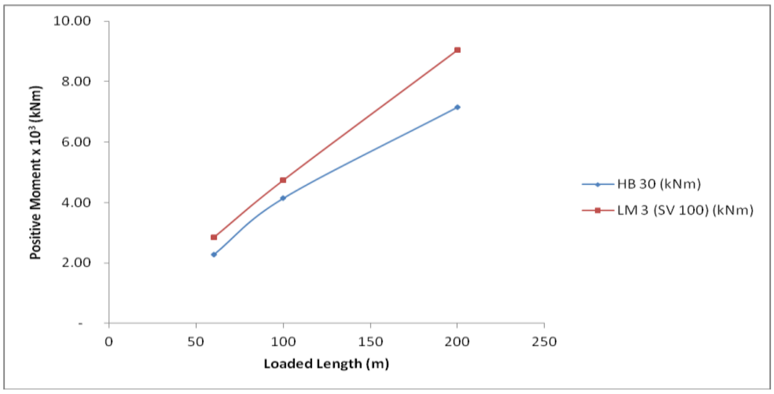


Figure 13: Comparison of Positive Bending Moment from British code BS (HB 30) and Eurocode EN (SV 100) for Two-Span Bridge Models

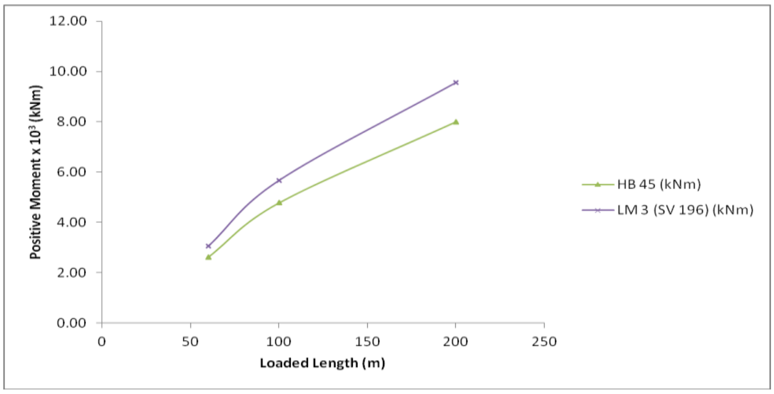


Figure 14: Comparison of Positive Bending Moment from British Code BS (HB45) and Eurocode EN (SV 196) for Two-Span Bridge Models

However, the comparison of HB 45 and SV 196 shows incompatible replacement of loads for medium to longer span. However, in the case of short span, the difference found from the analysis is to be 22%. Clearly that the vehicle axle configurations dictate significant load distribution on the bridge deck and thus affecting the bending moment response to the structure.

Similar trend of variation of moment against loaded length can be observed for two-span models. As the span length increased, the variation of bending moment produced by these two codes has becoming greater. At loaded length of 200m, the difference was found to be 24%.

A comparison between BS and EC against the JKR SV20 loading were also made. This is in view that the SV 20 has been used once as the bridge loading standard in Malaysia. It can be deduced from Table 9 that the SV20 loading has the highest bending moment value and yield to represent the highest vehicle model.

Table 9: Comparison of Positive Bending Moment for HB 45 and SV 196 against JKR SV20 loading for loaded length of single span 30m, 50m and 100m respectively.

Type	Loaded Length (m)		
	30	50	100
HB 45 (kNm)	2,642.29	5,490.29	7,498.78
SV 196 (kNm)	3,182.82	6,892.46	8,354.50
SV 20 (kNm)	3,317.12	9,489.52	15,491.70

6. Conclusion

Malaysia has always in line with British code of practice has been undergone many shift of bridge loadings since pre-independent period. The design of our local bridge has been very much influenced by the british code although there were attempts to instate our local bridge loading.

In the nutshell, the changeover bridge design guide from current British Code to the latest Eurocode would not significantly differ in terms of the structural response output except some decretions are required when deals with long-span bridge. The handling of the load intensity and application of the latest Eurocode design guides need to be clearly envisaged during the design process in line of current British Standard practice.

7. References

[1] Ryall M J 2008 *Loads and load distribution. ICE Manual of Bridge Engineering* (United Kingdom : Institute of Civil Engineers)

[2] Henderson W 1954 *British Highway bridge loading. Road Engineering Division Meeting, Road Paper No.44*

[3] Tharmabala T, Tautant D, Sani K M and Salleh R 2001 *Strength Evaluation and Load Testing of Bridges in Malaysia* (Kuala Lumpur : JKR)

[4] The Highway Agency and British Standard Institution 2001 *BD37/01 Design Manual for Road and Bridges*

[5] British Standard Institution 2003 *Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges* (London : British Standard Institution)

[6] British Standard Institution 2003 *UK National Annex to Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges* (London : British Standard Institution)

[7] Azmi N 2015 *Comparison of Bridge Loading Between BS5400/BD 37-01 and EN 1991-2* (MSc Thesis : University Putra Malaysia)