International Journal of Bridge Engineering (IJBE), Vol. 4, No. 3, (2016), pp. 49-60

A COMPARATIVE STUDY OF LIVE LOADS FOR THE DESIGN OF HIGHWAY BRIDGES IN PAKISTAN

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ABSTRACT: This paper discusses different Live Load Models currently in practice for the design of highway bridges in Pakistan. These include the models from the Pakistan Code of Practice for Highway Bridges 1967 and American Association of State Highways and Transportation Officials Load Resistance Factored Design, Bridge Design Specifications. To study the effect of these Live Load Models, a typical simply supported RC-girder bridge having 12.8 meter span was selected as a case study. A weigh station was installed in field from which load data of various trucks were recorded. Then line analysis was performed by taking the Live Load Models currently in practice, the actual live loads traversing the bridge and the legal load limits specified by the National Highway Authority, Pakistan. The results show that the highway loading in Pakistan produces much greater load effects than anticipated from the 1967 bridge design code usually used for their design.

KEY WORDS: Axle Weights, Live Load, HL-93 Loading, Standard Truck

1 INTRODUCTION

Highway bridges need to be designed to safely carry heavy vehicular loads, generally trucks that are expected to move over them during the service life of the bridge. Such loads are called Live Loads. Since future loads are not deterministic, present truck loading and its configurations is used to forecast loads that if used for design should result in safe and rational design. Government departments have the mandate to regulate the weight of trucks. In Pakistan the National Highway Authority (NHA), is the largest government organization that builds roads and bridges [1]. NHA is responsible to enforce limits on axle weights and gross weights for which they have installed weigh stations on National Highways [2].

However, it is globally seen that due to rising fuel prices, development of powerful truck engines and competition between freighters results in trends of illegal overweight [2], [3]. Similar, circumstances of overloading in Pakistan also exists. This calls for to review the effects of each live load on bridges. This paper presents a discussion of various live load models that are used in Pakistan for design of highway bridges and compares the results of those with legal weight limits imposed by NHA and actual truck data obtained in a field study in Peshawar. Many developed countries such as USA, Canada, Japan, UK and Germany specify notional live load models for design of their bridges. These live load models account for the variability of live loads to which the bridge should be designed for the years to come [4]. The first bridge design code in Pakistan was issued in 1967 [5], which was mainly based upon AASHO Standard of 1961 [6]. The live load model used in this code of 1967 was introduced in 1935 by the British who came to India. Since then this code has been never updated. Typically bridge owners ask to design bridge superstructure using the 1967 live load model. Since the loading has increased significantly over the last decades which results in overstressing the infrastructure [2], [3]. The circumstances thus warrant study of current load and its effects on bridges and strive towards development of indigenous live load model that suits the conditions of Pakistan.

This paper discusses the various live load models currently in practice in Pakistan, the legal load limits defined by NHA and sample data of current truck traffic taken from Peshawar. A case study of a bridge is also presented which shows the implications of each load case thus concluding in quantifiable terms the current status which supports the requirement of indigenous live load model for the design of bridges in Pakistan.

2 REVIEW OF LOADS IN CONTEXT OF PAKISTAN

The specification of a standard loading for bridges to cater the need of military transport and its heavy equipment was realized during the First World War (1914-1918). In 1922, Britain introduced for the first time a standard loading train. In subcontinent the technological advancements and industrial progress led Indian Road Congress (IRC) to the development of some sort of standard loading for the design of highways bridges. Later on these loadings were then adopted by the CPHB, 1967.

AASHTO founded in 1914 as AASHO, introduced the concept of a train of trucks in 1935. In 1944, AASHTO developed a new concept of hypothetical trucks, called the H (with two-axles) and the HS (with three-axles) classes of trucks. These were fictitious trucks, used only for design and they did not resemble any real truck on the road.

2.1 CPHB, 1967 live loading

According to CPHB, 1967 the highway loading on the roadway of bridge consists of a truck train loading and 70 ton military tank. In CPHB, 1967 the design live loads are classified as Class-A, Class-B and Class-AA loading.

Class-A Loading (Standard Loading Train)

The Class-A loading was proposed with the objective of covering the worst combination of axle loads and axle spacing likely to arise from the various types of vehicles that are normally expected to use the road. This load train is reported to have been arrived at after an exhaustive analysis of all lorries made in all the countries of the world. The loading consists of a train of wheel loads (8-axles) that is composed of a driving vehicle and two trailers of specified axle spacing and loads as shown in Figure 1. In case of two parallel lorries, the distance "X" as shown in Figure 1 must be maintained according to the roadway width and is provided in Table 1. To simulate the effect of tire pressure the ground contact area for Class-A loading is provided in Table 2. This loading in bridge designing is generally adopted on all roads on which permanent bridges and culverts are constructed.

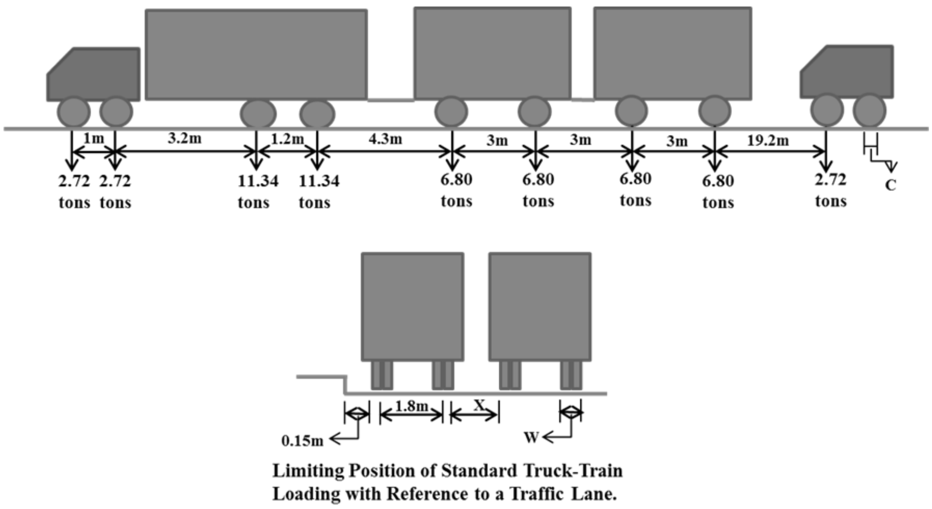

Figure 1. Standard Truck Train Loading

Table 1. Distance between two parallel lorries

Clear Road Width	"X"
5.08 m or less	0
5.08 m to 5.48 m	Increase Uniformly from 0 to 0.40 m
5.48 m to 7.31 m	Ditto 0.40 m to 1.21 m
Above 7.1 m	1.21 m

Table 2. Ground contact area for Class-A Loading

Class of Loading	Axle Loads (Tons)	Ground Contact Area (mm)	
		C	W
"A"	11.34	250	500
	6.80	200	375
	2.72	150	200

Class-B Loading

Class-B loading is similar to Class-A train of vehicles with reduced axle loads. This loading is to be normally adopted for temporary structure and for bridges in specified areas. Structures with timber spans are regarded as temporary structures. Class-B loading is 60% of Class-A loading. The positions of wheels and axle are same for both Class-A and Class-B loading. However, the ground contact area of the tires in case of Class-B loading is somewhat different from Class-A loading and is provided in Table 3.

Table 3. Ground contact area for Class-B Loading

Class of Loading	Axle Loads (Tons)	Ground Contact Area (mm)	
		C	W
"B"	5.67	200	375
	3.40	150	300
	1.36	125	175

Class-AA Loading (70 ton Military Tank)

Class-AA loading is based on the original classification methods of the Defense Authorities. This loading is to be adopted for design of bridges within certain municipal limits, in certain existing or contemplated industrial area, in other specified areas and along National Highway and State Highways. This loading consists of 70 tons tracked vehicle (military tank) having specified dimensions which are to be observed during the live load analysis in bridge design as shown in Figure 2. The nose to tail distance between two successive vehicles is not less than 91.4 meter. No other lived loads will cover any part of roadway of bridge when this vehicle is crossing the bridge. The minimum clearance between the roadway face of curb and the outer edge of the track shall be assumed 0.3 meter if roadway width is between 3.5 to 4.1 meter, 0.6 meter if roadway width is between 4.1 to 5.5 meter and 1.2 meter if roadway width is greater than 5.5 meter. Bridges designed for Class-AA loading should be checked for Class-A loading also. As under certain conditions heavier stress may be obtained under Class-A loading.

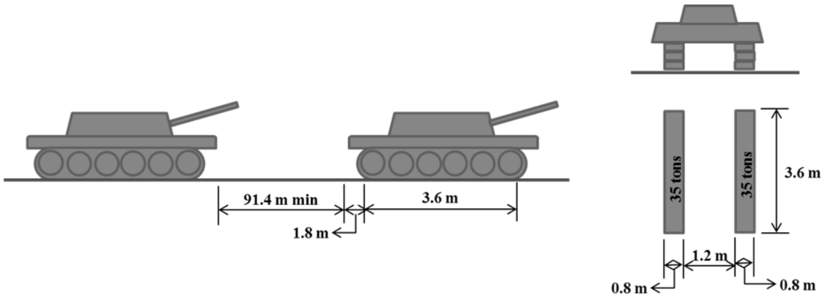

Figure 2. Military Loading (70 ton tank)

2.2 AASHTO LRFD live loading

AASHTO LRFD [7] Live Loading is commonly known as HL-93 Loading where H stands for highway and L stands for Loading, developed in 1993. This is a hypothetical Live Load Model proposed by AASHTO for the analysis of bridges with a maximum design period of 75 years. Reason for proposing this live load model is to prescribe a set of loads such that it produces extreme load effect approximately same as that produced by the exclusion vehicles. HL-93 Loading [7] consists of three basic live loads: design truck, design tandem and design lane.

Design Truck

It is commonly called as HS-20-44 where H stands for highway, S for semi-trailer, 20 ton (325 kN) weight of the tractor (1st two axles) and was proposed in 1994. HS20-44 indicates a vehicle with a front tractor axle weighing 4 tons (35kN), a rear tractor axle weighing 16 tons (145kN), and a semitrailer axle weighing 16 tons (145kN). Configuration of AASHTO Standard Truck and its limiting position with reference to traffic lane is shown in Figure 3.The two rear axles have a variable spacing that ranges from 4.3 to 9 meter in order to induce a maximum positive moment in a span.

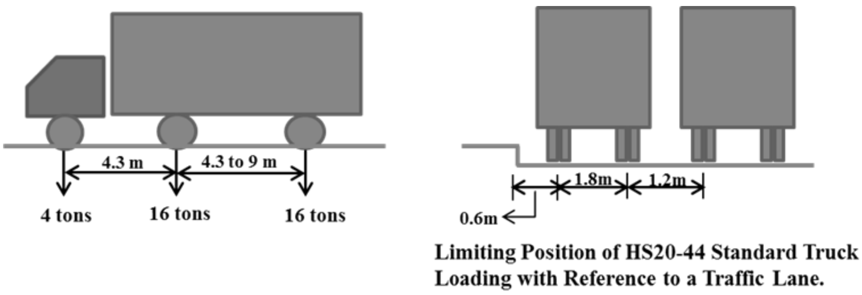

Figure 3. AASHTO Standard Design Truck (HS20-44)

Design Tandem

It consists of two axles weighing 12 tons (110kN) each spaced at 1.2 meter as shown in Figure 4.

Design Lane

It consists of uniformly distributed load of 9.3kN/m and is assumed to occupy 3 meter width in the transverse direction as shown in Figure 5.

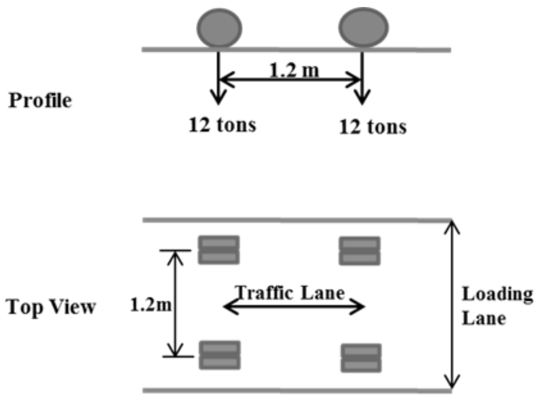

Figure 4. AASHTO Design Tandem

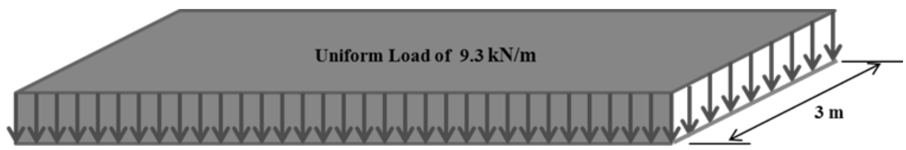

Figure 5. AASHTO Design Lane Loading

HL-93 Loading

The HL-93 design load consists of a combination of the design truck or design tandem, and design lane load as shown in Figure-6. Therefore the extreme load effect for the vehicular live load is the larger of the following:

- The combined effect of one design truck with the variable axle spacing with the design lane load, or
- The combined effect of the designed tandem with the design lane load, and
- For continuous spans, for both negative moment between points of dead load contra-flexure and reaction at interior piers only: the combination of 90% of the effect of two design trucks (spaced a minimum of 15.24 meter between the lead axle of one and the lead axle of the other truck) with 90%

of the effect of the design lane load. The distance between the rear two axles of each truck shall be taken as 4.3 meter.

When positioning is required for cases where analysis is used or required, it is essential to determine the position the trucks for the critical load effect. For exterior girders, this requires placing one wheel of a truck within 0.6 meter from the curb or barrier. The next truck, if considered, is placed within 1.2 meter of the first. A third truck, if required, is placed within 1.8 meter of the second so as to not infringe upon the traffic lane requirement. For an interior girder, one wheel is placed over a girder and the position of others follows a similar pattern. From a practical perspective, all trucks can be conservatively placed transversely within 1.2 meter of each other with little loss of "accuracy" when compared to the specification intent.

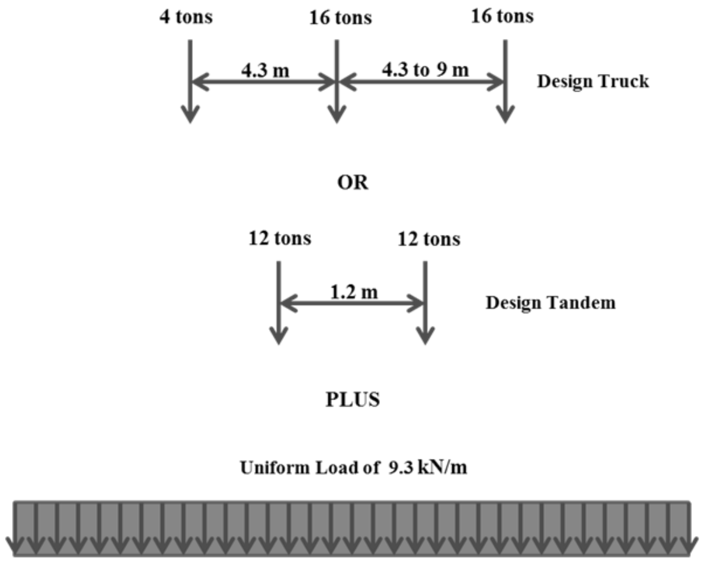

Figure 6. AASHTO HL-93 Loading

Axles which do not contribute to the extreme load effect under consideration shall be neglected. For long span bridges, the design lane load becomes the predominant load component with the vehicle becoming more and more insignificant with increasing span lengths. For short and medium-length spans, the design tandem or design truck loads are the predominant load components with the design lane serving to amplify the vehicle loads to loads of greater magnitude. Thus, for these span lengths, the force effects of the vehicles, which have a gross vehicle weight less than the legal loads, are magnified to super-legal load levels for design. Therefore, highway bridges are implicitly designed for loads above the legal limits without explicitly specifying individual super-legal vehicle loads in the specifications. These three components of the HL-93 Loading can be used to define short medium and long span bridges. Bridges for which the design tandem is the predominant load component can be characterized as short span bridges, those for which the design truck is predominant, as medium span bridges, and those for which the design lane is predominant as long span bridges.

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3 STUDY OF LIVE LOAD EFFECT'S ON HMC-BRIDGE (A CASE STUDY)

The bridge selected for the live load analysis is located near Hayatabad Medical Complex (HMC-Bridge), Hayatabad, Peshawar over a route which carries immense heavy traffic to Afghanistan. This bridge is 12.8 meter long and 8.6 meters wide accommodating two traffic lanes. The bridge has three contiguous spans with the deck supported by five identical rectangular RC-girders across the width over each span. The thickness of the deck is 190 mm. In order to observe the effect of live loads on the bridge, a simple line analysis was performed in order to determine the maximum moment and shear along its span. Live Loading from AASHTO LRFD, CPHB (1967), NHA legal limits and the one actually measured in the field were employed in the analysis to observe the maximum load effects. Multiple presence of vehicles over the span of the bridge was ignored in all the cases. As the bridge under consideration is a simply supported short span bridge therefore the spacing between the rear axles of the design truck in HL-93 loading was kept minimum (4.3 meters) in order to produce maximum load effects.

3.1 Field measurement of live load

Axle loads of the trucks passing through HMC-Bridge were obtained from the field weighing station set near to the bridge site. Axle weight record from 504 trucks measuring a total gross weight equal to 16,250 tons obtained over a period of ten days was considered to establish the loading trends of different type of trucks traversing the bridge site. Table 4 shows the typical axle widths and axle spacing for different types of trucks. The average and maximum axle weights observed for different types of trucks are shown in Table 5 & 6 respectively.

Table 4. Typical axle width and axle spacing for different trucks

Truck Type	Axle Configuration	Axle Width (m)	Axle Spacing (m)				
			1-2	2-3	3-4	4-5	5-6
2-Axle	1+1	2.18	4.6				
3-Axle	1+Tendem	2.32	6.1	1.37			
4-Axle	1+1+Tendem	2.55	3.38	6.84	1.34		
5-Axle	1+1+Tridem	2.5	3.28	5.13	1.36	1.36	
5-Axle	1+Tendem+Tendem	2.45	4.39	1.37	4.57	1.34	
6-Axle	1+Tendem+Tridem	2.49	3.52	1.23	5.83	1.37	1.28

Table 5. Average axle weight of trucks obtained from the weighing station data

Truck Type	Average Weight in Tons						
	Axle-1	Axle-2	Axle-3	Axle-4	Axle-5	Axle-6	Average Truck Wt.
2-Axle	5.20	13.33					18.53
3-Axle	7.15	13.26	11.78				32.19
4-Axle	5.09	10.55	7.13	7.37			30.15
5-Axle	6.14	16.67	6.80	8.33	8.30		46.25
6-Axle	5.88	12.34	12.28	8.63	10.60	9.89	59.62

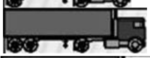
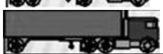
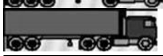
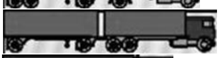
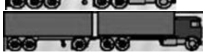
Table 6. Maximum measured weight of trucks obtained from the weighing station data

Truck Type	Maximum Weight in Tons						
	Axle-1	Axle-2	Axle-3	Axle-4	Axle-5	Axle-6	Maximum Truck Wt.
2-Axle	9.12	21.3					30.42
3-Axle	11.02	18.85	19.23				49.1
4-Axle	6.63	19.15	14.30	15.24			55.32
5-Axle	5.94	20.47	6.34	10.91	10.71		54.37
6-Axle	7.07	20.28	17.78	16.45	13.76	12.78	88.12

3.2 NHA legal load limits

The gross weights for trucks with different axle configurations allowed to operate legally on the highways in Pakistan are presented in Table 7. The axle load limitation for these trucks is such that the weight of front, rear, tandem and tridem axle must not exceed 5.5, 12, 22 and 32 tons respectively.

Table 7. NHA Legal Load Limits

Truck Type		Permissible Gross Load (Tons)
	2-Axle (Bedford)	17.5
	2-Axle (Hino/Nissan)	17.5
	3-Axle	27.5
	3-Axle	29.5
	4-Axle	39.5
	4-Axle	39.5
	4-Axle	41.5
	5-Axle	48.5
	5-Axle	49.5
	5-Axle	51.5
	5-Axle	51.5
	6-Axle	58.5
	6-Axle	61.5

4 RESULTS

The line load analysis yield that AASHTO HL-93 loading is defined by the combination of design truck and the design lane. In case of CPHP (1967), Class-A loading produced the maximum results of shear and moment in the bridge span. Results of maximum moments and shears observed from the line analysis of the bridge using different loading configurations are summarized in Table 8 & 9 respectively. The bold values in each column of the tables indicate the maximum effect produced by using different live loads.

Trucks with five and six number of axles dominate the results of maximum moment and shear for this particular bridge because of their heavy axle pairs.

Table 8. Comparison between the maximum moments observed from the line analysis of the bridge using HL-93 loading, Class-A loading, weighing station data and legal weight limit specified by NHA

Truck Type	Moment (ton-m)				
	AASHTO HL-93	CPHB Class-A	Avg. Wt. Weighing Station	Max. Wt. Weighing Station	NHA Legal Limits
2-Axle	---	---	47.9	77.5	44.1
3-Axle	**87.3**	---	73.6	111.0	63.9
4-Axle	---	---	42.0	85.1	63.2
5-Axle (Single Tridem)	---	---	69.8	83.3	**89.9**
5-Axle (Two Tandems)	---	---	79.0	90.8	80.0
6-Axle	---	---	**80.7**	**120.7**	88.0
8-Axle	---	**76.8**	---	---	---

Table 9. Comparison between the maximum shear forces observed from the line analysis of the bridge using HL-93 loading, Class-A loading, weighing station data and legal weight limit specified by NHA

Truck Type	Shear (ton-f)				
	AASHTO HL-93	CPHB Class-A	Avg. Wt. Weighing Station	Max. Wt. Weighing Station	NHA Legal Limits
2-Axle	---	---	16.7	27.1	15.5
3-Axle	**31.8**	---	26.5	40.5	23
4-Axle	---	---	17.9	35.4	25.6
5-Axle (Single Tridem)	---	---	28.1	33.8	33.7
5-Axle (Two Tandems)	---	---	30.5	36.2	31.9
6-Axle	---	---	**33.2**	**51.4**	**34.8**
8-Axle	---	**27.1**	---	---	---

5 CONCLUSIONS

Bridges in Pakistan are potentially subjected to extreme effects under the influence of prevailing traffic trends than they were actually designed for. The HL-93 loading which is generally considered conservative as compared to Class-A loading is not capable to envelop the load effects from the prevailing traffic loads on the route. Therefore, there is a need to develop a new design live load model for the Highway Bridges in Pakistan by analyzing actual prevailing load measurements.

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