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AN ASSESSMENT OF VEHICULAR LIVE LOADS FOR BRIDGE DESIGN IN PAKISTAN

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ABSTRACT: Bridges in Pakistan are mostly designed to the local Class A loading having eight axles; weighing 543kN; and 18.9m in length. The objective of this research is to check the adequacy of Class A loading, as permissible axle loads are quite high locally. Numerous moving load analyses were conducted for simple spans from 6m to 50m. Calculations were performed for single and two-lane loaded bridges. Results were tabulated by comparing the maximum effects due to legal trucks with those of Class A loading. The results raised a concern as they revealed the inadequacies of Class A loading. For a single vehicle per lane, the critical case was of the shorter spans where bending moment and shear of legal trucks were 24% and 16% higher than Class A loading, respectively. With multiple vehicles per lane the results further deteriorated for Class A loading. The critical case was of the longer spans where both bending moment and shear of legal trucks were 58% and 55% higher than Class A loading, respectively. It was concluded that Class A loading is not representative of the domestic truck loading, legally operational over the highway bridges of Pakistan. Based on the permissible axle loads, a vehicular live load model for Pakistan is proposed.

KEYWORDS: Axle loads; Class A loading; HL-93 loading; Live load.

1 INTRODUCTION

Bridges are an integral part of infrastructure of any country. They become essential for a country like Pakistan which has a vast network of rivers and canals. These bridges provide the vital links for communication across cities, provinces and countries. It is essential that these vital links remain functional, day in and day out, throughout the design life of the structure. Even a minor disruption of a bridge on a highway can be consequential.

This paper focuses on a particular design issue i.e. the design live load for bridges in Pakistan. Bridge designers in Pakistan continue to utilize to date the vehicular live load model from the Code of Practice of Highway Bridges (CPHB) issued in 1967 by Government of West Pakistan [1]. There have been no changes to the composition of this load over the last 50 years, though the advancements in local trucking industry have kept pace with the international market. Constant advancements in research, lessons through experience dictate the necessity that the code be revised periodically.

It is expected that those responsible for structure design of bridges in Pakistan will alert to the need for such revisions. Suggestions for updating the code along these lines are encouraged. Moreover, the national institutions have set axle load limits which are relatively higher when compared to developed countries. Lastly, overloading remains a common phenomenon in Pakistan which may benefit the trucking industry but is also detrimental to both pavements and bridges.

The aim of this research is to analyze and compare the load effects caused by the allowable truck configurations in Pakistan with the vehicular live load model of CPHB 1967. These allowable truck configurations are defined in the National Highways Safety Ordinance (NHSO) 2000 as permissible gross vehicles weight (GVW) [2]. These are also adopted and regulated by the National Highway Authority (NHA) which is the custodian on all national highways and bridges in Pakistan. The research also utilizes a standard benchmark to compare these effects. The benchmark adopted is the AASHTO LRFD 6th edition which is a widely used and accepted bridge design specification across the globe by clients and consultants.

2 CODES OF PRACTICE FOR BRIDGE DESIGN IN PAKISTAN

In Pakistan, the first bridge design guidelines were issued in 1967 [3], and were based upon working stress design approach with loading models developed from historical sources. The design live loads were taken same as introduced by British in India in 1935 (BS 153, 1937) and have never been updated [1].

Moreover, no legislation has been made over this code to give it a legal cover. Now the engineers and consultants of Pakistan have adopted different codes with the existing to overcome advancements in the field of bridge engineering. In Pakistan's perspective, there are three bridge design specifications which are utilized for bridge design:

- AASHTO Standard Specifications for Highway Bridges, 17th Edition
- AASHTO LRFD Bridge Design Specifications, 6th Edition
- West Pakistan Code of Practice for Highway Bridges (CPHB 1967).

AASHTO Standard and AASHTO LRFD are the most widely used and accepted codes for the design of bridges by professionals all over the world.

These codes are predominantly based on the use of statistical analysis on the measured data and on load effects that result from various forms of traffic model [4]. In principle, the first one is now the design standard for the maintenance and rehabilitation of older, existing structures designed to this specification. However, as it has prevailed in the industry for over 76 years, a lot of clients and consultants continue to use it where the design code explicitly specifies the second one. Presently, for new bridge designs AASHTO Standard specifications has been superseded by the AASHTO LRFD [5]. Because of the federal mandate of the LRFD Bridge Design Specification in October 2007, AASHTO Standard Specifications will now no longer be updated [6]. The last revision remains 17th edition in 2002.

The AASHTO-LRFD is based on the load and resistance factor design philosophy [5]. Since the first edition was published in 1994, the provisions have continued to be updated and improved based on continuing research and the experience of the user community. As of October 2007, the LRFD design code is mandated by Federal Highway Administration (FHWA) for all State projects using Federal funding in U.S.A. Latest edition is 7th in 2014 with interims in 2015 and 2016. The AASHTO LRFD is used in the Middle East as well as in Pakistan.

2.1 Vehicular live load models

Different live load models are given to represent various truck or vehicle configurations. These are called notional loads as they do not necessarily represent a particular truck or vehicle but have the capability to capture the load effect from exclusion vehicles. The vehicular live load model under both the AASHTO specifications is HL-93 [7, 8]. Whereas, CPHB 1967 defines three notional loads as Class A, Class B and Class AA [3].

2.1.1 HL-93 Loading

HL-93 is a combination of the design truck or design tandem in combination with the design lane load. The design truck is a 325 kN truck with 3 axles and the design tandem is a pair of 110 kN axles. Design lane load is a 9.3kN/m uniformly distributed load over a 3m width. Figure 1 and Figure 2 illustrate these notional loads.

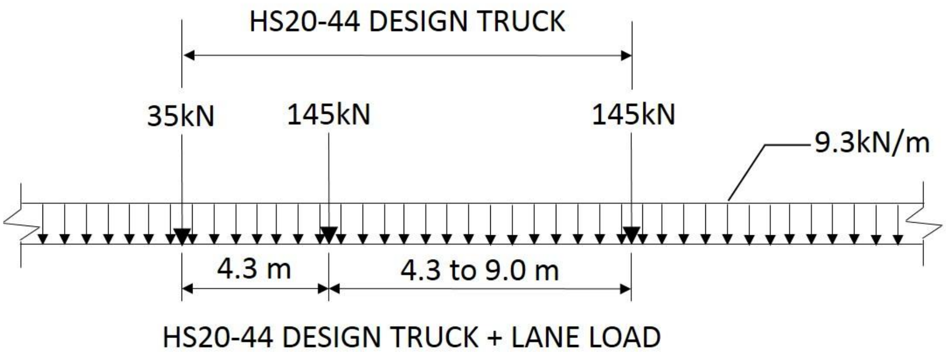

Figure 1. Design truck with lane load

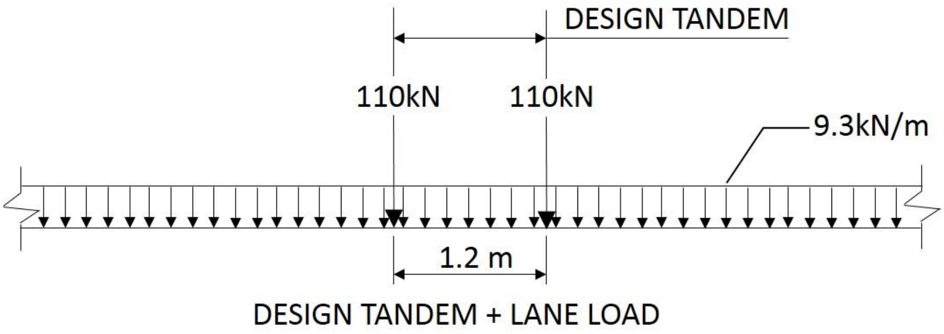

Figure 2. Design tandem with lane load

2.1.2 Class A, class B & class AA loading

Howard, Needles, Tammen & Bergendoff Int. Inc an American consulting firm drafted the code of practice for design of Highway Bridges for West Pakistan (CPHB 1967)[3]. NHA adopts the vehicular live load model for design of bridges in Pakistan from CPHB 1967. The live load models (vehicular and military) from this document are:

- Class A (Vehicular loading): This is a truck-train loading of a four axle truck followed by two trailers, each trailer having two axles. It weighs 544kN and is 18.8m long.
- Class B (Vehicular loading): This is equal to 60 percent of Class A loading.
- Class AA (Military loading): This is a military tank with a gross weight of 70T (686kN) with a track length of 3.6m. Whereas the tank length is 7.2m.

Figure 3 and Figure 4 illustrate these Class A & Class AA loads. These live load models are exactly the same as specified by Indian Road Congress (IRC) in the Indian bridge design code (IRC-6 -2000) [9].

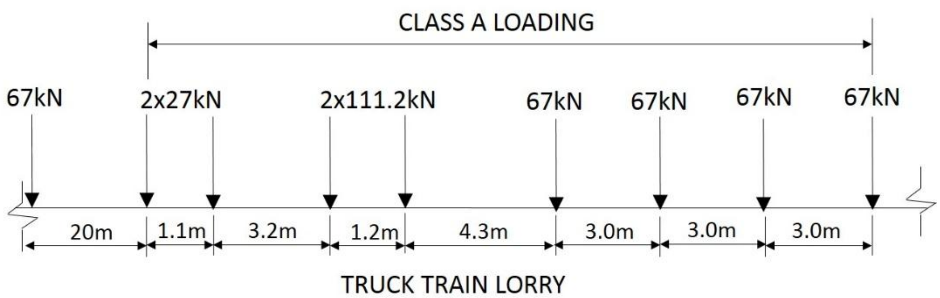

Figure 3. Class A loading

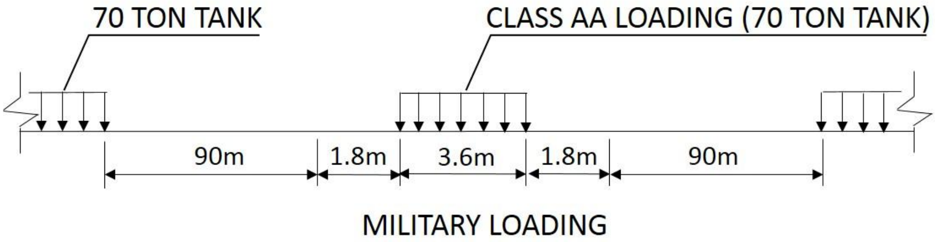

Figure 4. Class AA loading

3 DESIGN CRITERIA

NHA has a well-defined criterion for design of bridges in Pakistan. It specifies the use of latest edition of AASHTO LRFD, however obliges use of Class A and Class AA loading from the CPHB 1967 instead of HL93 loading [1]. For other agencies/clients, the design criterion varies e.g. District Administrations and Provincial Highway Authorities most of the time do not require the use of Class AA loading.

4 TRUCKING INDUSTRY IN PAKISTAN

Over the period of years, the truck industry has progressed; high powered engines, stronger materials, efficient design and economy of use end towards higher axle loads. The axle loads are enacted and enforced by the Government of Pakistan through the National Highways Safety Ordinance (NHSO) [2]. The axle load limits for single, tandem and tridem axles are given in Table 1. Where tire configuration is the number of tires in a single axle followed by the number of axles (2 for tandem and 3 for tridem).

Table 1. Axle Load Limits in Pakistan

S. No.	Legal axle limits in Pakistan	Tire configuration	Gross Weight (Ton)
1.	Single axle front	2	5.5
2.	Single axle rare	4	12
3.	Tandem axle	4x2	22 (11 per axle)
4.	Tridem axle	4x3	31 (10.33 per axle)

In addition to the axle loads, allowable truck configurations are also defined as permissible gross vehicle weight's (GVW's) in this ordinance and are given in Table 2. These axle load limits and permissible GVW's are also adopted and regulated by NHA in Pakistan [10].

Table 2. Permissible GVW's in Pakistan

S. No.	Axle Configuration	Tire configuration	Gross Weight (Tons)
1.	2 axle (1+1) (Bedford)	2+4	17.5
2.	2 axle (1+1) (Hino / Nissan)	2+4	17.5
3.	3 axle (1+ tandem)	2+(4x2)	27.5
4.	3 axle (1+1+1)	2+4+4	29.5
5.	4 axle (1+1+ tandem)	2+4+(4x2)	39.5
6.	4 axle (1+ tandem +1)	2+(4x2)+4	39.5
7.	4 axle (1+1+1+1)	2+4+4+4	41.5
8.	5 axle (1+1+ tridem)	2+4+(4x3)	48.5
9.	5 axle (1+ tandem + tandem)	2+(4x2)+(4x2)	49.5
10.	5 axle (1+1+1+ tandem)	2+4+4+(4x2)	51.5
11.	5 axle (1+ tandem +1+1)	2+(4x2)+4+4	51.5
12.	6 axle (1+ tandem + tridem)	2+(4x2)+(4x3)	58.5
13.	6 axle (1+ tandem +1+ tandem)	2+(4x2)+4+(4x2)	61.5

The axle load limits and the GVW's for United States of America (USA) is provided by the Federal Bridge Formula [11]. According to the Federal Bridge Formula the weights of the single axle and tandem axle must not exceed 10 tons and 17 tons, respectively. Moreover, for any axle configuration the allowable GVW is limited to 40 tons which is a good measure of controlling the individual and tandem axles. Clearly the axle load limits and the GVW's in Pakistan are on a higher side as compared to USA.

5 ASSESEMENT OF LIVE LOADS

A moving load analysis was performed in MS Excel over simply supported spans from 6 to 50 meters with maximum up to two design lanes to compute maximum shears and moments. The analyses parameters were selected to encompass all the possible design scenarios with the perspective of Pakistan and are shown in Table 3. Four different load cases were considered and load effects were evaluated for Class A loading, Class AA loading, HL-93 loading and permissible GVW's from NHSO 2000. For the notional loads the traffic in same lane was defined within the model. For the permissible GVW's, a lane load is utilized to model the effects of traffic present in the loaded lane. However, in case of bridges with multiple loaded lanes, effects of multiple presence of vehicles were considered according to AASHTO LRFD. Table 4 gives the comprehensive spectrum of research scenarios or cases considered for modeling and analysis within this research.

Table 3. Parameters considered in analyses

Parameter	Variations
Span Lengths	6, 10, 15, 20, 25, 30, 35, 40, 45 and 50m
Number of loaded lanes	1-2 (Mostly the National & Provincial Highways in Pakistan have maximum two lanes)
Number of maximum vehicles in one lane	5
Notional Load Models	HL93, Class A, Class AA, Permissible GVW's (6 different cases considered) and Proposed Notional Load (HLP-16)
Load Effects	Moment and Shear

Table 4. Research Scenarios

S. No.	Case	Traffic in same lane considered	Multiple lanes considered
1	A single permissible GVW. One lane loaded	None	None
2	Two permissible GVW's side by side. Two lanes loaded	None	Yes, two lanes. Factored by multiple presence factor
3	A single permissible GVW. One lane loaded	Yes. Modeled by the lane load from AASHTO LRFD	None
4	Two permissible GVW's side by side. Two lanes loaded	Yes. Modeled by the lane load from AASHTO LRFD	Yes, two lanes. Factored by multiple presence factor

- Case 1

This case considers a single permissible GVW on a one lane loaded bridge with no traffic in the same lane. This case is presented for a basic comparison of axle load limits among the different load models and permissible GVW's in Pakistan. Comparisons for moment and shear for this case are given in Figure 5 and Figure 6, respectively. Moment and Shear curves for this scenario show that load effects from permissible GVW's are higher than Class A loading, which itself yields higher load effects than HL-93 loading. From this comparison the concept of high axle load limits in Pakistan is reinforced.

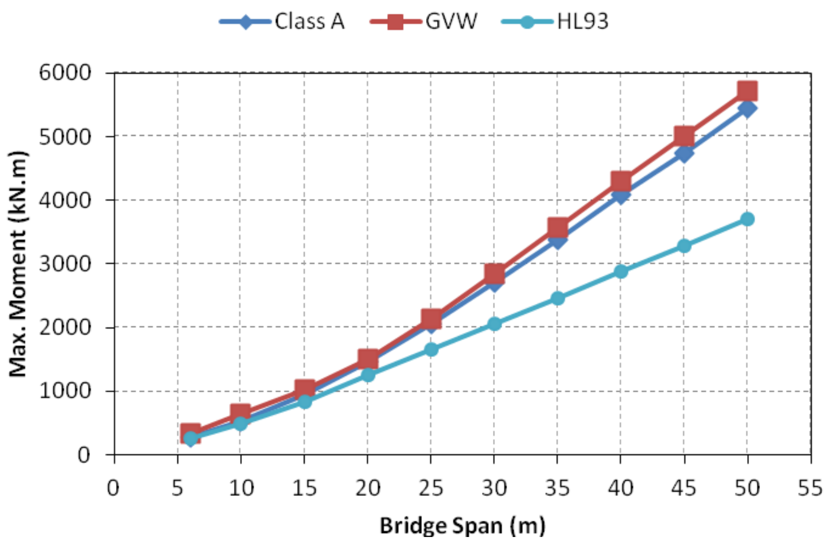

Figure 5. Maximum moment verses span length for Case 1

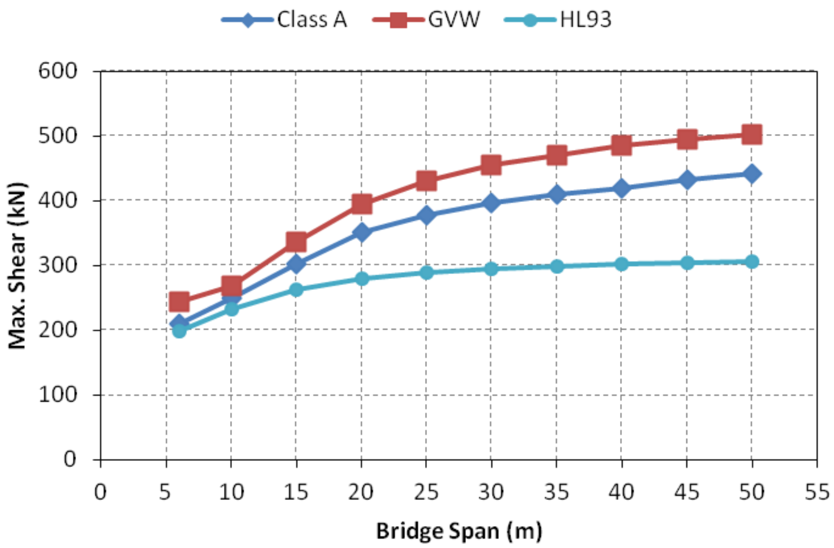

Figure 6. Maximum shear verses span length for Case 1

- Case 2

This case presents two permissible GVW's traversing side by side on a bridge with two parallel lanes with no other traffic in the respective lanes. The case is similar to Case 1 with two loaded lanes and without preceding traffic in the same lane. This case is presented for highlighting the limitations of Class AA loading when applied to a two lane bridge. Comparisons for moment and shear for this case are presented in Figure 7 and Figure 8, respectively. Moment and Shear curves for this scenario show that the load effects from permissible GVW's are higher than Class AA loading, when we analyze bridges with multiple lanes and spans greater than 12m. Thus the idea that use of Class AA loading yields a conservative design applies only to a single lane bridge or bridges with spans shorter than 12m in case of multiple lanes.

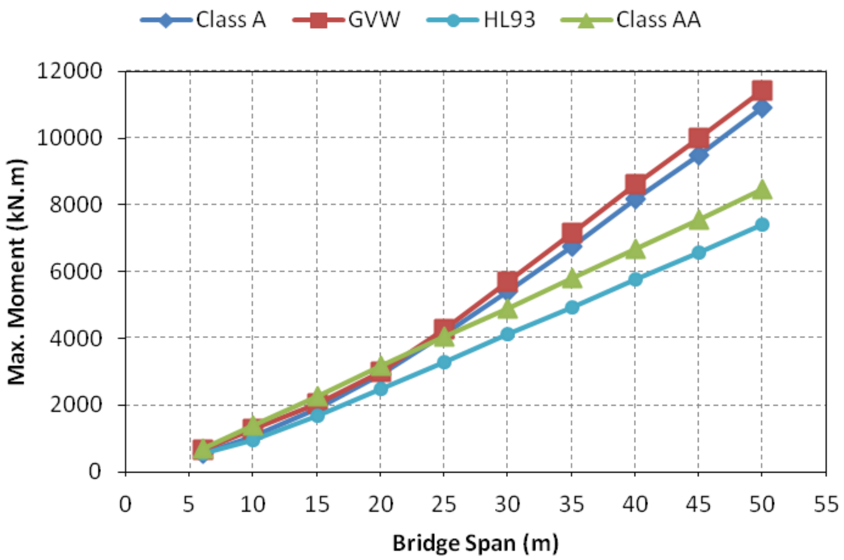

Figure 7. Maximum moment verses span length for Case 2

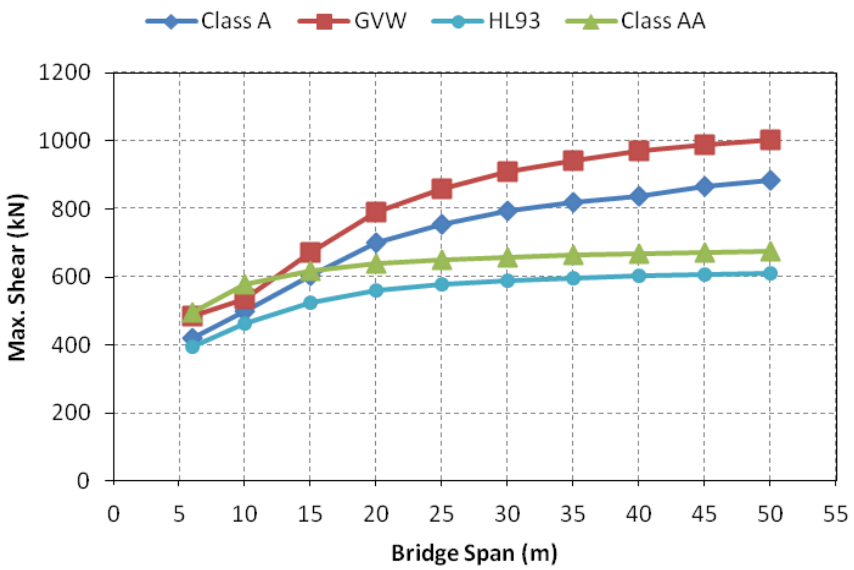

Figure 8. Maximum shear verses span length for Case 2

- Case 3

In this case, a single GVW with traffic in the same lane is considered. This case is applicable to a single lane bridge or when only one lane is loaded in a multiple lane bridge. For the notional loads the traffic in same lane is defined within the model. For the permissible GVW's, a lane load is utilized to model the effects of traffic present in the loaded lane.

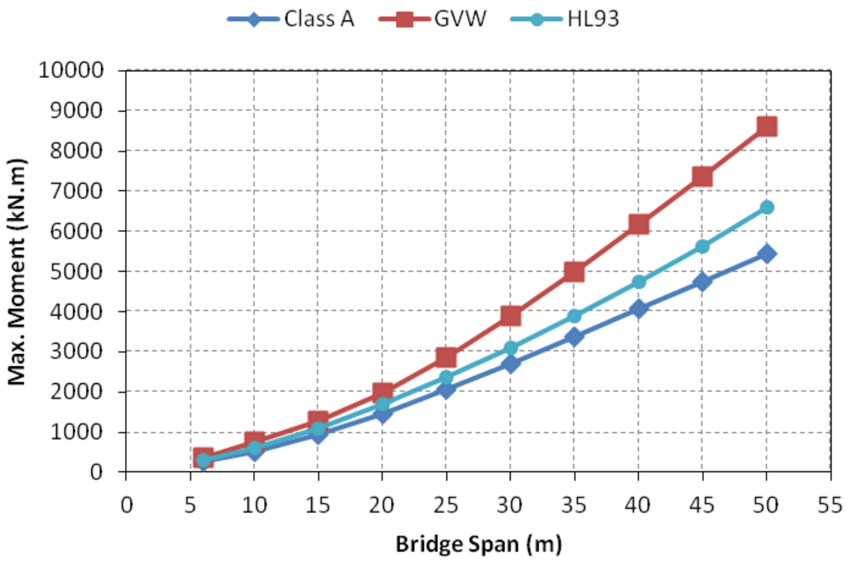

Figure 9. Maximum moment verses span length for Case 3

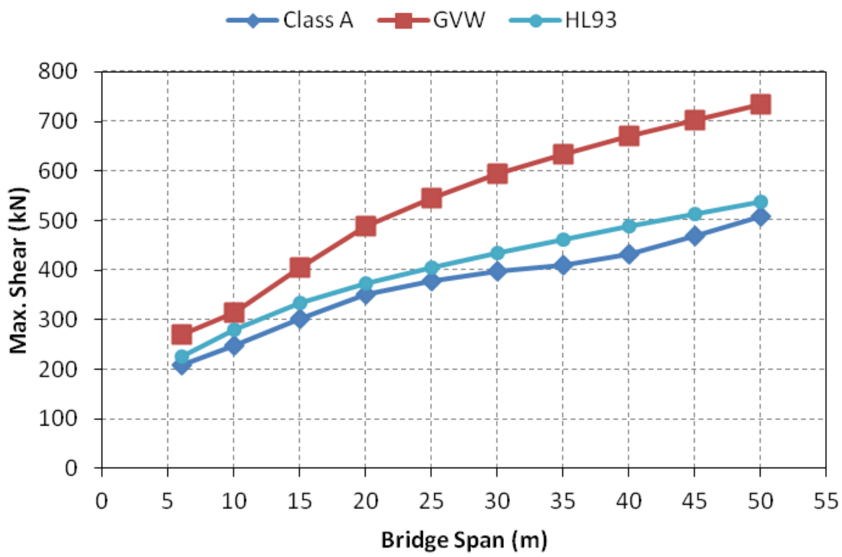

Figure 10. Maximum shear verses span length for Case 3

The magnitude of the lane load is taken as 9.3N/m which is the same as suggested by AASHTO LRFD. Comparisons for moment and shear for this case are given in Figure 9 and Figure 10, respectively. Moment and Shear curves for this scenario clearly show that load effects from permissible GVW's are higher than HL-93 loading which are in turn higher than Class A loading. This case reinforces the need of having a notional load for design which is tailored for the axle load limits and permissible GVW's in Pakistan.

- Case 4

This case presents two permissible GVW's traversing side by side on two lanes on a multilane bridge with preceding traffic in the respective lanes.
This case reinforces in addition to Case 2, the limitations of Class AA loading when applied to a multilane bridge. Comparisons for moment and shear for this case are given in Figure 11 and Figure 12, respectively. Moment and Shear curves for this scenario clearly show that load effects from permissible GVW's are higher than HL-93 loading which are in turn higher than Class A and Class AA loading. This case also reinforces the need of having a notional load which is tailored for the axle load limits and permissible GVWs in Pakistan.

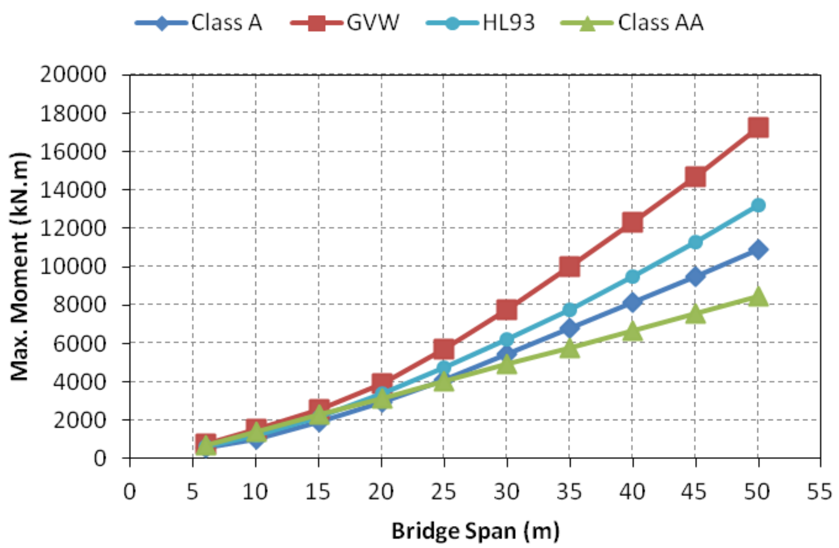

Figure 11. Maximum moment verses span length for Case 4

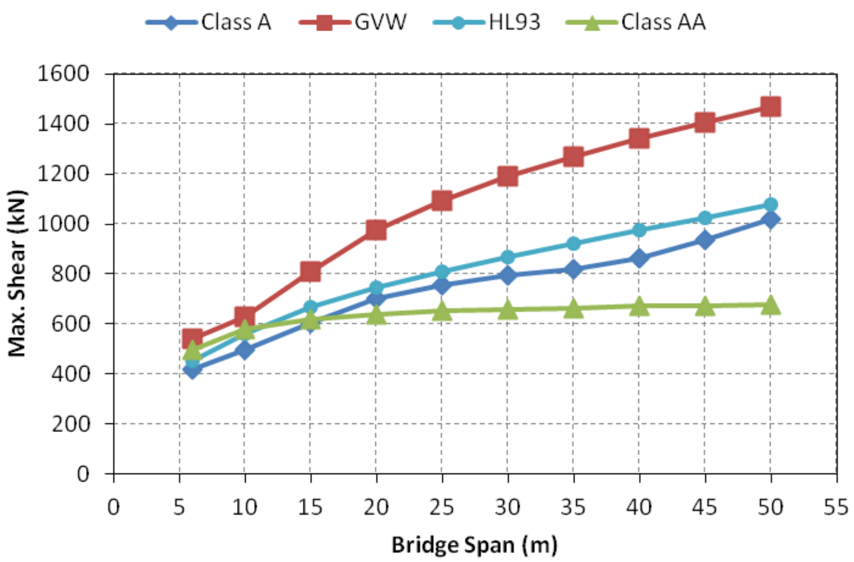

Figure 12. Maximum shear verses span length for Case 4

6 PROPOSED NOTIONAL LOAD

Within the range of parameters defined above, a notional load named “Highway Load of Pakistan -2016” (HLP-16) is proposed to model the vehicular live loads in Pakistan. HLP-16 envelopes the analyses results carried out under this research. HLP-16 utilizes one of the AASHTO-LRFD notional load model; i.e. a combination of design truck and design lane load. Class AA Loading is checked where applicable, as it affects the single lane bridges or short spans in case of multilane bridges. HLP-16 is given in Figure 13.

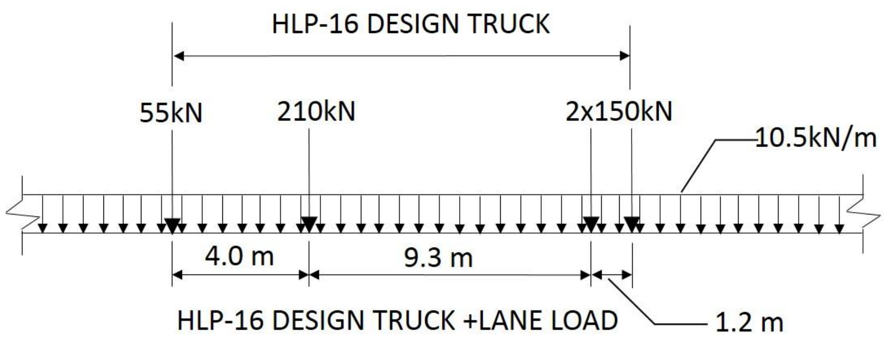

Figure 13. HLP-16 Loading

The proposed notional load is presented over Case 3. The results of an envelope of NHA trucks are compared with HLP-16 within the parameters of the research and are found satisfactory. Comparisons for moment and shear are given in Figure 14 and Figure 15, respectively. From the curves, it is evident that the proposed notional load HLP-16 envelopes very closely the load effects from permissible GVW's.

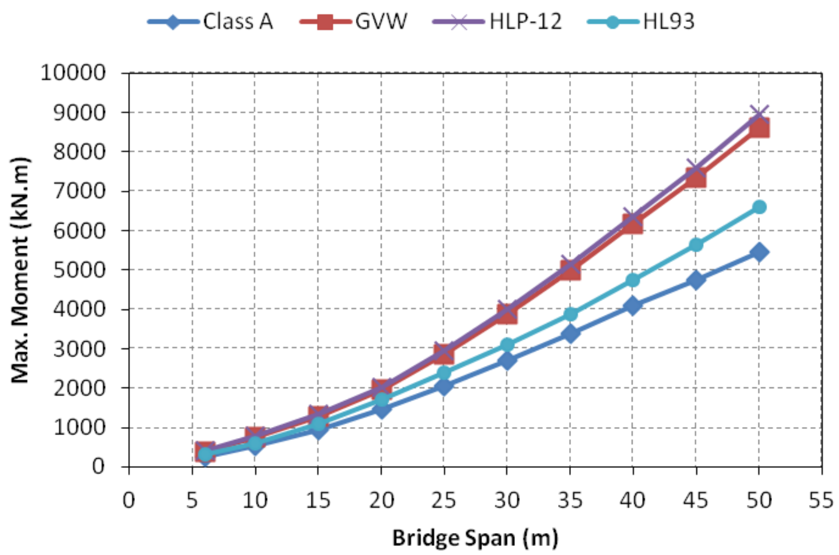

Figure 14. Comparison of moments from HLP-16 Loading with the moments from existing models at different span lengths

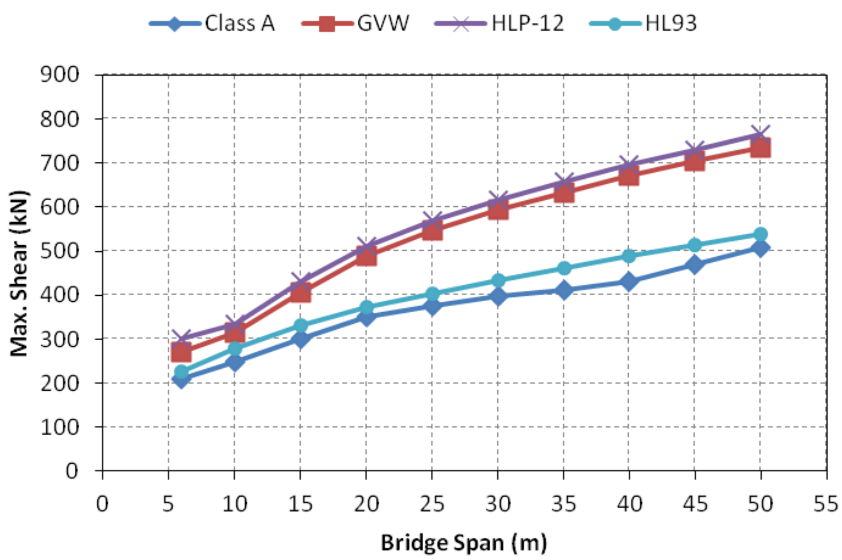

Figure 15. Comparison of shears from HLP-16 Loading with the moments from existing models at different span lengths

7 CONCLUSIONS

In Pakistan, the permissible GVW's are relatively higher as compared to the notional load models used in the design of highway bridges. Moreover, vehicles with tridem axles are legally allowed to operate over these bridges by the domestic regulatory authorities, which tend to produce load concentration over a relatively shorter length, thereby yielding critical load effects. The results from the analysis show that Class A and HL-93 loading are not representative of the permissible GVW's as none of these notional loads are able to capture the actual load effects. Class AA loading may be used to design single lane bridges with spans ≤ 35m. However, for multilane bridges, Class AA loading may not be used in design as CPHBP 1967 does not permits the use of multiple presence criterion in case of tank loading. It is therefore, concluded that there is a need to revise the CPHB 1967 live loads and to adopt a live load model which is representative of actual live loads operational over highway bridges in Pakistan for a complete range of design parameters. As an interim measure the proposed notional load (HLP-16) is recommended within the defined parameters.

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