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DEVELOPMENT OF LIVE LOAD CALIBRATION FACTOR FOR STATE HIGHWAY BRIDGE DESIGN OF PAKISTAN

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ABSTRACT: The most dynamic of all the loads for a bridge structure are the live loads that play a vital role in determination of strength of the structure. Bridge is a structure that has to bear the combined effect of all the axle loads traversing it and therefore it is very necessary for the structure to be carefully designed for the heavy live loads, it is expected to be traversed in its life time. Bridge unlike pavements (designed to withstand millions of application of such axle loads) may not withstand even a single such heavier load for which it is not designed. Overloading of vehicles on state highway has been monitored and properly analyzed in this research study. The effects of vehicular live load models as dictated by "West Pakistan Code of Practice for Highway Bridges (WPCPHB)"and "American Association of State Highway and Transportation Officials (AASHTO)" have been compared with the traffic data collected and statistically analyzed from weigh-in-motion (WIM) station. The WIM station located at N-5, the largest and the most overly crowded highway of Pakistan is selected. This research has been conducted to propose the methodologies and protocols necessary for addressing the current traffic characteristics of Pakistan. Calibration factors have been proposed with both WPCPHB and AASHTO live load models to be used for the designing of highway bridges in Pakistan.

KEYWORDS: WIM, Live load modeling, AASHTO, Bridge Modeling

1 INTRODUCTION

In Pakistan, WPCPHB's Class-A and Class-AA live loadings are still being used along with AASHTO codes. WPCPHB is an old code that needs to be revised. The capacity of the bridges to carry loads is directly influenced by the design loads that relates to the durability of the bridges [1]. Live load effects on the bridges are characterized by a number of factors other than Gross Vehicular Weight (GVW) such as span of bridge, axle spacing, number of axles, vehicular occupancy, number of lanes and number of vehicles [2].

In Pakistan, the unhealthy market competitions and illegal modification/ manufacturing/ fabrication of trucks on the road sides or in the backstreet yards mainly has put the design and service condition of bridge in a state of overloading. The illegal manufacturing of trucks and their corresponding inadequate number of axles (due to lack of vehicle design specifications) and also limited spacing puts the bridge structure in a state of distress and therefore the loss in the structural strength is observed and in such a case if the sufficient amount of strength has been lost then even the design vehicle can also be considered as an overload to the superstructure of the bridge [3].

The problem is aggravated when the overloaded vehicle has obscured axle spacing, thereby putting the structure to such effects that cannot be predicted by any reliable analysis tool [4]. This situation has led to the issuance of Overload Permits by the traffic control officers in Pakistan which is primarily based on their own perceptions or intellect. According to a study carried out by the National Highways Authority, almost 80% of the vehicles are overloaded in Pakistan. Among them 70% of overloaded vehicles are 2, 3 & 4 axle trucks. Not only the illegal modification but also the brands of trucks have gone major modifications with the advancement in technology [5].

In Pakistan there is only one legal document National Highway Safety Ordinance, NHSO 2000 that regulates the axle load control regime in the entire country but unluckily due to lack of enforcement, there are no such restrictions actually being followed in the country [6]. The regulations have been worldwide found to play a vital role in axle load control regime as it certifies the life of costly structures like bridges which are designed to perform their intended function for long period of time spanning to 100 of years or even more [7].

1.1 Historical Background

The emphasis upon the effects of live loads over bridges got its initiation soon after the World War II when the heavy war equipment had to be transported through the then bridges and their structural reliability was a question. In the beginning the comparative studies among various Bridge Design Codes has occupied the attention of scientists and researchers that later on resulted in the calibration of different codes of practice.

1.1.1. Relevant International Researches

Nowak (1993) described the live loads as function of certain parameters such as truck weight transmitted to axle loads, truck configuration, and occupancy of vehicle on the bridge longitudinally and transversely, number of vehicles on bridge, spacing of the girders, span length and structural stiffness of slabs and girders. However the effect of these factors has been considered separately. He used the truck statistical data, Weigh-In-Motion data and other data to produce the live load model that formed the basis of live load provisions in AASHTO

LRFD and OHBDC codes.

The Research Report UMCE 94-22 (December 1994) conducted by Michigan Department of Transportation proposed a method for evaluating the spectrum of live loads for Michigan bridges using the Gross Vehicular Weight (GVW) along with axle loads and their spacing to evolve the statistical parameters to model the actual live loads. The research provides valuable information on fatigue of steel bridges based on actual live loads moving on Michigan bridges.

Dr. Heywood & Ellis (1996) proposed a new traffic loading for design and construction of bridges in Australia. The research was aimed at developing the load model for the traffic likely to ply the bridge in its lifetime (anticipated load), truck loads and the innovations of heavy fleet traffic in Australia. In another study carried out by Kulchki (2006) for the evaluation of interstate vehicular models that took into account the interstate traffic effects in AASHTO since 1965 whereas some states were using HS25 instead of HS20 to cater for their heavy traffic but that still did not provide the actual traffic representation to the full. Simultaneously, the changes in the configuration of bridge structures added to the problem and therefore the need felt for updating the specifications including live load models, girder distribution factors, multiple presence factor etc. and finally formulated the post Interstate design era. AASHTO LRFD provides sounder basis for evaluation of structural response and behavior than was done at beginning of interstate era which took HL 93 into account. Statistics for Structural load and resistance can be used to attain a more uniform level by employing load ratings of bridges (Load and Resistance Factor Rating Code (LRFR)).

In an Interim Report (SPR 635 – June 2006), Oregon Department of Transportation conducted the load rating bridges by using calibration factors of LRFR. The LRFR’s live load codes are based on a single heavy truck as a representative of the truck traffic in the nationwide. However this study entailed the use of Weigh-In-Motion truck traffic data and conducted analysis to derive the calibration factors for Oregon. Oregon Department of Transportation is using a tailored calibration of the one described in the report. However the enforcement of legal limits has reduced the calibration factors to a great extent. Similar exercise had been adopted by Michigan State who conducted a research (MDOT Research R-1511) in April 2008 and calibrated the live loads specific to the Michigan truck traffic obtained from WIM Stations. In a research done for Latvian roads and bridges by Andris, Ainars presented in the 28th International Baltic Road Conference wherein it was mentioned that bridges are designed for a service life up to a hundred years and that the actual traffic characteristics differ from those recommended by the design codes.

Analyzing the design codes of Lativa for last 20 years generated a difference of almost 200% between the two loads. In order to save the cost of maintenance of bridges it is necessary to accommodate the actual traffic conditions in the load models. In the past, it was a tough task to gather the unbiased traffic data however now a days with the introduction of Weigh-In-Motion stations, a reliable truck traffic data base is in access. The data can be obtained for number of axles, load per axles, vehicular mass and speeds etc. of the plying vehicles so as to correctly simulate the true traffic. This includes data such as - number of axles, vehicle wheelbase, speed and axle loads which altogether shapes the picture of actual load waging on the roads and bridges.

The research presented the traffic load model and also calibration factor alpha with Eurocode load model LM1 for bridges in Lativa upto a span of 30 meter. As for spans greater than this different load models have to be generated. Sivakumar, Ghosn, Moses in NCHRP 135 (2008) presented the protocols and methodologies for generating the live load calibrated models using the recent varied truck traffic data to correctly represent the U.S current traffic loadings. HL 93 is a combination of the HS20 and a lane load and whereas HS20 was developed by Ontario Ministry of Transportation using 1975's traffic data that has no rational basis to be followed owing to the drastic variation in truck traffic volume and other characteristics such as increased GVW, traffic density and complex truck configurations, since 1970s.

Dr. Mertz (2009) suggested that the ratios of live loads and spans increases with span length and in order to attain the uniform reliability for all the span ranges, it is necessary to apply a varying load factor with HS20-44. This lead to the development of a new live load model called HL-93 notional live load model that combined the HS20-44 and a lane load and produced a more uniform and consistent bias for all ranges of span.

Tamakoshi and Nakasu (2010) proposed the calibration of live load model to generate the load and resistance factors that according to him could show much enhanced performance based designing in Japan. In the research the load factors were targeted at the levels of the current specification based design. In this way more rational bridge designs based on the performance level can be achieved. Sivakumar, Ghosn, Moses in NCHRP report 683 (2011) presented the protocols and methodologies for generating the live load calibrated models using the recent varied truck traffic data to correctly represent the U.S current traffic loadings. HL 93 is a combination of the HS20 and a lane load and was developed by Ontario Ministry of Transportation using 1975's traffic data that has no rational basis to be followed owing to the drastic variation in truck traffic volume and other characteristics such as increased GVW, traffic density and complex truck configurations, since 1970s. The traffic for the research was collected from WIM Stations of 13 different sites and was found reliable to actually represent the current traffic trends.

The calibration of live loads of the AASHTO was used for modeling the traffic conditions of different states and the factor was tabulated for different US States such as Florida, Indiana and California etc. Two methods were devised to cater for the variation in truck traffics of different states. In Method I, a factor “r” was applied to calibrate the live loads of AASHTO and (r) was obtained from the ratios of Maximum Bending Moments from WIM Data and Maximum Bending Moments from AASHTO LRFD. In the second method of calibration, structural reliability index was targeted. The study had certain important findings as follows:

- Number of axles does not have a large impact on r values.
- Increase in GVW also does not have a large impact on r values.
- Truck configurations were found to have most pronounced effect than GVW or the axle numbers on r values.
- Over loaded trucks not complying with the legal regulations lead to high rise in r values.
- The legal loads exercised with some permit vehicles give only a small rise in r values.

Missouri Department of Transportation conducted a research (2011) and observed that bridge serviceability and reliability is a function of many factors such as configuration of bridges, GVW, traffic density/volume, resistance to the carrying loads, GDF etc. It was established that the configurations of bridges, GVWs and traffic densities greatly vary with the regions. A country wide study showed the difference in ADDT’s and therefore the calibration of the live loads is done based on traffic data obtained from 24 WIM Stations in Missouri.

In the research the traffic data specific to Missouri had been used to investigate the structural reliability index. It was found that most of the bridges in Missouri had a reliability index of less than 3.5 and therefore the live loads need to be re-calibrated for Missouri. Hwang, Nguyen and Kim in 2012 devised the methodology for determining the live load factors for the reliability based evaluation and design of bridges in Korea. A new proposed live load model had been generated by collecting the WIM System, max GVW, ADTT volume and multiple presence effect. He found the live load factors for evaluation of bridges to be different from design load factors. For evaluation of bridges, he found the factors to be in the range of 1.24 to 1.58 depending on ADTT volumes and for designing of the bridges it was taken as 1.8. Difference in the statistical live load models for design and evaluation of bridges was carried out. The comparison was also carried out with some of the international codes.

ACECOM (2013) presented a report for NZ Transport Agency. In the report it was emphasized that the current vehicular loading for the highway bridges in New Zealand was introduced in 1972 and does not provide with a true and appropriate loading for the design or evaluation of bridges in NZ any more. The study suggested that as the bridges are designed for long lives therefore the heavy vehicular masses likely to accompany the NZ bridges in future should be taken into account at present. In a research by Austroads conducted for Australian highway bridge loadings it was found that the limits for economically optimal mass were almost double of the existing limits and therefore the bridge loadings should be indefinitely increased to ensure the strength and reliability of the bridges with future loadings. In the same study a comparison of loadings of NZ Transport Agency Bridge Manual has been carried out with the international standards. After detailed investigation/analysis it was concluded that either modifying the NZ Bridge Manual (existing) or the Australian Standard for bridge loading AS5100 can be the solution for the accommodation of current traffic scenario. The report also recommended the loading model which is 80% of the Australian design vehicle for design of new bridges in New Zealand. The recommended loading generates the actions that are 50% higher than current bridge manual loading.

1.1.2. Relevant domestic researches

Prior to NHSO2000, Pakistan did not have any of the legislation regarding control for the overloading of the trucks and as a result, deterioration of structures and roads was leading to the high maintenance cost and therefore overburdening the National Exchequer.

Although some studies were done earlier but the National Transport Research Center carried out its first study in 1982 as a requirement of the third highway project financed by World Bank & IDA. Axle load data was measured at 35 stations. The then traffic data revealed the composition of 96.5 % of the traffic was the 2-Axle Breford trucks. The trucks with other axles did not occupy the attention in the study much because of their insignificant presence in the traffic composition. The damaging factor was investigated to be 3.2 in comparison to 18 kip standard axle. In the same year 1982, another study relating to the axle configurations of the vehicles was carried out. The study did not covered the axle loads but only the composition was provided in detail.

A study was done on the Pakistan road freight industry in 1986 by Hine and Chilver for the Transport and Road Research Laboratory (R-314), for which 3500 truck drivers were interviewed and data regarding the vehicular age, type, make, body, value of money, ownership, tariffs, operational performance, loads, costs and ratio of accidents was recorded. At that time larger vehicle were not yet introduced much into Pakistan’s traffic streams.

Associated Consulting Engineers in 1988 conducted a study in which the data of 2460 vehicles was recorded by procedure described in Road Note 40 using a portable machine for axle weighing of a total of 17 stations. The study was carried out for traffic of N-55 (National Highway from Peshawar to Karachi). In this study damaging factor ranging minimum for tractor trolley to maximum for 4-axle rear tandem (a prime mover with trailer) was given.

In 1989 a survey of the loaded trucks only was carried out by the Punjab Highway Institute for Road Research and Material testing for Lahore and Faisalabad vicinity. The number of loaded vehicles that were surveyed was 302. Out of these 52 were the tractor trollies.

National Engineering Services Pakistan Pvt. Ltd. (1993) conducted the axle load study and found that the ACE and NTRC studies as aforementioned do not relate to the current traffic conditions as it found that the equivalent standard axles/vehicle have increased many folds. The axle load survey was carried out for the Sheikupura-Multan-D.G. Khan Motorway. It had provided with the values of the standard axles/vehicles for vehicles with different axle configurations.

NTRC (1995) carried out the axle load study to know the extent of overloading of the commercial vehicles in Pakistan. The data collection for all the axle loads, all types of trucks, volume of traffic, tire pressure, vehicular configuration (type, make etc.) and the goods transported by these trucks was performed.

A number of studies have been followed regarding the pavements part of roads in Pakistan, however the damaging effect of axle loads on part of the structures/bridges has not been emphasized much. Although the structural collapse or failure is a critical phenomenon that depends mainly on the occupancy of the live loads plying over the bridge.

Akhtar (2005) in his technical publication emphasized upon updating the codes in practice on periodic basis regarding loadings used for bridge designs in Pakistan. He proposed a new loading “Class A -1” comprising of 3-Axle Single tandem truck to counter for the growing traffic needs of Pakistan plying on the bridges. He mentioned that the length of such a vehicle should be 31ft. He also recommended the reduction in the distance between the two consecutive vehicles from 65 ft to 30 ft so as to simulate the current traffic conditions (congestion). He also mentioned that by applying the recommended loadings, the bending moments will compare well with the loadings of Japan and France and shall be conservative. But the research had certain short comings such as the vehicle train was considered along longitudinal section only and the occupancy of the vehicle along the transverse section was not calculated.

Multiple Lane presence factor had not been introduced that significantly reduces the probability of occupancy of heavy truck traffic in the second lane. Single vehicle occupying the bridge span had been used. Only a narrow range of spans 30 ft, 60 ft and 80 ft was covered. No statistical truck traffic data had been used. A very basic sort of research just to highlight the necessity of updating the current codes of practice or live loads had been discussed.

2 RESEARCH METHODOLOGY

2.1 WIM Data and sorting:

Weigh in motion data presents the current traffic conditions of the area and has been utilized to monitor the overloading vehicles. The data available at WIM Systems is generally of two types:

1. Data sheets having record of number of axles only

2. Data sheets having record of GVW as well as axle load

The WIM station data obtained from Mulaan Mansoor weighing station was of type two that had the Gross Vehicular Weights as well as the axle loads. The sorting of the data was then carried out in MS Access (a Microsoft Office application) and was transferred to MS Excel sheets and was statistically analyzed using Log Normal Distribution. After conducting the detailed calculations, the axle loads thus generated were used for analysis of the structure. The axle loads have been calculated for all different types of trucks and have been tabulated in Table 1. The overloading is as much as 245% which is alarming and requires the special attention. This overloading is observed to be more like a tradition and custom in Pakistan and WIM Stations can be utilized for upgrading of the loading limits in Pakistan.

Table 1. Gross vehicular weights (Tons) for the month of June-2009

Truck	**Axle No.**	**Permissible GVW (TONS)**	**WIM Station's observed Max GVW (TONS)**	**Percentage overloading ratio**
2-Axle	1+1	17.5	42.76	244.34
3-Axle	1+Tendem	27.5	54.21	197.13
4-Axle	1+1+Tendem	39.5	64.41	163.06
5-Axle	1+1+Tridem	48.5	76.16	150.87
5-Axle	1+Tendem+Tendem	49.5	73.17	153.86
6-Axle	1+Tendem+Tridem	58.5	98.67	168.67

3 SOFTWARE DATA INPUT

The bridge's structural ideology is of a Pre-stressed Concrete Bridge as being the most widely used bridge type in Pakistan. The Bridge Cross Section is the standard one recommended by National Highway Authority of Pakistan for the two lane Highway Bridges.

A set of six different form of simply supported bridge models have been generated for each span and a total of twenty four (24) models have been modeled in the software for all spans taken into consideration, as shown in Figure 1 to Figure 4. The placement of the vehicle has then been checked to achieve the maximum stresses/moments.

Detailed analysis has then been carried out using a hybrid or combination model using Grillage and FEM both and the desired output are recorded in the tables already standardized in the post analysis strategy phase, carried out in the initiation of the phase. The girders have been modeled using the Grillage analogy whereas the slab has been modeled as fine mesh i.e. the Finite Elements. Grillage analysis is old known famous method adopted for bridge analysis as is simple whereas Finite Element Method is also famous as the results get more accurate due to the increase in mesh. The properties of slab about its own axes has been excluded from the composite section properties.

Design softwares like STAADPro and CSI SAP 2000 are mostly renowned bridge analysis and design softwares around the world and mostly used in the region as well. However for this research STAADPro has been used for structural modeling and designing.

The steps taken for recording the input into the code editor file in general are as follows

Bridge Model

First of all the nodes of the whole structure are modeled. Each span of bridge had unique set of coordinates and was modeled likewise.

Like all other structural analysis and design softwares, STAADPro also starts with defining i.e. material defining (slabs, girders and diaphragms.), defining of member properties (girders, diaphragms and dummy members), defining of element/plate properties (slab) etc. Each bridge has different set of members and Elements; therefore separate member and element incidences defined for each model Geometric Properties of girders, diaphragms, dummy members and element properties such as A, Ix and Iz are calculated, defined and assigned.

Note: *Material properties are same in the models for all the bridge spans, so as to develop some rational base line.*

Therefore define and assign job has been accomplished at this stage.

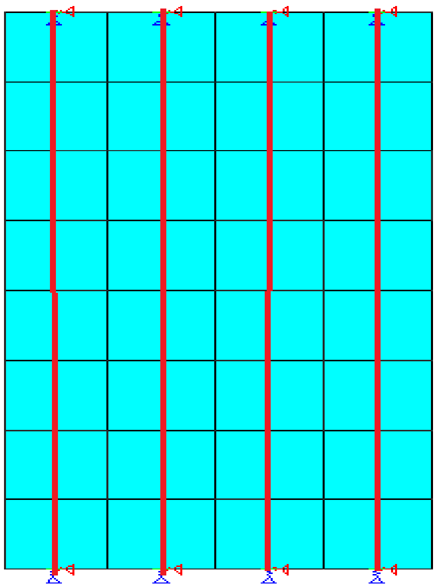


Figure 1. Superstructure model for 20meter span

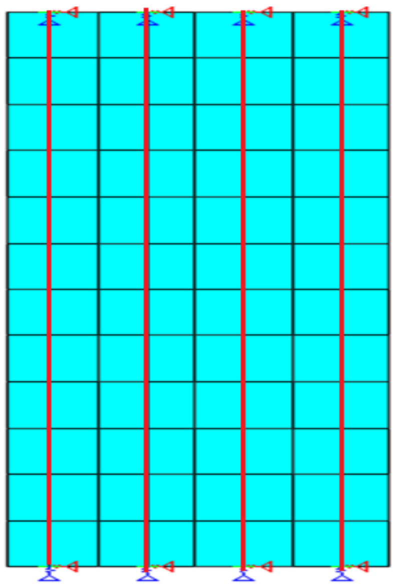


Figure 2. Superstructure model for 30meter span

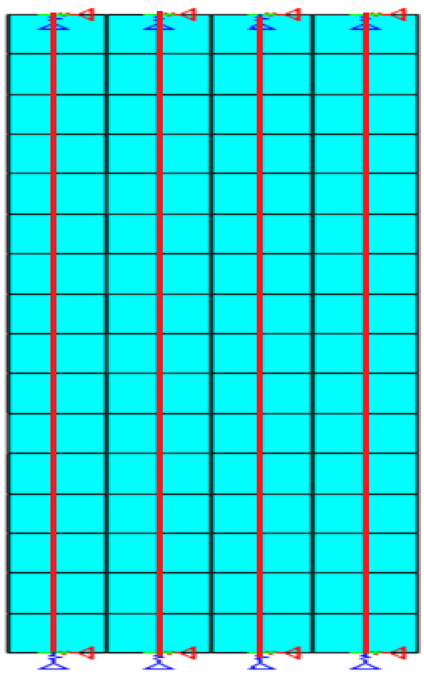


Figure 3. Superstructure model for 40meter span

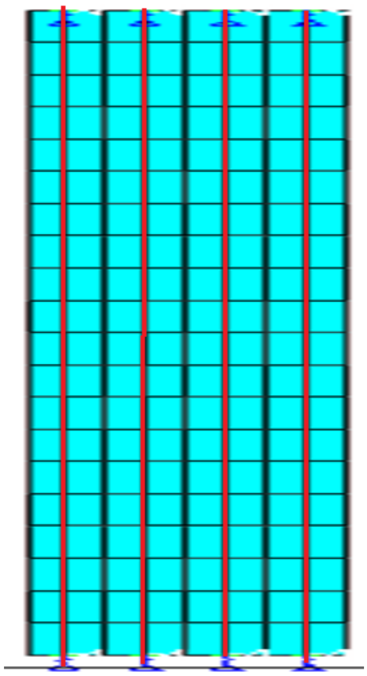


Figure 4. Superstructure model for 50meter span

3.1 Loads definition/generation

Moving loads and lane loads defined. Multiple Presence factor catering for the probability of presence of heavy vehicle in one, two or more lanes. Impact factor has also been incorporated but no live load factor as the analysis is done for service load conditions. However, multiple presence factors and Impact factor are use in consistency with the Design codes i.e. WPCPHB factors with its loading and AASHTO LRFD factors with its own loadings. Loads have been defined for following cases:

Case-I: One-lane, single vehicle occupancy.

Case-II: One-lane, two vehicle occupancy, parallel to each other.

Case-III: Two-lane, two vehicles (one in each lane).

Case-IV: Two-lane, four vehicles, two vehicles paralleled in each lane.

Load generation has been done to simulate the moving live loads traversing the bridge. Load generation has been conducted following the respective codes for all six cases which are as follows;

AASHTO LRFD:

- AASHTO LRFD loading
- NHSO 2000 permitted loading w.r.t. AASHTO LRFD
- WIM Overloading w.r.t. AASHTO LRFD

WPCPHB:

- WPCPHB loading
- NHSO 2000 permitted loading w.r.t. WPCPHB
- WIM Overloading w.r.t. WPCPHB

Run analysis

All the 26 different models have been analyzed with the sets of different live loads incorporated in 6 models for each span and together make 20m x 6 models, 30m x 6 models, 40m x 6 models and 50 m x 6 models. The model for each span was generated once and the only difference was the change in the loadings for the respective span. Each of the vehicle whether truck, tandem, military tank or lane loading, has been assigned a different loading nomenclature and evaluated for single lane with single vehicle occupancy, single lane with two vehicle occupancy, two lanes with two vehicle (one in each lane) and two lanes with four vehicles (two in each lane).

4 RESULTS & DISCUSSIONS

A detailed comparison of the live load effects of NHSO 2000 permitted loadings and WIM station overloading w.r.t. AASHTO and WPCPHB live load model effects has been made and tabulated in the following format to evaluate the final objective of the research i.e. the calibration factor needed to be applied with AASHTO or WPCPHB to ensure the strength and reliability of structures under present loading conditions as prevailing in Pakistan. The overloading factors show the tremendous increase in the loads and overburdening the structural components beyond their strength. The calibration factor is the ratio of the Max. Live load effects of WIM System traffic data to the Max. Live load effects of renowned coded live load models in Pakistan i.e. WPCPHB and AASHTO (for this study), as tabulated in Table 2 to Table 5.

$$\text{Calibration factor} = \mathbf{r} = \frac{\text{(Maximum Live Load Effects of WIM System traffic)}}{\text{(Maximum Live Load Effects of renowned codes)}}$$

Calibration factor is used in almost all of the developed countries to update their design codes as per prevailing traffic characteristics and Americans have done this exercise under AASHTO for its states and even interstate highways. If the proposed calibration factor is applied to the respective live load model, the structural reliability is increased and safeguarded as well [8].

Table 2. Calibration factor “r” – 20 meter (no units)

r	**NHA STANDARD**		**OVERLOADING**	
	AASHTO	**WPCPHB**	**AASHTO**	**WPCPHB**
B.M	0.81	1.07	1.11	1.47
S.F.	0.86	0.94	1.19	1.29

Table 3. Calibration factor “r” – 30 meter (no units)

r	**NHA STANDARD**		**OVERLOADING**	
	AASHTO	**WPCPHB**	**AASHTO**	**WPCPHB**
B.M	0.83	1.17	1.15	1.62
S.F.	0.88	1.10	1.22	1.49

Table 4. Calibration factor “r” – 40 meter (no units)

r	**NHA STANDARD**		**OVERLOADING**	
	AASHTO	**WPCPHB**	**AASHTO**	**WPCPHB**
B.M	0.90	1.16	1.25	1.60
S.F.	0.86	1.08	1.22	1.50

Table 5. Calibration factor “r” – 50 meter (no units)

r	**NHA STANDARD**		**OVERLOADING**	
	AASHTO	**WPCPHB**	**AASHTO**	**WPCPHB**
B.M	0.97	1.56	1.05	1.55
S.F.	0.93	1.59	1.32	1.51

Table 5 shows that the WIM data, when analyzed using the AASHTO guidelines, show an increase of almost 32% of the live load effects at maximum from AAHTO LRFD for spans ranging up to 50 meters and therefore a calibration factor of 1.35 can be applied to AASHTO LRFD live load model to address the overloading issue in Pakistan with short to medium spans (20 to 50meter). Although this research has also been done for the calibration of live load model of WPCPHB which is an out dated code that was developed in 1967 and since then has never been updated and was soon realized by the Bridge Engineers of Pakistan that AASHTO is much sophisticated a design manual and therefore the same stand point validates here and it is recommended that WPCPHB design methodology should not be adopted and if has to be used then only the live load model (as a brand) with the proposed calibration factor. Table 2 shows an increase of 62% for WIM traffic when compared with WPCPHB and therefore a calibration factor of 1.65 with WPCPHB live load model is recommended when compared with the results shown in Figure 5 till Figure 8.

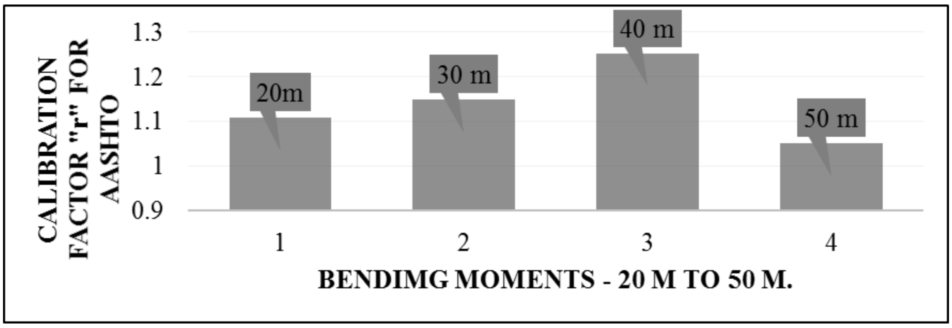


Figure 5. Calibration factor “r” with AASHTO (B.M.) for spans- 20 to 50 meter

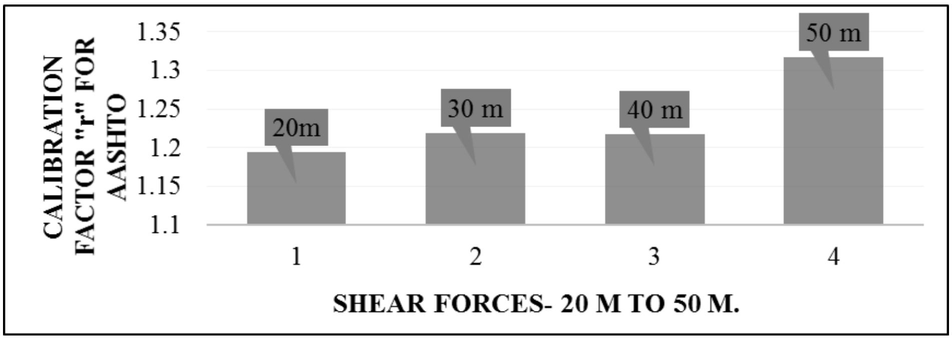


Figure 6. Calibration factor “r” with AASHTO (S.F.) for spans- 20 to 50 meter

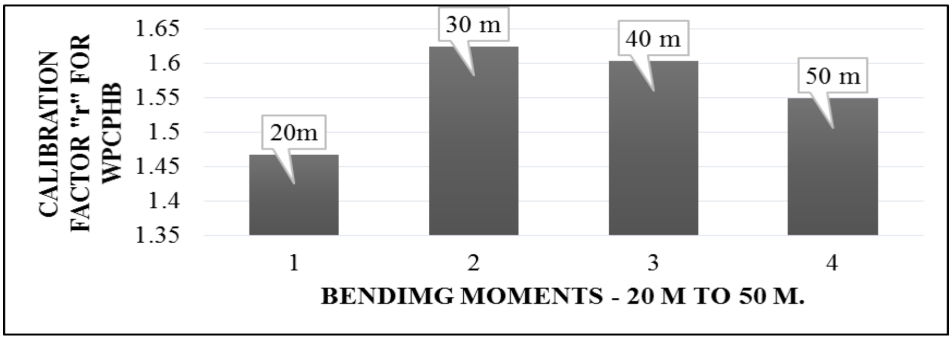


Figure 7. Calibration factor “r” with WPCPHB (B.M.) for spans- 20 to 50 meter

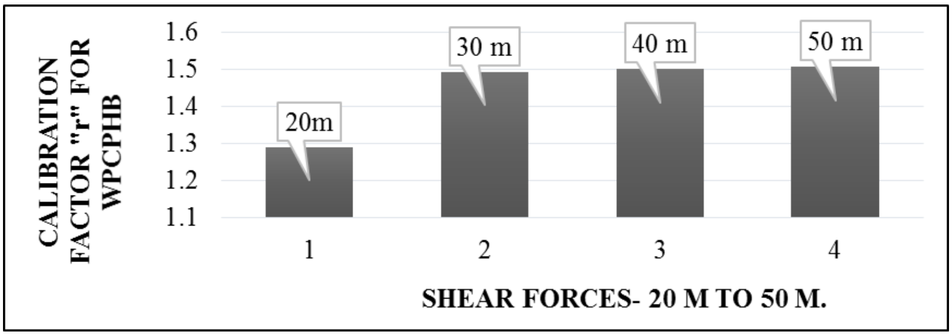
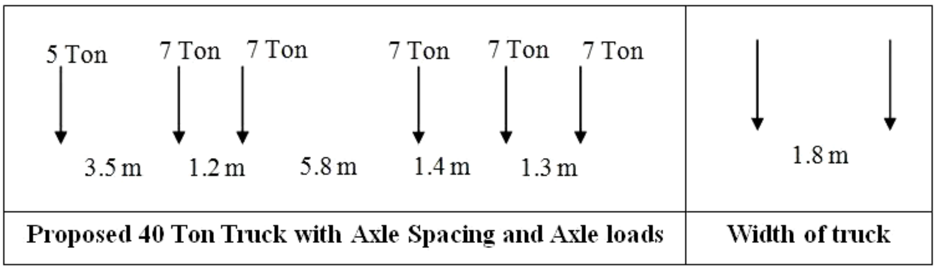


Figure 8. Calibration factor “r” with WPCPHB (S.F.) for spans- 20 to 50 meter

5 CONCLUSIONS & RECOMMENDATIONS

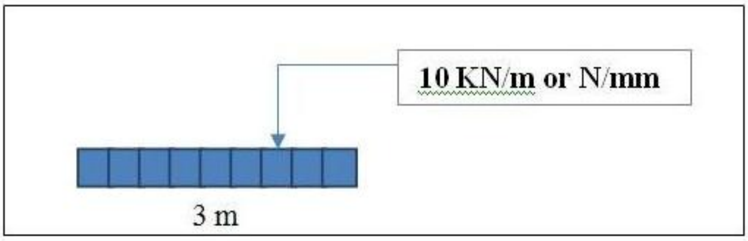
Conclusions:

1) It can very easily be predicted from the results obtained after conducting a thorough analysis for spans ranging from 20 to 50 meter that live load model of WPCPHB requires an enhancement of 65% whereas AASHTO live load model needs 35% increase to address the traffic streaming of Pakistan. It is therefore concluded that WPCPHB or AASHTO live load model does not govern for Pakistan traffic conditions.
2) It is recommended that the calibration factor i.e. the live load factor of 1.35 with AASHTO live load model be used to compensate the current excessive loading conditions is Pakistan.
3) Similarly a calibration factor of 1.65 with WPCPHB live load model is recommended.
4) As an illustration of the standard practice carried out worldwide for the development of the live load model to simulate the specific traffic conditions, this research also concluded a six-axle truck (1+Tendem+Tridem) with GVW of 40 Tons and fixed axles spacing is shown as a Design vehicle:



5) The occupancy of the line of such proposed trucks that actually make the most critical combination of loading, is also cater for; by adding the 10

N/mm or KN/m UDL as a lane load over a width of 3 meters (fixed by trial and error method) for each lane occupancy with the 40 Ton truck as proposed and mentioned above. The results generated worked in best agreement with the current traffic scenarios in Pakistan.



A Uniformly Distributed Load as a Lane Load

Recommendations:

1) It is recommended that the AASHTO LRFD or WPCPHB live load models should be used with calibration factors calculated using the Weigh in Motion data i.e. 1.35 for AASHTO and 1.65 for WPCPHB.
2) The use of the proposed live load model i.e. 40 ton truck with specified axle spacing and axle loads plus a UDL of 10 N/mm, for each lane occupancy, should be adopted.

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