



# Comparison of Live Load Effects for the Design of Bridges

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## Abstract

Design and lifelong structural performance of bridges is primarily governed by the live load models representing truck traffic. In Pakistan, bridges are designed as per Pakistan Code of Practice for Highway Bridges 1967 ("PHB Code") and American Associations for State Highway and Transportation officials LRFD (Load and resistance factor design) Bridge Design Specifications ("AASHTO"). Further, National Highway Authority (NHA) has specified legal limits on the live loads to prevent overstressing of bridges. Different states of US had calibrated the AASHTO live load model based on the actual truck weights and traffic volume present in the respective states. In Pakistan, service-level truck traffic is significantly different in axle weights, axle configuration, gross vehicle weights (GVW) and traffic volume than that of United States and Canada. Further, in Pakistan, over the years, service-level truck traffic has changed significantly in axle weights, axle configuration, GVW and traffic volume due to developments in truck industry to meet the heavier loads carrying demands by various industries. Thus, live load models specified in 1967 PHB Code, AASHTO live load model and NHA legal limits may not be a true representation of today's service - level truck traffic of Pakistan. After discussing the different Live Load Models currently in practice for the design of highway bridges in Pakistan, this paper compares the load effects produced by the actual trucks on sample bridges with the load effects of code specified live load models. Three simply supported, Pre-stressed concrete girders/bridges were considered to study the effects of actual trucks and live load models. Maximum load effects were calculated using influence lines by running each truck on the sample bridges. Maximum load effects were also calculated for live load models of respective codes. Normalized load effects were calculated by dividing the truck load effect with the load effect due to code specified load model and results were plotted on probability plot to compare the results. The results show that the highway loading in Pakistan produces much greater load effects than anticipated from the bridge design codes.

**Keywords:** Live Load, HL-93 loading, Class A loading, Lane loading, Gross Vehicle Weight.

## 1 Introduction

Estimation of accurate live load due to truck traffic is essential for safe and economical designing of bridges. Main combination of loads for bridge design consists of combination of dead load, live load, environmental load and other loads. Being dynamic, live load is random and unpredictable in nature therefore requires careful consideration in its modelling and estimation.

Live load is divided into static and dynamic components and its sum presents the total live load on bridge structure. In this study only static component was considered. WIM (weigh in motion) is used for collecting the data pertaining to live load due to trucks on bridges. The information include the GVW, axle spacing, axle weight, number of axles and average daily truck traffic (ADTT). Live load effects include the moment, shear and stresses which are used for effective evaluation of a bridge structure. In this study only moment and shear due to single truck on the bridge under consideration is considered. WIM

data was acquired in the raw form. The same was filtered to get the data in required form and was used for analysing the effects of live load on the sample bridges.

## 2 Review of Live Loads in Context of Pakistan

Design of bridges is primarily governed by the live load models representing truck traffic. In Pakistan, live load models of PHB Code 1967 and AASHTO LRFD code is being practiced for design of bridges. These live loads models are proposed loading keeping in view the objective of covering the worst combination of axle load and axle spacing, likely to arise from the various types of vehicles that are normally expected to use the roads.

### 2.1 Live Loading - PHB CODE 1967.

PHB Code 1967 is primarily based on AASHTO Bridge Design Specification, 1961. According to PHB code 1967, the highway loading on the bridge consists of a truck train loading and 70 ton military tank. The design live loads are classified as Class A, Class B and Class AA loading.

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### 2.1.1 Class A Loading (Standard Train Loading)

This load train is reported to have been arrived at after an exhausted analysis of all lorries made in all 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. This loading in bridge designing is generally adopted on all roads on which permanent bridges and culverts are constructed.

### 2.1.2 Class B Loading

Class B Loading is similar to Class A loading with a slightly reduced axle loads. This loading is normally adopted for temporary structures and for bridges in specified areas. Example of temporary structures is structures with timber spans. Class B Loading is 60 per cent of Class A Loading as shown in Figure 2. The positions of wheels and axle are same for both Class A and Class B Loading.

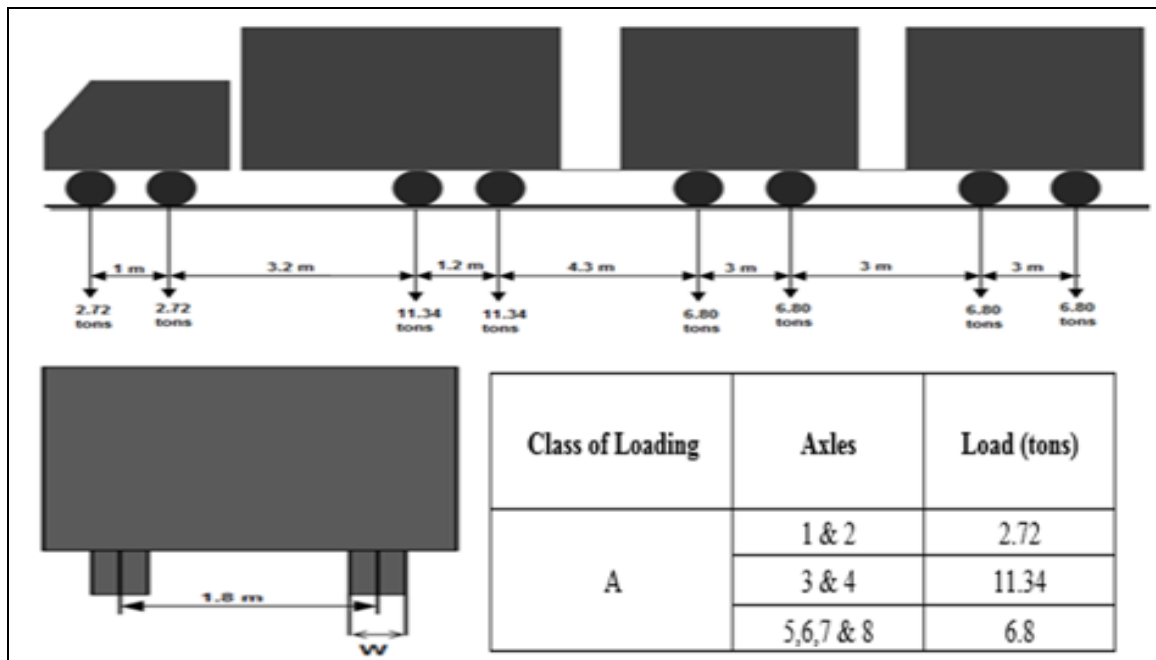


Figure 1: Train Loading Class A (PHB CODE, 1967) – 8 Axle

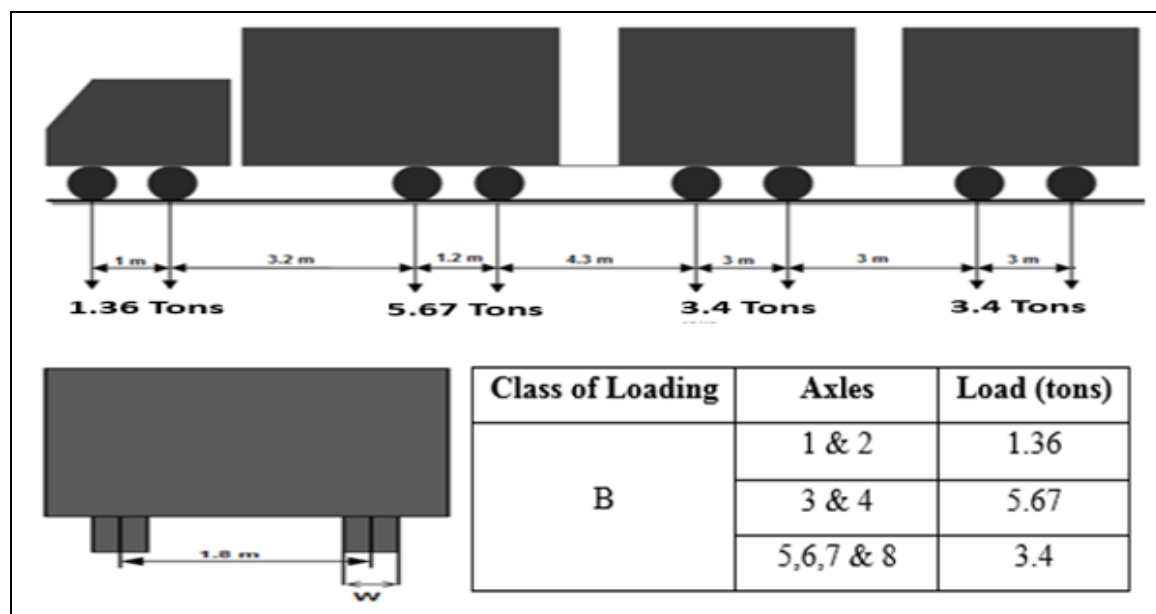


Figure 2: Train Loading Class B (PHB CODE, 1967) – 8Axle

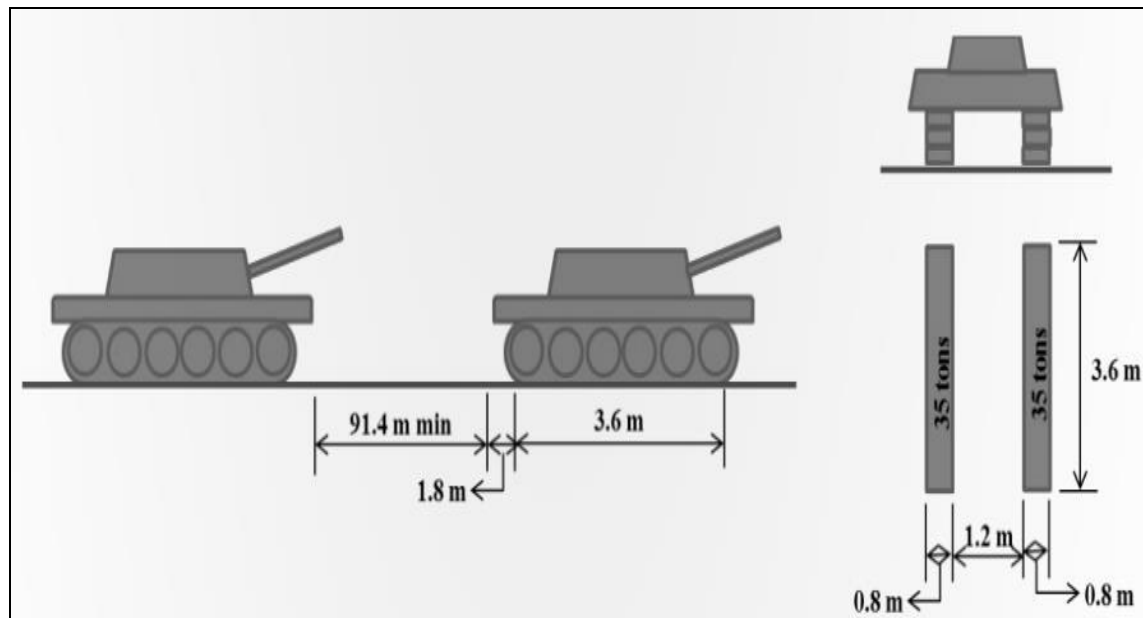


Figure 3: Military Loading (70 Ton tank)

### 2.1.3 Class AA Loading (70 ton Military Tank)

Class AA loading is based on the original classification of the defence Authorities. This loading is to be adopted for the design of bridges with 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 vehicles (Military Tanks) having specified dimensions which are to be observed during the Live load analysis in bridge design. The nose to tail distance between two successive vehicles is not less than 91.4 meter. No other live 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. Bridge designed for Class AA loading should be checked for Class A loading too. As under certain conditions heavier stress may be obtained under Class A loading. Figure 3 shows a typical Class AA loading.

### 2.2 AASHTO LRFD Live Loading

AASHTO LRFD live loading commonly known as HL-93 loading where H stands for Highway and L stands for Loading, was developed in 1993. AASHTO live load model, included in AASHTO Specifications, was developed using truck data from the Ontario Ministry of Transportation, Canada. This is a hypothetical live load model proposed by AASHTO for the analysis of bridges with a 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 effects approximately same as that produced by the exclusion vehicles. HL-93 loading consists of three components:

#### 2.2.1 Design truck

It was proposed in 1994 and is commonly called as HS20-44 where H stands for Highway and S stands for Semi-trailer, 20 ton weight of the tractor (1st two axles). HS20-44 indicates a vehicle with a front tractor axle weighing 4 tons (8 kips), a rear tractor axle weighing 16 tons (32 kips), and a semitrailer axle weighing 16 tons (32 kips). Two rear axles have a variable spacing ranging from 4.3 (14 feet) to 9 (30 feet) meter in order to influence a maximum positive moment in a span. Design Truck is shown in Figure 4 below.

#### 2.2.2 Design tandem

It consists of two axles weighing 12 tons (25 kips) each spaced at 4 feet as shown in Figure 4.

#### 2.2.3 Design lane

It consists of uniformly distributed load of 0.64 kips/feet (0.94 ton/meter) and is assumed to occupy 10 feet width in traverse direction as given in Figure 4.

#### 2.2.3 HL-93 Loading

HL-93 design load consists of a combination of the design truck or design tandem (whichever is greater), plus the design lane load as shown in Figure 5. Therefore the extreme load effects for the vehicular live load are the larger of the following:

- a. The combined effect of one design truck with the variable axle spacing with the design lane load as shown in Figure 5, or
- b. The combined effect of the designed tandem with the design lane load as shown in Figure 5.

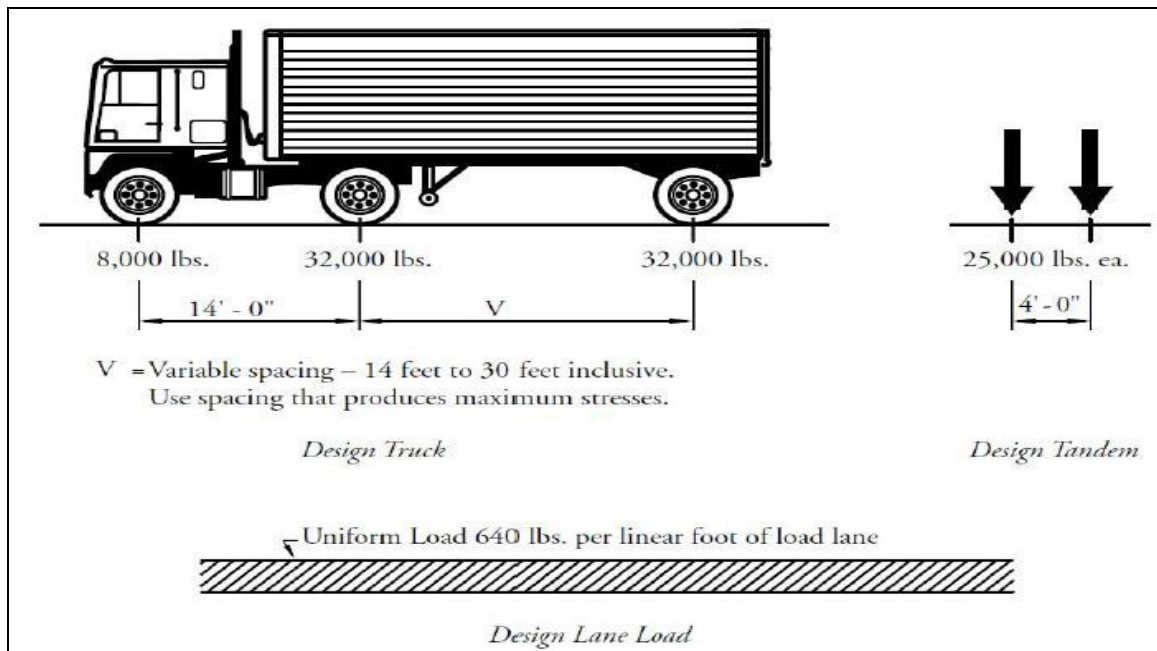


Figure 4: AASHTO Design Vehicle – HL-93 (Reproduced from Kozikowski, 2009)

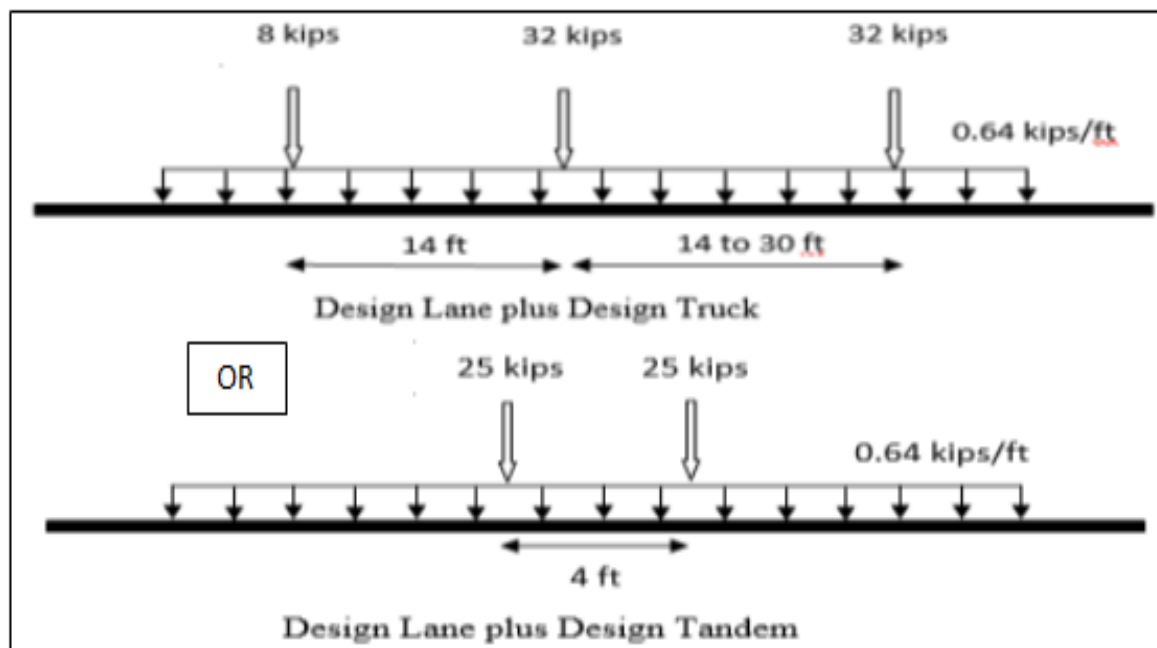


Figure 5: AASHTO Design Vehicle – HL-93 (greater of the two combinations)

### 3. Data Base

WIM is used for collecting the data pertaining to live load due to trucks on bridges. The information include the gross vehicle weight (GVW), axle weight, number of axles and average daily truck traffic (ADTT). In this study, three weigh stations were selected for data collection corresponding to the location of sample bridges. Location of these weigh station is shown in Figure 6.

Quality of WIM data is more important than the quantity for developing a live load model. Data recorded at various stations in Pakistan are prone to various errors due

to limitation of the equipment being used. These errors need to be recognized before processing the recorded data for achieving reliable results. In Pakistan, mostly slow moving WIM stations (< 8 kmph) or stop and go WIM stations are installed for data recording. Inbuilt limitation of these instruments is its inability of separating the vehicles if either the speed of the truck is greater than 8 kmph or if the length of the truck is too large. Two or more trucks may be recorded as one truck. The filters can be used to screen the database for bad data or unlikely trucks during the data transfer process. Some of the guide lines given in National Cooperative Highway Research Program 683 (NCHRP

683, 2012) were considered for filtering out the bad data. Truck record that did not meet the following was eliminated:

- Total number of axles  $\geq 2$
- Total number of axles  $\leq 12$
- Sum of axle spacing is greater than the length of truck.
- Sum of axle weight is greater than GVW of truck.

Maximum numbers of axle were restricted to 12 only with the reason that, trucks above 12 axles resulted in very high load effects. These high values are the representative of a special or permit vehicle. To achieve optimum reliability, special or permit trucks needs to be dealt separately. WIM data was acquired from three different stations the details of which are:

Sangjani Weigh Station is located on National Highway 5 (N-5). Total of about 273,399 trucks of different configuration were recorded at this site for six months. Before processing, the data was filtered for errors in the recording by deleting the wrong or abnormal entries. A total of 42,656 (15.6 percent) trucks were removed after the application of filter on the raw data. Maximum entries comprised of trucks from 2 axles to 6 axles while few entries consists of above 6 axles trucks. Maximum of truck data up to 12 axles were included in the data as was done by Kozikowski and Nowak, (2009) for processing. Summary of number of vehicles as per axles and their maximum GVW is summarized in Table 1, while histogram, probability density function (PDF) and Cumulative distribution function (CDF) of the GVW for Sangjani Weigh station is shown in Figure 6:

### 3.1 Sangjani Weigh Station

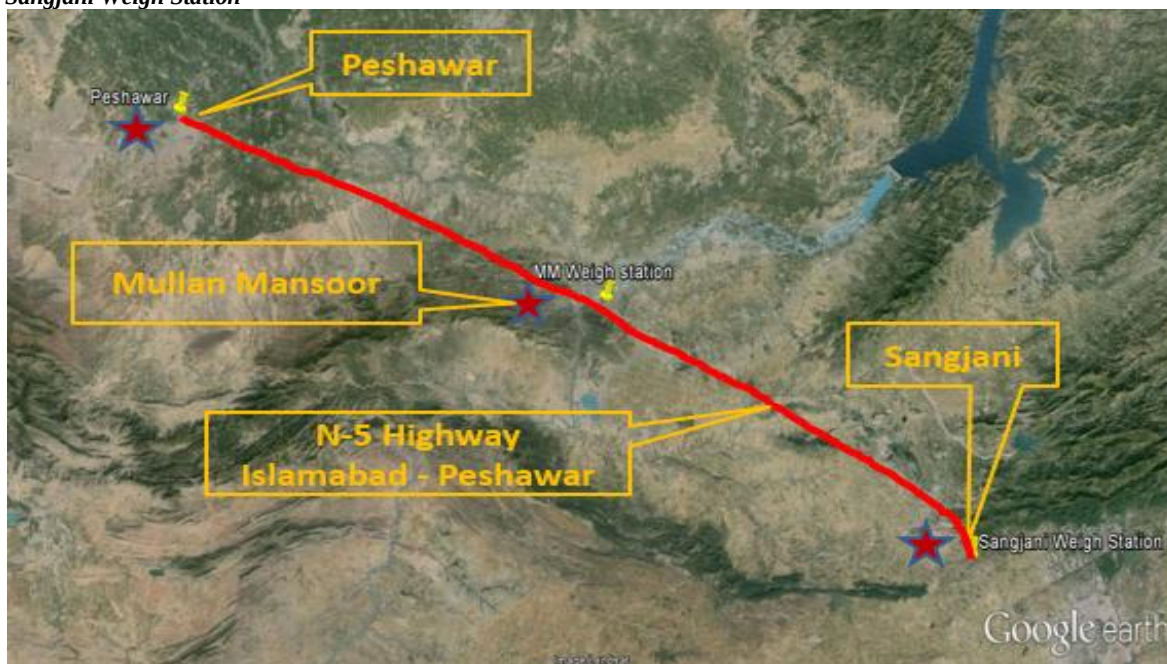


Figure 5: Location of Weigh Stations

Table 1: Number of vehicles and maximum GVW in each category - Sangjani

|                  | Truck Configuration (Number of Axles) |        |       |       |        |        |        |        |        |        |        |        |        | Total  |
|------------------|---------------------------------------|--------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                  | 2                                     | 3      | 4     | 5     | 6      | 7      | 8      | 9      | 10     | 11     | 12     | 13*    | 14*    |        |
| Number of Trucks | 101022                                | 114606 | 9282  | 1787  | 4014   | 13     | 5      | 8      | 3      | 2      | 1      | 1      | 4      | 230743 |
| Max GVW (tons)   | 32.43                                 | 56.59  | 66.82 | 86.30 | 109.30 | 106.05 | 123.70 | 143.80 | 124.80 | 136.00 | 163.40 | 158.92 | 195.18 |        |

\* Data not included in the Total



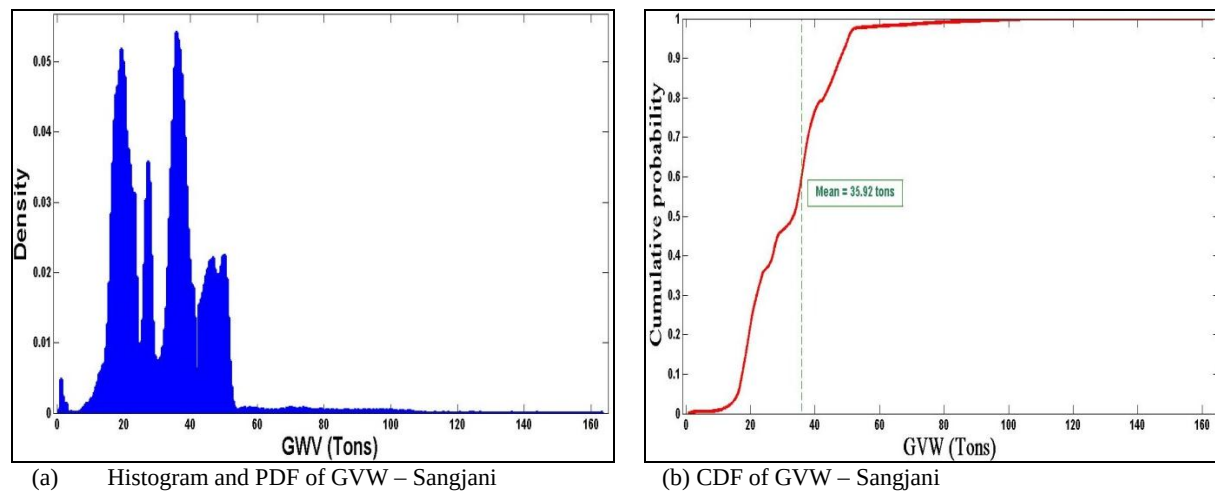


Figure 6: Histogram and PDF of GVW – Sangjani and CDF of GVW – Sangjani

The results show that maximum GVW recorded at Sangjani from the filtered data is 163.4 tons and its corresponding configuration is 12 axles. Mean GVW for the data recorded at this site is 35.92 tons. Mean GVW of this site is much lower as compared to the mean GVW of Ontario truck data which is 75 tons (Kozikowski and Nowak, 2009). Comparison of GVW of actual truck to GVW of design truck is shown in Figure 7. Result shows that 39.18 percent and 2.17 percent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.

### 3.2 MullanMansoor (MM) Weigh Station

Three months of truck data was recorded at this site comprising 116,009 trucks of different configuration. Axle spacing was missing in the data files provided by NHA; therefore it was decided to apply the standard axle spacing measured on ground at Peshawar by Ali *et al.* (2012).

Unlike the data recorded at Sangjani, the truck configurations were restricted to 6 axles at MM. A total of 11,456 (9.9 per cent) trucks were removed after the application of filter on the raw data. Summary of number of vehicles as per axles and their maximum GVW is summarized in Table 2. Histogram, PDF and CDF of the GVW for MM Weigh station is shown in Figures 8.

The results show that maximum truck GVW is 108.3 tons and its corresponding configuration is 6 axles. Average GVW for the data recorded at this site is 39.17 tons. Mean value of this site is larger than Sangjani (35.92 tons) but is lower than the Ontario truck data (75 tons). Comparison of GVW of actual truck to GVW of design truck for this site is shown in Figure 9. Result shows that 27.76 per cent and 8.8 per cent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.

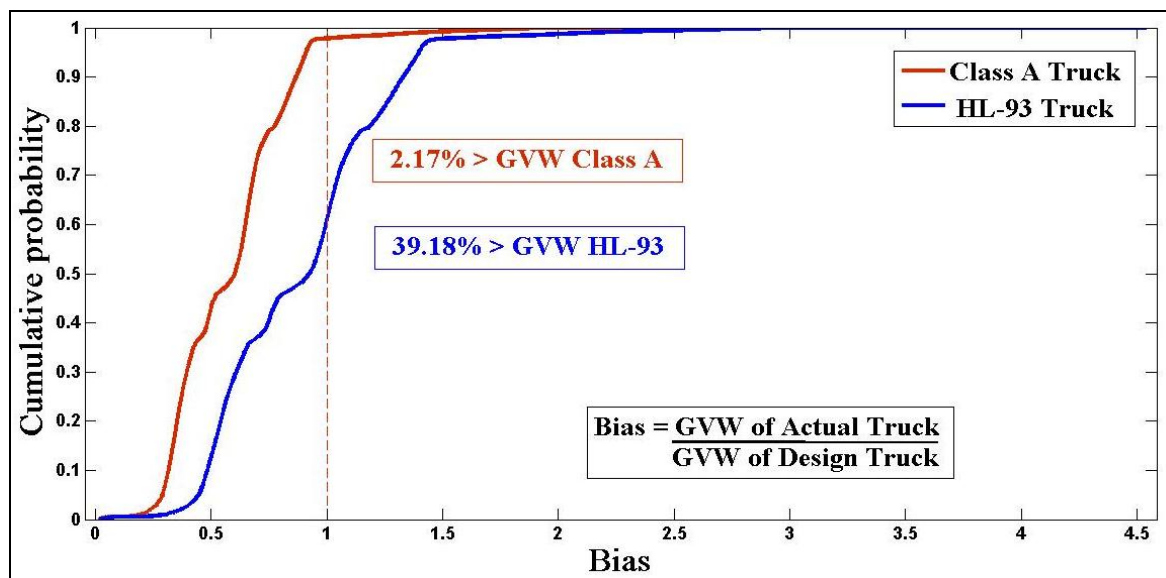
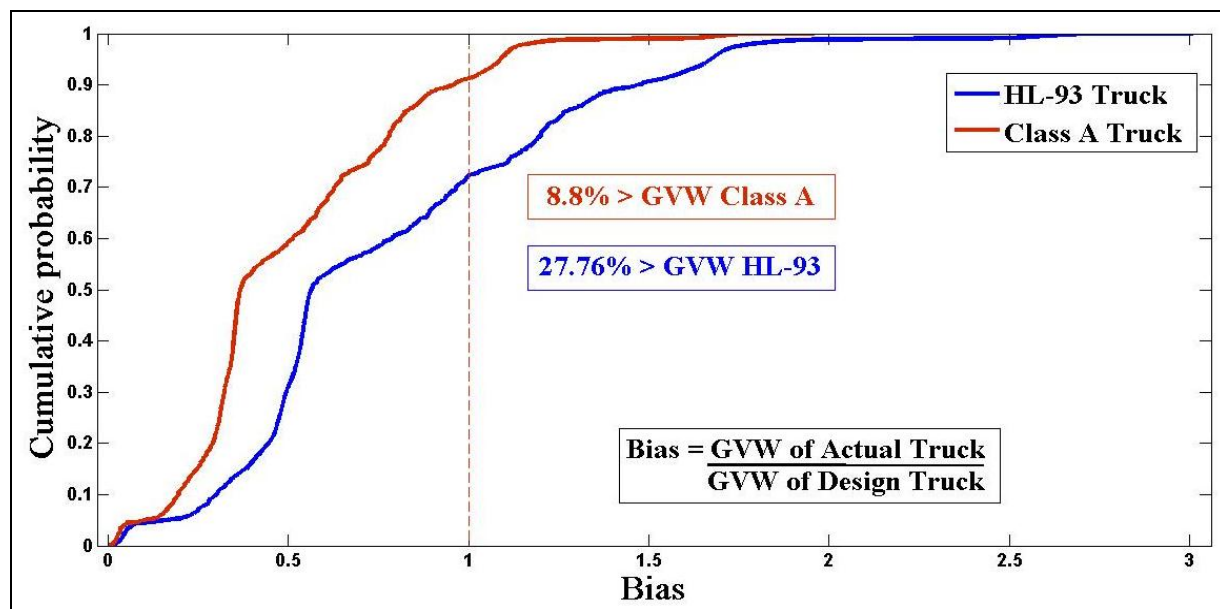
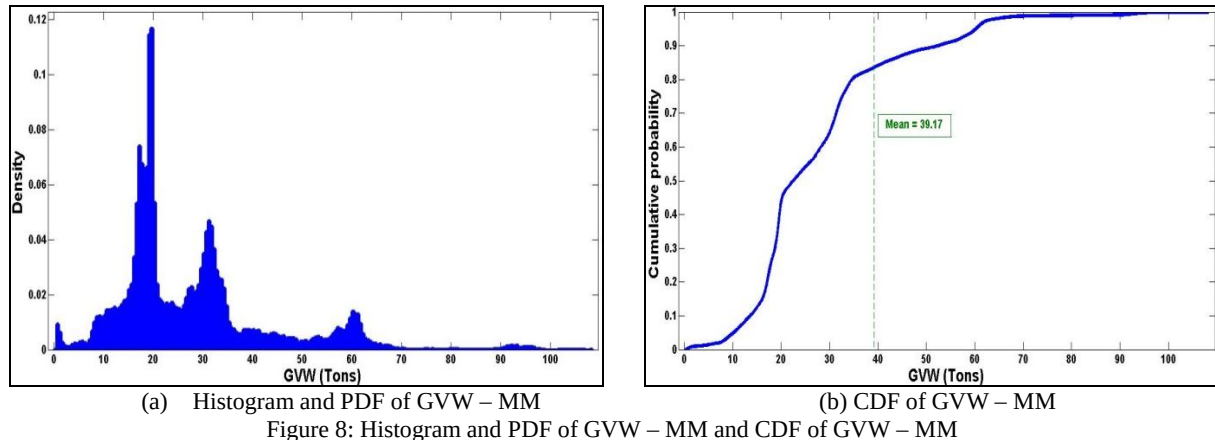


Figure 7: Comparison of GVW of actual trucks to GVW of Design Trucks – Sangjani

Table 2: Number of vehicles and maximum GVW in each category - MM

| Vehicle type   | 2 axle | 3 axle | 4 Axle | 5 axle | 6 axle | Total  |
|----------------|--------|--------|--------|--------|--------|--------|
| No of vehicles | 47593  | 28908  | 16287  | 2274   | 9491   | 104553 |
| Max GVW (tons) | 42.76  | 67.14  | 69.92  | 83.87  | 108.29 |        |



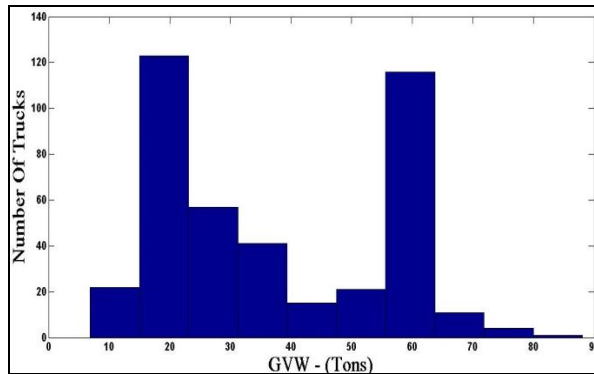
### 3.3 Peshawar (Temporary Weigh Station)

A temporary weigh station was established at Hayatabad in Peshawar to monitor the truck traffic by researchers of UET Peshawar (Ali *et al.*, 2012) in collaboration with Peshawar Development Authority (PDA). Data acquired at this site was limited to very few trucks i.e 411 trucks. The data includes the vehicles up to 6 axles only. Summary of number of vehicles as per axles and their max GVW is summarized in Table 3. CDF of the GVW for Peshawar survey data is shown in Figures 10.

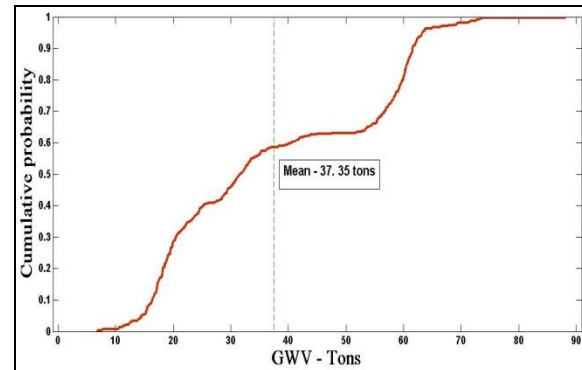
The results show that maximum truck GVW is 88.12 tons and its corresponding configuration of truck is 6 axles. Average GVW for the data recorded at this site is 37.35 tons. Comparing between GVW of actual truck to GVW of design trucks (Class A and HL-93 trucks) is shown in Figure 11. Result indicates that 42.58 per cent and 37.71 per cent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.

Table 3: Number of vehicles and maximum GVW in each category - Peshawar

| Vehicle type   | 2<br>axle | 3<br>axle | 4<br>axle | 5<br>axle | 6<br>axle | Total |
|----------------|-----------|-----------|-----------|-----------|-----------|-------|
| No of vehicles | 154       | 66        | 33        | 3         | 155       | 411   |
| Max GVW (tons) | 30.42     | 37        | 44.93     | 54.37     | 88.12     |       |



(a) Histogram and PDF of GVW – Peshawar



(b) CDF of GVW – Peshawar

Figure 10: Histogram and PDF of GVW – Peshawar and CDF of GVW – Peshawar

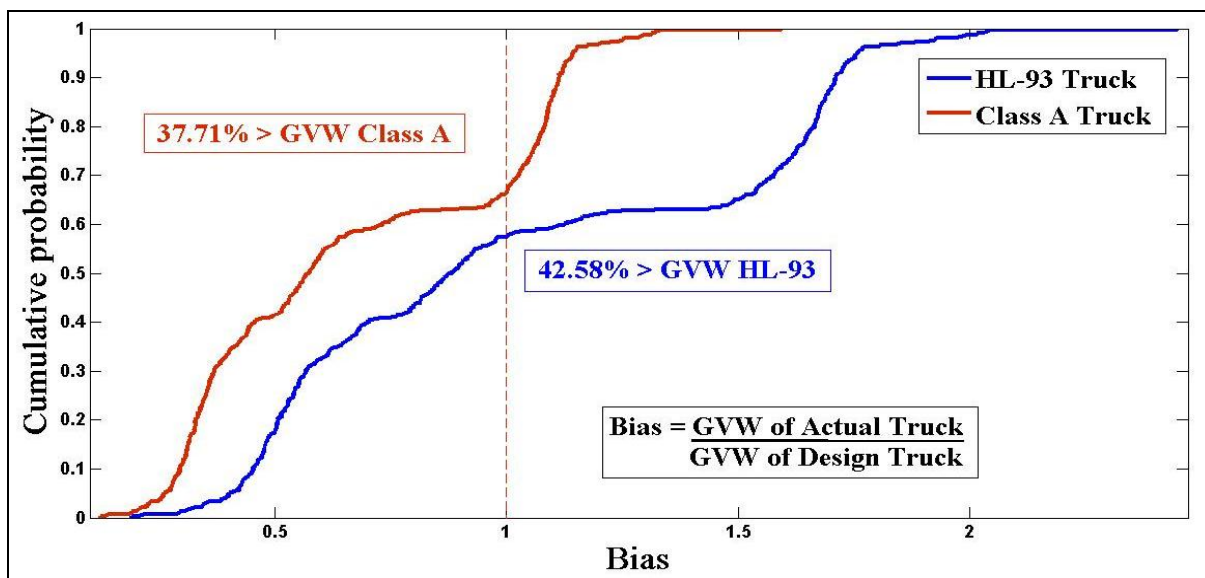


Figure 11: Comparison of GVW of actual trucks to GVW of Design Trucks - Peshawar

#### 4 Determination of Maximum Moment and Shear Using Influence Lines

For a simply supported bridge, calculation of load effects (moments & shear) involves determination of both the location of point in the beam and the position of loading on the beam. For calculating absolute maximum moments/shear for a large number of trucks, code was developed in a computer program using MS Excel. Code was developed for all the trucks as per number of axles separately. Three sample bridges for each site were selected for Reliability analysis. All these Bridges are simply supported, pre-stressed concrete girder bridges and details are as under:-

- Muhammad Wala Bridge –Sangjani.** Muhammad Wala Bridge was constructed in 2010. This bridge consists of pre-stressed and simply supported girders having a clear span of 47.2 meters. Overall width of the bridge is 12.09 meters and Road way width is 12.05 meters. This is a three lane bridge, having 180 millimeter deck thickness, 100 millimeter thick wearing surface and consists of four pre-stressed concrete girders.
- Mansoor Bridge – MM.** Mansoor Bridge is identical to Muhammad Wala Bridge with a clear span of 47.19 meters. This bridge was constructed in 2009. It consists of four pre-stressed girders having a span of 47.19 meters and 3.03 meters spacing



between girders. This is a three lane bridge, having 180 millimeter deck thickness and 100 millimeter (average) thick wearing surface.

- c. **Bagh-e-Naran Bridge - Peshawar.** This is a 20 years old bridge having a clear span of 12.8 meters. This bridge consists of pre-stressed and simply supported girders. Overall width of the bridge is 8.69 meters and road way width is 7.39 meters. This is a two lane bridge, having 190 millimeter deck thickness and 100 millimeter thick wearing surface. It consists of five pre-stressed concrete girders and spacing between each girder is 1.9 meters.

#### 4.1 Determination of Maximum Moment

Maximum moment was calculated using influence lines for all three sites. Similarly, maximum moment was also calculated for HL-93 and Class A design truck. Normalized moments were calculated by dividing the calculated actual truck moment with the moment of HL-93 and Class A design truck. Results of the normalized moments were plotted on probability paper. In case of Muhammad Wala bridge-Sangjani, results shows that 44.80% and 11.66% of actual trucks produce moments higher than that produced by HL-93 and Class A design trucks as shown in Figure 12. Maximum value of moment is about 2.97 and 2.70 times higher than the moment produced by HL-93 and Class A truck, respectively. 17.93% and 10.62% of actual trucks produce moment higher than that produced by HL-93 and Class A design truck at Mansoor bridge. Similar increasing

trend was observed at this bridge and maximum value of moment was in order of 2.07 times higher than the moment produced by both HL-93 and Class A truck as shown in Figure 13. In case of Bagh-e-Naran bridge-Peshawar, 39.17% and 38.69% of actual trucks produce moment higher than that produced by HL-93 and Class A design truck as shown in Figure 14. Maximum value of moment was 152% and 160% higher than the moment produced by HL-93 and Class A truck respectively.

#### 4.2 Determination of Absolute Maximum Shear

Same procedure was adopted for calculating maximum shear for each truck in the data. Normalized shear was also calculated by dividing the truck shear with the design truck shear. Results at Muhammad Wala bridge-Sangjani indicate that 42.80% and 12.20% of actual trucks produce maximum shear higher than that produced by HL-93 and Class A design trucks as shown in Figure 15. Maximum value of shear is 2.99 and 2.70 times higher than the shear produced by HL-93 and Class A truck, respectively. In case of Mansoorbridge 17.64% and 11.20% of actual trucks produce maximum shear higher than that produced by HL-93 and Class A design truck as shown in Figure 16. Maximum value of shear was in the range of 212% higher than the moment produced by HL-93 and Class A truck. At Bagh-e-Naran bridge-Peshawar, about 44% of actual trucks produce higher shear higher and maximum value of shear was about 170% higher than the moment produced by HL-93 and Class A truck respectively as shown in Figure 17.

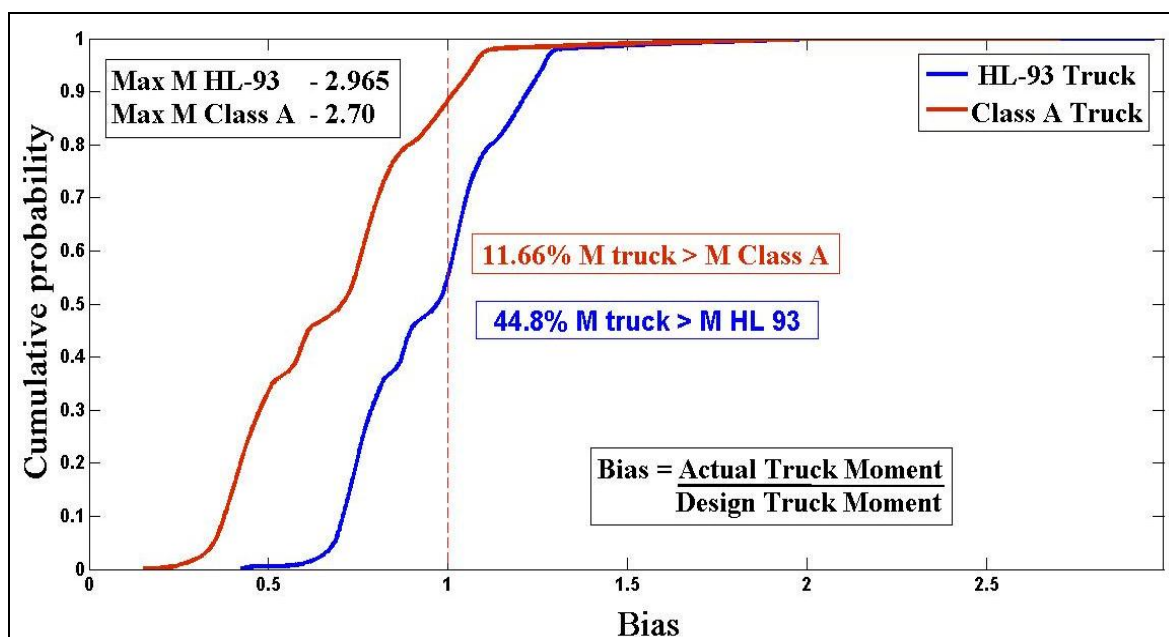


Figure 12: CDF of Simple Span Moment – Sangjani

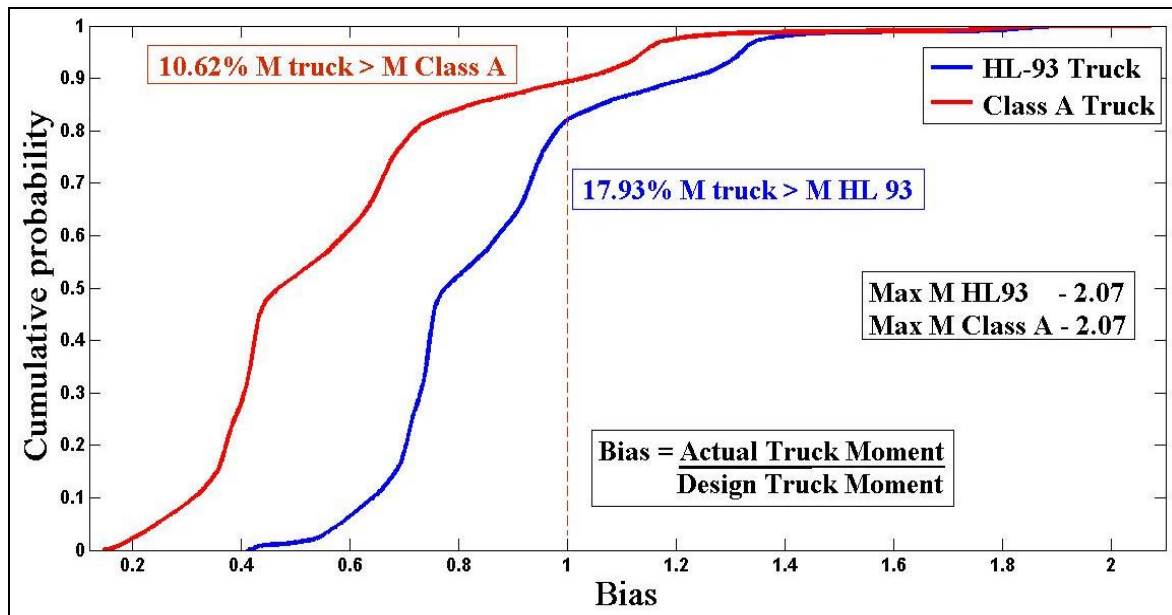


Figure 13: CDF of Simple Span Moment – MM

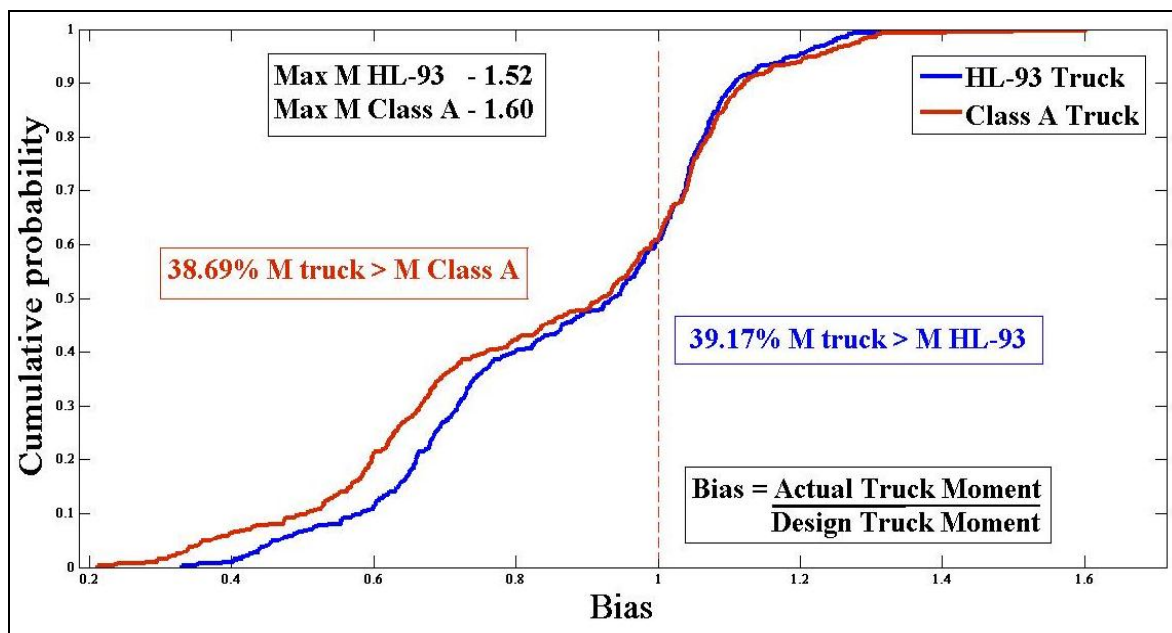


Figure 14: CDF of Simple Span Moment – Peshawar

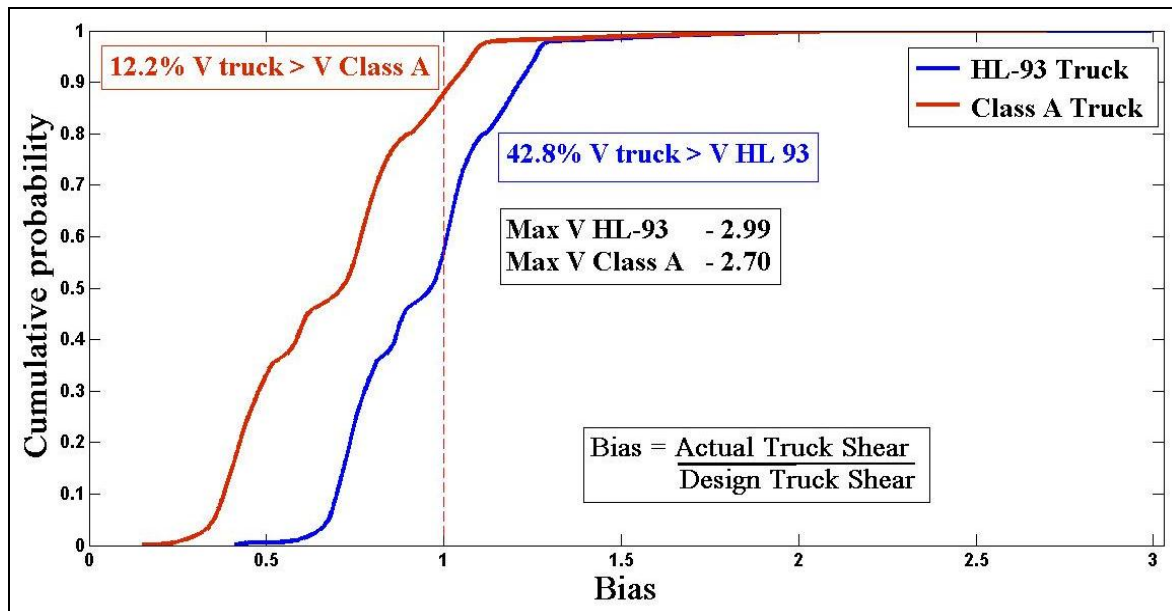


Figure 15: CDF of Simple Span Shear – Sangjani

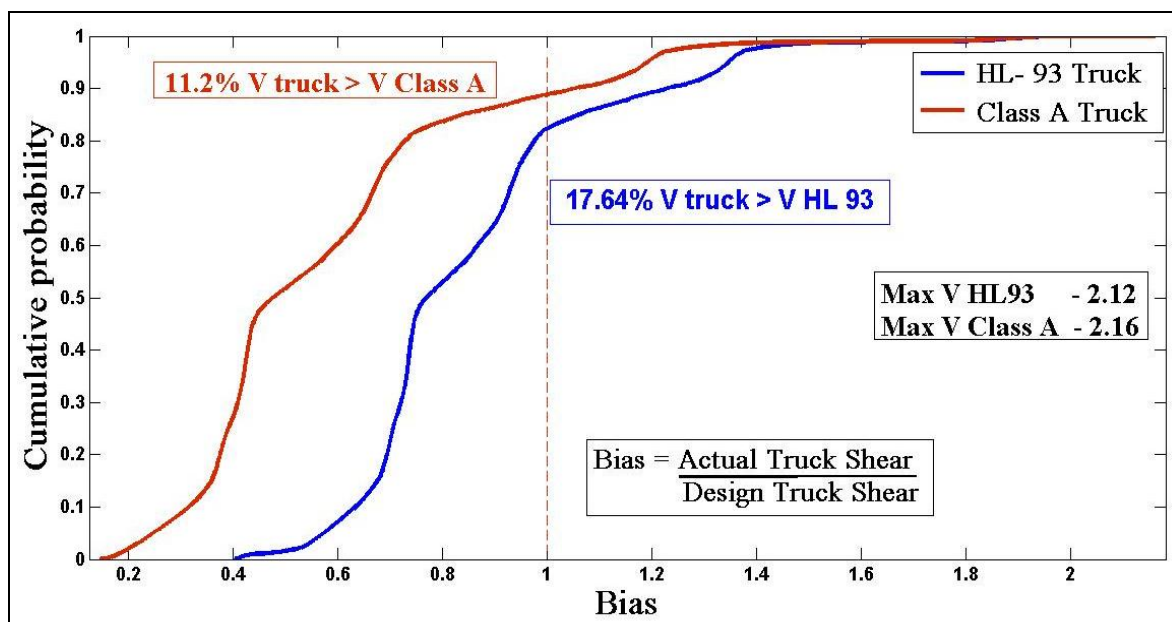


Figure 16: CDF of Simple Span Shear – MM

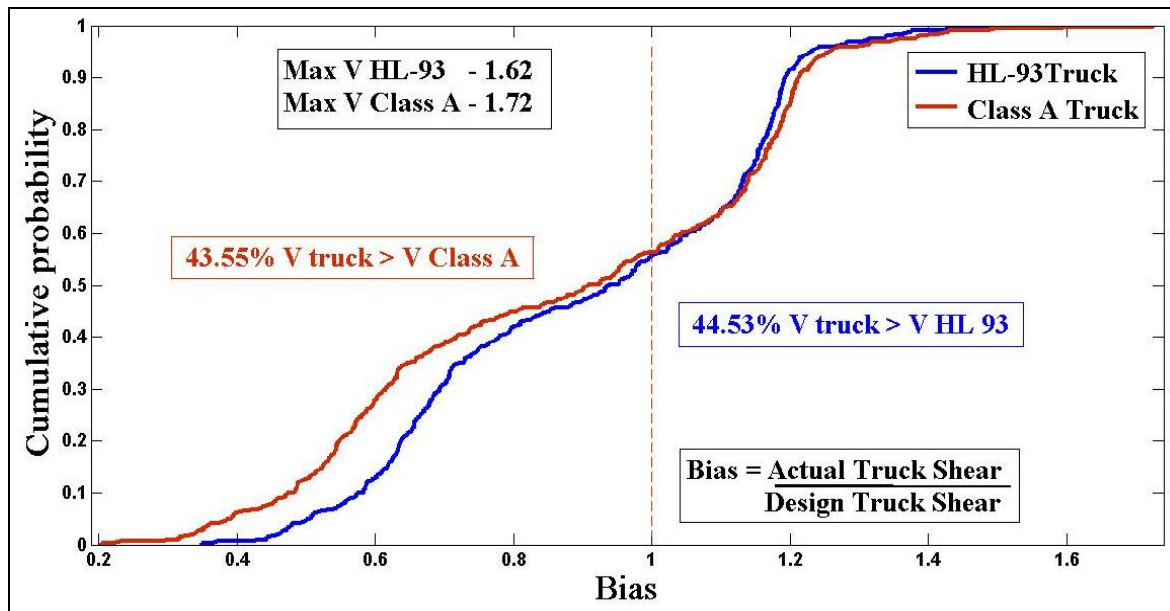


Figure 17: CDF of Simple Span Shear – Peshawar

## 5 Results and Discussion

Safety and reliability of bridge infrastructure is a major concern for state highway departments. Bridges that are structurally deficient must be replaced or repaired for the desired function with desired level of safety. Biggest threat to the bridges is the aging effects and the increase in traffic volume. Along with increase in the traffic volume, the traffic also influences the structure by increase in the GVW and axle weights. By accurately predicting the expected load during the entire life time of the bridge and the load carrying capacity, structural deficiency can be avoided. Predicting the accurate load on the bridge is very complicated specially the live load. WIM data can provide the unbiased truck traffic data and it can be a remarkable basis to develop the statistical model of live load. Following conclusions were reached based on the results of this study:

### 5.1 WIM Data

- 15.6 per cent and 9.9 per cent wrong entries were removed respectively from Sangjani weigh station and MM weigh station
- Wrong recording of these data was due to the limitation of WIM instrument installed by NHA
- Data recorded at Peshawar was limited to selected trucks which were loaded. All the trucks were not diverted to get the true data.

### 5.2 Live Load Effects –Sangjani

- Truck Load. Result shows that 39.18 percent and 2.17 percent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.
- Moment. 44.80 per cent and 11.66 per cent of actual trucks produce maximum moment higher than that produced by HL-93 and Class A design truck. While Maximum value of moment is 296.5 per cent and

270.4 per cent higher than the moment produced by HL-93 and Class A truck, respectively.

- Shear. 42.8 percent and 12.2 percent of actual trucks produce maximum shear higher than that produced by HL-93 and Class A design truck. Maximum value of shear is 299 percent and 270 percent higher than the moment produced by HL-93 and Class A truck respectively.

### 5.3 Live Load Effects –MM

- Truck Load. Result shows that 27.76 per cent and 8.8 per cent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.
- Moment. 17.93 per cent and 10.6 per cent of actual trucks produce maximum moment higher than that produced by HL-93 and Class A design truck. While Maximum value of moment is 207 per cent higher than the moment produced by HL-93 and Class A truck.
- Shear. 17.64 percent and 11.2 percent of actual trucks produce maximum shear higher than that produced by HL-93 and Class A design truck. Maximum value of shear is 212 percent and 216 percent higher than the moment produced by HL-93 and Class A truck respectively.

### 5.4 Live Load Effects –Peshawar

- Truck Load. Result shows that 42.58 per cent and 37.71 per cent of GVW of actual trucks are higher than GVW of HL-93 and Class A design trucks, respectively.
- Moment. 39.17 per cent and 38.69 per cent of actual trucks produce maximum moment higher than that produced by HL-93 and Class A design truck. While Maximum value of moment is 152 per cent and 160 per cent higher than the moment produced by HL-93 and Class A truck, respectively.

- c. Shear, 44.53 percent and 43.55 percent of actual trucks produce maximum shear higher than that produced by HL-93 and Class A design truck. Maximum value of shear is 162 percent and 172 percent higher than the moment produced by HL-93 and Class A truck respectively.

## 6 Conclusion

This study result indicates that bridges in Pakistan are subjected to extreme load effects under the influence of prevailing traffic trends than they were actually designed for. The results are concluded as:

- a. Actual truck traffic of Pakistan is significantly different in axle weights, axle configuration and GVW.
- b. Load effects caused by actual truck traffic are much higher than those caused by live load models of PHB Code and AASHTO Specification thus bridges may be significantly overstressed which may reduce the design life of a bridge.
- c. Existing live load model of PHB Code is not the true representation of actual truck traffic of Pakistan therefore Live load model needs to be revised and developed as per actual truck traffic in Pakistan.

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