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Extrapolation of Live Load Effects to 75 Years Return Period for Highway Bridges

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Abstract

Design of bridges is primarily governed by the live load models representing truck traffic. In Pakistan, bridges are designed as per live load models of Pakistan Code of Practice for Highway Bridges 1967 (called herein as "CPHB") and American Associations for State Highway and Transportation officials AASHTO LRFD Bridge Design Specifications (called herein as "AASHTO"). CPHB is based on 1961 American Association of State Highways and Transport Officials (AASHTO) Bridge Design Specifications.Further, National Highway Authority (NHA) has specified legal limits on the live loads to prevent overstressing of bridges. Live load models are usually developed from existing truck data. Load model for highway bridges are primarily based on truck load, dead load and dynamic load. Live load data required for bridge design includes the Gross vehicle weight (GVW), axle weight, axle spacing and truck configuration.Correct estimation of data plays a vital role in designing of the bridge for intended design period which is 75 years as per AASHTO LRFD code. Estimating the traffic data is nearly impossible for 75 years as data recording for such a long time is not possible.However a reasonable result can be achieved by projectingthe collected data to 75 years. Data which is to be projected is usually collected over a short period ranging from 3 months to one year.Various techniques are used for extrapolation to 75 years but this paper aims at describing and comparing the test results using non-parametric fit method as was used by (Kozikowski and Nowak, 2009), Convolution method (NCHRP 683, 2012)and CDF (Cumulative Distribution Function)projection method adopted by MDOT(Michigan Department of Transportation) for investigation of current design/truck load to calculate maximum 75 years load effect on the bridge (RC-1413, 2002).

Keywords: Highway Bridge, truck load, Live Load, Weigh in Motion, Non-parametric fit.

1 Introduction

Dead Load, live load (static and dynamic), environmental loads (temperature, earthquake, Wind) and miscellaneous loads (impact, braking, collision etc) forms the major load components of highway bridges. Dead load is a gravity load due to self-weight of bridge componentswhich can be easily estimated and remains nearly constant throughout the design life. Dynamic load and other miscellaneous loads can be estimated approximately for the design of bridges but their event of occurring is restricted to the particular area and environment. Moreover dynamic load like high intensity earthquake's occurrence is also estimated over a larger return period for extreme event.

Live load over bridges is primarily produced by the moving vehicles whose intensity and occurrence is highly variable in nature. Live load effects is influenced by a number of parameters like span, vehicle weight, number of axle, axle weight, axle spacing, position of vehicle, girder spacing etc. These parameters can be recorded using available technologies for a certain period but is highly site specific. To get the realistic data for 75 years (design life of a bridge) is nearly impossible due to involvement of data collection for the same period (75 years).To solve this problem, data is collected for a particular site for limited period (say one month, two months or even a year),which is then projected using statistical approach for finding the maximum load effects on the bridge for 75 years.In this paper only three methods (non-parametric fit method, Convolution or numerical integration method and CDF projection method) were used to project the load effects. Weigh in Motion (WIM)data was acquired from Sangjani weigh station, Mullan Mansoor weigh station and truck data recorded at Peshawar.

2 Data Base

Live load is divided into static and dynamic components and its sum presents the total live load on bridge structure. This study is concern mainly with the static portion of the load. 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 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. Simply supported pre-stressed Sample Bridge of 47 m span was selected for WIM data collected at Sangjani and Mullan Mansoor. While simply supported pre-stressed bridge of 12.8 meter span was selected for the truck data collected at Peshawar.

2.1 Sangjani Weigh Station

Data acquired from Sangjani weigh station was recorded in year 2012 for a duration of six months. Number of tucks recored during this period was 230743 trucks of different configuration. Table 1 shows the Summary of recorded data. ADTT at this station represents 1289 vehicles.

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2.2 Mullan Mansoor Weigh Station

104553 trucks of different configuration were recordedfor a period of three months at Mullan Mansoor weigh station located on national highway 5 (Islamabad – Peshawar section). Table 2 shows the Summary of recorded data.

2.3 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, 2012) in collaboration with Peshawar Development Authority (PDA). Data acquired at this site was limited to very few trucks i:e 411 trucks.**Table 3** shows the Summary of recorded data at Peshawar.

3 Maximum Load Effects

Three bridges were selected for calculating the maximum load effects. All these bridges are simply supported, pre-stressed concrete girder bridges. Maximum load effects were calculated using influence lines by running each actual recorded truck on the bridge. Load effects include maximum moment and maximum shear due to single truck. Details of bridges under study are as under:

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**	
Number of Trucks	101022	114606	9282	1787	4014	13	5	8	3	2	1	**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	

Table 2: Number of vehicles and maximum GVW in each category – Mansoor

Truck Configuration (Number of Axles)												Total
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Number of Trucks	47593	28907	16286	2270	9489	2	2	-	1	-	-	**104553**
Max GVW (tons)	42.76	67.14	69.92	83.87	108.30	90.29	95.70	-	101.80	-	-	

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

Truck Configuration (Number of Axles)												Total
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Number of Trucks	150	66	33	3	154	1	1	1	-	-	-	**411**
Max GVW (tons)	30.42	37	44.93	54.37	88.12	80.456	82.70	87.80	-	-	-	

1) **Muhammad Wala Bridge – Sangjani**
Muhammad Wala Bridge was constructed in 2010. This bridge consists of pre-stressed and simplysupported girders having a clear span of 47.2 m. Overall width of the bridge is 12.09 m and road waywidth is 12.05 m. It is a three lane bridge, having 180 mm deck thickness and 100 mm thick wearingsurface and consists of four pre-stressed concrete girders.

2) **Mansoor Bridge–Mullan Mansoor**
Mansoor Bridge is identical to Muhammad Wala Bridge with a clear span of 47.19 m. This bridgewas constructed in 2009. It consists of four pre-stressed girders having a span of 47.19 m and 3.03 mspacing between girders. Again it is a three lane bridge, having 180 mm deck thickness and 100 mm(average) thick wearing surface.

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

Similarly, maximum load effects were also calculated for HL-93 (AASHTO design truck) and Class Adesign truck described in 1967 Pakistan Code of Practice for HighwayBridges 1967. Normalized load effects were calculated by dividing the actual truck moment with the momentof HL-93 and Class A design truck.

4 Extrapolation of live load effects to 75 Years Return Period

As per AASHTO LRFD code, moment and shear effects obtained from actual recorded truck data needs to be extrapolated to 75 years using statistical techniques for predicting the maximum value the bridge has to encounter over its design life period. Different techniques were earlier used to extrapolate the value for data projection to 75 years by Nowak (1993, 1994, NCHRP 1999) and Kozikowski (2009) etc. In this paper three methods (non-parametric fit method, Convolution or numerical integration method and CDF projection method were used for projecting the load effects to 75 years as was done in previous researchers.

For calculating maximum mean live load effect in 75 years, extrapolation of a CDF plotted on probability plot is required. ADTTis used to find the standard normal variable 'z', a corresponding values on vertical axis for different return period. ADTT is also used to find the standard normal variable (z) on vertical axis of CDFs of moment and shear fordifferent return periods. ADTT for one day at Sangjani represents 1289 vehicle. Correspondingprobability is 1/1289=0.000775795 and its 'z' value is 3.16. Similarly the data for two weeks represents18,275 vehicles. Corresponding probability is 0.0000547 and 'z' value is equal to 3.87. In the same waysix months of truck traffic probability is equal to 4.33383E-06 and standard normal variable is equal to4.45. Similar calculations for standard normal variable were done for other two bridges. Fordetermination of probability and standard normal inverse for 75 year return period we assumed that noabrupt increase in the traffic volume occurs during the same period using available ADTT for six monthsas was done by earlier researchers (Kozikowski, 2009). Table 4 summarizes the different values ofnumber of trucks 'N', probability '1/N' and standard normal inverse 'z' for 75 years return period for allthe three bridges. Number of trucks for 75 years is calculated by multiplying 75 with number oftrucks in one year. 'N' for Sangjani for 75 years is:

N_{75} = 75 x 461486 = 34611450

4.1 Non-parametric Method

Extension of upper tail was performed using non-parametric approach. Method was applied for both shear and moment. CDF and non-parametric fit for moment ratio with AASHTO design vehicle (HL-93) and CPHB design vehicle (class A only)for Sangjani bridge at Sangjani are shown in Figure 1 and for shear ratio in Figure **2** respectively.Trend of the tail fit depends on the distance of last point of the data set with the others. Extreme value theory is used to determine the distribution of 75 years live load. All the mean maximum values for 75 years return period and statistical parameters for both moment and shear is summarized in Table 5.

For Sangjani bridge, mean maximum value of moment ratio corresponding to 75 years return period using non-parametric fit having a 'z' value of 5.43 (refer Table 4) is 3.15 and the COV is 0.22 for HL-93 truck as shown in Figure 1. Mean value of maximum moments for class A truck is equal to 3.002 and the COV (coefficient of variation) is 0.39 as shown inFigure 2. In case of extrapolated values of shear for HL-93 truck, the mean maximum shear is equal to 3.19 (refer figure 3)and the COV is 0.23whereas, for class A truck, the mean maximum shear is 2.99 (refer figure 4) and COV is 0.39.Similarly, the mean maximum moment/shear for other two bridges is tabulated in Table 5.

3.1.2 Convolution Method

Convolution method also called numerical integration was used in NCHRP (National Cooperative Highway Research Program) 683 (NCHRP 683, 2012) for calculation of maximum load effect. This method is used to obtain the maximum expected value for the required return period (75 years in case of bridge design) by using the numerical integrations of the collected WIM data. Procedure as explained in NCHRP-683 was applied for normalized moment and shear using the design vehicles of AASHTO and CPHB. Using MATLAB, normal or linear fit was applied for extrapolating and estimating the mean maximum load effect. Figures 5 to 8 provides the information about the normal fit load effects and projected values of moments and shear for Sangjani Bridge.

Table 4**:** Number of trucks with corresponding probability and Time Period

Time Period 75 years	**Number of Trucks (N)**	**Probability (1/N)**	**Standard Normal Inverse 'z'**
Sangjani	34611450	2.88922E-08	5.43
Mansoor	28478400	3.51143E-08	5.39
Peshawar	101606400	9.8419E-09	5.61

Following techniques were used to obtain Mean Maximum Moment and Shear for 75 years return period:

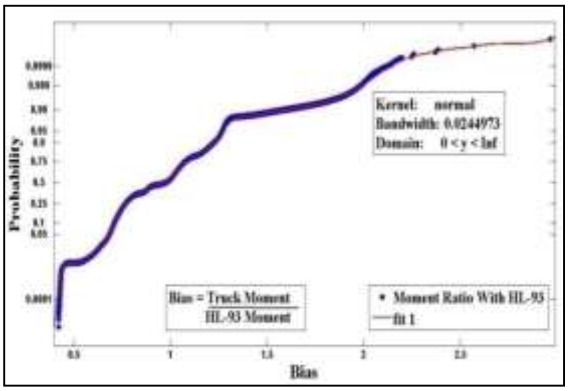

Figure - 1a: Nonparametric fit– $M_{HL\text{-}93}$ – Sangjani

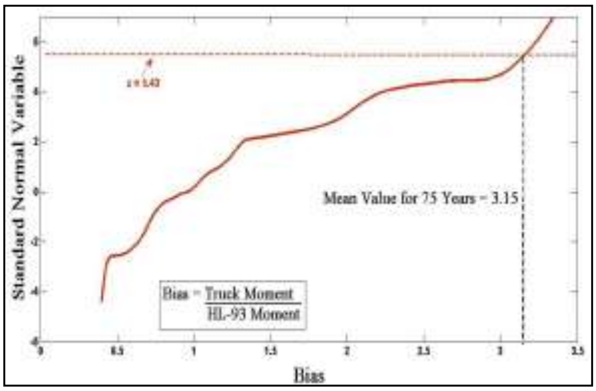

Figure- 1b: Extrapolation of $M_{HL\text{-}93}$ by Nonparametric fit - Sangjani

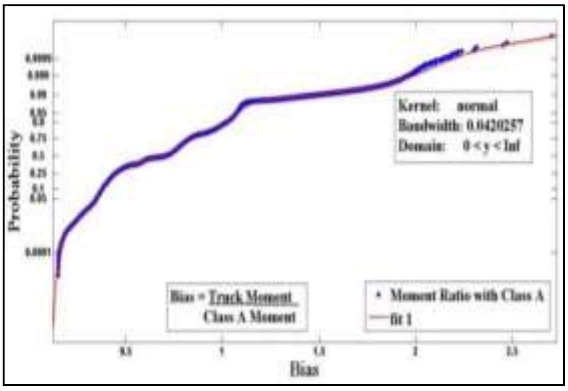

Figure -2a: Nonparametric fit – $M_{Class\ A}$- Sangjani

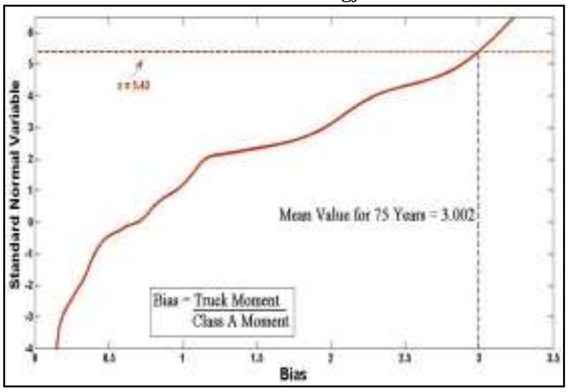

Figure -2b: Extrapolation of $M_{Class\ A}$ by Nonparametric fit - Sangjan

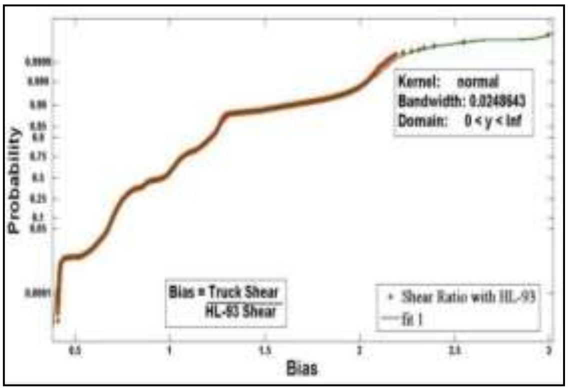

Figure -3a: Nonparametric fit – $V_{HL\text{-}93}$- Sangjani

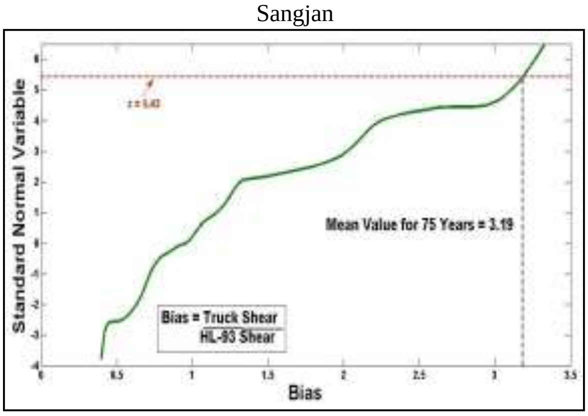

Figure -3b: Extrapolation of $V_{HL\text{-}93}$ by Nonparametric fit – Sangjani

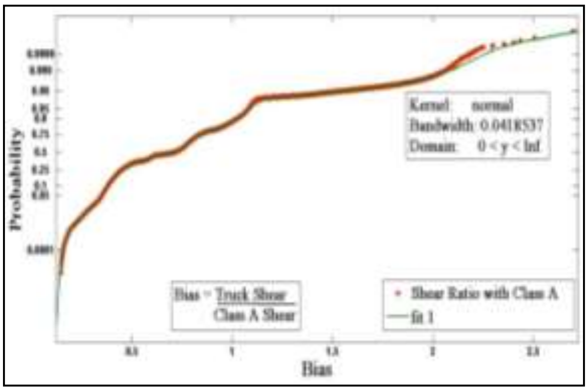

Figure-4a: Nonparametric fit – $V_{Class\ A}$-Sangjani

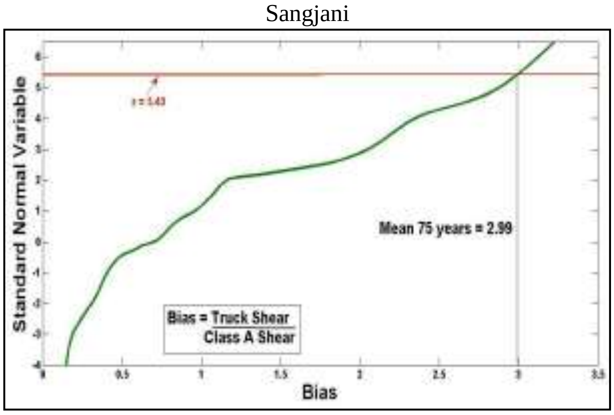

Figure-4b: Extrapolation of $V_{Class\ A}$ by Nonparametric fit – Sangjani

Table 5: Mean Maximum Moment(M) and Shear(V) for 75 years by Nonparametric fit

Stations	Moment/Shear	Recorded Data	Extrapolated value to 75 Years	COV
Sangjani – Bridge	M_{Truck}/M_{HL-93}	2.96	3.15	0.22
	$M_{Truck}/ M_{Class\ A}$	2.70	3.002	0.39
	V_{Truck}/V_{HL-93}	2.99	3.19	0.23
	$V_{Truck}/ V_{Class\ A}$	2.70	2.99	0.39
Mansoor - Bridge	M_{Truck}/M_{HL-93}	2.07	2.21	0.27
	$M_{Tuck}/M_{Class\ A}$	2.07	2.39	0.48
	V_{Truck}/V_{HL-93}	2.12	2.27	0.28
	$V_{Truck}/V_{Class\ A}$	2.16	2.49	0.49
Peshawar - Bridge	M_{Truck}/ M_{HL-93}	1.52	2.16	0.26
	$M_{Truck}/M_{Class\ A}$	1.60	2.42	0.31
	V_{Truck}/ V_{HL-93}	1.62	2.65	0.29
	$V_{Truck}/V_{Class\ A}$	1.72	3.13	0.36

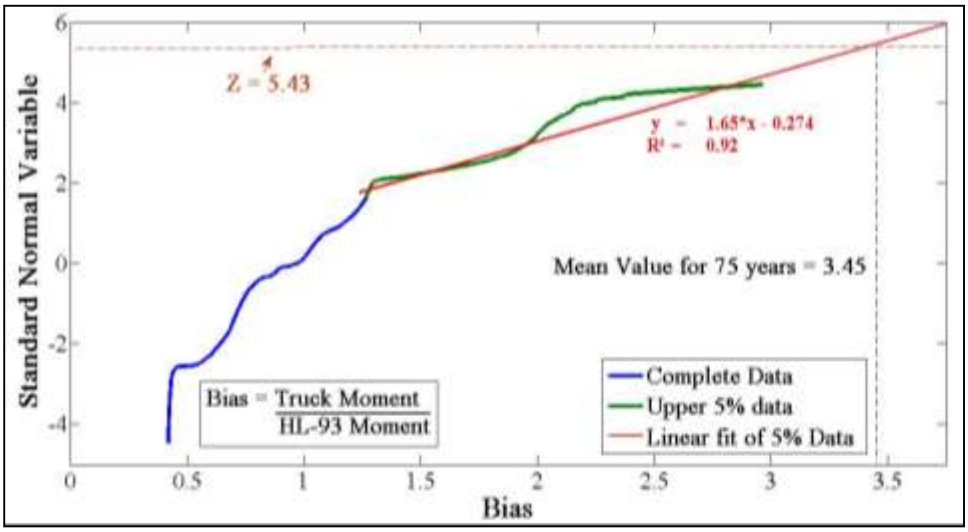

Figure 5: Extrapolation by Convolution Method for M_{HL-93}– Sangjani

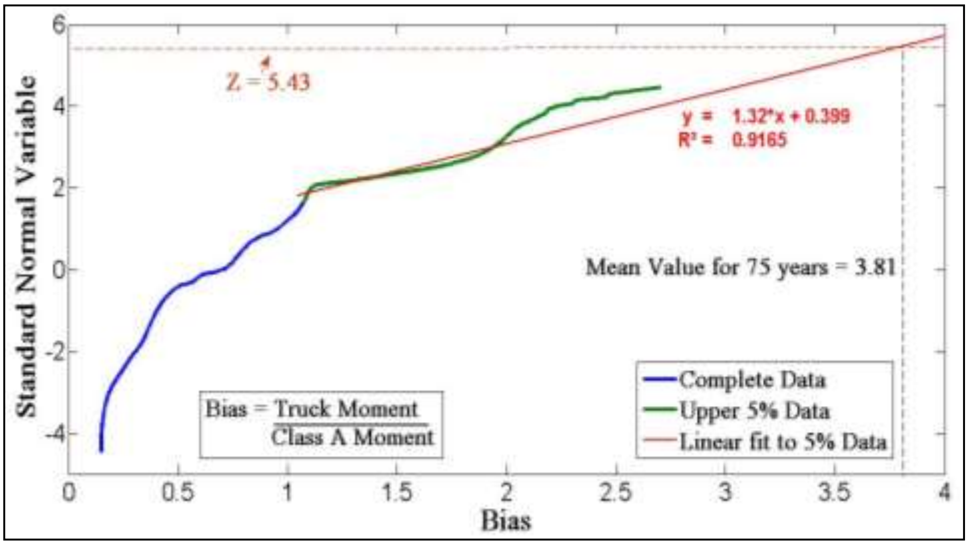

Figure 6: Extrapolation by Convolution Method for $M_{Class\ A}$ – Sangjani

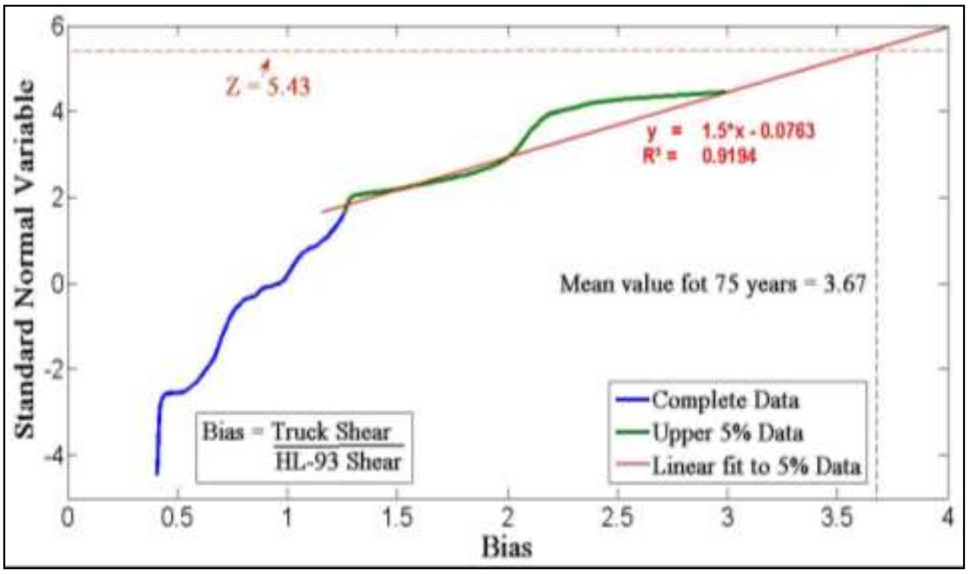

Figure 7: Extrapolation by Convolution Method for V_{HL-93}– Sangjani

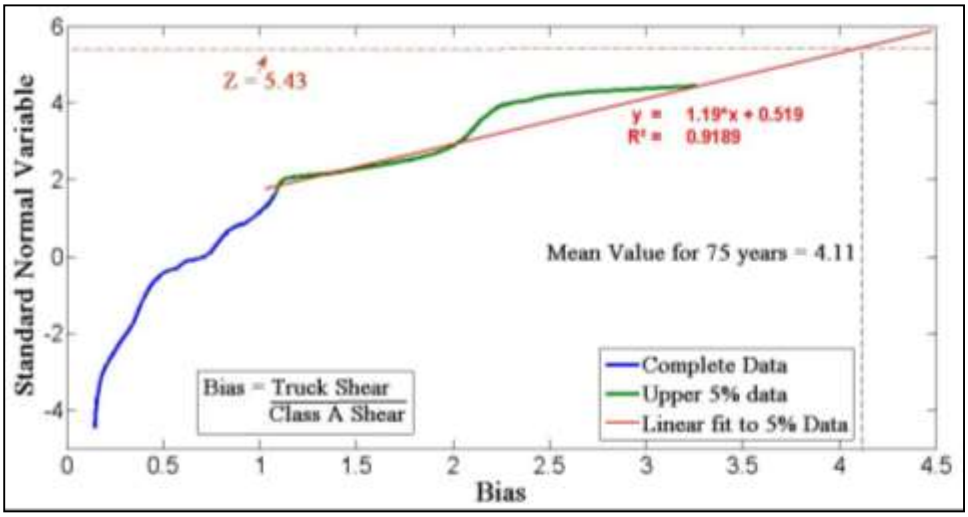

Figure 8**:** Extrapolation by Convolution Method for $M_{Class\ A}$ – Sangjani

Coefficient of determination 'R^2' found from regression analysis is around 0.92 which shows that it is not a good fit in all the cases.Summary of the extrapolated values for 75 years using convolution method is tabulated in Table 6 for all the three bridges.

3.1.3 CDF Projection Method

Research report RC-1413 conducted by John W. van de Lindt, Gongkang Fu, Reynaldo M. Pablo Jr, and Yingmin Zhou for Michigun Department of Transportation in 2002 for investigation of current design load, was followed to reach to maximum 75 years load effects on the bridge. ADTTacquired for all the three sites were used to projects the live load effects using AASHTO design vehicle and CPHB class 'A' design vehicle. EDD (equivalent days of data) for each data set was calculated from ADTT using the formula:-

EDD = m / ADTT (1)

where, 'm' is the total length of the data set. RDD (required days of data) was calculated next as the number of days in one year multiplied by the number of years to which the data is to be projected i:e

RDD = 75 years x 365 days per year

= 27375 days

From the empirical cumulative distribution function, ith ranked load effect can be expressed as

Fi = i / m (2)

'n' value is required to be calculated so that CDF can be projected from EDD in each data set. n value is calculated as

n = RDD / EDD (3)

The projected CDF (F_{75}) can be calculated as $F_{75} = F_i^n$ (4)

An assumption is made here that each time period of duration EDD within the RDD time period is statistically independent of each other. Mean value of the projected dataset 'F_{75}' can be read directly as the point on abscissa corresponding to 0.5 on the CDF. Standard deviation of the projected dataset can be determined by using the best fit numerical technique. Therefore COV can be easily calculated by dividing the standard deviation with mean value of the projected data set. Results of the normalised moments and shear for Sangjani are shown in Table 7. 90th percentile value was selected here to find the projected value. 90th percentile means only 10 % values are above it. Empirical CDF and projected CDF for moment and shear ratios with HL-93 design truck and Class A design truck at Sangjani is shown in Figure 9 to 12.

Projected mean maximum values of normalised moments and shear for all the three sites with the methods explained is tabulated in theTable 7.

4 Comparison of Results

Maximum mean 75 years extrapolated values for Sangjani, Mullan Mansoor and Peshawarusing all the three methods are presented in Table 8 below.

Table 6: Mean Maximum Moment(M) and Shear(V) for 75 years by Convolution Method

Stations	Moment/Shear	Recorded Data	Extrapolated value to 75 Years	COV	R^2
Sangjani – Bridge	$M_{Truck}/M_{HL\text{-}93}$	2.96	3.45	0.22	0.92
	$M_{Truck}/M_{Class\ A}$	2.70	3.81	0.39	
	$V_{Truck}/V_{HL\text{-}93}$	2.99	3.67	0.23	
	$V_{Truck}/V_{Class\ A}$	2.70	4.11	0.39	
Mansoor Bridge	$M_{Truck}/M_{HL\text{-}93}$	2.07	3.32	0.036	0.87
	$M_{Tuck}/M_{Class\ A}$	2.07	3.66	0.041	
	$V_{Truck}/V_{HL\text{-}93}$	2.12	3.43	0.036	
	$V_{Truck}/V_{Class\ A}$	2.16	3.83	0.041	
Peshawar Bridge	$M_{Truck}/M_{HL\text{-}93}$	1.52	2.22	0.025	0.86
	$M_{Truck}/M_{Class\ A}$	1.60	2.42	0.027	
	$V_{Truck}/V_{HL\text{-}93}$	1.62	2.44	0.026	0.97
	$V_{Truck}/V_{Class\ A}$	1.72	2.70	0.028	

Table 7: Mean Maximum Moment (M) and Shear (V) for 75 years by CDF Projection Method

Stations	Moment/Shear	Recorded Data (90th Percentile)	Extrapolated value to 75 Years (90th Percentile)	COV
Sangjani Bridge	$M_{Truck}/M_{HL\text{-}93}$	1.22	2.0	0.22
	$M_{Truck}/M_{Class\ A}$	1.02	1.99	0.39
	$V_{Truck}/V_{HL\text{-}93}$	1.21	2.06	0.23
	$V_{Truck}/V_{Class\ A}$	1.03	2.08	0.39
Mansoor Bridge	$M_{Truck}/M_{HL\text{-}93}$	1.22	1.90	0.27
	$M_{Tuck}/M_{Class\ A}$	1.03	1.87	0.48
	$V_{Truck}/V_{HL\text{-}93}$	1.23	1.98	0.28
	$V_{Truck}/V_{Class\ A}$	1.05	1.96	0.49
Peshawar Bridge	$M_{Truck}/M_{HL\text{-}93}$	Applying this method for projection to 75 years return period on small dataset of Peshawar having only 411 trucks, resulted in zero values		
	$M_{Truck}/M_{Class\ A}$			
	$V_{Truck}/V_{HL\text{-}93}$			
	$V_{Truck}/V_{Class\ A}$			

Table 8: Comparison ofMean Maximum Moment (M) and Shear (V) for 75 years using Different methods

Stations	Moment/Shear	Recorded Data	Nonparametric Fit Method	Convolution Method	CDF Projection Method
Sangjani Bridge	$M_{Truck}/M_{HL\text{-}93}$	2.96	3.15	3.45	2.0
	$M_{Truck}/M_{Class\ A}$	2.70	3.002	3.81	1.99
	$V_{Truck}/V_{HL\text{-}93}$	2.99	3.19	3.67	2.06
	$V_{Truck}/V_{Class\ A}$	2.70	2.99	4.11	2.08
Mansoor Bridge	$M_{Truck}/M_{HL\text{-}93}$	2.07	2.21	3.32	1.90
	$M_{Tuck}/M_{Class\ A}$	2.07	2.39	3.66	1.87
	$V_{Truck}/V_{HL\text{-}93}$	2.12	2.27	3.43	1.98
	$V_{Truck}/V_{Class\ A}$	2.16	2.49	3.83	1.96
Peshawar Bridge	$M_{Truck}/M_{HL\text{-}93}$	1.52	2.16	2.22	No results produced
	$M_{Truck}/M_{Class\ A}$	1.60	2.42	2.42	
	$V_{Truck}/V_{HL\text{-}93}$	1.62	2.65	2.44	
	$V_{Truck}/V_{Class\ A}$	1.72	2.16	2.22	

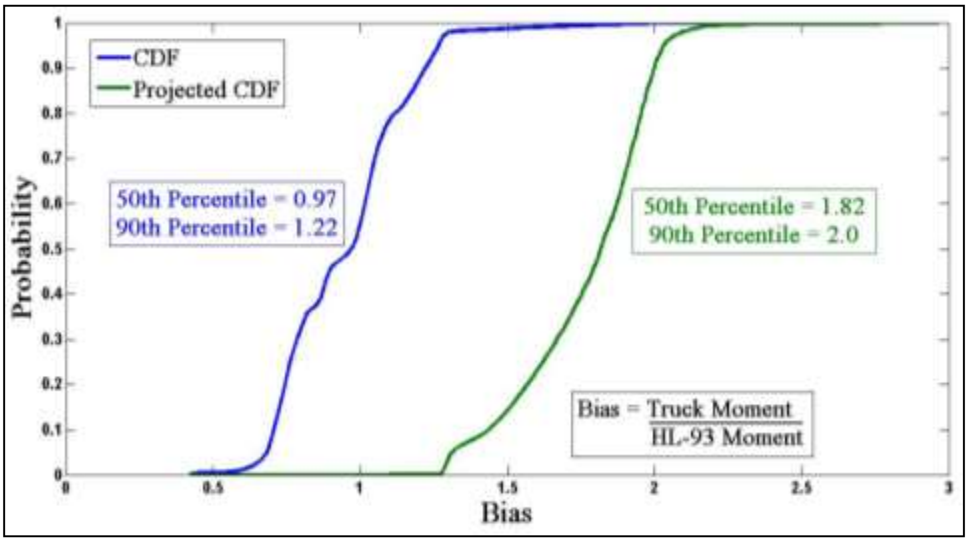

Figure – 9: 90th percentile of projected M_{HL-93} to 75 years – Sangjani

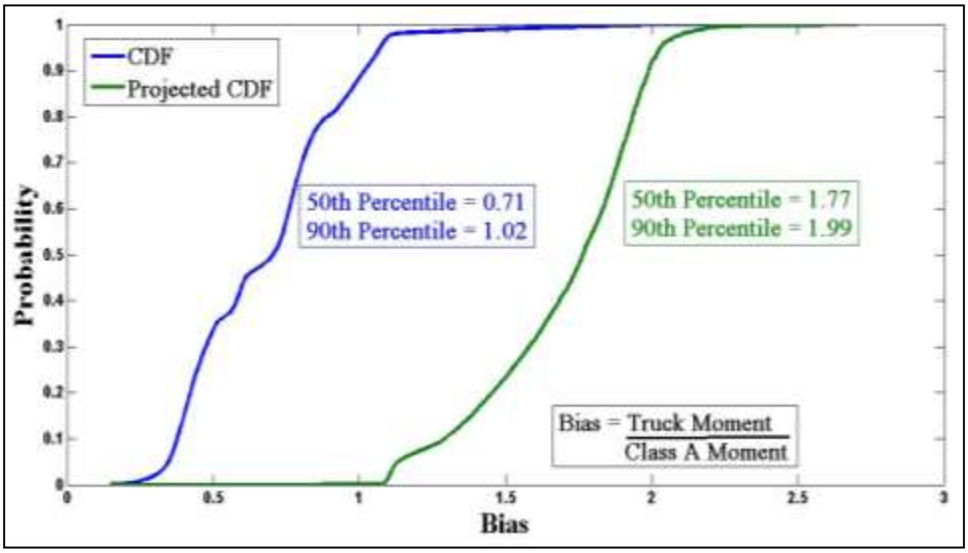

Figure – 10: 90th percentile of projected M_{ClassA} to 75 years – Sangjani

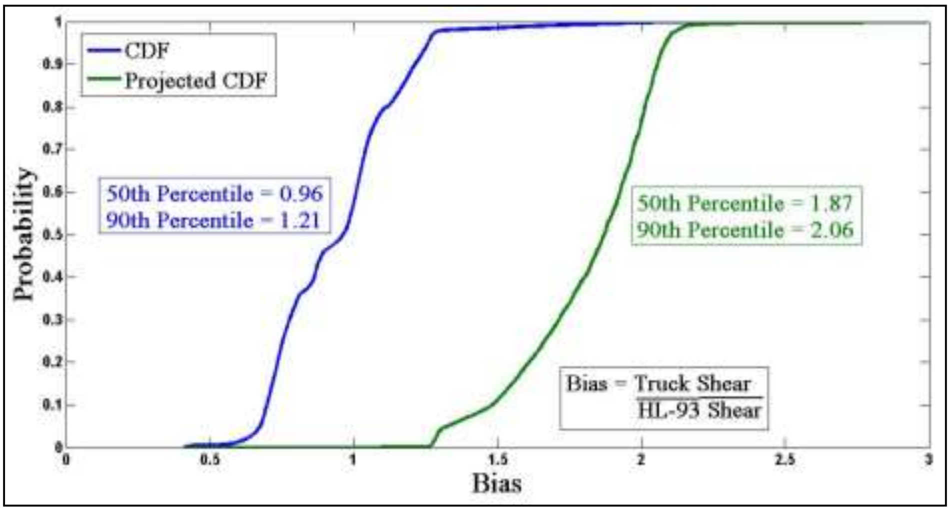

Figure – 11: 90th percentile of projected V_{HL-93} to 75 years – Sangjani

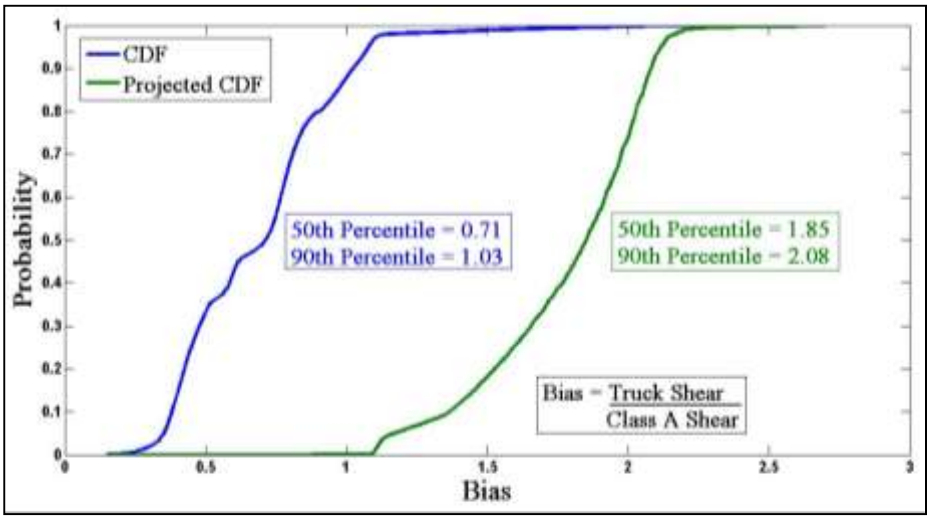

Figure – 12: 90th percentile of projected V_{ClassA} to 75 years – Sangjani

5 Conclusion

Non-parametric method was used for projecting the load effect as it did not involve any known type of distribution. This method is developed on the basis of given data without involving any parameters like skew, mean, variance etc. The advantage of this method over the parametric one is that it instead of following any defined shapes it adjusts itself to the probability density function to any distribution of data (Faucher *et al.* 2001). The results achieved by using this method are closer to the realistic value as compared to the other methods. The convolution method adopted in NCHRP 683 uses the linear fit to extrapolate the maximum value. Accuracy of results also depends on the coefficient of determination (R^2) value which shows how best the data has been fit. Normally anything above 0.95 is considered to be a good fit in engineering practices. R^2 values for all the data sets are below 0.95. Hence the resulting extrapolated values using convolution method were not used for reliability analysis. CDF Projection Method resulted in zero values for small data set of Peshawar. Moreover the values obtained for Sangjani and Mullan Mansoor were lesser than the values calculated from other methods. Extrapolated values using this method was not used for reliability analysis.

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