CRITICAL LOADING FOR DESIGN OF CONCRETE GIRDER FOR BRIDGES: AASHTO-LRFD VERSUS WEST PAKISTAN CODE OF PRACTICE FOR HIGHWAY BRIDGES

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ABSTRACT: *In this paper, the results of a research study have been presented which was carried out to compare two design specifications for the design of highway bridge girder: AASHTO LRFD 2010 and West Pakistan Highway Code of Practice 1967. Type of girder, span length and number of lanes were taken as parameters of the research study. Four different span lengths were investigated: 20m, 25m, 30m, and 35m. The bridge with one lane, two lanes, three lanes and four lanes loaded was investigated for I-girder and inverted-T girder. For analysis of bridge subjected to above mentioned loadings, bridge module in SAP2000 version 14.2.2 was employed in this study. In first part of the paper, major difference in the above mentioned specifications is highlighted and then in the second part of the paper, it has been explored that for any given condition in terms of span length, number of loaded lanes and types of girder, which specification gives critical service and ultimate moment values.*

Keywords: Concrete girder: highway bridge; WPCPHB; AASHTO-LRFD; critical moment;

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1. INTRODUCTION

Bridges have been the most important component of the transportation system since ancient times. Innovative bridges with long spans and aesthetic elevations having adequate structural strength and rigidity are always required for the transportation system of each country on the globe.

In Pakistan, first vehicular live load model was introduced in West Pakistan Highway Code of Practice (WPCPHB) 1967 **[4]**. This model was based on 1935 load model introduced by the British rulers of that era. Since then to date, enormous changes in the loading trucks and overloading have been observed, whereas live load model has never been updated. Considering the example of USA where HS20-44 was the live load model in American Association of State Highway and Transportation Officials (AASHTO) introduced in 1944 and 1993, realizing the problem of heavy vehicular loading, this model was upgraded to US live load model as “HL-93”.Nowadays, in Pakistan highway bridge girders are being designed by the structural engineers considering live loadings specified in WPCPHB**[4]** and AASHTO-LRFD **[6]** bridge design specification. In order to save time which is required for analysis and design of highway bridge girders following two different specifications, there is a need to study in detail which loading is more critical in different conditions in terms of different number of lanes loaded, different span lengths and different types of girders.

2. Research Significance

Bridges must be able to resist a wide variety of live loads. For the bridge engineer to consider every possible live load (truck) configuration which may act on a bridge during analysis and design procedure is excessively time consuming and unfeasible. Finding of this study will provide necessary information to the engineers that for any given condition in terms of number of lanes loaded, span length and type of girder, which loading (WPCPHB or AASHTO-LRFD) is critical, so that only analysis is carried out considering only critical live loading.

3. Design Specifications

Currently in Pakistan, two types of design specifications are being followed. Brief detail of both specifications is given below:

3.1 AASHTO-LRFD 2010

American Association of State Highway and Transportation Officials (AASHTO) standard specification **[1]** has been the main bridge design specification in the United States since the 1940s. AASHTO-LRFD specification **[3]** is based on the latest developments in structural analysis and materials to assure desired serviceability and ultimate behavior, safety, aesthetics, and economy. This new specification resulted in design procedures significantly different compared to the earlier methods. The new LRFD specification is based on a probability-based approach in which load and resistance factors are based on a specific level of structural failure. The changes in the new LRFD design methods are significant and challenge the bridge engineers working with standard specification and other bridge specifications for so many years.

The design vehicular load currently used by AASHTO-LRFD **[5]** is designated as HL-93, in which “HL” is an abbreviation for highway loading and “93” represents the year of 1993 in which the loading was accepted by AASHTO. The HL-93 live load is based on a study carried out by the Transportation Research Board (TRB) in 1990, and it consists of three different load types; Design truck, Design tandem and Design lane load.

- **Design truck** as shown in Fig.1 consists of two axles of 145 kN and one front axle of 35 kN which is 4.3 m apart from middle axle. The transverse distance between wheels of axle is 1.8 m.
- **Design tandem** as shown in Fig.2 consists of two axles of 110 kN which are 1.2 m apart and the transverse spacing of wheels of axle is 1.8 m.
- **Design lane load** is 9.3 kN/m and assumed to occupy width of 3m transversely.

As per AASHTO LRFD design specifications **[5]**, critical live load effect will take maximum out of the following two cases:

1. Design Truck + Design Lane
2. Design Tandem + Design Lane

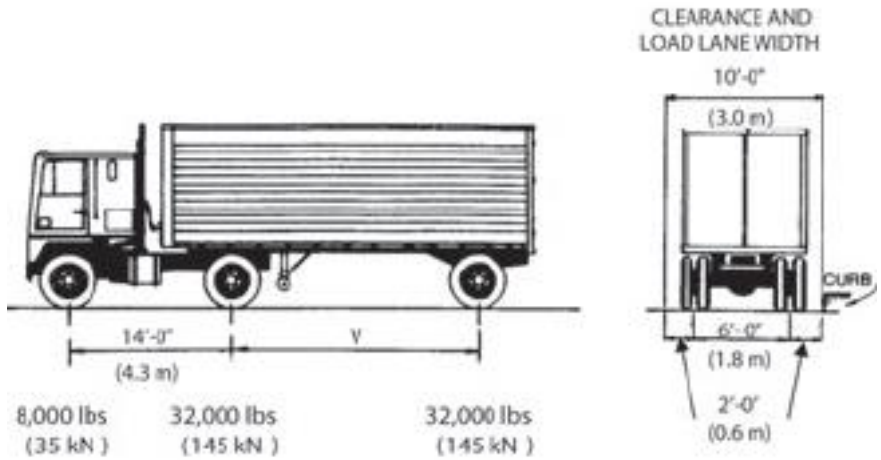


Fig 1: Design truck in HL-93 (AASHTO-LRFD) Loading

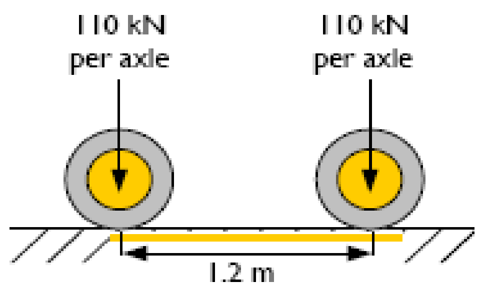


Fig 2 Design tandem in HL-93 (AASHTO-LRFD) Loading

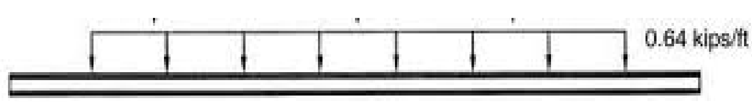
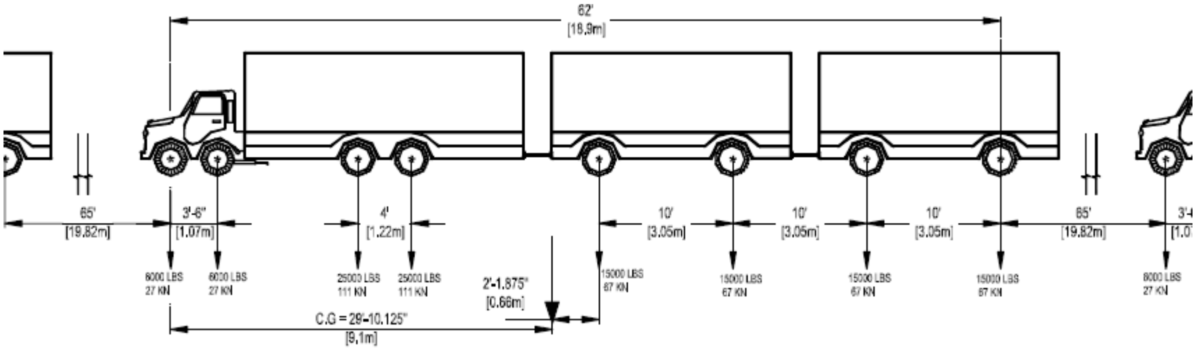


Fig 3 Design lane load in HL-93 (AASHTO-LRFD) Loading

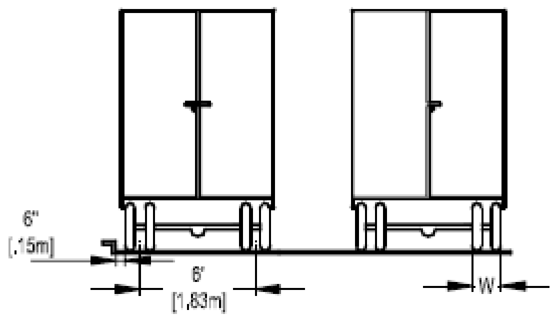
2.2 West Pakistan Code of Practice Highway Bridges (WPCPHB) 1967

The purpose of WPCPHB **[4]** was to establish minimum standards and uniform procedures and practices for the design of the usual types of highway structures in province of West Pakistan. Following different types of vehicular live loads are considered in this code:

- **Class "A"** loading has truck and trailer as shown in Fig. 4. The total axle load (including truck and trailer) is 55.35 tons.
- **Class "B"** loading which is identical to class A loading with the exception of total axle loads which is 60% of class "A" loading.
- Military loading named as **Class "AA"** which is a tracked vehicle of 70 tons as shown in Fig.5.



a) Longitudinal view



b) Cross sectional view

Fig 4: Class A Truck Loading

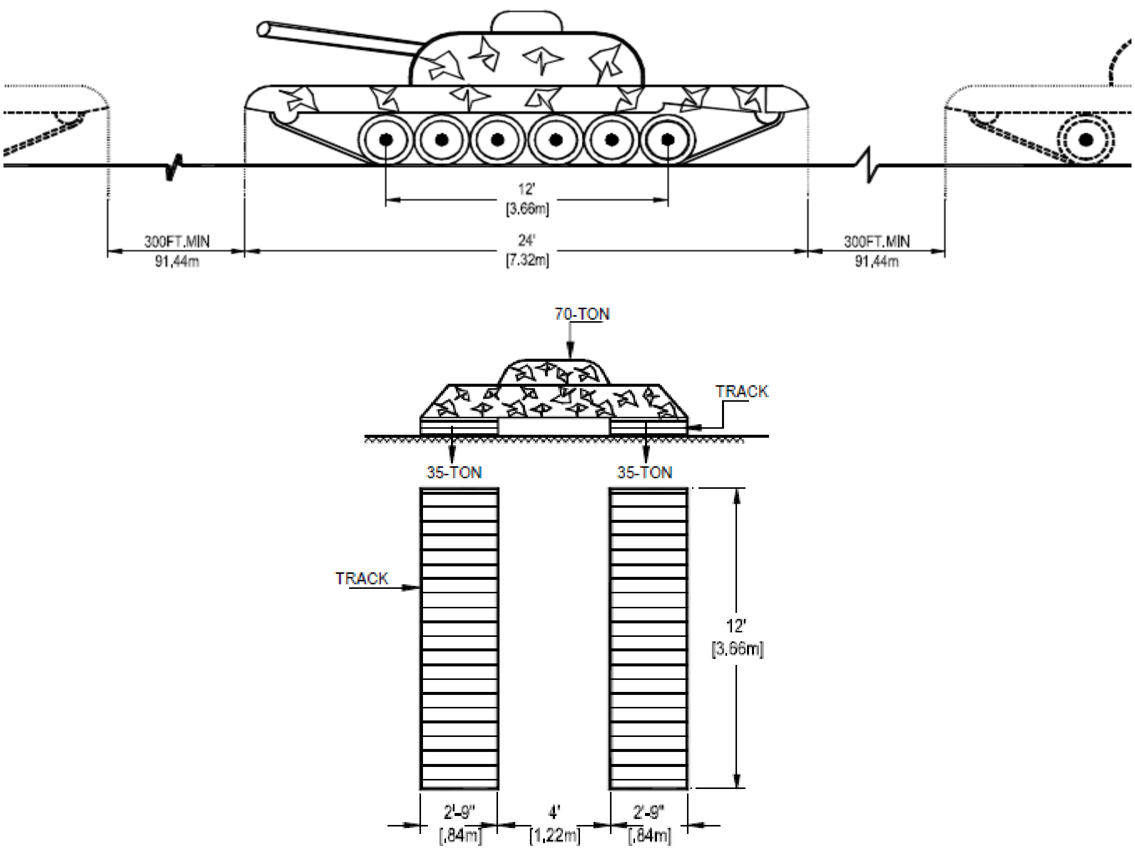


Fig 5: Class A A military tank loading

3. METHODOLOGY

Bridges must be able to resist a wide variety of expected live loads (trucks). A notional vehicular load is a theoretical or imaginary load that does not actually exist, but that conservatively represents the load affects of vehicles that may legally act on the bridge. The design vehicular loads currently used by WPCPHB and AASHTO are notional vehicular loads. When designing a bridge for live load, the bridge engineer must determine the number of design lanes acting on the bridge **[5].** The number of design lanes is directly related to the roadway width. A design lane generally has a width of 12 feet (3.65m). The number of design lanes is simply computed as the roadway width in meter divided by the 3.65 m design lane width, rounded to the nearest integer.

Depending upon the number of loaded lanes, it will be interesting to know that which specification will give more critical results because with the change of number of design lanes, multiple presence factors/reduction factors and live load distribution is different in different specification.

In order to minimize the working time required to analyze and design bridge girder for different loadings, there is a need to study in detail to find out which loading produces critical service and ultimate bending moment due live plus dead loads for any particular situation in terms of different number of loaded lanes, different span lengths and different types of girders.

The study has been divided into the following stages:

- Selection of width of bridge considering required number of loaded lanes
- Selection of different spans that are normally considered in Pakistan
- Selection of different types of girders which are commonly used in Pakistan
- Analysis of bridge super-structure subjected to Loadings as per AASHTO-LRFD and WPCPHB.

For analysis of super-structure of bridges, SAP2000 **[7]** version 14.2.2 has been used in this study to will be used which is latest and one of the most powerful versions of structural analysis software based on finite element method. Extruded views of three different types of girders along with deck slab in SAP2000 are shown in Fig.6.

5. Major Difference between AASHTO & WPCPHB

In AASHTO-LRFD **[6],** for truck and tandem a constant value of impact factor is considered which is independent of span length and is equal to 33% while in WPCPHB, for truck loading the impact factor is calculated using the relation given below in eq.1. For tank loading in WPCPHB, impact of 10% is taken for 30ft to 150ft span and for span greater than 150ft, it is 8.8%.

$$I = \frac{15}{L+20} \quad \text{(Maximum30\%)} \qquad \text{Eq.(1)}$$

Where *I* is impact factor and L is span in feet.

Multiple Presence Factor (MPF) is considered in AASHTO-LRFD which depends upon the number of lane loaded: for one lane loaded the value of MPF is 1.2, for two lanes loaded, its value is 1.0, for three lanes loaded, its value is 0.85 and for number of lanes loaded equal or greater than four, its value is 0.65. In WPCPHB, a Reduction Factor (RF) in load intensity is used which depends upon the number of truck passes on the bride. For one and two trucks, there is no reduction in load intensity, for three trucks, the value of RF is 0.90 and for four or more trucks, its value is 0.75.

Load combinations to calculate ultimate load values in AASHTO-LRFD and WPCPHB are given in equations 2 and 3, respectively. It can be noticed that dead load due to wearing surface is kept separate from other dead loads in AASHTO LRFD. Moreover, overload factors for dead and live loads are different in these two specifications.

$$U_{WPCPHB} = 1.5D + 2.5L \text{ ....Eq.(2)}$$

$$U_{AASHTO-LRFD} = 1.25D + 1.5DW + 1.75L \text{ ....Eq.(3)}$$

Where U is ultimate factored load, D is dead load, DW is dead load due to wearing surface and L is live load.

6. Configuration of Super-Structure of Bridges

For different number of loaded lanes and different types of girders, data related to deck width, number of girders, center to center spacing of girders and overhang portion of deck slab are given in Table 1. In Table 1, in case of I-girder usual spacing b/w girders varies from 1.5to 3m**[8].** and in case of an inverted T-girders it is taken 1m as per MoT/C&CA **[9].**

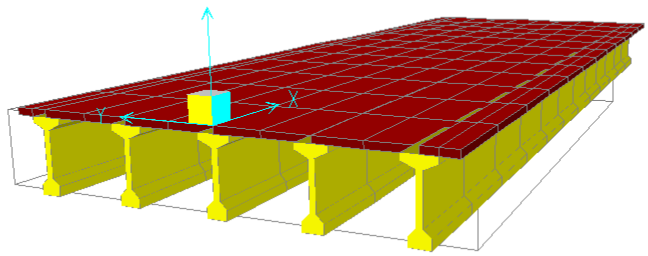
The overhang portion of deck slab in each case is taken as 0.45 times the beam spacing or 1.3 times the depth of girder**[10].**

7. Dimensions of Girders

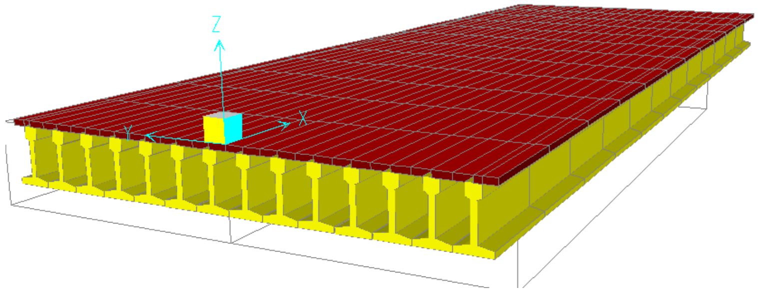
Typical shapes of the I-Girder and inverted T-girder are shown in Fig.7 and Fig.8, respectively. Dimensions of these two girders for different number of lane loaded and spans are given in Table 2 and Table 3, respectively.

8. RESULTS & DISCUSSIONS

In this section of paper for each span length (20m, 25m, 30m, & 35m), service and ultimate moments due to AASHTO and WPCPHB loadings is graphically represented and discussed for 1, 2, 3 and 4 lanes loaded bridge.



a) I-Girder along with decks slab



b) Inverted T-Girder along with decks slab

Fig 6: Extruded views of different girders in SAP2000

Table 1: Configuration of Super-Structure

		I-GIRDER			**INVERTED-T GIRDER**		
No of lanes	Deck width (m)	No of girders	c/c spacing (m)	Overhang (m)	No of girders	c/c spacing (m)	Overhang (m)
1	5.45	2	3	1.225	5	1	0.725
2	10.5	4	2.8	1.05	10	1	0.75
3	14.15	5	3	1.075	14	1	0.575
4	17.8	7	2.7	0.8	17	1	0.9

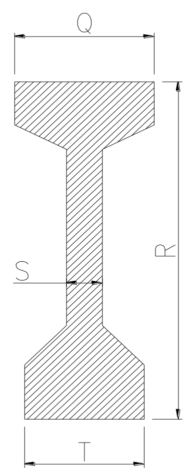


Fig7: Typical I-Girder

Table 2: Dimensions of I-girder

Dimensions (m)	SPAN			
	20 m	**25 m**	**30 m**	**35 m**
Q	0.7	0.7	0.7	1.0
R	1.8	2.0	2.0	2.4
S	0.18	0.18	0.18	0.18
T	0.6	0.6	0.6	0.65

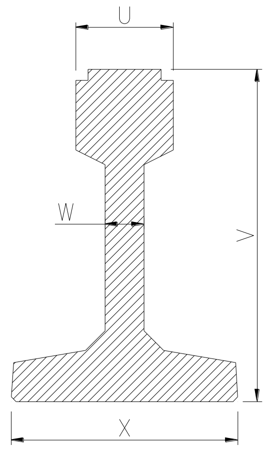


Fig 8: Typical Inverted T Girder

Table 3: Dimensions of Inverted T-girder

Dimensions (m)	SPAN			
	20 m	**25 m**	**30 m**	**35 m**
U	0.4	0.4	0.4	0.4
V	0.88	1.12	1.36	1.6
W	0.16	0.16	0.16	0.16
X	0.93	0.93	0.93	0.93

8.1 SPAN 20M

Combined effect of service live plus dead loads is considered for moment calculation and the values for I girder and inverted T-girder bridges are graphically presented in Fig.9 and Fig.10, respectively for different number of lanes. Following service load combinations for WPCPHB and AASHTO LRFD were used to calculate service load moments and finally check that which specification governs for 20m span considering 1, 2, 3 and 4 lanes loaded in case of I-girder and inverted T-girder bridges to produce maximum/critical moments.

- $SERVICE_{WPCPHB} = D + (L + I)$
- $SERVICE_{AASHTO-LRFD} = D + (L + I)$

It can be observed in Fig.9 that in case of **I-girder Bridge,** WPCPHB tank produces maximum moment for 1, 2, 3 & 4 Lanes Bridge while in Fig.10 it can be noticed that for **Inverted T-girder Bridge,** WPCPHB tank governs for 1 & 3 Lanes Bridge and AASHTO truck governs for 2 & 4 Lanes Bridge.

The ultimate moments considering the live loadings as per WPCPHB and AASHTO LRFD specifications and dead loads are also compared. Following ultimate load combinations are used to calculate moments and the values for I-girder and inverted T-girder bridges are graphically presented in Fig.11 and Fig.12, respectively for different number of lanes loaded.

- $U_{WPCPHB} = 1.5D + 2.5L$
- $U_{AASHTO-LRFD} = 1.25D + 1.5DW + 1.75L$

It can be observed in Fig.11 that in case of **I-girder Bridge,** WPCPHB tank gives maximum moment for 1, 2, 3 & 4 Lanes Bridge similarly in Fig.12 it can be noticed that for **Inverted T-girder Bridge,** WPCPHB tank also governs for 1, 2, 3 & 4 Lanes Bridge.

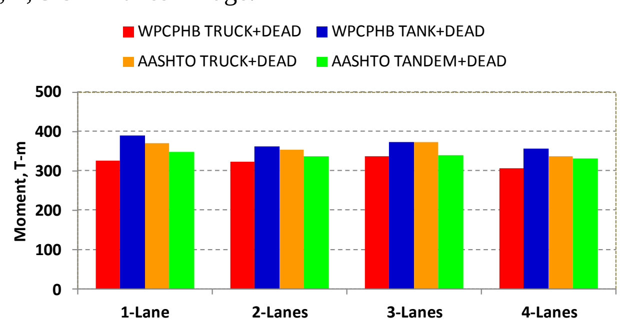


Fig 9: Service live plus dead load moments (*I-Girder*)

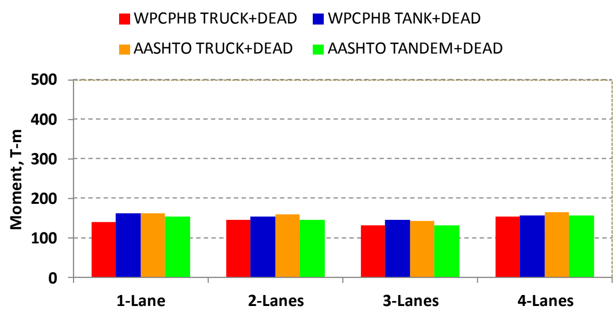


Fig 10: Service live plus dead load moments (*Inverted T-Girders*)

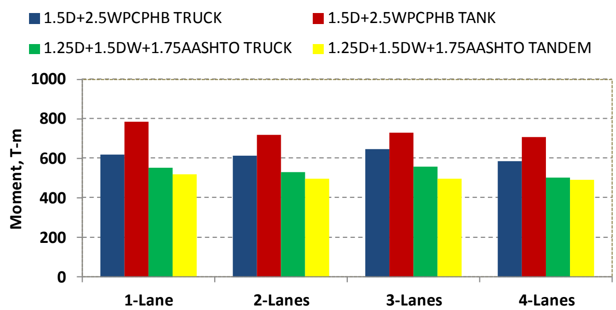


Fig 11: Ultimate live plus dead load moments (*I-Girders*)

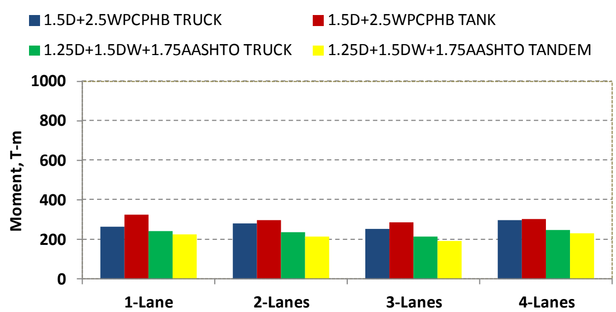


Fig 12: Ultimate live plus dead load moments (*Inverted T-Girders*)

8.2 SPAN 25M

Service loads (live plus dead) moment for 25m span I-girder and inverted T-girder bridges considering 1, 2, 3 and 4 lanes are shown in Fig.13 and Fig.14. It can be observed in Fig.13 that in case **I-girder Bridge** WPCPHB tank gives maximum moment for 1 and 4 lanes bridge and AASHTO truck governs for 2 and 3 lane bridge. In Fig.14, it is clear that in case of **inverted T-girder Bridge** AASHTO truck governs for1, 2, 3 & 4 Lanes Bridge.

For 25m span, the ultimate live plus dead loads moment for 1,2,3 and 4 lanes I-girder and inverted T-girder bridges were also computed and are shown in Fig. 15 and Fig.16, respectively. It can be observed in Fig.15 that in case of **I-girder Bridge,** WPCPHB tank gives maximum moment for 1, 2, 3 & 4 Lanes Bridge while in Fig.16 it can be noticed that for **Inverted T-girder Bridge,** WPCPHB tank governs for 1 & 3 lanes bridge and WPCPHB truck governs for 2 & 4 lanes bridge.

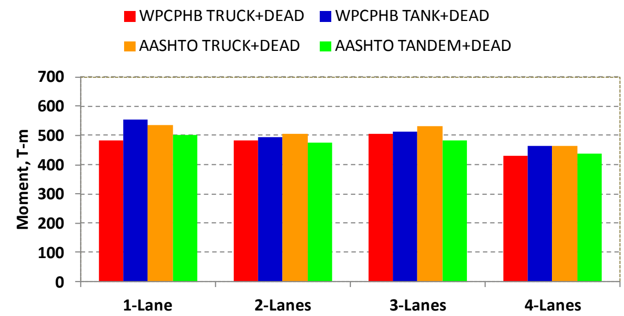


Fig 13: Service live plus dead load moments (*I-Girder*)

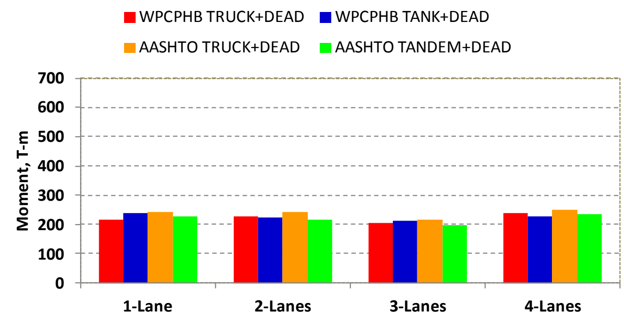


Fig 14: Service live plus dead load moments (*Inverted T-Girders*)

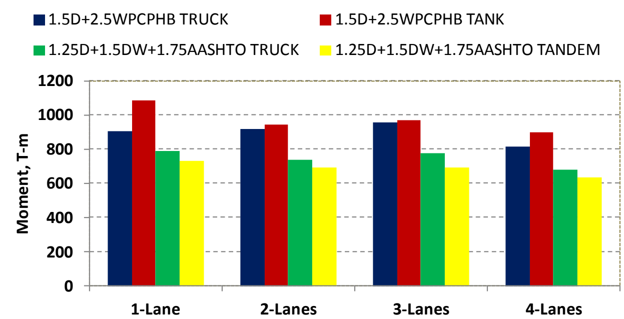


Fig 15: Ultimate live plus dead load moments (***I-Girders***)

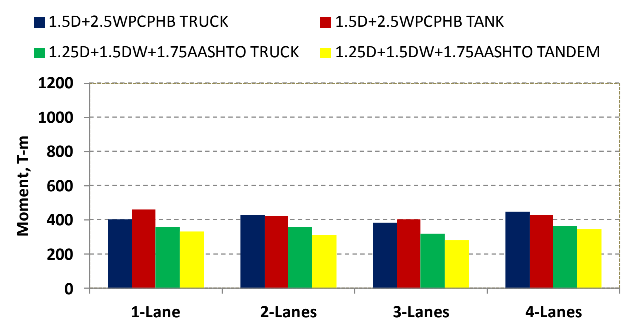


Fig 16: Ultimate live plus dead load moments (*Inverted T-Girders*)

8.3 SPAN 30M

Service loads (live plus dead) moment for 30m span I-girder and inverted T-girder bridges considering 1, 2, 3 and 4 lanes are shown in Fig.17 and Fig.18. It can be observed in Fig.17 that in case of **I-girder Bridge** WPCPHB tank gives maximum moment for 1 Lane Bridge and AASHTO truck governs for 2, 3 & 4 lane bridge. In Fig.18, it is clear that in case of **Inverted T-girder Bridge** AASHTO truck governs for1, 2, 3 & 4 lane bridge.

For 30m span, the ultimate live plus dead loads moment for 1, 2, 3 and 4 lanes loaded I-girder and inverted T-girder bridges were also computed and are graphically represented in Fig. 19 and Fig.20, respectively. It can be observed in Fig.19 that in case of **I-girder Bridge** WPCPHB tank gives maximum ultimate moment for 1 & 4 lanes bridge and WPCPHB truck governs for 2 &3 lane bridge. In Fig.20 it can be noticed that for **Inverted T-girder Bridge** WPCPHB tank governs for 1 lane bridge and WPCPHB truck governs for 2, 3 & 4 Lanes Bridge.

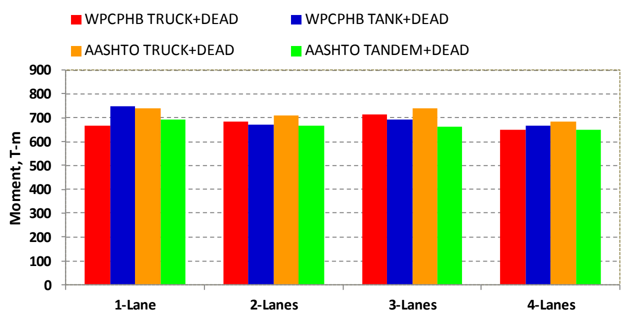


Fig 17: Service live plus dead load moments (*I-Girder*)

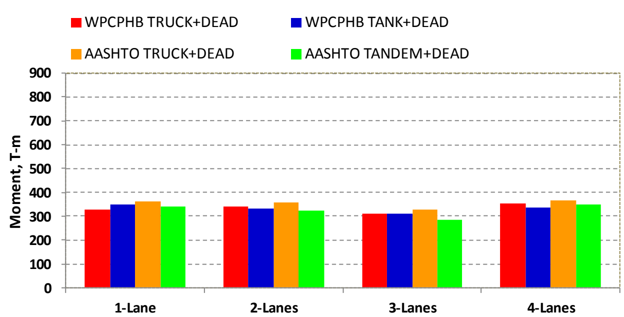


Fig 18: Service live plus dead load moments (*Inverted T-Girders*)

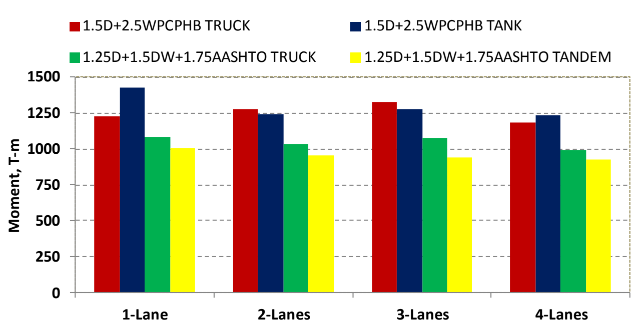


Fig 19: Ultimate live plus dead load moments (*I-Girders*)

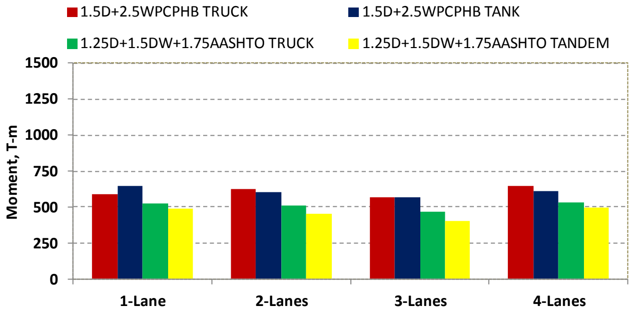


Fig 20: Ultimate live plus dead load moments (*Inverted T-Girders*)

8.4 SPAN 35M

Service loads (live plus dead) moment for 35m span I-girder and inverted T-girder bridges calculated for 1, 2, 3 and 4 lanes are shown in Fig.21 and Fig.22. It can be observed in Fig.21 in case of I-girder Bridge AASHTO truck gives maximum moment and for 1, 2, 3 & 4 lanes bridge and in Fig.22, it is clear that in case of Inverted T-girder Bridge AASHTO truck governs for 1, 2, 3 & 4 lane bridges.

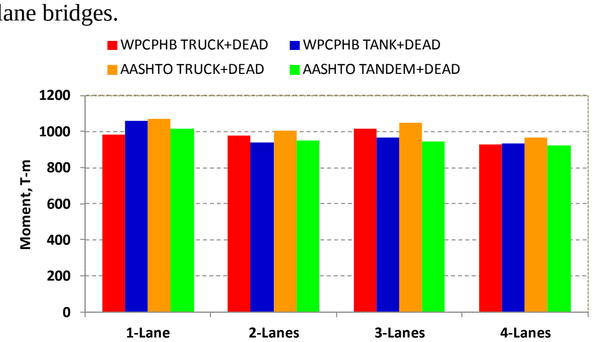


Fig 21: Service live plus dead load moments (*I-Girder*)

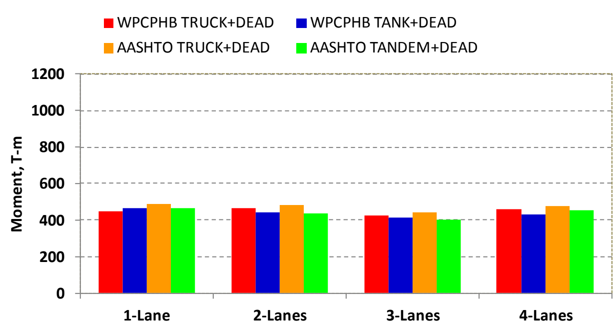


Fig 22: Service live plus dead load moments (*Inverted T-Girders*)

For 35m span, the ultimate live plus dead loads moment for 1, 2, 3 and 4 lanes loaded I-girder and inverted T-girder bridges were also computed and are shown in Fig. 23 and Fig.24, respectively.

It can be observed in Fig.23 that in case of In case of **I-girder** WPCPHB tank gives maximum ultimate moment for 1 & 4 lanes bridge and WPCPHB truck governs for 2 &3 lanes bridge while in Fig.24 it can be noticed In case of **Inverted T-girder** WPCPHB tank governs for 1 lane bridge and WPCPHB truck governs for 2, 3 & 4 lanes bridge.

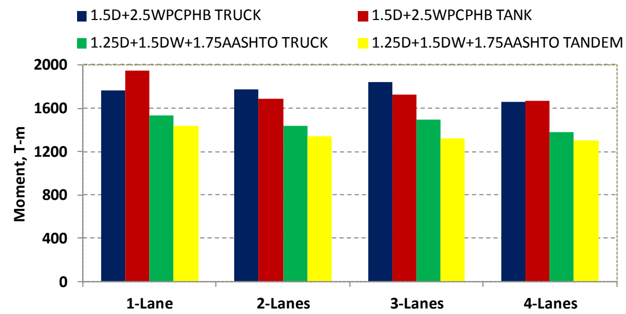


Fig 23: Ultimate live plus dead load moments (*I-Girders*)

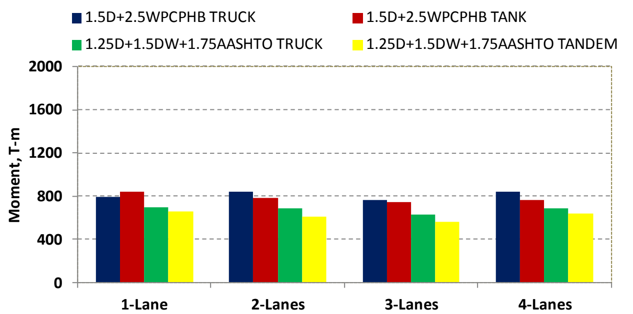


Fig 24: Ultimate live plus dead load moments (*Inverted T-Girders*)

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9. CONCLUSIONS

From the findings of this study, following conclusions may be drawn:

1. The AASHTO truck usually governs in case of larger spans. From analysis results it is clear that in case of 35m 1, 2, 3 & 4 lane bridge for I, inverted T-girder bridge, AASHTO truck produces maximum/critical moment in service combination.
2. For smaller spans like 20m, WPCPHB tank governs for 1, 2, 3, 4 lane I-girder bridge both in service and ultimate combination.
3. From analysis results it is clear that either WPCPHB tank or AASHTO truck governs in service combination for selected spans, lanes & girder types but WPCPHB truck and AASHTO tandem do not give governing moment in service combination.
4. WPCPHB have a very high load factors as compared to AASHTO LRFD so it is observed that WPCPHB gives governing ultimate moment in this study.

REFERENCES:

[1] AASHTO (2002), Standard Specification for Highway Bridges, 17th Edition, Washington, DC, USA.
[2] AASHTO (2007). LRFD Bridge Design Specifications, American Association of State Highway and Transportation Officials, 4th Edition, Washington, D.C.
[3] S. Nowak, (1995), “Calibration of LRFD bridge code,” ASCE Journal of Structural Engineering, vol. 121, no. 8, pp. 1245–1251.
[4] WPCPHB, (1967) Government of West Pakistan Highway Department, Code of Practice Highway Bridges.
[5] Publication No. FHWA-NHI-08-048 Structures Engineering Series No. 1, (2007), Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures Design Manual-US Units.
[6] AASHTO, (2010), LRFD Bridge Design Specifications, Washington, DC, USA.
[7] CSI, (2007), *SAP2000 (Structural Analysis Program) v. 14.2.2*, Computers and Structures, Inc., Berkeley, CA.
[8] Zahid A. siddiqi (2009), Concrete Structures PartII.
[9] B.H.Manton, C.B.Wilson (1971), MOT/C&CA standard bridge beams.
[10] Seongyeong Yang, Todd Helwig, Richard Klingner, Michael Engelhardt, Jeremiah Fasl, (2010) Impact of Overhang Construction on Girder Design.