Live Load Model for Puerto Rico Routine Heavy Permit Vehicles

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Abstract *— An analysis was made to establish a model of vehicle loads on bridge design that represents the permits' loads that are considered as routine permits by Puerto Rico Highways and Transportation Authority. In addition, was studied if the HS30 can be a representative design guideline model for those routine permit loads. Following the parametric studies, two families of vehicles were studied by calculating the envelope of force effects from each of them. Based on this study, we conclude that the HS30 live load model is representative of the permit vehicles of Puerto Rico. It is recommended that the PRHTA consider the two families of vehicles studied, as possible vehicles to represent routine permit vehicles in their design guidelines.*

Key Terms *— Bridges, Design Vehicle, HS30, Impact, Inventory, Load Rating, Operating, Routine Permit Vehicles and Traffic.*

INTRODUCTION

Puerto Rico as a commonwealth of the United States, is required to follow the National Bridge Inspection Standards (NBIS) [1] as stated in the Code of Federal Regulations 23, part 650 subpart c (23CFR650.3) for the safety inspection of its bridges. The NBIS sets guidelines for the inspection and evaluation of bridges to ensure their safety and functionality. These inspections involve assessing the physical and functional condition of bridges, evaluating their load-carrying capacity, and maintaining a continuous record of their condition.

Puerto Rico Department of Transportation and Public Works (DTOP) and, Puerto Rico Highways and Transportation Authority (PRHTA) follow a Regulation [2] by law, that limits the vehicle loads that travel on public highways. This Regulation says in Section 6.4 that except through the granting of a Special Permit or Authorization, no vehicle or combination of vehicles with a weight greater than 110,000 pounds will be able to travel on public roads. Also, for indivisible loads that exceed the maximum vehicle weight and/or dimensions, Regulation [2] requires a special permit from the PRHTA. To comply with Federal regulation the NBIS in section 23CFR650.313(c) requires that bridges be evaluated for routine permits and it establishes the codes and guidelines to follow to determine the load capacity (load rating) of the bridge. The AASTHO Manual of Bridge Evaluation [3] is the main guideline for load rating of bridges according to the regulation [2].

On the other hand, according to PRHTA [4] they issue over 350 special permits a year and about 90 percent of those are less than 150 kips of total vehicle weight and do not exceed dimensions significantly, which are considered routine permit vehicles. Vehicles over 150 kips are considered as super loads and special analyses and requirements may be required. Thus, PRHTA wants to make sure that new bridge construction considers routine permits in their design, and that older bridges have a load rating capacity for them.

OBJECTIVES

Considering those aspects, the main objectives of this article are:

- Establish a model of vehicle loads on bridge design that represents the permits' loads that are considered as routine permits by PRHTA which are less than 150 kips.
- Since Puerto Rico already uses the HS30 as a vehicle for load rating in bridge design, the study focused on determining if the HS30

Design Vehicle accounts for these routine permits' loads.

LOAD RATING

Bridge load rating provides a basis for determining the safe load capacity of a bridge. One of the methodologies established by the Manual [3] for load rating is the Load and Resistance Factor Rating (LRFR) method developed to provide uniform reliability in bridge load ratings, load postings, and permit decisions. The LRFR method is comprised of three distinct procedures:

- **Design load rating:** First-level assessment of bridges based on current design standards, which includes two levels of rating, inventory and operating.
- **Legal load rating:** Second-level assessment of the bridge's capacity to safely carry standard legal loads, such as those defined by state or federal regulations.
- **Permit load rating:** Third-level assessment of bridges that evaluates the ability to handle special permit loads, which are typically heavier than the standard legal loads.

In this project, two procedures of the three mentioned before are going to be used for the analysis. The first one, is the design load rating procedure for the design vehicle HS30, shown in Figure 1 [5], as established in the Puerto Rico Design Directive 310 [6].

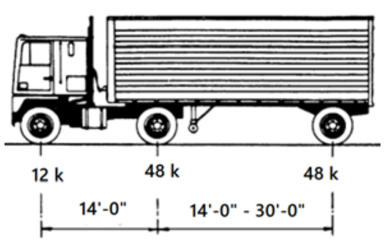


Figure 1
Design Truck HS30

This design vehicle load rating procedure includes the analysis of the HS30 at inventory and operating levels to compare both scenarios. On the other hand, the second procedure to be used is the permit load rating for the exclusion vehicles that are going to represent the routine vehicles that are evaluated for permits in the PRHTA.

SELECTION OF EXCLUSION VEHICLES FAMILIES FOR PERMIT LOAD RATING

Vehicle configurations representing the grandfather provision exclusions vehicles can be found in the Manual [3] and they represent various types of special hauling vehicles that are common in the United States and Puerto Rico. In this project, we are going to define a global vehicle weight (GVW) limit of 150 kips for a tractor and a semi-trailer combination as configurations for routine permit loads. The origin of this value of 150 kips GVW is because the most common and frequent heavy load presented for routine permits to the PRHTA to transport on the public roads are heavy construction equipment such as Bulldozers D8 or D9 which are shown in Figure 2 [7] and Figure 3 [7].

Figure 2
Example of a Bulldozer D8

Figure 3
Example of a Bulldozer D9

For the loads given above, we have a weight of approximately 87 kips for the D8 and 110 kips for the D9, therefore the range of weight for the transporting of these two loads is in the top range of what PRHTA considers a routine permit. Eventually, these kinds of loads are recently transported in trailers at a length of 18 ft to 20 ft of space, an example of this kind of trailer is shown in the next Figure [8], these dimensions were obtained from a report summited to permits in the PRHTA. This trailer has a weight of approximately 25 kips, therefore, considering the weight of the truck, trailer and the heavy load the GVW of the vehicle is close to 150 kips which was considered in this analysis.

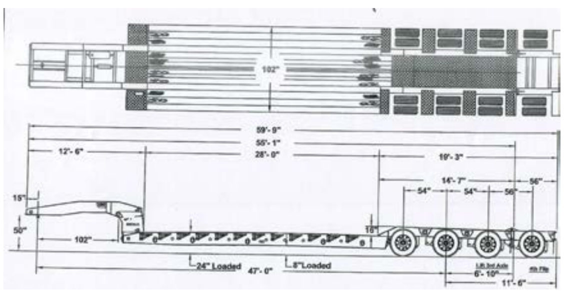


Figure 4
Example of a trailer configuration presented for a permit to the PRHTA

The two-family vehicles considered herein, shown in Figure 5 [5], and Figure 6 [5], are going to be F.M.3-S2 WB36 and the F.M.3-S2 WB54, both modified for the GVW of 150 kips. The selected live loads were processed using influence line analysis. However, considering the length of the trailer shown before, the vehicle WB36m is slightly conservative, because it has a space for the load less than 20 feet for this type of load. But is still a good representation of a more compact vehicle compared with the WB54m. On the other hand, when these configurations of vehicles were modified for a GVW 150 kips, the loads were distributed and incremented on all axles except the first axle. Because a semi-trailer distributes the load between the axles that support the drag.

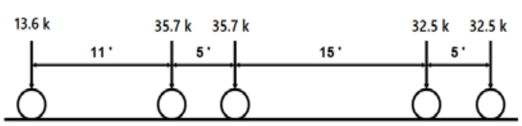


Figure 5
Exclusion Vehicle F.M.3-S2 Modified (WB36m)

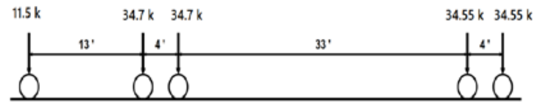


Figure 6
Exclusion Vehicle F.M.3-S2 Modified (WB54m)

COMPARISON OF PERMIT LOADS MODELS WITH THE STANDARD DESIGN HS30 LIVE LOAD

Following the parametric studies of the *Transportation Research Circular* [5]. The force effect from these three families of vehicles, WB36m, WB54m, and the Design Vehicle HS30, were studied by calculating the envelope of force effects from each of the representative vehicles in a family for:

- Positive moment at 0.5L of a simply supported beam.
- Positive moment at the 0.4L point of a two-span continuous girder, with equal spans.
- Positive ends shear ($+V_{ab,}$) and shear at an interior support ($-V_{ba}$) of a two-span continuous girder with equal spans.
- Negative moment at the interior pier of a two-span continuous girder with equal spans.

Comparisons of the various force effects, identified above, for spans from 10 to 200 feet generated by the permit's vehicles of WB36m and WB54m compared with the HS30 truck. The reason for this range of lengths selected is because in the PRHTA a considerable percent of the cases summited for permits are between these ranges. This comparison is developed by plotting the ratio of the force effect from the envelope of the permit's vehicles divided by the corresponding force effect from the HS30 vehicle on a vertical axis, against the span length on the horizontal axis. A complete match of force effects, indicating that the HS30 vehicle was an accurate and representative model of the permit's loads, would be indicated by a horizontal line passing through the vertical axis at a value of 1.0.

Cases Performed on the Analysis

As stated previously, two procedures of load rating are going to be used for the analysis, one for the permit's vehicles, WB36m and WB54m, and the other for the design vehicle HS30. For each permit vehicle, based on the AASHTO Manual [3], the following cases are going to be studied:

- **Traffic + Impact:** This case represents the vehicle considering traffic and without speed control.
- **Traffic + No impact:** It represents the vehicle considering traffic and reduction of speed.
- **No traffic + No impact:** Representing no traffic on the road and a reduction of speed, considering a minimum speed of 5 mph.

On the other hand, for the design vehicle HS30 two levels of load rating are going to be considered, and each one is going to be compared with the previous cases of permits vehicles:

- **Inventory level:** Generally, corresponds to the rating at the design level of reliability for new bridges but reflects the existing bridge and material conditions regarding deterioration and loss of section.
- **Operating level:** Indicates the maximum permissible live load the bridge can carry without risking its structural integrity. However, it's important to consider that this is the case less conservative of both levels, especially for existing bridges.

Therefore, two groups of results are going to be obtained from the analysis, one comparing the permit vehicles with the HS30 at the inventory level and the other with the HS30 at the operating level.

Results: HS30 in Inventory Level

Parametric studies were developed to obtain the following results between each permit vehicles and the HS30 model at Inventory Level.

Maximum Ratio Values

In Tables 1 and 2 it can be seen a summary of the maximum ratio values between each permit vehicle and the HS30 in Inventory Level. The ratio between each of the representative permit vehicles of Puerto Rico and the HS30 model in the majority except for the negative moment case, is less or close to 1.0. This implies that the load rating of the HS30 is greater than or equal than the load rating of each of them. This shows us that Puerto Rico's permit's vehicles trucks are contemplated in the theoretical load of the HS30.

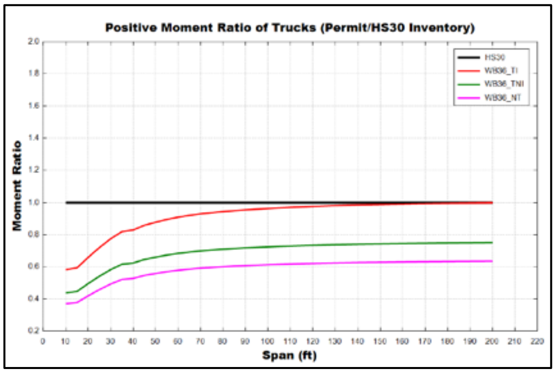
Table 1
Maximum Ratio of WB36m / HS30 in Inventory Level

Permit's Vehicle	Forces Effects	Maximum Ratio (Permit/HS30 in Inventory)		
		Traffic + Impact	Traffic + No Impact	No Traffic + No Impact
WB36m	Positive Moment	1.0	0.75	0.64
	Negative Moment	1.45	1.09	0.92
	Positive Shear	0.99	0.75	0.63
	Negative Shear	1.01	0.76	0.64

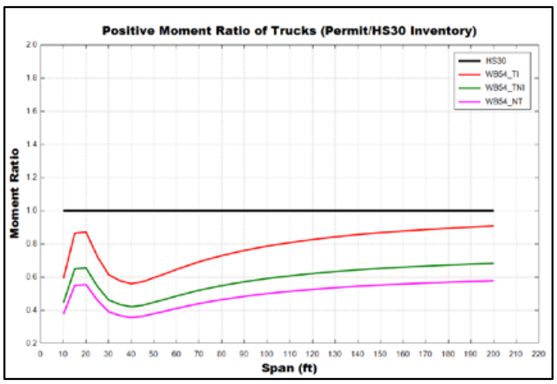
Table 2
Maximum Ratio of WB54m / HS30 in Inventory Level

Permit's Vehicle	Forces Effects	Maximum Ratio (Permit/HS30 in Inventory)		
		Traffic + Impact	Traffic + No Impact	No Traffic + No Impact
WB54m	Positive Moment	0.91	0.68	0.58
	Negative Moment	1.34	1.0	0.85
	Positive Shear	0.94	0.71	0.60
	Negative Shear	0.98	0.74	0.62

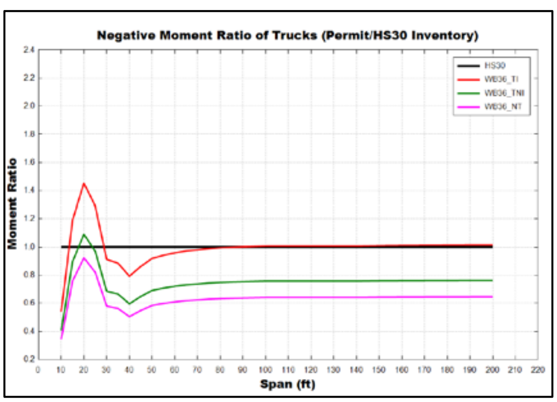
On the other hand, the full behavior of these trucks, WB36m and WB54m, are represented in Graphs 1 to 8. To understand the graph's values, the red line shown in the legend as TI represents the vehicle with Traffic + Impact. The second green line is called in the graph as TNI, which represents the vehicle with Traffic + No impact. Finally, the magenta line shown as NT represents the case of the vehicle without traffic and impact. Contemplating these results, even in the case of the negative moment that both vehicles exceed the ratio 1.0, as shown in Graphs 3 and 4 this only happens in a range of span of 10 feet to 50 feet, in shorter spans.



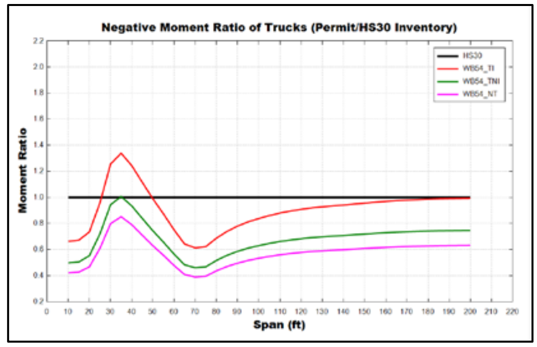
Graph 1
Positive Moment Ratio of WB36m/HS30 in Inventory Level



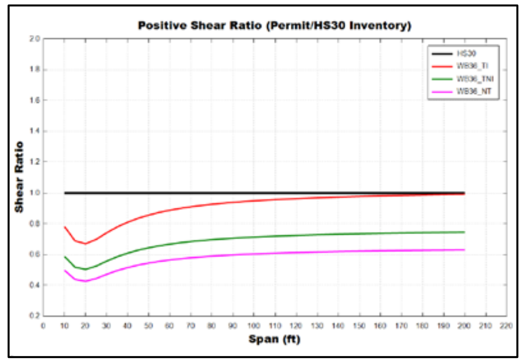
Graph 2
Positive Moment Ratio of WB54m/HS30 in Inventory Level



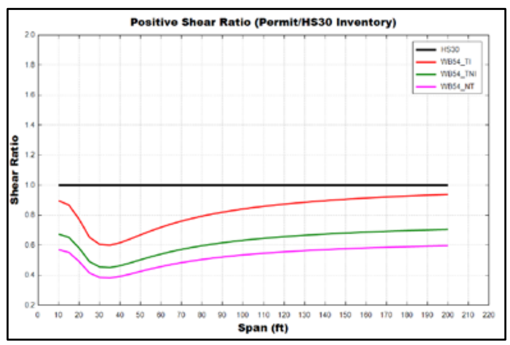
Graph 3
Negative Moment Ratio of WB36m/HS30 in Inventory Level



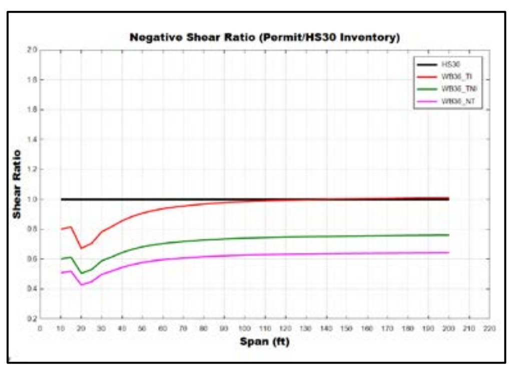
Graph 4
Negative Moment Ratio of WB54m/HS30 in Inventory Level



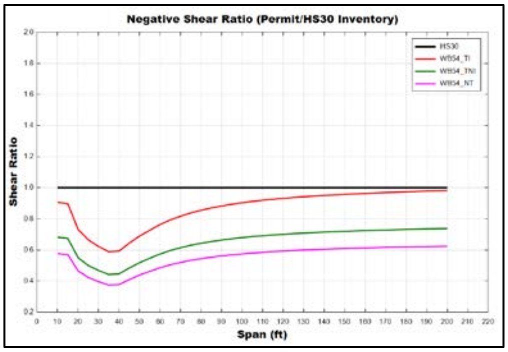
Graph 5
Positive Shear Ratio of WB36m/HS30 in Inventory Level



Graph 6
Positive Shear Ratio of WB54m/HS30 in Inventory Level



Graph 7
Negative Shear Ratio of WB36/HS30 in Inventory Level



Graph 8
Negative Shear Ratio of WB54m/HS30 in Inventory Level

Table 3
Maximum GVW of WB36m / HS30 in Inventory Level

Permit's Vehicle	Forces Effects	Maximum GVW (Permit/HS30 in Inventory)		
		Traffic + Impact (kips)	Traffic + No Impact (kips)	No Traffic + No Impact (kips)
WB36	Positive Moment	150	200	235
	Negative Moment	110	140	160
	Positive Shear	150	200	235
	Negative Shear	150	195	235

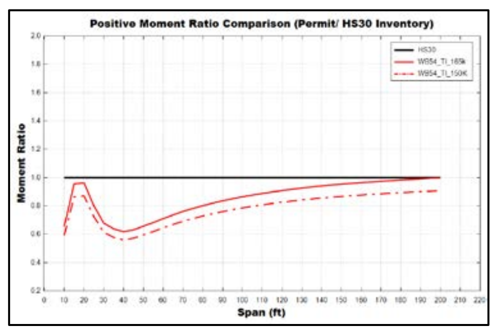
Table 4
Maximum GVW of WB54m / HS30 in Inventory Level

Permit's Vehicle	Forces Effects	Maximum GVW (Permit/HS30 in Inventory)		
		Traffic + Impact (kips)	Traffic + No Impact (kips)	No Traffic + No Impact (kips)
WB54	Positive Moment	165	220	260
	Negative Moment	115	150	175
	Positive Shear	160	210	250
	Negative Shear	155	200	240

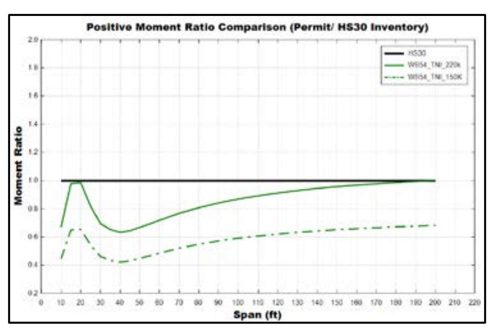
Maximum GVW Values

After obtaining the maximum ratio results of both permit vehicles for each force effect a regression analysis was made to obtain those peak values what was the maximum GVW that these permit vehicles could have to be nearest or equal to a ratio of 1.0. In other words, what is the maximum GVW, so these vehicles still be covered or are contemplated in the theoretical load of the HS30 design vehicle? The summary of these results is shown in Table 3 and Table 4.

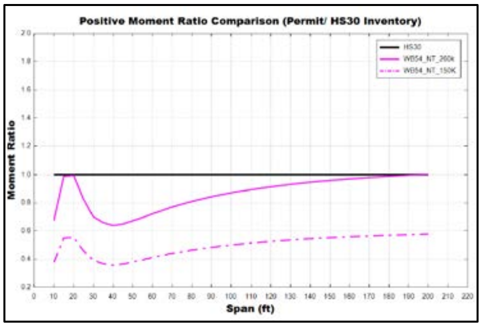
On the other hand, a graphical example of the full behavior is contemplated in Graphs 9-14. Graphs 9-11 show the three cases of positive moment ratio for the vehicle WB54m: traffic + impact, traffic + no impact, and no traffic + no impact. On each graph, the dashed line represents the previous behavior of the truck with the GVW of 150 kips. Otherwise, the solid line represents the new behavior of the truck as increments the span length with the new GVW value, which is shown in the legend at the left upper side of each graph. Therefore, as is observed for each one the maximum GVW could be greater than 150 kips. However, on Graph 12-14 the opposite happens for the first two cases on vehicle WB36m, on these two cases the maximum GVW is less than 150 kips, but only in shorter spans in a range of 10 to 40 feet.



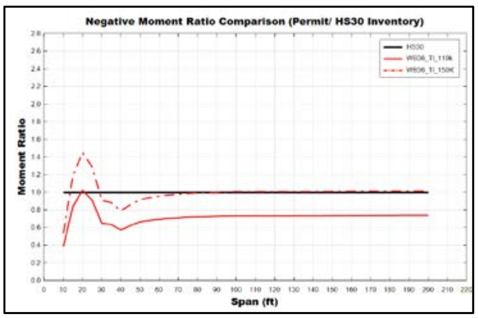
Graph 9
Traffic + Impact Comparison of WB54m/HS30 Maximum GVW for the Effect of Positive Moment



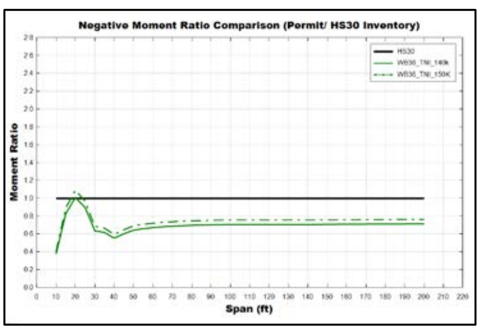
Graph 10
Traffic + No Impact Comparison of WB54m/HS30 Maximum GVW for the Effect of Positive Moment



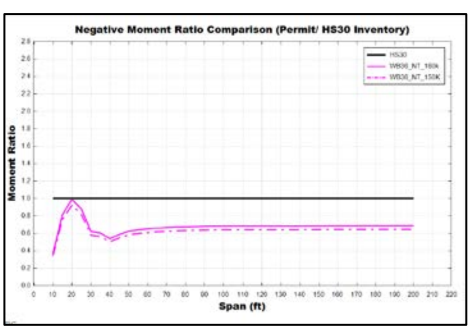
Graph 11
No Traffic + No Impact Comparison of WB54m/HS30 Maximum GVW for the Effect of Positive Moment



Graph 12
Traffic + Impact Comparison of WB36m/HS30 Maximum GVW for the Effect of Negative Moment



Graph 13
Traffic + No Impact Comparison of WB36m/HS30 Maximum GVW for the Effect of Negative Moment



Graph 14
No Traffic + No Impact Comparison of WB36m/HS30 Maximum GVW for the Effect of Negative Moment

RESULTS: HS30 IN OPERATING LEVEL

Similar to previous case, parametric studies were performed to obtain the following results between the permit vehicles and the HS30 at Operating Level.

Maximum Ratio Values

In Tables 5 and 6 it can be seen a summary of the maximum ratio values between each permit vehicle and the HS30 now in Operating Level. Remember that this level is more conservative for existing bridges, in both vehicles in the case of traffic + impact the ratio values are greater than 1.0. However, in other cases, except for the negative moment, the ratio between each permit's vehicles and the HS30 model is less or close to 1.0. This implies that Puerto Rico's permits vehicles and trucks even at operating level, if impact is controlled, are contemplated in the theoretical load of the HS30.

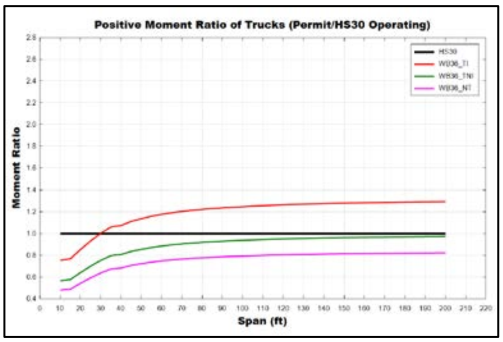
Table 5
Maximum Ratio of WB36m / HS30 in Operating Level

Permit's Vehicle	Forces Effects	Maximum Ratio (Permit/HS30 in Operating)		
		Traffic + Impact	Traffic + No Impact	No Traffic + No Impact
WB36m	Positive Moment	1.30	0.97	0.82
	Negative Moment	1.88	1.41	1.20
	Positive Shear	1.29	0.97	0.82
	Negative Shear	1.33	0.99	0.84

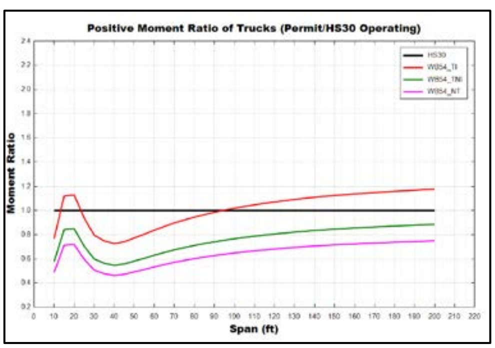
Table 6
Maximum Ratio of WB54m / HS30 in Operating Level

Permit's Vehicle	Forces Effects	Maximum Ratio (Permit/HS30 in Operating)		
		Traffic + Impact	Traffic + No Impact	No Traffic + No Impact
WB54m	Positive Moment	1.18	0.89	0.75
	Negative Moment	1.74	1.31	1.10
	Positive Shear	1.22	0.91	0.77
	Negative Shear	1.27	0.96	0.81

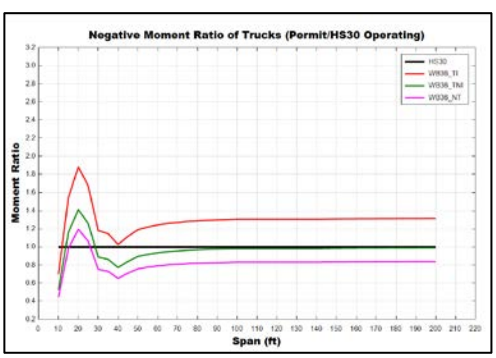
In addition, the full behavior of these trucks, WB36m and WB54m, are represented in Graphs 15 to 22. After observing these results, for all cases, it is needed to control the impact effect of vehicles so the HS30 design vehicle withstand heavy loads. Even in the case of the negative moment where the greatest ratio values were obtained, as shown in Graphs 17 and 18, those cases do not are similar to HS30 in a span range of 10 feet to 60 feet, after those ranges if we controlled the impact effect the HS30 can be representative to these permit loads.



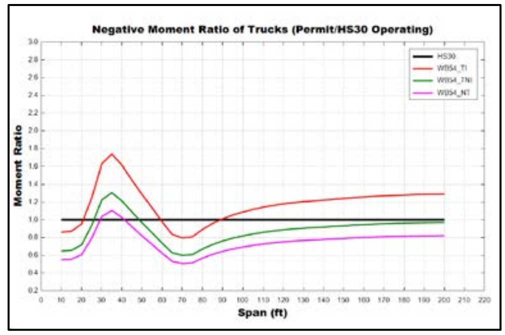
Graph 15
Positive Moment Ratio of WB36m /HS30 in Operating Level



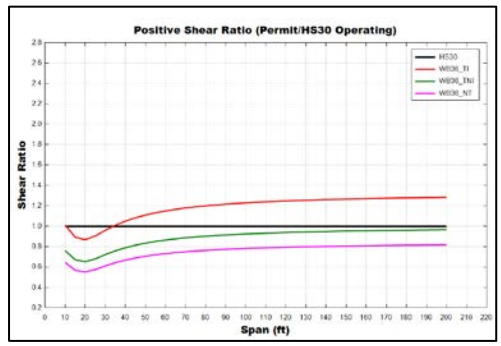
Graph 16
Positive Moment Ratio of WB54m /HS30 in Operating Level



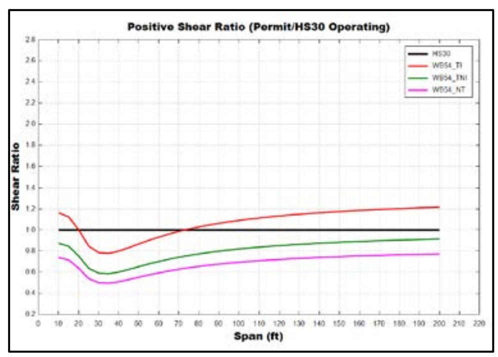
Graph 17
Negative Moment Ratio of WB36m /HS30 in Operating Level



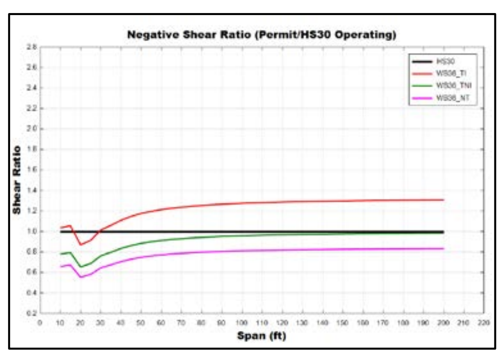
Graph 18
Negative Moment Ratio of WB54m /HS30 in Operating Level



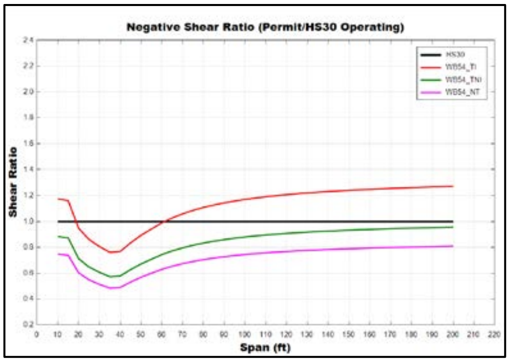
Graph 19
Positive Shear Ratio of WB36m /HS30 in Operating Level



Graph 20
Positive Shear Ratio of WB54m /HS30 in Operating Level



Graph 21
Negative Shear Ratio of WB36m /HS30 in Operating Level



Graph 22
Negative Shear Ratio of WB54m /HS30 in Operating Level

Maximum GVW Values

The same process made as the inventory level was made for the operating level. After obtaining the maximum ratio results the regression analysis was made to obtain the maximum GVW these vehicles could have to be nearest or equal to a ratio of 1.0. The summary of these results is shown in Tables 7 and 8.

Table 7
Maximum GVW of WB36m / HS30 in Operating Level

Permit's Vehicle	Forces Effects	Maximum GVW (Permit/HS30 in Inventory)		
		Traffic + Impact (kips)	Traffic + No Impact (kips)	No Traffic + No Impact (kips)
WB36m	Positive Moment	115	155	180
	Negative Moment	85	110	130
	Positive Shear	115	155	185
	Negative Shear	115	150	180

Table 8
Maximum GVW of WB54m / HS30 in Operating Level

Permit's Vehicle	Forces Effects	Maximum GVW (Permit/HS30 in Inventory)		
		Traffic + Impact (kips)	Traffic + No Impact (kips)	No Traffic + No Impact (kips)
WB54m	Positive Moment	125	170	200
	Negative Moment	90	120	140
	Positive Shear	125	165	195
	Negative Shear	120	155	185

CONCLUSION

Based on this study, it was demonstrated that the HS30 at the Inventory level, as well as considered for design, can represent the routine permit vehicles mostly with only speed restrictions. In addition, if the traffic was controlled it meets all cases. On the other hand, the study presents that in most of the cases bridges that are designed for HS30 at the operating level also resist routine permit vehicles.

Due to the above, it is recommended that the PRHTA consider WB36m and WB54m as possible vehicles to represent routine permit vehicles in their design guideline [4].

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