Summary of NCHRP Research on Recalibration of the LRFR Load Factors in the AASHTO Manual for Bridge Evaluation

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Abstract

This paper summarizes the findings of research conducted under NCHRP Project 20-07, Task 285 "Recalibration of the LRFR Load Factors in the AASHTO Manual for Bridge Evaluation". The objectives of the project were to (1) develop and recommend reliability indices better aligned with current permit operations for routine and special permit calibrations and (2) recalibrate LRFR live load factors for the recommended reliability indices for use with either the LRFD distribution formulas or refined methods of analysis such as finite element analysis.

Introduction

For single and multiple-trip special permits that are allowed to mix with traffic (without restrictions on other traffic), the Load and Resistance Factor Rating (LRFR) live load factors were derived to provide a higher level of reliability consistent with the AASHTO inventory ratings and Load and Resistance Factor Design (LRFD) design loading. The prescribed higher target reliability considers the increased risk of structural damage and benefit/cost associated with very heavy special permit vehicles compared to other truck classes. Though this higher level reliability index is justified based on structural safety, it has caused operational difficulties for bridge owners because the past permitting practices have allowed permits to operate at a lower reliability level.

The target reliability index for routine permit crossings is currently established at either a reliability index beta of 2.5 or 3.5. This reliability index needs to be compared with reliability indices used in current routine permit practices and adjusted as appropriate to meet operational needs.

The live load distribution for special permits is based on the tabulated LRFD one-lane distribution factors with the built-in multiple presence factor (i.e., 1.2) divided out. The live load distribution analysis for routine permits uses LRFD two-lane distribution factors assuming the simultaneous side-by-side presence of non-permit heavy trucks on the bridge. The load factors are higher for spans with higher average daily truck traffic (ADTT) and lower for heavier permits. The current LRFR permit load factor calibration for routine and special permits is tied to the LRFD distribution analysis method and does not provide guidance on the use of refined methods of analysis for heavy permits or for permits with non-standard gage widths. Therefore, live load factors and analysis guidance that are appropriate for analysis methods other than the LRFD distribution formulas need to be derived.

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This paper summarizes the research conducted under this project to achieve the research objectives. This summary is based on the contractor's final report authored by Mr. Bala Sivakumar of HNTB Corp., New York and Dr. Michel Ghosn of the City College of New York, New York.

Analysis of Representative WIM Data

To verify that the AASHTO LRFR produces acceptable and uniform levels of reliability for typical U.S. bridges under current loading conditions, it is critical to use the most representative statistical information on truck weights, truck configurations, and multiple presence data. In this study, weigh-in-motion (WIM) data were analyzed to obtain projections for the maximum bridge load effects from six sites located on interstate highways in New York, Mississippi, Indiana, Florida, California, and Texas. The data were gathered in 2005 and 2006 for each traffic direction and included the number of axles, axle spacings, and axle weights for each truck. Multiple presence probabilities were assembled from a representative site in New York (Sivakumar et al 2008). Table 1 lists descriptive information for each site including the average daily truck traffic (ADTT) and the number of truck records after filtering the data to eliminate any questionable data.

Table 1 WIM Data for LRFR Recalibration

Site	State	Interstate Route (Direction)	#Trucks Recorded	ADTT	Mean GVW (kips)	Mean of top 10% GVW (kips)
0001	CA	I-5 (E/N)	1,537,613	5,058	56.0	80.6
		I-5 (W/S)	1,470,924	4,839	53.3	81.9
0526	TX	I-20 (E/N)	1,330,799	4,070	55.6	80.8
		I-20 (W/S)	1,174,954	3,593	56.7	81.5
2606	MS	I-55 (N)	564,393	1,622	66.5	108.7
		I-55 (S)	604,919	1,733	63.2	83.5
9121	NY	I-81 (N)	531,042	1,715	57.2	101.7
		I-81 (S)	525,733	1,614	57.8	98.3
9512	IN	I-74 (E)	931,971	2,596	60.7	82.5
		I-74 (W)	1,003,443	2,795	60.1	87.3
9926	FL	I-75 (N)	1,096,076	4,136	48.4	84.1
		I-75 (S)	1,032,680	3,897	53.5	84.6

Maximum Live Load Effects

The statistical analysis of the WIM data for each direction of the six WIM sites was performed to project the expected maximum live load (L_{max}) effects on simple span bridges for five-year projection periods. The load effects studied are the moment at midspan and the shear near the supports for a single truck and side-by-side trucks.

As an example, Figures 1 through 4 present the plots of the L_{max} values versus span length for each direction of the six WIM sites with ADTT of 5000. L_{max} values were normalized by the corresponding effect of the HL-93 load. These plots show large variability in L_{max} between the sites.

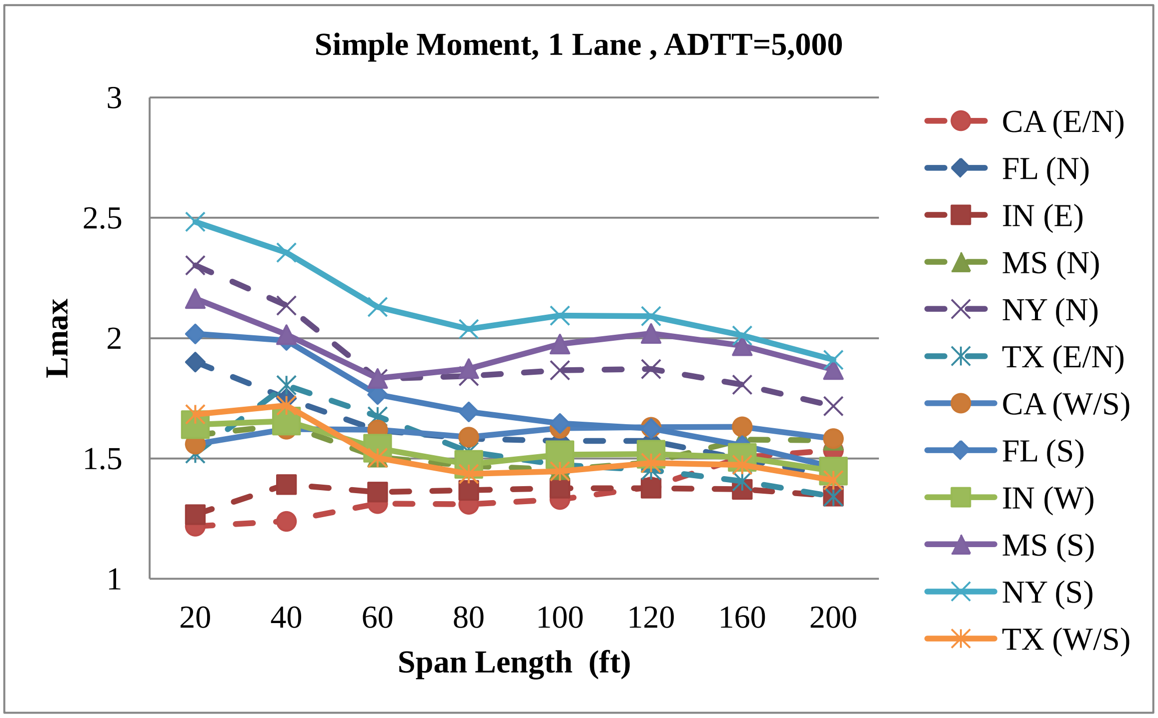

Figure 1 L_{max} Versus Span Length for Single Truck Moment

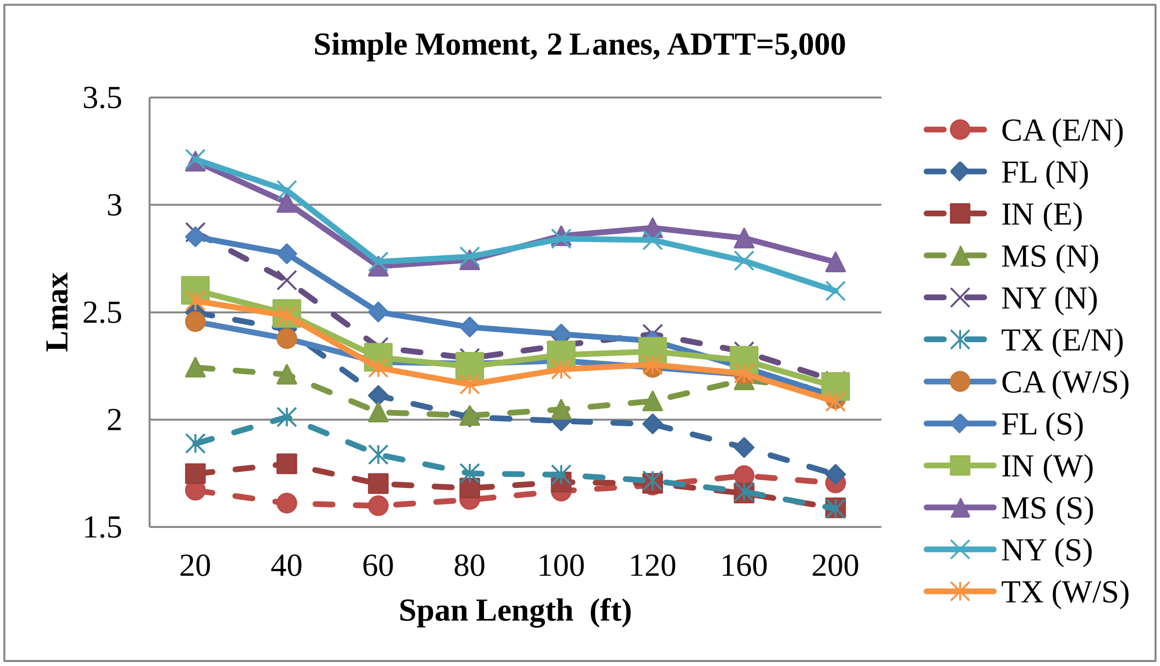

Figure 2 L_{max} Versus Span Length for Side-by-Side Truck Moment

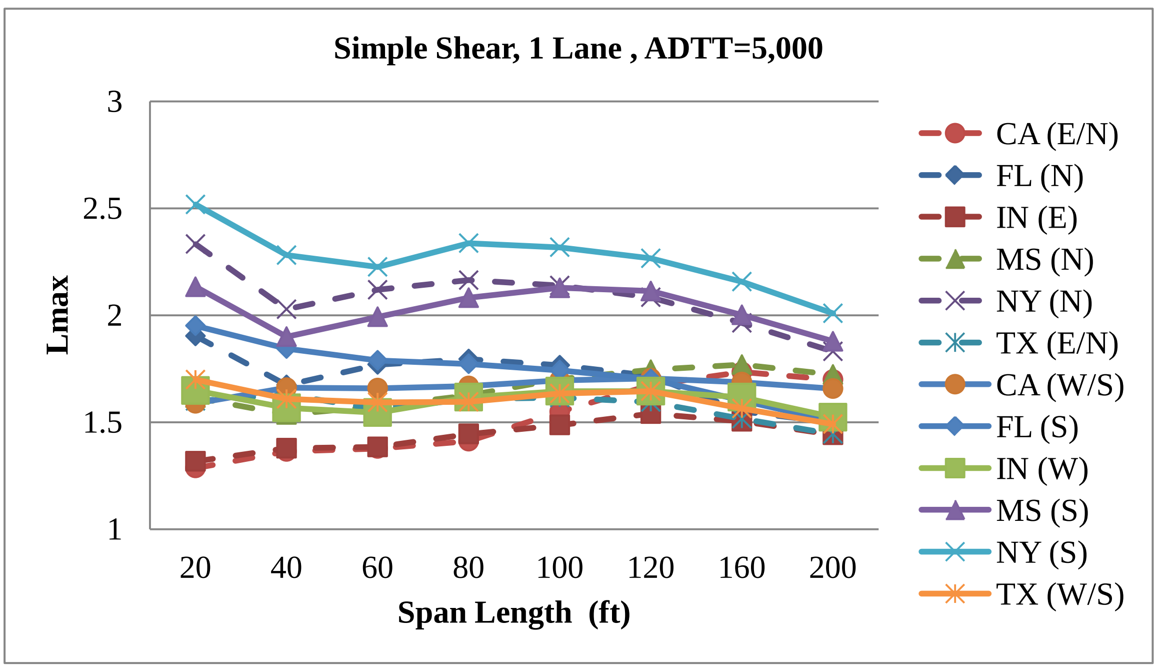

Figure 3 L_{max} Versus Span Length for Single Truck Shear

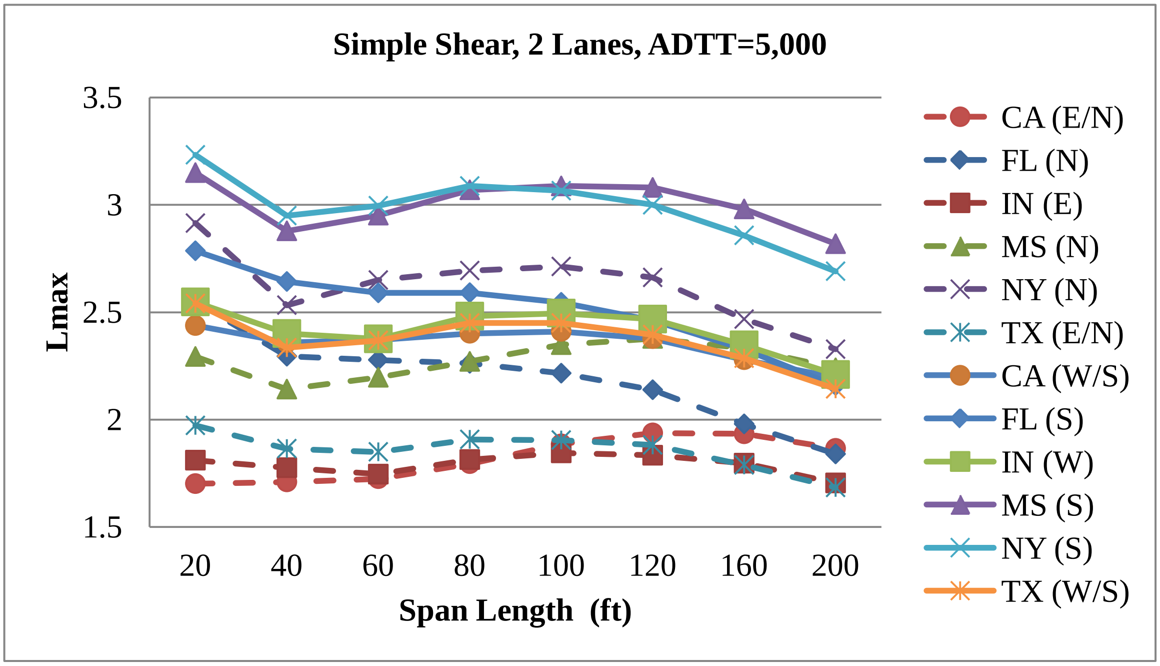

Figure 4 L_{max} Versus Span Length for Side-by-Side Truck Shear

Current Reliability Levels for LFR Ratings at the Operating Level

To find the reliability levels implied when a bridge is rated using the current AASHTO Load Factor Rating (LFR) criteria, the set of bridge configurations previously used for the AASHTO LRFD calibration is used with three different ADTT volumes: 5000, 1000, and 100. The analyzed bridge configurations are: T-beam, prestressed concrete, and noncomposite and composite steel bridges with spans varying between 20 ft and 200 ft with beams spaced from 4 ft to 12 ft center to center. The analysis was performed for the midpsan moment and maximum shear. The current reliability levels for LFR rating at the operating level was calculated for the three different cases: Random trucks on two-lane bridges, permit trucks on two-lane bridges, and permit trucks on single lane bridges.

Random Trucks on Two-Lane Bridges

In this case, all the bridges are assumed to be two-lane bridges. The bridge member resistances were calculated assuming that LFR operating rating factor is 1.00, live loads are the AASHTO legal loads (Type3, Type 3S2, and Type 3-3), and live load factor is 1.30. Table 2 provides a summary of the average reliability index values for each bridge type and ADTT for both moment and shear; the overall average is 1.35. This relatively low value is due to the high loads observed on many of the WIM sites used to project the L_{max} values. This indicates that the AASHTO legal trucks do not provide an adequate envelope of the actual loads on highway bridges leading to lower reliability levels than might have been anticipated.

Table 2 Average Reliability Index Values for Random Trucks on 2-Lane Bridges

Bridge Type	ADTT=5000		ADTT=1000		ADTT=100	
	Moment	Shear	Moment	Shear	Moment	Shear
T-Beam	1.291	0.978	1.855	1.180	1.855	1.558
Prestressed Concrete	1.083	0.995	1.329	1.204	1.783	1.595
Noncomposite Steel	1.124	0.809	1.361	1.067	1.799	1.547
Composite Steel	1.113	0.793	1.351	1.052	1.790	1.533

Permit Trucks on Two-Lane Bridges

The reliability analysis was performed for the selected bridge configurations assuming that AASHTO LFR operating rating factor for each permit truck of the set of typical permit trucks is equal to 1.00. The member resistances that would be required to allow a permit truck to cross each bridge are calculated assuming that the bridges are being evaluated using the current AASHTO LFR operating rating criteria with a live load factor 1.3 applied on the routine permit and using the two-lane distribution factor.

Table 3 provides a summary of the average values for each bridge type and ADTT for both moment and shear. The overall average reliability index is 2.94. This average value is considerably higher than that observed for previous case (random trucks on span). This difference is because the rating process uses the actual permit load and assumes that the random truck alongside the permit is of equal weight. The difference is also due to the fact that the permit trucks weights are much better known and are associated with lower coefficient of variation values than the random trucks. Although the permit truck may still cross the bridge with a random truck, the chances of having a permit truck alongside a truck of equal or higher weight are relatively low. These factors lead to significantly higher reliability index values for the permit trucks than in the cases of random loading.

Table 3 Average Reliability Index Values for Permit Trucks on 2-Lane Bridges

Bridge Type	ADTT=5000		ADTT=1000		ADTT=100	
	Moment	Shear	Moment	Shear	Moment	Shear
T-Beam	2.71	2.58	2.75	2.61	2.83	2.68
Prestressed Concrete	2.99	2.66	3.05	2.69	3.25	2.76
Noncomposite Steel	3.01	3.10	2.99	3.14	3.10	3.23
Composite Steel	2.93	3.09	2.98	3.13	3.10	3.23

Permit Trucks on Single Lane Bridges

The reliability analysis approach used for permit trucks on two-lane bridges was applied using the one lane distribution factor; the results are presented in Table 4. The average reliability index for all the cases considered is 3.62, which is higher than that obtained for the permits crossing over two-lane bridges. This difference is because the permit truck on a 1-lane bridges is alone on the bridge and thus the total applied load is better known than in the case where the truck may cross alongside a random truck which would govern the analysis of permit truck crossing two-lane bridges.

Table 4 Average Reliability Index Values for Permit Trucks on Single Lane Bridges

Bridge Type	All ADTTs	
	Moment	Shear
T-Beam	3.60	3.39
Prestressed Concrete	4.01	3.04
Noncomposite Steel	3.91	3.56
Composite Steel	3.91	3.55

<u>Reliability Targets for Permit Load Recalibrations</u>

Target reliability index for the calibration is set at 2.5 with the goal of achieving a minimum reliability index values for all conditions above 1.5.

Permit Load Classifications

The recalibration of the live load factors for permits considered the following four cases:

I. Permit vehicle alone on a bridge which can occur whether the permit has been issued for a single trip or multiple trips.

II. Unlimited crossings of multiple trip permits in which two permit trucks could cross a bridge simultaneously side-by-side.

III. Unlimited crossings where a permit truck mixes with other random vehicles.

IV. Limited number of trips (1 and less than 100) where the permit truck can mix with other random trucks.

Cases I, II, and III consider routine permits where the actual truck weight may sometimes exceed the weight limit. Cases I, II, and IV consider special permits where the weights are assumed to be fully controlled and are not expected to exceed the permit weight allowed. For routine permits, it is Case III that is expected to govern, while Case IV should govern for special permits. Case I is analyzed to check the safety of escorted permit trip. The analysis of Case II is performed to verify that it will be overshadowed by Cases III and IV.

Case I is not affected by the WIM data for the random trucks. Case II considers the probability of having two permit trucks side-by-side cross a bridge within the five year rating period. In the reliability analysis, it assumed up to 100 permits per day as an upper limit for the number of trips (Moses 2001). The probability of having two side-by-side permits is 0.5% based on the WIM data collected on New York state sites on low truck traffic volume days (Sivakumar et al, 2008).

For cases III and IV, the reliability analysis should account for the number of random vehicles that may cross the bridge simultaneously with the permit truck. Following the AASHTO LRFR classifications sites with ADTT of 5000, 1000, and 100 are considered. The percentage of side-by-side vehicles (P_{sxs}) is 2%, 1.25%, and 0.5% for sites with ADTT of 5000, 1000, and 100, respectively. These P_{sxs} values are upper bounds obtained from the headway data collected at ten WIM sites in New York State (Sivakumar et al 2008).

Key Findings

The calculations performed demonstrate that using a live load factor of 1.10 for escorted special permit loads will provide average reliability index values greater than 2.5 when the single lane AASHTO LRFD load distribution factors are used to check whether the permit truck can be allowed to cross a bridge. When performing a refined analysis of the bridge, it is recommended to use the same live load factor (i.e., 1.10) for escorted special permits. Special permits travelling over bridges at crawl speed should still be checked with a dynamic allowance factor of 1.05 to satisfy the minimum reliability index of 1.5.

For the case when a refined analysis is performed for special permits that may mix with traffic, the target reliability is also exceeded when a live load factor of 1.00 is applied on the permit truck while a live load factor of 1.10 is applied on the governing AASHTO legal truck placed in the adjacent lane.

For the cases of routine permits, where data shows that permit loads may exceed the permit weight limits, having live load factors varying from 1.40 for sites with ADTT of 5000, 1.35 for sites with ADTT of 1000, to 1.30 for sites with ADTT of 100 will lead to average reliability index greater than 2.5 while the minimum reliability index values remain above 1.5. These checks should be performed with the two-lane AASHTO LRFD load distribution factors.

The above live load factors for routine permits can be reduced for the cases where the permit truck's gross vehicle weight is high in order to reflect the lower probability of having a random truck of equal or higher weight crossing alongside the permit truck. Specifically, for trucks with GVW/AL < 2.0 kip/ft (i.e., gross vehicle weight (GVW) over front axle to rear axle length (AL)), it recommended to use the above mentioned live load factors (1.40, 1.35, and 1.30 for sites with ADTT of 5000, 1000, and 100, respectively). For trucks with GVW/AL between 2.0 and 3.0 kip/ft, the recommended live load factors are 1.35, 1.25, and 1.20 for sites with ADTT of 5000, 1000, and 100, respectively. For trucks with GVW/AL above 3.0 kip/ft, the live load factors are 1.30 1.20, and 1.15 for sites with ADTT of 5000, 1000, and 100, respectively.

The research also recommended revisions to LRFR permit rating specifications with commentary suitable for inclusion in the AASHTO Manual for Bridge Evaluation including a new table of LRFR permit load factors.

Acknowledgments

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