NEW APPROACH FOR SCREENING OVERWEIGHT VEHICLES: ALLOWABLE RANGES OF AXLE CONFIGURATIONS

Goran Milutinovic
Purdue University, School of Civil Engineering
550 W Stadium Ave, West Lafayette, IN 47907
Tel: (929) 321-9081; Fax: (765) 494-0395; Email:gmilutin@purdue.edu

Chris Kusiak
Purdue University, School of Civil Engineering
550 W Stadium Ave, West Lafayette, IN 47907
Tel: (765) 494-2166; Fax: (765) 494-0395; Email:ckusiak@purdue.edu

Mark Bowman, Corresponding Author
Purdue University, School of Civil Engineering
550 W Stadium Ave, West Lafayette, IN 47907
Tel: (765) 494-2220; Fax: (765) 494-0395; Email:bowmanmd@purdue.edu

Arun Prakash
Purdue University, School of Civil Engineering
550 W Stadium Ave, West Lafayette, IN 47907
Tel: (765) 494-6696; Fax: (765) 494-0395; Email:aprakash@purdue.edu

Word count: 4,685 words text + 9 tables/figures x 250 words (each) = 6,935 words

Submission Date – July 30, 2016

ABSTRACT

Throughout the U.S., state agencies are issuing an increasingly large number of permits for overweight vehicles every year. There are various methods used by state agencies to process permit requests. The Indiana Department of Transportation employs a screening process that consists of the Tennessee Formula (allowable weight is determined and checked, for every axle group) in combination with the Gross Vehicle Weight limit. If a permit truck satisfies these two screening criteria, it is permitted; otherwise, it is further processed with refined analyses. However, the Tennessee Formula is based on Allowable Stress Design. As a result, there were cases observed when the load effects produced by a truck that would be permitted by the Tennessee Formula actually exceeded load effects produced by the set of rating vehicles when the LFR or the LRFR method was employed (the set of rating vehicles is considered a minimum threshold that any non-posted bridge must be able to withstand). Consequently, a different approach for evaluating overweight vehicles permit requests is presented herein. Load effects from the set of rating vehicles and typical permit vehicles were directly compared. As a result, the screening vehicles – with defined ranges of axle weights and axle spacings – were developed and recommended for permitting decisions. This method is (a) safe, (b) simple, since it can be easily used by nontechnical personnel, and (c) practical, since a large number of actual permit trucks fall within the proposed screening vehicles.

Keywords: Overweight vehicles, Permitting procedures, Screening Method

INTRODUCTION

In the United States, any vehicle that has (a) a Gross Vehicle Weight (GVW) more than 80 kips, (b) axle weights more than 20 kips, or (c) does not satisfy the Federal Bridge Formula, is considered an overweight vehicle and it must be permitted in order to operate on U.S. roads *(1)*. As reported in many studies, state agencies throughout the country are issuing an increasingly large number of permits for overweight vehicles every year; this is true when the number of permits are counted annually for the entire U.S. *(2)(3)* as well as for many individual states *(4)(5)*.

There is a wide variety of different types of permits. First, permits can be classified by the number of trips a truck can have with one permit, so permits can be defined as either single-trip or multi-trip permits. Second, depending on whether a truck is allowed to operate only on a defined route or it has unlimited access to all highways in a region, permits can be "point-to-point" or routine permits, respectively.

In order to process a large number of permit requests, many U.S. state agencies take a two-step approach to review permits *(2)*:

(a) screening the permits in two groups, one acceptable for permitting and the other requiring further refined analyses, and

(b) performing refined analyses, if needed.

For instance, the Indiana Department of Transportation (INDOT) – through the Indiana Department of Revenue (IDOR) – employs the Tennessee Formula *(6)* and a GVW limit of 200 kips as the screening criteria. Using the Tennessee Formula, allowable weight is determined and checked for every axle group. If a permit truck satisfies the Tennessee Formula and its GVW is less than 200 kips, it is automatically permitted for its defined route as a single trip, "point-to-point" permit. Otherwise, the truck is further processed by refined analysis.

The Tennessee Formula was developed based on Allowable Stress Design *(6)*. However, the predominant methods used for load rating of bridges today are Load Factor Rating (LFR) and Load and Resistance Factor Rating (LRFR). To address any inconsistency resulting from this, the primary focus of this study was to develop a screening method that is better suited to LFR and LRFR.

The first step in the permit screening method by the Tennessee Formula is calculating the Allowable Ratio (R) (i.e. the percentage above the legal weight allowed before referring the truck to further refined analyses):

$$\mathrm{R} = \mathrm{a} + \mathrm{b} * (\mathrm{GVW}) + \mathrm{c} * (\mathrm{GVW})^2 \qquad (1)$$

where GVW is the gross vehicle weight (in kips), and a, b, and c are sensitivity constants set to 1.4, 0.002333 and -0.0000133, respectively. The next step is the calculation of the ratio between the actual weight and weight allowed by the Federal Bridge Formula (FBF) for each axle group. If none of the axle-group ratios exceed the "Allowable Ratio" (R), the permit truck passes the Tennessee Formula screening method.

The bases for development of the Tennessee Formula were twofold:

(a) an additional 25% above the weight allowed by FBF is permitted for each axle group because the operating stress (0.75 Fy) instead of the design stress (0.6 Fy) in the members is assumed to be adequate for permit loading *(6)*; and

(b) an additional 26% above the weight allowed by FBF is permitted for each axle group because that is the amount by which an HS-20 truck violates the FBF (and the majority of bridges were designed for HS-20 loading) *(6)*.

Therefore, the total increase of approximately 1.5 (1.25x1.26≈1.5) times the weight allowed by the Federal Bridge Formula was taken by the Tennessee formula as being adequate for permit loads with GVW between 75 kips and 100 kips. Starting from these assumptions, the authors of the Tennessee Formula also analyzed a 175-kips vehicle along with standard curve-fitting procedures and engineering judgment. A 5% decrease of the R ratio (Equation 1) was also recommended.

The set of federal and state legal loads comprise rating vehicles that is considered to be a minimum threshold that any non-posted bridge must be able to withstand. However, there were cases observed when the load effects, produced by a truck that would be permitted by the Tennessee Formula (an ASD-based method), exceeded the load effects produced by the set of rating vehicles used in Indiana, when LFR and LRFR methods are employed. Since the intent of this study was to devise a simple, safe, and consistent permit evaluation method in order to process an increasingly large number of permits requested each year, a new procedure was developed. The new screening method employs only the axle weights and spacing information in a permit request to determine whether or not it can be permitted. The specific span configurations of the bridges, which a truck will pass on its route, are not explicitly a part of the input for the screening process, making the new method very easy to implement and use in practice. This study is based on the permit and rating vehicles specific to Indiana, but the approach is general and can be applied to any state or region.

Load effects from the set of rating vehicles used in Indiana were directly compared with typical permit vehicles. As a result of these analyses, the screening vehicles – with defined ranges of axle weights and axle spacings – were developed and recommended for permitting procedures. In other words, a truck can be safely permitted as a single trip, “point-to-point” permit if its axle weights and axle spacings fall within any of the proposed screening vehicles ranges (without considering types, capacities or span configurations of the bridges that a permit truck will actually pass on its route). Otherwise, if a truck is not within the defined ranges, it should be further evaluated by some other method. In order to ensure that the method proposed herein is safe, the comprehensive set of “permutation” trucks was constructed for each screening vehicle, analyzed and checked against the defined set of rating vehicles. Also, in order to make the permitting process practical, the proposed screening vehicles were constructed to include within their ranges as many actual permit trucks as possible. This method is simple to use; it can be easily automated and employed by nontechnical personnel.

The acceptability of a permit request depends upon bridge load capacity and proposed truck loading. Thus, the main idea is to propose acceptable (and as typical as possible) truck axle configurations, with the GVWs as large as possible, which at the same time do not exceed the already established bridge capacities. The trucking industry can possibly adjust their truck inventory to these acceptable axle configurations, if needed.

DATABASE OF AXLE CONFIGURATIONS OF PERMIT TRUCKS PROCESSED BY IDOR IN 2014

The Indiana Department of Revenue (IDOR) provided for this study a database of the axle configurations – axle weights and axle spacings – for all overweight vehicle permit requests from 2014. A significant subset of these overweight vehicles corresponds to trucks that weigh between 80 and 200 kips; a total of 277,100 such permit requests were made in 2014. This database was used throughout the study as representative of permit vehicles used today.

As a basis for the development of the screening method presented herein, the type of the permit with the name “Overweight Commodity Permits” was considered. Approximately one-third of all permit requests in 2014 in Indiana were this type of permit.

According to IDOR's Oversize/Overweight Vehicle Permitting Handbook *(7)*, these single-trip, "point-to-point" Overweight Commodity Permits must satisfy the following conditions:

(a) GVW ≤ 97 kips, if a truck is carrying agricultural goods;
(b) GVW ≤ 120 kips, if a truck is carrying steel goods;
(c) single axles can weigh up to 20 kips; and
(d) one tandem can weigh up to 48 kips, while other tandems in the same truck can carry up to 40 kips.

Overweight Commodity Permits with the GVWs less than or equal to 97 kips were named "Agricultural" Permits herein, while Overweight Commodity Permits with the GVWs more than 97 kips and less than or equal to 120 kips were called "Steel" Permits. These names were provided only for easier designation of the screening vehicles described later. Overweight Commodity Permits will be referred in the text as OC Permits.

The term "permit" can also be interpreted as a "request for permitted trip". Underlying several of these permits, there were "unique" trucks that applied multiple times for permits in 2014. Therefore, these unique trucks showed up several times in IDOR's database. In other words, a truck had to have a separate permit for each trip.

It is also noted that although the analyses for the new screening method in this study were based on one specific type of permit that has been issued in Indiana, the method can be extended to any type of permit, regardless of its administrative name or purpose.

SET OF BRIDGES, SET OF RATING VEHICLES, LOAD AND IMPACT FACTORS USED IN ANALYSES

Set of bridges considered

The proposed screening method employs only the axle weights and spacing of a permit request to determine whether or not it can be permitted. Actual capacities and specific span configurations of bridges that a permit truck will pass on its route are not explicitly taken into account with this screening method. Instead, a comprehensive suite of bridges was considered when developing the method. The suite of bridges was constructed to consider a wide range of span lengths and number of spans possibilities in the state of Indiana. It covered span lengths from 20 ft. to 200 ft., in 10-ft. increments. There were 190 bridge span configurations in total. The number of spans and ratios between different spans (aspect ratios) were as follows:

(a) one span (20', 30',…200'; 19 bridges total),
(b) two spans ($3 \times 19 = 57$ bridges)
  - two equal spans,
  - two unequal spans with aspect ratios of 60%,
  - two unequal spans with aspect ratios of 80%,
(c) three spans ($3 \times 19 = 57$ bridges)
  - three equal spans,
  - unequal middle and end spans with aspect ratios of 60% $\left(\frac{\text{exterior span}}{\text{interior span}} = 0.6\right)$,
  - unequal middle and end spans with aspect ratios of 80% $\left(\frac{\text{exterior span}}{\text{interior span}} = 0.8\right)$,

(d) four spans ($3 \times 19 = 57$ bridges)
  - four equal spans,
  - unequal exterior and interior spans with aspect ratios of 60% $\left(\frac{\text{exterior span}}{\text{interior span}} = 0.6\right)$,
  - unequal exterior and interior spans with aspect ratios of 80% $\left(\frac{\text{exterior span}}{\text{interior span}} = 0.8\right)$.

The set of Rating Vehicles, the load factors and the impact factors considered

The set of rating vehicles, used in the analyses herein, consists of the AASHTO rating vehicles (as defined in Manual of Bridge Evaluation – MBE *(8)*) and the Indiana Legal Loads (as defined in Indiana Bridge Inspection Manual *(9)*). This set is referred in the text as the "Indiana Rating Vehicles" (IRVs) (Table 1). These vehicles represent the set of rating vehicles used currently in Indiana. For other states, the set can be modified according to the state's own regulations, and the process of developing new screening vehicles can be repeated.

Impact and load factors were used in accordance with the current AASHTO and Indiana rating requirements *(8)(9)(10)(11)*. The load factors for permit vehicles were taken as prescribed for single-trip permits in MBE *(8)*: 1.2 for the LRFR method and 1.3 for the LFR method. The load factors and the impact factors for the IRVs were used as specified in Table 1. For permit loads, the same impact factors were used as those for IRVs.

TABLE 1 – The Indiana Rating Vehicles and the corresponding load and impact factors

<table>
<tr><th colspan="2">LRFR</th></tr>
<tr><td>Impact Factor = 1.33</td><td>Live Load Factor = 1.45
(*except for H-20, where LLF = 1.75)</td></tr>
<tr><td colspan="2">Indiana Rating Vehicles:
1. AASHTO trucks:
• Types 3 Unit
• Type 3S2 Unit
• Type 3-3 Unit
2. Notional Rating Load - NRL
3. Lane-Type Legal Load Model (two trucks case)
4. H 20 truck*
5. H 20 lane loading *
6. HS 20 truck
7. HS 20-44 lane loading
8. HS 25 truck
9. HS 25 lane loading</td></tr>
<tr><th colspan="2">LFR</th></tr>
<tr><td>Impact Fraction = 50/(L+125) < 30%
(where L is span length in feet)</td><td>LLF=1.3
(*except for H-20, where LLF=2.17)</td></tr>
<tr><td colspan="2">Indiana Rating Vehicles:
1. AASHTO trucks:
• Types 3 Unit
• Type 3S2 Unit
• Type 3-3 Unit
2. Notional Rating Load - NRL
3. H 20 truck*
4. H 20 lane loading *
5. HS 20 truck
6. HS 20-44 lane loading
7. HS 25 truck
8. HS 25 Lane Loading is encompassed by HS 20 Lane Loading on Inventory Level</td></tr>
</table>

ANALYSES PERFORMED – COMPARISONS BETWEEN PERMIT AND RATING VEHICLES

The load effects of the vehicles in the database provided by IDOR were extensively studied. An in-house computer program was written such that every permit truck can be analyzed and checked against the set of rating vehicles on the entire set of 190 bridges, as a part of an automated process. Moment and shear envelopes were determined for each permit truck from the IDOR database by first developing the moment and shear influence lines at tenth points for each of the 190 bridges and then computing the effect of running a particular permit truck over them to obtain the corresponding envelopes of moments and shear for the entire set of bridges.

The moment and shear “envelope of the envelopes” were also computed for the IRVs. The term “envelope of envelopes” refers to a single envelope that encompasses envelopes for all vehicles in a group of vehicles (in this case the defined set of rating vehicles – the IRVs). Finally, moment and shear envelopes from every permit truck were compared to the rating vehicles’ "envelopes of envelopes." Load and impact factors were used as described in Table 1.

As an example, the graphical comparison of a particular permit truck's moment envelope and the Indiana Rating Vehicles' moment "envelope of envelopes" is provided for a bridge with two equal spans of 60 feet each (Figure 1). The graph presents the case when positive moments, produced by the permit truck, exceed positive moments caused by the IRVs. In this case, then, the permit truck load would not be acceptable, unless a more refined analysis found that it was permissible.

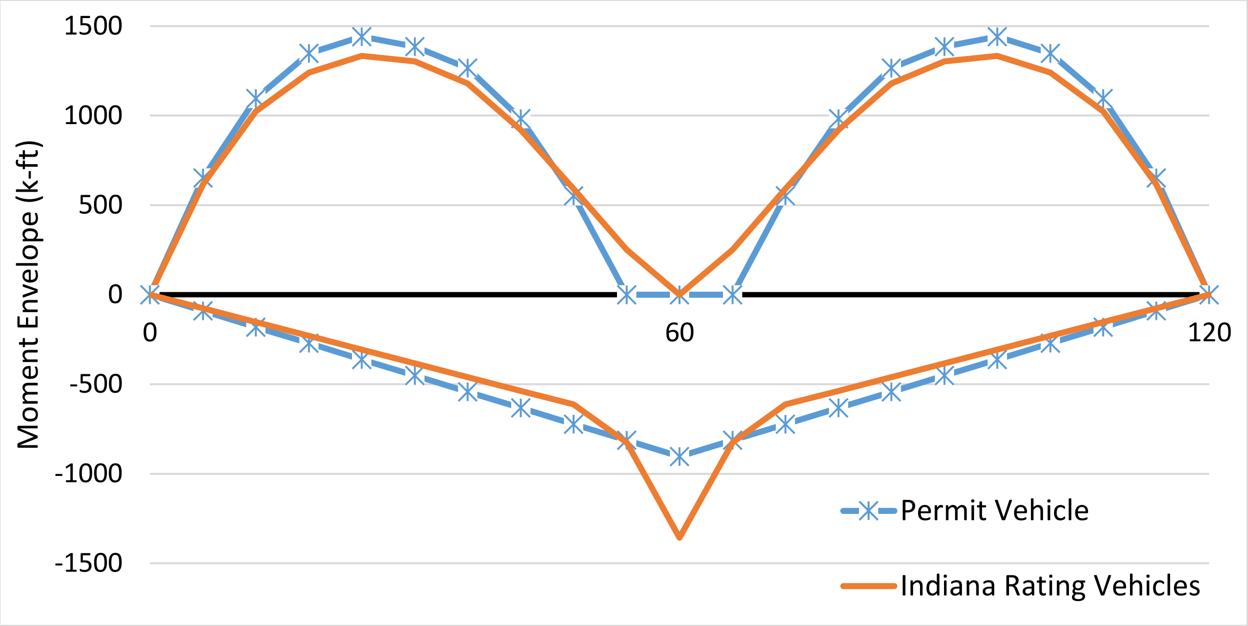

FIGURE 1 – Comparison of a permit truck's moment envelope and Indiana Rating Vehicles' moment "envelope of envelopes" for a bridge with two equal spans of 60 feet

While comparing the load effects from permit trucks and from the IRVs (i.e., while checking exceedances produced by permit trucks), only conventional design points were considered. These conventional design points include the following:

- Positive Moment
    - 40% from exterior supports
    - Midspan(s) of all interior span(s)
- Negative Moment
    - Interior supports
- Positive and negative shear
    - Just to the right of the "first" support
    - Just to the left and just to the right of all interior supports
    - Just to the left of the "last" support

Precision in analyses was limited mostly to two significant figures. Since exceedances were recorded in terms of percents, the use of two significant figures leads to rounding to the nearest whole percent. Consequently, all exceedances less than 0.5% were rounded to zero (i.e. tolerable exceedance was taken as less than 0.5%).

DEVELOPMENT OF THE NEW PROPOSED SCREENING METHOD

Using the type of analyses described in the previous section, the new proposed screening vehicles were developed. To ensure the safety of the new method, sets of “permutation” trucks were constructed (as described below), and their moment and shear envelopes were computed and compared with the Indiana Rating Vehicles’ “envelope of envelopes” (for the entire set of 190 bridges defined previously). Load and impact factors were used as listed in Table 1. Again, only conventional design points, described above, were considered while comparing load effects from “permutation” trucks and from the IRVs. The tolerable exceedance was taken as less than 0.5%.

The screening vehicles were constructed by selecting combinations of axle weights and spacings that were found to be safe for both methods, LFR and LRFR. However, it is a matter of engineering judgment or preference which method to use (or to use both) that might be decided by bridge owners for a specific state or region.

The crucial assumption underlying the new screening method is that all bridges in a region (state) are load rated using the defined set of rating vehicles (e.g., the “IRVs” in Indiana – Table 1). Consequently, a posted bridge is not allowed on permit truck route.

The screening vehicles were developed in two steps, as described below. The first step was defining the screening vehicles which will include in their axle weight and spacing ranges large numbers of real permit trucks from the 2014 IDOR permit database. The second step was a systematic check needed to ensure the safety of each screening vehicle (and done for each screening vehicle separately).

Step 1 – Determining typical axle configuration ranges

Typical ranges of axle configurations were identified from IDOR’s database of permit vehicles in the following manner. First, ranges of axle weights and axle spacings were constructed and organized as a screening vehicle. Several screening vehicles are shown as an example in Figure 2 (each arrow represents a single axle load, while letters “W” and “S” represent corresponding axle weights and axle spacings). Then, the number of real permit trucks (from the IDOR database) with axle weights and axle spacings that fall within the screening vehicles were counted. If a significant number of permit vehicles were within ranges of the considered screening vehicle, then Step 2 was initiated to check the safety of that screening vehicle. All screening vehicles are shown in Table 2.

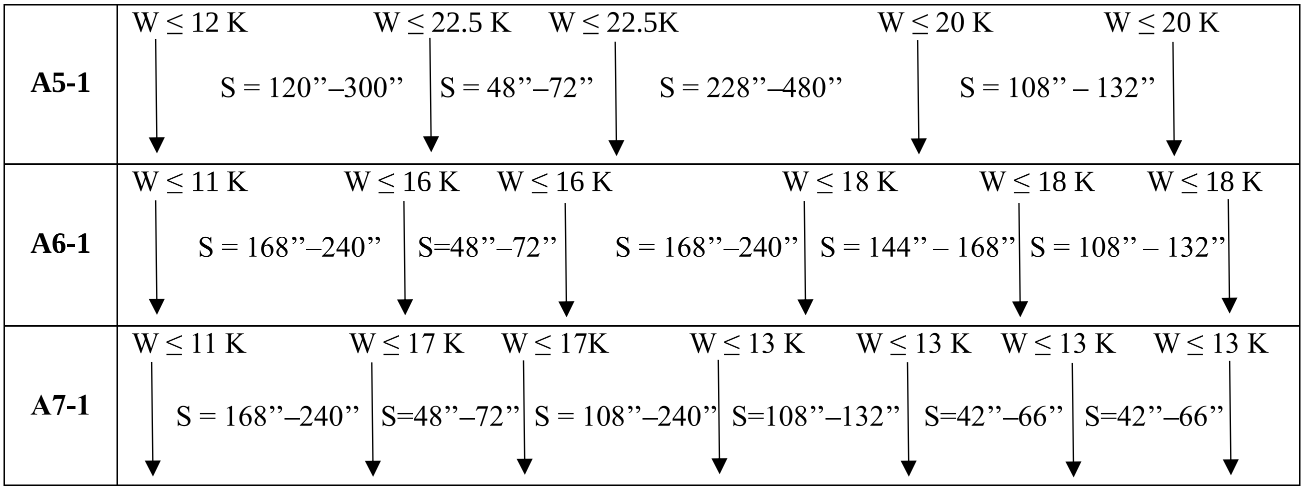

FIGURE 2 – Examples of screening vehicles

TABLE 2 – All screening vehicles with their defined ranges of axle weights and axle spacings

	Axle Weights (less than) [kips]							Axle Spacings (given limits included) [in]					
	1	2	3	4	5	6	7	1	2	3	4	5	6
A5-1	12	22.5	22.5	20	20	-	-	120-300	48-72	228-480	108-132	-	-
A5-2	17	20	20	20	20	-	-	144-300	48-72	228-420	108-132	-	-
A5-3	12	22.5	22.5	20	20	-	-	120-300	48-72	228-480	48-72	-	-
A5-4	12	20	20	22.5	22.5	-	-	168-300	48-72	228-420	48-72	-	-
A5-5	13	22	22	20	20	-	-	120-300	48-72	228-480	48-72	-	-
A5-6	13	22	22	20	20	-	-	120-300	48-72	228-480	108-132	-	-
A5-7	13	20	20	22	22	-	-	168-300	48-72	228-420	48-72	-	-
A5-8	17	20	20	20	20	-	-	120-300	48-72	228-420	48-72	-	-
A6-1	11	16	16	18	18	18	-	168-240	48-72	168-240	144-168	108-132	-
A6-2	11	16	16	18	18	18	-	168-240	48-72	144-240	108-132	108-132	-
A6-3	13	18	18	16	16	16	-	156-300	48-72	168-420	108-132	108-132	-
A6-4	12	17	17	17	17	17	-	156-240	48-72	168-300	108-132	48-72	-
A6-5	12	17	17	17	17	17	-	156-240	48-72	120-288	108-132	108-132	-
A6-6	12	17	17	17	17	17	-	168-264	42-66	168-420	42-66	42-66	-
A6-7	13	18	18	16	16	16	-	168-264	42-66	168-420	42-66	42-66	-
A7-1	11	17	17	13	13	13	13	168-240	48-72	108-240	108-132	42-66	42-66
A7-2	14	16	16	12.75	12.75	12.75	12.75	168-240	48-72	108-240	108-132	108-132	108-132
A7-3	12	13.5	13.5	14.5	14.5	14.5	14.5	168-240	48-72	108-240	108-132	108-132	108-132
A7-4	13	20	20	11	11	11	11	168-240	48-72	108-240	108-132	108-132	108-132
A7-5	12	18.5	18.5	12	12	12	12	168-240	48-72	108-240	108-132	108-132	108-132
S5-1	20	24	24	20	20	-	-	144-360	48-72	252-480	114-132	-	-
S5-2	20	24	24	20	20	-	-	132-143	48-72	252-348	114-132	-	-
S5-3	20	24	24	20	20	-	-	168-360	48-72	276-432	48-72	-	-
S5-4	20	20	20	24	24	-	-	180-300	48-72	276-420	48-72	-	-
S6-1	13	20	20	18	18	18	-	180-264	48-72	264-420	48-72	48-72	-
S6-2	12	24	24	20	20	20	-	244-254	52-72	237-242	122-132	122-132	-
S6-3	13	22	22	20	20	20	-	180-203	48-72	216-240	114-132	114-132	-
S6-4	13	22	22	19	19	19	-	198-300	50-72	174-215	110-132	110-132	-
S6-5	14	19.5	19.5	20	20	20	-	192-300	48-72	253-420	108-132	108-132	-
S6-6	13	24	24	18.5	18.5	18.5	-	192-300	50-72	198-240	122-132	122-132	-
S6-7	13	22	22	20	20	20	-	204-300	48-72	216-252	114-132	114-132	-
S6-8	18	18	18	20	20	20	-	180-300	48-72	192-252	108-132	108-132	-
S6-9	12	17.5	17.5	18	18	18	-	180-264	51-72	108-360	108-132	48-72	-
S7-1	15.4	16	16	18	18	18	18	234-270	51-72	150-360	108-132	108-132	109-132
S7-2	15.5	17	17	17	17	17	17	183-239	48-72	111-264	112-132	112-132	112-132
S7-3	15.4	16	16	18	18	18	18	204-264	52-72	113-149	119-132	119-132	119-132
S7-4	11	18	18	18.25	18.25	18.25	18.25	192-264	48-72	228-252	108-132	108-132	108-132
S7-5	12	16	16	17.5	17.5	17.5	17.5	204-264	48-72	108-180	108-132	108-132	108-132
S7-6	12	16.5	16.5	18	18	18	18	208-264	52-72	117-180	110-132	110-132	110-132
S7-7	12	18	18	18	18	18	18	216-264	52-72	132-264	122-132	122-132	122-132
S7-8	16	16	16	18	18	18	18	228-300	52-72	126-240	110-132	122-132	122-132
S7-9	16	16	16	18	18	18	18	201-300	52-72	174-360	110-132	110-121	110-132
S7-10	13	15.5	15.5	17.5	17.5	17.5	17.5	168-264	48-72	108-264	108-132	108-132	108-132

For the screening vehicles, the letter "A" designates "Agricultural" Permits (a subtype of OC Permit used as the base for calculation) and the letter "S" designates "Steel" Permits (also a subtype of OC Permit); the number after the letters "A" or "S" represents the number of axles. The number following the "dash" in the screening vehicle designation is the serial number of the screening vehicle within one category. For example, A5-2 is the second screening vehicle for Agricultural Permits with five axles.

Step 2 – Checking "permutation" trucks for every screening vehicle

The set of "permutation" trucks was constructed for each screening vehicle shown in Table 2. For all axle spacings except for the 1st and 3rd, minimum values specified in the ranges were used while making "permutation" trucks. Regarding the 1st and 3rd axle spacings, numerous possible permutations were considered. In other words, the 1st axle spacing remained the same at the minimum, while the 3rd axle spacing was varied by using a one-foot increment over the range being considered; next, the 1st axle spacing was increased by one foot, and the 3rd axle spacing was varied again by using a one-foot increment, and so on. For example, for the A5-1 screening vehicle shown in Figure 2, there are 16x22=352 "permutation" trucks. Axle weights of "permutation" trucks were the same as the maximum specified axle weights for each screening vehicle.

The "permutation" trucks for each screening vehicle were analyzed using the appropriate impact and load factor (as for permit loading) and their moment and shear envelopes were computed. Then, the "permutation" trucks' moment and shear envelopes were compared with moment and shear "envelope of envelopes" produced by the IRVs for the entire suite of bridges. Illustrative examples of comparing the envelopes are shown in Figures 3 through 6, for one bridge from the suite of bridges (again, for a bridge with two equal spans of 60 feet each). Moment "envelope of envelopes" for all 352 permutation trucks for A5-1 screening vehicle was compared with the IRVs moment "envelope of envelopes" in Figures 3 and 4 (separately for LFR and for LRFR). Further, moment "envelope of envelopes" for all permutation trucks for all screening vehicles (from Table 2) was compared with the IRVs moment "envelope of envelopes" in Figures 5 and 6 (again, separately for LFR and for LRFR). No exceedances were observed for either the LFR or LRFR method for any of the screening vehicles. Consequently, a permit vehicle that has axle weights and axle spacings that fall within the ranges of any screening vehicle (from Table 2) can be safely permitted as a single-trip, "point-to-point" permit.

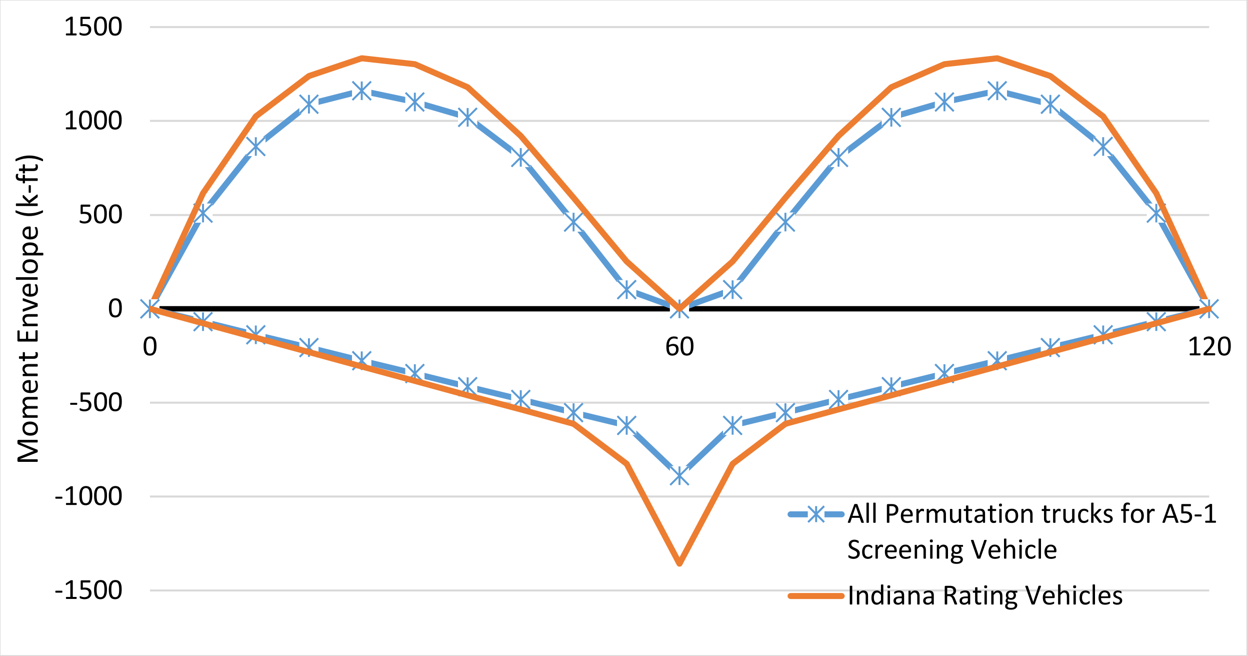

FIGURE 3 – Moment "envelope of envelopes" for all 352 permutation trucks for A5-1 Screening Vehicle against IRVs moment "envelope of envelopes" – LFR analysis

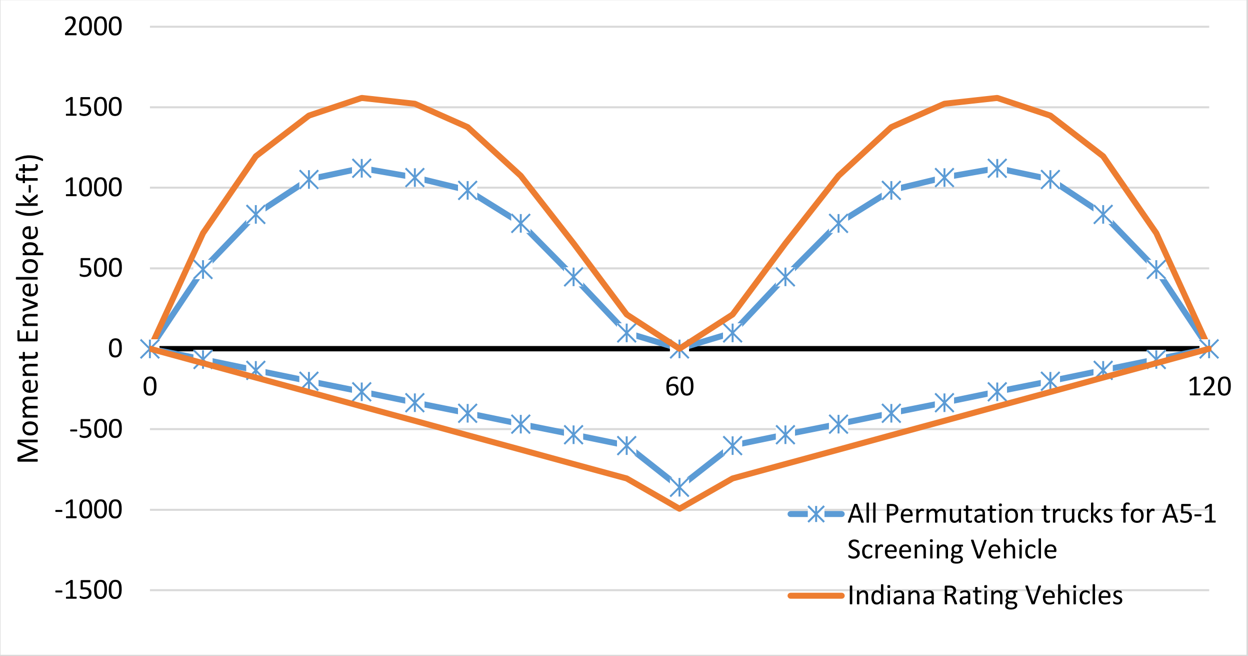

FIGURE 4 – Moment "envelope of envelopes" for all 352 permutation trucks for A5-1 Screening Vehicle against IRVs moment "envelope of envelopes" – LRFR analysis

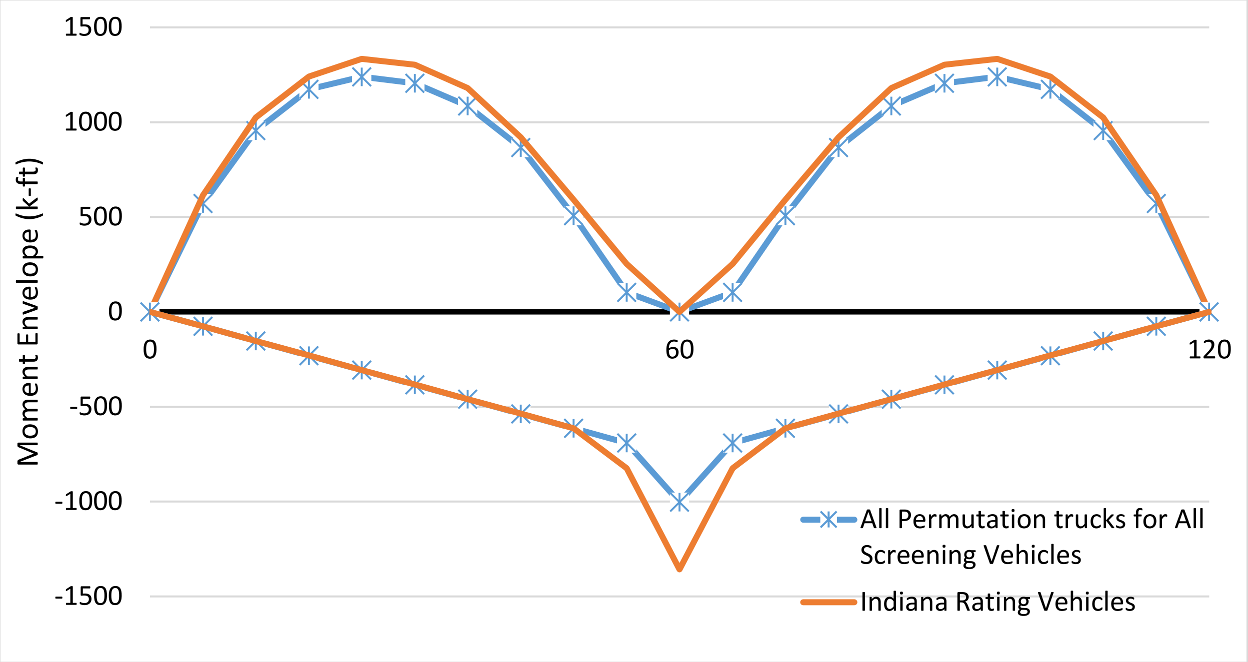

FIGURE 5 – Moment "envelope of envelopes" for all permutation trucks for All Screening Vehicles against IRVs moment "envelope of envelopes" – LFR analysis

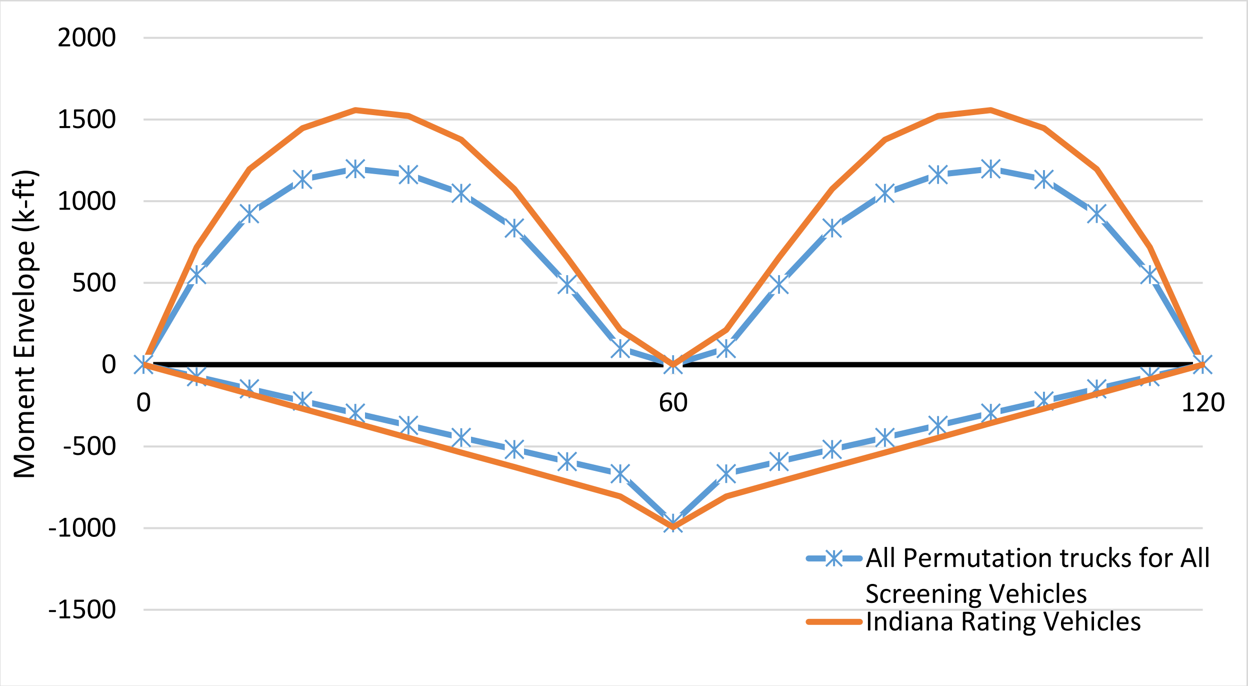

FIGURE 6 – Moment "envelope of envelopes" for all permutation trucks for All Screening Vehicles against IRVs moment "envelope of envelopes" – LRFR analysis

DISCUSSION OF THE NEWLY DEVELOPED SCREENING METHOD

The new screening method presents a systematic approach based on the principle that permit load envelopes must not exceed the “envelope of envelopes” of the load effects due to IRVs which is taken to be the minimum threshold that any non-posted bridge must be able to withstand. In this study, we focus on the “Overweight Commodity Permits” which is an important class of permit requests commonly encountered in Indiana as the basis for developing the new screening method. Note that this is a subset of the 2014 IDOR permit truck database (which contains vehicles with GVWs between 80 and 200 kips) of vehicles with GVWs between 80 and 120 kips that are designated as “commodity” vehicles. Consequently, the “screening vehicles” presented in the paper were calibrated for this specific set of permit loads. Nevertheless, the approach of developing screening vehicles can be extended to any group of vehicles (with a different range of GVWs) and calibrated against that set if needed.

It is well known that there is high non-uniformity of permitting processes for overweight vehicles among different states; therefore, a permit truck often needs to change its multi-state route (and use the longer and more expensive one) since the permit was approved in all states except one *(2)(3)*. If the approach presented in this paper is widely adopted, then the non-uniformity of permitting processes could be decreased by developing new screening vehicles applicable for multiple states.

In all of the recommended screening vehicles shown in Table 2, the first and third axle spacings are given as variable spacings within a closed interval. A common assumption is that longer trucks necessarily produce smaller load effects than shorter trucks with the same GVW and, thereby, have smaller chances to exceed load effects produced by a set of rating vehicles. However, the study showed that this conclusion is not entirely correct when the comprehensive suite of bridges is considered. The explanation lies in the shape of the influence line for the moment above the support, where a longer truck’s axles can actually be positioned above larger values of the influence line than axles of a shorter truck. Consequently, a longer truck will often produce a larger negative moment above the support. So, fictitious trucks with all possible permutations of axle spacings (within closed intervals for first and third axle spacings) need to be checked, although it has been noticed that vehicles with the shortest axle spacings usually control the calculations. Strictly speaking, all spacings in the screening vehicles ranges are given as variables. But all these ranges, except first and third, vary by only two feet or less; it was assumed acceptable to consider only the lowest value for all spacings except first and third.

The numbers of real permit trucks within proposed screening vehicles ranges

The practical value of the new screening method is best described by the percentage of real permit trucks that do not exceed the load effects of the IRVs (labelled as “not-exceeding-IRVs” permits in Table 3 below) and fall within the proposed screening vehicle axle weight and spacing ranges. Note that the “not-exceeding-IRVs” real permit trucks are defined as vehicles from IDOR’s database whose load effects do not exceed load effects produced by the IRVs – on any bridge from the considered suite of bridges. These “not-exceeding-IRVs” vehicles are the ones acceptable for permitting when using the screening method. The intent of the new method was to “replicate” with the screening vehicles only these “not-exceeding-IRVs” vehicles to the greatest possible extent.

In the IDOR database of permit trucks, there were 81,037 OC Permits that satisfy the Tennessee Formula. Table 3 shows – by the number of axles and by the type of permit – that of these 81,037 OC permits, 40,357 permits are “not-exceeding-IRVs” permits and of these, 34,286 fall within the proposed screening vehicles. So, 85% (34,286/40,357=0.85) of all "not-exceeding-IRVs" OC Permits (that satisfy the Tennessee Formula) are captured by the proposed screening vehicles, shown in Table 2.

TABLE 3 – The number of Overweight Commodity Permits that satisfy the Tennessee Formula within proposed screening vehicles

	Agricultural Permits			**Steel Permits**				**All Permits**
No. of axles	5	6	7	5	6	7	8-11	All axles
No. of OC Permits satisfying Tennessee Formula	5,568	608	182	23,258	40,763	9,500	1,428	**81,307**
No. of "not-exceeding-IRVs" OC Permits	5,568	598	182	23,256	6,614	4,139	276	**40,357**
No. of OC Permits that fall within the screening vehicles	4,872	524	148	23,074	3,507	2,161	0	**34,286**
No. of OC Permits that fall within the screening vehicles regarding axle spacings only	5,308	558	152	23,074	36,991	8,927	0	**75,010**

In addition, an important aspect of the method is a number of vehicles that fall within the proposed screening vehicles ranges regarding axle spacings only, and not necessarily when axle weights are considered. In these cases, if a truck's axle weights are reduced – to accommodate defined axle weight requirements – the same truck can still be used and permitted with modified axle weights. In other words, an overweight truck that does not satisfy the screening vehicles due to overweight axles and possibly GVW can be made to satisfy the screening criteria by simply modifying the axle weight to an acceptable axle configuration that passes the screening criteria. Note that a majority of the permit trucks (75,010 of 81,307 permits) have axle spacings that fall within the proposed screening vehicles axle spacing limits (Table 3). Therefore, these 75,010 vehicles can immediately be approved for permit (if they satisfy the screening vehicles) or they can simply reduce the axle weights in order to get permitted. Note that the analyses showed (Table 3) that a significant number of overweight vehicles that would be permitted by the Tennessee Formula actually exceeded the load effects produced by IRVs, when LFR or LRFR method was employed (on at least one bridge from the suite of bridges defined earlier).

In terms of practical implementation, if the new screening method is employed to evaluate a permit request then a permit request is either found to be acceptable and a permit can be issued immediately or an alternative analysis must be explored. If the screening fails, one option is to use a refined analysis to further evaluate the acceptability of the permit request. However, this option will take additional time since it must be referred to the DOT for analysis and evaluation of the actual affected bridges. A second alternative is for the trucking company to decrease the axle weights for the proposed truck spacing until it passes one of the screening vehicles. A third option is for the trucking company to use a different truck axle configuration that passes one of the screening vehicles ranges. The advantage of the last two options is that permit trucks can be immediately checked for possible acceptability using the new screening method by nontechnical personnel.

CONCLUSIONS

The focus of this study is on developing a new screening method where permit loads and rating vehicles are directly compared in accordance with the current load rating requirements. The new method employs a set of screening vehicles as a solution for rapid evaluation of overweight permit requests. Only by checking whether a truck's axle weights and axle spacings are within any of the proposed screening vehicles ranges, a permit truck can be safely permitted as a single trip, "point-to-point" permit (without considering actual bridges that a truck will pass on its route). A simple computer program or a spreadsheet, containing all listed screening vehicles, can be easily made to implement this method. Using this computer program or spreadsheet, non-technical personnel can automatically determine whether or not a permit truck belongs to any of the proposed screening vehicles.

Finally, it can be concluded that the presented screening method has the following features:

(a) it is safe – the extensive sets of "permutation" trucks constructed for each screening vehicle were checked against the defined set of rating vehicles (taken as the minimum threshold that any non-posted bridge must be able to withstand), on the comprehensive suite of bridges;
(b) it is practical – a large number of actual permits can be easily evaluated using this method;
(c) it can be easily implemented and used by non-technical personnel;
(d) it helps to identify acceptable truck axle configurations to which the trucking industry might adjust in order to obtain maximum GVWs, which are still acceptable for the bridge inventory in the country; and
(e) if widely adopted, it could decrease the non-uniformity of permitting processes for overweight vehicles among different state.

ACKNOWLEDGMENTS

This study was supported by the Joint Transportation Research Program administered by the Indiana Department of Transportation and Purdue University. The authors wish to thank Raju Iyer and Ms. Angela Woodard of the Indiana Department of Revenue for their assistance. The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policies of the sponsoring organizations. These contents do not constitute a standard, specification or regulation.

REFERENCES

1. *Bridge Formula Weights*. US Department of Transportation, 2006.
2. G. Fu, C. F. *Bridge Rating Practices and Policies for Overweight Vehicles: Synthesis of Highway Practice. NCHRP Synthesis 359*. Washington, D.C., 2006.
3. Cooperative, N. *Multi-State, Multimodal, Oversize/Overweight Transportation; NCHRP Report 830*. 2016.
4. Titi, H., N. Coley, V. Latifi, and M. Matar. Characterization of Overweight Permitted Truck Routes and Loads in Wisconsin. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2411, 2014, pp. 72–81.
5. Li, Y., J. T. Le, D. R. Middleton, and C. A. Quiroga. Mapping Oversized and Overweight Truck Routes with Procedure Based on Geographic Information Systems. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2291, No. 1, 2012,

pp. 8–16.

6. Chou, C. C., J. H. Deatherage, T. D. Leatherwood, and A. J. Khayat. Innovative Method for Evaluating Overweight Vehicle Permits. *Journal of Bridge Engineering*, Vol. 4, issue 3, No. August, 1999, pp. 221–227.
7. *Oversize/Overweight Vehicle Permitting Handbook*. Indiana Department of Revenue, 2016.
8. *Manual of Bridge Evaluation*. 3rd edition with 2016 interim revisions AASHTO, Washington, D.C., 2012.
9. *Bridge Inspection Manual - Part 3*. Indiana Department of Transportation, 2016.
10. *LRFD Bridge Design Specification*. 7th edition AASHTO, Washington, D.C., 2015.
11. *Standard Specifications for Highway Bridges*. 17th Edition AASHTO, Washington, D.C., 2002.