TRC1701

Bridge Load Posting Based on Actual Arkansas Truck Traffic

Ernie Heymsfield, Ph.D., P.E.
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University of Arkansas

Final Report

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DISCLAIMER

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16. Abstract

Bridge load posting limits are a safety and economic decision. Bridge load posting limits restrict truck traffic to ensure safety. Therefore, trucks that exceed bridge load posting limits are required to take alternate routes. The Arkansas Department of Transportation (ARDOT) uses a family of CMV (commercial motor vehicle) configurations and loadings with the designations ‘CODE 4’, ‘CODE 9’, and ‘CODE 5’ as their weight limit posting vehicles. These trucks are used to represent trucks using Arkansas bridges. These truck configurations were initially considered in the 1980’s. Since then, truck configurations and axle loadings have significantly changed. Therefore, currently used ARDOT load posting truck configurations and weights may be outdated and may not be representative of critical truck loads actually supported by Arkansas bridges. Consequently, there is a need to correctly identify Arkansas truck traffic weights and configurations so that ARDOT bridge engineers can accurately assess bridge weight limit values for bridge posting.

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Abstract
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Introduction

Bridge design incorporates live load as defined in the AASHTO specifications (AASHTO 2014). The AASHTO live load is a notional load that conservatively envelops the effects of all possible truck configurations. However, a family of truck configurations is used for load posting to more accurately replicate actual truck traffic within a state and therefore, not be overly restrictive. Federal standards require states to load rate bridges as a function of the existing bridge condition and limit truck traffic at deficient bridges to ensure structural bridge safety. Bridge inspection requirements are included in 23 CFR 650.313, which references the AASHTO Manual for Bridge Evaluation, 2nd edition for bridge inspection details. The Arkansas Department of Transportation (ARDOT) Structural Inventory and Rating Section is responsible for determining the safe load capacity of approximately 13,000 existing bridges in Arkansas (ARDOT Bridge Division 2015).

Whereas bridge load rating is an engineering activity, bridge load posting is a safety and economic decision (AASHTO 2011). Bridge load posting controls bridge usage by establishing a limiting value for the maximum truck weight, as a function of axle configuration, permitted to use a load posted bridge. Consequently, bridge load posting is a safety decision coupled with economic consequences. ARDOT currently rates its bridges using a set of truck vehicles developed in the 1980s. Although truck configurations and loads have significantly changed over the last 30 years, ARDOT has not updated this set of truck vehicles. Therefore, the researchers in this study summarized the truck fleet that currently uses Arkansas roads and investigated the impact of this updated truck fleet on existing bridge load posting values. The ARDOT Transportation Research Committee (TRC) met with the TRC1701 project investigators on November 2, 2016. The project process outline to obtain the study objectives is included in Figure 1.

Per the project objectives, weigh-in-motion (WIM) data were obtained from ARDOT and filtered to develop unique (representative) trucks for each of the Federal Highway Administration (FHWA) truck classes. Next, bridge response was determined as a function of each of the FHWA truck classes pertinent to this study. Bridge response as a function of moment and shear was evaluated considering multiple span configurations and span lengths. Bridge response due to actual truck traffic was then compared to the bridge response calculated considering the current ARDOT load posting truck family. Cases where bridge response due to actual truck traffic exceeded the maximum bridge response developed from the current ARDOT load posting truck family are highlighted in this report. An unanticipated finding in this study was the high percentage of trucks that exceeded the Federal Bridge Formula (FBF) weight limits. The report summarizes the study findings with recommendations for future bridge load posting protocol. Each of the project processes is described in the following report sections.

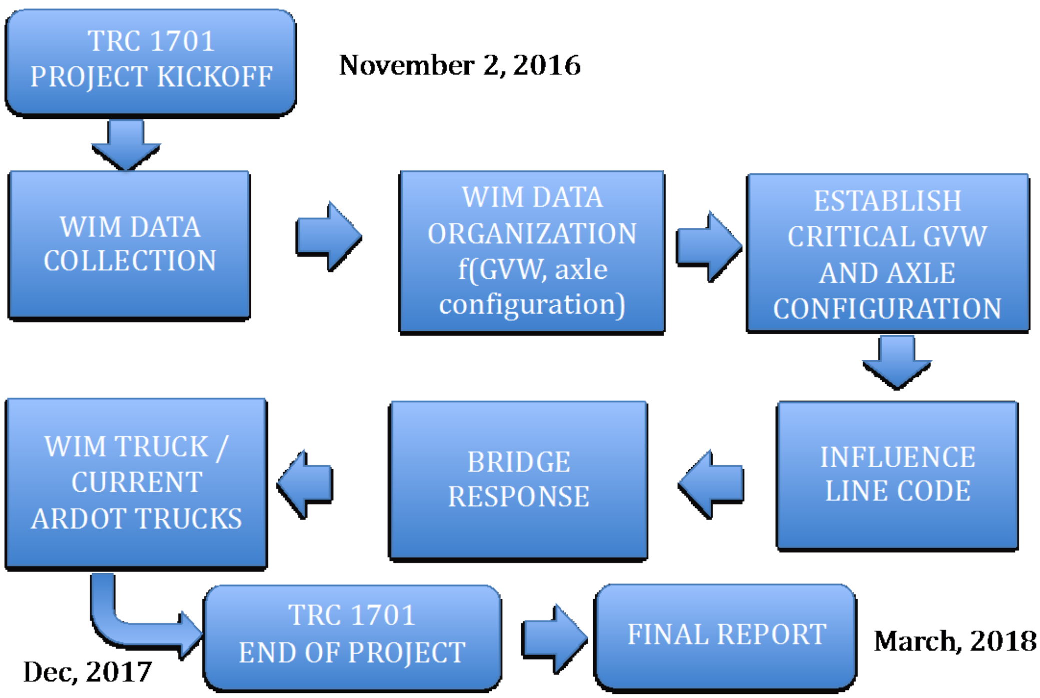

Figure 1. Project Process Outline

Grouping Current Arkansas Truck Types

WIM stations provide a method to monitor traffic volumes and loads on highways. These stations continuously collect information on axle weights, axle spacing, and vehicle classification. WIM data from 2005 to 2015 collected by ARDOT were used in this study to discern common truck configurations in terms of axle spacing and weight. The following sections of this report describe the methods used to identify unique (representative) trucks from the historical WIM data.

Description of Truck Data from WIM Sites

Truck weights and their corresponding truck axle configuration are collected within Arkansas using static weigh stations and WIM systems. Static weigh stations are used for enforcement of oversized and overweight vehicles while WIM systems are used for data collection. WIM systems are used to collect data for pavement design and management, bridge design and loading restrictions, geometric design, air quality, federal data reporting requirements, and freight transportation planning programs (FHWA 2016). Static weigh stations are typically located at state border crossings whereas WIM systems are widely deployed across the state for data collection purposes. A limitation to static weigh stations is that they are evident. Consequently, drivers of overweight and oversized vehicles may use alternate driving routes to bypass static weigh stations. WIM sites are less obvious and, therefore, more likely to capture the actual truck traffic in a region. In this project, WIM data served as the primary source of truck data used for the latter bridge analysis section of the study.

Arkansas WIM Sites

ARDOT maintains 61 WIM sites in Arkansas, Figure 2. Data from these sites for the years 2005 through 2015 were made available to the study team.

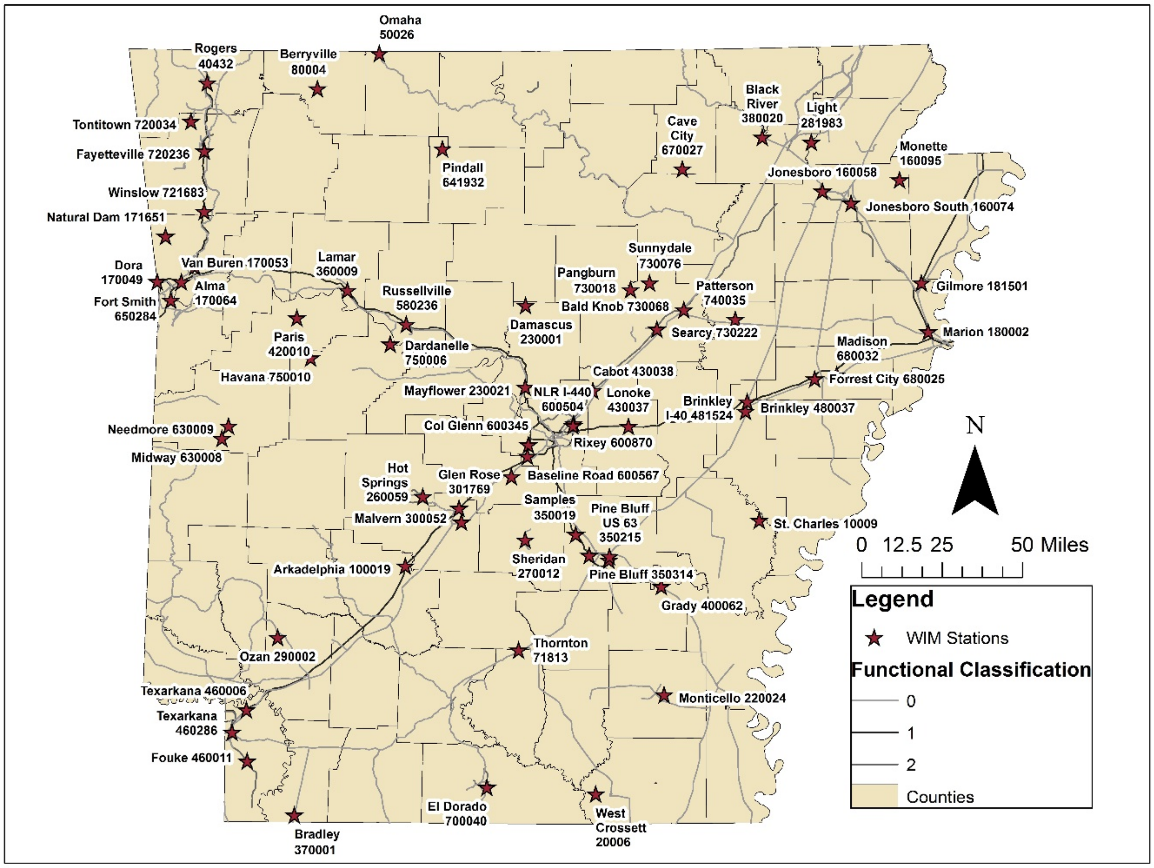

Figure 2. WIM Site Locations Maintained by ARDOT

The number of WIM sites reporting continuous data varied by year. Table 1 summarizes the WIM stations by identification number, county, route, median Annual Average Daily Truck Traffic (AADTT), and the percent of volume of FHWA Class 9 trucks (i.e. five axle tractor trailers or '3S2' configurations). The stations listed in Table 1 contain complete location information.

Table 1. Station Information

Station	**County**	**Route**	**Median AADTT**	**% FHWA Class 9 Trucks**
10009	Arkansas	AR 1	220	51.4
20006	Ashley	US 82	450	56.7
40432	Benton	I-540/I-49	2300	44.7
50026	Boone	US 65	525	34.9
71813	Calhoun	US 79	745	49.3

Station	County	Route	Median AADTT	% FHWA Class 9 Trucks
80004	Carroll	AR 21	130	20.6
100019	Clark	I-30	9000	66.7
160058	Craighead	AR 63	765	30.8
160074	Craighead	AR 63	970	42.1
160095	Craighead	AR 18	275	24.0
170049	Crawford	I-40	3850	66.2
170053	Crawford	US 64	580	29.4
170064	Crawford	I-540/I-49	2830	56.9
171651	Crawford	AR 59	95	23.1
180002	Crittenden	I-55	6110	19.9
181501	Crittenden	I-55	6445	76.0
220024	Drew	AR 35	110	26.2
230001	Faulkner	US 65	555	31.3
230021	Faulkner	I-40	6045	57.3
260059	Garland	US 70	340	23.1
270012	Grant	AR 46	145	34.4
281983	Greene	US 412	380	50.4
290002	Hempstead	US 278	245	42.4
300052	Hot Spring	US 270	454	47.6
301769	Hot Spring	I-30	9090	66.2
350019	Jefferson	I-530	1295	46.0
350215	Jefferson	US 65	260	20.2
350314	Jefferson	I-530	1360	40.9
360009	Johnson	I-40	4495	57.4
370001	Lafayette	AR 29	505	62.0
380020	Lawrence	US 63	550	41.3
400062	Lincoln	US 65	750	58.4
420010	Logan	AR 22	170	23.2
430037	Lonoke	I-40	10890	67.6
430038	Lonoke	US 67	1470	35.0
460006	Miller	I-30	8300	66.5
460011	Miller	I-549/I-49	825	47.6
460286	Miller	I-49	1310	42.8
480037	Monroe	US 70	450	41.0
580236	Pope	I-40	5150	57.5
600345	Pulaski	I-430	840	17.9
600504	Pulaski	AR 440	8995	62.9
630008	Scott	AR 71	565	54.5
630009	Scott	AR 71	420	44.6

Station	County	Route	Median AADTT	% FHWA Class 9 Trucks
641932	Searcy	US 65	400	40.0
670027	Sharp	AR 115	105	13.1
680025	St. Francis	I-40	10910	67.9
700040	Union	AR 167	860	47.8
720034	Washington	US 412	1155	40.5
720236	Washington	I-49	2925	49.9
721683	Washington	I-49	2405	44.5
730018	White	AR 16	170	22.8
730068	White	US 67	1215	48.8
730076	White	AR 124	190	31.8
730222	White	AR 367	145	15.9
740035	Woodruff	US 64	545	50.8
750006	Yell	AR 7	285	27.7

WIM Data Elements

WIM systems collect axle weight and axle spacing data in order to estimate vehicle class based on specified vehicle classification schemes. Raw WIM data records consist of time stamped individual truck axle weights, axle spacing, and total truck weight measurements (Lu et al. 2002).

The WIM sensor configurations at each WIM site vary slightly but are typically configured as shown in Figure 3 with a pair of piezo-electric (PE) sensors straddling an inductive loop detector (ILD) (Hallenbeck and Weinblatt 2004).

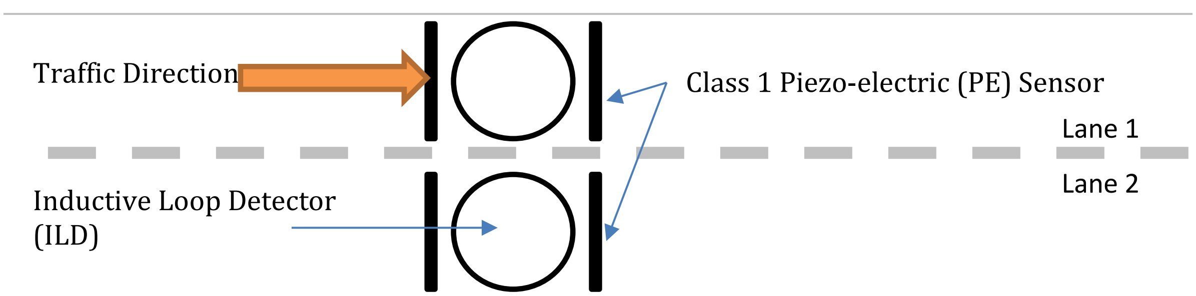

Figure 3. WIM Site Configuration

Figure 4 is an example of a WIM site and provides a street view of the PE sensors and ILD at the I-49 Fayetteville WIM site. The ILD detects the presence of a vehicle. The PE sensors are used to measure axle loads and axle spacing. The PE sensors measure the applied axle force during the time the truck axles are in contact with the PE sensor. The force is then converted to an axle weight measurement. The total weight of the vehicle is calculated as the sum of all vehicle axle weights. To determine how axles are configured and grouped for each vehicle, vehicle speed is calculated by measuring the time the front vehicle axle triggers the PE sensor to the time the rear vehicle axle triggers the PE sensor. Raw WIM data are typically summarized as a function of truck class volume, gross vehicle weight (GVW, the total weight of the vehicle), axle load spectra (i.e. load distributions by axle type), and equivalent single axle loads (ESAL).

Figure 4. Street View of WIM Site (Image from Google Maps)

WIM data may possess errors in speed, axle spacing, and weight measurements (Hallenbeck et al. 2014). These inaccuracies can result from both random and system errors. Random errors correspond to the vehicle and result from vehicle dynamics (such as an off-center vehicle or an accelerating vehicle within the WIM site configuration). System errors correspond to the recording equipment and cause consistent errors in the data collection process. System errors result from sensor calibration issues which cause measurements to be consistently over or under estimated values (Prozzi and Hong, 2007). Mathematical algorithms are available to identify and correct for the system error component (Southgate 2001; Chou and Nichols 2015). In this project, appropriate data pre-processing consisting of random error filters and system error correction procedures were applied to ensure that the WIM data used in the study analysis represented the actual truck traffic operating in Arkansas.

WIM Vehicle Classification

An important purpose of deploying WIM sensors as part of a continuous data collection program is to gather axle-based vehicle classification data along with vehicle weight (FHWA 2016). Vehicle classification is possible by using axle configuration and vehicle weight measurements attained using the WIM system. The most commonly used classification scheme, and that required for reporting to the Highway Performance Monitoring System (HPMS), is the thirteen-class FHWA scheme (FHWA 2014). The thirteen-class FHWA classification scheme was developed during the 1980's (Hallenbeck et al. 2014). The Long Term Pavement Performance (LTPP) program further refines the FHWA classification scheme to include a more detailed axle based classification scheme shown in Table 2 (Hallenbeck et al. 2014). As shown in Table 2, the LTPP scheme defines sub-classes for each of the FHWA classes. The LTPP scheme was used to classify trucks used in this study.

Table 2. LTPP Classification Rules for SPS WIM Sites (adopted March 2006 by the Traffic Expert Task Group (ETG)).

Class	Vehicle Type	No. Axle	Axles 1 & 2 (ft)	Axles 2 & 3 (ft)	Axles 3 & 4 (ft)	Axles 4 & 5 (ft)	Axles 5 & 6 (ft)	Axles 6 & 7 (ft)	Axles 7 & 8 (ft)	Axles 8 & 9 (ft)	Gross Weight Min-Max (k)	Axle 1 Weight Min (k)
1	Motorcycle	2	1.00-5.99	----	----	----	----	----	----	----	0.10-3.00	----
2	Passenger Car		6.00-10.10	----	----	----	----	----	----	----	1.00-7.99	----
3	Other (Pickup/Van)		10.11-23.09	----	----	----	----	----	----	----	1.00-7.99	----
4	Bus		23.10-40.00	----	----	----	----	----	----	----	12.00 >	----
5	2D Single Unit		6.00-23.09	----	----	----	----	----	----	----	8.00 >	2.50
2	Car with 1 Axle Trailer	3	6.00-10.10	6.00-25.00	----	----	----	----	----	----	1.00-11.99	----
3	Other with 1-Axle Trailer		10.11-23.09	6.00-25.00	----	----	----	----	----	----	1.00-11.99	----
4	Bus		23.10-40.00	3.00-7.00	----	----	----	----	----	----	20.00 >	----
5	2D with 1-Axle Trailer		6.00-23.09	6.30-30.00	----	----	----	----	----	----	12.00-19.99	2.50
6	3-Axle Single Unit		6.00-23.09	2.50-6.29	----	----	----	----	----	----	12.00 >	3.50
8	Semi, 2S1		6.00-23.09	11.00-45.00	----	----	----	----	----	----	20.00 >	3.50
2	Car with 2-Axle Trailer	4	6.00-10.10	6.00-30.00	1.00-11.99	----	----	----	----	----	1.00-11.99	----
3	Other with 2-Axle Trailer		10.11-23.09	6.00-30.00	1.00-11.99	----	----	----	----	----	1.00-11.99	----
5	2D with 2-Axle Trailer		6.00-26.00	6.30-40.00	1.00-20.00	----	----	----	----	----	12.00-19.99	2.50
7	4-Axle Single Unit		6.00-23.09	2.50-6.29	2.50-12.99	----	----	----	----	----	12.00 >	3.50
8	Semi, 3S1		6.00-26.00	2.50-6.29	13.00-50.00	----	----	----	----	----	20.00 >	5.00
8	Semi, 2S2		6.00-26.00	8.00-45.00	2.50-20.00	----	----	----	----	----	20.00 >	3.50
3	Other with 3-Axle Trailer	5	10.11-23.09	6.00-25.00	1.00-11.99	1.00-11.99	----	----	----	----	1.00-11.99	----
5	2D with 3 Axle Trailer		6.00-23.09	6.30-35.00	1.00-25.00	1.00-11.99	----	----	----	----	12.00-19.99	2.50
7	5-Axle Single Unit		6.00-23.09	2.50-6.29	2.50-6.29	2.50-6.30	----	----	----	----	12.00 >	3.50
9	Semi, 3S2		6.00-30.00	2.50-6.29	6.30-65.00	2.50-11.99	----	----	----	----	20.00 >	5.00
9	Truck+Full Trailer (3-2)		6.00-30.00	2.50-6.29	6.30-50.00	12.00-27.00	----	----	----	----	20.00>	3.50
9	Semi, 2S3		6.00-30.00	16.00-45.00	2.50-6.30	2.50-6.30	----	----	----	----	20.00 >	3.50
11	Semi+Full Trailer, 2S12		6.00-30.00	11.00-26.00	6.00-20.00	11.00-26.00	----	----	----	----	20.00 >	3.50
10	Semi, 3S3	6	6.00-26.00	2.50-6.30	6.10-50.00	2.50-11.99	2.50-10.99	----	----	----	20.00 >	5.00
12	Semi+Full Trailer, 3S12		6.00-26.00	2.50-6.30	11.00-26.00	6.00-24.00	11.00-26.00	----	----	----	20.00 >	5.00
13	7-Axle Multi-trailers	7	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	----	----	20.00 >	5.00
13	8-Axle Multi-trailers	8	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	----	20.00 >	5.00
13	9-Axle Multi-trailer	9	6.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	3.00-45.00	20.00 >	5.00

WIM Data Processing

The WIM data from ARDOT was stored in an open-source database system, PostgreSQL. Each data record included an identifier for the WIM site and characteristic information for each recorded vehicle. WIM site information includes the ID number for the WIM site and the date the information was recorded. For each recorded vehicle, information is provided for the vehicle's class, individual axle weights, gross vehicle weight, and the vehicle's number of axles. Table 3 summarizes the total number of annual records contained in the 2005 – 2015 historical WIM data. Each Table 3 record corresponds to a vehicle that passed over an Arkansas WIM site. Note that in some years (e.g. 2010) only truck records were included in the data (i.e. FHWA classes 5 through 14).

Table 3. Approximate Number of Records per Year

Year	Approximate Number of Records
2005	43,000,000
2006	39,000,000
2007	36,000,000
2008	29,000,000
2009	33,000,000
2010	17,000,000
2011	25,000,000
2012	31,000,000
2013	25,000,000
2014	33,000,000
2015	35,000,000
TOTAL	**346,000,000**

These data records were filtered to eliminate random and system errors. The algorithms used to filter the WIM data are described in the following text.

Existing Processing Methods

National Cooperative Highway Research Program (NCHRP) Report 683 describes filters used to review and eliminate "bad or unreliable [WIM] data" (Sivakumar et al. 2011). These filters are designed to check WIM data against possible recording errors. The NCHRP Report 683 method represents the state-of-the-practice approach for eliminating faulty WIM data due to site calibration issues. To avoid faulty data, truck data satisfying the Table 4 filters are removed from the WIM data set.

Table 4. NCHRP WIM Data Filters

Property	Filter
Speed	<10 mph
Speed	>100 mph
Truck Length	>120 ft
Total Number of Axles	>12
Total Number of Axles	<3
Gross Vehicle Weight	<12 k
Any Individual Axle	>70 k
Sum of Axle Spacing	>Length of Truck
Steer Axle	>25 k
Steer Axle	<6 k
First Axle Spacing	<5 ft
Any Axle Spacing	<3.4 ft
Any Axle	<2 k
Gross Vehicle Weight	+/- 0.1*(Sum of Axle Weights)

After filtering the data as per Table 4, NCHRP Report 683 recommends that the data pass through 'quality control checks.' Quality control checks typically use FHWA Class 9 tractor-trailer configured trucks as a reference for data quality (Ott and Papagiannakis 2014). The NCHRP Report 683 quality control checks include:

1. Percentage of trucks by class. Class 9 trucks should be the most prevalent truck class in the population.
2. Class 9 truck GVW histogram. The characteristic bi-modal shape of the GVW histogram should show an "unloaded" truck GVW peak between 28 k and 32 k, and a "loaded" GVW truck peak between 72 k and 80 k.
3. Overweight Class 9 trucks. The percentage of Class 9 trucks over 100 k should be small.
4. Class 9 truck steer-axle weight histogram. The weight of the front axle of Class 9 trucks should be between 9 k and 11 k. There should not be a significant deviation from this range.
5. Class 9 truck drive-tandem weight histogram. The weight of the drive tandem should not deviate significantly from the estimated values given in NCHRP Report 495 (Fu et al. 2003).
6. Class 9 truck axle-spacing histogram. The spacing between the steer axle and the drive tandem axle as well as the spacing between the drive tandem axles should be fairly consistent.

Applying the Filtering Processing Method to the Current Study

Figure 5 summarizes the processing methods applied to discern unique truck configurations from the raw WIM data records. The process follows two key sub-processes and filters: *(i)* Calibration Filter and *(ii)* Select Unique Trucks.

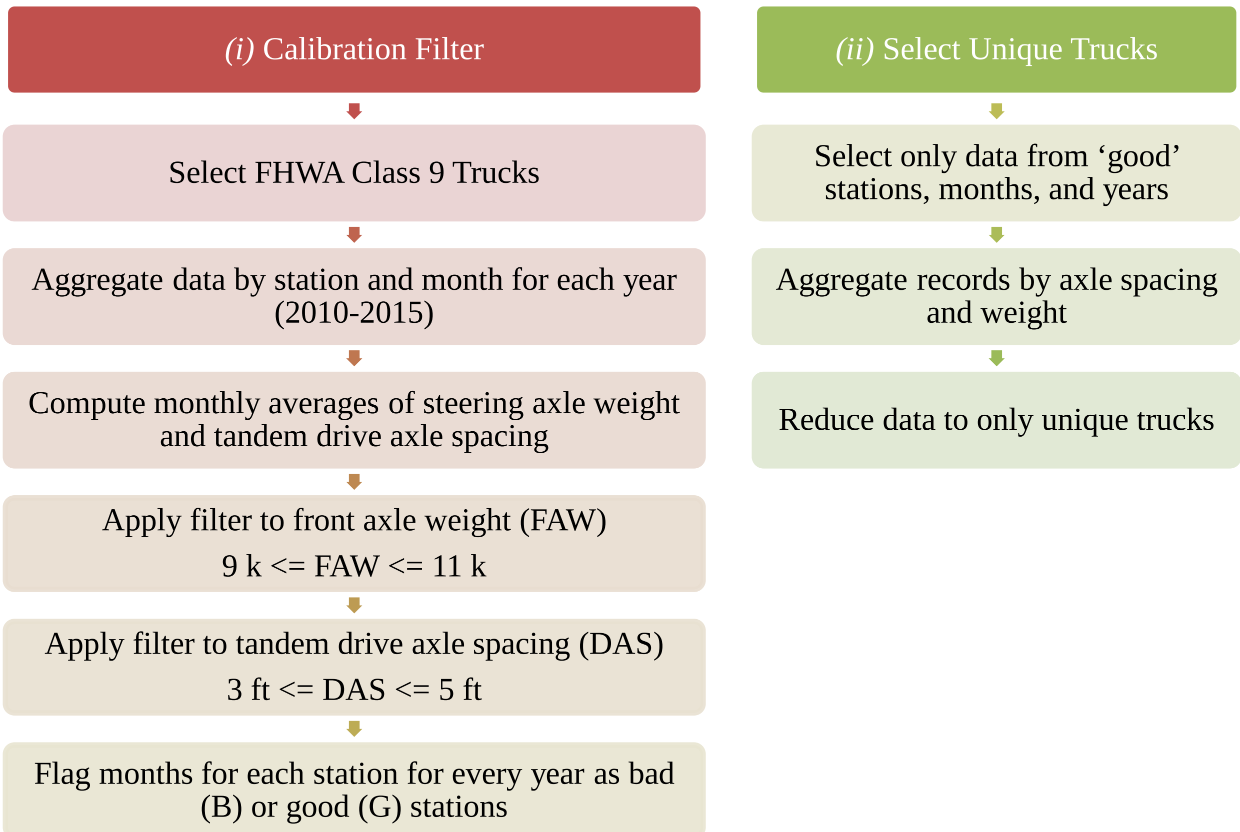

Figure 5. WIM Calibration and Unique Truck Identification

The calibration filter sub-process shows how WIM sensor calibration issues were detected. The calibration filter is primarily based on checking the median front axle weight (FAW) and the tandem drive axle spacing (DAS). Only calibrated data were used in the selection of unique trucks in this study.

Calibration Filter

The calibration filter was applied to LTPP Class 9 '3S2' trucks to identify WIM stations that were consistently over/under measuring truck weight or axle spacing on a monthly basis. WIM data from each WIM station were aggregated by month and year to determine the FAW and DAS. It should be noted that median measurements were used, rather than the mean. The use of median is more appropriate when high volumes of outliers are present. If the monthly median values did not meet the following criteria:

1. the median FAW between 9 k and 11 k and/or
2. the median DAS between 3 ft and 5 ft,

then data for that particular station, month, and year were removed from further analysis. These ranges represent conservative restrictions on data quality. Any station with monthly median FAW and/or DAS data that did not meet these criteria was flagged as having a calibration status of 'bad;' otherwise, the data were marked as 'good.' The WIM site calibration status was stored in the PostGreSQL database for future reference. The percentage of good months per station per year can be seen in Appendix A of this report.

Unique Truck Processing

Records passing the calibration filter (i.e. station, month, and year marked as 'good') were then consolidated according to their axle weight and spacing configurations using the LTPP classification scheme. Axle weight was aggregated to 1 k increments and the spacing between axles was aggregated to 1 ft increments. For example, given two FHWA Class 5 (two axle single unit) trucks, Truck A and Truck B. Truck A has a front axle weight of 1.2 k, a rear axle weight of 2.3 k, and a 10.1 ft axle spacing. Truck B has a front axle weight of 1.7 k, a rear axle weight of 2.7 k and an axle spacing equal to 10.9 ft. With these two sets of values, Truck A and Truck B would be aggregated into the same unique (representative) truck. The unique truck would be represented as having a front axle weight of 2 k, a rear axle weight of 3 k, and an inter-axle spacing of 11 ft. Finally, unique truck configurations containing less than six total vehicles were removed from further analysis. This was done to remove outliers that could potentially be due to inaccurate records caused by random errors in measurement.

WIM Results and Summary of WIM Data Characteristics

As shown in Figure 2, the WIM sites in Arkansas are dispersed across the state representing different highway types, traffic volumes, and vehicle characteristics. Table 5 summarizes the WIM sites by highway functional class. Several Arkansas WIM site datasets did not have a functional class listed in the site characteristics data and therefore are not included in Table 5. The majority of sites are either on the interstate (30.43%) or along principal arterials (30.43%). Figure 6 shows the number of sites by AADTT for each year of available ARDOT WIM site data. Thirty-four percent of sites have AADTT in the range of 100 to 500 trucks per day. Figure 7 shows the percent of each FHWA vehicle class for each year for all the WIM sites. The majority (approximately 65% each year) of trucks fall into the FHWA Class 9, five axle tractor-semi trailers. The second most common truck type is the FHWA Class 5, two-axle, single unit truck representing approximately 18% of the total volume. All of the other truck classes each represent less than 10% of the total volume per year.

Table 5. Arkansas WIM Sites by Functional Class

Functional Class	Description	Number of WIM Stations in AR	Percent of WIM Stations
1	Interstates	14	30.43%
2	Other Freeways and Expressways	4	8.70%
3	Other Principal Arterials	14	30.43%
4	Minor Arterials	8	17.39%
5	Major Collectors	6	13.04%
6	Minor Collectors	0	0.00%
Total		**46**	**100.0%**

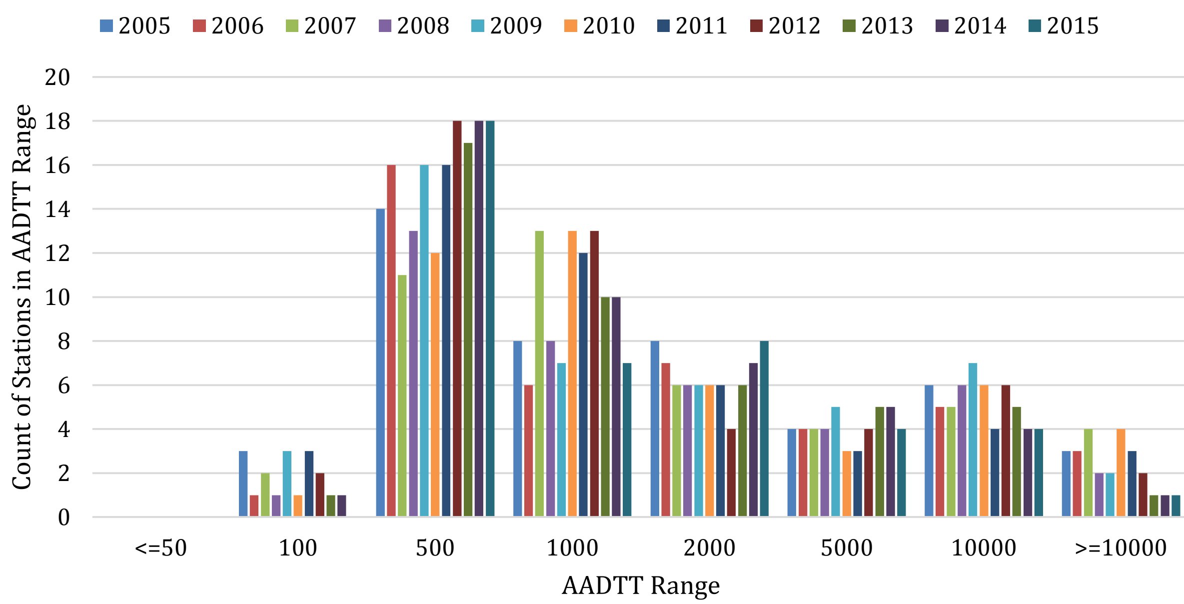

Figure 6. AADTT by WIM Year for AR WIM Sites

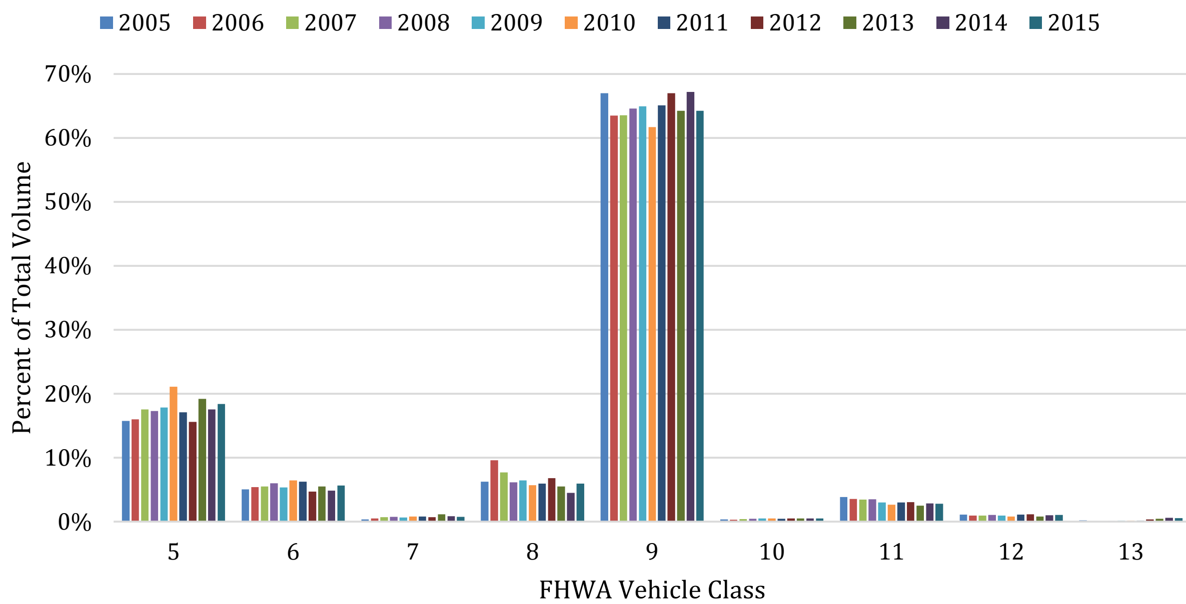

Figure 7. FHWA Class Volume by Year for AR WIM Sites

Summary of WIM Data Reduction

The raw WIM data were first checked for sensor calibration issue (i.e. systematic over or under weight and axle spacing measurements) and then reduced to develop a set of unique (representative) trucks (see Figure 5). Table 6 summarizes the number of sites reporting data in each year, the average number of months of data that were reported, and the average percent of 'good' months per station; a 'good' month is one in which the median FAW and median DAS were within acceptable ranges. The average number of months of data per station provides a measure of the breadth of data from the site. Table 6 reflects the reality that WIM sites may stop reporting data for periods at a time, sometimes spanning a day or in some cases extending for a month.

Table 6. Available Data by Year After Using the Calibration Filter

Year	Number of Sites with Data	Average Number of Months of Data Per Station	Average Percent of 'Good' Months Per Station
2005	48	7.7	34%
2006	46	9.6	55%
2007	48	8.8	52%
2008	45	8.4	79%
2009	49	9.2	81%
2010	49	7.7	82%
2011	51	7.9	74%
2012	53	8.8	84%
2013	47	9.9	79%
2014	49	10.3	77%
2015	45	10.3	74%

Table 7 details the data reduction from total number of raw records to unique truck configurations. The second column (raw number of records) is the total number of truck records without any quality filter applied. The third column is the number of records per class that remain after applying the calibration filter described in the previous section. The fourth column is the total number of trucks that are represented by a unique truck configuration after removing configurations with less than 6 records. The fifth column is the number of unique configurations where each configuration differs by 1 ft of inter-axle spacing and 1 k of axle weight. By grouping data into unique truck configurations, the raw WIM data was filtered to 0.4% of the amount of raw data collected. Reducing the WIM truck data to a unique truck study group significantly reduced the computational burden involved in determining bridge responses for the vehicle study group.

Table 7. Summary of Data Reduction

FHWA Vehicle Class	Raw Number of Records	Number of Records After Calibration Filter	Number of Records Represented by Unique Configurations	Number of Unique Configurations
5	43,977,574	33,222,625	31,180,985	44,672
6	13,817,615	11,204,608	9,411,260	39,990
7	1,672,234	1,362,099	73,839	5,174
8	16,399,926	12,262,826	2,346,060	84,724
9	163,815,413	130,348,887	61,688,150	794,346
10	923,230	745,999	192	30
11	7,935,274	6,232,768	1,200,670	40,450
12	2,569,721	2,028,894	51,670	3,241
13	312,556	266,520	715	50
Total	**251,423,543**	**197,675,226**	**105,953,541**	**1,012,677**

There is a significant difference in the size of the data sets representing the "Number of Records After Calibration Filter" and the "Number of Records Represented by Unique Configurations" for several FHWA vehicle classes. For example, for FHWA Class 10, only 192 records were considered from the 745,999 calibrated records in deriving unique Class 10 truck configurations. This large reduction is due to requiring a minimum of six records in a configuration grouping for representing a unique vehicle configuration. The restriction of having a minimum of six vehicle records was utilized as an additional filter in an attempt to rule out records that may contain measurement errors. When considering a ten-year period and more than 40 WIM sites, it was assumed that unique configurations represented by less than six trucks was due to random error.

Summary of Unique Trucks

In the following sections, a summary of the over 1 million unique truck configurations (1,012,677) is presented. The inter-axle spacing and gross vehicle weights are summarized for each vehicle class.

Unique Configurations by Vehicle Class

Tables 8, 9, and 10 summarize the unique configurations for single unit trucks (Class 5, 6, and 7), multi-unit trucks with single trailers (Class 8, 9, and 10), and multi-unit trucks with multiple trailers (Class 11, 12, and 13), respectively. Each FHWA vehicle class is subdivided into more specific vehicle configurations. For example, FHWA Class 5 single unit trucks are subdivided into single units with and without trailers. The average (avg.) and standard deviation (st. dev.) are provided to explain the variability in axle spacing and weights within each FHWA class.

Table 8. Summary of Unique Configurations for Single Unit Trucks (Class 5, 6, and 7)

FHWA Class	Description	Number of Trucks Represented	Number of Unique Config.	Avg. Total Axle Spacing in ft (std. dev.)	Avg. Gross Vehicle Weight in k (std. dev.)
5	2 axle single unit	27,002,296	8,194	17.6 (3.5)	32.9 (16.4)
5	2 axle single unit with one or two axle trailer	4,174,812	36,152	37.3 (6.1)	17.5 (2.4)
5	2 axle single unit with three axle trailer	3,877	326	45.6 (4.3)	18.0 (2.2)
6	3 axle single unit	9,411,260	39,990	21.8 (3.3)	37.0 (13.6)
7	4 axle single unit	73,327	5,098	22.5 (2.8)	58.6 (7.3)
7	5 axle single unit	512	76	24.9 (1.3)	70.6 (5.3)
Total		**40,666,084**	**89,836**	**27.8 (9.3)**	**30.0 (15.7)**

Table 9. Summary of Unique Configurations for Multi-Unit Trucks with Single Trailers (Class 8, 9, and 10)

FHWA Class	Description	Number of Trucks Represented	Number of Unique Config.	Average Total Axle Spacing in ft (std. dev.)	Avg. Gross Vehicle Weight in k (std. dev.)
8	3 axle semi tractor-trailer (2S1)	980,486	26,379	46.8 (10.7)	43.3 (39.4)
8	4 axle semi tractor-trailer (3S1)	567,086	29,202	53.8 (6.6)	40.2 (11.9)
8	4 axle semi tractor-trailer (2S2)	798,488	29,143	48.1 (6.4)	31.5 (7.2)
9	5 axle semi tractor-trailer (3S2)	61,685,687	794,118	60.5 (4.5)	55.4 (17.6)
9	5 axle truck plus full trailer (3-2)	16	2	57.5 (6.4)	45.5 (2.1)
9	5 axle semi tractor-trailer (2S3)	2,447	226	45.8 (4.1)	26 (2.9)
10	6 axle semi tractor-trailer (3S3)	192	30	60.6 (6.3)	47.5 (7.6)
Total		**64,034,402**	**879,100**	**59.4 (6.0)**	**53.8 (19.0)**

Table 10. Summary of Unique Configurations for Multi-Unit Trucks with Multiple Trailers

FHWA Class	Description	Number of Trucks Represented	Number of Unique Config.	Average Total Axle Spacing in ft (std. dev.)	Avg. Gross Vehicle Weight in k (std. dev.)
11	5 axle Semi plus full trailer (2S12)	1,200,670	40,450	67.5 (1.6)	54.8 (10.2)
12	6 axle semi plus full trailer (3S12)	51,670	3,241	75.4 (2.2)	62 (8.6)
13	7 axle multi trailers	715	50	89.8 (1.9)	57.8 (1.7)
Total		**1,253,055**	**43,741**	**68.1 (2.7)**	**55.4 (10.3)**

Overloaded Trucks

Trucks using the interstate system are required to have a gross weight and axle weights that satisfy the FBF (CFR 658), equation (1). However, trucks operating on the state highway system and the local highway system are not required to satisfy FBF axle weight limits. Critical axle groups for the 5-axle semi truck for compliance with the FBF include: the outer group (axles 1-5), the tractor group (axles 1-3), and the trailer group (axles 2-5).

$$w = \frac{500\left[\frac{l(n)}{n-1} + 12n + 36\right]}{1000} \tag{1}$$

where:
w = the maximum allowable total weight within the axle group (k),
l = length between outer axles of the considered axle group (ft), and
n = number of axles within the considered axle group

Equation (1) results in *w* increasing as the number of axles increases and/or the length between outer axles increases.

Truck loads must also satisfy:

(1) w (gross vehicle weight, GVW) ≤ 80 k
(2) w (single axle) ≤ 20 k
(3) w (tandem axles) ≤ 34 k, where tandem axle spacing ≤ 8 ft
except for *n* = 4 (2 * 2 (two tandems)) and l ≥ 36 ft, *w* = 2* 34 k/tandem axle = 72 k.

Additional truck loadings and configurations are permitted through grandfather clauses (i.e. trucks that were permitted prior to the implementation of the FBF in 1975). These trucks normally have short axle spacing configurations.

The FBF was developed using research conducted on single-span bridges. Therefore, it may not be totally appropriate for multi-span bridges (FHWA 1995). A notable finding during this TRC1701 project study was the number of Class 7 vehicles that exceeded the calculated FBF maximum allowable weight. An overloaded truck is defined as a truck with a given vehicle axle spacing that has a measured weight that exceeds the calculated FBF maximum allowable weight. All axle groups for each study truck considered in developing the unique truck configurations and each unique truck configuration were evaluated using the FBF for maximum allowable weight. The number and percentage of Arkansas trucks over the 2005 – 2015 time period that exceeded the FBF maximum allowable weight are shown in Table 11. The total truck percentages are represented graphically in Figure 8. The majority (75.1%) of Class 7 vehicles (single unit trucks with four or more axles) exceed the FBF maximum allowable weight.

Table 11. Overloaded Trucks

	TOTAL TRUCKS			UNIQUE TRUCKS		
TRUCK CLASS	No. TRUCKS	OVERLOADED TRUCKS	% OVERLOADED TRUCKS	No. TRUCKS	OVERLOADED TRUCKS	% OVERLOADED TRUCKS
1	16837	418	2.5	207	31	15.0
2	1885231	0	0.0	3792	0	0.0
3	29433424	0	0.0	17100	0	0.0
4	2453590	266873	10.9	25623	10011	39.1
5	31180985	507704	1.6	44672	3892	8.7
6	9411260	565730	6.0	39990	9670	24.2
7	73839	55430	75.1	5174	3703	71.6
8	2346060	46269	2.0	84724	3532	4.2
9	61688150	2639244	4.3	794346	68256	8.6
10	192	0	0.0	30	0	0.0
11	1200670	55	0.0	40450	9	0.0
12	51670	0	0.0	3241	0	0.0
13	715	0	0.0	50	0	0.0
-99	2992656	20721	0.7	55244	1579	2.9

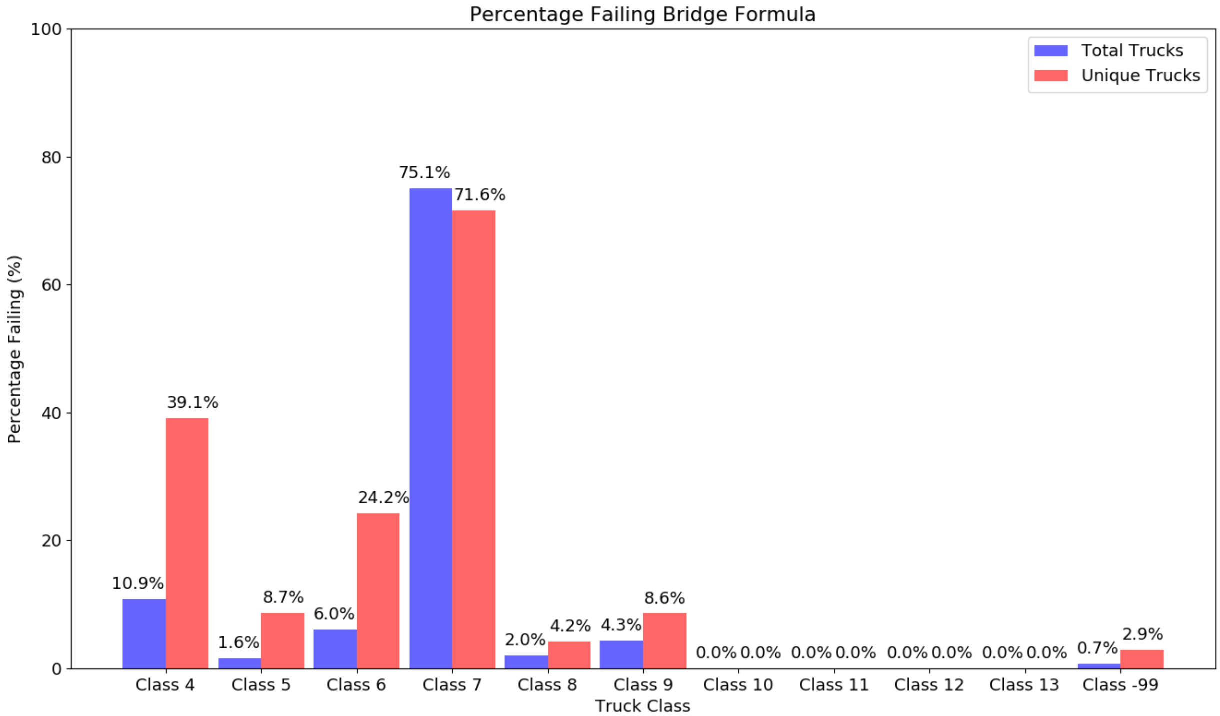

Figure 8. Percentage of Overloaded Trucks Failing the FBF

Figure 9 maps the overloaded FHWA Class 7 (4 and 5 axle single unit trucks) trucks during 2015. Figure 9 demonstrates the regional distribution of the overloaded FHWA Class 7 trucks and that overloaded Class 7 trucks are not limited to a specific region within the state.

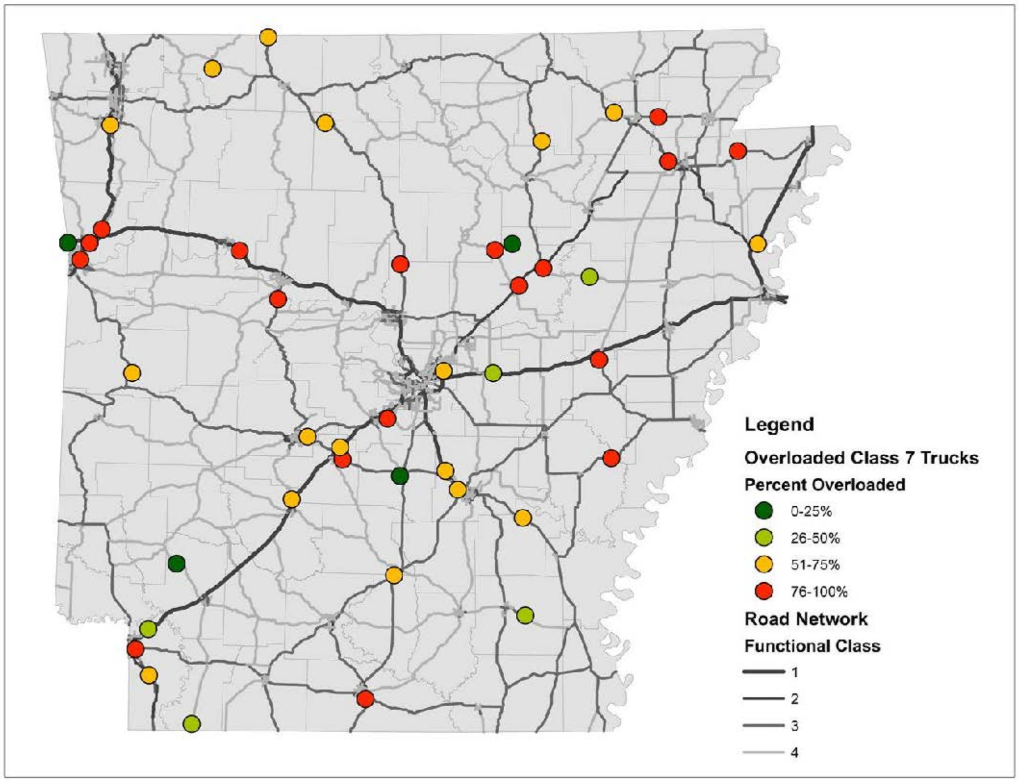

Figure 9. Overload Class 7 Trucks, Regional Distribution Considering 2015 WIM Data.

Figure 10 further details the 2015 regional distribution of Class 7 overloaded trucks. The map in Figure 10 shows the spatial and temporal distributions of overloaded trucks to better understand possible links between overloaded trucks and particular industries / commodity movements. The average monthly volume of Class 7 and Class 9 trucks (five axle semi-tractor trailers) are included for comparison. The FHWA Class 9 volume includes the overall truck volume recorded at each WIM site and, therefore, can be used as a metric for assessing data quality at the WIM site. Sites that have low FHWA Class 9 volumes (i.e. approximately less than 50 trucks per day) may be more susceptible to calibration errors. The bar charts on the Figure 10 map illustrate the percent of overloaded trucks per month at each of the WIM sites. The bar height is proportional to the 100% bar height shown in the legend. Bar charts with missing bars indicate missing data for that month. A review of the map shows that there are no clear spatial or temporal trends in overloaded truck volumes. Therefore, overloaded trucks in this TRC1701 study are not related to a particular region, season, or industry. Rather, it appears that overloaded trucks are common across Arkansas. Without supplemental data from field observations, it is not possible to discern from the WIM data what truck body type the overloaded trucks tend to be.

However, there is anecdotal evidence that the overloaded trucks tend to be heavy dump trucks, concrete mixers, or other specialized hauling vehicles (SHVs). Although not in the scope of this project, future studies should validate this conclusion by investigating axle configurations and making assumptions between the axle configuration and body type. In addition, field observations should be considered in any future study. These future field observations should include selecting a set of representative sites and collecting data throughout the year to investigate seasonal dependency.

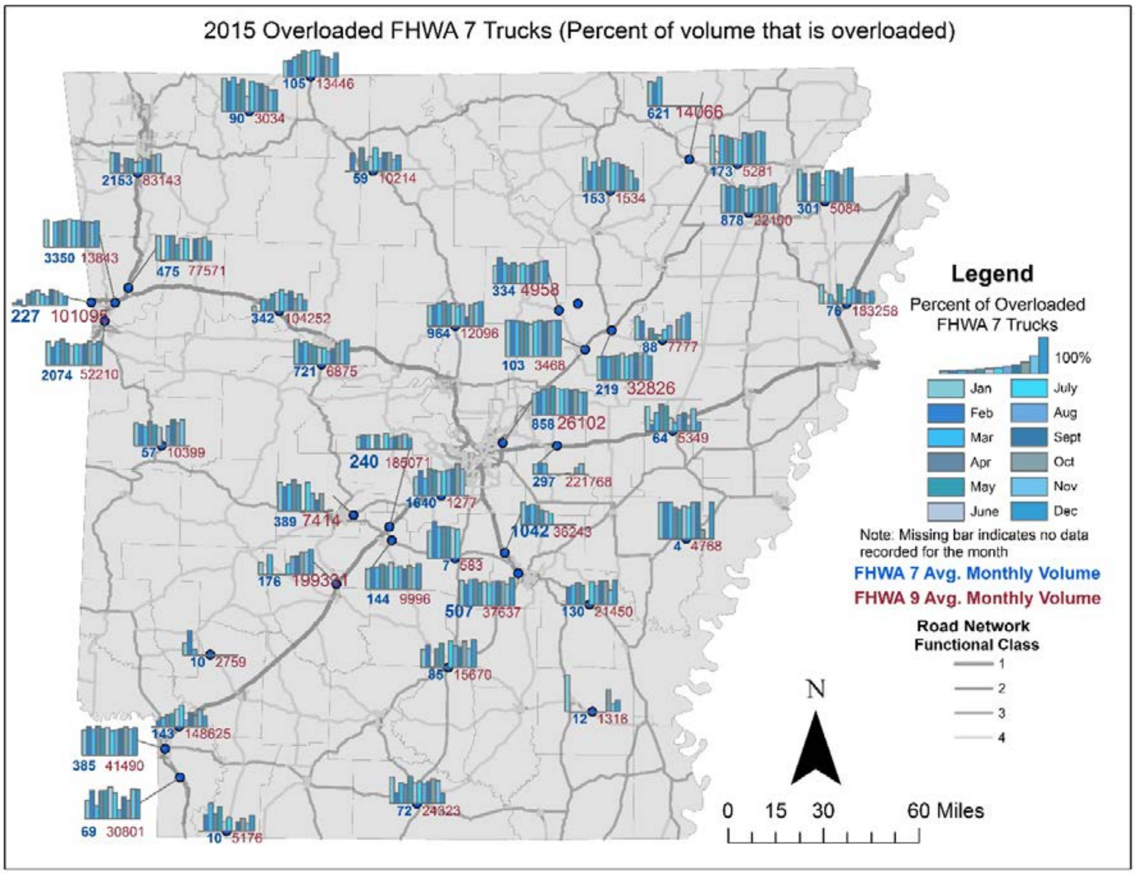

Figure 10. Overloaded FHWA Class 7 Trucks by WIM Site Considering 2015 Data.

Bridge Load Posting

Bridge load posting limits are safety and economic decisions. Bridge load posting limits restrict truck traffic to ensure safety. When a bridge is load posted, trucks that exceed the posting limits are required to take alternate routes. Therefore, bridge load posting can be a financial burden to the public.

An inadequate bridge rating factor may lead a State Department of Transportation (DOT) to load post the bridge. Bridge rating represents the ratio of the available live load plus impact capacity to the required live load plus impact capacity (White et al. 1992). A value greater than one indicates that the bridge is adequate, and a rating value less than one requires reducing the gross weight for the rating analysis vehicle. Three rating approaches are used for load rating: allowable stress rating (ASR), load factor rating (LFR), and load and resistance factor design rating (LRFD). Of these three load rating methods, LFR is most preferred by states. Bridge rating is determined as:

$$Rating\ Factor\ (RF) = \frac{Member\ Capacity - Dead\ Load\ Effect}{Live\ Load + Impact} \tag{2}$$

Load factor rating is calculated at two levels, inventory and operating.

Load rating at the inventory level:

$$RF\ (inventory) = \frac{\phi M_n - 1.3 * M_{DL}}{1.3 * \frac{5}{3} * M_{LL+I}} \tag{3}$$

and load rating at the operating level:

$$RF\ (operating) = \frac{\phi M_n - 1.3 * M_{DL}}{1.3 * M_{LL+I}} \tag{4}$$

where:
ϕM_n = girder moment capacity,
M_{DL} = dead load moment, and
M_{LL+I} = live load + impact moment

The equations' numerators are the available live load + impact and the denominators are the required moment capacity for the specific rating vehicle. The 5/3 factor for the inventory level rating considers the uncertainty in the live load force value and, therefore, represents an overload factor to consider the force effect of an infrequently occurring overloaded vehicle.

Consequently, load rating at the inventory level represents live load capacity for an infinite number of load cycles, while load rating at the operating level represents the maximum permissible live load that is acceptable for the specific bridge element.

Bridge load posting does not need to be considered if the load rating for each AASHTO and Arkansas rating analysis truck has a rating factor (RF) greater than one. However, if a bridge has an inadequate RF (less than one) it may be judged that the bridge should be load posted. A bridge is load posted using an upper bound truck weight as a function of truck class to ensure that the bridge member capacity is not exceeded. The safe bridge posting load using ASR or LFR is:

$$Safe\ Bridge\ Posting\ Load(ASR\ or\ LFR) = RF * Rating\ Truck\ Vehicle\ Weight\ (tons) \quad (5)$$

Bridge load posting using the LRFD rating approach is discussed in section 6A.8.2 of the Manual of Bridge Evaluation, 2nd Edition. Bridge load posting using LRFD is appropriate for bridges designed using LRFD and is therefore limited to newer bridge designs (AASHTO 2011).

The rating factor calculated using LRFD is:

$$Safe\ Bridge\ Posting\ Load\ (LRFD) = \frac{Rating\ Truck\ Vehicle\ Weight}{0.7}(RF - 0.3) \quad (6)$$

A lower limit value of 0.3 is used for the LRFD Safe Bridge Posting Load. Therefore, truck types having a RF less than 0.3 are prohibited from using the bridge.

Load Posted Bridge Types

In 2016, 1441 Arkansas bridges were load posted (Linz 2016). These load posted bridge types include: steel, concrete, precast channel section, wood, and iron. A breakdown of the bridge types are included in Table 12 and shown graphically for steel and concrete in Figure 11. Sixty-six percent of load posted bridges are steel bridges. Of these, 92% are simply supported.

Therefore, 61% of load posted bridges are simply supported steel bridges. A minimal number of load posted bridges are precast channel, wood, or iron. The range of the maximum span lengths for steel and concrete bridges is included in Figure 11. Simple span, two-span, and three span bridges comprise 99.1% of the total number of load posted bridges. Therefore, less than 1% of ARDOT load posted bridges are continuous with four or more spans.

Table 12. Arkansas Load Posted Bridges, 2016

	NUMBER OF BRIDGES				
SPANS	STEEL	CONCRETE	PRECAST CHANNEL	WOOD	IRON
SIMPLE	882	261	5	193	5
CONTINUOUS					
2 SPANS	47	8	0	0	0
3 SPANS	20	7	0	0	0
4 SPANS	5	4	0	0	0
> 4 SPANS	3	1	0	0	0
TOTAL	957	281	5	193	5

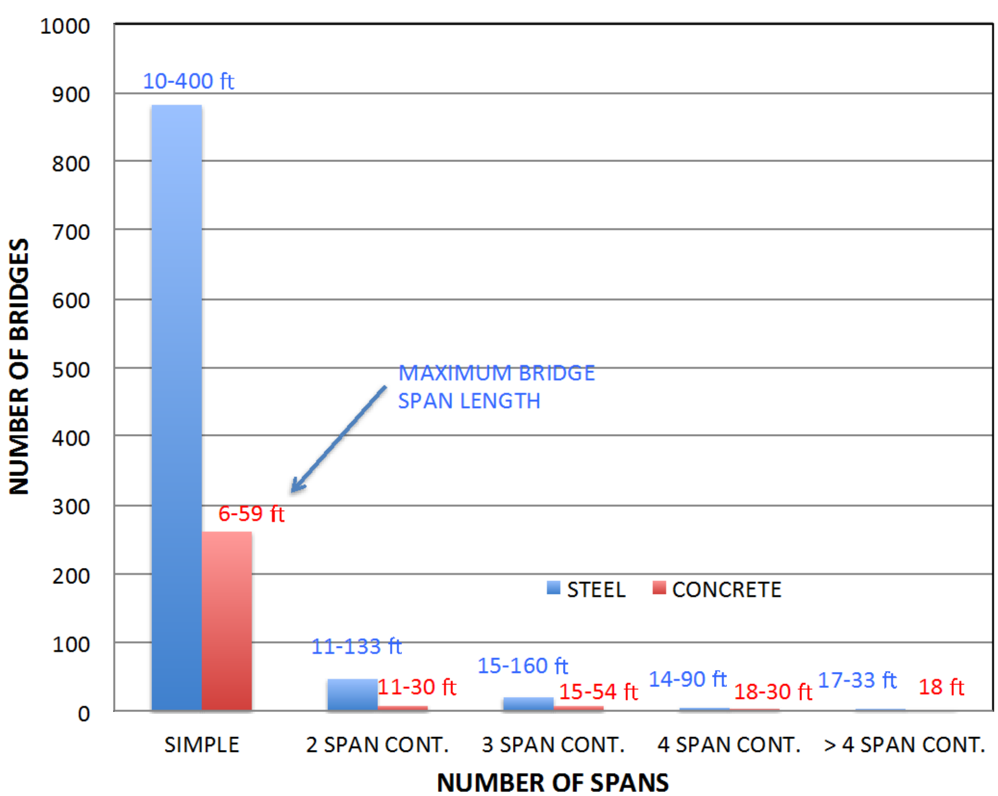

Figure 11. AR Load Posted Bridge Types (as of 2016)

Load Posting Vehicles

AASHTO defines 3 truck types for load posting evaluation: Type 3 (GW = 50 k), Type 3S2 (GW = 72 k), and Type 3-3 (GW = 80 k) as shown in Figure 12 (AASHTO 2011). The AASHTO typical legal loads (Type 3, Type 3S2, and Type 3-3) were developed in the 1970s to represent existing commercial truck traffic weights and axle spacing (Sivakumar 2007).

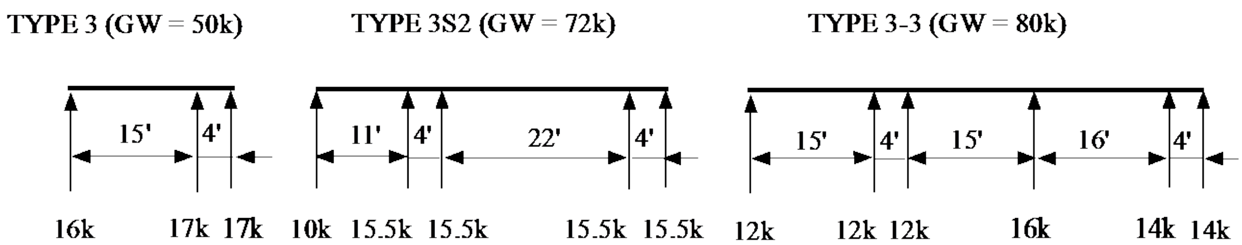

Figure 12. AASHTO Typical Legal Loads for Bridge Posting

Since the inception of the FBF, the trucking industry has modified truck axle configurations to increase the maximum allowable gross weight permitted by the FBF. SHVs use closely spaced multi-axle configurations within the truck frame length to distribute the truck load to more axles and, therefore, satisfy the FBF. SHVs typically use lift axles to convert a dump truck from three axles to a multi-axle configuration that satisfies the FBF. Longer trucks use split tandem axles to increase the spacing between adjacent axles, which allows for a larger permissible truck weight using the FBF. Although these new truck configurations satisfy the FBF, they may develop load effects greater than that calculated by the Type 3, Type 3S2, and Type 3-3 AASHTO typical legal loads. Shorter bridge spans are especially sensitive to the force effects produced by the SHVs. AASHTO has responded to this trend by adopting SHVs in the load posting evaluation process. New AASHTO load posting models shown in Figure 13 were developed from research conducted by Sivakumar et al. (2007). These AASHTO SHVs represent single unit, short-wheelbase multi-axle vehicles.

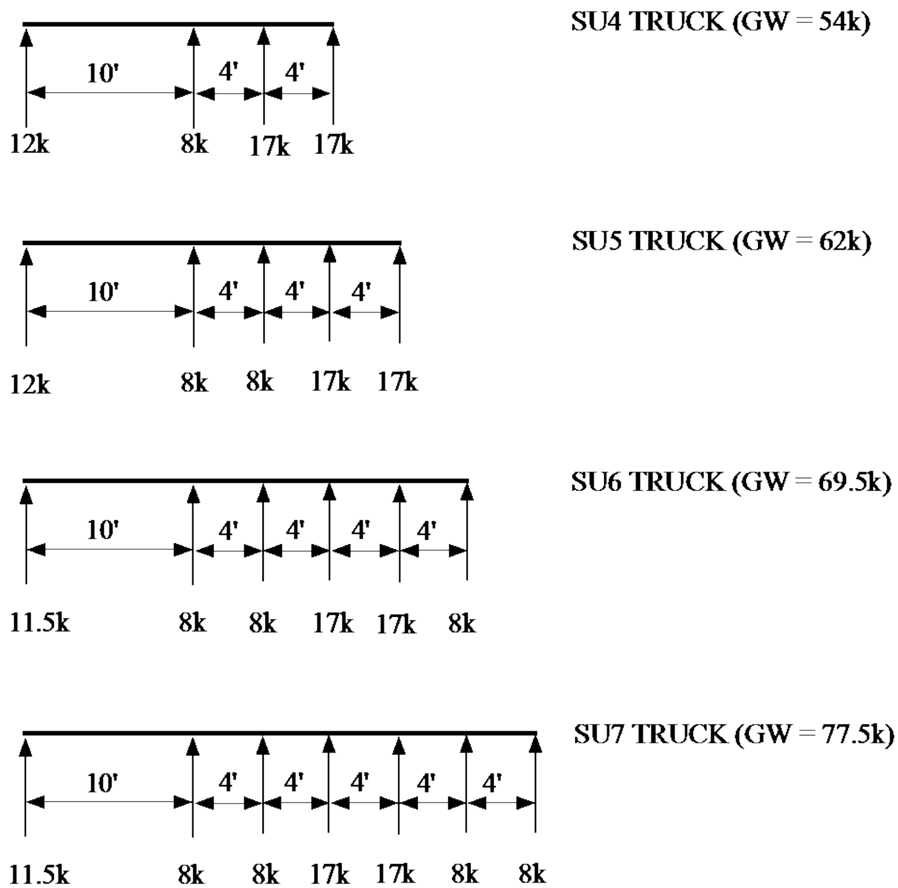

Figure 13. AASHTO Single-Unit Legal Loads for Bridge Posting (SHVs)

The notional rating load (NRL), shown in Figure 14, is a fictitious load that envelops the structural member response of all of the AASHTO SHVs shown in Figure 13. The NRL is used as an initial screening model to analyze the effect of single unit trucks. The NRL does not represent an actual truck, but instead represents a load configuration that envelops the member load effects of the SU4 through SU7 specialized hauling vehicle configurations. When evaluating a bridge’s structural members, notional rating truck axles that do not contribute to the maximum load effect are to be ignored. If a bridge is adequate for the notional rating load, truck cases SU4 - SU7 do not need to be considered for evaluating the bridge’s structural components. However, if the rating factor based on the notional load is less than one, then each of the SU4 – SU7 specialized hauling vehicles is required to be checked. The analysis approach conducted in this TRC1701 study for AASHTO vehicle response omitted the NRL and, instead, determined maximum beam response considering each of the SU4 – SU7 trucks.

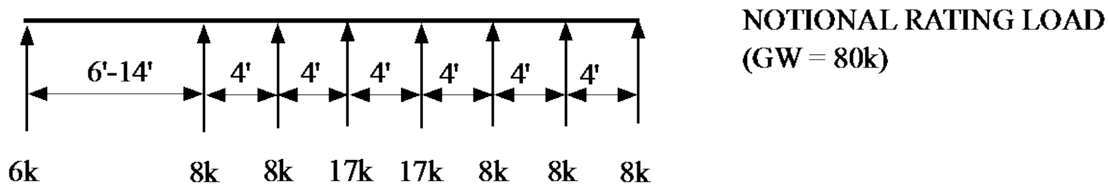

Figure 14. AASHTO Notional Rating Load

The AASHTO Manual for Bridge Evaluation, 2nd Edition, 6A.8.2 requires that an analysis for bridge legal loads include:

- the three typical AASHTO legal loads or state legal loads, and
- the four AASHTO single-unit legal loads (SHVs).

ARDOT uses three weight limit posting vehicle configurations for bridge load posting (see Figure 15). ARDOT weight limit posting vehicle configurations presumably represent the critical Arkansas truck traffic and, therefore, are currently used for evaluating a bridge structure's capacity. These vehicle configurations are used by ARDOT to calculate a structural member's response to the maximum live load of routinely used vehicles in Arkansas. The CODE 4 truck is a single unit vehicle. The 45 k GVW equals the FBF calculated maximum allowable GVW. The CODE 9 and CODE 5 ARDOT weight limit posting vehicles exceed the FBF calculated maximum allowable GVW. The CODE 9 weight limit posting vehicle is a single unit vehicle. The CODE 9 vehicle's GVW is 62 k, which exceeds the FBF maximum allowable GVW of 52.5 k. In addition, the 50 k rear axle grouping exceeds the 34 k FBF maximum allowable axle group weight for the given axle spacing. The heaviest ARDOT weight limit posting vehicle is the CODE 5 truck with an 80 k GVW. The CODE 5 weight limit posting vehicle is a short wheel based semi-trailer truck. The short axle base concentrates the vehicle weight within a short bridge length. The CODE 5 GVW of 80 k exceeds the 63 k calculated FBF maximum allowable GVW based on its axle spacing. Since the inception of ARDOT weight limit posting vehicles in the 1980's, the axle loads and configurations of truck traffic vehicles have significantly changed (Sivakumar 2007). Therefore, these previously discussed ARDOT weight limit posting vehicle configurations and weights currently being used for bridge load posting may be outdated or inappropriate.

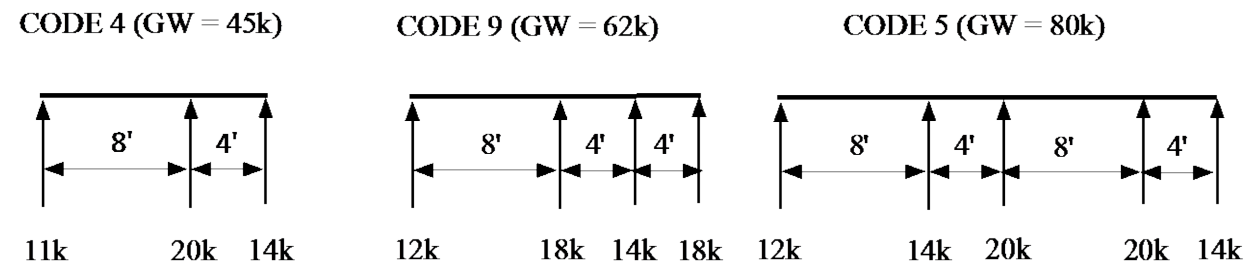

Figure 15. ARDOT Weight Limit Posting Vehicles

Influence Line Code Formulation

Multiple bridge configurations were considered in this TRC1701 project to analyze the bridge response due to truck loadings derived from data collected at WIM sites throughout the state. Bridges were evaluated for moment response and shear response. In order to expedite the calculation process, a computer code to create moment influence lines (WIMfluence) was incorporated into the analysis. Moment influence lines were generated for the pier supports, and these values were used to determine the moment and shear response for any point along the beam length. The moment and shear response for each study truck was calculated at 20^{th} points for each span of the *n* span bridge as the study truck moved along the bridge at 1 ft increments. Each truck was analyzed with the truck moving across the bridge in either direction.

Consider an *n* span bridge where the left abutment support is support *1* and the end abutment support is *n+1* (see Figure 16). Beam ends are assumed to consist of a pin and roller support. *x* is the distance from the left end of the beam to the influence line analysis point.

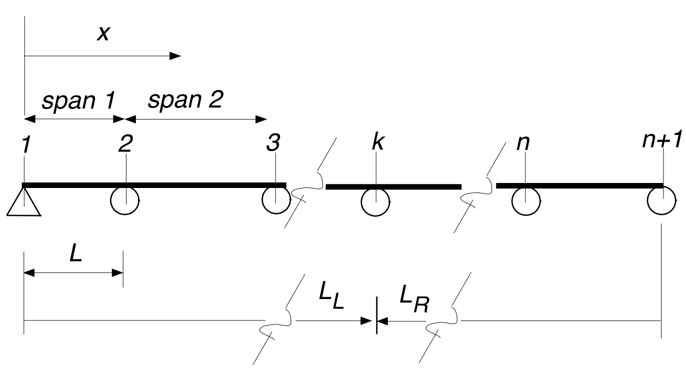

Figure 16. Beam Configuration Used for Influence Line Formulation

Moment and shear responses at any analysis point are calculated using the moment response values at the interior supports. The moment influence line for each interior support is developed using superposition. The beam is initially assumed to be simply supported between support *1* and support *n+1* (see Figure 17). The moment influence line is calculated for the statically indeterminate structure using the Muller-Breslau concept (Michalos & Wilson 1965). The moment influence line is calculated for the determinate structure and then corrected to ensure that the moment influence ordinate is equal to 0 at all the beam supports. Five steps are described in the following text to determine the moment influence line at support *k*, $(i(M'_k))$:

Step 1) The moment influence line $\frac{i_s}{L}(M'_k)$, for support *k* is calculated assuming the beam to be simply supported at the beam ends (statically determinate case), where i_s is the influence line for the statically determinate beam. Next the moment influence ordinates are determined at each interior support location, $\frac{i_s}{L}(M'_k@j)$ where j = 2, 3, …, n .

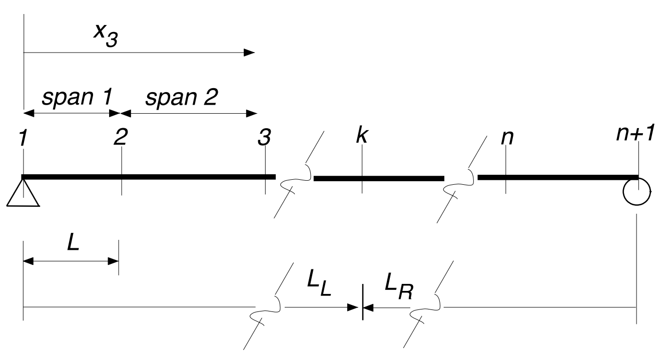

Figure 17. Simple Beam Configuration Assumed for the Influence Line Derivation

For the simply supported beam shown in Figure 17, the normalized moment influence line for support *k*, $\frac{i_s}{L}(M'_k@j)$, has an influence ordinate at j equal to:

$$\frac{i_s}{L}(M'_k@j) = \frac{x_j}{L}\frac{\left(\frac{L_L}{L}\right)_k}{\left(\frac{L_{TOTAL}}{L}\right)};\ x_j < x_k \tag{7}$$

$$\frac{i_s}{L}(M'_k@j) = \left(\frac{L_L}{L}\right)_k \frac{\left(\frac{L_{TOTAL}}{L} - \frac{x_j}{L}\right)}{\left(\frac{L_{TOTAL}}{L}\right)};\ x_j > x_k \tag{8}$$

where:
L = *span 1* length,
$\left(\frac{L_L}{L}\right)_k$ = bridge span length left of support k divided by the *span 1* length,
$\left(\frac{L_R}{L}\right)_k$ = bridge span length right of support k divided by the *span 1* length, and
$\frac{L_{TOTAL}}{L}$ = total bridge length divided by the *span 1* length

Step 2) The statically determinate moment influence line is corrected by calculating correction factors so that the final moment influence line for support k has a 0 value at each beam support. The displacement (Δ_{ij}) is calculated at each interior support i due to a unit load applied at each beam interior support j. The displacement at the support i location, x_i, due to a unit load at the support j location, x_j , is dependent on if x_i is less than or greater than x_j:

$$\frac{\Delta_{ij}}{\Delta_{jj}} = \frac{1}{2}\frac{\left(\frac{L_L}{L}\right)_i}{\left(\frac{L_L}{L}\right)_j^2\left(\frac{L_R}{L}\right)_j}\left[\left(\frac{L_L}{L}\right)_j\left\{2\left(\frac{L_{TOTAL}}{L}\right)-\left(\frac{L_L}{L}\right)_j\right\}-\left(\frac{L_L}{L}\right)_i^2\right];\ x_i < x_j \tag{9}$$

$$\frac{\Delta_{ij}}{\Delta_{jj}} = \frac{1}{2}\frac{\left(\frac{L_R}{L}\right)_i}{\left(\frac{L_L}{L}\right)_j\left(\frac{L_R}{L}\right)_j^2}\left[\left(\frac{L_L}{L}\right)_i\left\{2\left(\frac{L_{TOTAL}}{L}\right)-\left(\frac{L_L}{L}\right)_i\right\}-\left(\frac{L_L}{L}\right)_j^2\right];\ x_i > x_j \tag{10}$$

The correction to the simple beam influence line is written as a correction factor at each support i times the normalized displacement at i due to a unit load at j , ($\frac{X_i}{L} * \frac{\Delta_{ij}}{\Delta_{jj}}$).

Step 3) The sum of the simple beam moment influence line ordinates at each interior support, ($\frac{i_s}{L}(M_k'@j)$, plus the corrected displacements at each interior support is set to zero to ensure that the moment influence ordinate at each interior support (2 through n) is equal to 0:

$$\sum_{j=2}^{j=n}\left[\sum_{i=2}^{i=n}\left(\frac{X_i}{L}\right)\frac{\Delta_{ji}}{\Delta_{jj}} + \frac{i_s}{L}(M_k'@j) = 0\right] \tag{11}$$

where $(\frac{X_i}{L})$ are correction factors. As an example, for a three span bridge, equation (11) can be written as:

$$\frac{X_2}{L}\frac{\Delta_{22}}{\Delta_{22}} + \frac{X_3}{L}\frac{\Delta_{23}}{\Delta_{33}} + \frac{i_s}{L}(M_k'@support\ 2) = 0$$

$$\frac{X_2}{L}\frac{\Delta_{32}}{\Delta_{22}} + \frac{X_3}{L}\frac{\Delta_{33}}{\Delta_{33}} + \frac{i_s}{L}(M_k'@support\ 3) = 0 \tag{12}$$

or in matrix form:

$$\left[\frac{\Delta}{L}\right]\left\{\frac{X}{L}\right\} = -\left\{\frac{i_s}{L}(M_k')\right\} \tag{13}$$

Step 4) The $(\frac{X_j}{L})$ correction factors are determined using equation (14):

$$\left\{\frac{X}{L}\right\} = -\left[\frac{\Delta}{L}\right]^{-1}\left\{\frac{i_s}{L}(M_k')\right\} \tag{14}$$

Step 5) For the actual statically indeterminate structure, the moment influence line, $\frac{i}{L}(M_k'@x)$ is:

$$\frac{i}{L}(M_k'@x) = \sum_{j=2}^{j=n}\left(\frac{X_j}{L}\right)\frac{\Delta_{xj}}{\Delta_{jj}} + \frac{i_s}{L}(M_k'@x) \tag{15}$$

where:

$\frac{i}{L}(M_k'@x)$ = statically indeterminate moment influence ordinate for support *k* at beam analysis location *x*,

Δ_{xj} = displacement at *x* due to a unit load at *j* assuming a simple beam, and

Δ_{jj} = displacement at *j* due to a unit load at *j* assuming a simple beam

The simply supported beam displacement at analysis point *x* due to a unit load applied at *j* is:

$$\frac{\Delta_{xj}}{\Delta_{jj}} = \frac{1}{2}\frac{\frac{x}{L}}{\left(\frac{L_L}{L}\right)_j^2\left(\frac{L_R}{L}\right)_j}\left[\left(\frac{L_L}{L}\right)_j\left\{2\left(\frac{L_{TOTAL}}{L}\right) - \left(\frac{L_L}{L}\right)_j\right\} - \left(\frac{x}{L}\right)^2\right];\ x < x_j \tag{16}$$

and

$$\frac{\Delta_{xj}}{\Delta_{jj}} = \frac{1}{2}\frac{\left(\left(\frac{L_{TOTAL}}{L}\right)-\frac{x}{L}\right)}{\left(\frac{L_L}{L}\right)_j\left(\frac{L_R}{L}\right)_j^2}\left[\left(\frac{x}{L}\right)\left\{2\left(\frac{L_{TOTAL}}{L}\right)-\frac{x}{L}\right\}-\left(\frac{L_L}{L}\right)_j^2\right];\ x > x_j$$

(17)

For a three span bridge, the moment influence line for support *2*, $\frac{i}{L}(M_2'@x)$, is:

$$\frac{X_2}{L}\frac{\Delta_{x2}}{\Delta_{22}} + \frac{X_3}{L}\frac{\Delta_{x3}}{\Delta_{33}} + \frac{i_s}{L}(M_2'@x) = \frac{i}{L}(M_2'@x)$$

(18)

where $\frac{i}{L}(M_2'@x)$ is the moment influence ordinate at *x* for the support *2* moment influence line. The shear and moment responses due to a unit load at any point along the beam are calculated using the moment influence lines at the bridge interior supports (see Figure 18). M_L and M_R represent the internal moments at the beam span ends.

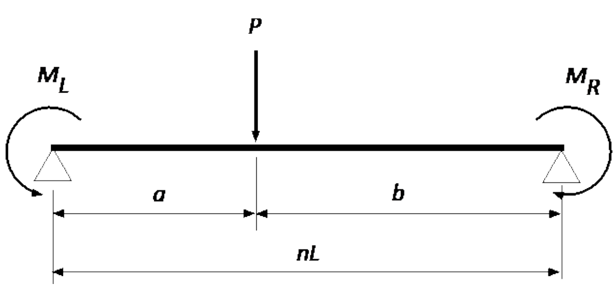

Figure 18. Beam Response at Any Beam Location

For a wheel load, *P*, shear is equal to:

$$V_x = P\left(1-\frac{a}{nL}\right)-\frac{(M_R-M_L)}{nL};\quad x < a$$

(19)

$$V_x = -P\frac{a}{nL}-\frac{(M_R-M_L)}{nL};\ a < x$$

(20)

and moment is equal to:

$$\frac{M_x}{L} = \frac{x}{L}\left[P\left(1-\frac{a}{nL}\right)-\frac{(M_R-M_L)}{nL}\right]-\frac{M_L}{L};\ x < a$$

(21)

$$\frac{M_x}{L} = n\left(1-\frac{x}{nL}\right)\left[P\frac{a}{nL}+\frac{(M_R-M_L)}{nL}\right]-\frac{M_R}{L};\ a < x$$

(22)

Bridge Response

Starting at the left bridge support, the truck to be evaluated was moved at an incremental 1 ft step length. At each step, bridge response was determined considering the truck moving forward and a second response was determined by rotating the truck 180° (so that both traffic flow directions were considered, see Figure 19).

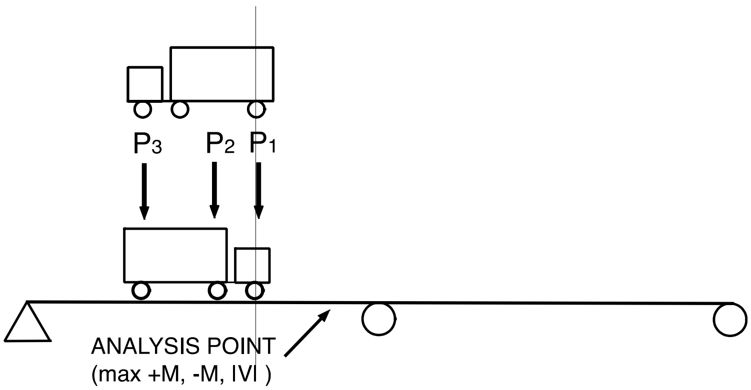

Figure 19. Beam Response Due to Truck Load

At each truck position, the positive moment, negative moment, and absolute shear were calculated at 20th points (0.05 * span length) for each span within the continuous beam configuration. One through six span continuous girder bridges were analyzed considering varying interior span length to end span length ratios (*n*) (see Table 13). Each interior span has the same *n* value. Since each evaluated live load vehicle has set dimensions, nine subgroups were considered for the actual span 1 length (characteristic length): 20 ft, 30 ft, 40 ft, 50 ft, 60 ft, 70 ft, 80 ft, 90 ft, and 100 ft. Consequently, 279 bridge configurations were analyzed. Each of the 1 million unique truck beam response values were divided by either the ARDOT weight limit posting vehicle value or the AASHTO legal load value to obtain a normalized value. These calculations were performed for 279 bridge configurations. Live load distribution was not included since response was normalized with another truck load.

Table 13. Analysis Bridge Configurations.

# of spans	Span 1:	Span 2:	Span 3:	Span 4:	Span 5:	Span 6:
	n=	*n*=	*n*=	*n*=	*n*=	*n*=
1	1					
2	1	1, 1.1, 1.2, 1.3, 1.4, 1.5				
3	1	1, 1.1, 1.2, 1.3, 1.4, 1.5	1			
4	1	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1		
5	1	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1	
6	1	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1, 1.1, 1.2, 1.3, 1.4, 1.5	1

where *n* = span length / end span length

At each analysis point, the maximum beam response was determined for each of the current ARDOT weight limit posting vehicles and AASHTO legal loads. In addition, each unique (representative) WIM truck was analyzed within its truck class group for maximum beam response. These values were compared at each analysis point to determine the maximum unique WIM truck to load posting vehicle response ratio and recorded for future evaluation. A greater than 1 ratio indicates that the WIM truck creates a greater beam response than the considered load posting trucks (ARDOT or AASHTO). These values were compared to examine which truck group induced the greatest beam response. This comparison was applied to each of the beam configurations and each unique (representative) WIM truck.

AASHTO / ARDOT Load Posting Truck Response

An analysis was conducted to compare the current ARDOT weight limit posting vehicles with the AASHTO legal loads for bridge posting. Each of the three ARDOT weight limit posting vehicles (CODE 4, CODE 9, and CODE 5) were analyzed for each of the Table 13 beam configurations and compared with the response of the AASHTO legal loads (Type 3, Type 3S2, Type 3-3, and the four AASHTO SHVs). At each beam response point, the largest response considering the seven AASHTO legal loads was compared with the largest response of the three ARDOT weight limit posting vehicles. Table 14 includes a summary of the ratios for bridges comprised of equal span lengths (n = 1). Other bridge configurations ($n \neq 1$) are included in Appendix B.

Table 14. Maximum Beam Response (AASHTO / ARDOT), *n*=1 (equal span lengths)

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.03	TYPE 3
	5	1.06	SU7, (SU6)	1.03	SU6, (SU7)	1.03	TYPE 3
	4	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.03	TYPE 3
	3	1.05	SU6, (SU7)	1.03	SU6, (SU7)	1.02	TYPE 3
	2	1.05	SU6	1.03	SU6, (SU7)	1.03	TYPE 3
	1	NA	NA	1.02	SU6	NA	NA
30	6	1.10	TYPE 3S2, (SU7)	1.03	SU6, (SU7)	-	-
	5	1.10	TYPE 3S2, (SU7)	1.03	SU6, (SU7)	-	-
	4	1.10	TYPE 3S2, (SU7)	1.03	SU6, (SU7)	-	-
	3	1.09	TYPE 3S2, (SU7)	1.03	SU6, (SU7)	1.02	TYPE 3S2
	2	1.04	TYPE 3S2, (SU7)	1.02	SU7, (SU6)	-	-
	1	NA	NA	1.00	SU7	-	-
40	6	1.03	TYPE 3S2	-	-	-	-
	4	1.03	TYPE 3S2	-	-	-	-
	5	1.02	TYPE 3S2	-	-	-	-

Table 14 includes the cases where the maximum response due to an AASHTO legal load caused a greater response than the maximum response due to an ARDOT weight limit posting vehicle. The AASHTO truck types that caused the response are included. A truck type in parentheses corresponds to a truck that did not cause maximum response, but still caused a response with a greater than one ratio. The maximum AASHTO truck response was due to the single unit trucks (SU6 & SU7 SHVs, and Type 3) and the single trailer truck (3S2). Analysis points not included in Table 14 indicate that the maximum response due to the AASHTO legal loads was less than the maximum response due to ARDOT weight limit posting vehicles. For equal span bridges (*n* = 1), the positive moment response ratio and the shear ratio have a maximum ratio of 1.03 (3%), which is tolerable for most work. However, the negative moment ratios have values as high as 10%, which is unacceptable.

The Table 14 results are further detailed for negative moment in Table 15. The cases where the AASHTO / ARDOT ratio exceed 1 correspond to shorter span lengths and are near the interior supports (within 0.1 of the span length).

Table 15. AASHTO /ARDOT Load Posting Truck –M Response Ratio

SPAN LENGTH (ft)	# of SPANS	-M RATIO AASHTO / ARDOT	LOCATION		AASHTO TRUCK TYPE	-M (AASHTO) (ft-k)	ARDOT TRUCK TYPE	-M (ARDOT) (ft-k)
			SPAN #	10th POINT				
20	6	1.06	1	9.0	SU6	-66.07	5	-62.63
	5	1.06	5	1.0	SU7	-66.08	5	-62.63
	4	1.06	1	9.0	SU6	-66.15	5	-62.71
	3	1.05	3	1.0	SU6	-67.09	5	-63.65
	2	1.05	2	1.0	SU6	-80.47	5	-76.92
30	6	1.10	1	9.5	3S2	-140.69	5	-128.01
	5	1.10	5	0.5	3S2	-140.69	5	-128.02
	4	1.10	4	0.5	3S2	-140.76	5	-128.15
	3	1.09	1	9.5	3S2	-141.62	5	-129.87
	2	1.04	2	0.0	3S2	-186.65	5	-178.77
40	6	1.03	4	0.0	3S2	-228.95	5	-221.94
	4	1.03	3	0.0	3S2	-230.88	5	-224.37
	5	1.02	4	0.0	3S2	-230.18	5	-225.44

Figure 20 is a graphical representation for a three-span continuous beam with equal 30 ft spans. Beam response is controlled by ARDOT load posting vehicles for most of the beam length.

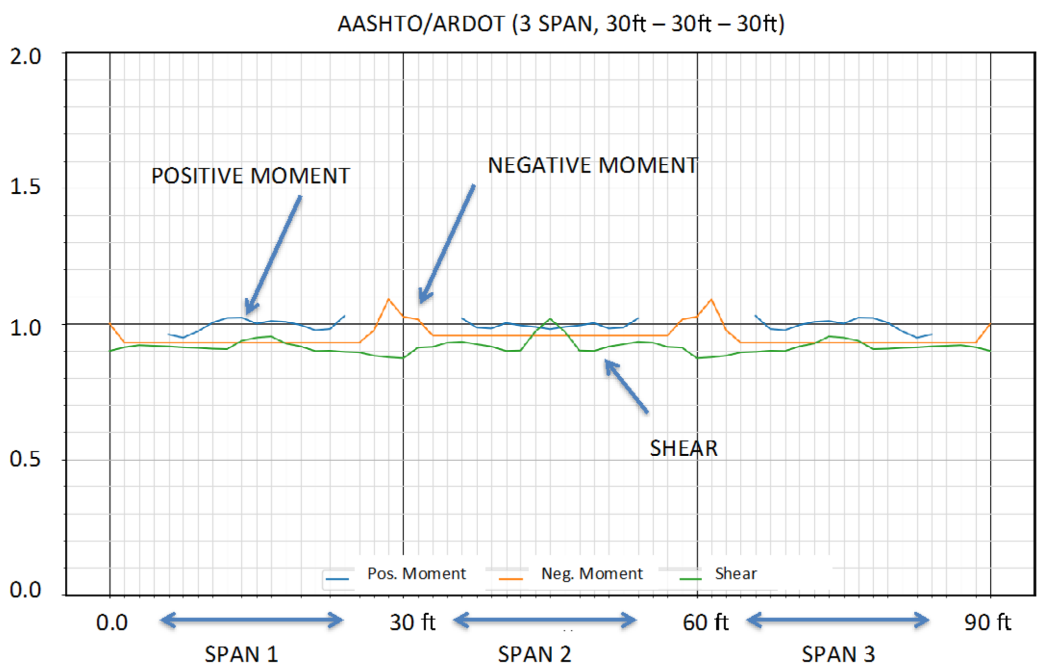

Figure 20. Beam Response (AASHTO / ARDOT), 3 Spans (30 ft – 30 ft – 30 ft)

Span configurations other than equal spans show a similar maximum response ratio for positive moment, approximately 4%. The maximum negative moment ratio significantly increases for multi-span short bridges where there is a significant difference in the span length ratio (*n*=1.4 and 1.5). For these cases, the maximum negative moment response ratio is 26% (see Table B4). The AASHTO shear response significantly increases in short, unequal span bridges. The

AASHTO Type 3S2 truck causes a 25% overload for shear for a two-span bridge with 20 ft and 30 ft spans (*n*=1.5) (see Table B5). Maximum moment and shear response for unequal span bridges were produced by the single unit trucks (SU6 & SU7 SHVs, and Type 3) and the single trailer truck (3S2).

In order that ARDOT weight limit posting vehicles envelop the beam response of the AASHTO legal load truck family for the considered beam configurations, ARDOT weight limit posting vehicle axle loads will need to increase significantly. Tables 16, 17, and 18 summarize the maximum overload ratios for each beam configuration set (*n* = 1 – 1.5) as a function of the ARDOT truck that corresponds to the highest AASHTO/ARDOT ratio. This organization of the AASHTO/ARDOT demonstrates the percentage increase required for ARDOT weight limit posting vehicles to match the maximum AASHTO legal load beam responses.

Table 16 summarizes these values for positive moment. In order that the positive moment response of ARDOT weight limit posting vehicles envelop the response of the AASHTO legal loads, the CODE 9 and CODE 5 axle loads will need to increase by 4% and 2%, respectively.

Table 16. AASHTO / ARDOT Response Ratio for +M (positive moment)

+ MOMENT						
INTERIOR SPAN RATIO (*n*)	AASHTO/ARDOT RATIO	ND SPAN LENGT (ft)	# of SPANS	CRITICAL TRUCK AASHTO/ARDOT	ANALYSIS POINT SPAN	TENTH POINT
1.0	1.03	20	4	SU6 / CODE 9	4	0.35
1.0	1.02	30	6	SU7 / CODE 5	1	0.45
1.1	1.03	20	5	SU6 / CODE 9	1	0.65
1.1	1.02	30	5	SU7 / CODE 5	1	0.45
1.2	1.03	20	3	SU6 / CODE 9	1	0.65
1.2	1.02	30	3	SU7 / CODE 5	1	0.45
1.3	1.03	20	3	SU6 / CODE 9	1	0.65
1.3	1.02	30	3	SU7 / CODE 5	1	0.45
1.4	1.03	20	3	SU6 / CODE 9	1	0.65
1.4	1.02	20	2	SU7 / CODE 5	2	0.45
1.5	1.04	20	3	SU6 / CODE 9	2	0.20
1.5	1.02	30	5	SU7 / CODE 5	5	0.55

Table 17 summarizes the critical AASHTO / ARDOT values for negative moment. In order that the negative moment response of ARDOT weight limit posting vehicles envelop the response of the AASHTO legal loads, the CODE 9 and CODE 5 axle loads will need to increase by 22% and 26%, respectively.

Table 17. AASHTO / ARDOT Response Ratio for –M (negative moment)

- MOMENT						
INTERIOR SPAN RATIO (n)	AASHTO/ARDOT RATIO	ND SPAN LENGT (ft)	# of SPANS	CRITICAL TRUCK AASHTO/ARDOT	ANALYSIS POINT	
					SPAN	TENTH POINT
1.0	1.10	30	6	3S2 /CODE 5	1	0.95
1.0	1.05	20	6	SU6 /CODE 9	5	0.10
1.1	1.07	30	2	3S2 / CODE 5	2	0.05
1.1	1.06	20	6	SU7 / CODE 9	5	0.10
1.2	1.08	20	2	SU6 / CODE 5	2	0.10
1.2	1.06	20	6	SU6 / CODE 9	5	0.90
1.3	1.17	20	2	3S2 /CODE 5	2	0.10
1.3	1.07	20	6	SU6 /CODE 9	5	0.90
1.4	1.26	20	2	3S2 /CODE 5	2	0.10
1.4	1.11	20	6	3S2 /CODE 9	5	0.90
1.5	1.22	20	6	3S2 /CODE 9	2	0.10
1.5	1.15	20	5	SU7 / CODE 5	3	0.05

Table 18 summarizes the critical AASHTO / ARDOT values for shear. In order that the shear response of ARDOT weight limit posting vehicles envelop the response of the AASHTO legal loads, the CODE 9 and CODE 5 axle loads will need to increase by 17% and 25%, respectively.

Table 18. AASHTO / ARDOT Response Ratio for V (shear)

SHEAR						
INTERIOR SPAN RATIO (n)	AASHTO/ARDOT RATIO	ND SPAN LENGT (ft)	# of SPANS	CRITICAL TRUCK AASHTO/ARDOT	ANALYSIS POINT	
					SPAN	TENTH POINT
1.0	1.03	20	2	TYPE 3 / CODE 9	1	0.45
1.0	1.03	20	6	TYPE 3 / CODE 5	4	0.50
1.1	1.08	20	3	3S2 / CODE 9	2	0.50
1.2	1.11	20	2	3S2 / CODE 9	1	0.45
1.3	1.15	20	2	3S2 / CODE 5	1	0.45
1.3	1.09	20	6	3S2 / CODE 9	1	0.45
1.4	1.20	20	2	3S2 / CODE 5	1	0.45
1.4	1.13	20	6	3S2 / CODE 9	1	0.45
1.5	1.25	20	3	3S2 / CODE 5	1	0.45
1.5	1.17	20	3	3S2 / CODE 9	3	0.55

For the configurations discussed in this report, to produce a beam response that exceeds the AASHTO response, the axle loads for the ARDOT CODE 9 truck will need to increase by 22% and the axle loads for the ARDOT CODE 5 truck will need to increase by 26%. These percentage increases are significant and, therefore, it is recommended to use a load posting family that includes, in addition to the ARDOT CODE 9 and CODE 5 weight limit posting vehicles, the AASHTO Type 3S2, Type SU6, and Type SU7 legal loads. Including these additional legal load vehicles will ensure a bridge response that exceeds AASHTO requirements.

Bridge Response Due to Unique Trucks Developed From WIM Data

Over 1 million unique (representative) trucks were analyzed for positive moment response, negative moment response, and shear response for 279 bridge configurations. At each beam analysis point (20th points along each span), maximum response due to a WIM truck was normalized with the ARDOT weight limit posting vehicle that created the greatest response of the three ARDOT weight limit posting vehicles. In addition, WIM truck response was normalized with the AASHTO legal load that created the greatest response. After initial studies, the unique trucks were filtered to remove trucks that exceeded the FBF maximum allowable load. To avoid misleading ratios due to ratios of small numbers, critical sections along the beam length were defined. These critical sections for each of the beam response types are shown in Figure 21. The critical sections along the beam length for positive moment were taken within 70% of the end span and the middle 40% ($0.3L_{INT} – 0.7L_{INT}$) of the interior spans. For negative moment and shear, the critical sections were confined to the support area where negative moment and shear are high, ($0.7L_{INT}$ (*span i*)– $0.3L_{INT}$ (*span i+1*)).

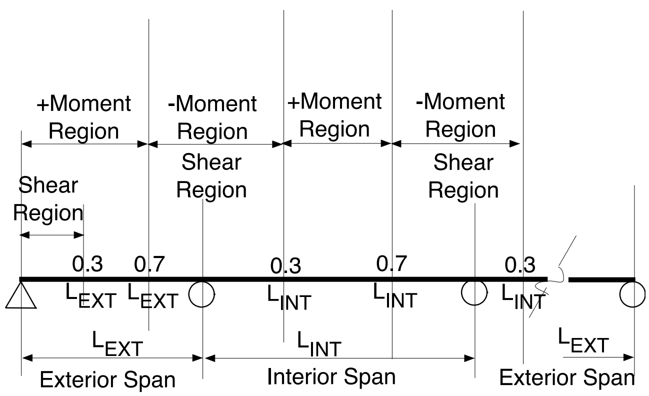

Figure 21. Critical Analysis Sections

Table 19 summarizes the WIM data analysis for equal span bridges ($n = 1$). Tables summarizing the bridge response for unequal spans ($n \neq 1$) are included in Appendix B. Since the study bridges are symmetric, results are shown for only half of the bridge. Only bridge configurations that had a response from an analysis truck obtained from WIM data that exceeded the maximum ARDOT truck response, termed as violation, are included in the table. The violation region is the length along the girder span in tenths of the girder span where the ratio exceeds one. The truck class that causes the maximum response is included in the table. Shear was not exceeded in the critical shear regions and is therefore, not included. Class 7 (single unit, multi axle) and Class 9 (single trailer) trucks caused maximum negative moment response. However, the majority of violations were due to the Class 9 truck. Significant negative moment overload occurred at spans that were 60 ft or less. For bridges with 20 ft end spans, some unique WIM trucks exceeded the ARDOT weight limit posting vehicle responses for positive moment. These trucks were Class 9 (single trailer) trucks and had a maximum overload of 6.9%. Other span configurations with $n \neq 1$ had a maximum ratio less than or equal to 3.9% (see Table B10).

Table 19. WIM Truck Response / ARDOT Load Posting Truck Response, Violation %
(n=1.0, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	40	1.00	10.1	9	-	-	-	-	-	-
	50	1.00	6.9	9	-	-	-	-	-	-
	60	1.00	3.8	9	-	-	-	-	-	-
3	20	0.90	2.8 (0.0)	7	-	-	-	-	-	-
	30	0.95	4.1 (0.0)	9	-	-	-	-	-	-
	40	0.95	8.1	9	-	-	-	-	-	-
	50	0.95	4.1	9	-	-	-	-	-	-
4	20	0.90	3.2 (0.0)	7	-	-	-	-	-	-
	30	0.95	4.9 (0.0)	9	-	-	-	-	-	-
	40	0.95	9.2	9	-	-	-	-	-	-
	50	0.95	5.1	9	1.00	7.9	9	-	-	-
	60	0.95	1.0	9	1.00	5.3	9	-	-	-
5	20	0.90	3.3 (0.0)	7	-	-	-	-	-	-
	30	0.95	4.9 (0.0)	9	-	-	-	-	-	-
	40	0.95	9.3	9	1.00	8.0 (5.8)	9	-	-	-
	50	0.95	5.2	9	1.00	7.1	9	-	-	-
	60	0.95	1.1	9	1.00	4.5	9	-	-	-
	70	-	-	-	1.00	1.2	9	-	-	-
6	20	0.90	3.3 (0.0)	7	-	-	-	-	-	-
	30	0.95	4.9 (0.0)	9	-	-	-	-	-	-
	40	0.95	9.3	9	1.00	7.9 (5.8)	9	1	8.9	9
	50	0.95	5.2	9	1.00	7.0	9	1	8.0	9
	60	0.95	1.1	9	1.00	4.4	9	1	5.4	9
	70	-	-	-	1.00	1.2	9	1	2.1	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70 (0.0)	2	9	-	-	-	-	-	-
4	20	-	-	-	0.70	6.7 (5.4)	9	0.3	6.7 (5.4)	9
5	20	-	-	-	0.70	3.0 (1.7)	9	0.30-0.35	6.9 (5.1)	9
6	20	-	-	-	0.70	3.1 (1.8)	9	0.30 - 0.35, 0.70	6.9, 3.1 (5.0, 1.4)	9

Table 20 summarizes the impact of supplementing the ARDOT truck group with the AASHTO legal load truck group in an analysis of a bridge consisting of equal spans. Other bridge configurations are included in Appendix B. Analysis points where there is a reduced WIM truck / ARDOT violation percentage because of considering the AASHTO legal loads are listed in Table 20. These values from the AASHTO analysis are superimposed on Table 19, showing the revised ratio value in parenthesis. Only violation cases that had a reduced WIM truck / ARDOT violation percentage are included in Table 20. Considering the AASHTO load posting trucks, the violation percentages on short span bridges with 20 ft end spans and interior spans between 20 ft and 26 ft were significantly reduced. After including the impact of the AASHTO load posting vehicles, the violation percentage at two span bridges with 20 - 28 ft spans (*n*=1.4) and 30 - 42 ft spans (*n*=1.4) still have high violation ratios of 16.0% and 17.8%, respectively (see Table B14). Excluding these two span configurations from the considered bridge configurations lowers the violation ratio percentage to 11.4% (see Table B10). Although 99.1% of the 2015 AR load posted bridges are three span continuous or less, considering only three span continuous bridges or less only reduces the violation percentage from 11.4% to 10.0% (see Table B8). Although the violation percentage is high (17.8%), designing a two-span bridge with one span 40% or more longer than the other is unlikely and, therefore, not considered as being viable. The maximum negative moments for the study cases are produced by ARDOT CODE 9 and CODE 5 weight limit posting vehicles. Therefore, including AASHTO legal loads and a 10% increase in ARDOT CODE 9 and CODE 5 axle loads is warranted to envelop the WIM truck responses.

Table 20. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.0, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.90	0.0	7	-	-	-	-	-	-
	30	0.95	0.0	9	-	-	-	-	-	-
4	20	0.90	0.0	7	-	-	-	-	-	-
	30	0.95	0.0	9	-	-	-	-	-	-
5	20	0.90	0.0	7	-	-	-	-	-	-
	30	0.95	0.0	9	-	-	9			
	40	0.95	-	9	1.00	5.8	-	-	-	-
6	20	0.90	0.0	7	-	-	-	-	-	-
	30	0.95	0.0	9	-	-	-	-	-	-
	40	0.95	-	9	1.00	5.8	9	1	5.6	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70	0.0	9	-	-	-	-	-	-
4	20	-	-	-	0.70	5.4	9	-	-	-
5	20	-	-	-	0.70	1.7	9	0.30-0.35	5.1	9
6	20	-	-	-	0.70	1.8	9	0.30 - 0.35, 0.70	5.0, 1.4	9

Load Posting Signs

The load posting sign currently used in Arkansas is shown in Figure 22. The Arkansas load posting sign includes three truck silhouettes. Each silhouette represents an ARDOT weight limit posting vehicle. The number adjacent to the silhouette indicates the maximum truck weight in tons for the specific configuration. If a number is not included, there is no weight restriction for the bridge for that truck configuration. The top silhouette is a single unit truck with three axles (a steer axle and two rear axles). This truck configuration is equivalent to the CODE 4 ARDOT weight limit posting vehicle. The middle silhouette is a single unit truck with four axles (a steer axle and three rear axles). This silhouette is used to represent single unit trucks with three or more rear axles. This truck configuration is equivalent to the ARDOT CODE 9 truck and replaces the AASHTO SHVs in the current ARDOT load posting analysis. The bottom silhouette is a single trailer truck. This truck configuration is equivalent to the ARDOT CODE 5 truck. The current ARDOT load posting sign does not have a restriction specific to tandem trailer trucks.

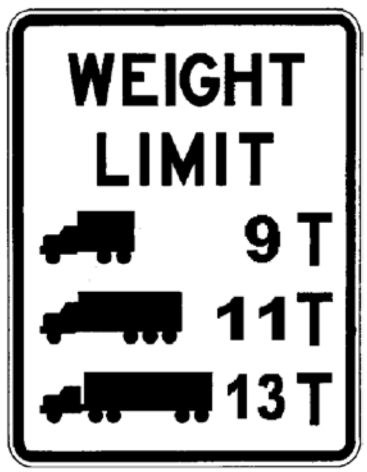

Figure 22. ARDOT Truck Weight Limit Sign

The R12-5 load posting sign included in the Manual of Uniform Traffic Control Devices is shown in Figure 23 (MUTCD 2017). Three silhouettes are included on the R12-5 load posting sign. The top silhouette on the R12-5 load posting sign represents a single unit vehicle. The middle silhouette on the R12-5 load posting sign represents a single trailer truck. A dual trailer truck is represented by the bottom silhouette. The number adjacent to the silhouette is the maximum allowable truck load in tons for the truck configuration. Single unit trucks, regardless of the number of rear axles, are grouped together under the single unit silhouette. Therefore, SHVs are represented by the top silhouette.

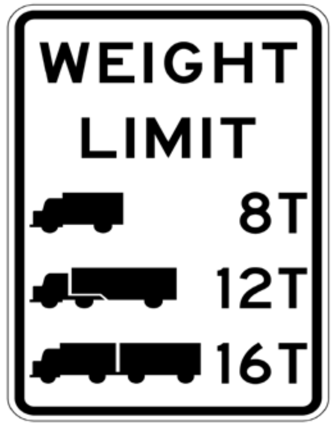

Figure 23. R12-5 MUTCD Truck Weight Limit Sign

Implementation

The truck traffic fleet has changed since the inception of the current ARDOT CODE 4, CODE 9, and CODE 5 weight limit posting vehicles in the 1980's (Sivakumar 2007). ARDOT should use, in addition to their current weight limit posting vehicles, the AASHTO Type 3, Type 3S2, Type 3-3, Type SU6, and Type SU7 legal loads. This will ensure beam responses that envelop the response of the current AASHTO legal loads. In order to meet the load demands of the current and near-future Arkansas truck traffic, ARDOT should incorporate a load posting group that includes the AASHTO Type 3, 3S2, 3-3, SU6, and SU7 legal loads along with increasing the current ARDOT CODE 9 and CODE 5 axle loads by 10%. The ARDOT CODE 4 truck did not govern in any of the study cases and therefore is not warranted. ARDOT should use the R12-5 MUTCD signage to represent these loads using three silhouettes: a single unit vehicle, a single trailer truck, and a tandem truck. The tandem truck is to be included to consider the increasing usage of this vehicle type. All single unit vehicles, including three or more rear axles, will be represented by the single unit vehicle silhouette.

Conclusions

Bridge load posting limits are safety and economic decisions. Therefore, load posting bridge limits must be done using load posting vehicles that represent the current truck traffic. ARDOT currently uses three analysis vehicles to determine bridge posting loads. These vehicles include: the CODE 4, CODE 9, and CODE 5. This TRC1701 study investigated the potential bridge response due to estimated Arkansas truck traffic collected from WIM sites throughout the state and then compared these values to ARDOT weight limit posting vehicle responses and AASHTO legal load responses. Arkansas truck traffic data were attained through ARDOT WIM data records. These records covered the 2005 – 2015 time period. A high percentage (75.1%) of Arkansas Class 7 truck traffic exceeded the FBF maximum allowable weight. This conclusion is based solely on truck data collected from WIM sites. Because of WIM data inaccuracy, this conclusion should be confirmed in future studies by considering other data sources such as weigh station data and weight ticket data. Multiple continuous bridge configurations were considered in this TRC1701 study. Over one million trucks were analyzed considering 279 bridge configurations. Bridge configurations used included equal-end span lengths and various interior span length to end span length ratios (*n*). In addition, multiple bridge lengths were considered. In order for ARDOT to have a load posting truck family that meets or exceeds AASHTO load posting requirements and meets the response created by the current Arkansas truck traffic, ARDOT will need to increase their current weight limit posting vehicle loads by 10% and include the AASHTO Type 3, Type 3S2, Type 3-3, Type SU6, and Type SU7 legal loads.

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Appendices

Appendix A: Summary of Station Status by Year

Table A1. Summary of Station Status by Year

Notes:

1. Column A is the percent of 'good' months in percent
2. Column B is the number of months recorded for the station
3. Empty cells indicate that no data was collected for that station ***in*** that year.

Stat.	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
5618	0	1																				
10009			100	9	55	11	33	9	92	12	100	8	100	10	63	8	50	12	0	12	0	12
20006	0	8	17	12	59	12	100	10	50	12	45	11	33	9	0	9	0	1				
40432	0	11	0	12	20	10	100	7	100	4							100	8	89	8		
50026					100	3	80	10	100	9	100	11	100	10	100	10	100	12	100	12	58	12
71813	89	9	83	12	10	10	100	9	100	12	100	11	100	7	100	10	92	12	92	12	80	10
80004	0	8	45	11	20	10	0	1	67	6	100	8	38	8	100	11	75	12	50	8	100	12
100019	0	3			100	1			88	8	100	2	88	8	100	9	100	1	75	8	0	8
160058	40	5	100	7	100	10	100	11	100	6	100	10	100	10	100	11	100	9	100	12	100	12
160074	100	5																				
160095																			63	8	100	11
170049	0	9	58	12	25	12	100	10	100	12	67	6			100	4	100	3	67	9	18	11
170053											100	3	11	9	73	11	100	12	100	12	100	11

Stat.	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
170064	0	2			100	3	100	9	100	6	100	3	100	6	100	7	100	12	100	12	100	10
171651	100	11	83	12	50	10	90	10	82	11	73	11	67	9	70	10	91	11	91	11		
180002	0	6																				
181501	90	10	56	9	33	9	100	4	86	7	60	5	100	10	100	10	100	10	100	7	100	11
220024	0	9	0	12	20	10	90	10	70	10	90	10	30	10	71	7	50	12	0	12	0	4
230001	0	9	0	12	55	11	82	11	75	12	100	9	17	6	67	9	100	12	100	12	92	12
230021	11	9	33	12	42	12	18	11	60	10	100	3	67	3	18	11	0	3				
260059	50	2	92	12	33	9	100	11	100	12	100	10	83	6	100	7	100	12	100	10	30	10
270012	33	6	0	12	55	11	100	9	100	12	100	10	80	10	90	10	40	10	8	12	100	7
281983	100	11	100	12	80	10	100	8	100	10	100	8	22	9	45	11	82	11	100	11	92	12
290002	0	10	0	12	18	11	36	11	38	8	75	8	33	9	100	11	13	8	50	12	33	3
300052			63	8	92	12	91	11	33	12	70	10	100	9	100	10	100	12	92	12	100	12
301769			25	4	20	5	70	10	56	9	0	1			89	9	100	4	100	11	100	10
350019			100	11	55	11	45	11	36	11	83	12	100	8	100	8	100	11	100	12	100	7
350215	0	5	0	1																		
350314	0	10	71	7	64	11	100	11	100	12	100	11	90	10	56	9	100	12	100	12	100	12
350512	0	4	0	5	25	8	0	1														

Stat.	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
360009									90	10	86	7	100	4	100	8	100	12	100	12	27	11
370001	0	11	25	12	64	11	90	10	92	12	100	9	100	6	100	10	75	12	64	11	64	11
380020													43	7	80	10	100	11	100	7	100	3
400062											100	7	44	9	91	11	100	10	100	12	100	10
420010	0	10	0	9	20	10	33	6	0	3			100	8	89	9						
430037	44	9	100	5	33	6	100	4	75	4	0	3	80	5	71	7			50	2	63	8
430038	100	10	100	12	67	12	100	8	100	11	100	10	100	6								
460006	63	8	85	13	43	7	67	3	63	8	100	3	100	3	100	4	100	7	100	11	45	11
460011	100	5	56	9	57	7	64	11	100	12	100	6	100	8	100	11	100	12	100	12	25	12
460286	40	10	82	11	20	5							0	3	71	7	44	12	100	12	100	12
480037	100	10	100	11	50	8	100	6	75	12	57	7	100	7	100	9	75	12	91	11	100	12
481524	100	9	100	5	100	1	100	6	86	7	100	5	100	7	100	5						
560093																					100	4
580236	0	8	25	8																		
600345					71	7	100	11	100	4	100	12	100	8	67	3						
600504			100	3	33	12	100	8	100	2	100	1										
600567			100	7	100	11	100	11	100	7	80	10	100	9	50	4			0	2		

Stat.	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
600870	100	10	100	11	71	7	100	5	82	11	100	7	100	11	100	11	100	12	100	11	100	12
620012	0	1																				
620176											40	5	90	10	55	11	67	12	60	10	73	11
630008	0	10	0	12	29	7																
630009									100	4	100	11	78	9	100	8	82	11	100	12	100	10
641932	0	11	20	5	8	12			100	6	100	10	45	11	57	7	100	12	100	12	100	10
650284	0	9	0	11	20	5	100	7	80	10									100	3	100	12
651653	0	2																				
670027	0	11	8	12	33	6	100	8	91	11	70	10	88	8	100	8	44	9	100	12	92	12
680025	75	8	100	7	50	8	50	4	100	9	100	4	100	8	100	7	100	2				
680032	73	11	67	12	40	10	50	10	33	6	11	9	11	9	44	9						
700040									100	11	100	10	100	9	100	11			100	12	100	12
720034	0	7					100	10	92	12	100	2	71	7	100	11	100	12	25	8		
720236					100	4	70	10	58	12	25	4	11	9	100	4	100	5	100	12	100	10
721683	0	6	0	4																		
730018															100	9	33	9	91	11	100	12
730068	44	9	73	11	62	13	40	10	75	12	50	12	100	10	100	9	100	12	100	10	100	12

Stat.	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
730076													0	1	30	10	25	12	91	11	0	12
730222													100	9	100	10	50	12	0	12	0	12
740035	100	11	100	12	83	12	89	9	100	8	75	12	78	9	100	10	100	11	92	12	50	10
750006	50	2	75	12	89	9	100	10	73	11	67	12	78	9	100	10	100	10	27	11	75	12
750010	20	10	82	11	25	12	88	8	58	12	90	10	80	10	100	10	50	12	0	9		

Appendix B: Bridge Response For Unequal Span Bridges

AASHTO / ARDOT Beam Response

Table B1. Maximum Beam Response (AASHTO / ARDOT), *n*=1.1

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.06	SU7, (SU6)	1.03	SU6, (SU7)	1.07	3S2 (TYPE 3)
	5	1.06	SU7, (SU6)	1.03	SU6, (SU7)	1.07	3S2 (TYPE 3)
	4	1.06	SU7, (SU6)	1.03	SU6, (SU7)	1.07	3S2 (TYPE 3)
	3	1.05	SU7, (SU6)	1.03	SU6, (SU7)	1.08	3S2
	2	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.06	3S2
	1	NA	NA	-	-	-	-
30	6	1.05	3S2, (SU7)	1.02	SU6, (SU7)	-	-
	5	1.04	3S2, (SU7)	1.02	SU6, (SU7)	-	-
	4	1.05	3S2, (SU7)	1.02	SU6, (SU7)	-	-
	3	1.03	SU7	1.02	SU6, (SU7)	-	-
	2	1.07	3S2, (SU7)	1.02	SU7, (SU6)	-	-
	1	NA	NA	-	SU7	-	-

Table B2. Maximum Beam Response (AASHTO / ARDOT), *n*=1.2

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.05	3S2
	5	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.05	3S2
	4	1.06	SU6, (SU7)	1.03	SU6, (SU7)	1.05	3S2
	3	1.06	SU6, (SU6)	1.03	SU6, (SU7)	1.05	3S2
	2	1.08	SU6, (SU7)	1.03	SU6, (SU7)	1.11	3S2
	1	NA	NA	-	-	-	-
30	6	1.07	3S2, (SU7)	1.02	SU7, (SU6)	-	-
	5	1.06	3S2, (SU7)	1.02	SU7, (SU6)	-	-
	4	1.07	3S2, (SU7)	1.02	SU7, (SU6)	-	-
	3	1.04	SU7	1.02	SU7, (SU6)	-	-
	2	1.07	3S2	1.01	SU7, (SU6)	-	-
	1	NA	NA	-	SU7	-	-

Table B3. Maximum Beam Response (AASHTO / ARDOT), *n*=1.3

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.07	SU6, (SU7)	1.03	SU6, (SU7)	1.09	3S2
	5	1.07	SU6, (SU7)	1.03	SU6, (SU7)	1.09	3S2
	4	1.07	SU6, (SU7)	1.03	SU6, (SU7)	1.09	3S2
	3	1.07	SU6, (SU7)	1.03	SU6, (SU7)	1.08	3S2
	2	1.17	3S2, (SU7)	1.03	SU6, (SU7)	1.15	3S2
	1	NA	NA	-	-	-	-
30	6	1.10	3S2	1.02	SU7, (SU6)	-	-
	5	1.10	3S2	1.02	SU7, (SU6)	-	-
	4	1.10	3S2	1.02	SU7, (SU6)	-	-
	3	1.09	3S2	1.02	SU7, (SU6)	-	-
	2	-	-	1.02	SU7, (SU6)	-	-
	1	NA	NA	-	SU7	-	-

Table B4. Maximum Beam Response (AASHTO / ARDOT), n=1.4

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.26	3S2, (SU7)	1.03	SU6, (SU7)	1.14	3S2
	5	1.11	3S2, (SU7)	1.03	SU6, (SU7)	1.13	3S2
	4	1.11	3S2, (SU7)	1.03	SU6, (SU7)	1.13	3S2
	3	1.09	3S2, (SU7)	1.03	SU6, (SU7)	1.13	3S2
	2	1.26	3S2, (SU7)	1.03	SU6, (SU7)	1.20	3S2, (SU7)
	1	NA	NA	-	-	-	-
30	6	1.01	3S2	1.02	SU7, (SU6)	-	-
	5	1.01	3S2	1.02	SU7, (SU6)	-	-
	4	1.02	3S2	1.02	SU7, (SU6)	-	-
	3	1.02	3S2	1.02	SU7, (SU6)	-	-
	2	1.03	3S2	1.01	SU7	-	-
	1	NA	NA	-	-	-	-

Table B5. Maximum Beam Response (AASHTO / ARDOT), n=1.5

SPAN LENGTH (ft)	# of SPANS	- MOMENT		+ MOMENT		SHEAR	
		AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK	AASHTO/ARDOT	AASHTO TRUCK
20	6	1.22	3S2, (SU7)	1.04	SU6, (SU7)	1.18	3S2
	5	1.22	3S2, (SU7)	1.04	SU6, (SU7)	1.18	3S2
	4	1.22	3S2, (SU7)	1.04	SU6, (SU7)	1.18	3S2
	3	1.19	3S2, (SU7)	1.04	SU6, (SU7)	1.17	3S2
	2	1.15	3S2, (SU7)	1.03	SU6, (SU7)	1.25	3S2, (SU7)
	1	NA	NA	-	-	-	-
30	6	-	-	1.02	SU7, (SU6)	1.00	3S2
	5	-	-	1.02	SU7, (SU6)	1.00	3S2
	4	-	-	1.02	SU7, (SU6)	1.00	3S2
	3	-	-	1.02	SU7, (SU6)	-	-
	2	-	-	1.02	SU7	1.04	3S2
	1	NA	NA	-	-	-	-

Violation Percentage

Table B6. WIM Truck Response / ARDOT Load Posting Truck Response, Violation % (*n*=1.1, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	1.9 (0.0)	7	-	-	-
	30	-	-	-	0.05	5.3 (0.0)	9	-	-	-
	40	1.00	0.2	9	0.05	4.5	9	-	-	-
	50	-	-	-	0.05	0.2	9	-	-	-
3	40	1.00	6.7	9	-	-	-	-	-	-
	50	1.00	3.7	9	-	-	-	-	-	-
	60	1.00	0.8	9	-	-	-	-	-	-
4	30	-	-	-	1.00	0.1 (0.0)	9	-	-	-
	40	1.00	6.4	9	1.00	9.4	9	-	-	-
	50	1.00	3.4	9	1.00	6.4	9	-	-	-
	60	1.00	0.6	9	1.00	3.6	9	-	-	-
5	40	1.00	6.3	9	1.00	9.1	9	-	-	-
	50	1.00	3.4	9	1.00	6.1	9	-	-	-
	60	1.00	0.5	9	1.00	3.4	9	-	-	-
6	40	1.00	6.3	9	1.00	9.1	9	1.00	9.4	9
	50	1.00	3.4	9	1.00	6.1	9	1.00	6.5	9
	60	1.00	0.5	9	1.00	3.3	9	1.00	3.7	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70	1.3 (0.0)	9	-	-	-	-	-	-

Table B7. WIM Truck Response / ARDOT Load Posting Truck Response, Violation % (*n*=1.2, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	6.4 (0.0)	7	-	-	-
	30	-	-	-	0.05 - 0.10	9.3 (4.9)	9	-	-	-
	40	-	-	-	0.05	7.4	9	-	-	-
	50	-	-	-	0.05	3.0	9	-	-	-
3	20	-	-	-	0.10	0.5 (0.0)	7	-	-	-
	30	-	-	-	0.05	1.0 (0.0)	9	-	-	-
	40	1.00	4.0	9	-	-	-	-	-	-
	50	1.00	1.3	9	-	-	-	-	-	-
4	20	-	-	-	0.10	0.6 (0.0)	7	-	-	-
	30	-	-	-	0.05	1.3 (0.0)	9	-	-	-
	40	1.00	3.8	9	1.00	8.7	9	-	-	-
	50	-	-	-	1.00	5.5	9	-	-	-
	60	-	-	-	1.00	1.4	9	-	-	-
5	20	-	-	-	0.10	0.6 (0.0)	7	-	-	-
	30	-	-	-	0.05	1.3 (0.0)	9	-	-	-
	40	-	-	-	1.00	8.5	9	-	-	-
	50	-	-	-	1.00	5.2	9	-	-	-
	60	-	-	-	1.00	1.2	9	-	-	-
6	20	-	-	-	0.10	0.6 (0.0)	7	-	-	-
	30	-	-	-	0.05	6.0 (0.0)	9	1	6.3	9
	40	-	-	-	1.00	8.4	9	1	8.7	9
	50	-	-	-	1.00	5.2	9	1	5.4	9
	60	-	-	-	1.00	1.2	9	1	1.4	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70	0.6 (0.0)	9	-	-	-	-	-	-
5	20	0.70	0.8 (0.0)	9	-	-	-	-	-	-
6	20	0.70	0.8 (0.0)	9	-	-	-	-	-	-

Table B8. WIM Truck Response / ARDOT Load Posting Truck Response, Violation % (*n*=1.3, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	15.8 (0.0)	9	-	-	-
	30	-	-	-	0.05 - 0.10	10.0	9	-	-	-
	40	-	-	-	0.10	1.2	9	-	-	-
3	20	-	-	-	0.10	3.4 (0.0)	9	-	-	-
	30	-	-	-	0.05	12.6 (3.8)	9	-	-	-
	40	-	-	-	0.05	6.2	9	-	-	-
	50	-	-	-	0.05	1.1	9	-	-	-
4	20	-	-	-	0.10	3.9 (0.3)	9	-	-	-
	30	-	-	-	0.05 , 1.00	13.9, 8.6 (3.9, 3.9)	9	-	-	-
	40	-	-	-	0.05, 1.00	7.1, 7.4	9	-	-	-
	50	-	-	-	0.05, 1.00	1.8, 4.2	9	-	-	-
5	20	-	-	-	0.10	4.0 (0.4)	7	-	-	-
	30	-	-	-	1.00	7.8 (4.0)	9	-	-	-
	40	-	-	-	1.00	6.6	9	-	-	-
	50	-	-	-	1.00	3.4	9	-	-	-
6	20	-	-	-	0.10	4.0 (0.4)	7	-	-	-
	30	-	-	-	1.00	7.7 (4.0)	9	1	8.7	9
	40	-	-	-	1.00	6.6	9	1	7.3	9
	50	-	-	-	1.00	3.4	9	1	4.1	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
4	20	0.70	0.9 (0.0)	9	-	-	-	-	-	-
5	20	0.70	1.1 (0.0)	9	-	-	-	-	-	-
6	20	0.70	1.1 (0.0)	9	-	-	-	-	-	-

Table B9. WIM Truck Response / ARDOT Load Posting Truck Response, Violation % (*n*=1.4, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10 - 0.15	23.8 (16.0)	9	-	-	-
	30	-	-	-	0.10	19.7 (17.8)	9	-	-	-
	40	-	-	-	0.10	9.5 (4.8)	9	-	-	-
3	20	-	-	-	0.10	6.5 (0.0)	7	-	-	-
	30	-	-	-	0.05 - 0.10	8.8 (6.2)	9	-	-	-
	40	-	-	-	0.05	5.9	9	-	-	-
	50	-	-	-	0.05	1.3	9	-	-	-
4	20	-	-	-	0.10	7.6 (0.0)	7	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	7.2, 9.3	9	-	-	-
	40	-	-	-	0.05, 1.00	4.4, 6.4	9	-	-	-
	50	-	-	-	1.00	2.5	9	-	-	-
5	20	-	-	-	0.10	7.7 (0.0)	7	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	7.1. 8.0	9	-	-	-
	40	-	-	-	0.05, 1.00	4.3, 5.1	9	-	-	-
	50	-	-	-	1.00	1.2	9	-	-	-
6	20	-	-	-	0.10	7.7 (0.0)	7	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	7.1, 8.0	9	1	9.4 (8.1)	9
	40	-	-	-	0.05, 1.00	4.3, 5.0	9	1	6.3	9
	50	-	-	-	1.00	1.1	9	1	2.2	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
4	20	0.70	2.4 (0.1)	9	-	-	-	-	-	-
5	20	0.70	2.7 (0.5)	9	-	-	-	-	-	-
6	20	0.70	2.7 (0.5)	9	-	-	-	-	-	-

Table B10. WIM Truck Response / ARDOT Load Posting Truck Response, Violation %
(n=1.5, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1 VIOLATION REGION	SPAN 1 MAX VIOLATION %	SPAN 1 CLASS #	SPAN 2 VIOLATION REGION	SPAN 2 MAX VIOLATION %	SPAN 2 CLASS #	SPAN 3 VIOLATION REGION	SPAN 3 MAX VIOLATION %	SPAN 3 CLASS #
2	20	-	-	-	0.10 - 0.15	12.5 (3.2)	9	-	-	-
	30	-	-	-	0.10	8.7	9	-	-	-
	40	-	-	-	0.10	1.3	9	-	-	-
3	20	-	-	-	0.10	14.2 (0.0)	9	-	-	-
	30	-	-	-	0.05 - 0.10	8.4	9	-	-	-
4	20	-	-	-	0.10	17.2 (0.0)	9	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	11.2, 9.3	9	-	-	-
	40	-	-	-	1.00	5.6	9	-	-	-
	50	-	-	-	1.00	0.7	9	-	-	-
5	20	-	-	-	0.10	17.4 (0.0)	9	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	11.4, 7.6	9	-	-	-
	40	-	-	-	0.10, 1.00	0.1, 3.9	9	-	-	-
6	20	-	-	-	0.10	17.4 (0.0)	9	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	11.4, 7.5	9	1	9.4	9
	40	-	-	-	0.10, 1.00	0.1, 3.8	9	1	5.5	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1 VIOLATION REGION	SPAN 1 MAX VIOLATION %	SPAN 1 CLASS #	SPAN 2 VIOLATION REGION	SPAN 2 MAX VIOLATION %	SPAN 2 CLASS #	SPAN 3 VIOLATION REGION	SPAN 3 MAX VIOLATION %	SPAN 3 CLASS #
4	20	0.70	3.4 (1.2)	9	-	-	-	-	-	-
5	20	0.70	3.9 (1.6)	9	-	-	-	-	-	-

Reduced Violation Percentage Due To Considering AASHTO Trucks

Table B11. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.1, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05	0.0	9	-	-	-
4	30	-	-	-	1.00	0.0	9	-	-	-

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70	0.0	9	-	-	-	-	-	-

Table B12. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.2, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05 - 0.10	4.9	9	-	-	-
3	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05	0.0	9	-	-	-
4	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05	0.0	9	-	-	-
5	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05	0.0	9	-	-	-
6	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05	0.0	9	1	0.0	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

NUMBER of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
3	20	0.70	0.0	9	-	-	-	-	-	-
5	20	0.70	0.0	9	-	-	-	-	-	-
6	20	0.70	0.0	9	-	-	-	-	-	-

Table B13. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.3, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10	0.0	9	-	-	-
3	20	-	-	-	0.10	0.0	9	-	-	-
	30	-	-	-	0.05	3.8	9	-	-	-
4	20	-	-	-	0.10	0.3	9	-	-	-
	30	-	-	-	0.05 , 1.00	3.9, 3.9	9	-	-	-
5	20	-	-	-	0.10	0.4	7	-	-	-
	30	-	-	-	1.00	4.0	9	-	-	-
6	20	-	-	-	0.10	0.4	7	-	-	-
	30	-	-	-	1.00	4.0	9	1	4.2	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

# of SPANS	EXTERIOR SPAN LENGTH (ft)	SPAN 1			SPAN 2			SPAN 3		
		VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
4	20	0.70	0.0	9	-	-	-	-	-	-
5	20	0.70	0.0	9	-	-	-	-	-	-
6	20	0.70	0.0	9	-	-	-	-	-	-

Table B14. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.4, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10 - 0.15	16.0	9	-	-	-
	30	-	-	-	0.10	17.8	9	-	-	-
	40	-	-	-	0.10	4.8	9	-	-	-
3	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05 - 0.10	6.2	9	-	-	-
4	20	-	-	-	0.10	0.0	7	-	-	-
5	20	-	-	-	0.10	0.0	7	-	-	-
6	20	-	-	-	0.10	0.0	7	-	-	-
	30	-	-	-	0.05 - 0.10, 1.00	-	9	1	8.1	9

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
4	20	0.70	0.1	9	-	-	-	-	-	-
5	20	0.70	0.5	9	-	-	-	-	-	-
6	20	0.70	0.5	9	-	-	-	-	-	-

Table B15. WIM Truck Response / AASHTO Load Posting Truck Response, Violation % for Reduced WIM/ARDOT Violation Cases
(*n*=1.5, interior span length / end span length)

NEGATIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

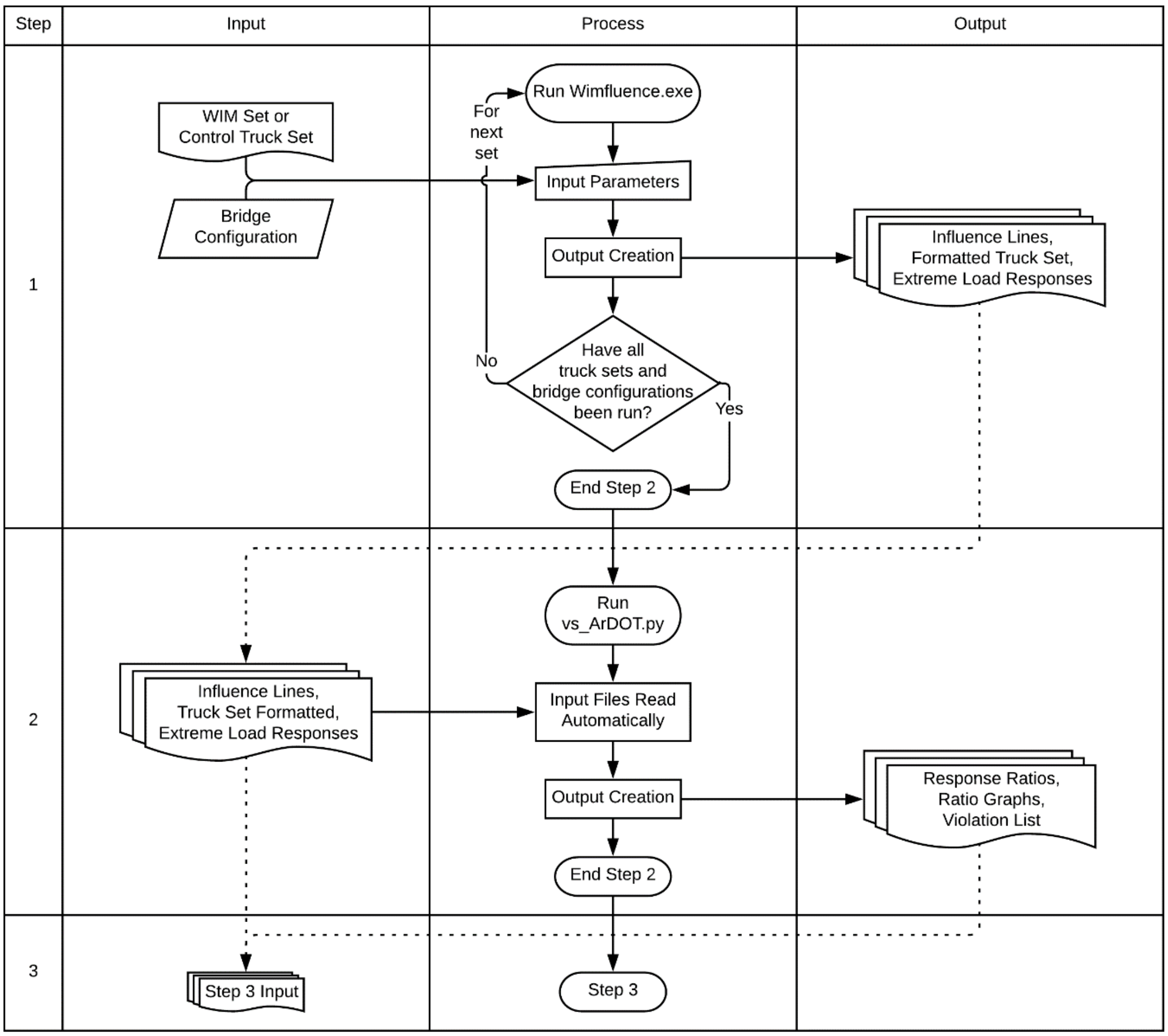
#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
2	20	-	-	-	0.10 - 0.15	3.2	9	-	-	-
3	20	-	-	-	0.10	0.0	9	-	-	-
4	20	-	-	-	0.10	0.0	9	-	-	-
5	20	-	-	-	0.10	0.0	9	-	-	-
6	20	-	-	-	0.10	0.0	9	-	-	-

POSITIVE MOMENT VIOLATIONS WITHIN CRITICAL ANALYSIS SECTION

#	EXTERIOR SPAN	SPAN 1			SPAN 2			SPAN 3		
of SPANS	LENGTH (ft)	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #	VIOLATION REGION	MAX VIOLATION %	CLASS #
4	20	0.70	1.2	9	-	-	-	-	-	-
5	20	0.70	1.6	9	-	-	-	-	-	-

Appendix C: Research Code Users Manual For WIMfluence

This manual aims to comprehensively explain the operation of, inputs for, and outputs of the program and scripts developed for TRC1701. The flowchart below gives an overview of the operation steps involved. The installation of Python and the necessary modules follows this introduction. Each main operation step has its own explanation section afterward. An appendix of code requirements finishes the manual.



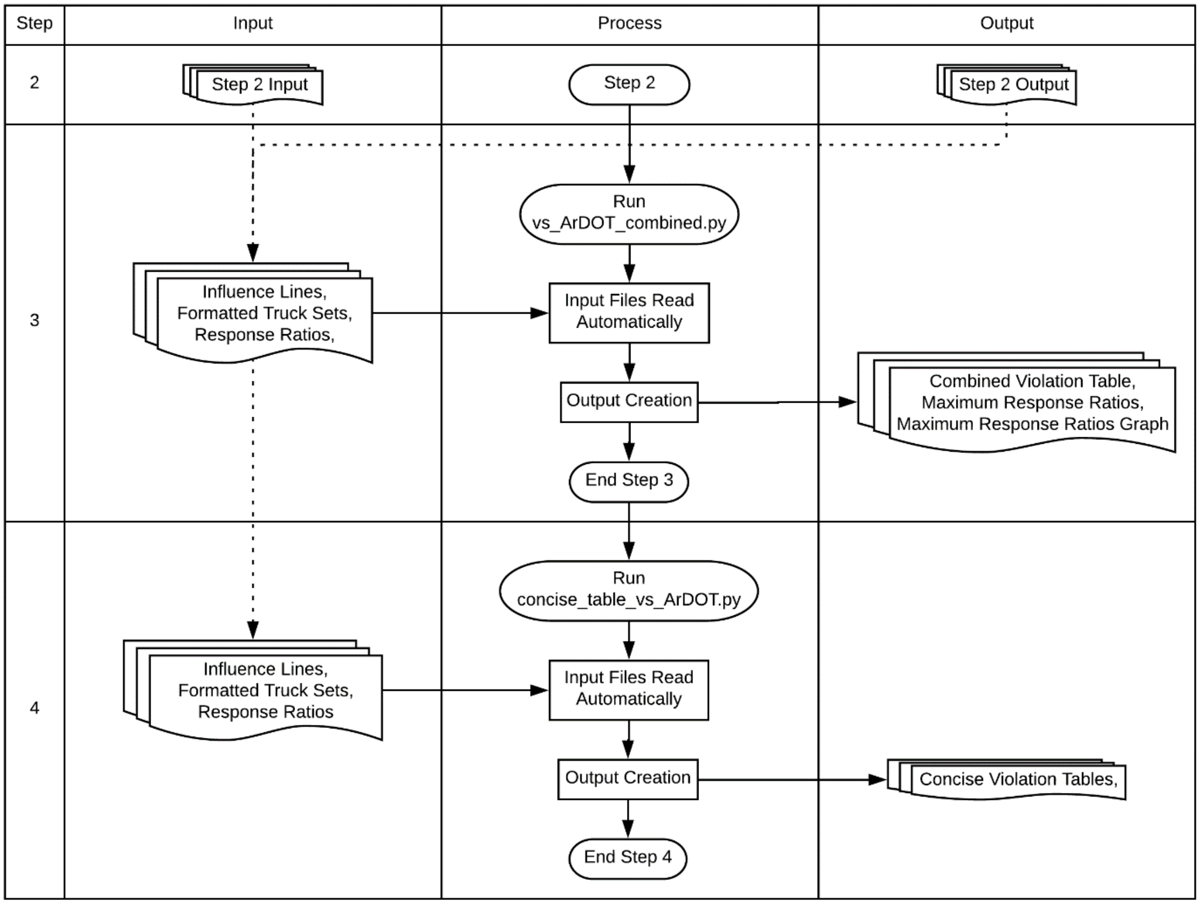


Figure C1. WIMfluence Flowchart

Python Installation and Setup

These scripts are created for use with the Anaconda distribution of Python. Navigate to the web address below in an internet browser. From there, download the Anaconda Windows installer for Python 3.X. Run the installer and follow the installation dialog box to install.
https://www.anaconda.com/download/

If these scripts are the only things Python is needed for, Anaconda includes more than is necessary. In that case installing Python and each necessary module independently may be preferential. If inexperienced in such things, the excess overhead of Anaconda can be worthwhile if trying to avoid potential headaches of installing each piece independently. Based on this and the scripts being written for Anaconda, use of the Anaconda distribution is the recommended method for Python installation.

To uninstall Anaconda, follow the instructions presented at the website below.
https://docs.anaconda.com/anaconda/install/uninstall

If the Python scripts do not run after double clicking, the .py file extension may need to be associated with Python. Note that the exact wording of the selections in these instructions may vary depending on the Windows version. Right click a script file, select “Open with,” then select “Choose another app.” From the dialog box that opens, select Python. If multiple Python entries are available, select the one with an icon appearing to represent a program window. The other entry should appear to represent a sheet of paper. Now check the box for “Always use this app to open .py files.” If neither entry is available or these steps do not work, additional help may be found on the internet. Alternatively, the python scripts can still be run via command line as described in the “Operation” subsection of each script section.

Step 1:
Wimfluence.exe

Description:
This code reads a file of truck configurations to find the maximum positive moment, negative moment, and shear values at analysis points along a given bridge configuration. The analysis points are spaced at 20th intervals within each span of the bridge.

Output

Within the following file names, “CLASS” is replaced with the appropriate class name and “BRIDGE” is replaced with a description of the bridge on which the response values are for. Output files are contained in a folder describing the bridge configuration within the “output” folder.

- **IL_BRIDGE.csv**: This includes the influence lines for the moment of, shear at the left of, and shear at the right of each analysis point. Analysis points are given as both actual values and ratios to the length of the first span. Influence factors are in terms of the length of the first span.
    - *spans*: the number of spans in the bridge configuration
    - *span lengths*: the lengths (ft) of each span in order from left to right
    - *span length ratios*: the ratios of span length to first span length in order from left to right
    - *internal support positions*: the position (ft) of internal supports in order from left to right
    - *internal support position ratios*: the ratios of support positions first span length in order from left to right
    - *analysis_point*: the location at which the response factors are determined
    - *analysis_point_ratio*: the ratio of the *analysis_point* to the length of the first span
    - *load_point*: the location of the point load causing the responses at *analysis_point*
    - *moment*: the moment response value in terms of point load value (*P*) at *load_point* and first span length (*L1*). Multiply this value by *P* and *L1* to find the actual moment response value.

    - *left_shear*: the shear value at the left side of *analysis_point* in terms of the point load value (*P*) at *load_point*. Multiply this value by *P* to find the actual shear response at the left side
    - *right_shear*: the shear value at the right side of *analysis_point* in terms of the point load value (*P*) at *load_point*. Multiply this value by *P* to find the actual shear response at the right side
- **CLASS_formatted.csv**: This is an alternative format list of the trucks given in the truck input file. This format is potentially friendlier for database-like tools. Depending on the size of the input truck file, this file can easily exceed the row limit of a Microsoft Excel spreadsheet.
    - *truck_index*: the number *n* meaning the *n*th truck in the set
    - *num_axles*: the number of axles on the truck
    - *axle_num*: the number *n* meaning the *n*th axle of the truck
    - *axle_weight*: the weight (kips) of the axle defined by *axle_num* and *truck_index*
    - *axle_rel_pos*: the relative position in feet of the axle defined by *axle_num* and *truck_index* to the first axle of the truck defined by *truck_index*. The negative value indicates the axle being behind the first axle. A value of -5 means the axle is 5 feet behind the first axle.
- **CLASS_extreme_response_BRIDGE.csv**: This gives the maximum and minimum values for moment, left shear, and right shear at each analysis point. The "NaN" values are simply placeholders to allow a script that used this file to run properly. There are six rows per analysis point — a minimum and maximum value for each of the three responses.
    - *truck_index*: the truck number producing the extreme response value within the same row. This corresponds with the truck index given in the alternative format truck file.
    - *truck_direction*: the direction the truck is facing to produce the extreme response. "f" denotes a truck traveling forward along the bridge (left to right) and "b" denotes a truck traveling backward (right to left).
    - *first_axle_pos*: the position in feet of the front (steering) axle of the truck along the bridge. A forward-facing truck will have other axles to the left of the steering axle while a backward-facing truck will have other axles to the right. A negative value means the first axle is off the bridge to the left of it (before it). This occurs in conjunction with a backwards facing truck resulting in at least the rear axle being on the bridge.
    - *analysis_point*: the location in feet at which the extreme response value is being found on the bridge.
    - *moment*: the extreme moment (kip-ft) values at each analysis point. These are the maximum and minimum moment values. In the case of no negative moment values, the minimum value will be zero.
    - *shear_left*: the extreme shear (kip) values at the left side of the analysis point. These are the maximum and minimum left shear values.
    - *shear_right*: the extreme shear (kip) values at the right side of the analysis point. These are the maximum and minimum right shear values.

Input

- Truck set (WIM)1 file within folder "input" with file extension of ".txt" or ".csv"
- The name of the file before the period is used as the name of the truck set in subsequent files.
  - The first line is a header line that is ignored by the code. This can contain anything the user desires, such as column names or truck set descriptions
  - Subsequent lines detail individual trucks. The first value in the line shall be the number of axles on the truck. The following value is the weight (kips) of the first axle. Following those are the alternating axle spaces (ft) and axle weights (kips) in order from front to back. Axle spaces shall be integer values. Anything on the line after the last axle weight is ignored by the code, so truck labels can be placed there if desired. Labels can be left off if so desired. Spaces shall separate values. Any other delimiter will cause the code to fail. The following example lines detail the AASHTO SU5 truck and ArDOT Code 4.

```
5 12 10 8 4 8 4 17 4 17 AASHTO SU5
3 11 8 20 4 14 ArDOT Code 4
```

Operation

With the input files in the "input" folder, run the executable (run via double click, command line, etc.). Follow the prompt that follows.

- Input the name of the truck set file to be ran. (Ex. "ArDOT.txt", "Class_7.csv")
- Tell whether the truck file is in metric ("y") or not ("n"). If the file is in metric units, then the axle spaces and weights describe in the Inputs section shall be in decimeters and 100 kilograms (0.1 tonne). Metric units will be converted to kips and nearest foot values.
- Input the number of spans
- Input the length (ft) of each span. Span lengths shall be in integer feet values.

The program then creates the "output" folder and the subfolder describing the bridge configuration. The folder location is given in the command line interface and the output file names are shown. A description of the bridge configuration is given followed by the run time of the code.

Repeat this process for each input file and bridge configuration desired.

The program can be run quickly at the command line by echoing the input parameters in order then piping that into the program execution.

Example:

```
(echo ArDOT.txt n 2 30 20) | Wimfluence.exe
```

The PowerShell equivalent is given below.

```
"ArDOT.txt n 2 30 40" | ./ Wimfluence.exe
```

In the two examples above, the truck input file is given followed by the yes or no for metric units, the number of spans, and the lengths of each span. That information is then piped into the input text stream of the program execution.

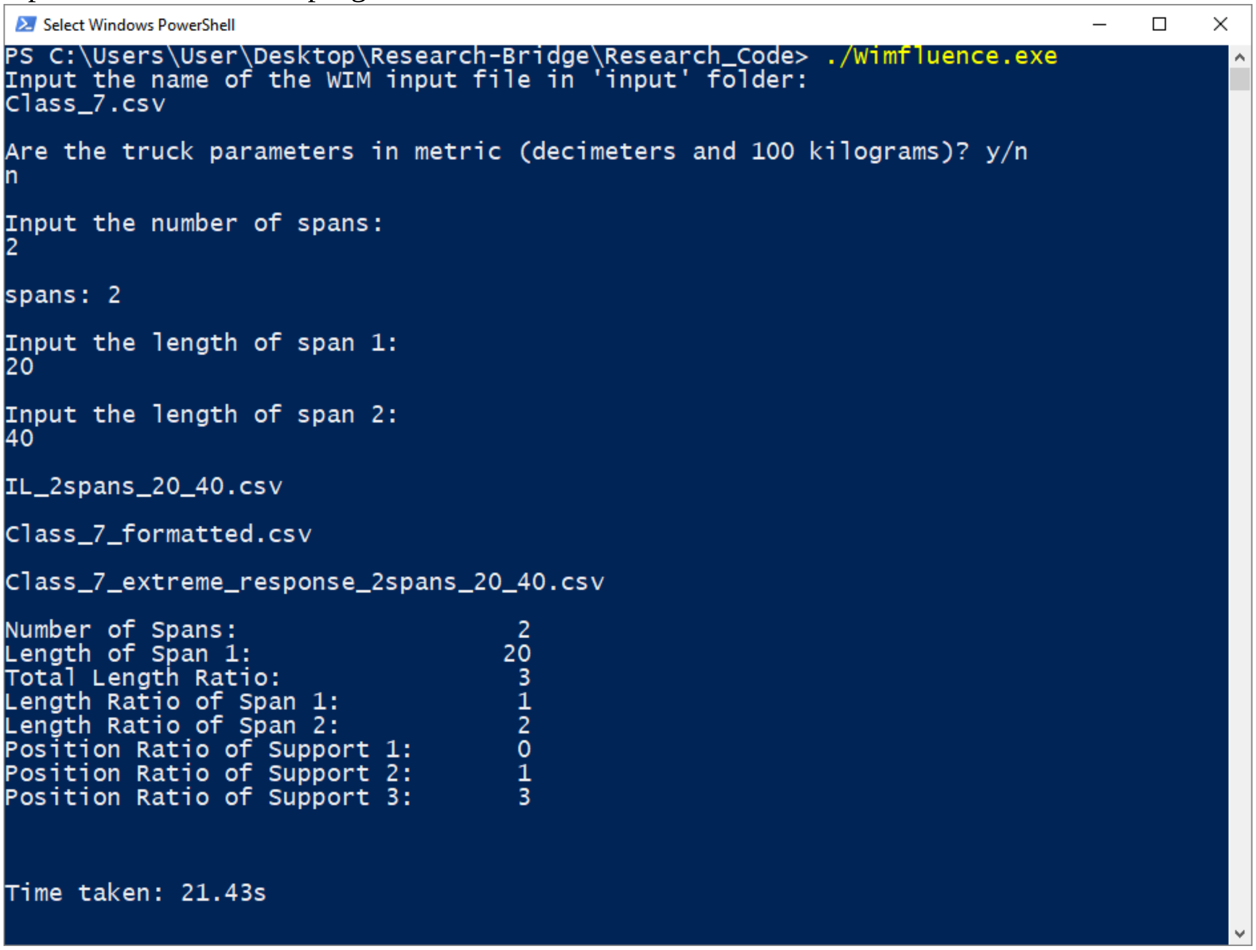


Figure C2. WIMfluence Input Window

Steps 2-4:
Data Analysis Python Scripts

The Python scripts are written for the Anaconda distribution of Python 3. The use of Anaconda is recommended, but the modules can be installed individually if so desired. These require truck set files have been named “Class_#.csv” or “Class_#.txt” when run through the above program. Either control truck set (ArDOT or AASHTO) must have also been already run. These scripts should be placed within the “output” folder produced by the above code. They are listed in the order to be run.

Step 2:
vs_ArDOT.py / vs_AASHTO.py

Python Modules: os, winsound, numpy, pandas, matplotlib, timeit

Description: This script walks through the folders within "output" to find response ratios for each truck class compared to the control truck set (ArDOT or AASHTO). Files are created detailing the response ratios for shear, positive moment, and negative moment; the corresponding response values; and the trucks creating those response values.

Output

Within the following file names, "#" is replaced with the appropriate class number, "CONTROL" is replaced with either "ArDOT" or "AASHTO" for whichever is used as a control, and "BRIDGE" is replaced with a description of the bridge on which the response values are for.

The following four files are within the bridge-specific folder within the "output" folder.

- **ratios_moment_neg_Class_#_vs_CONTROL_BRIDGE.csv**: gives the negative moment ratios for each analysis point as well as the moment and trucks creating them.
- **ratios_moment_pos_Class_#_vs_CONTROL_BRIDGE.csv**: gives the positive moment ratios for each analysis point as well as the moment and trucks creating them.
- **ratios_shear_Class_#_vs_CONTROL_BRIDGE.csv**: gives the shear ratios for each analysis point as well as the shear and trucks creating them.
- The following columns are the same for the three previously described files. "RESPONSE" should be replaced with the corresponding response type (moment_neg, moment_pos, shear)
    - *analysis_point*: the location (ft) along the bridge at which the response ratio occurs
    - *span_position*: the location of the analysis point within its bridge span. The integer part tells which support is left of the analysis point. The fractional part tells how far within the span the analysis point occurs. In "0.35", the "0" indicates the external support is to the left of the analysis point. The ".35" indicates the analysis point is 35% of the way through the span. "2.85" indicates 85% through the third bridge span. "2.00" indicates the end of the second span and the beginning of the third.
    - *ratio_moment_neg_max*: the ratio of the negative moment values of the truck class to the control set. "max" refers to the response values being the extreme ones produced by the truck set when run through the previous program.
    - *Class_#_RESPONSE_max*: the response value in class # producing the corresponding ratio
    - *CONTROL_RESPONSE_max*: the response value in the control set producing the corresponding ratio
    - *Class_#_truck_index*: the truck number of class # producing the corresponding response value

- *Class_#_truck_direction*: the direction the class # truck is facing to produce the corresponding response value. "f" denotes a truck traveling forward along the bridge (left to right) and "b" denotes a truck traveling backward (right to left).
- *Class_#_first_axle_pos*: the location (ft) of the first axle of the class # truck to produce corresponding response value. A forward-facing truck will have other axles to the left of the steering axle while a backward-facing truck will have other axles to the right. A negative value means the first axle is off the bridge to the left of it (before it). This occurs in conjunction with a backwards facing truck resulting in at least the rear axle being on the bridge.
- *CONTROL_truck_index*: the truck number of the control set producing the corresponding response value
- *CONTROL_truck_direction*: the direction the control set truck is facing to produce the corresponding response value. "f" denotes a truck traveling forward along the bridge (left to right) and "b" denotes a truck traveling backward (right to left).
- *CONTROL_first_axle_pos*: the location (ft) of the first axle of the control set truck to produce corresponding response value. A forward-facing truck will have other axles to the left of the steering axle while a backward-facing truck will have other axles to the right. A negative value means the first axle is off the bridge to the left of it (before it). This occurs in conjunction with a backwards facing truck resulting in at least the rear axle being on the bridge.

- **Class_#_vs_CONTROL_BRIDGE.png**: a graph of the three response ratios for each analysis point along the bridge. The positive moment is not graphed near the supports due to small moment values creating large ratios (e.g. 0.1 kips / 0.01kips = 10).

The following file is within the “output” folder.

- **violation_list_vs_CONTROL.csv**: a list of bridge configuration and class combinations and whether a ratio exceeds 1 or not
  - *span_configuration*: description of the bridge span for which the response ratios are found
  - *class*: the truck class for which the response ratios are found
  - *mom_pos_max_ratio*: the maximum positive moment ratio produced by *class* in *span_configuration*
  - *mom_pos_position*: the location (ft) within the bridge at which the positive moment ratio occurs
  - *mom_pos_span_position*: the position within the span at which the positive moment ratio occurs. The integer indicates the support to the left of the position (0 being the left external support). The decimal indicates how far into the span the point is (.35 being 35% into the span).
  - *mom_neg_max_ratio*: the maximum negative moment ratio produced by *class* in *span_configuration*
  - *mom_neg_position*: the location (ft) within the bridge at which the negative moment ratio occurs
  - *mom_neg_span_position*: the position within the span at which the negative moment ratio occurs. The integer indicates the support to the left of the position (0 being the left

external support). The decimal indicates how far into the span the point is (.35 being 35% into the span).

- *shear_max_ratio*: the maximum shear ratio produced by *class* in *span_configuration*
- *shear_position*: the location (ft) within the bridge at which the shear ratio occurs
- *shear_span_position*: the position within the span at which the shear ratio occurs. The integer indicates the support to the left of the position (0 being the left external support). The decimal indicates how far into the span the point is (.35 being 35% into the span).
- *violation*: boolean value telling whether a response ratio greater than 1 occurs or not

Input

The inputs for this script are the outputs of the previous program. Files are already in their proper locations.

Operation

Ensure Python and the necessary modules are installed first. See the Python installation section for more information.

Double click the script file to run it in the current directory. The script is open in a new command prompt window. This window will close after script execution.

If preferred, the script can be run via Command Prompt or PowerShell. Right click in the folder window the script is in then click "Open command window here" or "Open PowerShell window here." Type "**python vs_ArDOT.py**" or "**python vs_AASHTO.py**" then press Enter. This method will run the script within the current window and keep the window open after execution. During execution, the window will display the current folder it is walking through. With knowledge of the bridge configurations present, this output can be used to measure the script's progress. At the end, the duration of the run is reported in seconds.

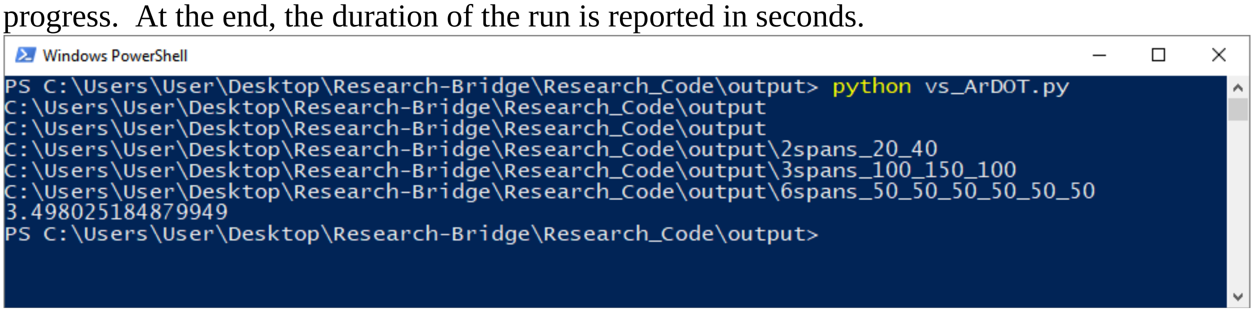


Figure C3. WIMfluence Execution Window for Each Truck Class

Step 3:
vs_ArDOT_combined.py / vs_AASHTO_combined.py / AASHTO_vs_ArDOT_combined.py

Python Modules: os, winsound, numpy, pandas, matplotlib, timeit, sys

Description: This script takes the response ratios produced by the previous script and combines them across all truck classes for each bridge configuration. The maximum response ratio among all truck classes is found for each analysis point. This allows one to focus on the response ratio behavior of specific bridge configurations regardless of which truck class produces the response ratios. The truck class producing each maximum response ratio is reported in the output files to track which classes consistently produce the greatest responses.
AASHTO_vs_ArDOT_combined.py does not combine the response ratios of different truck classes like the other two do. It still produces each of the output files produced by the other two, so its inclusion in this section is appropriate.

Output

Within the following names, "CONTROL" is replaced with either "ArDOT" or "AASHTO" for whichever is used as a control, "BRIDGE" is replaced with a description of the bridge on which the response values are for, and "RESPONSE" is replaced with the corresponding response type (moment_pos, moment_neg, shear or moment_positive, moment_negative, shear).

For **AASHTO_vs_ArDOT_Combined.py**, "All" is replaced with "AASHTO" to reflect the script's nature.

- **All_vs_CONTROL_RESPONSE_violation_table.csv**: This table shows problem response ratios and their corresponding truck class in a format somewhat reminiscent of the bridge configurations represented. It can be viewed as a text-based alternative to the response ratio figures also produced for each bridge configuration. This table has the benefit of showing all bridge configurations in a single file and reporting only the response ratios exceeding 1.
  - The first row is the span position of the response ratio reported. Span position refers to the fractional location of a position within its span of the bridge. The integer portion represents the support index (0 being the initial external support or leftmost support). The decimal portion is the percentage within the span at which the location occurs (ex. .35 indicates 35% within the span).
  - The first column gives the bridge configuration represented in each row. The numbers after "spans" gives the span lengths (ft) from left to right.
  - The rest of the table is the response ratios occurring at each span position for each bridge configuration. Ratios not greater than 1 are represented by "—" instead of being reported explicitly. This allows one to quickly pick out the issue response ratios across all bridge configurations and span positions. "N/A" is reported near each bridge support in the positive moment table. Ratios near the supports are neglected due to extreme ratios being produced by small moment values.

The following files are bridge-specific.

- **ratios_RESPONSE_All_vs_CONTROL_BRIDGE.csv**: the greatest response ratios at each analysis point across all truck classes
  - *analysis_point*: the location (ft) into the bridge at which the response ratio occurs
  - *span_position*: the position within the span at which the response ratio occurs. The integer indicates the support to the left of the position (0 being the left external support). The decimal indicates how far into the span the point is (.35 being 35% into the span).
  - *ratio_RESPONSE_max*: the greatest response ratio occurring at the analysis point across all truck classes
  - *class_RESPONSE_max*: the extreme response value of a class truck producing the response ratio
  - *CONTROL_RESPONSE_max*: the extreme response value of the control set truck producing the response ratio
  - *class_truck_index*: the truck number of the class truck producing the response ratio
  - *class_truck_direction*: the direction the class truck is facing to produce the response value. "f" denotes a truck facing forward (or to the right) along the bridge. "b" denotes a truck facing backward (or to the left) along the bridge.
  - *class_first_axle_pos*: the position (ft) onto the bridge of the first axle of the class truck to produce the response value. A negative value indicates the first axle is off the bridge and before (or to the left) of it.
  - *CONTROL_truck_index*: the truck number of the control set truck producing the response ratio
  - *CONTROL _truck_direction*: the direction the control set truck is facing to produce the response value. "f" denotes a truck facing forward (or to the right) along the bridge. "b" denotes a truck facing backward (or to the left) along the bridge.
  - *CONTROL _first_axle_pos*: the position (ft) onto the bridge of the first axle of the control set truck to produce the response value. A negative value indicates the first axle is off the bridge and before (or to the left) of it.
  - *truck_class*: the truck class of the truck producing the response value
- **ratios_RESPONSE_All_vs_CONTROL_BRIDGE.png**: A graphical representation of the contents of the previous file. The truck class producing each response ratio is reported toward the top of the figure.

Input

The inputs for this script are the outputs of the previous program and script. Files are already in their proper locations.

Operation

Ensure Python and the necessary modules are installed first. See the Python installation section for more information.

Double click the script file to run it in the current directory. The script is open in a new command prompt window. This window will close after script execution.

If preferred, the script can be run via Command Prompt or PowerShell. Right click in the folder window the script is in then click “Open command window here” or “Open PowerShell window here.” Type “python” and the script name separated with a space. Press Enter. This method will run the script within the current window and keep the window open after execution.

During execution, the window will display the base name of the current folder it is walking through. The period in the first line of output represents the parent directory of the script. As this is the first folder the script walks through, it is reported along with all the bridge-specific folders. The use of a period to represent the current folder path is a shorthand convention. With knowledge of the bridge configurations present, this output can be used to measure the script’s progress.

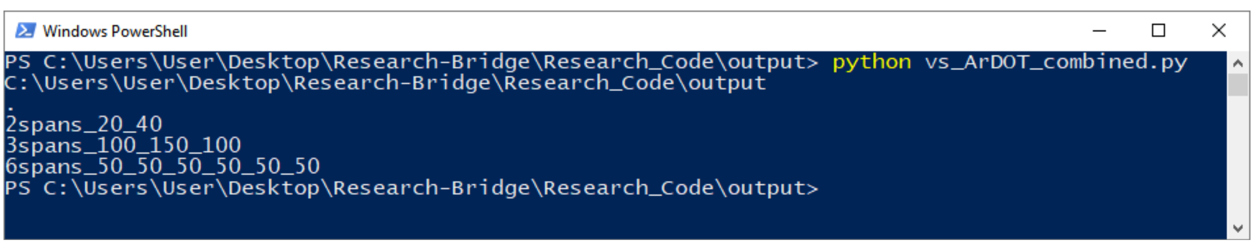


Figure C4. WIMfluence Execution Window for Maximum Response

Step 4:
concise_table_vs_ArDOT.py / concise_table_vs_AASHTO.py / concise_table_AASHTO_vs_ArDOT.py

Python Modules: os, winsound, pandas

Description: This script takes the response ratios produced by the first script and combines them across all truck classes for each bridge configuration. The maximum response ratio among all truck classes is found for each analysis point. This allows one to focus on the response ratio behavior of specific bridge configurations regardless of which truck class produces the response ratios. The truck class producing each maximum response ratio is reported in the output files to track which classes consistently produce the greatest responses. This script differs from the previous script in the format of the response ratio table.

concise_table_AASHTO_vs_ArDOT.py does not combine the response ratios across classes. It produces the same output table for only AASHTO compared to ArDOT.
This script will crash if it finds that there are no instances of response ratios greater than 1.

Output

- **RESPONSE_violation_vs_CONTROL_ordered_table.csv**: This gives the response ratios greater than 1 for each bridge configuration and reports other information for each ratio. It is sorted from greatest response ratio to least.
  - *ratio_RESPONSE*: the ratio of the greatest response produced by a truck class to the control truck set
  - *bridge_span*: a description of the bridge configuration on which the response ratio occurs
  - *truck_class*: the truck class producing the response ratio. This column is nonexistent for the output of **AASHTO_vs_ArDOT_combined.py** as the column contents would always be "AASHTO."
  - *analysis_point*: the location (ft) into the bridge at which the response ratio occurs
  - *span_position*: the position within the span at which the response ratio occurs. The integer indicates the support to the left of the position (0 being the left external support). The decimal indicates how far into the span the point is (.35 being 35% into the span).
  - *class_truck*: a description of the class truck producing the response ratio. Values preceding the dash are the lengths (ft) of the axle spaces from front to back. Values after the dash are the axle weights (kips) from front to back. For the output of **AASHTO_vs_ArDOT_combined.py**, this column is named *AASHTO_truck* and gives the name of the truck instead of a description of it.
  - *gross_weight*: the gross weight (kips) of the class truck producing the response ratio. This column is omitted in the output of **AASHTO_vs_ArDOT_combined.py**.
  - *total_length*: the total length (ft) of the class truck producing the response ratio. This column is omitted in the output of **AASHTO_vs_ArDOT_combined.py**.
  - *CONTROL_truck*: the name of the control set truck producing the response ratio.
  - *class_RESPONSE*: the actual response value producing the response ratio. Moment is in kip-ft and shear is in kips. This column is renamed *AASHTO_RESPONSE* in the output of **AASHTO_vs_ArDOT_combined.py**.
  - *CONTROL_RESPONSE*: the actual response value from the control set producing the response ratio

Input

The inputs for this script are the outputs of the previous program and scripts. Files are already in their proper locations provided the previous program and scripts have been run.

Operation

Ensure Python and the necessary modules are installed first. See the Python installation section for more information.

Double click the script file to run it in the current directory. The script is open in a new command prompt window. This window will close after script execution.

If preferred, the script can be run via Command Prompt or PowerShell. Right click in the folder window the script is in then click "Open command window here" or "Open PowerShell window here." Type "python" and the script name separated with a space. Press Enter. This method will run the script within the current window and keep the window open after execution.

During execution, the window will display the base name of the current folder it is walking through and the class truck set it is importing. The period in the first line of output represents the parent directory of the script. As this is the first folder the script walks through, it is reported along with all the bridge-specific folders. The use of a period to represent the current folder path is a shorthand convention. Class truck sets are imported once then kept in memory for the duration of the script run. Class truck sets are thus only reported after the first bridge configuration in which they are encountered. With knowledge of the bridge configurations and truck classes present, this output can be used to measure the script's progress.

NOTES

- The research program requires C++11. It may work with newer C++ standards, but that is untested.
- The research program is compiled using the GNU GCC compiler for C++11 with the following compilation flags
  - -std=c++11
  - -fexpensive-optimizations
  - -O3
- The Python scripts are written for Python 3.6.2 using Anaconda 4.3.29
- Python modules and versions:
  - os
  - matplotlib — 2.0.2
  - numpy — 1.13.1
  - pandas — 0.20.3
  - sys
  - timeit
  - winsound

Appendix D: File Directory

Directory *File*

- **analysis** — Directory of data analysis script output files; This is the working directory for data analysis minus the Wimfluence.exe outputs for the sake of minimizing directory size; Since this is a working directory, details on script outputs can be found in the program and script user manual
    - **n=#** — Directory of output files related to bridges with internal to external span length ratios of #
        - **AASHTO_vs_ArDOT_n=#** — Directory of script outputs for the comparison of AASHTO trucks to ArDOT trucks
            - **SPAN** — Directory of script outputs related to the bridge described by SPAN
        - **All_vs_AASHTO_n=#** — Directory of script outputs for the comparison of class trucks to AASHTO trucks
            - **SPAN** — Directory of script outputs related to the bridge described by SPAN
        - **All_vs_ArDOT_n=#** — Directory of script outputs for the comparison of class trucks to ArDOT trucks
            - **SPAN** — Directory of script outputs related to the bridge described by SPAN
- **class_distribution**
    - *bridge_formula_full_implementation_stats.txt* — A list of pass/fail percentages for the bridge formula for each vehicle class; percentages are included for both total vehicles and representative (unique) vehicles
    - *bridge_formula_failing_percentages.png* — A graphical representation of the failure percentages presented in *bridge_formula_full_implementation_stats.txt*
    - **figures** — Directory of figures pertaining to truck class distribution and statistics
        - **gross_weight_figures**
            - *Class_#_gross_weights.png* — A plot of gross weights of representative trucks in the order of appearance in the source file
        - **total_trucks_cumulative_figures**
            - *Class_#_cumulative_total_trucks.png* — A plot of cumulative total truck counts with increasing gross weight
        - **total_trucks_cumulative_percentage_figures**
            - *Class_#_cumulative_total_percentage* — A plot of cumulative percentages of total trucks with increasing gross weight
        - **total_trucks_per_gross_weight_figures**
            - *Class_#_total_trucks_per_gross_weight.png* — A plot of the distribution of total trucks with increasing gross weight
        - **unique_configurations_cumulative_figures**
            - *Class_#_cumulative_unique_configurations.png* — A plot of cumulative unique truck configuration counts with increasing gross weight
        - **unique_configurations_cumulative_percentage_figures**
            - *Class_#_cumulative_unique_percentage* — A plot of cumulative percentages of unique truck configurations with increasing gross weight

        - **unique_configurations_per_gross_weight_figures**
            - *Class_#_unique_configurations_per_gross_weight.png* —A plot of the distribution of unique truck configurations with increasing gross weight
- **code** — Directory of files related to the Wimfluence
    - **source** — Directory of source code for the Wimfluence
- **data_raw** — Working directory pulled directly from high powered computer; contains the program output for every bridge and truck set combination; nothing here is changed from when it was used
    - **input** — Input truck sets for the program
    - **n=#** — Directory of program runs for bridges with internal to external span length ratios of #
        - **AASHTO** — Directory of program runs for the AASHTO load posting trucks
        - **ArDOT** — Directory of program runs for ArDOT load posting trucks
        - **C#** — Directory of program runs for truck class #
        - **sh_scripts_n=#** — Directory of bash script templates for every bridge with internal to external span length ratios of #
    - **sh_scripts** — Directory of bash script templates for every bridge
        - **n=#** — Directory of bash script templates for every bridge with internal to external span length ratios of #
    - *Optimized-foot-steps.exe* — Program used to find extreme response values for each truck set; this is the same program produced by the source code in **code/source/**; the name here is to differentiate it from previous iterations of the program
- **manual_and_example** — Directory containing a user's manual for the program and scripts and an example usage of them
    - **example** — Directory containing an example for the program and scripts; additional details are within
    - *Wimfluence and Comparison Scripts Manual.docx* — User's manual for the program and scripts
- **ordered_tables**
    - **n=#** — Directory of response comparisons for bridges with an internal span length to external span length ratio of #
        - **AASHTO_vs_ArDOT_n=#** — Directory of response comparisons between AASHTO and ArDOT
            - *moment_negative_violation_vs_ArDOT_ordered_table.csv* — Comparison negative moment ratios exceeding 1 between AASHTO and ArDOT and corresponding details
            - *moment_positive_violation_vs_ArDOT_ordered_table.csv* — Comparison positive moment ratios exceeding 1 between AASHTO and ArDOT and corresponding details
            - *shear_violation_vs_ArDOT_ordered_table.csv* — Comparison shear ratios exceeding 1 between AASHTO and ArDOT and corresponding details
        - **All_vs_AASHTO_n=#** — Directory of response comparisons between all truck classes and AASHTO

            - *moment_negative_violation_vs_AASHTO_ordered_table.csv* — Comparison negative moment ratios exceeding 1 between all truck classes (maximum values) and AASHTO and corresponding details
            - *moment_positive_violation_vs_AASHTO_ordered_table*.csv — Comparison positive moment ratios exceeding 1 between all truck classes (maximum values) and AASHTO and corresponding details
            - *shear_violation_vs_AASHTO_ordered_table*.csv — Comparison shear ratios exceeding 1 between all truck classes (maximum values) and AASHTO and corresponding details
        - **All_vs_ArDOT_n=#** — Directory of response comparisons between all truck classes and ArDOT
            - *moment_negative_violation_vs_ArDOT_ordered_table.csv* — Comparison negative moment ratios exceeding 1 between all truck classes (maximum values) and ArDOT and corresponding details
            - *moment_positive_violation_vs_ ArDOT_ordered_table*.csv — Comparison positive moment ratios exceeding 1 between all truck classes (maximum values) and ArDOT and corresponding details
            - *shear_violation_vs_ ArDOT_ordered_table*.csv — Comparison shear ratios exceeding 1 between all truck classes (maximum values) and ArDOT and corresponding details
- **program_input_files** — Directory of input truck files used during the research process
    - **control_sets** — Directory of input truck files for the sets used as controls (ArDOT and AASHTO)
        - *AASHTO.txt* — Input file of AASHTO trucks used for load posting
        - *ArDOT.txt* — Input file of ArDOT trucks used for load posting
    - **truck_classes** — Directory of input truck files for the truck classes used
        - *Class_#.csv* — Input file of trucks from class #; -99 represents trucks that did not fall into one of the other truck classes
- **python_scripts** — Directory of Python scripts used in the research process
    - **scripts_AASHTO_vs_ArDOT** — Directory of Python scripts to compare AASHTO to ArDOT trucks
        - *AASHTO_vs_ArDOT_combined.py* — Python script to produce a table of ratios exceeding 1 presented in a format reminiscent of the bridges represented
        - *concise_table_AASHTO_vs_ArDOT.py* — Python script to take the ratios produced by *vs_ArDOT.py* and order them from greatest to least and couple them with corresponding data in a table
        - *vs_ArDOT.py* — Python script to compare truck set response values to ArDOT trucks
    - **scripts_vs_AASHTO** — Directory of Python scripts to compare truck classes to AASHTO trucks
        - *concise_table_vs_AASHTO.py* — Python script to take the ratios produced by *vs_AASHTO.py* and order them from greatest to least and couple them with corresponding data in a table

        - *vs_AASHTO.py* — Python script to compare truck set response values to the AASHTO trucks
        - *vs_AASHTO_combined.py* — Python script to produce a table of ratios exceeding 1 presented in a format reminiscent of the bridges represented
    - **scripts_vs_ArDOT** — Directory of Python scripts to compare truck classes to ArDOT trucks
        - *concise_table_vs_ArDOT.py* — Python script to take the ratios produced by *vs_ArDOT.py* and order them from greatest to least and couple them with corresponding data in a table
        - *vs_ArDOT.py* — Python script to compare truck set response values to ArDOT trucks
        - *vs_ArDOT_combined.py* — Python script to produce a table of ratios exceeding 1 presented in a format reminiscent of the bridges represented
    - *bridge_formula_filter.py* — Python script to apply to federal bridge formula as a filter to each truck class
- **ratio_figures_classes_combined**
    - **n=#** — Directory of ratio figures for spans with an internal to external span length ratio of #
        - **AASHTO_vs_ArDOT_n=#**
            - *ratios_moment_neg_AASHTO_vs_ArDOT_[SPAN].png* — Figure showing the negative moment ratios between AASHTO and ArDOT for the span described by [SPAN]
            - *ratios_moment_pos_AASHTO_vs_ArDOT_[SPAN].png* — Figure showing the positive moment ratios between AASHTO and ArDOT for the span described by [SPAN]
            - *ratios_shear_AASHTO_vs_ArDOT_[SPAN].png* — Figure showing the shear ratios between AASHTO and ArDOT for the span described by [SPAN]
        - **All_vs_AASHTO_n=#**
            - *ratios_moment_neg_All_vs_AASHTO_[SPAN].png* — Figure showing the negative moment ratios between all truck classes (maximum value) and AASHTO for the span described by [SPAN]
            - *ratios_moment_pos All_vs_AASHTO_[SPAN].png* — Figure showing the positive moment ratios between all truck classes (maximum value) and AASHTO for the span described by [SPAN]
            - *ratios_shear_All_vs_AASHTO_[SPAN].png* — Figure showing the shear ratios between all truck classes (maximum value) and AASHTO for the span described by [SPAN]
        - **All_vs_ArDOT_n=#**
            - *ratios_moment_neg_All_vs_ArDOT_[SPAN].png* — Figure showing the negative moment ratios between all truck classes (maximum value) and ArDOT for the span described by [SPAN]
            - *ratios_moment_pos All_vs_ArDOT_[SPAN].png* — Figure showing the positive moment ratios between all truck classes (maximum value) and ArDOT for the span described by [SPAN]

        - *ratios_shear_All_vs_ArDOT_[SPAN].png* — Figure showing the shear ratios between all truck classes (maximum value) and ArDOT for the span described by [SPAN]
- **unfiltered_inputs** — Directory of truck sets prior to the application of the federal bridge formula for filtering
    - *Class_#.csv* — Set of unique (representative) trucks belonging to class # prior to federal bridge formula filtering
    - *unique_trucks_all.csv* — all unique (representative) trucks from all truck classes; the contents of all *Class_#.csv* files combined within a single file
- **wide_tables**
    - **n=#** — Directory of response ratios for bridges with an internal to external span length ratio of #
        - **AASHTO_vs_ArDOT_n=#**
            - *AASHTO_vs_ArDOT_moment_negative_violation_table.csv* — Table of negative moment ratios between AASHTO and ArDOT exceeding 1 presented in a format reminiscent of the bridge configurations represented
            - *AASHTO_vs_ArDOT_moment_positive_violation_table.csv* — Table of positive moment ratios between AASHTO and ArDOT exceeding 1 presented in a format reminiscent of the bridge configurations represented
            - *AASHTO_vs_ArDOT_shear_violation_table.csv* — Table of shear ratios between AASHTO and ArDOT exceeding 1 presented in a format reminiscent of the bridge configurations represented
        - **All_vs_AASHTO_n=#**
            - *All_vs_AASHTO_moment_negative_violation_table.csv* — Table of negative moment ratios between all truck classes (maximum values) and AASHTO exceeding 1 presented in a format reminiscent of the bridge configurations represented
            - *All_vs_AASHTO_moment_positive_violation_table.csv* — Table of positive moment ratios between all truck classes (maximum values) and AASHTO exceeding 1 presented in a format reminiscent of the bridge configurations represented
            - *All_vs_AASHTO_shear_violation_table.csv* — Table of shear ratios between all truck classes (maximum values) and AASHTO exceeding 1 presented in a format reminiscent of the bridge configurations represented
        - **All_vs_ArDOT_n=#**
            - *All_vs_ArDOT_moment_negative_violation_table.csv* — Table of negative moment ratios between all truck classes (maximum values) and ArDOT exceeding 1 presented in a format reminiscent of the bridge configurations represented
            - *All_vs_ArDOT_moment_positive_violation_table.csv* — Table of positive moment ratios between all truck classes (maximum values) and ArDOT

exceeding 1 presented in a format reminiscent of the bridge configurations represented

- *All_vs_ArDOT_shear_violation_table.csv* — Table of shear ratios between all truck classes (maximum values) and ArDOT exceeding 1 presented in a format reminiscent of the bridge configurations represented