LOAD EFFECTS CAUSED BY PERMIT AND ILLEGALLY OVERLOADED VEHICLES

OLGA IATSKO, *e-mail: ozi0002@auburn.edu*
ANDRZEJ S. NOWAK
ANJAN RAMESH BABU
Department of Civil Engineering, Auburn University, Auburn, USA

Abstract: Many existing bridges in the US have signs of structural deterioration, such as fatigue cracks, corrosion of the structural steel elements and reinforcing bars. Thus, they are no longer able to carry the load they were originally designed for. Deterioration and failure of existing bridges can be prevented by providing the adequate safety margin in the design. This requires the knowledge of the actual live load. The illegally overweight vehicles create significant damage to the roads and shorten the bridge service life. The control of truck traffic violating the permit requirements, as well as, evaluation of the harmful effect caused by these vehicles is a complex issue. For the recent years, a considerable amount of weigh-in-motion(WIM) records has been collected by FHWA and most of the State DOTs. The database of permits regularly issued by State DOTs became available. These data used as a major source for analysis of the permit and illegal live load statistical parameters. A preliminary study of the WIM data indicates that live loads have changed with regard to traffic volume over the years, mix, and weight.

Keywords: weigh-in-motion, bridge live load, statistical parameters, probability paper, permit load

1. Introduction

Roads and bridges form a key component in daily operation and development of the State infrastructure. The transportation network provides the necessary connection between people, business, and industries. However, the repetitive load effects caused by moving vehicles leads to the rapid deterioration and consequent failure of the structural components or the whole structure.

According to Federal Highway Administration (1, 2), from 11% (Minnesota) to 52% (Massachusetts) of all bridges in the United States are structurally deficient or functionally obsolete. In particular, 3,608 of the 16,078 (22.4%) in Alabama are in an unsatisfactory condition (1, 2). While the average age of the bridge in the US is 42 years, one in nine bridges has the deterioration in one or more structural components (2). The percentages of roads in poor or mediocre condition, due to vehicle damage, vary from 17 in Indiana to 73 in Illinois (3).

The oversized and overloaded vehicle's load is often the most severe factor of damage for the roads and bridges (4). The overloaded vehicles are usually transporting the abnormal (e.g. cranes, agricultural or military machinery) or illegal cargo. The threatening effect caused by these trucks can be quite considerable, especially for aged bridges that are often in poor conditions and located in a rural area (5). Also, the stress-load relationship in case of overloaded vehicles is not linear (9). According to the study, the increase in truck weight by half will result in 80% increase of the fatigue damage in steel girders of the bridge.

The consequences of the overloaded traffic to the industry are also significant. The study confirms the growth of infrastructure costs as a direct impact of truck size and weight increase. In particular, the increase of the tridem weight allowance up to 225 kN (51,000 lb) will result in additional $ 24million annually for bridge maintenance and repair. Similarly, the annual effect of the legal gross vehicle weight (GVW) limit 355 kN (80,000 lb) removal estimated at $10 and $510 million for the deficient pavements and bridges replacement respectively (6).

Multiple sources reported the cases of bridge damage or failure due to extreme truck loading or collision involving oversized and overweight vehicles (5, 6, 9). Insufficient permit control and a route planning are the most probable causes of the bridge collapse (Figure 1b) (7). In addition to the excessive live load effects, the abnormal size and weight of the vehicles put them in a risk to be involved in a collision causing the damage of bridge structural components (Figure 1a) (5).

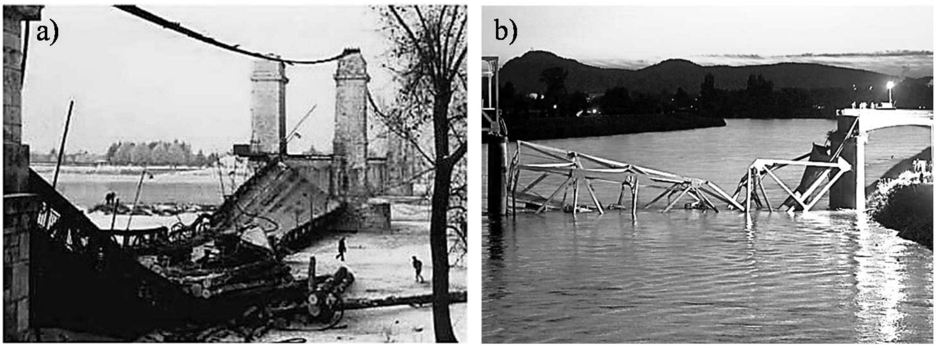

Fig. 1. Bridge collapse in a) Sully-sur-Loire, France (january 1986) due to a truck accident (5) and b) I-5 Skagit Bridge over Washington River, Mount Vernon, Washington (2013) (7)

There is also high rise in number and weight of vehicles in service due to large-scale construction projects. The problem of illegal overloading the trucks goes beyond the safety of the roads and bridges. The violators create a high competition in transportation service market, where the operator that follow the permit limits stay in disadvantage (4). This leads to the balancing the freight benefits and repair costs, even though overloading is related to violating the permit regulation (5, 9). Most of the states follow the federal weight limits to protect the roads and bridges from progressive damage. However, requests has been made by Transportation industry for increasing the cap weight for axle loads in order to reduce the transportation costs (9). The estimated annual savings due to GVW limit repeal exceeded $2 billion (6).

Knowledge of the actual loads including illegally overloaded vehicles can help in day-to-day and planned maintenance procedures and law-enforcement effort (10, 11). Nowadays, the traffic load monitoring systems are rapidly developing and incorporated by State DOTs. These are permanent or portable WIM (12) and Bridge-WIM stations (13) that aim to provide the comprehensive information about the traffic flow.

The permit regulations developed to provide the safe operation of the transportation structures (14). However, the problem of controlling the haulers violating the law remains unsolved, as well as the question to what extend the vehicles can be overloaded. Several sources reported about the relative law-abiding haulers. For example, 0.5% of 600,000 vehicles weighed annually in South Dakota violate the GVW or axle weight limit (15). From 8.6% in 2000 to 5.9% of 2002 exceeded the legal weight limit by 45 kN (10,000 lb).

The objective of this paper is to review and compare the permit traffic flow for a range of locations within the Alabama State using the available WIM and Permit databases and verify if the current permit regulation effectively limits the extreme live load presence.

2. Background

In the United States, vehicles are usually allowed to operate without any permit and considered legal, as long as they satisfy the weight guidelines of Federal Bridge Formula (FBF)

B, single and tandem axle limit, and gross vehicle limit. This holds good only on Interstate network. In other states and local highway system, each state has their set of weight guidelines. Many vehicles that don't obey Federal bridge formula B but obeys State's legal weight guidelines commonly referred to vehicles exempt from „grandfather rights" (16).

There are different vehicle configurations that don't comply with FBF B but are legal vehicles according to State's legal weight guidelines. These vehicles do not come under Federal weight guidelines, they are commonly referred as Specialized hauling vehicles (SHVs) (17). Also, many vehicles that contribute to states economy that has an exception under „grandfather rights „are included. However, these vehicles contribute to stress and premature effects on bridges".

There are many agencies at the State and local level that involves in determining the regulations of weight limits and Permit regulations for the state. Also, this makes permitting process very complex as it varies from state to state. Some states have electronic bridge models that they use for issuing Permits for various configuration of trucks, and they use it repeatedly to issue a permit (20, 18).

Each state has specific Permit regulations for the transportation of same goods through different states. Thus, the permit required for each state and vehicle weight, or axle configurations should be modified to comply. In this paper, the Alabama Jurisdiction for weight regulations are gathered from different sources to make a clear understanding of regulations to the readers, and the Alabama WIM data is analyzed to sort out Legal and Permit/Overloaded vehicles.

HL-93 load model has been developed on the basis to generate 75-year return period load effects for the „normal vehicular use of Bridge". NCHRP 683 infers under normal service traffic, the legal trucks and routine permits are considered [19]. The bridges are designed for 50 or 75-year design life, so the 75-year mean maximum is used (20). Figure 2 shows the different vehicle categories. All Non-Permit or Legal category consists of vehicles under Grandfather Rights. Also, vehicle category under Strength I and Strength II limit state shown in Figure 2. The Strength I is the basic load combination relating to the normal vehicular use of the bridge without wind. Strength II is the load combination that consists of the owner-specified special design live load, evaluation permit vehicles or both without the wind (11).

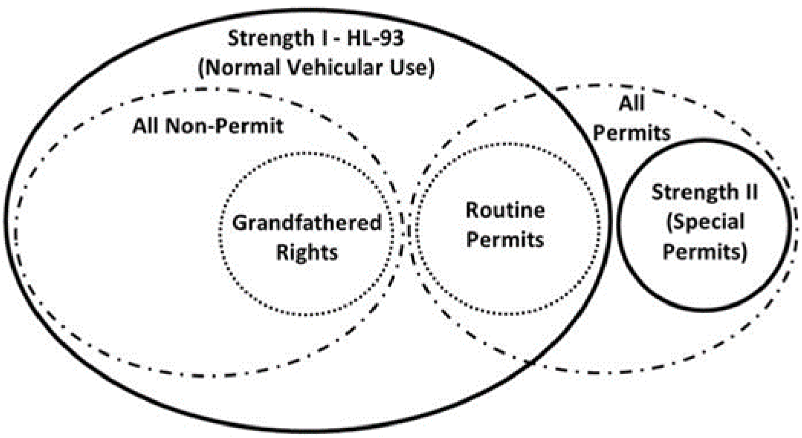

Fig. 2. Different vehicle categories (21)

Many researchers have developed filtering criteria for filtering Permit trucks, based on their past research experience. Some of the filtering criteria can be found in O'Brien et al. (22), Sivakumar et al. (17) and Modjeski and Masters et al. (23) who have different filtering rules. Since WIM data in this paper analyzed for a particular state, criteria for issuing permits is gathered from various sources and used. The benefits of separating the data and analyzing have been shown in Caprani et al. (24).

The consequences of changing the legal load limits are discussed in some studies (10, 11, 25, 26, 27). TxDOT considered the aspects of changes in permit weight and size limits according to different scenarios. The North American Trade Scenario discussed herein (6), envisages the reform of legal size and weight limit of the trucks. In particular, it includes the allowance of the heavier tridem up to 225 kN (51,000 lb). The Triples Nationwide scenario provides arranging 65,000-mile network for seven-axle triple vehicles weighing up to 590 kN (132,000 lb) (25). The effect of tridem semitrailer truck with GVW 430 kN (97,000 lb) on deficient bridges located in rural and urban areas in the US. The costs of bridge damage in case of allowance of Mexican (six-axles multi-trailer) and Canadian („Ctrain" short heavy double) legal trucks with GVW of 475 kN (107,000 lb) and 580 kN (128,000 lb) respectively.

3. Databases

The available traffic records from WIM stations, as well as a database of issued permit, can serve as a basis for the actual permit vehicles identification. WIM data collected from 13 locations around the State. Initially, WIM database covered the period from 2009 till 2014. Further on data recorded at the same WIM stations during 2006–2008 used in project „Development of Alabama Traffic Factors for Use in Mechanistic-Empirical Pavement Design" (2015) was also included. All available records for each location identified with a station code, name and year are summarized in Table 1, and the locations shown in Figure 3. The following information from each particular site was also specified: time of record, the direction of travel code, gross vehicle weight (GVW), vehicle type, axle spacing, axle loads, and also vehicle speed.

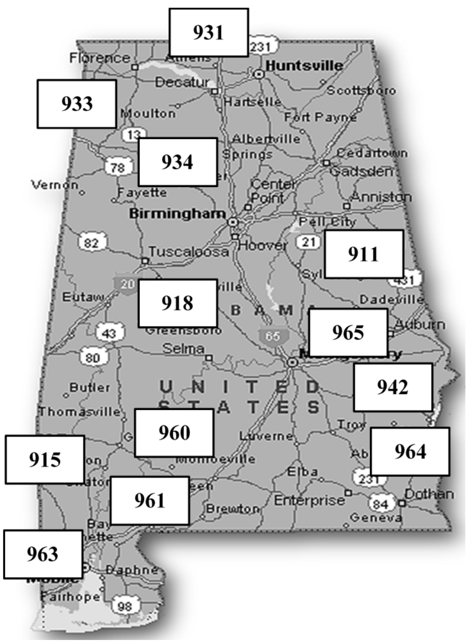

Figure 3. WIM stations in Alabama State

The Maintenance Bureau issues about 500–600 permits per day. About 200 of them are related to the weight limits. For each permit, the input data includes information about the route, vehicle geometry, and axle loads. The data file updated on a continuous basis (day-to-day). Currently, the permit data is available for 2014–2015. The reports details summarized in tables include permit ID, the period while the permit is valid, original and final destination, authorized roads, detailed itinerary, description and FHWA class of vehicle, GVW, axial load and spacing between adjacent axles. The data also contains the information about the size of vehicles, but this information is not used in the analysis. The total number of permits is 123,603 and 122,540 records for 2014 and 2015 respectively.

Table 1. Number of vehicles in the WIM database for years 2006 2014

Location code	Period of taking records, years	Total number of truck records
911	2006–2007; 2013–2014	3,033,572
915	2006–2007; 2010–2014	3,451,978
918	2006–2007	11,591,766
931	2006–2011; 2014	13,984,270
933	2006–2011; 2013–2014	9,342,842
934	2006–2008; 2013–2014	5,316,717
942	2006–2008; 2013–2014	4,804,486
960	2006–2008; 2013–2014	2,461,220
961	2006–2008; 2013–2014	8,882,836
963	2006–2008; 2013–2014	16,667,095
964	2006–2011; 2013–2014	6,562,458
965	2006–2008; 2013–2014	9,779,079
US231	2012–2014	2,050,360
		97,928,679

Since the WIM data for 2015 is not available yet the only 2014 permit data was analyzed. To process the database and convert it into MATLAB (28) format special routine was developed. However, for the present study, the data already collected for 2014 was used.

4. Analysis – sorting procedure

The available WIM data was filtered to sort the permit vehicles, to find statistical parameters and provide input for further analysis. Various sorting methods for Strength I and Strength II limit states are compared and discussed in NCHRP 683. The sorting procedure presented herein based on that most precise and rational approach of sorting that is used in Alabama State's permit and weight regulations. The Alabama WIM data checked for the compliance for the sorting criteria is shown in Figure 4 and the procedure is followed for each single vehicle in the Alabama WIM data. Special Matlab programs were developed to sort this data.

The WIM trucks selected by the Alabama State Permit criteria compared to the data of issued permits provided by Alabama DOT is shown in Table 2. Filtering algorithm was discussed with ALDOT representative and edited to verify the compliance of the trucks from WIM records and permit application.

Table 2. Summary of the vehicles with the permit required.

Location code	Permits in WIM database	%	Permits issued by ALDOT	%
911	13,014	2.41	6,154	1.14
915	18,454	6.90	13,619	5.09
918	No records	-	27,940	-
931	253,023	18.3	57,274	4.15
933	11,842	3.07	5,850	1.52
934	12,723	6.01	9,853	4.66
942	18,711	3.78	11,806	2.39
960	37,779	17.55	5,516	2.56
961	50,012	4.97	57,274	5.70
963	98,610	4.52	33,720	1.55
964	30,515	6.28	11,806	2.43
965	8,039	0.52	14,415	0.93
Total	552,722	6.34	255,227	2.93

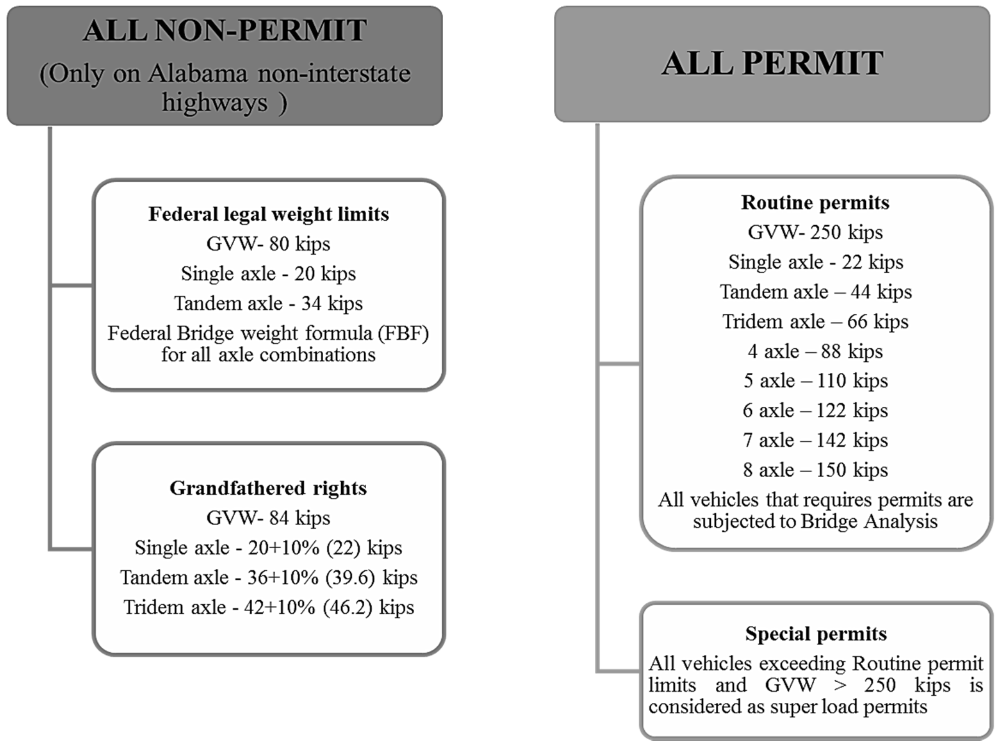

Fig. 4. Filtering criteria for permit vehicles (based on Alabama States's permit regulations)

Permits issued by Alabama DOT for passing a certain WIM station were selected based on the route description provided. The total number of permits in WIM database in WIM locations is twice higher than the number of permits issued by ALDOT (Table 2) because the permit trucks often pass more than one WIM station. However, the number of WIM trucks requiring permits (552,722) is significantly higher than the number of trucks having permits (255,227). Even though WIM data does not cover all the state (only 13 sites), this indicates that a substantial portion of overloaded truck traffic moves without permits.

To identify the WIM trucks with permits the special filtering algorithm was developed. Each permit document contains the information about the approximate time and axle configuration. These parameters were applied as an input to the searching procedure.

5. Results

The compliance of gross vehicle weight was considered for the both databases: WIM permit trucks and ALDOT permits. As an example, the cumulative distribution functions (CDF's) of GVW are plotted on the normal probability paper for two locations 933(US state road 72) and 963(Interstate #10) for year 2014 (Figure 5a, 5b).

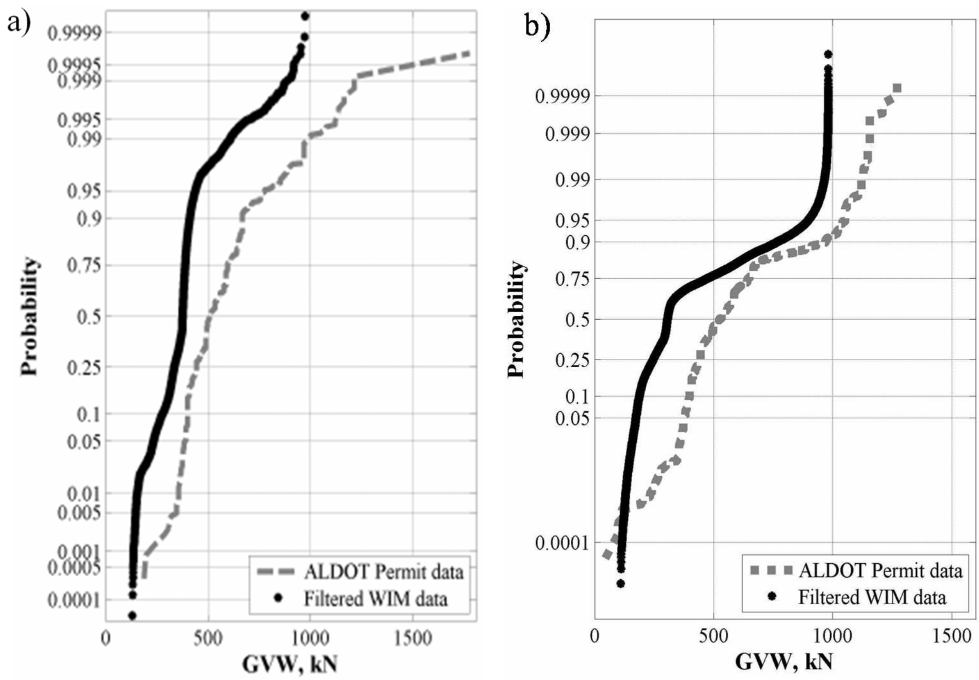

Fig. 5. CDF's of GVW for ALDOT and WIM permit vehicles for locations 933 (a) and 963 (b)

The analysis of the plotted data indicates that the shapes CDF's of the WIM and ALDOT permit data are mostly similar for two considered locations. However, the CDF's representing permits issued by Maintenance Bureau are shifted by about 220 kN (50 kips) to the right compared to the filtered WIM data representing permit vehicles (Figure 5). The mean values vary from 310 kN (70 kips) for the WIM data to 500 kN (110 kN) for the Alabama DOT permit data. From Figure 5 it is clear that from 1 to 10% of trucks with GVW below 220 kN (50 kips) were not covered by permit regulations. Similarly, the vertical segment at 220 kips in WIM records require a further consideration as a sign of the WIM system systematic malfunction.

The upper tails of the CDF's demonstrate a significant difference. According to ALDOT permit reports the heaviest vehicles have GVW in the range from 1750 to 1300 kN (300 and 400 kips) for WIM locations 933 and 963 respectively. At the same time, the maximum of the WIM truck does not exceed 1000 kN (220 kips). The maximum truck weight restricted by the permit is 2900 kN (650 kips).

The repeatable load effects caused by moving trucks often lead to the progressive damage of the roads and structural components of bridges. To access the magnitudes of the load effects each truck in WIM and ALDOT permit databases were run over influence lines and the maximum values of bending moment and shear force were calculated. The calculations were performed for simple spans of 9 (30), 18 (60), 27 (90), 37 (120) and 60m (200 ft). The resulting moments and shear forces divided by the corresponding HL-93 moments and shear forces. The CDF's of such a non-dimensional ratios is plotted on the normal probability paper. In Figures 6 and 7 the CDF's of moment ratios are plotted for the same location 933 (US state road 72) and 963 (Interstate #10). The data presented are for 9 (30), and 60m (200 ft) spans.

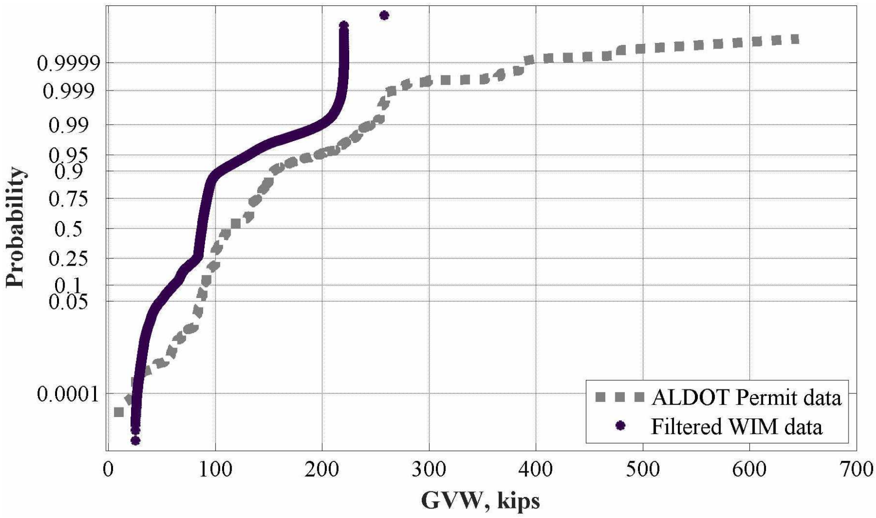

Fig. 6. Comparision of all ALDOT permit data and Filtered WIM data for year 2014

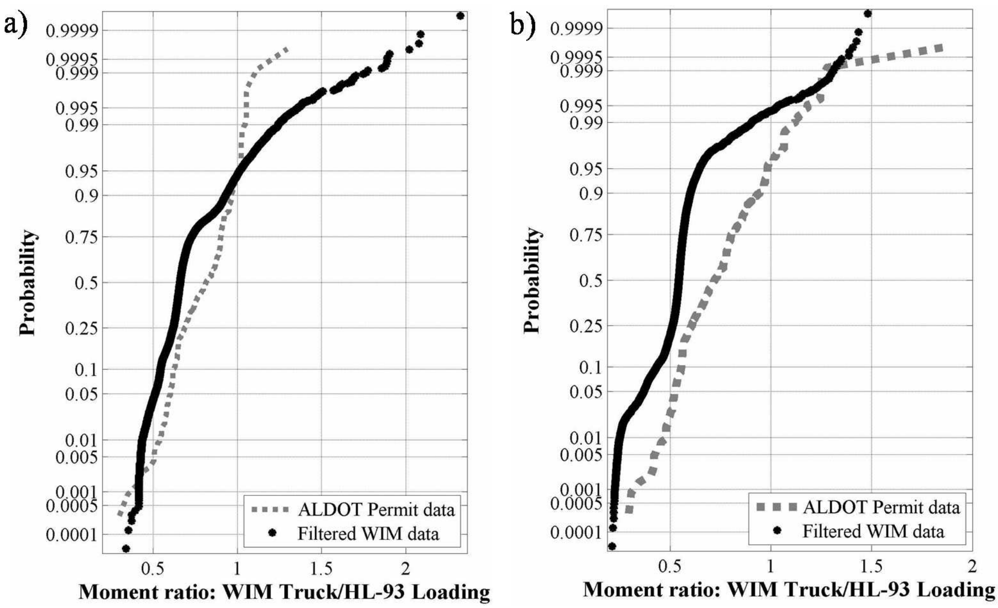

Fig. 7. CDF's of moment ratios for ALDOT and WIM permit vehicles for 9 m (30 ft), a) and 60 m (200 ft), b) and location 933 (US state road 72)

It is remarkable that WIM permit vehicles do not cause significant load effects on longer spans in comparison to the data listed in ALDOT permit reports. Similarly to GVW from 1 to 10% of WIM trucks causing 60 m (200 ft) span load effect up to 0.3 were not covered by permit regulations.

The overall shapes of CDF's representing load effects caused by the permitted trucks and WIM trucks requiring permits are not consistent. The mean value for 9 m (30 ft) moment ratio varies from 0.7 to 0.9 for both considered locations. From Figures 6a and 7a, it is clear that the upper tail of CDF representing the actual traffic records significantly overlaps ALDOT permit data. The maximum value caused by WIM permit trucks to the short spans varies from 2.3 to 2.6 while the maximum permitted is 1.3.

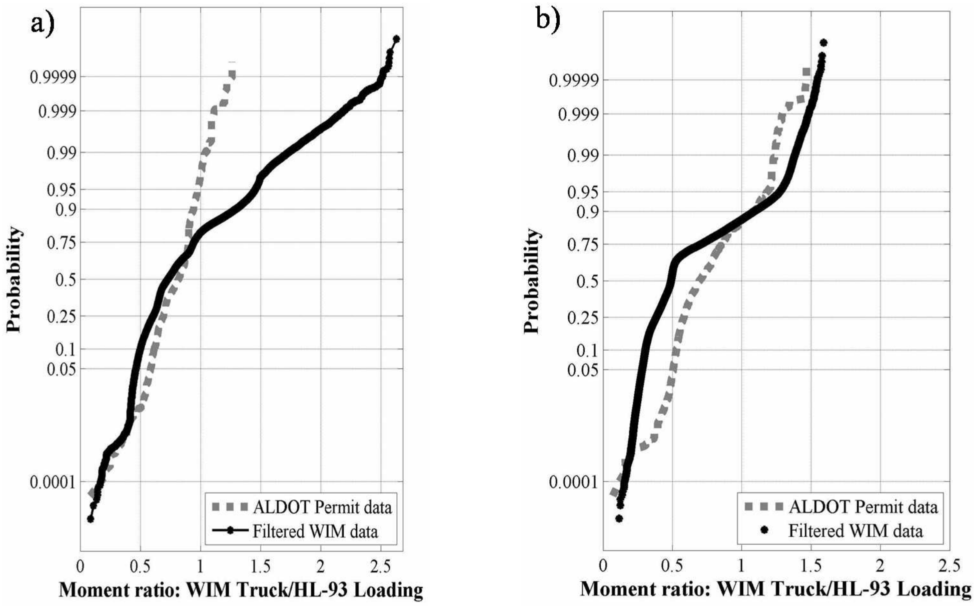

Fig. 8. CDF's of moment ratios for ALDOT and WIM permit vehicles for 9 m (30 ft) (a) and 60 m (200 ft) (b) and location 963 (Interstate #10)

The same algorithm was applied to process both databases. Thus, the inconsistency is a direct result of the possible difference between the vehicle parameters claimed in permit applications and actual ones.

6. Conclusions

About 97 million WIM trucks and 123,603 issued permits were analyzed in this study. The data represents the traffic situation is all the regions of the State. The conclusions are as follows:

The premature deterioration of road surface and fatigue cracking of the bridge structures often caused by heavy traffic operation.

The number of permits issued by ALDOT is substantially smaller than the number of WIM trucks requiring permits. Thus, over 50% of vehicles that require permits operate illegally.

CDF's of the recorded WIM and issued permit data are mostly consistent with regard to shape. Nevertheless, the curves of permitted truck load distribution are shifted by about 220 kN (50 kips) to the right, which shows that many of trucks went underloaded.

On average, from 1 to 10% of WIM trucks with GVW below 220 kN (50 kips) in most locations were not covered by the permit regulations.

The WIM data can be a source of the illegal and illegally overloaded vehicles identification.

The obtained permit and illegal load statistics can serve as a basis for the design provisions for the strength, fatigue and extreme events limit states.

The is a considerable difference between the WIM trucks that require permits and the actual ALDOT permit report in short span moment ratios. The largest values of moment ratio and shear force ratio (Truck/HL-93 Loading) for the WIM trucks is 2.6 while based on ALDOT permit records it should not exceed 1.3.

7. Future research

The analysis of the permit database issued by other State's DOT's is an important step to revise the live load statistics for Strength II and Fatigue limit states.

Illegal and illegally overloaded truck traffic effects require special attention to access the effect of illegal truck traffic operation on the roads and bridges.

Algorithms for converting WIM data and permit data into an index, or measure, of damage accumulated by the bridges along the route, are to be developed. These algorithms will allow comparisons between the damage accumulation associated with the regular traffic stream, various categories of trucks within the stream, and permit vehicles.

References

1. 2015 – Deficient Bridges by Highway System – National Bridge Inventory – Bridge Inspection – Safety – Bridges & Structures – Federal Highway Administration.
2. ASCE 2013 Report Card for America's Infrastructure Bridges: Conditions & Capacity.
3. ASCE 2013 Report Card for America's Infrastructure Roads: Overview.
4. The Damaging Effects of Overoaded Heavy Vehicles on Roads. Pretoria, South Africa: CSIR, Roads and Transport Technology; 1997 Apr.
5. Jacob B, Feypell-de La Beaumelle V. Improving truck safety: Potential of weigh-in-motion technology. IATSS Research. 2010 Jul;34(1):9–15.
6. Luskin DL, Walton CM. Synthesis Study of the Effects of Overweight/oversize Trucks. Vol. 2122. Center for Transportation Research, Bureau of Engineering Research, University of Texas at Austin; 2001.
7. Cutrufo J. US Accounts for Majority of G8 Bridge Failures Since 2000 [Internet]. Mobilizing the Region. 2013.
8. Malm BS. World's biggest traffic fine? Chinese driver whose overloaded truck collapsed a bridge gets a bill for £16 m.
9. Legal Load Limits, Overweight Loads and Pavements and Bridges [Internet]. Washington State Deparment of Transporation.
10. Nowak AS, Collins KR. Reliability of Structures, Second Edition. 2 edition. Boca Raton: CRC Press; 2012. 407 p.
11. AASHTO LRFD Bridge Design Specifications, 7th Edition [Internet]. Washington, D.C.; 2014.
12. Traffic Monitoring Guide. Washington, DC: U.S. Department of Transportation Federal Highway Administration Office of Highway Information Management; 1995.
13. SiWIM Bridge Weigh-in-Motion Manual: 4th Edition. Trzin, Slovenia: ZAG Ljubljana; 2011.
14. Cargo Securement Rules. Federal Motor Carrier Safety Administration. 2014.
15. Truck Weights and Highways. SDDOT Office of Research; 2003.
16. Moses F. Calibration of Load Factors for Lrfr Bridge Evaluation. NCHRP Report. 2001.
17. National Cooperative Highway Research Program, Transportation Research Board, National Academies of Sciences, Engineering, and Medicine. Legal Truck Loads and AASHTO Legal Loads for Posting. Washington, D.C.: Transportation Research Board.
18. SUPERLOAD – DOT Oversize Overweight Permit, Routing Software.
19. Nowak AS. Calibration of Lrfd Bridge Design Code. NCHRP Report 368. 1999.
20. Nowak AS, Szerszen MM. Structural Reliability as Applied to Highway Bridges. Structural Reliability of Hightway Bridges. 2000.
21. Leahy C, OBrien EJ, Enright B, Hajializadeh D. Review of HL-93 Bridge Traffic Load Model Using an Extensive WIM Database. Journal of Bridge Engineering. 2015;20(10):4014115.

22. OBrien E, Enright B, Leahy C. The Effect of Truck Permitting Policy on US Bridge Loading. Conference papers. 2013 Jun 1.
23. Bridges for Service Life Beyond 100 Years: Service Limit State Design. SHRP 2 Research Reports. Washington D.C.: Transportation Research Board; 2015.
24. Caprani CC, OBrien EJ, McLachlan GJ. Characteristic traffic load effects from a mixture of loading events on short to medium span bridges. Structural Safety. 2008;30(5):394–404.
25. Abowd GD, Dey AK, Brown PJ, Davies N, Smith M, Steggles P. Comprehensive Truck Size and Weight Study. In: International Symposium on Handheld and Ubiquitous Computing. Springer; 1999. p. 304–307.
26. Weissmann J, Harrison R. Impact of 44,000 kg (97,000 lb) Six-Axle Semitrailer Trucks on Bridges on Rural and Urban U.S. Interstate System. Transportation Research Record. 1998;(1624):180–183.
27. National Research Council (U.S.), editor. Regulation of weights, lengths, and widths of commercial motor vehicles. Washington, D.C: Transportation Research Board; 2002. 270 p. (Special report).
28. MATLAB. Natick, MA: The MathWorks Inc; 2014.
29. Ghosn M, Sivakumar B, Moses F, Transportation Research Board, National Cooperative Highway Research Program, Transportation Research Board. Protocols for Collecting and Using Traffic Data in Bridge Design. Washington, D.C.: National Academies Press; 2011.
30. ASTM E1318-09 – Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods. West Conshohocken, PA: ASTM International; 2009.