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ACCOMPANYING TRAFFIC LOAD MODEL FOR OVERWEIGHT VEHICLES IN REPUBLIC OF SERBIA

Summary: Every vehicle with gross vehicle weight (GVW) exceeding the legal limit in Serbia must obtain special permit from the local authorities before operating on public roads. This paper focuses on overweight vehicles exceeding legal limits and operate on normal speed, without restrictions on the presence of other vehicles. Its objective is to determine, in a probabilistic manner the appropriate load model for traffic accompanying these overweight vehicles on a bridge, using B-WIM measurements performed in Serbia. The accompanying traffic is treated as a random variable, with a probabilistic analysis which considers (1) the specific span configuration of the bridge and (2) the bridge type, i.e. with full and limited transverse load distribution. Sensitivity factors for the accompanying traffic, and then adjustment factor for the accompanying traffic load model, based on Eurocode Load Model 1, has been calculated.

Keywords: accompanying traffic, traffic load, existing structures, overweight vehicles

MODEL PRATEĆEG SAOBRAĆAJNOG OPTEREĆENJA ZA VOZILA VANREDNOG PREVOZA U REPUBLICI SRBIJI

Rezime: Svako vozilo sa bruto težinom vozila koje prekoračuje propisana ograničenja u Srbiji mora da pribavi specijalnu dozvolu nadležnih organa i predstavlja vanredni saobraćaj. Ovaj rad se fokusira na slučaj vanrednog saobraćaja kada vozilo sa prekoračenjem bruto težine vozila saobraća normalnom brzinom i bez restrikcija za prisustvo ostalih vozila. Cilj je da se odredi, na probabilistički način, odgovarajući model pratećeg saobraćajnog opterećenja za vozila vanrednog prevoza, koristeći B-WIM merenja u Srbiji. Prateći saobraćaj je tretiran kao slučajna promenljiva, sa probabilističkom analizom, uzimajući u obzir (1) konfiguraciju raspona mosta, i (2) tip mosta, tj. sa i bez poprečne raspodele saobraćajnog opterećenja. Koeficijenti osetljivosti, a zatim koeficijenti podešavanja, za model saobraćajnog opterećenja iz Evrokoda LM1, su sračunati.

Ključne reči: prateći saobraćaj; saobraćajno opterećenje; postojeće konstrukcije; vanredni transport

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1. INTRODUCTION

Every vehicle with gross vehicle weight (GVW) exceeding the legal limit (44 tons in Serbia [1]) must obtain a special permit from the local authorities before operating on public roads. A wide range of permit types exists for overweight vehicles across different jurisdictions, for example, permits allowing normal or reduced travel speed, or authorizations specifying whether other vehicles may access a bridge simultaneously with the overweight vehicle. This paper focuses on heavy vehicles that exceed legal load limits but operate at normal speed and without restrictions regarding the presence of other vehicles. Its objective is to determine, in a probabilistic manner, the appropriate traffic load model to accompany such overweight vehicle on bridges in Serbia. There are many kinds of special transports, with probably three main types of overweight vehicles that can be recognized [2], [3] [4]:

1. Mobile crane trucks – These vehicles exist in a limited number of models on the market, produced by only a handful of manufacturers. They have fixed wheelbases, and well defined axle weight characteristics typically distributing their weight relatively evenly across all axles;
2. Tractor-trailer combinations – Consisting of tractor unit and a semi-trailer, these vehicles exhibit much greater variability in axle spacing and axle-load distribution; and
3. Low loaders – Specialized heavy-haul vehicle with very low deck height allowing transport of tall cargo. These vehicles may have adjustable trailers, and are difficult to identify by wheelbase lengths or weight.

There are also route-specific permit types for overweight vehicles, as well as permits for overweight vehicle carrying specific goods, important for the economy of a region. However, in general, axle weights and axle spacings of heavy vehicles with special permits are random variables. Further, traffic that may accompany these overweight heavy vehicles is also random, with regards to the number of accompanying vehicles simultaneously present on the bridge with overweight heavy vehicle, their position on the bridge (in the same or adjacent lanes), as well as the axle weight and axle spacing characteristics of the accompanying vehicles.

2. CURRENT STATE-OF-THE-PRACTICE

Permit regulations vary from region to region, with numerous studies done throughout the world [5] [6]. As an example, in Switzerland, the load model for the accompanying traffic is based on Eurocode Load Model 1 (LM1) [7]. However, the Tandem System 1 (TS1, i.e. two axles in the first lane) is replaced by overweight vehicles, and uniformly distributed load (UDL) beneath it is omitted (Figure 1). The adjustment factors for this accompanying traffic, are currently the same one used for evaluation of existing structures according to the SIA 269 [8] for regular traffic load model, being in the range between 0.7 and 0.4, depending on the type of the loading (TS or UDL) and the associated lane. These adjustment factors are therefore not estimated in the same manner as the ones in [8], which are derived by probabilistic analysis. In order to verify or adapt these adjustment factors for accompanying load model, a probabilistic analysis needs to be performed by separating the load effects of overweight vehicle from the accompanying traffic. This is performed in a recent study [3], by assuming a deterministic overweight vehicle, and the effect of the accompanying traffic was modelled as random variable. This means that the uncertainty of traffic load effect is solely attributed to accompanying load. Based on the recommendation in [8] the sensitivity factor for leading action can be assumed as 0.7 if no FORM analysis is performed. Given that the overweight vehicles are assumed as deterministic the sensitivity factor of 0.7 apply solely to accompanying traffic. However, the assumption of deterministic overweight vehicles can be questioned as their weight vary significantly and the frequency of their occurrence needs to be considered. By modelling the overweight vehicles probabilistically, the sensitivity factor of 0.7 can be split in one for overweight vehicles and one for accompanying traffic leading to the sensitivity factor for the accompanying traffic smaller then 0.7.

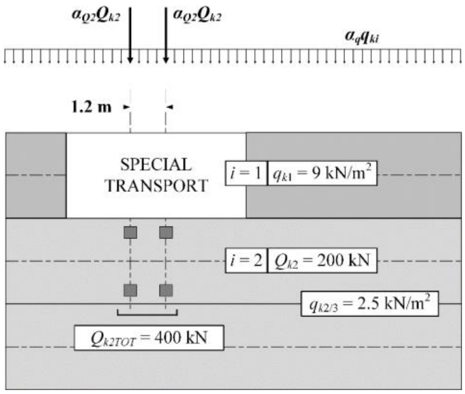


Figure 1: FEDRO load model for accompanying traffic in Switzerland [9]

According to Eurocode [7], Load Model No. 3 (LM3) is defined as a set of standardized vehicles intended to cover the effects of special convoys. These standardized vehicles are defined in Annex A (informative) to EN 1991-2; they are not intended to represent real vehicles, and for a national application it may be necessary to take into account also specific overweight vehicles that are not covered by this annex. These standardized vehicles characteristics are the result of a synthesis of permit arrangements of actual national codes. Load model LM3 is considered only where specified by the owner or operator. Lanes and the remaining area of the bridge deck that are not occupied by the LM3, should be loaded by Load Model 1 with its frequent values. In these cases, accompanying traffic is not modelled in a probabilistic way as a random variable, which is the focus of the approach presented in this paper. The full traffic (FT) load on the bridge can be seen, as a sum of two random variables – leading heavy vehicle (HV) and the accompanying traffic (AT)[10].

3. STRUCTURAL ANALYSIS

Main statistical sample for this study are B-WIM measurements performed by Public Enterprise “Putevi Srbije” in 2020 on 17 locations in Serbia, in duration of 14 days each [11]. As a part of the automated procedure, all vehicles recorded in the WIM database are analysed on each of 26 synthetic bridges (i.e. structural systems) representing the bridge inventory, together with any other vehicle present on the bridge at the same time. This constitutes the dataset used for this study. The set of synthetic bridges is specified to encompass the range of structures commonly encountered in practice. It includes simple-span beams and two-span continuous beams with spans ranging from 5m to up to 80m, resulting in a total of 26 distinct span configurations:

- One span (5, 10, 15, …, 45, 50, 60, 70, 80; 13 bridge total);
- Two equal continuous spans (2x5, 2x10, 2x15, …, 2x45, 2x50, 2x60, 2x70, 2x80; 13 bridges total).

Dynamic amplification factor (DAF) should be taken as 1.0, as recommended in the literature for evaluation of existing structures [4]. Regarding the transverse load distribution, two different types of bridges are considered:

- No transverse load distribution – represents bridges such as concrete box girder bridge, where loads from different lanes are assumed repositioned above centroidal axis of the girder. In other words, the stresses resulting from load eccentricity are assumed to be negligibly small;

- With transverse load distribution – represents multi girder bridges, where live load is not uniformly spread among the girders. Transverse distribution factors are computed using the so-called rigid method, (see [12] and [13]), which assumes bridge cross-section deflects and rotates as a rigid body. Distribution factors for different lanes can be computed, specifying the contribution of one girder, for the generic bridge cross section, shown in Figure 2.

Influence lines, as well as the moment and shear envelopes were computed for each of vehicle loading event in the WIM dataset and for each of 26 bridges configurations, using both transverse load distribution assumptions described above. Comparable structural analysis of a representative bridge set (i.e. structural systems) loaded by vehicles detected by WIM measurements, is performed in [5] [14] for heavy loads with permits in Indiana, U.S.A., and in [15], [16] for Serbia. The load model for accompanying traffic in Serbia is assumed to be the same as the one from SIA (Figure 1).

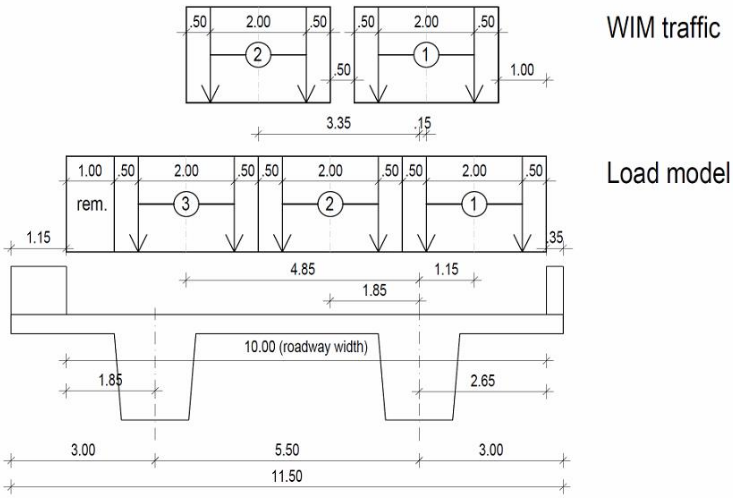


Figure 2: Generic bridge cross section with transverse load distribution analysis

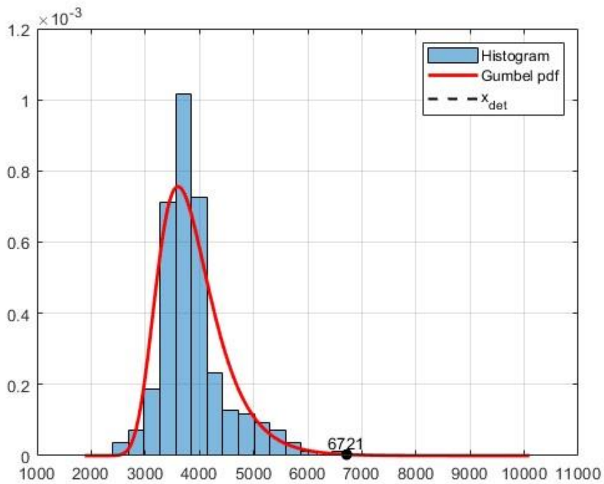


Figure 3: FT histogram for 35m-simple-span-midspan moment and Gumbel pdf (without transverse load distribution)

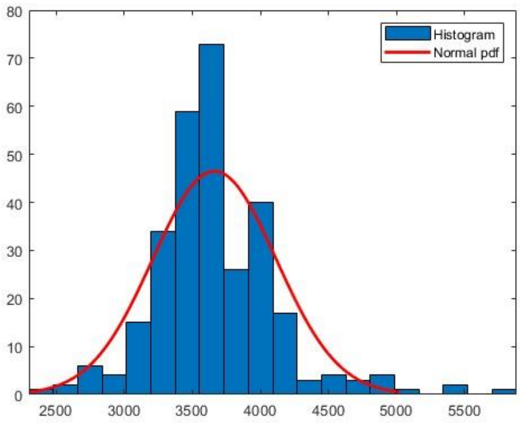


Figure 4: HV histograms for 35m-simple-span-midspan moment and normal pdf (without transverse load distribution)

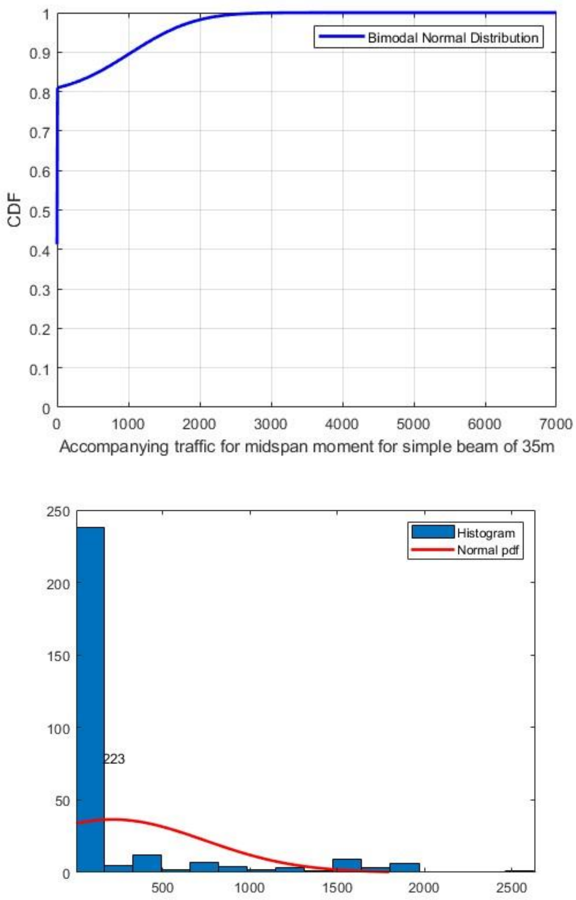


Figure 5: AT histogram and CDF for 35m-simple-span-midspan moment (without transverse load distribution)

4. PROBABILISTIC STUDY OF ACCOMPANYING TRAFFIC AS RANDOM VARIABLE

The central premise of this approach is that the full traffic on the bridge can be seen as a sum of two connected traffic flows – leading heavy vehicle and the accompanying traffic. The computation presented here is based on the direct analysis of WIM dataset and depend on both, the bridge span and the type of the bridge (i.e. with and without transverse load distribution). For each vehicle from WIM dataset exceeding 44 tons, the structural analysis, defined above, can be performed in two ways: (a) considering heavy vehicle (HV) alone, without any accompanying vehicle present on the bridge, and (b) considering the full "loading event", consisting of the heavy vehicle together with all other vehicles simultaneously present on the bridge. Accompanying traffic load effect is then obtained simply as the difference between these two load cases. By analysing only vehicles heavier than 450kN, overweight heavy vehicles are extracted from the entire WIM dataset. These analyses create a dataset of loading effects from WIM loading events, that can be further processed to calculate design values. For full loading events (consisting of both, HV and AT), extreme values are determined, for 78 different load effects (i.e. significant points – moments and shears on bridge configurations mentioned above). Each load effect of these 128 extreme values loading events are then separated into two parts: the part created by the heavy vehicle itself, and in the part created by the accompanying traffic. A key parameter in this study is the selection of the reliability index target value, which is typically determined by the bridge owners. For new structures, the reliability index is generally set at a relatively high level to ensure a low probability of failure, whereas for existing structure lower reliability index may be acceptable, leading to reduced partial safety factors. Increasing the reliability index for existing structures is significantly more costly than reaching the same reliability index in new construction [17], [18], [19]. Since the present analysis concerns traffic loading on existing bridges, an appropriate reliability level must be selected in this context. For illustration purposes, a reliability index of 4.2 is suggested here, corresponding to the value used in SIA 269.

The sensitivity factor, α, combined with the reliability index, β, can be used to find the value of the design point and its probability of exceedance:

$$PF = 1 - \Phi(\alpha * \beta) \quad (1)$$

The probabilistic study was performed according to the following steps:

1. Determining the value xdet based on extremes of the full loading events (including both, heavy vehicle and accompanying traffic). The reliability index can be set to 4.2, the sensitivity factor for traffic load to 0.707, and resistance sensitivity factor to 0.707 with the deterministic dead load. For the effect of traffic, the Gumbel distribution is assumed and using Equation 8, design value xdet is determined;
2. The limit state function (Equation 1) is used to quantify the contribution of (a) heavy vehicle, and (b) accompanying traffic simultaneously present on the bridge in the same or adjacent lane. Using FORM analysis, sensitivity factors for AT can be calculated for each of the above mentioned 78 load effects. Distribution parameters for HV and AT are derived from the corresponding values obtained from extremes loading events. HV was modelled using normal distribution and AT was modelled using bimodal normal distribution (by which null events, i.e. cases with no accompanying traffic on the bridge with heavy vehicle, are taken into account properly). Sensitivity factors for AT based on this limit state function should be multiplied additionally with 0.707, since the resistance is not included as the random variable in the limit state function (Equation 1);
3. Once the sensitivity factors for AT (αAT) are computed for each of the 78 load effects, characteristic value of AT was obtained as the value corresponding to the probability of failure associated with αAT and a reliability index of 4.2 using Equation 8. The resulting characteristic value is then divided by the design value of LM1 model for the accompanying traffic shown in Figure 1 (including partial load factor of 1.35 used in

Serbia, for example) to obtain the adjustment factor for AT. This procedure is applied to all 78 load effects.

Bimodal distribution is not widely used in the literature for modelling structural engineering applications [20], [21]. In this case, however, bimodal distribution for accompanying traffic is suggested due to large number of null events (i.e. load cases with no accompanying traffic present on the bridge with heavy vehicle). It can be noted that bimodal distribution results in CDF curve being shifted up by an amount equal to the amount of null events.

5. PROBABILISTIC STUDY OF ACCOMPANYING TRAFFIC FOR SERBIA

The above described analysis has been performed using Serbian WIM data. The full traffic (FT), accompanying traffic (AT) and heavy vehicle (HV) histograms are shown in Figures 3 to 5 and Figure 6 to 8, for the cases without and with transverse distribution, respectively, for 35m-simple-span-midspan moment. The adjustment factors for the accompanying traffic load model, across various spans, are presented in Figure 9 and Figure 10, for the cases without and with transverse distribution, respectively.

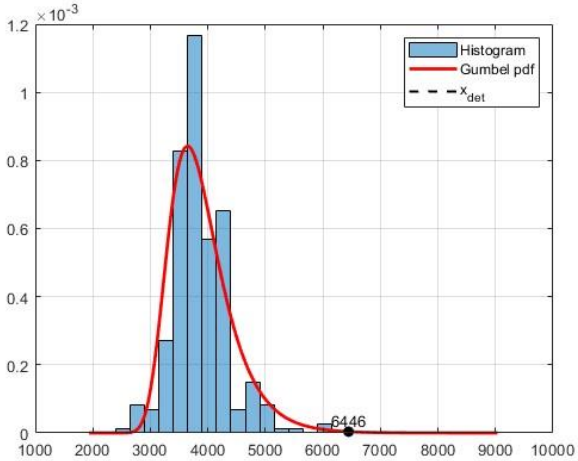


Figure 6: FT histogram for 35m-simple-span-midspan moment and Gumbel pdf (with transverse load distribution)

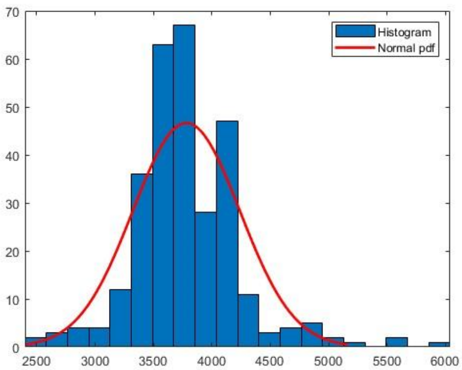
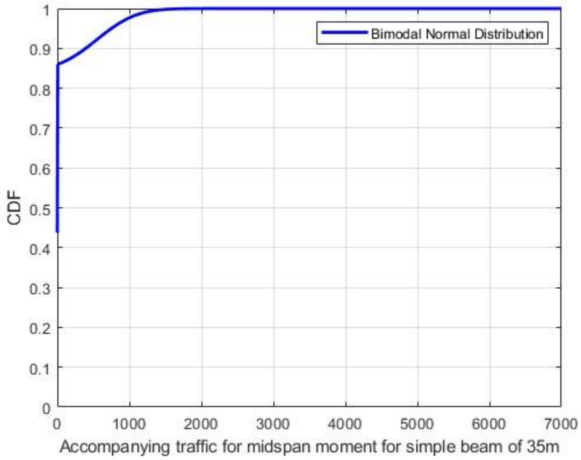


Figure 7: HV histograms for 35m-simple-span-midspan moment and normal pdf (with transverse load distribution)



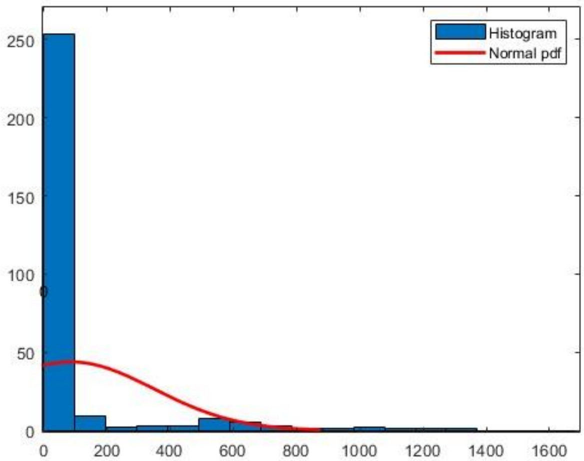


Figure 8: AT histograms and CDF for 35m-simple-span-midspan moment (with transverse load distribution)

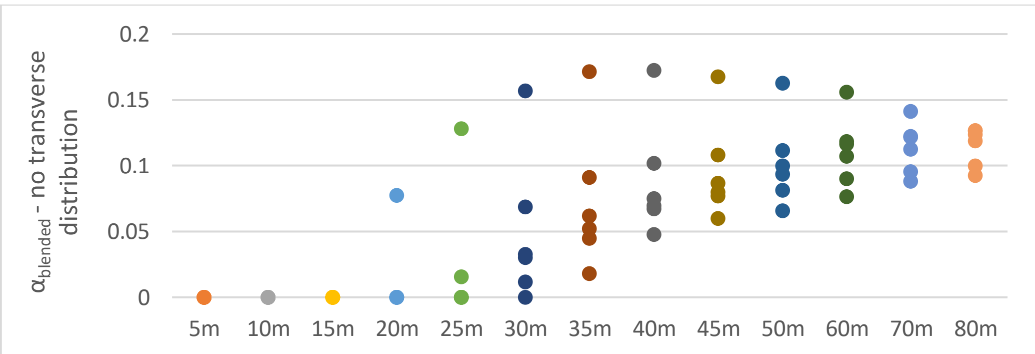


Figure 9: "Blended" adjustment factors for different spans (without transverse load distribution)

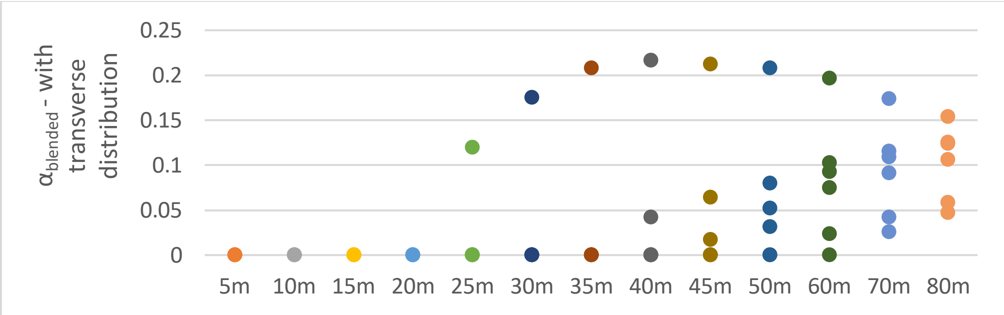


Figure 10: "Blended" adjustment factors for different spans (with transverse load distribution)

It can be concluded, based on Figures 9 and 10, that "blended" adjustment factor for the accompanying traffic in Serbia can be set to 0.25.

6. CONCLUSION

In current practice, load model for accompanying traffic is without sound scientific justification. In this paper, the effect of accompanying traffic is modelled as a random variable, with a suggested probabilistic analysis involving (1) a range of representative span configurations and (2) the bridge type, i.e. with and without transverse load distribution. Sensitivity factors for the accompanying traffic, and subsequently the adjustment factor for the accompanying traffic load model were computed for 78 different load effects across span lengths ranging from 5 m to 80 m. The resulting sensitivity factors is computed less than 0.7, for both cases, with and without transverse load distribution. Using the results shown in this paper, bridge owners in Serbia (i.e. Public Enterprise "Putevi Srbije") can evaluate permits for overweight vehicles under unrestricted traffic conditions by performing structural analyses that combine the specific axle configuration of the overweight heavy vehicle with an accompanying-traffic load model multiplied with the adjustment factor equal to 0.25, calibrated using the presented approach.

REFERENCES

[1] "Permissible Maximum Weights of Lorries in Europe." International Transport Forum, 2022. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/weights-2021_0.pdf

[2] Z. Despot and R. Hajdin, "TRUCK Bridge Rating Software," in Eighth Transportation Research Board Conference on Bridge Management, Denver, Colorado, 1999.

[3] "Memorandum - Revision of ASTRA 82001," Updating the load model for existing bridge structures-Subject:Investigation into αQ2 for the KUBA-ST model using direct WIM Method (VBWIM), 2022.

[4] M. Sjaarda, L. Mathevet, and A. Nussbaumer, "Revision of Astra 82001 Updating the load model for existing road bridges," 2022.

[5] G. Milutinovic, C. Kusiak, M. Bowman, and A. Prakash, "New Approach for Screening Overweight Vehicles: Allowable Ranges of Axle Configurations," Transportation Research Record, vol. 2642, no. 1, pp. 118–126, Jan. 2017, doi: 10.3141/2642-13.

[6] Oversize/Overweight Vehicle Permitting Handbook, Indiana Department of Revenue 2016.

[7] Eurocode, EN 1991 Eurocode 1: Actions on structures. European Committee for Standardization, Brussels, Belgium, 2001.

[8] SIA, SIA 269:2011 Existing structures - Bases for examination and interventions. Swiss Society of Engineers and Architects, Zurich, Switzerland, 2011.

[9] "KUBA 5 User Manual Part 3," FEDRO, KUBA-ST (KUBA 5 Anwendungshandbuch Teil 3 KUBA-ST), 2023.
[10] G. Milutinovic and R. Hajdin, "Probabilistic study of accompanying traffic load model with permit vehicle," in Proceedings of the IABMAS Conference 2026, Orlando, Florida, July 2026,
[11] G. Milutinovic, R. Hajdin, I. Andrijanic, M. Milosavljevic, and M. Bajic, "Overview of bridge traffic loads in Serbia using B-WIM," presented at the Proceedings of MASE Conference, Skopje, North Macedonia, 28–29 September 2023, 2023.
[12] AASHTO LRFD Bridge Design Specification, American Association of State Highway and Transportation Officials 2024.
[13] M. Sjaarda, T. Meystre, A. Nussbaumer, and M. Hirt, "A systematic approach to estimating traffic load effects on bridges using weigh-in-motion data," Stahlbau, Ernst & Sohn, 2020.
[14] G. V. Milutinovic, "New screening method for overweight vehicles," Master's Thesis, Purdue University, 2016.
[15] G. Milutinovic and R. Hajdin, "Preliminary estimation of adjustment factors for traffic load model LM1 for existing bridges in Serbia," in Proceedings of the DGKS Conference, Vrnjacka Banja, Serbia, 2024.
[16] G. Milutinovic and R. Hajdin, "Evaluation of bridge traffic load model using B-WIM measurements in Serbia," presented at the Proceedings of the SINARG Conference 2023, Nis, Serbia, 14–15 September 2023, 2023.
[17] fib Bulletin 80, "Partial safety factor methods for existing concrete structures," 2016.
[18] D. Gino, P. Castaldo, G. Bertagnoli, L. Giordano, and G. Mancini, "Partial factor methods for existing structures according to fib Bulletin 80: Assessment of an existing prestressed concrete bridge," Structural Concrete, vol. 21, no. 1, pp. 15–31, Feb. 2020, doi: 10.1002/suco.201900231.
[19] G. Milutinovic and R. Hajdin, "Naknadni proračun postojećeg mosta u skladu sa fib Biltenom 80 i Evrokodom / Load rating of an existing bridge according to fib Bulletin 80 and Eurocode," in Proceedings of the DGKS Conference 2024, Vrnjacka Banja, Serbia, 2024.
[20] Z. Hu and X. Du, "Reliability Methods for Bimodal Distribution With First-Order Approximation," ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, vol. 5, no. 1, p. 011005, Mar. 2019, doi: 10.1115/1.4040000.
[21] L. Li, G. Chen, M. Fang, and D. Yang, "Reliability analysis of structures with multimodal distributions based on direct probability integral method," Reliability Engineering & System Safety, vol. 215, p. 107885, Nov. 2021, doi: 10.1016/j.ress.2021.107885.