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Development of a new high-speed load model and validation on existing railway bridges

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Abstract

In the near past, dynamic calculations of train crossing for railway bridges have shown, that the applied HSLM model trains given in DIN EN 1991-2 do not cover the bridge acceleration response for certain real operating trains (e. g. of German ICE 4). Hence, the application of the current HSLM might lead to an unsafe design of new railway bridges and destabilization of the ballast layer may occur, leading to safety critical track position defects and eventually to train derailments. Hence, in November 2019 the consortium TU Darmstadt, KU Leuven, Austrian Institute of Technology and REVOTEC was commissioned by the German Federal Railway Authority to develop a completely new European high-speed load model for a new reliable dynamic design of railway bridges. The project runs from 2019 to 2023 and in this paper the draft version of the new developed load model and results of an already conducted validation process considering existing railway bridges are presented.

Keywords: railway bridges; train crossing; high-speed-load-models; train signature; acceleration response spectrum.

1 Introduction

When designing new railway bridges a dynamic calculation of the bridge for a train crossing must be carried out in accordance with DIN EN 1991-2 [1]. A limit value of

3.5 m/s² for the maximum vertical acceleration of the bridge deck must be fulfilled in accordance with DIN EN 1990/A1 [2] for railway bridges with ballast superstructure.

DIN EN 1991-2 provides a high-speed load model (HSLM-A) consisting of 10 different model trains, which have to be considered within the dynamic calculation of the bridge response for a train crossing. The 10 model trains have an axle load from 17 to 21 tonnes, carriage lengths between 18 and 27 m and a total length of 370 to 400 m. The HSLM-A is designed to cover common operating high-speed trains in Europe. In the near past, it has been detected that the HSLM-A model trains do not cover the bridge acceleration response for certain real operating trains (e. g. of German ICE 4) and hence, the application of the HSLM might lead to an unsafe design of new railway bridges. Hence, destabilization of the ballast layer may occur, leading to safety critical track position defects and eventually to train derailments.

As an example, Figure 1 shows the results of dynamic bridge train crossing calculations of an existing railway bridge considering the HSLM-A1 model train and the operating train ICE 4. More details on the executed experimental and numerical analyses of this railway bridge are given in Reiterer [3]. It is indicated that the maximum vertical bridge deck acceleration of the ICE 4 is significantly higher than the maximum acceleration of the HSLM-A. It is obvious that the currently operating trains must be considered within dynamic bridge train crossing calculations and that a strong need exists to develop a new high-speed load model.

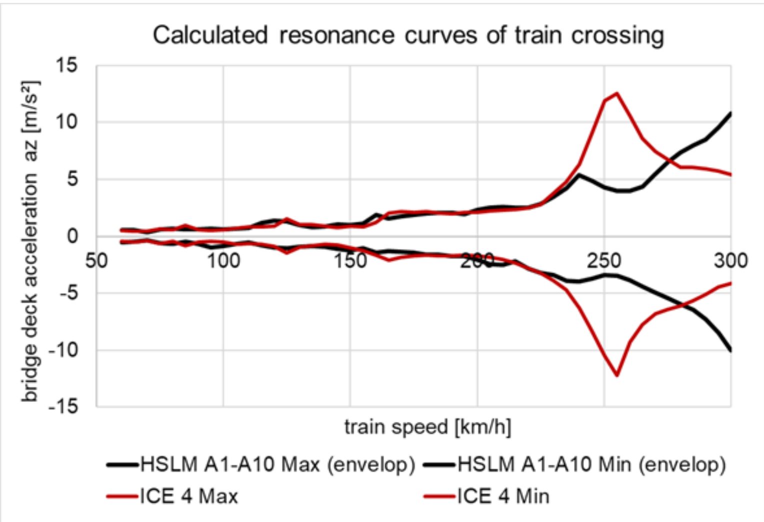

Figure 1: Exemplary results from dynamic bridge train crossing calculations considering the HSLM-A model trains and the operating train ICE 4 [3].

In November 2019, the consortium TU Darmstadt, KU Leuven, Austrian Institute of Technology and REVOTEC was commissioned by the German Federal Railway Authority to develop a completely new European high-speed load model for a new reliable dynamic design of new railway bridges. The project runs from 2019 to 2023 [4]. The new load model is supposed to cover all currently operating trains that travel in the European railway network.

2 Methods

As a basis for the development of the new European high-speed load model, almost 3200 train configurations currently in operation w were collected in a first project phase. Since it is known from [4-6] that there is a divergence between the train signature function defined in [7] and the results from full dynamic calculations of train crossings, the following two step approach was followed to develop the new load model [6]:

- Approach 1: The reference level is defined as the envelope of the dynamic train signatures S0 based on all collected operating trains and possible future configurations of high-speed trains.
- Approach 2: The reference level is defined as the envelope area based on the results of dynamic FEM-calculations of train crossings. These calculations are carried out on a generic bridge population adapted to the bridge stock in Germany and Austria and loaded with dynamically relevant trains

For the first approach, the train signature concept as used for the already existing HSLM [7] was applied and leads to a clustering of the trains. For the second approach, parametrized bridges were defined and adapted to the bridge portfolios of DB Netz AG and ÖBB-Infrastruktur AG. The defined bridges were dynamically loaded with 510 pre-selected relevant trains. This selection was made by choosing all trains from the 3200 considered that contribute to the envelope of the train signature function. Investigating a speed range of 60 to 420 km/h about 20 million dynamic calculations of train crossings have been carried out so far, which are being extended for spatial plate and multi-span models as part of the ongoing work.

For both envelopes, dynamic train signatures and FEM- calculations of train crossings, a mathematical optimization routine was carried out for defining a new load model. As seen in Figure 2, the envelope of operating trains (red) is higher than the reference train load model HSLM-A, which again clearly highlights the need for a new dynamic load model.

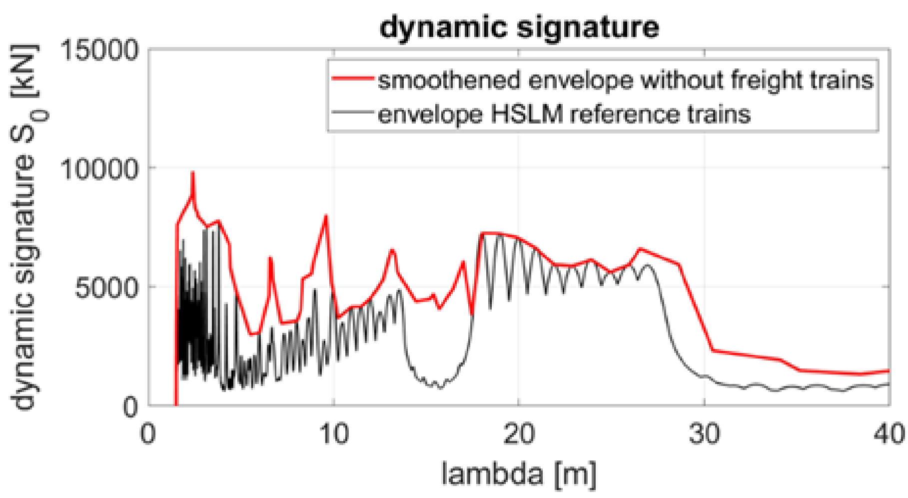

Figure 2: Calculated train signature envelope with generated train configurations compared with HSLM-A.

Currently, the two listed new high-speed load models have been developed within the project:

- Load model V1 signature (based on calculated train signature functions)
- Load model V2 dynamic (based on dynamic calculations of train crossings)

It is noted that the new high-speed load models V1 (signature) and V2 (dynamic) are not final yet, so the validation process has just started.

3 Results

The two developed preliminary new load models V1 (signature) and V2 (dynamic) are going to be validated on a set of 350 existing railway bridges with different construction type. The following bridge types are considered within the validation.

- steel deck bridges
- filler beam bridges
- concrete slab bridges
- concrete portal frame bridges
- steel composite bridges)

The span lengths of the considered railway bridges reach from 2 to 40 m. The train crossing calculations are carried out considering both, 2D beam and 3D plate models for the bridges. The following calculation assumptions were made:

- train speed ranging from 60 to 420 km/h with a speed step of 1 km/h
- longitudinal and transverse axle load distribution according to EN 1991-2
- damping coefficient ζ according to EN 1991-2
- additional damping $\Delta\zeta$ for train-bridge-interaction is not applied
- rail irregularity amplification factor (1 + φ'' / 2) for rails with careful maintenance according to EN 1991-2
- additional damping $\Delta\zeta_{BEF1}$ for the first bending mode of portal frame bridges is applied according to [8]
- horizontal elastic bedding of portal frame sidewalls is not applied according to [8]
- proportional vibrating mass of the train is not applied

The validation of the developed load models is illustrated for a single span simply supported concrete slab bridge with a span length of 9.05 m. The total bridge mass per unit length and the bending stiffness in uncracked state were determined from the construction plans with 17.31 t/m and 3.72e3 MNm². The resulting fundamental eigenfrequency of the considered bridge is 8.87 Hz.

The dynamic calculations of train crossings were carried out considering all 510 pre-selected relevant operating trains driving forward and backward, i. e. 1020 train configurations in total, and the two developed new load models V1 (signature) and V2 (dynamic). The results of the dynamic calculations are illustrated in Figure 3 in the form of envelope curves for the considered train models. It is indicated that the load model V2 (Figure 3b) covers all relevant operating trains over the considered range of train speed from 60 to 420 km/h. Contrary, the load model V1 does not cover all relevant operating trains (see Figure 3a).

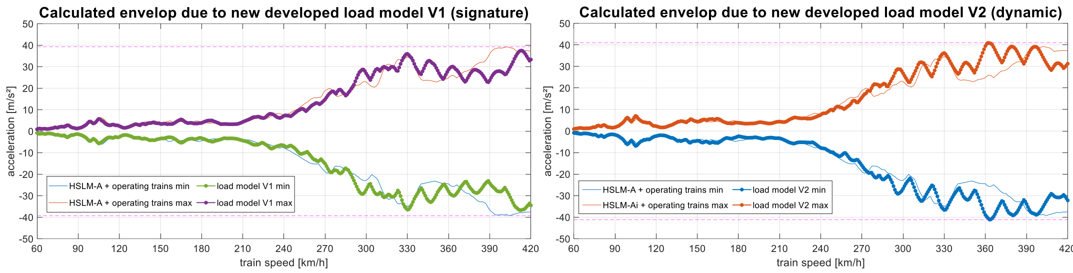

Figure 3: Results of dynamic calculations of train crossing considering an existing concrete slab bridge with 9.05 m span length: (a) results load model V1 (signature), (b) results load model V2 (dynamic).

4 Conclusions and Contributions

In this paper the development of a new high-speed load model for dynamic calculations of railway bridges and a first validation on an existing railway bridge are discussed and presented. The new load model is developed to cover the bridge deck acceleration response due to train crossing for all currently operating trains in the European countries. It was demonstrated that the current HSLM-A (given in EN 1991-2) does not cover the acceleration response of real operating trains as the ICE 4 and that there is a strong need to develop a completely new high-speed load model. It was noted, that considering only the HSLM-A within dynamic calculations of train crossing may lead to results on the unsafe side and hence, destabilization of the bridge ballast bed may occur.

The method for developing the new high-speed load model, which comprises of two different approaches, was presented. For approach 1, the train signature concept was applied to all 3200 collected train configurations of real operating trains in Europe and a pre-selection of 510 trains was made. For approach 2, a comprehensive set of parametrized bridges was defined and loaded with the pre-selected 510 relevant trains. Applying these two different approaches led to the currently developed two new high-speed load models V1 (based on the train signature) and V2 (based on dynamic calculations of train crossing). It is again noted that the currently developed two load models are not final and that they must be considered as preliminary.

A first validation of the developed new load models V1 (signature) and V2 (dynamic) was performed on an existing single span simple supported concrete slab bridge. It was shown that the new load model V2 covers all 510 relevant operating trains with drive direction forward and backward over the total considered range of the train speed from 60 to 420 km/h. In the next step of the project, a total number of 350 existing railway bridges will be considered within the validation phase and improvements of the developed load model will be made before finalization.

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References

[1] DIN e.V., „DIN EN 1991-2:2010-12 (2010): Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges“. 2010.

[2] DIN e.V., “DIN EN 1990:2002 + A1:2005 + A1:2005/AC:2010 (2010): Grundlagen der Tragwerksplanung,” 2010. (in German).

[3] Reiterer, M. (2020). Experimentelle und numerische Untersuchung einer bestehenden Eisenbahnbrücke bei Zugüberfahrt. In: Bautechnik 97, H. 07, S. 473-489. (in German)

[4] Reiterer, M., Firus, A., Vorwagner, A., Lombaert, G., Kohl, A., Schneider, J. (2021). Railway bridge dynamics: Development of an new high-speed load model for dynamic analyses of train crossing. In: Proceeding of IABSE Congress, Ghent 2021.

[5] Vorwagner, A., Kwapisz, M., Flesch, R., Kohl, A., Firus, A., Vospernig, M. (2021). FEM based approach for development of a new high-speed load model for railway bridges. In: Proceedings of IABSE Congress, Ghent 2021.

[6] Unterweger, H., Schörghofer-Queiroz, A. (2019). Neue Züge in Hochgeschwindigkeitsnetzen – Eignung der Zugsignatur als Ersatz für dynamische Berechnung an Brücken. Research Project at Technical University Graz, 2019 (in German).

[7] European Rail Research Institute (D-214 Committee, ERRI D-214). Rail bridges for speeds > 200 km/h. Calculations for bridges with simply supported beams during the passage of a train (RP6). Utretch: European Rail Research Institute, 1999.

[8] RW 08.01.04 (2022): Austrian Guideline for Dynamic Calculation of Railway Bridges, 2022. (in German)