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A need for the development of a new High-Speed Load Model for designing and assessment of railway bridges

A. Vorwagner[1], M. Kwapisz[1], A. Kohl[2], A. Firus[3], M. Reiterer[4], G. Lombeart[5], M. Ralbovsky[1]

[1]AIT Austrian Institute of Technology, Vienna, Austria
[2] Technical University of Darmstadt, Germany
[3] iSEA Tec GmbH, Friedrichshafen, Germany
[4] REVOTEC ZT GmbH, Vienna, Austria
[5] Katholieke Universiteit Leuven, Belgium

Abstract

The high-speed load model (HSLM-A) was developed more than 20 years ago. Since 1999, the vehicle technology and bridge design have developed accordingly. So new vehicle types, which are not always covered by the standardized load model, must be examined additionally.

Within this paper the need of a new dynamic load model for dynamic analysis of railway bridges will be demonstrated. Investigations were done based on currently running passenger trains, which results into a train database of about 3200 train configurations of operating trains within central Europe. To cover possible future train configurations, fictitious parameterized train sets were created.

Two different methods the train signature and FEM- computations on a large-scale set of bridges demonstrated that the existing HSLM-Model does not cover real operating passenger trains. 510 relevant trains could be identified as relevant and define a refence line for operating trains. On top 67 fictitious resonance trains were found on the variation of different geometric train vehicle parameters which could be a worst-case scenario All this demonstrates, the need for a new high-speed load model.

Keywords: railway bridges, high-speed-load-models, bridge dynamics, train signature.

1 Introduction

The European Commission stated in the resent sustainability strategy report in December 2020 a doubling of the highspeed railway traffic by 2030 and tripling by 2050 [1]. To make this vision happen, a reassessment of new and existing rail infrastructure is necessary. Bridges are a crucial factor. The compliance with the requirements of the (dynamic) load bearing capacity and the acceleration limit of 3.5 m/s² in the serviceability limit state must be verified for both, the design of new and the assessment of existing bridges [2]. Special attention is required if an increase in rail speed is intended, or new vehicle types are introduced.

There is a potential area of conflict between vehicle manufacturers and infrastructure operators. The bridges are often a bottleneck for track compatibility, especially when new trains are introduced. Recent experiences with the introduction of the ICE 4 have exhibited this conflict, since the short distance between the bogies or the almost integer ratio between long and short bogie distances lead to new excitation mechanisms, which have not been yet properly investigated.

The standardized high-speed load models (HSLM) were developed about 20 years ago with the aim of avoiding a possible track ballast destabilisation on bridges [3]. In case of new vehicle types, which are not always covered by the standardised load model [2], In case of new vehicle types, which are not always covered by the standardised load model [4] must be performed prior to the route approval.

The dynamic train signature is probably the most widely used method for describing the dynamic excitation capability of a railway vehicle [3]. The train signatures decompose the vibration response of the bridge deck into a Fourier series and pick out only the terms corresponding to a bridge resonance. The signature approach has been used in [3] for developing the existing HSLM, provided in [2]. This model is based on the envelope of undamped dynamic train signatures of relevant high-speed trains operating in 1999.

This leads to the necessity of a revision for a revision of the existing high-speed load-model. An international consortium consisting of the Technical University of Darmstadt (Germany), Austrian Institute of Technology (Austria), KU Leuven (Belgium), and REVOTEC (Austria), commissioned by the German Federal Railway Authority (EBA) is currently working on a new method for a standard-compliant dynamic load model for the dynamic analysis of railway bridges [5,6,7]. It is based on actual operating trains and possible future train configurations within the German rail.

2 Methods

In close contact with vehicle manufacturers and infrastructure managers, the bridge portfolio of the German and Austrian railway operators was analyzed and a collection of currently running passenger trains (PT) was carried out. This results in a train database of about 3200 train configurations. The majority includes diesel and electric multiple unit trains with and without powerheads, push-pull trains, locomotives, and locomotive hauled trains. It was determined based on information and extensive discussions with vehicle manufacturers and research of European train databases [5].

In order to cover possible future train configurations, fictitious parameterized train sets were created. The aim was the definition of possible ranges of axle configurations and to investigate their impact on the aggressiveness and resonance behaviour during a bridge crossing as a worst-case scenario. In coordination with vehicle manufacturers, geometric boundary conditions concerning axle distances have been defined. Figure 1 and Table 1 show the corresponding range of car body lengths (D), bogie distances (d) and distance between the pivots of the neighbouring cars (b). The variated parameters are defined in Table 1.

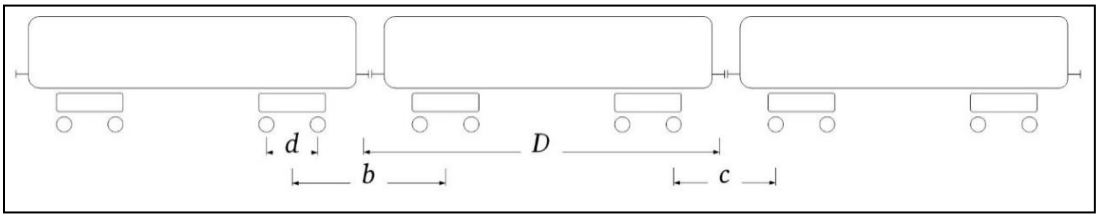

Figure 1: Parameter for fictive future trains.

Considering the chosen step sizes between these values, 2300 possible train configurations have been generated. The train signature S0, which is given in [3], can express the dynamic excitation capacity of a train at different bridge resonance frequencies and was chosen as a method for comparing the different trains. The train signature S0 is defined as maximum of different phases of excitations with respect to axle loads, distances, and is a function of the wavelength λ (ratio of train speed v and first resonance frequency f_0).

	Minimum	Maximum	Step
D	16.0 m	30.0 m	1.0 m
d	1.8 m	3.5 m	0.1 m
c	3.0 m	7.0 m	0.5 m
P	-	195.0 kN	-

Table 1: Parameter for possible fictive future trains.

The investigations are supplemented with a transient dynamic large-scale computational series [5, 7] on parametrized beam models, based on the bridge portfolio in Austria and Germany. This resulted in more than 1100 different bridges and more than 20 million dynamic computations

3 Results

The dynamic signatures S0 were calculated for all 3200 operating passenger trains PT and the 2300 artificial train combinations, from which the 67 most aggressive trains have been selected for further investigations (resonance trains RT). These train categories were grouped together -separately and are summarized in Figure 2. The obtained envelopes of the signatures (PT and RT) are illustrated in comparison to the envelope of the HSLM-A model trains considered as reference.

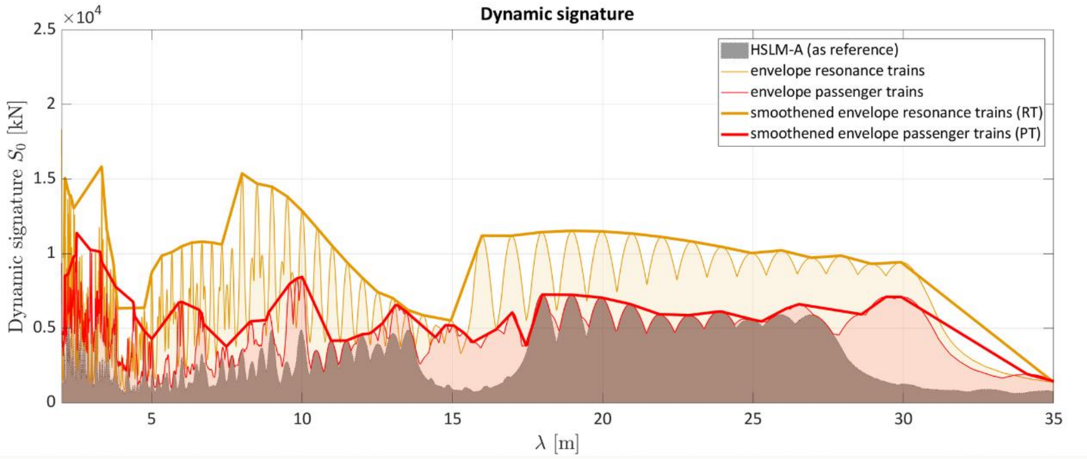

Figure 2: Dynamic signatures S_0, and envelopes for operating passenger trains (PT), artificial resonance trains (RS) and HSLM-A model trains.

It is clearly visible that both envelopes of operating and fictive trains exceed the one of the current standardized HSLM- model, which underlines the need for reassessment and development of a new load model. The envelope of the operating trains covers about 200 trains. Further investigations on the dynamic response have been performed using other methods like the LIR or DER- methods [3]. Through the employment of these methods about 510 preselected trains were identified as potentially relevant. All of them are exceeding the train signature of the existing standardised load model.

The analysis of 20 million different transient dynamic calculations of dynamic train crossings allows a consideration of the influence of different bridge parameters (length, stiffness, mass and damping), train type and operation speed *v*. Based on these results, about 230 trains for bridge dynamics could be identified as dynamically relevant for the track ballast acceleration. The multi-dimensional parameter space is far too complex to display all results in one diagram. Examples of the induced maximum bridge acceleration for train crossings at different speeds can be seen in Figure 3 or in [5,7].

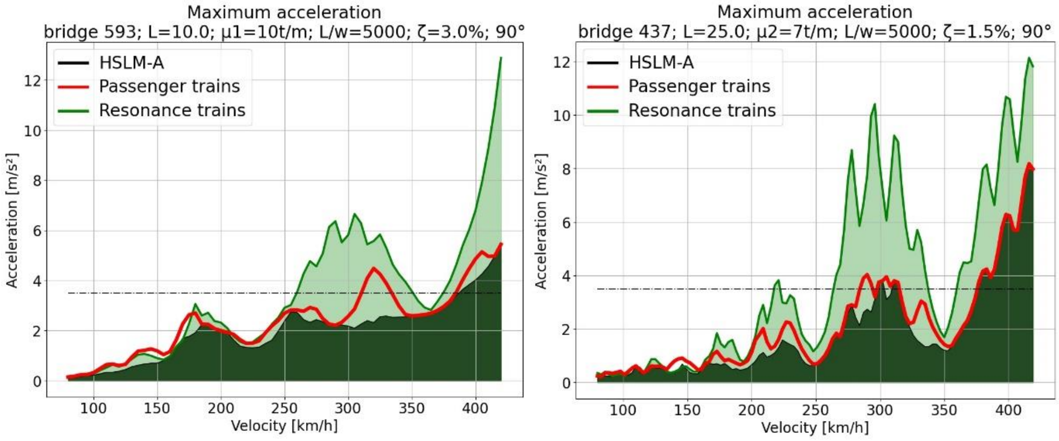

Figure 3: Dynamic calculations on different brides for operating passenger trains (PT-red), artificial resonance train (RT-green) and HSLM-A trains (black). Left with span L=10 m, mass μ=10t/m and & 3% damping. Right span L=25 m, mass μ=7t/m and 1.5% damping.

4 Conclusions and Contributions

The need of a new dynamic load model for dynamic analysis of railway bridges has been demonstrated in this paper. The vehicle technology and bridge design have developed have experienced a technological progress and the calculation method chosen at the time does not properly cover all real bridge cases. The HSLM-Model was developed based on the train signature, which emphasises only the dynamic aggressiveness. Important bridge parameters such as damping, vehicle-bridge interaction, load distributions within the ballast etc. are neglected. This underlines that the train signatures are not sufficient to evaluate the influence of a vehicle on the dynamic behaviour of a bridge structure.

A collection of over 3000 operating passenger trains defines a new envelope which was considered as reference. Two different methods, the train signature and FEM-computations on a large-scale set of bridges, demonstrated that the existing HSLM-Model does not cover real operating passenger trains. It is obvious that the currently operating trains must be considered. A new load model should cover all operating trains to eliminate the uncertainty within dynamic calculations of train crossings.

67 fictitious resonance trains were defined based on the variation of different geometric train vehicle parameters. These parameters were selected through an interactive exchange with vehicle manufacturers. These results are considered by the authors as a worst-case scenario and demonstrates what would potentially happen if the vehicle dimensions were chosen in an unfavourable way.

Within the ongoing international research project [5,6,7], a new dynamic high speed load model will be devolved. Based on the demonstrated results two different approaches FEM-Computations and train signature are used for defining the reference level and developing new model trains. This results in two different load models which will be validated and benchmarked on a set of 350 real bridges. The models are in prefinal stage and the validation process has started.

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