Modelling and numerical simulation of symmetric vibrations of the KNI 140070 viaduct – RHEDA track – ICE-3 train system

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Abstract

The paper presents results of the preliminary theoretical study in dynamics of railway bridges. The main purpose of the study is to develop a methodology for FE modelling and numerical simulation of symmetric vibrations of the bridge – track – train system using advanced CAE systems. The KNI 140070 viaduct of span length of 14.40 m with abutment zones has been selected as a representative for the study. The modernized ballastless track, based on the RHEDA 2000 system, includes the main and the stiffening rails, fastening systems and sleepers. The German ICE-3 high-speed train has been taken into consideration. Finite element (FE) models of the viaduct, the track and the train were developed using Altair HyperMesh and LS-PrePost software. All main components of the train FE model were considered as rigid bodies and were connected using cylindrical and revolute constrained joints and discrete springs and dampers. Dynamic analyses were performed using LS-DYNA solver. Selected time histories for displacements, accelerations and stresses are presented as the results of the study. In addition, contours of displacement and stress states, created for the maximum service velocity of 300 km/h are shown.

Keywords: steel structures, concrete, dynamics, impact, numerical analysis

1. Introduction

Theoretical and experimental studies in dynamics of railway bridges has been developing for more than 70 years now, due to rapid development of advanced technologies in railway bridges, railway lines and high-speed trains. Very often, researchers formulate simplified models to simulate numerically dynamic responses of the bridge to the moving train using writer's non-professional computer programmes [1-7]. However, at present, advanced computational techniques can be applied to simulate the dynamic bridge – train interaction.

The main purpose of the study presented in the current paper is to develop a methodology for modelling and numerical simulation of symmetric vibrations of the bridge – track – train (BTT) system applying commercial advanced CAE systems.

2. Description of the BTT system

The KNI 140070 viaduct, with composite (steel – reinforced concrete) superstructure, located on E-65 Polish Central Main Line, has been selected for modelling. The viaduct has the k = +2 classification coefficient and 14.40 m theoretical span length. The platform is made of C35 concrete reinforced with AII/18G2-b steel rebars. The side walls are made of C30 concrete and have vertical dilatations at 1/4, 1/2, and 3/4 of the span length.

The modernized ballastless RHEDA track was proposed. It includes 60E1 main rails equipped with the Vossloh 300-1 fastening system, additional 60E1 stiffening rails with SB3 fasteners, B355 and B355-U sleepers with 600 mm spacing, continuous reinforced concrete track plate, and approach reinforced concrete slabs in the abutment zones. Stabilized subsoil in the abutment zones and out of these zones has been designed.

The ICE-3 (German InterCity Express) high-speed train were taken into consideration. The typical trainset contains 8 cars [8], wherein the configuration of the four end cars is a mirror reflection of the four front cars. The top speed in service for the ICE-3 is equal to 300 km/h.

3. Physical and numerical modelling of the BTT system

Physical modelling of the viaduct has been performed assuming the full symmetry of the bridge cross-section, orthotropic homogenization of the reinforced concrete platform, and neglecting the wind bracing. Nonlinear viscoelastic properties of fasteners and viscous damping of separate system parts are taken into consideration. Lateral snaking of wheel sets has been omitted, thus vibrations of the system are symmetric.

FE models of the viaduct, the track and the train have been developed using Altair HyperMesh and LS-PrePost software. FE model of the bridge superstructure is depicted in Fig. 1. It consists of 3896 4-node shell elements (main beams) and 5568 8-node 48 DOF solid elements (reinforced concrete platform).

The RHEDA plate – sleepers system as well as the subsoil layers are modelled with 8-node brick elements. The FE model of the ballastless track in approach zone is presented in Fig. 2.

A numerical model of rails is composed of Hughes-Liu beam finite elements with a non-symmetric I-shape cross-section. The track section modelled numerically for the bridge – track – moving train system is 810 meters length.

Carbodies, bogie frames and wheel sets of rail-vehicles are considered as rigid bodies. Cylindrical and revolute constrained joints and discrete springs and dampers [9] were applied to connect all components of the FE model of rail-vehicles of the ICE-3 trainset.

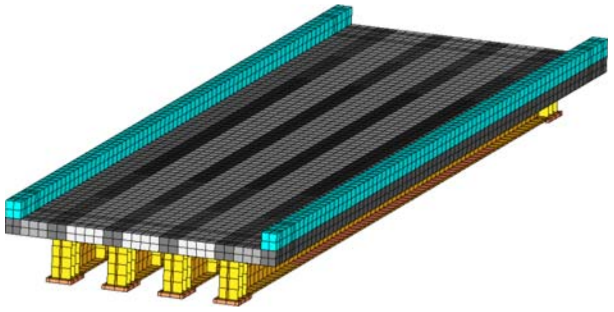

Figure 1. The FE model of the KNI 140070 viaduct superstructure

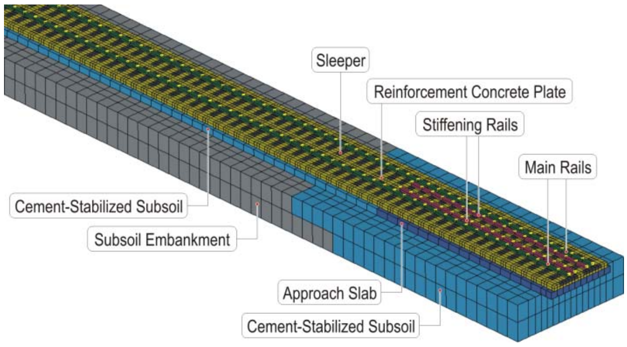

Figure 2. The FE model of the RHEDA track in approach zone

RAIL_TRACK and RAIL_TRAIN modules available in LS-DYNA system [9] were applied for approximate modelling the train – track interaction without simulation of wheels' rotation. A service velocity of the vehicle FE model was declared in two steps. For the initial moment, the INITIAL_VELOCITY option was used and next the PRESCRIBED_MOTION_RIGID was applied.

4. Results and conclusions

Selected time histories for displacements, accelerations and stresses are presented as the results of the study. Figure 2 shows one of the examplary results – time histories of selected vertical displacements at the midspan. Measurement point in the FE model in which the vertical displacements were registered are depicted in the figure as well.

In addition, several contours of displacement and stress states, created with LS-PrePost and HyperView software for the maximum service velocity 300 km/h, are presented in the paper.

Modelling and numerical simulation performed in the study, related to transient symmetric vibrations of the railway bridge induced by the ICE-3 high-speed train moving on the modernized RHEDA track, has appeared very effective. The FE model is of medium number of DOF, therefore it is useful in engineering practice and enables extended dynamic analysis of the system, e.g. influence of service velocity, comparison of responses for optional solutions of the abutment zones etc.

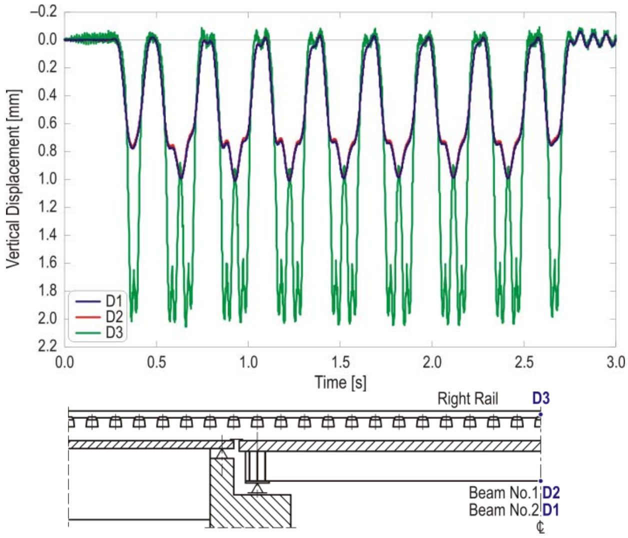

Figure 3. Time histories of selected vertical displacements at the midspan and measurement points in the FE model

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