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Vibrations of Bridge / Track Structure / High-Speed Train System with Vertical Irregularities of the Railway Track

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Abstract

The study presents the vibration theory and random dynamic analysis of the series-of-types (designed by the author) of composite (steel-concrete) bridges loaded by a German ICE-3 high-speed train. The vibration theory includes: a continuously welded ballasted track structure, viscoelastic suspensions of rail-vehicles with two two-axle bogies each, non-linear Hertz contact stiffness and one-sided contact between the wheel sets and the rails, the viscoelastic and inertia features of the bridge, the viscoelastic track structure on and beyond the bridge, approach slabs. The basic random factor, i.e. vertical track irregularities of the track, is taken into consideration.

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Keywords: composite steel–concrete bridge; ballasted railway track structure; high–speed train; random track irregularities; numerical analysis; modelling; random samples

1. Introduction

In Poland, the railway composite bridges are designed according to the norms [1 – 3]. Design guidelines one can find among others in the monograph [4]. Bridges loaded fast moving trains must be designed or modernized to ensure the safety of train movement and comfort of passengers. Too big sleepers acceleration may destabilize the ballast. This problem has been studied by ERRI in order to determine the critical value [5], later included in the Eurocodes [6, 7]. The conducted studies in the literature [8 to 16] confirmed that the rail track irregularities are considered as one of the main factors affecting the dynamic response of the ridge / track structure / high-speed train (BTT) system. Theoretical studies on the impact of irregularity track on the railway bridge vibration loaded by a train moving at high operating velocity, have so far been carried out on simplified models of the BTT, taking into account some factors or design features of the system.

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2. Modelling and vibration theory of BTT system

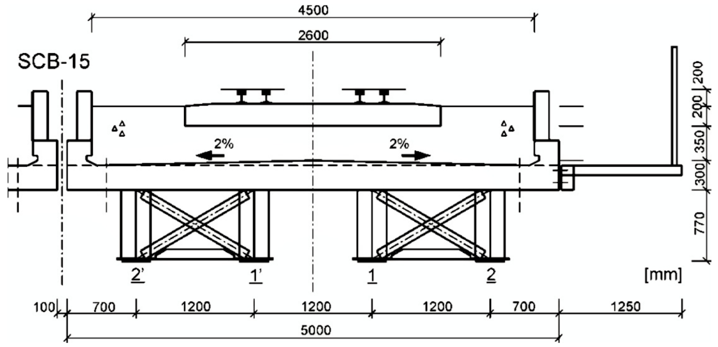

Fig. 1. Fully symmetric cross-section of SCB-15 bridge at midspan [17].

The BTT system is composed of a simply supported composite bridge, two approach slabs, a track structure with continuously welded rails and a high-speed train. The 1D physical and mathematical modelling of the BTT system is based on the following assumptions and ideas [18]. There is considered a finitely long deformable continuously welded track including the out-of-transition zones, the transition zones and the bridge zone. The track outside of these zones is non-deformable and straight. There may occur random vertical track irregularities identical for both main rails, described by a spatial function $r(x)$ which is a stationary ergodic Gaussian process defined by the PSD function determined experimentally. The BTT system has a vertical plane of symmetry coinciding with the track axis; this is the plane of vibration. The operating and side rails are viscoelastic prismatic beams deformable in flexure. The sleepers vibrate vertically and are modelled as point masses. The ballast is modelled as a set of vertical viscoelastic constraints with non-linear elastic characteristics. The ballast mass is discretized. Potential separation of the sleepers from the ballast is taken into consideration. The track-bed (subsoil) is a linearly viscoelastic layer with lumped mass distribution. The approach slabs are modelled as viscoelastic prismatic beams deformable in flexure. The bridge superstructure is reflected by a simply-supported, stepwise-prismatic beam, deformable in flexure, symmetrical relative to the bridge midspan. A set of eight rail-vehicles form a high-speed ICE-3 German train. Each vehicle has two independent two-axle bogies. The planar Matsuura model of a rail-vehicle is adopted in the extended version via inclusion of non-linear one-sided contact Hertz springs at wheel sets – rail contacts. Potential micro-separations of the moving wheels from the rails and potential impacts are taken into account. Vibrations of the BTT system are physically nonlinear and geometrically linear.

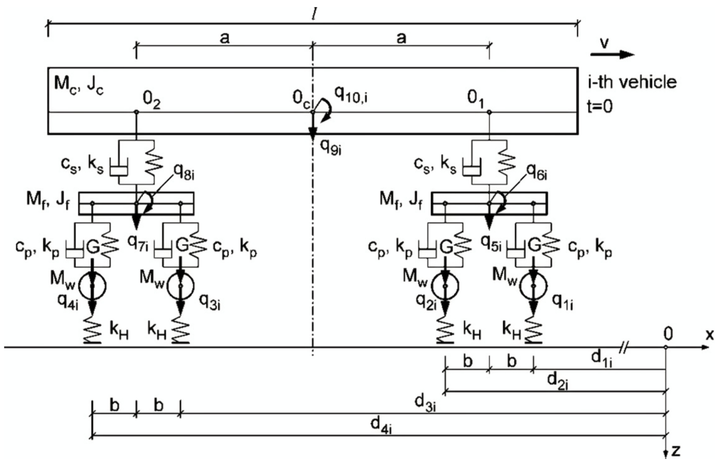

Fig. 2. Enhanced Matsuura model of rail-vehicle and its position at $t = 0$ [17].