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High Speed Trains Geotechnics: What Is a Tolerable Bump?

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Abstract

The problem of the bump at the transition between the embankment and the bridge is an important concern for railways and highways. These bumps can lead to a rough riding surface which creates discomfort at high speed and high maintenance costs. The current study addresses the problem for High Speed Trains (HST). One reason for the development of a bump is the difference in stiffness between the compacted soil embankment and the bridge typically resting on deep foundations. A 4-D finite element model, developed in LS-DYNA, was used to simulate the effect of this difference in stiffness at the transition between the embankment and the bridge. The modulus of the embankment is varied from 5 MPa for a very soft embankment to 120 MPa for a very stiff embankment. The bridge is considered to be rigid by comparison. This study will show that the dynamic amplification factor, DAF, defined as the ratio of the maximum dynamic rail/wheel impact force to the static load on the wheel, changes dramatically with the embankment modulus and train speeds.

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Keywords: bump; transition; HST; 4-D finite element model; DAF

Nomenclature

E	Elasticity modulus
ν	Poisson's Ratio
ρ	Unit mass
K_{eq}	Equivalent spring stiffness of train suspension system
C_{eq}	Equivalent damper coefficient of train suspension system
K_1,K_2	Primary spring stiffness of train suspension system
C_1,C_2	Primary damper coefficient of train suspension system
K_3	Secondary spring stiffness of train suspension system
C_3	Secondary damper coefficient of train suspension system

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M_{car}	Car body mass
M_{bogie}	Bogie mass
V_R	Rayleigh wave speed
V_S	Shear wave speed
DAF	Dynamic amplification factor

1. Introduction

The problem of bumps at the transition between the main track and the bridge is a main concern of the railway industry (Davis et al., 2003 [1]; Davis and Li, 2006 [2]; Li et al., 2003 [3]; Li and Davis, 2005 [4]; Plotkin et al., 2006 [5]). It is also a concern for highways at transitions between the road on top of the embankment and the bridge (Wahls, 1990 [6]; Stark et al., 1995 [7]; Briaud et al., 1997 [8]; Long et al., 1998 [9]; Seo et al., 2002 [10]; Dupont and Allen, 2002 [11]; Seo, 2005 [12]). A major source of track bumps is the transition zone between compacted soil embankments and bridge abutments resting on deep foundations. This irregularity is due to the difference in stiffness between the two rolling surfaces (Davis and Plotkin, 2009 [13]) that leads to a dynamic oscillation of the train wheels and to a cyclic variation of the contact force between the wheels and the rail. This dynamic effect results in an impact force near the bump or dip and associated deterioration of the track near bridges. This additional force acts at the train-track interface and may result in the formation of a bump or dip in the track. This dynamic effect becomes more intense as these irregularities, bump or dip, increase in size (Plotkin et al., 2006 [5]; Banimahd, 2008 [14]; Nicks, 2009 [15]; Davis and Plotkin, 2009 [13]). The dynamic loads caused by the difference in stiffness or by a bump or by a dip can vary in the range of 1.5 to 3 times the static load (Davis et al., 2003 [1]). In addition, an HST can intensify the impact loads due to the higher train speeds (Banimahd, 2008 [14], Nicks, 2009 [15]). Because the soil and embankment modulus is an important parameter in this case (Farritor, 2006 [16]), the current study will include the effect of changes in this modulus on the track response in the case of no bump or rip. This study also numerically models the influence of high train speeds beyond the range studied by Banimahd (2008) [14] and Nicks (2009) [15].

2. The four dimensional finite element model: numerical simulations

A 4-D model of a railroad track on soil subgrade was simulated in LS-DYNA to evaluate the response of the coupled train-track-soil system at speeds up to 200 m/s (720 km/h) without any bump or dip. The Finite Element Model (FEM) components included the train and the track/natural soil.

2.1. Track/soil model

The track was the steel rail and was modeled as a solid element with elastic material properties (Table 1). The steel rail was attached to the model of the railroad ties. The railroad ties were modeled as solid elements with elastic concrete material properties. They were spaced at 0.7 m from center to center and had dimensions of 0.3 m x 0.2 m x 2.4 m. The track and subgrade mesh is shown in Fig. 1. To perform the parametric studies, different soil moduli (Es) were considered for the subgrade (Table 1). To study the effects of the change in track stiffness when passing from the embankment to the bridge, the assumption is made that the track is placed on soil with a specified soil modulus from 5 MPa to 120 MPa (Table 1) and that it is placed on a rigid base representing the bridge.