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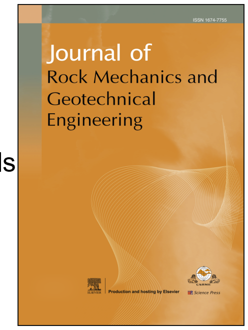

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Impact of train speed on the mechanical behaviours of track-bed materials

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Abstract: For the 30,000 km long French conventional railway lines (94% of the whole network), the train speed is currently limited to 220 km/h, whilst the speed is 320 km/h for the 1800 km long high-speed lines. Nowadays, there is a growing need to improve the services by increasing the speed limit for the conventional lines. This paper aims at studying the influence of train speed on the mechanical behaviours of track-bed materials based on field monitoring data. Emphasis is put on the behaviours of interlayer and subgrade soils. The selected experimental site is located in Vierzon, France. Several sensors including accelerometers and soil pressure gauges were installed at different depths. The vertical strains of different layers can be obtained by integrating the records of accelerometers installed at different track-bed depths. The experimentation was carried out using an intercity test train running at different speeds from 60 km/h to 200 km/h. This test train was composed of a locomotive (22.5 Mg/axle) and 7 "Corail" coaches (10.5 Mg/axle). It was observed that when the train speed was raised, the loadings transmitted to the track-bed increased. Moreover, the response of the track-bed materials was amplified by the speed rise at different depths: the vertical dynamic stress was increased by about 10% when the train speed was raised from 60 km/h to 200 km/h for the locomotive loading, and the vertical strains doubled their quasi-static values in the shallow layers. Moreover, the stress-strain paths were estimated using the vertical stress and strain for each train speed. These loading paths allowed the resilient modulus M_r to be determined. It was found that the resilient modulus (M_r) was decreased by about 10% when the train speed was increased from 100 km/h to 200 km/h. However, the damping ratio (D_r) kept stable in the range of speeds explored.

Keywords: field experimentation; conventional track-bed materials; train speed upgrade; mechanical behaviours; reversible modulus; damping ratio

1. Introduction

Nowadays, there is a growing need to reduce travel time in railway transportation. On the other hand, most of the European railway networks are composed of conventional lines with a service speed limited to 220 km/h. In France, almost 94% of the operational lines are conventional ones (Duong et al., 2015). Several studies aiming to describe the effect of train speed on railway track-bed materials were conducted (Hall and Bodare, 2000; Madshus and Kaynia, 2000; Alves Costa et al., 2010; Ferreira, 2010; Hendry et al., 2013; Ferreira and López-Pita, 2015). It is recognised that it is important to well understand the mechanical behaviours of the materials constituting the track-bed in order to optimise the upgrading operations (Haddani et al., 2011). In this context, the "INVICSA" project was initiated by SNCF (French Railway Company) in 2011, aiming at studying the impact of train speed on the behaviours of conventional tracks. Note that the main difference of track-bed between the conventional and the new high-speed tracks is the presence of a heterogeneous "interlayer" below the ballast layer in the conventional track (Cui et al., 2014). This layer was created mainly by the interpenetration of ballast grains and subgrade soils (Trinh et al., 2012; Cui et al., 2013; Duong et al., 2014). The nature and thickness of the interlayer depend on the site-specific conditions as well as the loading history of track.

Several authors studied the behaviours of track-bed materials under the effects of train passages (Bowness et al., 2007; Hendry, 2007; Powrie et al., 2007; Le Pen, 2008; Priest et al., 2010; Le Pen et al., 2014). Field monitoring is often adopted for this purpose (Hall and Bodare, 2000; Aw, 2007; Lamas-Lopez et al., 2014a). Fröhling (1997) studied the effect of spatial variation of track stiffness on track degradation. Aw (2007) studied the mud-pumping phenomenon in a track with saturated soft soils; larger surface deflections were measured when the subgrade was composed of soft soils, and there was a significant variation of pore pressure in the subgrade soil during train passing. A photo-sensitive array method was applied after some stability problems were observed in the presence of soft soils in the subgrade (Hendry, 2011; Hendry et al., 2010, 2013). It was also observed that the amplification of sleeper deflection increased with the increasing train speed, depending on the track characteristics and other subgrade mechanical properties such as damping ratio. Madshus and Kaynia (2000) analysed the relationship between the surface Rayleigh wave velocity and the amplification of track deflection, showing that the surface wave velocity was the key parameter in controlling the track deflections at a given train speed. Connolly et al. (2014) and Madshus et al. (2004) synthesised the influence of surface wave velocity on the deflection amplification. In addition, the track type is also an important factor for the amplification of deflection (Kempfert and Hu, 1999). Ballasted tracks are superior to slab tracks in amplifying the track-responses.

Some semi-analytical models were developed by Sheng et al. (2004) and improved by Alves Costa et al. (2015) to describe the track deflection amplifications. Finite element analyses were also conducted to investigate the influence of train speed on the behaviour of tracks (Kouroussis, 2009; Alves Costa et al., 2010; Connolly et al., 2013; Woodward et al., 2013). Some results showed a decrease of elastic modulus of track-bed materials with increasing train speed (Alves Costa et al., 2010).

In order to analyse the contribution of each track-bed constitutive layer to the settlement of a whole track, strain measurements using multi-depth deflectometers (MDD) or strain gauges were conducted (Fröhling, 1997;

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