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Technical Paper

Track-bed mechanical behaviour under the impact of train at different speeds

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Abstract

This paper aims to study the influence of train speed on the mechanical behaviour of track-bed materials based on field data recorded at a representative site of the conventional French network. Capacitive accelerometers and soil pressure gauges were installed in track-bed layers. The Intercity train was selected to perform this study as it is the most frequent train running on this site. In total, 1790 records corresponding to Intercity train passages were taken into account, with train speeds ranging from 60 to 200 km/h. The vertical strains of different layers were estimated by integrating the signals of accelerometers installed at different depths. It is observed that when train speed increased in the considered range, the traffic loadings, in terms of dynamic stress transmitted to track-bed materials, were amplified about 10%. However, the vertical strains of track-bed materials were also amplified by 2 in the same range of speeds. These amplifications appear mainly in shallower layers. The stress–strain amplitude ratios for all the recorded trains were calculated to analyse the evolution of resilient moduli (M_r) of track-bed materials. It is found that M_r of interlayer soil decreased by approximately 25% when train speed increased from 60 to 200 km/h.

Keywords: Conventional lines; Track-bed materials; Train speed; Mechanical behaviour; *'In-situ'* experimentation; Resilient modulus

1. Introduction

The European railway networks mostly involve conventional lines, with a service speed limited to 220 km/h (only 7000 km over almost 200.000 km of European lines are High-Speed lines, with higher service speeds). For instance, in France, almost 94% (about 29.800 km) of the operational lines are conventional ones (Duong et al., 2014a, 2014b). Seeking to reduce the travel time in railway transportation, the European railway administrators look to increase the speed of the trains. Several studies of train speed upgrade on European conventional lines have been conducted in the past (Hall and Bodare, 2000; Hendry et al., 2010; Madshus and Kaynia, 2000). However, the speed upgrade impact on the mechanical behaviour of track-bed materials (loading and response amplifications with train speed) is still an open question.

In order to better understand the mechanical behaviour of the materials composing the track-bed in the context of optimization of maintenance operations, the French railway company (SNCF) launched the 'INVICSA' project in 2011, aiming to investigate the train speed impact on the behaviour

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of conventional line tracks. Note that the main difference of track-bed between the conventional and new high speed lines is the existence of a heterogeneous "interlayer" below the ballast layer in the former (Cui et al., 2014). This layer was created over time between the ballast and the subgrade (Trinh et al., 2012), mainly by the interpenetration of ballast grains and fines from subgrade as well as from ballast attrition (Cui et al., 2013; Duong et al., 2014a, 2014b). The nature and thickness of the interlayer depends on the geological conditions and the loading history of track (Costa et al., 2015; Hall, 2003; Hendry et al., 2013; Madshus and Kaynia, 2000). Moreover, the interlayer and subgrade properties will determine the site surface wave velocity which is directly related to the critical speed at which the mechanical response of materials reaches a local maximum under train loading. The acceptance of speed upgrade is strongly conditioned by the mechanical properties of track-bed materials as their stiffness (Costa et al., 2015). Very often, the soil stiffness is determined through the shear wave velocity (Gunn et al., 2003; Kim et al., 2001; Sawangsuriya, 2012).

Several authors have studied the behaviour of track-bed materials with train passages (Bowness et al., 2007; Hendry, 2007; Le Pen, 2008; Le Pen et al., 2014; Powrie et al., 2007; Priest et al., 2010). Field tests tend to be adopted in the study of the mechanical behaviour of track-bed materials under train loading. Fröhling (1997) studied the effect of spatial variation of track stiffness on track degradation. Aw (2007) investigated the impact of subgrade soft soil saturation on the track behaviour in terms of mud-pumping. He showed that larger surface deflections occurred when the subgrade was composed of soft soils with low shear wave velocity or low stiffness. A photo-sensitive array method was applied after some stability problems due to the presence of soft soils in conventional tracks by Hendry (2011) and extensometers were used by Hendry et al. (2010, 2013). It was observed that the sleeper deflection increased with the increase of train speed, depending mainly on the subgrade mechanical properties, such as elastic modulus and damping ratio. Madshus and Kaynia (2000) showed the key role of surface wave velocity in the amplification of track deflection. When the surface wave velocity had the lowest value in the first meter of a track section, the track deflections reached their maximum values. The amplifications due to train speed and surface wave velocity were summarized by Connolly et al. (2014) and Madshus et al. (2004). The track typology was also recognized as an influencing factor for the deflection amplifications (Kempfert and Hu, 1999). Ballasted tracks transmit higher loads to the firsts track-bed layers compared to slab-tracks and consequently, and the response amplification of train loads could bring more significant defects if the speed upgrade is carried out for ballasted tracks.

Some semi-analytical models for track deflections were developed by Sheng et al. (2004) and Costa et al. (2015). Numerical analyses using FEM were also performed to investigate the influence of train speed on the behaviour of tracks (Alves Costa et al., 2010; Connolly et al., 2013; Kouroussis, 2009; Woodward et al., 2013). The results showed a decrease in the elastic shear moduli of track-bed materials with the increase intrain speed (Alves Costa et al., 2010).

Strain measurement using multi-depth deflectometers and strain gauges were carried out in several studies to analyse the contribution of each individual substructure layer to the differential settlement of the railway platform (Fröhling, 1997; Hall and Bodare, 2000; Mishra et al., 2014; Priest et al., 2010). Moreover, real scale physical models were developed to analyse the recorded load amplifications in the configuration of concrete slab (Bian et al., 2014; Chen et al., 2013; Xu et al., 2013).

Nevertheless, to the authors' knowledge, few analyses have been conducted on the evolution of mechanical behaviour of real tracks in terms of stress and strain amplitudes. The evolution of the recorded measurements over time, their dispersion and consistence need to be examined in-depth. Moreover, it is interesting to estimate such mechanical properties as the resilient modulus based on the records of sensors embedded in track-beds. In this study, firstly, the stress amplitude measurements under different axle types (locomotive and coach) were analysed. Then, the evolution of deflections with speed increase under both types of axle loads was calculated from the records of accelerometers installed at different depths. The vertical strain amplitudes of interlayer and subgrade soils were estimated from the calculated deflections at different levels of the track. The resilient modulus (M_r) based on the vertical stress and strain amplitudes was estimated for an Intercity train running over the experimental site during 5 months at a speed ranging from 60 to 200 km/h. Finally, the averages of kinematics variables (such as acceleration, particle velocity and deflection amplitude), the mechanical parameters (such as stress and strain amplitudes) and their influence on the resilient modulus and damping ratio are discussed in this paper.

2. Experimental site

The 'INVICSA' project involves setting up a full scale field experimental site on a conventional line track. The experimental site was chosen within the 30000 km French conventional network (Cui et al., 2014; Lamas-Lopez et al., 2014a, 2014b). The selection criteria were related to the speed limit on the site (200 km/h, close to the maximum speed for the conventional lines), the main characteristics of track (alignment, cutting zone, proximity to electrical connection) and the state of the rails and sleepers (without special maintenance operations since the last renewal works). The alignment of track is important to ensure that both rails of the track are loaded at the same level. The experimental site finally selected was located in Vierzon, France, at KP + 187 of the line connecting Orléans and Montauban. The instrumented section is 30 m long. Dynamic sensors such as capacitive accelerometers and soil stress sensors were installed at three different depths along the experimental site. The capacitive accelerometers were selected rather than piezo-electric accelerometers in order to better register the low-frequency range, where most of the displacements due to long wavelengths are produced.