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Numerical study of transition zone between ballasted and ballastless railway track

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ABSTRACT

Track stiffness plays an important role in design and construction stages of the railway track. Smoother travel and longer life time of a track depend on the immutable track stiffness. Nevertheless, changing the track stiffness is inevitable, especially in the transition zone, where the slab track connects to a conventional ballasted track. In this zone track stiffness changes abruptly and it causes differential settlement, which is the main cause for degradation of tracks and foundations at transition zones. A number of remedies have been proposed or used to provide gradual stiffness transition, such as the use of gradual pad stiffness, long sleepers and auxiliary rail in the transition zone. The emphasis of this study is held on the assessment of the behavior of different types of the transition zone under the train moving loads. For that reason, well-known commercial finite-element method package has been used to investigate the dynamic behavior of the transition zone under the passage of high-speed trains. The results of the dynamic analysis are presented and compared in two circumstances; one considering the common improvement in the superstructure by installing auxiliary rails or gradually increasing the length of the sleepers in transition area, and the other by enhancing the substructure through constructing two-part transition section.

Introduction

Conventional ballasted railway tracks require periodical tamping due to uneven settlements of the ballast during operation. The sleeper panel must be adjusted to guarantee a smooth run of the wheel sets. Based on the existing experiences this kind of maintenance works are significantly increased for high-speed tracks. Ballastless (slab) track constructions offer an alternative solution due to the enormous reduction of maintenance work and the long service life with constant serviceability conditions (Audley and Andrews, 2013; Esveld and Markine, 2006). However, connection between ballastless and ballasted railway tracks is unavoidable. Immediate change in the vertical support and discontinuity of support constituents material cause stiffness variation that builds a stress concentrated part and raises irregularities of track level. These changes make the connection area as one of the major sources of problems for the track. Therefore, a special design or remedy has to contemplate in transition area between two different kinds of track system to reduce the discontinuity of track stiffness. This area is called transition zone, and its purpose is to bring a gradual adjustment between the subgrade modulus of the slab track and the ballasted track. These zones are the main concern to railway infra-managers, since often an additional maintenance is required to preserve track level, and ride quality. This extra maintenance increases the exploitation costs, and

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eventually causes delays in the operation of the railway track. Many railway engineers have suggested different designs and recommendations for the construction of transition zones. However, it seems none of available designs are ultimate solution for mitigation of track degradation. For this reason, it is essential to understand efficiency of each approach, and choose the most suitable construction method or remedy for a track under the passage of high-speed trains. Another important aspect of the transition zones is the uneven settlement that causes other problems frequently, for example, hanging sleepers or unsupported sleepers. These sleepers normally appear in the vicinity of the track with higher stiffness values, which amplify the dynamic impact load on track. Hence, track degradation will rapidly increase. (Dahlberg, 2004; Shuguang et al., 2007; Ferreira and López-Pita, 2013).

Finite-element method (FEM) offers a significant aid to determine the dynamic response of complex geotechnical models, especially due to its capability of detailed simultaneous prediction of stress distribution and displacements in the system without assuming any failure modes. The use of the finite-element (FE) analysis has become widespread and popular in geotechnical practice for controlling and optimizing engineering tasks. Numerical simulation can be useful to quantify long and short term behavior of the track, besides estimation on required modifications and maintenance of whole track. For the simulation, one should consider the model simplifications and the choice of numerical techniques. Those simplifications help save time and money; however, there results need to be validated for practical purposes.

To solve the problem of railway transition zone, the dynamic effect of the transition should be analyzed, including the displacement, acceleration and stress distribution of each part of transitions. In this study, 3D finite-element models have been developed, wherein the transition is constituted by one section of ballasted track and one section of slab track. The ballast track consists of the rails, sleepers, ballast and soil, while the slab track consists of rails, concrete slab, mortar layer, support concrete and soil. In order to reduce these dynamic effects on the track due to the abrupt changes in the track stiffness, different types of remedies have been implemented. These methods are mostly designed for the transition zones in the vicinity of bridges such as installing auxiliary rails, and gradually increasing the length of the sleepers in transition zone. In fact, the basic theoretical aspects of changing the support stiffness at connection area are the same; hence, most of the improvements can be used in the transition area of ballasted and ballastless tracks. Consequently, the main objective of this study is the assessment of different transition zone's behavior under the train moving loads.

Methodology and material properties

Background

Change in the materials or structure of substructure (or superstructure) of the track cause abrupt change in track stiffness. Therefore, in the vicinity of that area, differential elastic track deflections happen, which result in increasing dynamic loads of the trains that can initiate localized degradation, for instance, where the conventional ballasted track connects to modern slab track. Fig. 1 illustrates abrupt variation in track stiffness due to change of substructure material.

To reduce the abrupt change of the stiffness in the transition zone, research communities have introduced different types of remedies such as installing auxiliary rails, gradually increasing the length of the sleepers in transition area, and partially replacing the subgrade with stiffer soils. The remedies are based on the basic technical guideline which given in literature (Lei and Mao, 2004; Read and Li, 2006; Shan et al., 2013). Normally having relatively high track stiffness is beneficial due to the fact that it provides sufficient track resistance to applied loads and results in decrease of track deflections. A rail with higher bending stiffness distributes the load over a greater number of sleepers, and as a result the transferred force to the sleepers and rail fastening system evidently decrease. Nevertheless, high stiffness is also a cause to increase in dynamic forces in the wheel – rail interface, sleepers and in ballast which is ultimate reason for track wear and fatigue (Hunt, 2005; Berggren et al., 2011).

Geometry and material properties

In a 2D model, load distribution of a train in longitudinal direction cannot be modeled. Moreover, the rail is discretely supported by the sleepers, while in a 2D plane strain model, it has been assumed that the transversal profile of the track is invariable in the longitudinal direction with continues support. The 3D model can model the

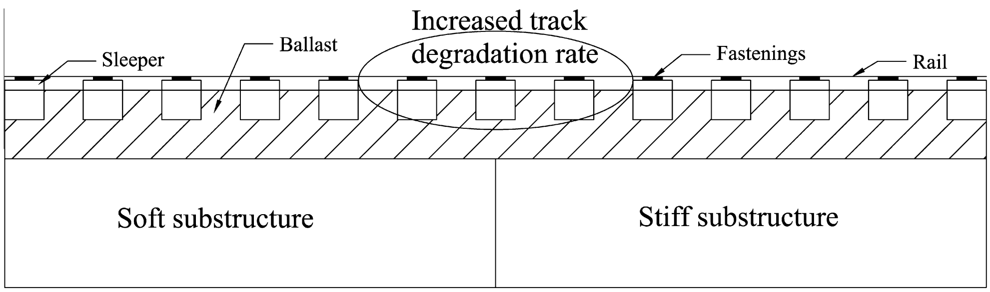

Fig. 1. Schematic representation of abrupt variations in track stiffness, after (Paixao et al., 2013).