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An investigation into the modeling of railway fastening

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ABSTRACT

In this paper, the influence of modeling the fastening with solid railpads on the vertical dynamics of railway tracks with monoblock sleepers is investigated. A 3D finite element (FE) model is presented with four different fastening representations: (1) commonly used spring-damper pair, (2) area covering spring-damper pairs, (3) solid railpad connected to the rail, and (4) solid railpad in frictional contact with the rail and fixed to the support by preloaded springs, which represent the clamps. The response of the four models to hammer excitation is simulated in the time domain, and the calculated response is transformed into the frequency domain to analyze how the models capture the seven main characteristics of tracks with monoblock sleepers. The numerical results show that the model with solid railpads and clamps reproduce the seven characteristics at a maximum frequency difference of 6%, while the conventional model with spring-damper pairs reaches only a 27%. In the improvement of the fit from multiple spring-damper railpad models to solid railpad models, the two key aspects identified are the Poisson's effect and the damping of the ballast. Additionally, the railpad type investigated showed a frequency-independent behavior, at least with acceptable error. In view of the close fit, the models with solid railpads can be used for track and fastening design and to derive track parameters to, for instance, study the deterioration of tracks.

1. Introduction

When trains roll over railway tracks, undesired vibrations and noise arise. On the one hand, the rolling noise, often high pitched, is a nuisance for the people living close to the railway tracks [1,2]. On the other hand, the high wheel/rail contact forces and vibrations of the track components contribute to the deterioration of the track itself [3–7], vehicles [8] and sometimes, buildings and structures in the surroundings [9,10].

To reduce the noise to acceptable levels and to delay or decelerate the deterioration of the track, vibration attenuation components are installed in the vehicle-track system. For instance, resilient wheels are often used in tram and metro lines [11,12]. In the track, the railpad is a key component because it influences the rolling noise [13] by attenuating the vibrations due to the interaction between the rail and the sleeper [14,15]. In addition, the stiffness of the railpad affects the growth of rail defects such as short pitch corrugation [16,17], and the condition of the support (i.e. railpad and clamps) influences the growth of squats [18,19]. Furthermore, impact forces at rail joints increase for stiff railpads [20] so that plastic deformation and ratchetting appears at the rail ends [7]. The relation between rail deterioration and fastening condition points to the need of closely examining the behavior of the support. The study of the fastening system may shed some light on the track deterioration process.

In the literature, numerous studies have been carry out to obtain information about the behavior of railpads under working conditions. The railpad is mainly represented as one pair of a linear spring and a viscous damper in parallel (see, for instance, [21–23]). By applying this approach, it was found that soft railpads are favorable to transfer the loads to the sleepers and ballast but wheel–rail contact forces are not always lowered [14]. Also, by reducing the railpad stiffness, the noise radiation from the rail is reduced [13].

In other models in which the rail seat is defined as an area or line instead of one connecting point between the rail and the sleeper, the railpad consists of multiple spring-damper pairs. Studies show that considering the longitudinal and/or lateral dimensions of the rail seat significantly influences the dynamic response of the track [24]. For instance, the dominant pin-pin resonance (i.e. when the rail vibrates with the nodes on the sleepers) becomes a significantly attenuated resonance if the longitudinal dimension of the railpad is considered [25]. Since the track dynamics are affected when the railpad is modeled covering an area, the vehicle-track dynamic response is influenced

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too. The magnitude and position of the characteristic wheel–rail contact forces significantly change depending on the configuration of the fastening system [18].

These studies identify the lateral and longitudinal dimensions of the railpad as relevant parameters for accurately numerically reproducing measured data. One can expect that not only the dimensions but also the displacement restrictions in the lateral and longitudinal directions have implications in the vertical track dynamics because the fastening is a rail fixing mechanism. The rail is fixed to the support by clamps which constraint the displacement of the rail in the vertical, lateral and longitudinal directions. These constraints result in interactions between the rail and the railpad, and the rail and the clamps in the vertical, lateral and longitudinal directions. With a spring-damper pair railpad, only the vertical interaction is considered; this may have implications for the reproduction of the vertical track dynamics.

In this paper, a Finite Element (FE) track model with two types of 3D solid railpads is presented. In the first railpad model, the solid railpad is connected to the rail. This model is compared to a track model with railpads defined as multiple spring-damper pairs presented in [26] so that the effects of simplifying solid railpads to spring-damper pairs is investigated. In addition, the influence of the lateral and longitudinal restraints applied to the rail foot is studied (i.e. fix the rail in the lateral and longitudinal directions), whereas in [26], the effect of the lateral and longitudinal dimensions was analyzed. In the second model, the solid railpad is in frictional contact with the rail, and clamps are defined to fix the rail to the support. In this manner, the influence of the clamps as a rail fixing mechanism is investigated. To complete the study, a railpad representation commonly used in railway track models is also considered. The response of all the four models to hammer tests is numerically calculated in the time domain. Then, the numerically calculated signals are transformed into the frequency domain so that the main characteristics of the track are compared to field measurements.

In summary, by examining the frequency responses of the four fastening models and by comparing them to a set of measurements, the consequences of the different simplifications of the fastening system in the reproduction of the vertical track dynamics are analyzed and quantified.

2. Reproducing field hammer test measurements

2.1. 3D Finite element models

To investigate the influence of the representation of the fastening in the vertical track dynamics, a 3D FE model is developed of a railway track with monoblock sleepers in a ballast bed (see Fig. 1). Monoblock sleepers are reinforced concrete beams and their use is increasing because they endure larger loads in comparison to other sleeper types [27]. Instead of a half-track model, a whole-track model is required to consider the origin of some important characteristics in the vertical dynamics of tracks with monoblock sleepers; these are the asymmetric bending modes of the sleepers with respect to the center of the track and the coupling of the two rails through the sleepers [26]. The rail ends are clamped and the track consists of 24 sleeper bays, which is a suitable model length for the reproduction of hammer test measurements [26].

The rails and sleepers are modeled with solid elements according to their respective nominal geometry. The rails are defined as elastic which is suitable for hammer loads which do not plastically deform the rail, unlike train passages, specially in the vicinity of rail surface defects [28,29]. The sleepers are also defined as elastic, which is considered suitable for the loads investigated [30].

The ballast is modeled with multiple pairs of one linear spring and one viscous damper (see the ballast close-up in Fig. 1). The spring-damper pairs are defined homogeneously under the sleepers. The upper ballast nodes, which are connected to the sleeper, are denoted by the letter R and are fixed in the lateral direction of the track (i.e. $u_{Rx}=0$) representing the lateral stiffness of the ballast, which is a suitable representation for reproducing hammer tests [26]. The lower nodes are fixed in all three directions. The sub-ballast and foundation layers are not considered because they are dominant contributors to the dynamic response of the track for frequencies lower than 250 Hz [31], whereas in this paper, the frequency range of interest starts at 300 Hz.

Due to 3D rails and 3D sleepers, the rail seat encloses an area, which the railpad entirely covers for a nominal case. The railpad is represented with multiple spring-damper pairs or with solid elements (see the upper close-up in Fig. 1). The railpad is part of the fastening system, which fixes the rail to the support. Four different models of representing the fastening are described in which railpads are modeled with spring-damper (SD) pairs or solid elements (see Fig. 2).

2.1.1. Line-SD model

In railway track models, rail and sleeper are often represented as beams and the railpad is mainly represented as one pair of linear spring and viscous damper in parallel [21–23]. Defining the railpad as one spring-damper pair is not possible in the 3D FE model because the inclined 3D rail is unstable with only one spring-damper pair connected to the sleeper. Thus, the common

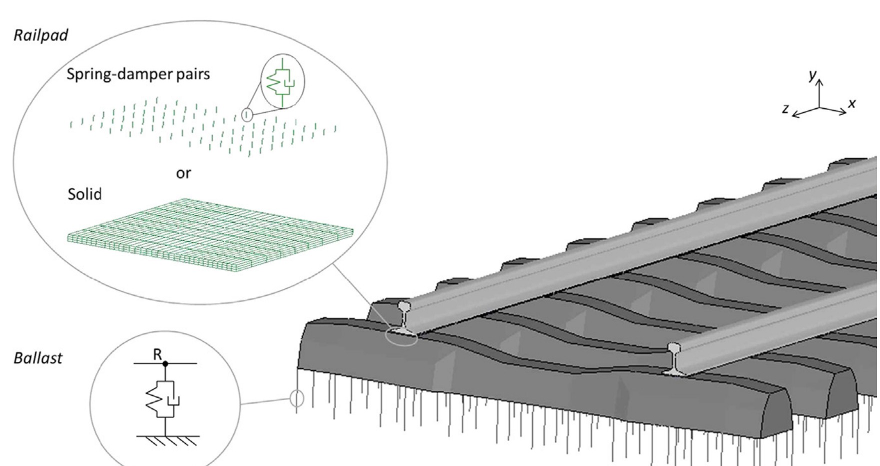

Fig. 1. Overview of the 3D finite element model of a track with monoblock sleepers and the close-ups of the railpad and ballast.