Transportation Geotechnics 12 (2017) 1–14

Contents lists available at ScienceDirect

Transportation Geotechnics

journal homepage: www.elsevier.com/locate/trgeo

Technical Paper

Track-soil dynamics – Calculation and measurement of damaged and repaired slab tracks

Lutz Auersch *, Samir Said

Federal Institute of Material Research and Testing BAM, 12200 Berlin, Germany

ARTICLE INFO

Article history:
Received 13 April 2017
Revised 8 June 2017
Accepted 10 June 2017
Available online 23 June 2017

Keywords:
Railway track
Slab track
Track-soil interaction
Field tests
Track damage monitoring
Finite element method
Boundary element method

ABSTRACT

The damage detection and repair control have become important tasks for ballast and slab tracks. Measurements which compare the damaged and the repaired status of the same track section at different times, or which compare a damaged and an intact track section at the same time, have been successfully performed at some sites in Germany. The loss of contact between the sleeper and the track plate, between the track plate and the base plate, and between the base plate and the base layer have been analysed. The soil properties of each site have been measured and have been used to establish realistic track-soil models. Theoretical results of the wavenumber domain and the finite-element boundary element method have been compared with the experimental results. The observed experimental and theoretical results, changes in the time histories of displacements and velocities due to train passages and in the transfer functions (receptances) due to hammer impacts, are encouraging that these measurements can be used to detect track damage.

Introduction

During the last years, the damage of slab tracks has become an important topic for railway transportation. The identification of slab track damage needs a good knowledge of the behavior of the intact track from calculation and experiment. This contribution presents a combination of finite-element boundary-element (FEBEM) and wavenumber domain calculations and hammer-impact and train-passage experiments. The static and dynamic behavior of the track is strongly influenced by the underlying soil. Therefore, wave velocity measurements have been performed at each site and the results have been included in the track-soil model.

Slab track damage is not only a problem in Germany but particularly in China with its largest high-speed net of the world which comprises a high portion of slab tracks. Therefore, many articles about the behavior of damaged slab tracks come from China, for example [28,22,31]. Beside the behavior of the damaged track, the damage process has been analysed [21,32], methods of damage detection have been developed [29,30], and safety problems of damaged slab track have been considered, for example in case of the missing contact between the track layers [15]. Therefore, a contribution about this problem had been prepared for the ISEV conference [11] in Hangzhou where geotechnical problems of slab tracks are in the focus at Zhejiang University [10]. The present article is an improved version of the conference contribution [9] which now includes the theory and adjusted calculations for the measured situations. This means, above all, that measurements of the soil properties have been evaluated to establish realistic slab track-soil models.

Track-soil dynamics is a quite new discipline of mechanics. In the 1980s; only singular methods have been developed that are using the continuous soil [14,24]. Meanwhile, many researchers participated to this field, for example [18,26,19,13] who have studied slab tracks. For the calculation of ballast and slab tracks, semi-analytic methods [27], wavenumber methods [25,18,7], finite element methods [16], and boundary element methods [6,13] are in use. The development has been intensified by the expansion of the high-speed traffic in many countries, and namely the effect of trains that are faster than the waves in the soil (trans-Rayleigh trains) has been of great interest [2,20].

On the experimental side, many measurements of train passages have been done at the track and in the surrounding soil. Hammer tests (receptance measurements) have sometimes been used in addition and compared with theoretical results [19,1,3]. BAM has investigated different slab tracks and slab track damages at three sites, see Fig. 1 and Table 1. A slab track with full sleepers has been tested at site W, a slab track with sleepers integrated in

* Corresponding author.
E-mail addresses: lutz.auersch-saworski@bam.de (L. Auersch), samir.said@bam.de (S. Said).

http://dx.doi.org/10.1016/j.trgeo.2017.06.003
2214-3912/

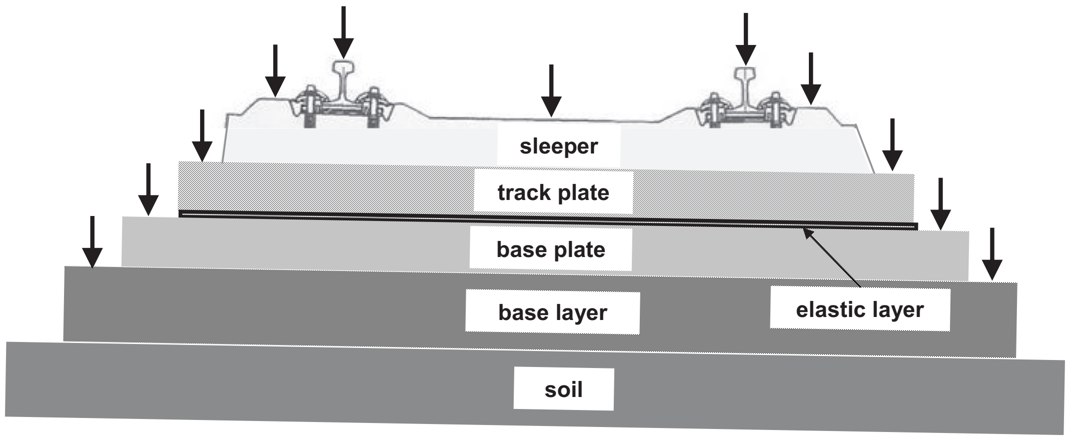

Fig. 1. Different slab track systems, plates and layers, excitation and measuring points.

Table 1
Heights of the different track elements at the different sites, the underlined track element has (not) lost the contact to the following track element.

	Site W	Site G	Site S
Sleeper	0.2 m	0.2 m	No
Track plate	0.15 m	0.3 m	0.15 m
Elastic layer	No	No	Yes
Base plate	0.17 m	No	0.15 m
Base layer	0.3 m	0.3 m	0.3 m

the track plate has been tested at site G, and a floating slab track with an elastic layer between track and base plate has been tested at site S.

The structure of the article is as follows.

The theoretical methods are described at the beginning, the combined finite-element boundary-element method in 'Calculations by the three-dimensional finite-element boundary-element method' and the wavenumber domain method in 'Calculations by the simplified two-dimensional wavenumber domain method'. Theoretical results for train passages and track receptances are presented in 'Theoretical results for intact and damaged slab tracks (receptances and train passages)'. The experimental methods used for this investigation are described in 'Experimental methods of multi-sensor vibration measurements'. The experimental results follow in the remaining sections, at first the wave measurements of the soil ('Wave velocity measurements'), the train measurements of the track ('Measured train passages at intact, damaged and repaired tracks'), and the hammer tests at different points of the track ('Track-soil receptances by hammer impact measurements').

Calculations by the three-dimensional finte-element boundary-element method

The track-soil systems are calculated in full detail by the combined finite-element boundary-element method [4,6]. The track including the rails (beam elements), the rail pads (truss elements), sleepers, and plates (volume elements) is modelled by the finite element method (Fig. 2) whereas the homogeneous or layered soil is calculated by the boundary element method. The dynamic stiffness matrix of the soil is established by using the Green's functions of an elastic layered half-space [5]. All calculations (Green's functions, boundary matrix and dynamic finite element matrices) are performed in frequency domain. The track is excited by a dynamic axle load (a pair of vertical forces, which acts on the rails above the central sleeper), and the frequency dependent displacements (receptances) are calculated. It is worth to notice that the important base of the finite-element boundary-element method, the point load solution for the layered soil, is established in wavenumber domain just as in the simplified method of the next section.

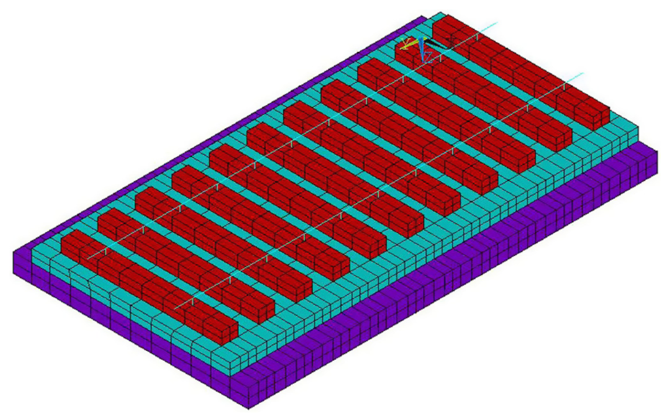

Fig. 2. Finite element model of the railway track, slab track with rails, rail pads, sleepers, track plate and base layer.

Calculations by the simplified two-dimensional wavenumber domain method

The slab tracks can also be modelled as multiple-beam systems: The first beam represents the two rails, and the second beam represents the track plate including the sleepers and the base layer. Additional beams have to be modelled if elastic elements lie between sleepers and track plate or between track plate and base plate.

Each beam is described by the bending stiffness EI_j and the mass per length m_j' which are assembled in a diagonal stiffness matrix $\mathbf{EI}$ and a diagonal mass matrix $\mathbf{m}'$. The global stiffness matrix $\mathbf{K}'$ is a n × n matrix assembled from the 2 × 2 dynamic stiffness matrices of each support section. The multi-beam system fulfils the set of differential equations for the beam displacements $\mathbf{u}$ under the track load $\mathbf{F_T}'$

$$\mathbf{EIu}'''' + \mathbf{m}'\ddot{\mathbf{u}} + \mathbf{K}'\mathbf{u} = \mathbf{F}_\mathbf{T}' \quad (1)$$

The dynamic stiffness of the multi-beam track model in the frequency-wave-number domain reads as

$$\mathbf{K_T} = k_y^4\mathbf{EI} - \omega^2\mathbf{m}' + \mathbf{K}' \quad (2)$$