Computers and Structures 89 (2011) 1468–1479

Contents lists available at ScienceDirect

Computers and Structures

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

Dynamic behaviour of railway tracks on transitions zones

José N. Varandas [a,*], Paul Hölscher [b], Manuel A.G. Silva [a]

[a] UNIC, Department of Civil Engineering, Faculdade de Ciências e Tecnologia, FCT, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
[b] Deltares, Stieltjesweg 2, P.O. Box 177, 2600 MH Delft, The Netherlands

ARTICLE INFO

Article history:
Received 1 June 2010
Accepted 22 February 2011
Available online 27 March 2011

Keywords:
Transition zones
Measurements
Non-linear
Ballast
Uneven track
Hanging sleepers

ABSTRACT

Transition zones between structures as bridges or box culverts frequently present higher degradation rates compared to the remaining railway. This paper presents a numerical model for the dynamic loads on the ballast caused by trains passing a transition. The model was validated with field data obtained from an extensive field survey conducted in two transition zones in the Netherlands. Results show that the forces on the ballast vary significantly both in time and space on a transition, especially with the appearance of voids under the sleepers. Implications of the results on the long-term behaviour of transition zones are presented.

1. Introduction

Transitions between embankments on soft soil and settlement free zones are problematic regions for railway maintenance. In the Netherlands, where soft soil conditions are typical, it was found that the maintenance frequency at transitions was 4–8 times higher than in normal track [1]. This leads to higher maintenance costs and reduces availability of the track. The increase of traffic, axle loads and train velocities on the European rail network, increases the loading on transition zones, requiring a track of higher quality. More effective measures are necessary to reduce the degradation and so the maintenance at transition zones.

The specific behaviour on a transition zone is due to significant changes of the substructure supporting the track within a short distance. The transition zone serves to make the stiffness transition sufficiently smooth and to avoid unwanted dynamic effects. Moreover, on a transition zone, the track level (longitudinal vertical profile) can deteriorate faster [2]. This deterioration is caused by differential settlements between the settlement free structure and the connecting track, leading to irregularities on the track level over some length. Some of the responsible degradation mechanisms at transition zones can be found in [3], the causes are explained in [4] and typical design solutions are presented in [5].

Field measurements on railway tracks provide decisive information in order to analyse their dynamic and long-term behaviour. However, they are scarce on transition zones. Recently, an extensive field survey was conducted in two transition zones in the Netherlands [6]. One of the important findings was the appearance of hanging sleepers. These are sleepers which are suspended by the rails on the unloaded condition and there is a void between the sleeper soffit and the ballast surface under it. The mean vertical height of the void will hereafter be called the hanging distance.

On ballasted track, the stiffness of the ballast/subgrade is non-linear as shown by field measurements [2,7] and also by laboratory tests [8]. If hanging sleepers occur and/or the track's support stiffness changes, the pre-load on the ballast due to the track weight differs strongly per sleeper. Due to the non-linear response, this variation implies a different receptance of each sleeper felt by the train passing over. Also, hanging sleepers and the track unevenness above transition zones may lead to high impact stresses during train passage at some sleepers and low (or even zero) stresses at others adjacent sleepers. This influences the long-term behaviour of the track [8,9].

A numerical study on the dynamic response of a transition zone requires the development of a model that takes into account (i) the spatially varying track support, (ii) the vertical profile of the track, (iii) the possible existence of voids under the sleepers, (iv) the non-linear constitutive relation for the substructure and (v) the dynamic vehicle–track interaction. Some computational studies dedicated to transition zones can be found in [10–15] and a descriptive review of numerical work made on this subject may be found in [1].

This paper presents a numerical model for the dynamic loads on the ballast by trains passing a transition. It takes into account all

* Corresponding author. Tel.: +351 212948580; fax: +351 212948398.
E-mail addresses: jnvs@fct.unl.pt (J.N. Varandas), paul.hoelscher@deltares.nl (P. Hölscher), mgs@fct.unl.pt (M.A.G. Silva).

0045-7949/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruc.2011.02.013

five essential requirements. It also proposes a method to calculate the initial state of the track based on its vertical level. This permits to determine the locations of eventual hanging sleepers which have impact on the obtained numerical dynamic results. The key parameters are selected from field tests that will be used to validate the model. Discussion of the results obtained for a case-study and the implications on the long-term behaviour of the transition zone are also presented.

2. Case description

The monitoring campaign near Gouda in the Netherlands concentrated on the transition zones to and from a culvert and on a switch. The monitoring program performed on the culvert is described in [6].

This culvert is a 2 m by 2 m square reinforced concrete structure approximately 60 m long. The culvert is founded on piles, thus settlement free. Fig. 1 shows a lateral and a longitudinal view of the track passing over the culvert. Only two of a total of four parallel tracks are shown at Fig. 1(a). At each side, two approach slabs of 4 m length, 120 cm width and 30 cm thickness, one under each rail, are usually placed. This is the standard design, used in the Netherlands since 1970. However, at this site, the field test performed with ground penetrating radar suggests that more slabs are placed continuous under the two rails.

The railway track is ballasted, with wooden sleepers at this location. The maximum train speed is 140 km/h. The track is supported on a 4 m sand embankment built on top of a peat/clay layer, which is now 7 m thick. On top of the culvert, the ballast/sub-ballast thickness is presently around 80 cm and on the free embankment about 40 cm. The measurements were concentrated on the outer track (right-hand side (RHS) in Fig. 1(a)).

Two types of measurements will be used in this paper:

- A monthly levelling of the track during one year. These measurements were performed with standard levelling equipment on the unloaded track and can be seen in [16].
- Dynamic measurements of track displacements during train passages.

The levelling showed a settlement of the embankment under the ballast layer of 1 mm/month. This causes differential settlements between the top and either side of the culvert, leading to an uneven track level. Fig. 2 shows two measured track levels (the trains travel from left to right) where a symbolic representation of the culvert and the approach slabs is included. The interval of time between the two measurements was 28 days. Periodic maintenance was performed immediately after the second measurement.

Train-induced track vibrations measured at three sleepers are shown in Fig. 3: before the transition (G7), above the approach slab (G3) and on top of the culvert (G1). These displacements were obtained by integrating velocities measured with geophones. Comparing the displacements above the culvert (G1) and above the embankment (G7), it can be found that the track stiffness differs by a factor of 2. Over the approach slab, the stiffness should vary gradually between these two stiffnesses. However, the measured displacement amplitudes on location G3 were much higher than at G7 and G1, indicating a sudden and local drop of the track stiffness [16].

The main cause for the higher displacement amplitudes registered on the transition zone is the existence of a group of consecutive hanging sleepers. Fig. 2 shows that the track level at each side of the culvert centre is similar to that of a uniformly loaded cantilever beam, which is a preliminary indication for the existence of consecutive hanging sleepers.

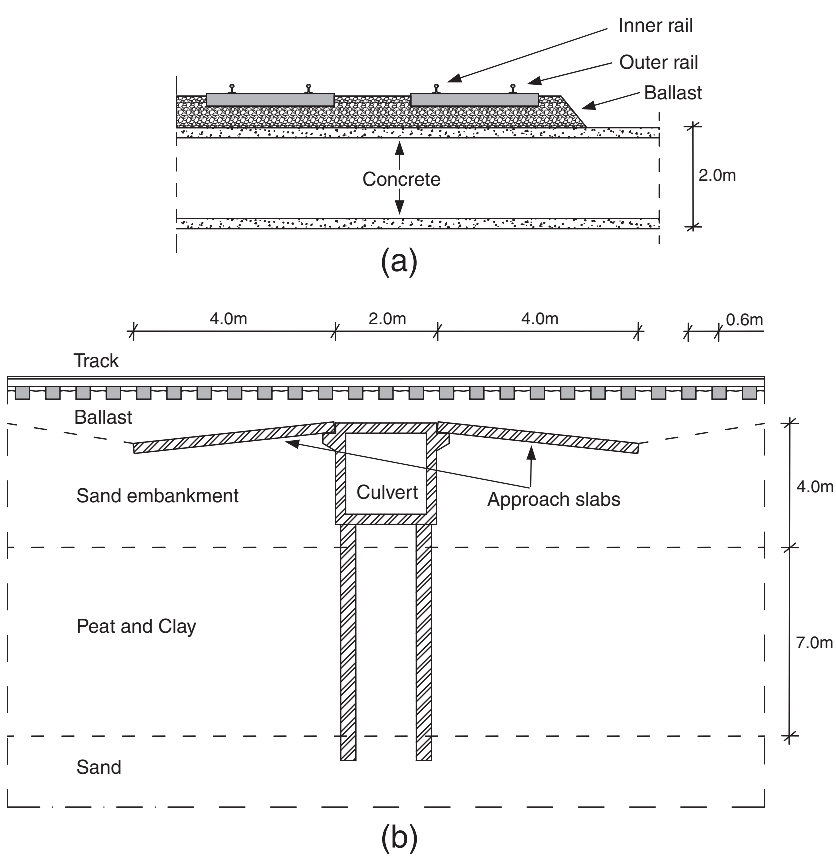

Fig. 1. Transverse view (a) and Longitudinal view (b) of the track passing over the culvert (not to scale).