Soils and Foundations 2014;54(3):502–514

The Japanese Geotechnical Society

Soils and Foundations

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Numerical method for evaluating the lateral resistance of sleepers in ballasted tracks

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Received 28 July 2013; received in revised form 24 December 2013; accepted 30 January 2014
Available online 29 April 2014

Abstract

Ballasted track sleepers have the important function of providing sufficient lateral resistance to prevent the lateral movement of rails. If the lateral force induced by the thermal expansion of steel rails overcomes the lateral resistance of sleepers, rail buckling may occur. More attention has been paid to this problem of lateral stability since the introduction of continuous welded rails. However, there is a high degree of uncertainty in the prediction of the lateral resistance of sleepers. In view of the foregoing, a series of laboratory tests was conducted on 1/5-scale models to evaluate the lateral resistance of sleepers. Single-sleeper pullout tests and track panel pullout tests were conducted on different types of concrete sleepers. The results of the pullout tests revealed the effects of the sleeper shape, the sleeper spacing, and the number of sleepers on the lateral resistance. Based on the model test results, a new numerical method for evaluating the lateral resistance of sleepers is proposed.

Keywords: Ballasted track; Lateral resistance; Sleeper shape; Piled group effect; Track panel pullout test

1. Introduction

Railway sleepers are small shallow foundations whose primary function is to support rails and traffic loads. However, under repeated traffic loading, sleepers may gradually settle, especially in the case of ballasted tracks. This is due to the plastic compression of the ballast and the underlying subgrade. Excessive settlement of the sleepers increases the possibility of railway accidents and reduces the comfort of rail rides. Therefore, efforts have been made to investigate the deformation characteristics of ballasted tracks (e.g., Ishikawa and Namura, 1995; Dahlberg, 2001; Namura et al., 2005; Momoya et al., 2005; Indraratna, 2011).

Another important function of sleepers on ballasted tracks is to provide sufficient lateral resistance to prevent the lateral movement of the rails. A significant increase in the temperature of steel rails may produce thermal elongation. The thermal elongation of steel rails induces excessive axial forces; this creates a tendency for the steel rails to bend and to exert a lateral force on the sleepers. If the lateral force overcomes the lateral resistance of the sleepers, rail buckling may occur, as shown in Fig. 1. More attention has been paid to this issue since the introduction of continuous welded rails (CWR) (e.g., Kerr, 2004; Xavier, 2012). CWR are long rails that allow for

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Peer review under responsibility of The Japanese Geotechnical Society.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sandf.2014.04.014
0038-0806/

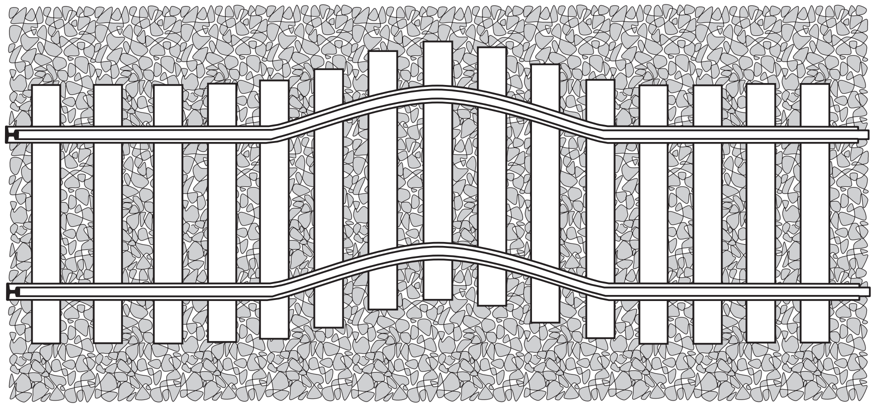

Fig. 1. Schematic view of lateral instability of ballasted tracks.

higher travel speeds and ensure more comfortable rides by reducing the number of joints. However, their length makes the investigation of buckling resistance even more important.

So far, several studies have been conducted to evaluate the buckling strength of CWR in ballasted tracks. Most of them were numerical studies. Asanuma et al. (2012) conducted elasto-plastic and finite displacement analyses to investigate the buckling temperature. They concluded that the lateral resistance of sleepers and initial track misalignments and track curvatures had significant effects on the minimum buckling resistance strength of CWR. Arbabi and Khalighi (2011) used Mathcad to conduct a parametric study of the combined effects of temperature and earthquakes on the lateral stability of tracks. They noted that the lateral instability of tracks can be induced by earthquakes because shaking ballasts significantly reduce the lateral resistance of sleepers. Bao and Barenberg (1997) conducted 3D stability analyses to investigate the effects of temperature and mechanical loads on the lateral instability of tracks. They emphasized the reduction in lateral resistance that occurs when the sleepers are lifted by the vertical loads of vehicles, as it significantly reduces track stability.

As mentioned above, the lateral resistance of sleepers is an important parameter in the evaluation of the lateral stability of ballasted tracks, irrespective of the analytical method. The method chosen to evaluate the maximum lateral resistance and the modeling of the displacement–load curve significantly affects the analytical results. Pullout tests are usually used to estimate the lateral resistance of full-scale sleepers in situ or by experiments. As noted by Le Pen and Powrie (2012), pullout tests are generally one of the following two types:

(1) Single-sleeper pullout test: a sleeper is detached from the rails and pulled out by a machine attached to the rails, and the load/deflection response is recorded.
(2) Track panel pullout test: a section of the track is pulled sideways from the rail head. The test section may be isolated (cut) or attached to the rest of the line (uncut).

For example, Le Pen and Powrie (2012) conducted full-scale model tests on a single concrete sleeper to determine the applicability of their proposed equilibrium calculations. They investigated the effects of the bottom resistance, the side resistance, and the end resistance of the sleepers on the total lateral resistance by changing parts of the ballast beside the sleeper. It was found that, out of the total for each component, 26–35% was for the base, 37–50% was for the side, and 15–37% was for the end. These values are different from those reported in Lichtberger (2007), which suggested 45–50% for the base, 10–15% for the side, and 35–40% for the end. These facts indicate that the situation is more complex than the conventionally assumed equal split, which is only approximately correct in certain circumstances.

On the other hand, Takatani et al. (1987) conducted full-scale model tests on a track panel with six sleepers. The sleepers were equally displaced in a rigid frame. The conclusions drawn from the test results were similar to those of Le Pen and Powrie (2012). In addition, they investigated the effects of the number of sleepers in the track panel pullout tests on the lateral resistance. It was found that the lateral resistance per sleeper of a track panel with two sleepers was higher than that of a track panel with six sleepers. The reason for this, however, was not identified. Moreover, Kabo (2006) reported that the levels of lateral resistance obtained from single-sleeper pullout tests were generally higher than those obtained from track panel pullout tests. He also noted that the boundary conditions of both tests differed from those in real life.

It can be seen, therefore, that several aspects must be considered in order to precisely evaluate the lateral resistance of the sleepers of ballasted tracks. First, there is a high degree of uncertainty when predicting the lateral resistance of a single sleeper. This is not only because of the complicated material properties of the ballast, but also because of the uncertain effects of the bottom, the side, and the end resistance of sleepers of various shapes. The effect of sleeper spacing on the lateral resistance is also not clear. The differences between the results of single-sleeper pullout tests and track panel pullout tests may be due to the effects of sleeper spacing, although the mechanisms have yet to be studied in detail. Finally, the effects of the boundary conditions of track panel pullout tests on the lateral resistance per sleeper have not been properly clarified. Increasing the number of sleepers in a longer track panel may reduce the effects of the free ends. However, pullout tests are