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Slope Stability, Retaining Walls, and Foundations

Edited by

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This Geotechnical Special Publication contains 35 peer-reviewed technical papers presented at the GeoHunan International Conference: *Challenges and Recent Advances in Pavement Technologies and Transportation Geotechnics,* which took place in Changsha, Hunan, China, from August 3 to 6, 2009. This proceedings examines topics such as:

- Soil Stabilization
- Dynamic Behavior of Soils and Foundations
- Earth Retaining Walls
- Slope Stability

This publication will be valuable to geotechnical engineering professors and students, as well as geotechnical engineers and professionals.

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SELECTED PAPERS FROM THE 2009 GEOHUNAN INTERNATIONAL CONFERENCE

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Preface

The papers in this Geotechnical Special Publication were presented in the session of Soil Stabilization, Dynamic Behavior of Soils and Foundations and in the session of Earth Retaining Walls and Slope Stability at GeoHunan International Conference: Challenges and Recent Advances in Pavement Technologies and Transportation Geotechnics. The conference was hosted by Changsha University of Science and Technology on August 3-6, 2009.

Design of Ballasted Railway Track Foundations under Cyclic Loading

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ABSTRACT: The foundations of ballasted railway tracks are usually consisted of a graded layer of granular media of ballast placed above a naturally deposited subgrade. Available methods for design of track foundations are based on determination of an adequate granular layer thickness of ballast so that subgrade shear failures and plastic deformations produced by the transmission of imposed train loads are prevented. However, the deformation of ballast itself is ignored in almost all available design methods. In addition, most available methods do not represent true cyclic loading situations and rather provide oversimplified solutions based on static loading conditions. In this paper, a method that can be used to calculate the deformation of ballast under train cyclic loading is presented. The method is deemed to complement the existing methods of design of ballasted railway track foundations.

INTRODUCTION

The design of ballasted railway track foundations requires an accurate estimation of the granular layer thickness of ballast that provides protection against subgrade failures and excessive track settlement induced by train cyclic loading. In order to achieve track stability, the total deformation of ballast and subgrade should not exceed an acceptable value. However, the deformation of ballast layer is ignored in almost all available design methods despite the fact that ballast can be responsible for up to 60% of track deformation, as experimentally investigated by Indraratna et al. (2001).

Several simplified theoretical and empirical methods have been proposed in the literature for design of railway track foundations. For example, the British Railways method (Heath et al. 1972) and American Railway Engineering Association method (AREA 1996). However, these methods do not consider the properties of each individual track layer and assume a single homogeneous elastic half-space to represent ballast and subgrade. Other more complex theoretical and numerical solutions have been also developed including the multi-layer theory and finite element method (e.g. Chang et al. 1980; Huang et al. 1986). However, these methods ignore (or improperly represent) the effects of repeated cyclic loads on ballast and subgrade. More recently, Li and Selig (1998) developed a method that considers the plastic deformation of subgrade layer under train cyclic loading but ignores the deformation of ballast layer.

In this paper, a method that can be used to calculate the deformation of ballast layer under true cyclic loading conditions is developed and presented. The method is based on a combination of experimental test results carried out on different types of ballast and 3D finite element simulation (PLAXIS). The method is intended to complement existing design methods of railway track foundations so that ballast deformation can be considered.

DESIGN METHODOLOGY

The proposed design methodology is based on the concept that the total deformation of railway track under repeated train loads is the summation of plastic (permanent) deformations of ballast and subgrade. The plastic deformations of ballast and subgrade can be obtained if their cumulative plastic strains are multiplied by the corresponding track thicknesses. The plastic strain of fine-grained subgrade under repeated train loads can be determined using the model proposed by Li and Selig (1998). In this paper, a laboratory based model that can be used to obtain the plastic strain of three different types of ballast (i.e. basalt, granite and dolomite) under train repeated loads is proposed as follows:

$$\varepsilon_b = a(\frac{\sigma_d}{\sigma_s})^m (1 + \ln N)^b \qquad (1)$$

where: ε_b is the percentage cumulative plastic strain of ballast; σ_d is the applied deviator stress; σ_s is the compressive strength of ballast which can be obtained from static triaxial loading tests; N is the number of repeated load applications; and a, b, m are regression parameters depend on the ballast type. Equation (1) above is calibrated using results of a series of large-scale triaxial, isotropically consolidated, drained cyclic compression tests reported by Alva-Hurtado (1980), Lackenby (2006) and Raymond and Williams (1978). The calibration results are shown in Figure (1) in which the solid lines represent the model prediction and $\alpha = \sigma_d / \sigma_s$.

For a certain track of N number of load cycles, ε_b can be determined by knowing σ_d applied on the track ballast layer and using Equation (1). In this paper, it is proposed that σ_d is obtained from a 3D finite element simulation similar to the one described in the next section.

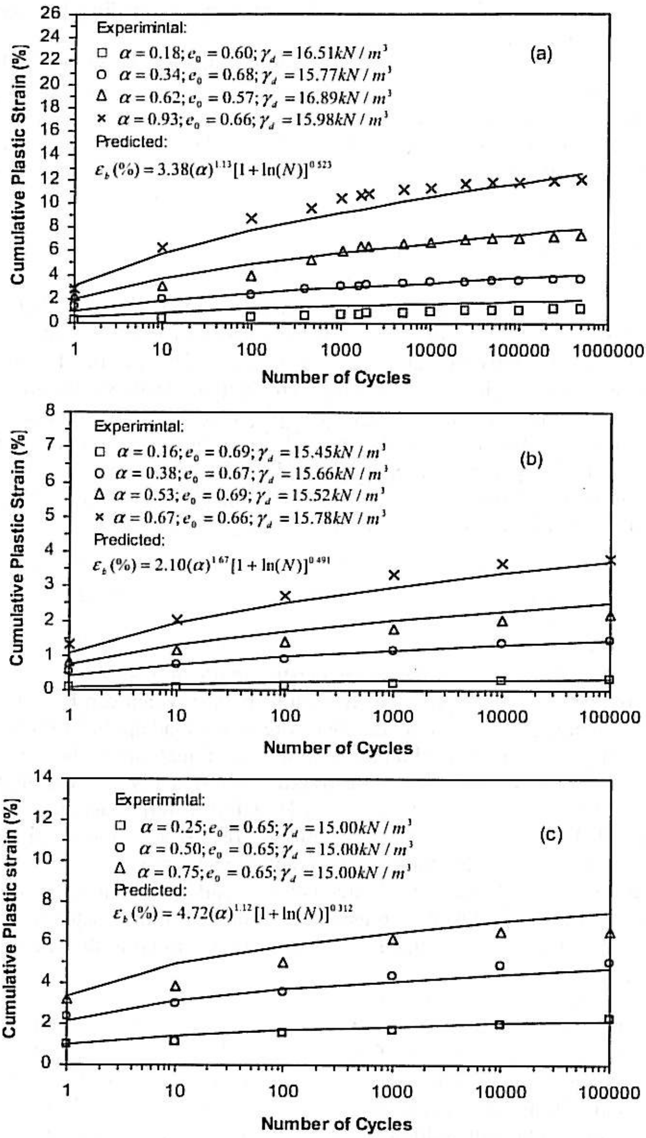

FIG. 1. Comparison of predicted versus measured cumulative plastic strains for: (a) basalt; (b) granite; (c) dolomite.

3D FINITE ELEMENT SIMULATION

Figure 2 shows an example of a 3D finite element simulation that can be used to determine the deviator stress σ_d needed for calculation of ballast plastic strain in Equation (1). The 3D finite element analysis is conducted using PLAXIS 3D Foundation Version 2.1 (PLAXIS 2007). As can be seen from Figure 2, the 3D track section is simulated using five sleepers spaced by a distance of 0.6 m centre-to-centre, therefore, the track has a length of 2.6 m. It should be noted that five sleepers are used in this work as a comparison study carried out by Shahu et al. (1999) using five and seven sleepers indicated that stresses and displacements in railway tracks can be sufficiently simulated using five sleepers. Due to symmetry, only one half of the track is considered in the numerical model.

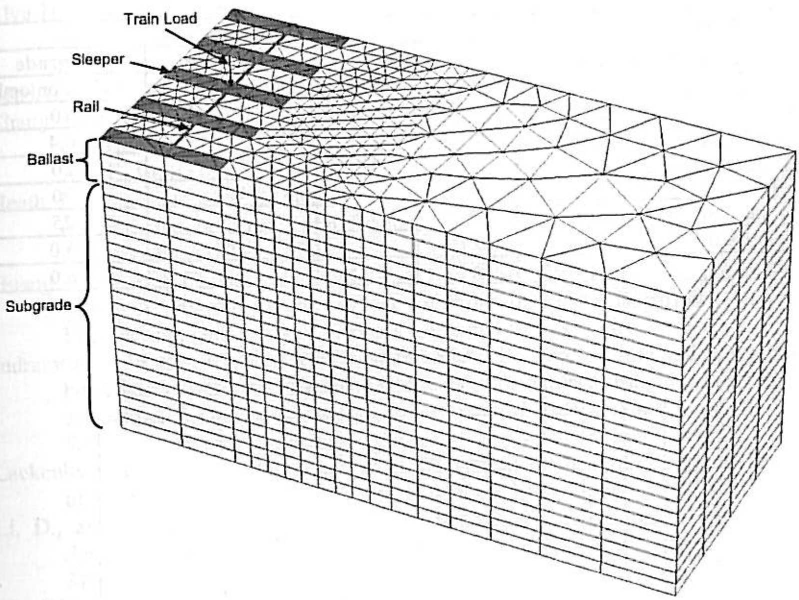

FIG. 2. Finite element configuration used in PLAXIS 3D simulation.

Roller boundary conditions are used in the vertical directions to warrant symmetry and to simulate end of soil, whereas fixed boundary conditions are used at the bottom to simulate bedrock. The track foundation is discretized using 15 node wedge elements available in PLAXIS. The rail is simulated using 3D beam element whereas the sleepers are modeled using 3D floor elements. The minimum required mesh discretization is determined by carrying out a sensitivity analysis on various mesh dimensions until an optimal mesh size is obtained. The gauge length of the track is 1.4 m, and the 3D track dimensions and material properties are given in Table 1. The train wheel load is modeled by applying a concentrated load of 150 kN at the centre sleeper. This load represents an axle train load of 25 tons with dynamic impact of 20%. This track is selected to represent timber sleeper tracks of the New South

Wales State Rail Authority, Australia.

The results of the finite element simulation are shown in Figure 3, from which σ_d applied on the ballast layer can be obtained. It should be noted that similar finite element simulation that was developed by the author and calibrated with published field measurements (see Shahin and Indraratna 2006) indicates the validity of the results obtained from the current model. As mentioned previously, σ_d obtained from Figure 2 can be substituted in Equation (1) so that the plastic strain of ballast can be calculated which then can be multiplied by the ballast thickness to obtain the deformation of ballast layer.

Table 1. Track Properties Used in the 3D Finite Element Analysis

Material Property	Track Component			
	Rail	**Sleeper**	**Ballast**	**Subgrade**
Material model	Elastic	Elastic	Mohr-Coulomb	Mohr-Coulomb
Modulus of elasticity, *E* (MPa)	210000	10000	150	10
Poisson's ratio, ν	0.15	0.15	0.35	0.4
Unit weight, γ (kN/m^3)	78	8	16	20
Cohesion, *c* (kPa)	N/A	N/A	0.0	20
Friction angle, φ (degree)	N/A	N/A	45	25
Thickness (m)	0.15	0.2	0.65	3.0
Width (m)	0.15	0.25	6.0	6.0

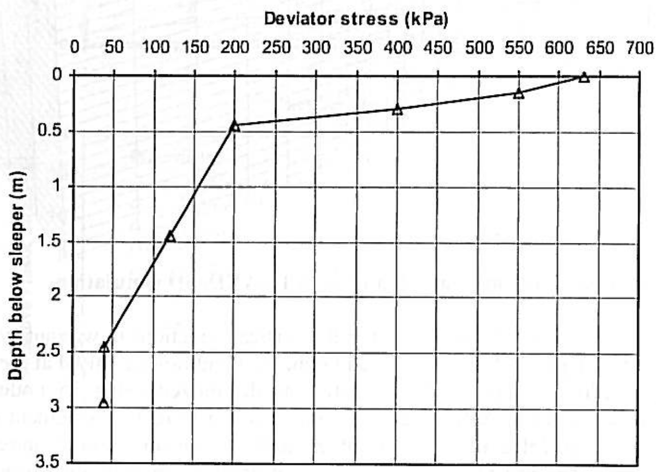

FIG. 3. Deviator stress of the 3D finite element simulation.

CONCLUSIONS

A method was developed and presented to obtain the deformation of ballast in design of railway tracks. The method was based on experimental results carried out on different types of ballast (i.e. basalt, granite and dolomite) and 3D finite element analysis. The method is a useful tool for design of ballasted track foundations and complement existing methods. However, for completeness, further improvement and verification with field cases are needed.

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