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Characterization of Contact Parameters for Discrete Element modelling of Swiss Railway Ballast

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Abstract

Ballast is an integral part of the rail network which helps for effective load transfer between the rails and subgrade. Modelling of ballast is often carried out using finite element methods which considers ballast as a continuous material in which properties such as void ratio, particle rearrangements cannot be directly modelled or monitored. Discrete element method on the other hand models ballast as an ensemble of discrete particles which interact with each other through contact models. The drawbacks of using finite element method for a discrete system can be overcome by using discrete element methods. The paper presented describes the contact parameter estimation procedure adopted to model the Swiss ballast in the discrete element method. The contact parameters required such as the Young's modulus, coefficient of restitution, friction coefficient, and Poisson's ratio are approximated using bulk calibration approach. The approximated parameters will be used further to model the ballast behaviour in the discrete element method.

Keywords: Swiss ballast, Discrete element method, Bulk calibration

1 Introduction

Ballast forms an integral part of the railway network which is mainly used for effective transfer of loads from rail to the subgrade apart from other benefits such as increased damping, improved drainage and the possibility of easy track corrections [1].

Modelling of ballast is traditionally carried out using finite element methods, where the particulate nature and size distribution of the ballast are not taken into account. In addition, FEM models the ballast as a continuum, which does not provide insights into the microscopic properties such as force chain characteristics and particle displacements.

The discrete element method (DEM) developed by Cundall and Strack , considers granular media as a collection of particles interacting with each other at each time step [2]. DEM is not only capable of modeling the shape of crushed stone particles [3]–[5], but also provides important microscopic information such as particle displacements, force transfer networks, and particle fracture.

With an aim to overcome the limitations in FEM modelling of ballast and to assess the behavior of ballast at high frequencies, DEM is used for representing the ballast behavior. The accuracy of the DEM model to represent the ballast behavior is highly dependent on the particle-to-particle contact parameters. This paper aims to discuss the contact characterization procedure adopted to model the Swiss ballast used in the study.

2 Methods

A bulk calibration approach is used to determine the contact parameters that are required to model Swiss ballast in DEM. Static experiments on the railway ballast were conducted and the results are compared with an equivalent DEM model to arrive at the contact properties. Figure 1 shows the experimental setup used for the calibration purpose. A box of dimension 750 mm x 750 mm is filled to a height of 300mm with Swiss ballast. A total of 194kg ballast is filled in the box such that the density of the ballast is 1320 kg/m3. A steel plate of 250 mm (length) x 250 mm (width) x 30 mm (thickness) is placed on top of the ballast layer on to which the loads are applied. Figure 1 also shows an actuator which applies a load of up to 35kN on the steel plate. The applied load and the displacement of the steel plate are measured by the force and displacement transducers in the actuators.

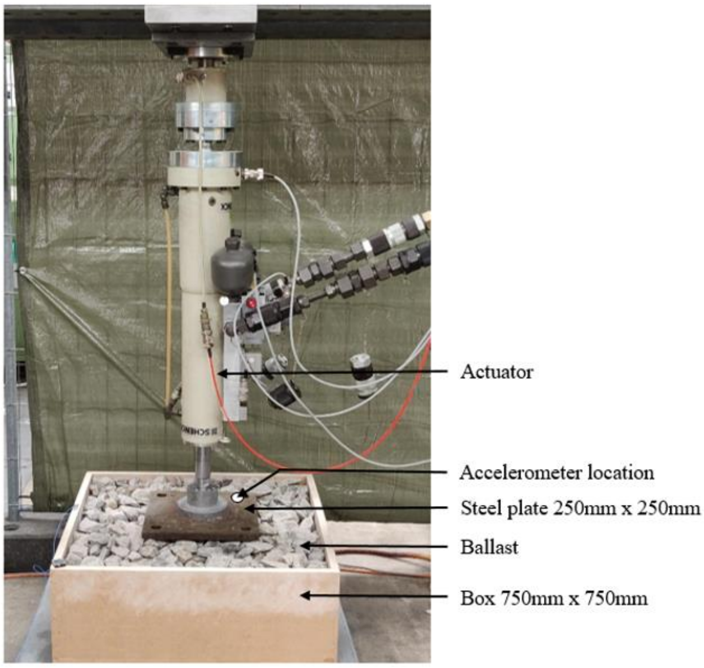


Figure 1: Experimental setup used for static experiments

The DEM model representing the static experiments is shown in Figure 2. A rigid cuboidal container with fixed boundaries is generated which closely represents the experimental setup used. The shape of the ballast is represented in DEM model as clumps, which are nothing but a collection of overlapping spheres. The nuber of spheres in a ballast particle is limited to achieve a realistic computing time.The ballast particles are introduced into the container in the ratio corresponding to the size distribution of the particles, and the particles are brought to rest by gravity to obtain a stable DEM model. The density of the gravel pack generated in the DEM model is 1350 kg/m3, which is very close to the density used in the experimental study. The steel cover plate resting on the ballast is modeled with a single layer of spherical particles which are rigidly bonded together to prevent any deformation of the plate. The density of the particles forming this rigid layer is set to exert the same average pressure on the underlying ballast particles as the 30mm thick cover plate in the actual experiment. The particles on the top plate undergo a static load of 35kN, which is equivalent to the load applied in the experiment.

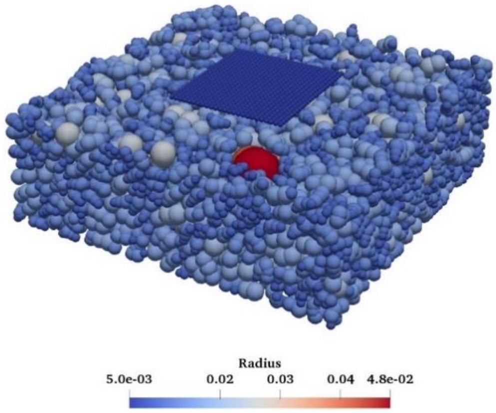


Figure 2: DEM model of the static experiment

3 Results

The ballast particles are modelled as clumps in DEM which interact with each other according to Hertz's contact law, which depends on the elastic modulus, Poissons ratio, the friction coefficient, and the restitution coefficient of the interacting particles. Initially, the contact parameters were assumed based on the literature values for ballast modelling and later the parameters are tuned to represent the Swiss ballast used. For the initial analysis, the Poisson ratio [6], friction coefficient [7], [8], restitution coefficient [6] and elastic modulus [9] were assumed to be 0.25, 0.8, 0.7 and 0.2 GPa, respectively. The static test results of DEM, obtained with the original parameter set, were compared with the experimental results, as shown in Figure 3. The original parameter set resulted in a softer static response than the experimental response. As a result, the elastic modulus of the particles was adjusted and a value of 0.35 GPa corresponded well to the static response of the macroscopic ballast (Figure 3). This value is low compared to the modulus of the rocks (60GPa). It should be noted that the clump representation of the ballast shape is an approximation, with large contact radii compared to the sharp angular surfaces of the gravel. When the clumps interact with each other, they have a larger contact radius compared to the actual gravel, so a lower elastic modulus provides an accurate contact stiffness of the ballast. The derived contact parameters, given in Table 1, are appropriate for the generated clump particles and particle size distribution used in the study. Figure 4 shows the comparison of the force displacement curve obtained from the experiment and DEM model. The static stiffness measured in experiment agrees well with the static stiffness obtained using DEM analysis for the contact parameters finalized as given in Table 1.

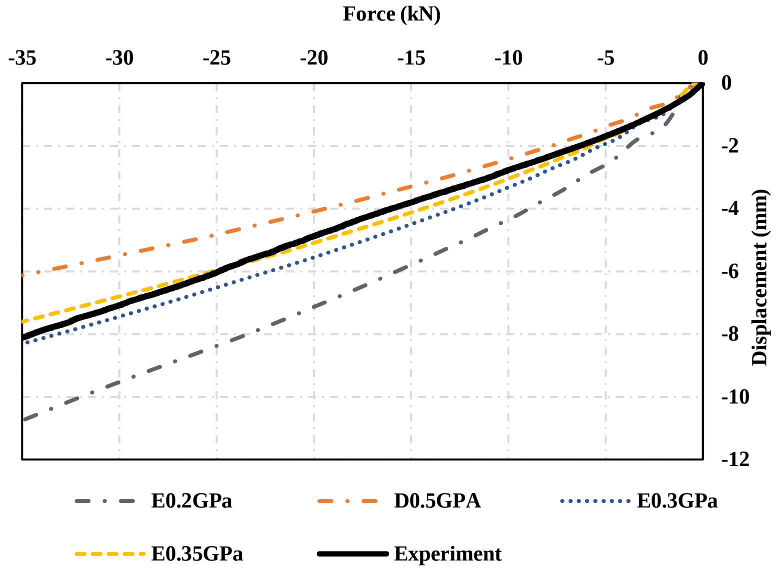
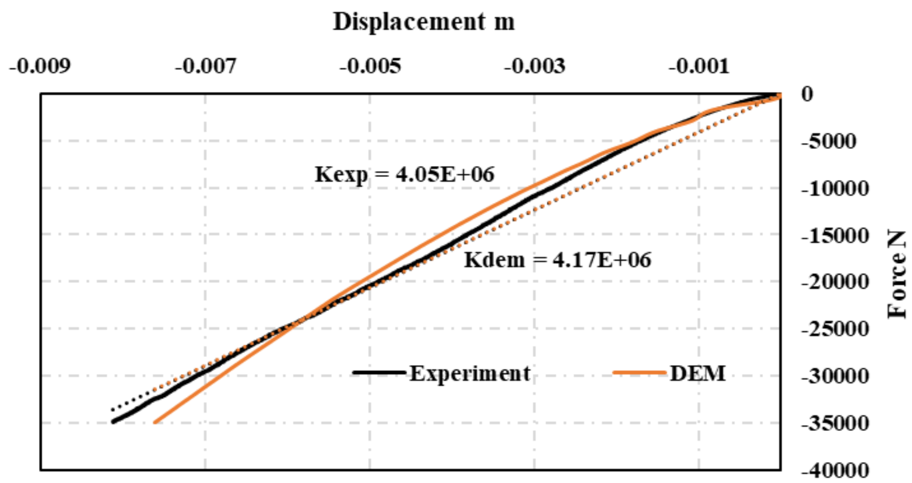


Figure 3: Variation of DEM results with change in contact parameters

Contact Parameters	Values
Young's Modulus	0.35GPa
Poisson's ratio	0.25
Coefficient of restitution	0.7
Friction coefficient	0.8

Table 1: Contact parameters used in the analysis



Dashed lines represent the linear fit in the respective colours

Figure 4: Static stiffness of the ballast measured using experiment and DEM

4 Conclusions and Contributions

The contact characterization procedure followed to determine the contact parameters required to model the Swiss ballast in discrete element method is presented in this paper. The shapes of the ballast particle are approximated as clumps which are spheres that are bonded together. A bulk calibration approach was adopted where initial set of parameters were obtained from the experiments. The parameters are then fine-tuned such that it represents the bulk behavior of the ballast subjected to static loadings. The DEM model is created to represent the experimental setup and it was found that the force displacement results obtained by the DEM modelling is in good agreement with the experimental results.

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