Measurement 63 (2015) 17–24

Contents lists available at ScienceDirect

Measurement

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

Analysis of ballast direct shear tests by discrete element method under different normal stress

Zijie Wang [a], Guoqing Jing [a,*], Qifan Yu [a], Hao Yin [b]

[a] Civil Engineering School, Beijing Jiao Tong University, 100044 Beijing, PR China
[b] Water Resources and Civil Engineering School, China Agricultural University, Beijing, PR China

ARTICLE INFO

Article history:
Received 19 June 2014
Received in revised form 14 October 2014
Accepted 19 November 2014
Available online 6 December 2014

Keywords:
Direct shear test
Discrete element method (DEM)
Irregular clump
Ballast

ABSTRACT

The discrete element method (DEM) was applied to simulate the direct shear tests of irregular ballast stones by constructing clump particles, where irregular clumped-particles have similar particle size distribution (PSD) with those of the real ballast stone. With these clumped particles, the interlock of ballast stones in the direct shear test is investigated. The nonlinear contact force model with Mohr–Coulomb is adopted to model the interaction of the clumped particles. With different normal loads, the simulated microscopic characteristics in the direct shear test were linked with that of tests. The results demonstrate that DEM numerical simulations can produce interrelated responses of the ballast behavior, including the critical state response and are in good agreement with experimental observations. The shear resistance value increases with the normal stress application, indicating that the lateral confinement of ballast bed leading to less vertical settlement and more track stability. In addition, the DEM can further provide details of the microstructure evolutions during shearing processes.

1. Introduction

As a safety, environment-friendly and high efficiency means of transportation, Railway plays a vital important role in a country and promotes the economic development. The granular ballast, one of the most essential components in ballasted track system, meets a standard grading and is compacted beneath the sleeper to supports rails and protects the subgrade. Ballast is free draining granular material that helps to transmit and distribute the induced cyclic load to the underlying sub-ballast and subgrade at a reduced and acceptable level of stress [1]. Large-scale biaxial and triaxial tests have been carried out to study the mechanical behavior of ballast-based materials under static and cyclic loading. Many works have been performed on ballast [2–5].

As a conventional test, the direct shear test was widely applied for characterizing the granular material's mechanical property, for example the soil and ballast. Meanwhile it was also helpful in determining the parameters applied for constructing numerical models [6–9]. Obert et al. [10] proved that the increasing of normal stress did provide an increase of normal confinement which resulted in an increase of the shear strength. According to Indraratna et al. [11], the increase of shear strength obtained by normal stress's increasing was not linearly correlation to the normal stress. From another perspective, the shear band's growing and developing was detected through stereo photography by Finno during shear test [12].

However the routine tests can only get macroscopic responses and discussion on the particulate level is deficiency due to the lack of microscopic measurement. Discrete element method (DEM) introduced by Cundall and Strack [13] can provide a microscopic view reflecting directly from granular particle's motions to inter-lock

* Corresponding author.

http://dx.doi.org/10.1016/j.measurement.2014.11.012
0263-2241/

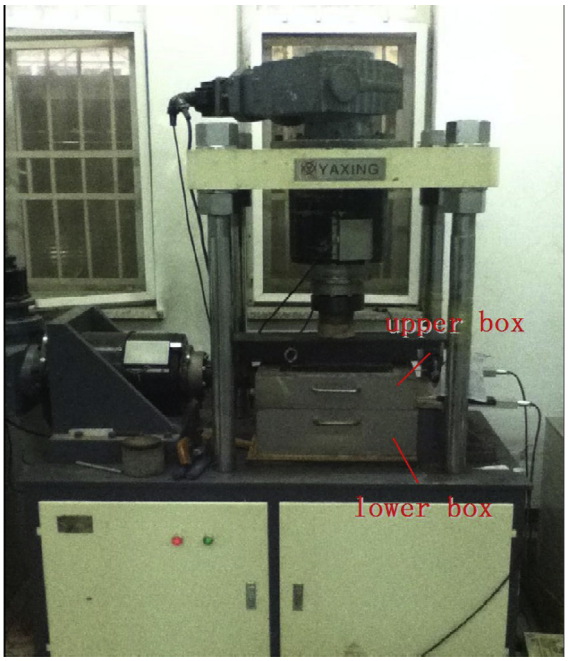

Fig. 1. Shear test box.

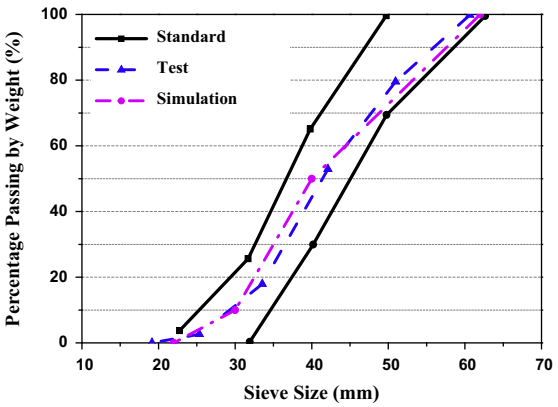

Fig. 2. Ballast size distribution.

force's transmission. It rapidly becomes a powerful tool for those who want to explore the microscopic level of granular systems, such as the particles' rotation, sliding, contact force chain and even energy consumption. Basing on the digital aided ballast particles generation, Huang [14] established a DEM shear test model and found that the friction angle played a vital important role in the simulation, while the normal and shear stiffness's influence was negligible. Estrada et al. [15] presented a detailed analysis on the influence of sliding and rolling through shearing a discrete 2 dimensional granular model in terms of shear strength and force transmission.

However most research was lack of test's validation, and during the simulation investigation, the ballast particle shape and gradation effects were not well considered, and less reported related with ballast in railway, especially on the microscopic level. Considering this issue, this paper aims to present a microscopic view on the behavior of railway ballast, using DEM and experiments, by similar ballast size and particle size distribution. For this purpose a medium-scale direct shear apparatus was employed and several tests were conducted on dry, clean railway ballast of high speed lines. In the tests, the materials were compacted dry and subjected to normal stress and shear loading. Considering the effect of normal stress level, most of the tests were conducted under 3 different normal stress levels. The DEM simulated behavior of railway ballast is compared and discussed and the evolution of the contact force chain is presented blew as well as the displacement of each particles. The influence of friction coefficient is also discussed in this paper.

2. Material and method

2.1. Apparatus

A middle-scale direct shear apparatus ($30 \times 36 \times 24$ cm) was used for testing as illustrated in Fig. 1. The apparatus has an upper and a lower shear box, and the sample was sheared strain-controlled by pushing the lower shear box horizontally. Two gauges were used to measure lateral displacements and shearing forces.

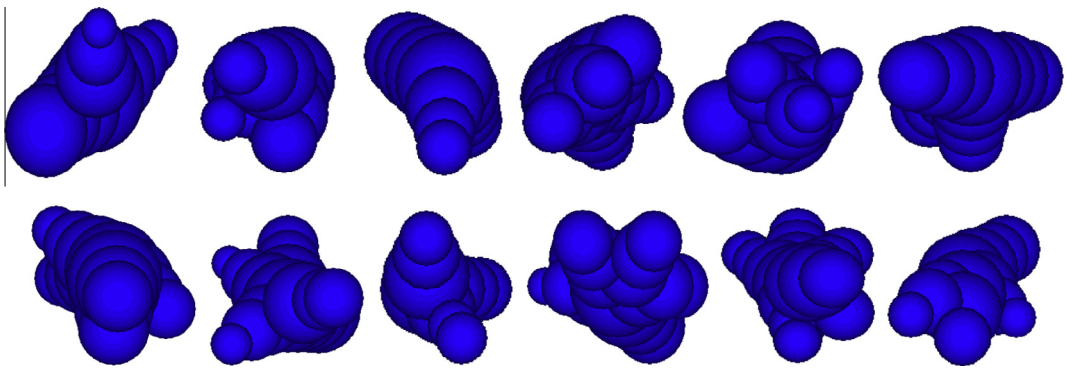

Fig. 3. Ballast clump particles.