Meso-Structure Parameters of Discrete Element Method of Sand Pebble Surrounding Rock Particles in Different Dense Degrees

J.F. Lu, C.W. Zhang and P. Jian

Abstract Through large-scale triaxial test of coarse-grained soils, we obtained stress-strain curve of sand pebble soil in different dense degrees and concluded that the peak stress of sand pebble soil increase with the sample dense degree. On this basis, we established triaxial test 3D simulation model of sand pebble soil using particle discrete element software, and obtained values of meso-structure parameters of sand pebble soil through comparing with results of large triaxial test, finding that particle contact modulus, friction coefficient and porosity are three main meso-structure parameters that affect the strength of sand pebble soil, while rigidity ratio and particle density are nearly of no effect to the strength to sand pebble soil.

1 Introduction

In recent years, with increasing mileage of subway in planning and construction, more and more cities have started urban subway constructions. However, we may be encountered with some complex geological conditions in actual construction, for instance the sand pebble soil stratum that is widely distributed in Chengdu area has brought great impact to Chengdu subway construction. Therefore, before tunnel excavation, we need to conduct related indoor test to collect some geotechnical parameters [1, 2]. With defects such as higher cost and longer time consumption, triaxial test of sand pebble soil can hardly determine the strength and strain indexes of sand pebble soil accurately and conveniently in actual construction. At present, discrete element numerical simulation has been widely used as a new research approach.

Currently, experts from home and broad have conducted researches on discrete element numerical simulation method. Shao et al. obtained stress-strain curve using 3D particle flow calculation program, which is consistent with that obtained by

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indoor test, and thus concluded that granular flow method can well simulate large scale triaxial test process of rockfill material [3]. Chen et al. simulated biaxial test of cohesive soil by combining bond theory in particle flow code and Mohr-Coulomb failure criterion, and explored the relation between macroscopic strength indexes and meso-structure parameters of cohesive soil [4]. Geng et al. analyzed the effect of particle meso-structure parameters on coarse-grained soil strength according to graded triaxial test PFC3D model of coarse-grained soil [5]. Zhou and Jia established granular flow models for sand soil and cohesive soil, respectively, simulated soil surface strain test, and researched effect of meso-structure parameters on macro mechanical response [6]. Zhou et al. built relationship between 3D meso-structure parameters and geotechnical granular materials and its macroscopic mechanical strength parameters on the basis of large amounts of numerical triaxial compression tests [7]. Wang et al. explored the sensitivity of meso-structure parameters in affecting macro mechanical properties during reinforced sand experiment [8]. Liu et al. explained the influence of meso-structure parameters of coarse-grained soil to its macro mechanical properties during numerical simulation test with the consideration of intergranular bonding force [9]. Wang and Leung explored basic mechanical behavior of cemented sand through triaxial and numerical test of artificial cemented sand, and the results show that with the increase of cement concentration, the strength and dilatancy effect of portland cement sand become more and more significant [10]. Yang et al. conducted 3D numerical simulation experiment of coarse material granular flow, and by comparing the test results of coarse materials true triaxial granular flow model and its indoor true triaxial test results, they found that 3D particle flow code can effectively simulate 3D mechanical properties of such materials [11]. Li et al. made numerical simulation of triaxial consolidated-undrained shear test of loess using PFC3D and compared the simulated results with indoor test results [12].

In this paper, by selecting sand pebble soil stratum in Chengdu area as research object, we used particle discrete element model to simulate triaxial test of sand pebble rock in different dense degrees on the basis of indoor triaxial test, and obtained different stress-strain curves. By comparing these stress-strain curves, it can conclude values of particle meso-structure parameters and analyze the impact degree of each meso-structure parameter on strength of sand pebble rock.

2 Research Method

2.1 Large Triaxial Test

In this triaxial test, we used YLSZ30-3 stress type large-scale triaxial testing machine with pressure chamber dimension of φ300 × 600 mm (see Fig. 1), due to the limitation of pressure chamber, the largest particle size of sand pebble soil that can be tolerated by such testing machine is 60 mm.

Fig. 1 Stress type large-scale triaxial testing machine

Table 1 Percentage of each particle size

Particle size (mm)	60–40	40–20	20–10	10–2	2–0.5	<0.5
Percentage (%)	35.07	31.88	7.03	8.39	6.67	11.97

For this test, the sand pebble soil at certain subway line section of Chengdu was selected as research object. Due to the limitation of coarse grained soil particle size and soil sample size, it is needed to scale down original grading size. In this test, we converted natural gradation into simulated gradation based on equal amount replacement, and obtained groups of grain sizes shown in Table 1 by calculation. The advantage of this method is that the gradation remains unchanged coarse material percentage after replacement, and the content and property of fine material remain unchanged also. The specific sample preparation process is shown in Fig. 2.

(a) Sample collection **(b)** Sample preparation

Fig. 2 The sample preparation process of Sandy pebble soil Triaxial test

2.2 Digital Triaxial Test

The triaxial numerical model size is φ300 × 600 mm, which is exactly the same with that of indoor test model. Pressure chamber consists of two rigid planes and one flexible cylinder, wherein outside of flexible cylinder, it can be applied with different confining pressures such as 100, 200, and 300 kPa. Sand pebble soil particle can be approximated as spherical particles. In addition, based on sample grading curve and porosity, particles of each group are successively generated according to content of each particle group. The resulted particle sizes of each group follow the gauss distribution, and parallel-bond model is set between particles. However if in Strict Accordance with indoor test, the minimum particle size of generated particles is 0.075, and thus there will be around 450 thousand of particles generated in total quantity, which cost too much time. Therefore, in actual simulation, we set the minimum particle size of generated particles as 5 mm, and thus there will generate around 40 thousand of particles, which greatly reduces time cost. Model is programmed and established using built-in language of discrete element software (see Fig. 3).

To reflect loading process of indoor test, we assigned a smaller velocity value for two rigid planes, making them relatively move and thus generating a vertical load. During moving process, rigid planes and flexible cylinder are free from mutual influence. The lateral confining pressure is maintained stable by servo controller which automatically controls radial displacement of flexible cylinder.

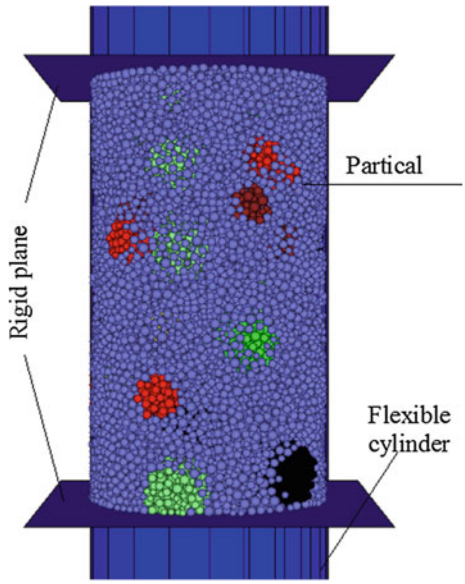

Fig. 3 Three-axis numerical simulation diagram

3 Result Analysis

3.1 Analysis of Large-Scale Triaxial Test Results

Through large scale triaxial test, it can obtain stress-train curve of sand pebble rock sample in different dense degrees under saturation condition (see Figs. 4, 5 and 6).
Through analysis of Figs. 4, 5 and 6, follow conclusions can be reached.

(1) Under saturation condition, the peak stress of sand pebble soil increases with sample dense degree;
(2) Stress-strain curve will show fluctuations at certain point, nevertheless it generally shows a significant development trend, which is because that point contact is the dominant in triaxial shear test, so that stress concentration emerges at contact point, local stress exceeds shear strength of sand pebble rock mixture, leading to particle breakage and fluctuation of deformation curve.

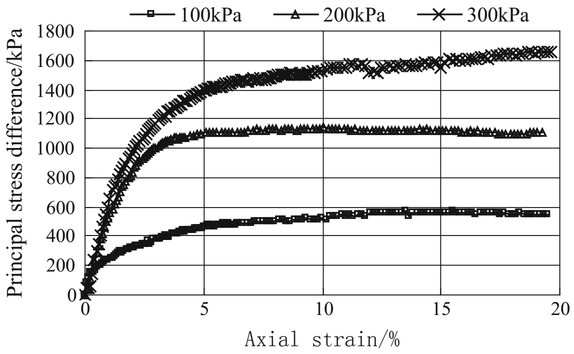

Fig. 4 Stress strain curve of dense sample

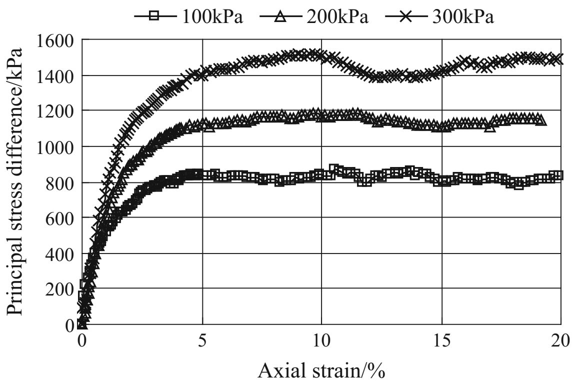

Fig. 5 Stress strain curve of medium dense sample

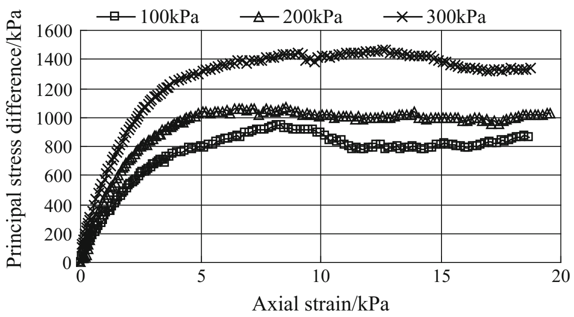

Fig. 6 Stress strain curve of loose sample

3.2 *Determination of Meso-Structure Parameter Value of Particle*

To obtain meso-structure parameters of sand pebble soil by numerical simulation of triaxial test, the meso-structure parameters of particle aggregation are changed after comparing with indoor test results, so that it can obtain the stress-strain curve (see Figs. 7, 8 and 9) of sand pebble soil in different dense degrees under saturation condition. The values of meso-structure parameters after modification are shown in Table 2.

Through analysis of Figs. 7, 8 and 9, it can obtain conclusions as below:

(1) The stress-strain curves obtained by numerical simulated triaxial test and indoor test are generally consistent with each other. With the increase of sample dense degree, peak values of principal stress differences as well as initial elastic modules increase accordingly;
(2) Under the condition of low confining pressure, the material in numerical simulation test will show significant strain softening situation, which makes principle stress difference decrease in certain degree after peak stress.

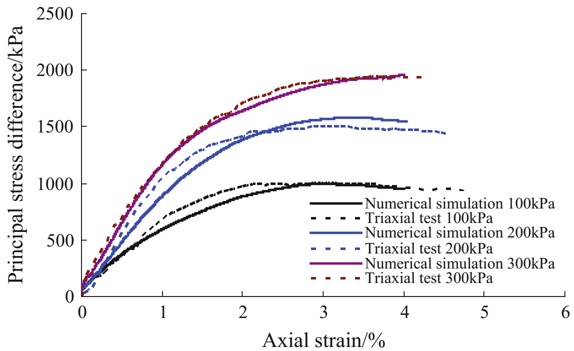

Fig. 7 Stress strain curve of dense sample

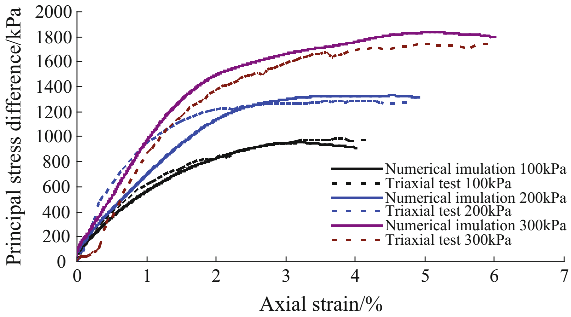

Fig. 8 Stress strain curve of medium dense sample

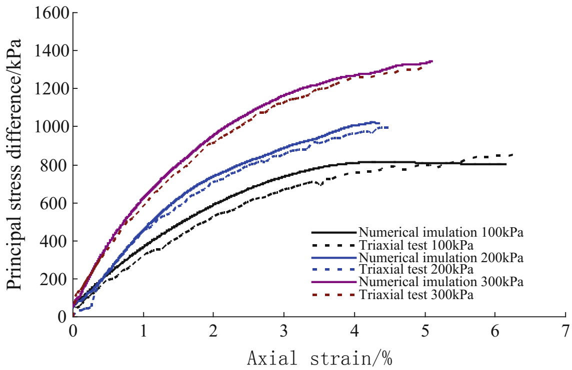

Fig. 9 Stress strain curve of loose sample

Table 2 The values of mesoscopic parameters on saturated state

Dense degree	Meso-structure parameters in numerical simulation test				
	Contact modulus Ec (kPa)	Friction coefficient fric	Porosity poro	Rigid ratio Kn/Ks	Particle density dens
Dense	4e7	0.4	0.12	1.5	2050
Medium dense	3e7	0.3	0.22	1.5	2050
Loose	2e7	0.2	0.32	1.5	2050

According to Table 2, it can be known that under the condition of increasing dense degree, contact module and friction coefficient increase, while porosity decreases, leaving rigid ratio and particle density unchanged.

4 Conclusions

On the basis of large-scale indoor triaxial test of sand pebble soil stratum sample at Chengdu area, this paper established discrete element numerical model of sand pebble rock using discrete element software, analyzed the stress-strain curve of saturated sand pebble rock sample in different dense degrees, and finally obtained following conclusions:

(1) In large scale triaxial test, the peak stress and initial module of sand pebble soil increase with sample dense degree;
(2) The tress-strain curves obtained by numerical simulated triaxial test and indoor test are generally consistent with each other. With the increase of sample dense degree, peak values of principal stress differences as well as initial elastic modules increase accordingly.
(3) Under the condition of low confining pressure, the material in numerical simulation test will show significant strain softening situation, which makes principle stress difference decrease in certain degree after peak stress.
(4) Through comparing indoor test results and numerical simulation results, it can obtain values of particle meso-structure parameters. By analyzing each meso-structure parameter, it can find that under condition of different dense degrees, particle contact modulus, friction coefficient and porosity are 3 main meso-structure parameters that affect the strength of sand pebble soil, while rigidity ratio and particle density are nearly of no effect to the strength to sand pebble soil.

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