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EXTENDED ABSTRACT

Numerical and Experimental Investigations of the Effect of Gradation and Shape of Particles on the Mechanical Behavior of Granular soils

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1. Introduction

Because testing on different materials often requires a lot of time and money, numerical simulation can be an acceptable method to avoid conducting several tests. One of the most effective methods to investigate the behavior of granular materials is discrete element method. This method, as a new approach, can simulate the behavior of material realistically, without implementing complex constitutive models (Wang et al, 2007; Shamsi and Mirghasemi, 2012; Tian et al, 2018).

We know that the behavior of the particle assembly is influenced by the experimental test conditions, particle size distribution, particle shapes, etc. Previous researches show that particle shape has a significant effect on the mechanical behavior of granular soil (Tian et al, 2018). Therefore, to properly model the behavior of granules, it is better to simulate the particle shape as close to reality as possible.

The main objective of this paper is to evaluate the effect of gradation and realistic particle shape on the mechanical behavior of granular soil in three dimensional discrete element method modeling in order to increase accuracy and precision of the simulation results. In this regard, in this study, irregular particles are modeled using a set of spheres that have different radii, overlap with each other and form a rigid object (clump) as shown in Fig. 1. Then, a series of consolidated drained triaxial compression tests have been performed on the specimens containing particles with various shapes. Finally, the results of the modeling were compared qualitatively with the experimental results.

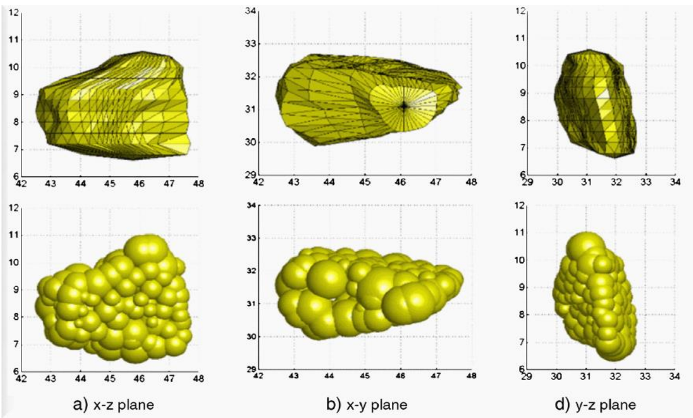

Fig. 1. An example of 3D modeling of particle with 100 spheres (Matsushima and Saomoto, 2002)

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2. Methodology

The research method consists of two parts, laboratory tests and numerical simulations using discrete element method.

2.1. Experimental study

The sands used in this study are Firuzkooh sand (rounded) and Jajrud sand (angular) which the grain size distribution curves shown in Fig. 2. In addition, the effect of well and poor graded Firuzkooh sands on their mechanical behavior is also investigated (the well and poor graded sands curves are shown in Fig. 2).

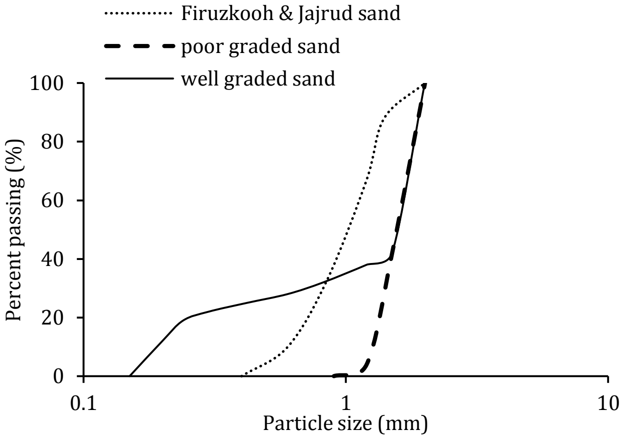


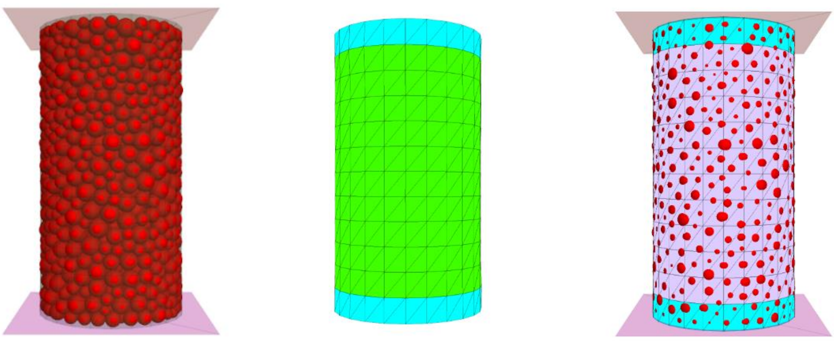
Fig. 2. Grain size distribution for sands

A series of strain-controlled consolidated drained triaxial (CD) tests were performed on the mentioned sandy samples in 75% relative density at 200kPa confining pressure.

2.2. DEM modeling

After that, the consolidated drained triaxial tests were simulated by DEM. In this model, the assembly of particles was generated according to particle size distribution curves shown in Fig. 2 in cylindrical container with flexible boundary, 1.5 cm in diameter and 3 cm in height (e=0.45). The contact model between particles was chosen linear model.

The use of flexible lateral membrane boundaries allows the model to accurately visualize the deformation properties resulting from the development of shear zones. The flexible boundaries used in this study are very close to the experimental conditions in laboratory. The top and bottom rigid platens were considered frictionless.



(a) (b) (c)

Fig. 3. a) Initially generated assembly without any overlap, b) flexible cylindrical boundary, c) specimen in triaxial test

The triaxial test consists of two stages: consolidation and shearing. Consolidation was done by applying the stress to the top platen of the specimen and the membrane walls. The confining pressure was constantly checked to maintain the target value during the test. The shearing stage was strain-controlled and carried out by moving downward the top platen at a constant velocity of 3×10^{-6} m/s. Fig. (3-a), (3-b) (3-c) show the initially generated assembly without any overlap, flexible cylindrical boundary and specimen in triaxial test.

3. Results and discussion

It is obvious that the real soil is rarely composed of spherical or uniform particles. Most aggregates have complex geometries and particle shape as a key parameter affects the behavior of assembly.

In many previous simulations, all particles are assumed to be spherical. Simulating soil particles with non-spherical shaped particles can better represent the true behavior of the soil. Based on clump logic, arbitrary shapes can be created as components of the model. In fact, a clump is made up of several spherical elements with different radii that are joined together to form rigid particle in the discrete element method. These simplified forms can be modeled in PFC software. The higher angularity in particle needs the more spheres to simulate, which increases the volume and time required for computation. Samples with clump-shaped particles have higher shear strengths than spherical ones. This is because as the angularity of the particles increase, the locking between them increases, leading to increase friction between the particles, resulting the higher shear strength is obtained.

It is observed that with increasing elongation ratio (aspect ratio), the particles tend to be spherical and the mobilized friction angle decreases at a given confining pressure. Because the interlocking between spherical particles is less than others and as a result its shear strength decreases.

The peak shear strength, residual strength and initial elastic modulus of poor graded sand samples are more than well graded ones.

The microscopic parameter often used to express the assemble structure is the average number of contacts (coordinate number). In fact, the number of contacts per particle is the most important parameter at the particle scale in the assembly .The average number of contacts is defined as the ratio of the twice of total number of contacts between particles to the total number of particles. It is seen that the CN initially decreases with axial strain and slowly reaches a stable value in the steady state. This micro-parameter in rounded sand particle sample is lower than angular sample.

4. Conclusions

The shape and gradation of particles are the effective parameters in mechanical behavior of granular soil. In this research, a series of consolidated drained triaxial tests were performed on the rounded, angular, poor and well graded sand samples to evaluate the effect of shape and gradation particle on soil behavior. Then, these samples were simulated by DEM. Clump logic was used to model non-spherical particles. Regarding the qualitative compatibility of the experimental results with the results of DEM modeling, it is observed that the discrete element method realistically captures the general behavior of assemble. The simulation results showed that samples with non-spherical particles have higher shear strength than spherical ones. Because the angularity of the particles increases the inter-locking between them, this phenomenon increases friction and consequently increases the shear strength of samples.

The peak shear strength (friction angle) and initial elastic modulus of the specimens containing the elongated particles are higher. The peak shear strength, residual strength and initial elastic modulus in poor graded sand samples are more than well graded ones. The value of CN for the sample with non-spherical shapes is greater than the spherical shapes.

5. References

Matsushima T, Saomoto H, “Discrete element modeling for irregularly shaped sand grains”, Proc. NUMGE 2002: Numerical Methods in Geotechnical Engineering, Mestat (ed.), 2002, 239-246.

Shamsi MM, Mirghasemi AA, “Numerical simulation of 3D semi-real-shaped granular particle assembly”, Powder Technology, 2012, 221, 431-446.

Tian J, Liu E, Jiang, L, Jiang X, Sun Y, Xu R, “Influence of particle shape on the microstructure evolution and the mechanical properties of granular materials”, Comptes Rendus Mécanique, 2018, 346 (6), 460-476.

Wang L, Park JY, Fu Y, “Representation of real particles for DEM simulation using X-ray tomography”, Construction and Building Materials, 2007, 21 (2), 338-346.