EFFECT OF TRIMODALITY ON STRUCTURAL AND MECHANICAL PROPERTIES OF GRANULAR PACKINGS WITH DIFFERENT PARTICLE SIZE RATIOS AND PARTICLE SIZE FRACTIONS

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1. Introduction

Over the last few decades, a number of studies has been conducted to investigate the relation between the structural properties and the mechanical behavior of particulate assemblies with the particle size heterogeneity [1-3]. Although investigations were devoted to systems with various degree of polydispersity, a review of the literature shows that studies on properties of ternary granular packings with *PSD* uniform and nonuniform by number of particles are very limited. Since ternary mixtures are commonly used in many branches of industry (e.g., chemistry, pharmacy, and metallurgy) and exhibit interesting and unexplained behavior, an examination of their properties is very important and necessary. Therefore, this study focuses on the analysis of the effect of particle size ratio and the number fraction of mixtures composed of three grain size fractions on their structure and mechanical properties. Knowledge gained from presented project may lead to better understanding of real granular mixtures with more complex *PSD*s and may find application in industries dealing with granular materials.

2. System description and numerical procedures

The 3D simulations were conducted using the EDEM software, based on the Discrete Element Method [4]. A simplified viscous-elastic non-linear Hertz-Mindlin contact model was used. The input parameters for DEM simulations, corresponding to the mechanical parameters of steel rods and steel walls were used in this study.

A confined uniaxial compression test of granular packings was simulated, which is a standard laboratory test procedure to measure mechanical properties of granular materials. The spheres with random initial coordinates were generated inside the box with rectangular cross-section. Spheres settled down onto the bottom of the test chamber under gravity in a dispersed stream. Next, spheres were compressed through the top cover of the chamber that moved vertically downwards at a constant velocity until a maximum vertical pressure on the uppermost particles reached 100 kPa.

Simulations were carried out for samples composed of three particle size fractions. The samples were described by particle size ratio g, defined as a ratio between the diameter of the largest and the smallest spheres. The particle size ratio varied from 1.25 to 5. Samples had particle size distribution uniform by number of particles (*i.e.* an equal number of particles of different sizes) or nonuniform by number of particles (*i.e.* a different number of particles of different sizes). Mixtures with *PSD* nonuniform by number of particles were described by factor f which defined a percentage contribution of spheres representing different particle size fractions to total number of particles in mixture.

3. Results

The study included an effect of the particle size ratio and the number fraction on porosity, compression index, number of contacts, distribution of contact forces, pressure ratio and elastic modulus.

Figure 1a shows the evolution of the porosity of samples (Φ) with different values of g, subjected to compressive loads. An increase in value of g form 1.25 to 2.5 resulted in a substantial decrease in porosity, that was not observed for larger g values. In the entire range of compressive load, the differences between porosities of mixture with $g \geq 2.5$ fell within the range of scattering. The exceedance of g=2.5 did not change significantly volume of empty space between large particles providing approximate porosities.

Figure 1b shows the evolution of effective elastic modulus (E) with compressive loads in samples with different g values. No evident relation between the modulus of elasticity and particle size ratio was observed and differences between *E* values calculated for different *g* lied within the range of scatter.

a) b)

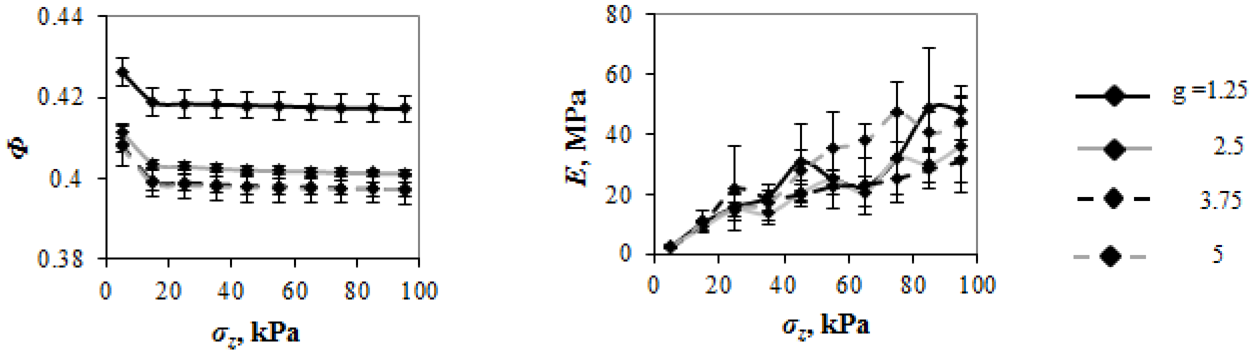

Fig. 1. Evolutions of porosity (a) and effective elastic modulus (b) of mixtures with various values of *g* with imposed compressive pressures.

Figure 2a shows the porosities of packings with various number fraction of particles with *g*=1.25 and *g*=3.75. Regardless of *g* value, the porosity increased with an increase in the number fraction of coarse spheres. The largest porosities were obtained for mixtures composed of the same number of coarse and medium spheres (*f*=442). Figure 2b presents the lateral-to-vertical pressure (*k*) ratio in mixtures with different *g* and *f*. Regardless of *g* value, the pressure ratio was greater in mixtures with *f*=424 as compared to samples with *f*=244, that increased by few percentage for samples with *f*=442. The *k* values were larger for smaller *g* indicating that, in mixtures with *PSD* non-uniform by number of particles, the pressure ratio is determined by both, geometric and statistic factors.

a) b)

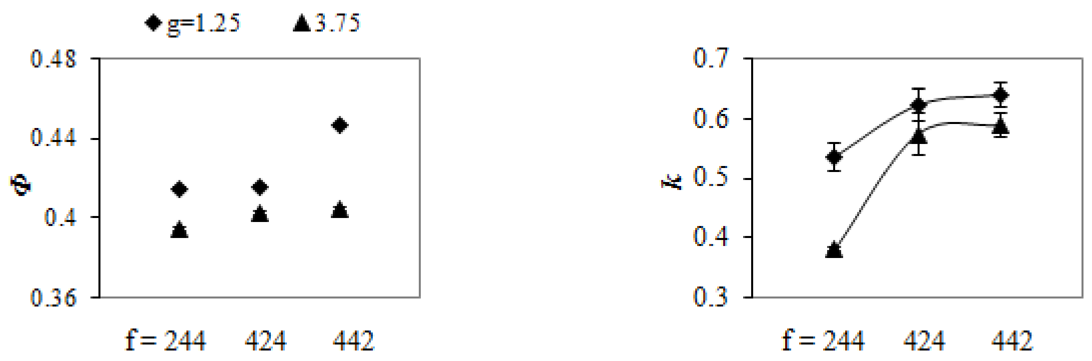

Fig. 2. Evolutions of porosity (a) and lateral-to-vertical pressure ratio (b) for mixtures with *g*=1.25 and *g*=3.75, and different number fraction of particles.

4. Conclusions

A study on the effect of the particle size ratio on the properties of ternary mixtures with *PSD* uniform by number of particles has shown that the *g* value significantly affected packing structure, while the mechanical properties were found to be negligibly influenced by the particle size ratio. An evident effect of the contribution of the particle size fractions in ternary packing on its porosity, coordination number, and pressure ratio was also observed, which increased with an increase in value of *g*.

References

[1] R.K. McGeary, Mechanical Packing of Spherical Particles, *J. Am. Ceram. Soc.*, 44: 513-523, 1961.
[2] F. Göncü, O. Durán and S. Luding, Constitutive relations for the isotropic deformation of frictionless packings of polydisperse spheres, *C.R. Mecanique*, 338: 570-586, 2010.
[3] J. Wiącek, M. Stasiak and P. Parafiniuk, Effective elastic properties and pressure distribution in bidisperse granular packings: DEM simulations and experiment, *Arch. Civ. Mech. Eng.*, 17: 271-280, 2017.
[4] P.A. Cundall and O.D. Strack, A discrete element model for granular assemblies, *Géotechnique*, 29: 47-65, 1979.