DISCRETE ELEMENT MODELLING OF ELASTIC MODULUS OF A GRANULAR POROUS MIXTURE

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Summary Mixed porous granular materials exist in various natural phenomena and engineering applications, such as rock and soil aggregates, railway ballast in windy desert areas. This paper aims to investigate the elastic modulus of a granular porous mixture with two types of particles with different diameters using discrete element method. The small regular particles are modelled by spheres and large irregular particles by clumps of spheres. The quaternion method is adopted to model the motion of clumps of spheres. The simulation results show that the elastic modulus remains a constant when the smaller particle content γ is less than 30%, and decreases linearly with increasing γ when γ is larger than 30%. The internal mechanism of the relationship between the elastic modulus and the mixture content is discussed through the force chain distribution in the porous mixture.

INTRODUCTION

Granular materials, as a kind of typical porous media, present unique mechanical characteristics on macro scale. However, based on the continuum constitutive model, it is difficult to take properties of granular materials into account such as particle size, particle shape, void ratio and roughness. As an effective numerical model, discrete element model (DEM) has been applied to bridge the micro and macro of granular materials with the simulation of the interaction between particles[1]. The elastic modulus of granular materials has been investigated with numerical simulation, analytical solution and physical experiments [2-3]. It shows the elastic modulus is dominated with particle packing pattern, particle shapes and material properties and the confining pressure[4].
Most previous work focused on granular materials with identical particles or similar particle sizes. However, mixed granular porous materials exist widely in industrial, geotechnical and geophysical applications. The objective of this study is to determine the elastic modulus of mixed granular porous materials using DEM with various mixture ratios. Moreover, the micro mechanisms are discussed based on the force chains in the porous materials.
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ELASTIC MODULUS OF MIXED GRANULAR POROUS MATERIAL

The granular mixture consists of two types of particles with different diameters. The small regular particles have constant diameters of 5mm. The sizes of larger irregular particles are in the range of [33.4, 58.5]mm, with lognormal probability distribution of the mass. The granular mixture is filled randomly in a rigid cylinder with diameter 30cm. Under cyclic compressive loading, the relationship between load p and displacement u can be obtained, and the elastic modulus Me can be calculated as

$$M_{\mathrm{e}} = \left(1 - \frac{2k_0 \mu h_0}{r}\right)\left(1 - 2\nu k_0\right)\frac{h_0}{u}\frac{P}{A} \tag{1}$$

where k_0 is the transfer coefficient from normal stress to radial stress, μ is the friction coefficient, h_0 is the initial height of the sample, r is the sample radius, A the bearing area of the sample, ν is the Poisson's ratio.
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DEM SIMULATION OF ELASTIC MODULUS OF THE GRANULAR POROUS MIXTURE

Small particles are modelled by regular spheres, and the large ones, with irregular shapes, are resembled by clumps of overlapping spheres as shown in Fig. 1. For the discrete element models of clumps of spheres, the quaternion method is introduced to transform the motion and force of a clump between local and global coordinates [5].
The discrete element model is shown in Fig.2. With the introduction of the parameter γ, the small particle content, the elastic modulus of the granular mixture is obtained with different mixture ratios as shown in Fig. 3. The elastic modulus keeps a constant value when γ <30%, while it decreases linearly with increasing γ when γ >30%, and has the minimum value for pure small regular particles. This is consistent with the trend of measured elastic modulus.

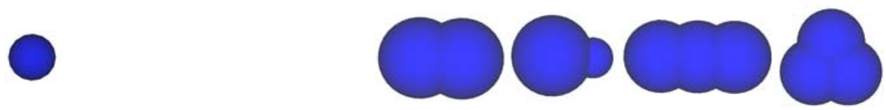

Fig.1 Shapes of small regular particles (left) and large irregular clumps of spheres

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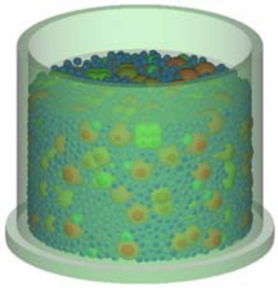

Fig. 2 Granular sample for $\gamma = 45\%$.

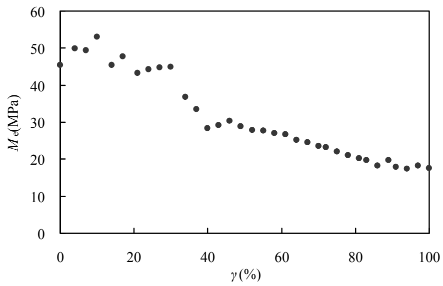

Fig. 3 Elastic modulus simulated with DEM with various mixture ratios

ANALYSIS OF ELASTIC MODULUS WITH DIFFERENT MIXTURE RATIO ON MICROSCALE

The elastic modulus of mixed granular materials is dominated by the strength and spatial structure of force chains on micro scale. The granular mixtures and their force chains distributions are plotted as Fig. 4 when $\gamma = 0.0\%$ and 34%. For lower γ, the force chains are constructed between large particles with high strength and loose distribution; for higher γ, the force chains are constructed between small particles with low strength and dense distribution.

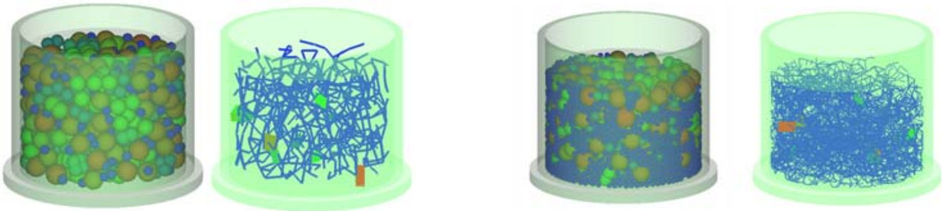

Fig. 4 DEM models and its force chain distributions with $\lambda = 0.0\%$ (left) and $\lambda = 34\%$ (right)

The simulated force chain number, mean strength of force chain and mean coordination number Z are plotted in Fig. 5. With increasing γ, the force chain number increases linearly, but the mean strength decreases rapidly, a cross point appears at $\gamma = 30\%$. For the coordination numbers, Z decreases with increasing γ when $\gamma<30\%$, and increases with increasing γ when $\gamma>30\%$, there is an inflection point at $\gamma = 30\%$. This is because when $\gamma<30\%$ small particles can move freely in cavities among large particles and when $\gamma>30\%$ force chains generate between small and large particles, and there can be about a hundred small particles in contact with a large one. Moreover, dense stable force chain can be easily generated for small regular particles.

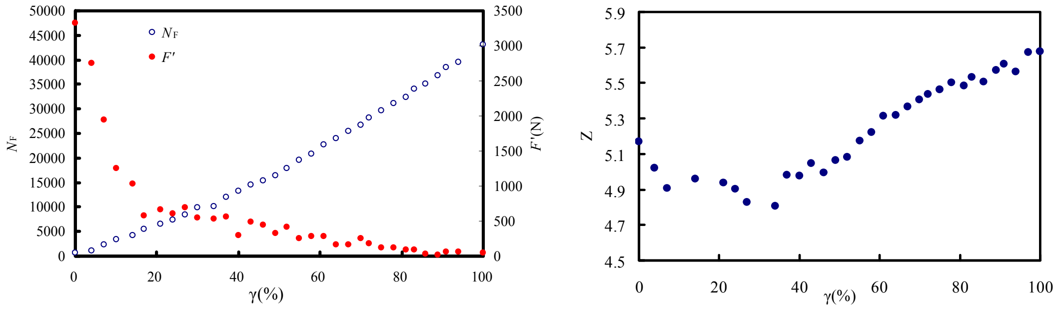

Fig. 5 Force chain number, mean contact force (left) and coordination number (right) of porous materials

CONCLUSIONS

The discrete element model is adopted to simulate the elastic modulus of mixed granular porous materials under various mixture ratios. The results show that there is a critical mixture ratio of 30%. The elastic modulus is about a constant when the small particle content γ is less then the critical ratio γ_c, while decreases with increasing γ when γ is larger than γ_c. The characteristics of force chains (strength, spatial structure and coordination number) under various mixture ratios are also analyzed and the mechanism of the critical mixture ratio for elastic modulus is discussed on micro scale.

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