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An Investigation of Fines and Coarse Contents in Granular Mixtures by Using Discrete Element Method

S. Zoghi, E. Seyedi Hosseininia*
Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT: It is believed that the addition of fine-grained soil to a base coarse-grained soil would result in shear strength increment due to filling up the voids among coarse-grained content and reducing global void ratio. However, this belief was against the following experiments. Instead of the definition of classical void ratio, two variables referred to as equivalent inter-granular and inter-fine void ratios, have been proposed to resolve this problem. Using these variables can help how a binary soil behaves. In this paper, by using the discrete element method, several binary soil samples were created by mixing two coarse and fine-grained soils. The two fine and coarse-grained soils have different gradations. The soil samples were prepared by considering zero, 10, 30, 40, 70, 100 percent fines content. Simulations were performed in two-dimension in which, the particles were circular. After each soil sample preparation, it was consolidated under isotropic confining pressure followed by biaxial compression loading. Each sample was tested under three different confining pressures. The biaxial loading condition was continued until the samples reached the critical state. This is the case where there is no variation in the deviatoric stress as well as the volume change along with the increase in the axial strain. Based on the simulated results, the required parameters to estimate the portion of the role of coarse and fine-grained parts in the global soil behavior were obtained. Comparison of the results of this study with those of experiments showed good agreements. The threshold fines content after which, the mechanical behavior of the binary soils is governed by fine grains, was assessed. It was shown that for the two-dimensional samples, the critical state can be obtained and the critical state line (CSL) can be constituted in the q-p'-e space. It was also seen that for the two groups of samples where either of coarse or fine-grained content are dominant, a unique critical state line can be obtained if the inter-granular and inter-fine void ratios are used instead of the global void ratio. The influence factors were back-calculated and the values were justified in comparison with the experiments.

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1. INTRODUCTION

In the early researches, it was thought that the increase of fines content in granular soils would augment the soil strength since the fine grains fill the voids and hence, the soil density increases. The example in this regard is the soil strength against liquefaction [1, 2]. On the other hand, there are other researches that indicate the decrease of shear strength of gravelly soils where the amount of fines content increases [3, 4]. The point is that fines content itself is not a proper criterion to judge about the shear strength, but the active and inactive voids of a granular soil should be paid attention [5, 6].

In classical soil mechanics, the global void ratio represents the density of the soil, but not global soil behavior. The critical state soil mechanics is the framework by which, the soil mechanical behavior can be well described in terms of both the void ratio and the confining stress level. For Binary soils in which, two sets of fine and coarse-grained soils are mixed, the void ratio of the mixture is a function of the presence of the fines content and thus, each set of the soil has its own critical state line. There have been many attempts in the literature to find a solution to describe the mechanical behavior of binary soils independent to the fines content.

*Corresponding author's email: eseyedi@um.ac.ir

In binary soils, either of the fine or coarse-grained parts has a dominant effect on the global mechanical behavior. The threshold fines content (fc_{th}) is a measure beyond which, the contacts among the particles in the soil mixture is governed by the fines content. Rahman and Lo [7] has obtained the following relationship for fc_{th}:

$$fc_{th} = 0.4\left(\frac{1}{1+\exp(\alpha-\beta\chi)}+\frac{1}{\chi}\right) \quad (1)$$

where a = 0.5 and b = 0.13 are suggested. c is defined as D_{10}/d_{50} where D_{10} is the effective diameter of the coarse-grained part and d_{50} is the mean diameter of the fine-grained part.

In order to consider the effect of fines content participation when the coarse grains are dominant, Thevanayagam and Martin [8] introduced the concept of equivalent inter-

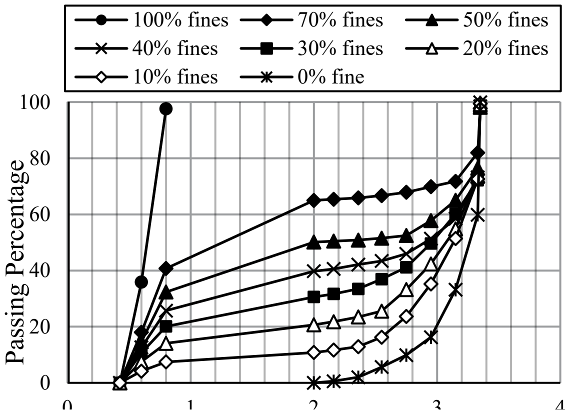

Fig. 1. Soil gradation curves of all samples

granular void ratio (e_{ceq}) as follows:

$$(e_c)_{eq} = \frac{e + (1+b)fc}{1-(1-b)fc} \tag{2}$$

The parameter b is the influence factor, which represents the fraction of fines that take part actively in the load-bearing microstructure. There are many works that have introduced different values of b [8, 9].

If the fine-grained part of the soil mixture governs the soil behavior, Thevanayagam and Martin [8] introduced the equivalent inter-fine void ratio (e_{feq}) as follows:

$$(e_f)_{eq} = \frac{e}{fc + \dfrac{1-fc}{(R_d)^m}} \tag{3}$$

where $R_d = D_{50}/d_{50}$ and m is an experimental exponent. D_{50} and d_{50} are the mean diameter of coarse and fine-grained parts of the binary soil.

In this paper, the role of fine and coarse-grained parts of a binary soil was investigated numerically by using the discrete element method (DEM). To this aim, two sets of coarse and fine-grained soils were considered separately and then, the mechanical behavior of the mixtures was studied. The influence factor b was back-calculated and the values were discussed and compared with the experiments. It was also aimed to investigate the behavior of such a soil mixture as a unique critical state. In this study, the assemblies were considered in two-dimensional space with circular particles.

2. METHODOLOGY

In this study, the numerical discrete element method was applied in order to simulate the mechanical behavior of two-dimensional assemblies. The particles were circular in shape. Two sets of soils with fine and coarse grains were considered. The corresponding gradation curves were in accordance with Figure 1. The particle size of the fine-grained soil was in the range of 0.2-0.8 mm, while the diameter of the coarse-grained soil was from 2.0 to 3.4 mm. Other six samples were prepared by mixing these two gradations. The fine contents of these samples were 20, 30, 40, 50, and 70 percent. The gradation curves of all the eight samples are shown in Figure 1.

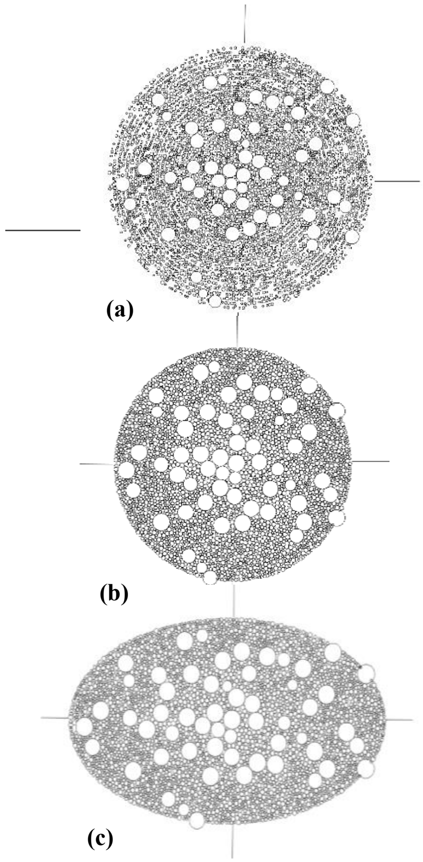

Fig. 2. Soil sample with 70% fines content: (a) loose generated; (b) isotropically compacted; (c) biaxially-loaded assemblies

Each test on the soil samples included three stages as are depicted in Figure 2. The soil samples had a circular shape. In order to prepare the soil samples, the particles of the soil were laid out randomly inside the sample space according to the corresponding soil gradation curve. The bigger particles were first laid out and then, smaller particles were placed inside the sample in order to fill the potential voids among the bigger particles. After the soil preparation, a loose assembly of the particles was generated and is shown in Figure 2a. The assembly is then compacted isotropically under a defined confining pressure. A compacted sample is shown in Figure 2b. After reaching a stable condition, where both confining stress and the sample volume became constant, the biaxial compression loading started. The loading condition is such that the stress level in the horizontal direction keeps constant and equal to the initial value, while the sample is vertically loaded and the upper and lower boundaries get closer. Consequently, as depicted in Figure 2c, the sample becomes ellipse under the biaxial loading.

The biaxial loading was continued until the assemblies reached the critical state. This was the case where no variation was observed in the values of deviatoric stress as well as the volume. It should be noted that each sample was tested under three different confining pressures of 50, 100, and 200 kPa. The inter-particle friction coefficient was set to 0.5 in an exception that the value was set to zero for the initial

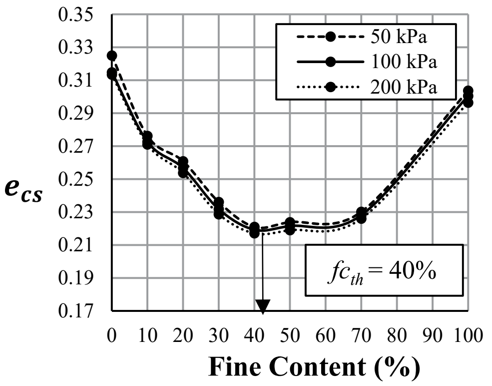

Fig. 3. Assessment of fc_{th}: from the simulations

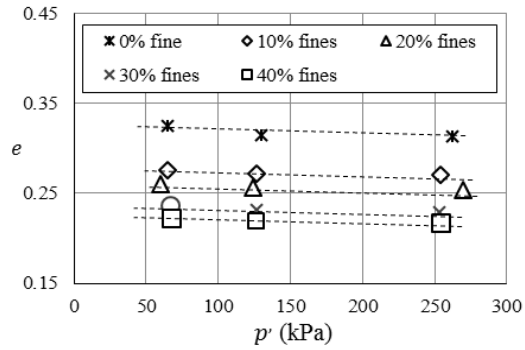

Fig. 4. Presentation of CLS in terms of global void ratios and confining pressure

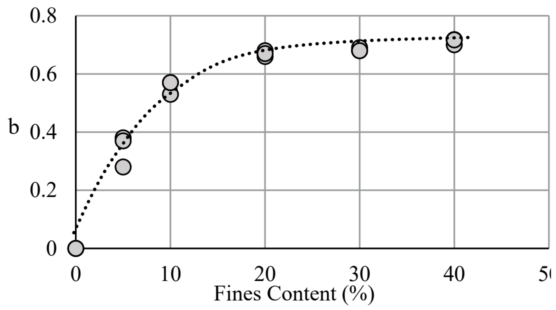

Fig. 5. Variation of b value with fines content

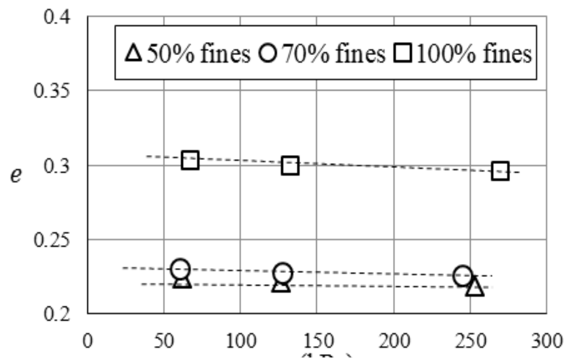

Fig. 6. Presentation of CLS in terms of global void ratios and confining pressure

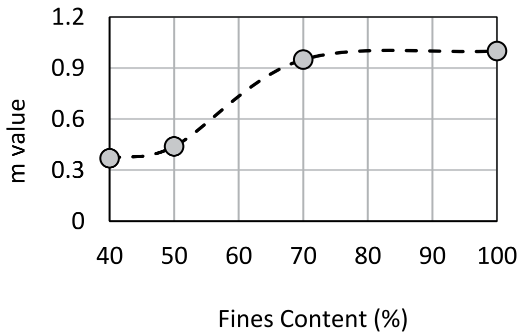

Fig. 7. Back-calculated value of m

compaction in order to reach higher compaction. The normal (k_n) and tangential (k_s) stiffness of contact springs were set to $k_n = k_s = 10^9$ N/m. For more information about the simulation procedure, the reader is referred to the literature [10, 11].

3. RESULTS AND DISCUSSION

In order to find the role of fines content on the behavior of binary soils, the threshold fines content has been firstly determined. Rahman and Lo [7] explained the procedure on how to assess fc_{th}: they defined fc_{th} as the minimum void ratio of the samples when the critical state is reached. Figure 3 presents the variation of void ratios of each sample at the critical state. As can be seen, one finds that fc_{th} =40%. Furthermore, fc_{th} can be estimated from Eq. (1), which gives 38%. These two methods give almost the same result.

According to Figure 3, coarse-grained particles were dominant in the behavior of the samples with fines content less than or equal to than 40%. Figure 4 presents the CSL of the four samples with the fines content of zero, 10, 20, 30, and 40%. The CSLs were drawn based on the global void ratio. To have a unique CSL in terms of $(e_c)_{eq}$, the *b* parameter in Eq. (2) was back-calculated.

The back-calculated values of parameter *b* are depicted in Figure 5. As shown, the *b* value was augmented with the increase of fines contents from zero to around 0.7, which was qualitatively in agreement with the experiments.

The CSLs of the samples with the fines content of greater than 40% (*fc* = 50, 70, and 100%) are depicted in Figure 6.

Again, it was attempted to have a unique CLS for all these samples by using Eq. (3) and the parameter *m* was calculated according to Figure 7.

4. CONCLUSIONS

In this paper, a series of two-dimensional granular assemblies were simulated using DEM in order to investigate the effect of fines content effect on mechanical behavior. The main conclusions are as follow:

1- It was possible to find the threshold fines content in soil mixtures whose value was in good agreement with the experiments.

2- It was possible to use equivalent inter-granular and inter-fine void ratios in order to define unique critical state lines.

3- The back-calculated values of b were matched with the experiment.

4- It was possible to study the behavior of binary soils by two-dimensional granular assemblies.

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