NUMERICAL INVESTIGATION ON PEAK FRICTION REDUCTION DUE TO GRADATION CHANGE IN PARTICLE CRUSHING

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Abstract

Internal angle of friction which is also termed as friction angle of granular materials is a very important parameter since many of strength parameters such as shear strength and bearing capacity are depend on it. The friction angle varies with the confining pressure even without the consideration of particle crushing. High confining pressure leads to particle crushing and particle crushing alter the friction angle further by changing the particle number, particle size and shape of PSD curve. This study was carried out to identify the relation between the friction angle and gradation change occurs at particle crushing.

Since it is difficult to perform such analysis with conventional laboratory equipments due to the difficulty of controlling the PSD, constitutive modelling was used. The numerical approach called Discrete Element Modelling (DEM) provided more advanced benefits such as ease of controlling and obtaining micro parameters such as coordination number and unbalanced force.

Numerical samples were generated with different gradations and the same PSD with different particle numbers. All samples were subjected to conventional triaxial test with different confining pressures. The variation of peak friction angle was obtained and the results showed that this analysis can be used to predict the reduction of peak friction angle when crushing occurs at high confining pressures.

The stress-strain and volumetric responses were obtained and compared with the experimental behaviours. They showed a good consistency with each other and confirmed the validity of the simulation.

Keywords: gradation effect, DEM, Particle crushing, Coordination number

1. Introduction

Particle crushing is the main reason to change the gradation of soil particles which are being subjecting to high confining pressures. Other than the gradation change, particle crushing will alter many physical parameters such as particle shape, angularity, particle size and porosity. (Marachi, 1972). All these alterations affect the strength properties and therefore the prediction of strength changes due to particle crushing is very important in civil engineering applications. This study concerns only the effect of gradation change and increase of particle number on the peak friction angle since it is difficult to consider all the parameters simultaneously. The peak friction angle is the friction angle corresponding to the ultimate strength which is the measurable stage of many laboratory experiments. Therefore the changes in soil strength parameters can be obtained by referring to the behaviour of peak friction angle.

The effect of gradation in two dimensional space have been numerically investigated by Sitaram (2000) and concluded that the peak friction angle is heavily influenced by the change of PSD curve. (Figure 1). But the behaviour of the friction angle in three dimensional interstice has not been unveiled and the effect of particle crushing too. The controversial fact is that even though the reduction of peak friction angle with increasing confining pressure has been identified as consequence of particle crushing, the same behaviour is resulted at the analysis where the particle crushing is not considered.(Sitaram, 1999). This factor was also a motivation to carry out this study.

The numerical analysis has been identified as a fast, easy and valid technique in modern investigations and the constitutive modeling technique called discrete element method (DEM) (Cundall, 1979) was used in this study. Numerical approaches also advance the ordinary laboratory tests by providing opportunity for micro mechanical investigations which can describe the macro behaviors of granular media more realistically.

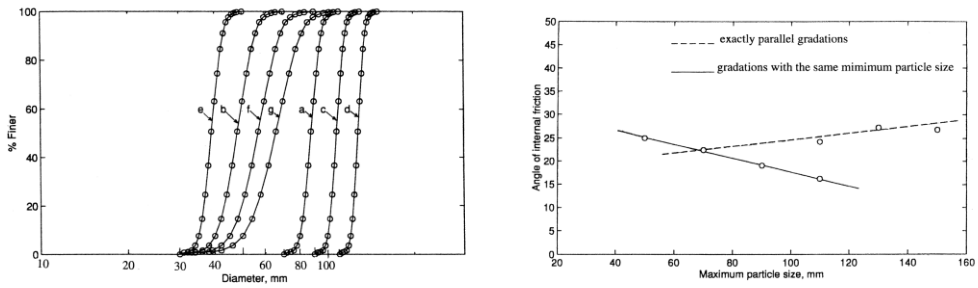


Figure 1: PSD curves of samples and variation of friction angle (Sitaram, 2000)

2. Methodology

Numerical samples were generated in two series to identify the effect of particle number and gradation. Initially, three different PSD curves were selected and three sets of samples were generated with 4000, 5000 and 6000 particles to identify the effect of the increasing of particle number at the particle crushing. The second series of samples were generated such that the PSD curves of samples were similar to figure 2 and each sample contained 4000 particles.

For the preparation of samples, the particles were initially placed in a cubicle frame so that there was no any contact between particles or boundary walls (Figure 3). The samples were then isotropically compressed up to the confining pressure which the samples were supposed to be sheared.

Numerically drain tests were conducted on the isotropically compressed samples. The first series of samples were sheared under confining pressure of 400 kPa while the second series was subjected to triaxial shear under confining pressures of 100, 200 and 400 kPa. The deformation of samples were controlled and measured using six rigid boundary walls during triaxial compression. The upper and lower walls were moved vertically under strain controlled condition and the lateral confining pressures were controlled automatically by a servo mechanism.

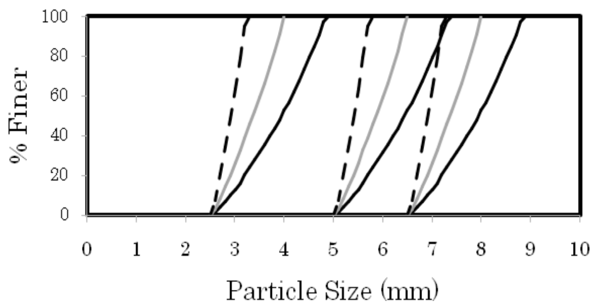


Figure 2: PSD curves of samples used in the simulation

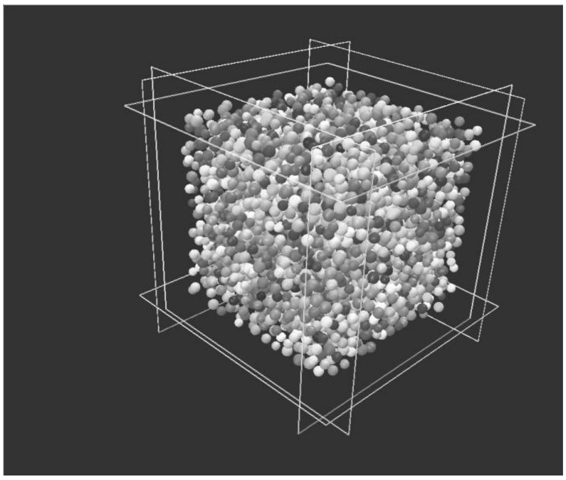


Figure 3: Particle placement in cubical frame

The program code YADE (Kozicki, 2009) was used for the preparation of the samples as well as for the triaxial compression. Generally, numerical simulations require some parameters called input parameters which should be selected through a separate DEM based sensitivity analysis. The input parameters for the quantitative analysis are very important and those should be obtained from the experimental investigations. However for the qualitative investigations, they can be decided through a separate series of simulations performed by considering the effect of each parameter. The input parameters used for the triaxial compression in this study are given in the table 1.

Table 1: Input Parameters used in simulation

Parameter	**Value**
Particle shape	Sphere
Number of Particles	4000
Inter Particle Friction Angle (deg)	30
Particle Young's Modulus (MPa).	15
Stiffness Ratio	0.5
Damping Coefficient	0.4

3. Results and Discussion

The micromechanical parameter coordination number which is defined as the average number of contacts per particle was used to describe the behaviour of friction angle in this study. Figure 4(a) and (b) illustrate the variation of peak friction angle and the coordination number for samples having same PSD with different particle numbers. It is found that the effect of particle number is comparatively small even though there is a slight increase in coordination number. Therefore it can be concluded that the consideration of change of gradation and effect of confining pressure only is capable of estimating the change of peak friction angle due to particle crushing.

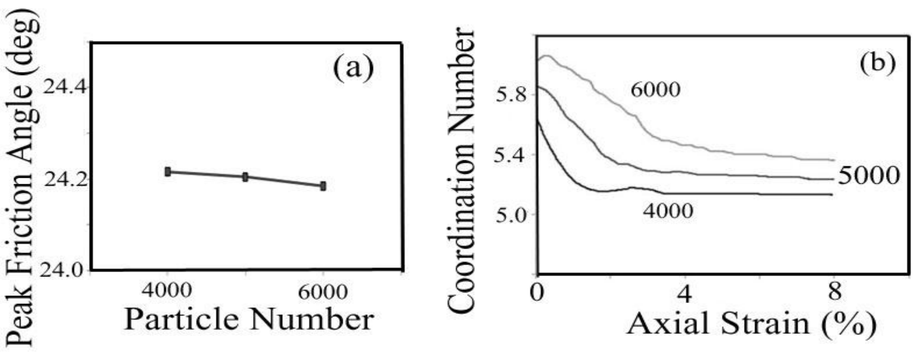
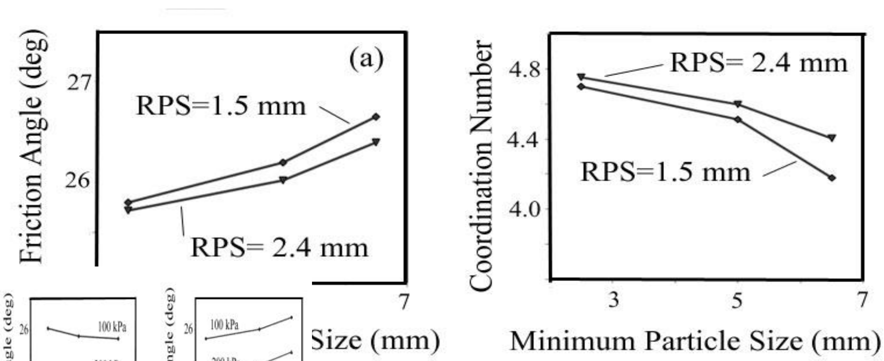
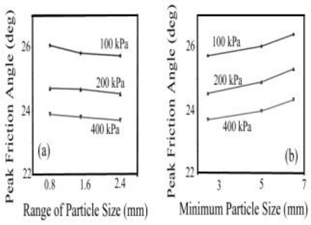


Fig. 4: Effect of particle number on (a) Peak friction angle & (b) Coordination number

Since the two parameters particle size and shape of PSD curve are the critical factors emerging the effect of gradation, they were considered separately within this study. The size effect was analyzed using parallel gradations and the shape effect by using samples whose PSD curves having constant minimum particle size. The samples are defined by the minimum particle size (MPS) and the range of particle sizes (RPS) which is the difference of maximum and minimum particle sizes. Figure 5(a) and (b) shows the variation of friction angle and coordination number at residual state while range of particle sizes reduces from 2.4 mm to 1.5 mm. The coordination number defined as the average contacts per particle is the critical factor influencing the friction angle since the higher coordination number leads to lower friction angle due to dispersal of the normal contact forces of particles.

For the samples having parallel gradations, the peak friction angle reduces as particle size reduces and the amount of the reduction is decreases with the increase of confining pressure. (Figure 6(a)). Similarly an increment of peak friction angle can be observed as the particle range reduces and the quantified increment reduces with the increase of confining pressure. (Figure 7 (b)). The behavior of friction angle can be described by the variation of coordination number.





radation on (a) peak friction angle and (b) coordination number

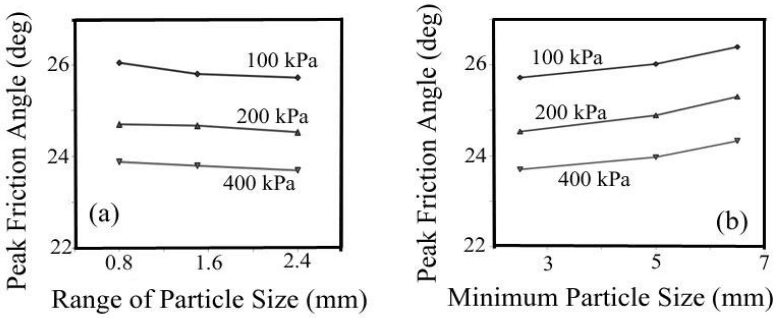


Fig. 6: Combined effect of confining pressure and (a) curvature, (b) size on peak friction angle

4. Conclusion

Forecasting of the reduction of peak friction angle due to particle crushing can be performed by analysing the effects of gradation and confining pressure. This study was carried out by considering only the gradation change due to particle crushing and a complete estimation may be possible by concerning all the changing parameters due to particle crushing.

The friction angle reduces with the reduction of particle size and increase with the reduction of particle range and the rate of changes reduces with the increase of confining pressure.

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