THE EFFECT OF MIDDLE PRINCIPAL STRESS ON SANDY SOIL STRENGTH

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ABSTRACT

According to Mohr-Coulomb failure criterion, the strength of soil specimen is mainly related with the maximal principal stress and the minimal principal stress, which fails to reflect the effect of the middle principle stress. However, more and more triaxial experiments show that the middle principle stress has a certain impact on soil strength. Generally speaking, when the middle principal stress increases, the soil strength tends to increase uniformly at beginning and then decrease later. The effect of the middle primary stress is widely applied in many soil engineering issues such as Excavation, Curve Slope Stability, Failure of The Rock Structure and so on. Therefore, it's not only of important theoretical significance but also of vast value in engineering to study the effect of the middle principle stress on sandy oil strength. The particle flow code, PFC3D, is used to simulate a true triaxial test in order to study and analyze the effect of the middle principle stress on sandy soil strength.

Keywords: Sandy soil strength; Middle primary stress; DEM; PFC3D

INTRODUCTION

For a long time, Mohr-Coulomb Failure Criterion (Fang K Z, 1986) is widely used in many soil mechanics engineering issues, especially in the stability analysis of the retaining wall pressure, the slope, the foundations and other types of soil mass. The criterion has been proved to be appropriate and soil shear failure is concerned as the sign of instability.

Mohr-Coulomb Failure Criterion shows that the soil shear strength is described by the internal friction angle **φ** and the soil cohesion **c**. The internal friction angle **φ** is concerned to be relevant to maximum principal stress **σ1** and the minimum principal stress **σ3**, little affected by the middle principal stress **σ2** (Tang L, 1981). More and more research results show that the effect of the middle principal stress **σ2** on soil shear strength and deformation of soil mass is non-ignorable. The theory is also tested by Dr. W.Kjellman (1936) and L.Rendulic (1936), they believe this effect is significant. Decades of research made the most scholars agree with the conclusion that the middle principal stress affects soil shear strength in some way. Therefore, some three-dimensional failure criteria considering the effect of the middle principal stress have been applied in many studies, such as Lade-Duncan criterion (Lade et al., 1975), Matsuoka-Nakai criterion (MATSUOKAH, 1976), as well as uniform isotropic guidelines. Increasingly, **$\sigma 2$** considered as a parameter is used in the most researches on soil shear strength issues. This is a new trend of research on soil shear strength even geotechnical soil strength issues (You M Q, 2001).

NUMERICAL SIMULATION METHOD OF THE TRIAXIAL TEST

Preparation of the numerical simulation

Plane strain state is one of the most commonly stress state in hydraulic structure engineering and geotechnical engineering, such as in the dam, slope, foundations, retaining walls and so on. Generally, the parameter of soil shear strength used in geotechnical is mostly obtained by the triaxial compression test. However, the effect of the middle principal stress in the plane strain condition hardly reflects in the triaxial compression test due to certain factors, which results in the difference between the calculated intensity value and the actual one. Actually, soil strength in the plane strain is greater than the conventional triaxial compression condition (Li et al., 2004).

A series of true triaxial tests showed that parameters of soil strength are various by the different main stress ratios. Many domestic and foreign scholars have done further researches of this issue, such as Kong Dezhi (Kong et al., 2005) proposed the empirical formula for sand strength parameters changed with the main stress ratio and spatial mobilization plane theory (SMP) (Liuetal.,2005).

Numerical simulation of true triaxial test process by PFC3D is often like the following steps:

(1) Sample preparation:

Six faces are expected to be built used to be the ‘walls’ which keep the particles move out of range and are placed in a certain distance, looked like a cuboid container. After, so many particles aggregation in the certain porosity can be generated in this container.

(2) Consolidation:

Servo-controlled system is used to achieve the desired target consolidation stress by continuously adjusting the movement speed of the wall. Before the process of loading, the soil sample is expected to be initialized as a three-dimensional equaling consolidation.

(3) Loading:

The vertical walls is enabled to move at a fixed speed by the closure of the servo control system. During the process, the force and deformation on the soil sample is recorded for further analysis. The speed and direction of the loading walls movement are changed to get different experimental result.

The middle principal stress coefficient (HABIB, 1953) is defined as a principal stress factor **b**, which is relevant to three kinds of principal stress.

$$b = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} \quad \text{and} \quad \sigma_3 \le \sigma_2 \le \sigma_1$$

Consequently, the value of **b** represents the range of the middle principal stress by the above formula:

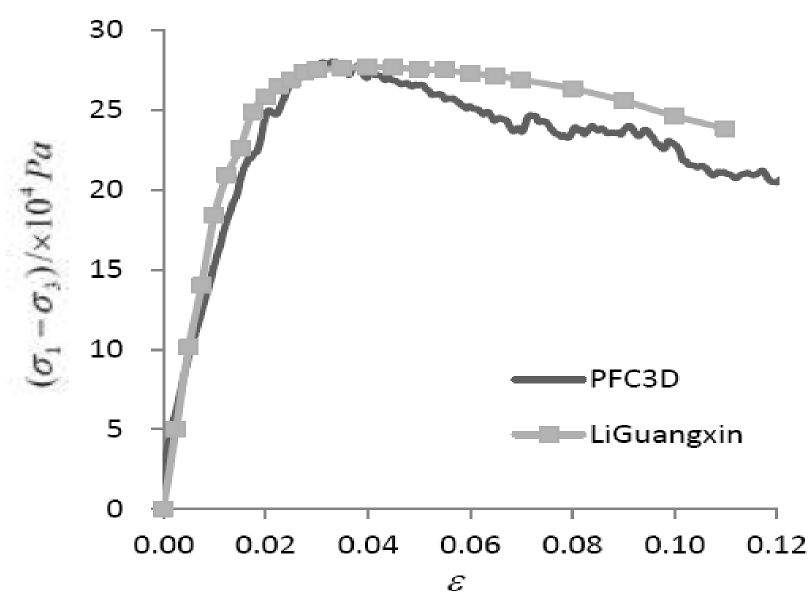
When the value of b is 0, it means **σ3=σ2**. This is a conventional triaxial tests and the stress state is symmetrical.

When the value of b is 1, it means **σ1=σ2.** This is a triaxial extension test and the stress state is symmetrical as well.

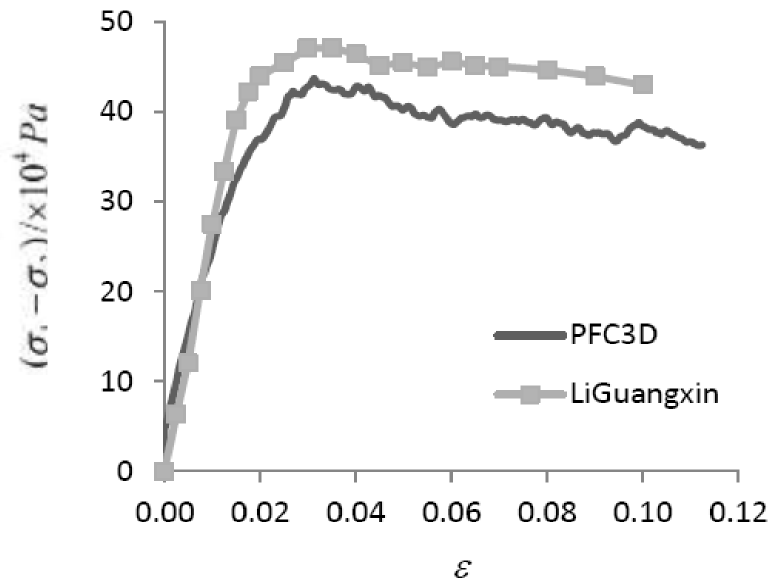
We can see that in the conventional triaxial test and triaxial extension test are the two of the special case of true triaxial test.

Model feasibility test

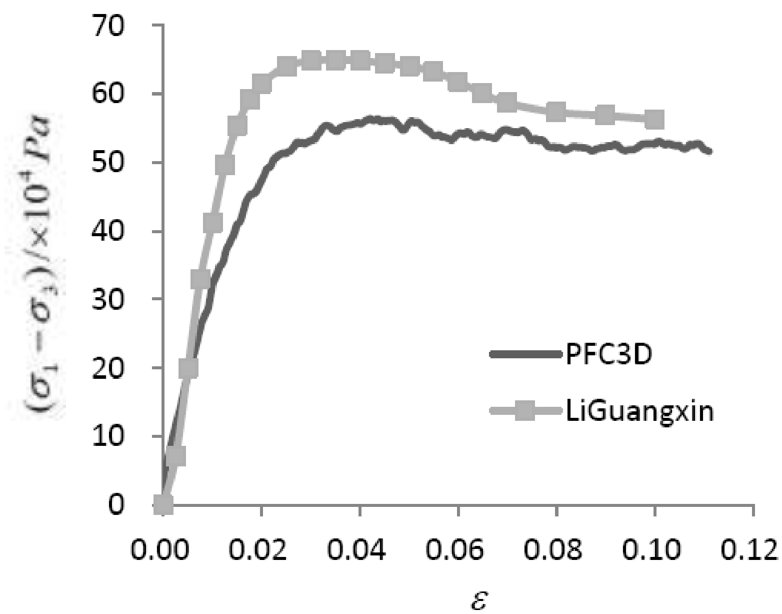
In order to test the feasibility of the numerical model, the soil sample is expected to be placed in the set containers and undertaken the confining pressure test. The stress - strain curves got from the above test is plot in order to compare with the test results from Li Guangxin using the Chengde dense soil.



$(a)\ \sigma = 100kPa$



$(b)\ \sigma = 200kPa$



$(c)\ \sigma = 200kPa$

Figure 1. Simulation results of the PFC and the triaxial test are compared with different confining stress.

Figure 1(a), (b) and (c) show that the numerical simulation curve plotted by PFC3D fits the experiment curve of Chengde dense soil well when the deformation is little. As the initial confining pressure increases, the difference between the two curves gets enlarged and apparent. the model is feasible. Generally speaking, the small balls of numerical simulation generated by PFC3D are idealized particles with perfect granular feature. However, natural soil particles shape strangely and vary in size. This is why the curves do not fit very nice all the time. It is unnecessary to fit two curves perfectly at all.

After the above analysis and comparison, the soil sample of the numerical simulation is proved to be feasible. Changing the value of the stress, the particle size and internal friction angle develops the numerical simulation authenticity.

The final parameters of the numerical simulation particle are listed.

Table 1. Key parameters of the soil sample

Sample size (mm)	100*100*200
Granular density (kg • m^{-3})	3630
Initial void ratio	0.655
Maximum size (mm)	14.94
Minimum size (mm)	9.03
Particle number	1447

Numerical results and analysis

To study the effect of the middle principal stress on the soil shear strength, the value of **b** is expected to increase from 0 to 1 by 0.05 when the minimal principal stress is fixed. In every loading process, the value of **b** and **σ3** is constant, the relation between the soil failure strength (represented by the difference between the **σ1** and **σ3**) and the middle principal stress **σ2** is supposed to study.

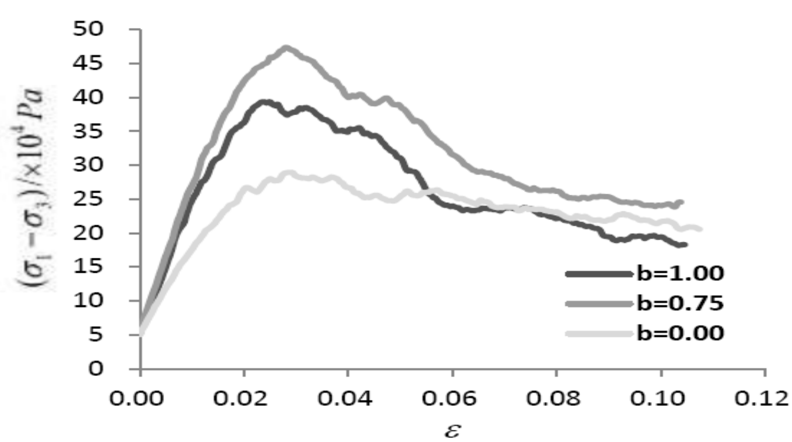


Figure 2. Evolution of soil shear stress with different value of b

Three representative groups of status are plotted into Fig 2 above. These curves indicate that the soil shear strength is varied as the value of **b** changes between 0 and 1. It also shows that the soil shear strength is higher than the one in the case of **σ1=σ2** (**b**=1) and **σ3=σ2** (**b**=0) with the same axial strain. Furthermore, the soil shear strength does not increase as the value of **b**. The maximum soil failure strength achieves at a certain value of **b** within 0 to 1.

It should be pointed out that the soil failure strength depends on the difference between **σ1** and **σ3.** For comparison of the experimental data and numerical simulation results, we plot the two curves in a same figure to find out the effect of the middle principal stress to the soil strength.

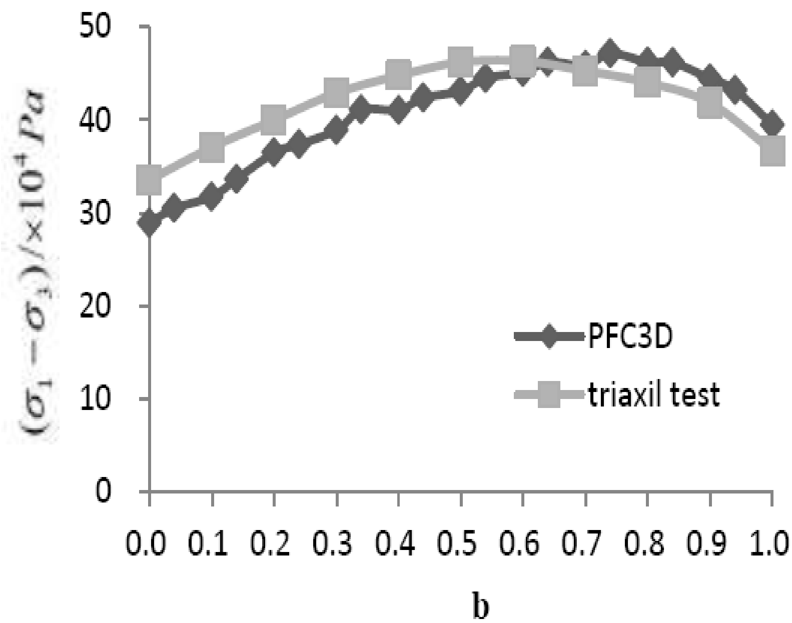


Figure 3. Comparison of the soil strength between the triaxial test and PFC3D with different value of b

From the curves plotted in Figure 3, during the value of **b** changing, the soil failure strength increases at first and decreases in the second half. Obviously, the value of the middle principal stress **σ2** increasing or decreasing is supposed to change the maximum soil strength. Since some of key parameters of the sandy soil sample are not exactly the same with the numerical simulation particle's, which causes the difference between the smooth curve (triaxial test) and the rough one (PFC3D), the small difference can be ignored.

CONCLUSION

Mohr-Coulomb Failure Criterion indicates the influencing factors to the soil strength and gets the solving methods and formulas, only referring to the case of plane strain. It failed to reflect the effect of the middle principal stress to the soil mass.

The changing range of the middle principal stress is between the maximum principal stress and the minimum principal stress. In lab, the triaxial compression test and the soil triaxial elongation test are easily conducted. But they are just a special case of the true triaxial tests at **σ1=σ2** (**b**=1) and **σ3=σ2** (**b**=0).

From the microscopic view, the strength of the infinitesimal particles rises up as the middle principal stress increases from **σ3=σ2** (**b**=0). Impacted by the existence of the stress **σ3,** the effect of the middle principal stress is limited**.** On the other hand, when the increasingly stress **σ2** is approaching to the stress **σ1,** the soil sample will be yielded at the plain of (**σ2 —— σ3)** then turn into failure. Contrarily, the more increase of the middle principal stress does not enhance the value of the soil shear strength. Although the effect of the middle principal stress shows difference in various kinds of sandy soil samples, the trend line of the changing soil failure strength is almost the same just like a downward parabola. The vertex of the parabolic curve is considered as the real maximum soil shear strength when the value of **b** equals about 0.5. And the two extremes of the curve represent the two kinds of test which are easily performed in the lab. More important, the results about the final soil failure strength from these two experiments are similar. That's a main reason why so many scholars once believed the summary that the middle strength has no effect on the soil shear stress.

The study of the effect of the middle principal stress on the soil strength still has some theoretical defects and some details about the set of the numerical simulation are not clear. It will be better if the change of internal friction aroused by the increase of the middle principal stress is also concerned.

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