Comparing the Behavior of Dense Sandy Soils Inside and Outside the Shear Band in the Direct Shear Test Using the Two-dimensional Discrete Element Method

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ABSTRACT

Shear banding is one of the most significant behavioral characteristics of granular soils, which is actually the result of the localization of deformations under loads applied to the soil sample. Many studies have been conducted on the phenomenon of shear band formation. However, the comparison of the behavior of soil inside and outside the shear band has received less attention. The purpose of this study is to compare the behavior of soil inside and outside the shear band in the direct shear test at macro and micro scales using the two-dimensional discrete element method. To achieve this, the micro-material parameters were first calibrated through the comparison of simulation and experimental results. Then a parametric study was conducted by performing 9 direct shear tests with different vertical stresses on three soil samples with different relative densities. During the tests, quantities such as shear stress, porosity, particle rotation, coordination number, and interparticle plastic energy were measured both inside and outside the shear band. The results of the present study showed that the particle rotations at the end of the test inside the shear band were 5 to 17 times higher than those outside the shear band. Furthermore, the results showed that the dissipated energies at the end of the test inside the shear band were 12 to 96 times larger than those outside the shear band. Moreover, it was found that the coordination numbers at the end of the test inside the shear band were on average 3-19% lesser than those outside it.

KEYWORDS

Direct shear test, discrete element method, sandy soil, inside and outside of the shear band, PFC^{2D}.

1. Introduction

In soil mechanics, the area where shear strains are concentrated is called a shear band. This phenomenon can be observed after the highest level of resistance or maximum strength, in experiments conducted on the compressive stress path. The soil sample in this case exhibits two different behaviors in terms of volume and strength. Over the past four decades, the study of shear bands has increased dramatically among researchers in most disciplines in order to better understand their mechanisms. The researches can be divided into two parts: theoretical and laboratory, in the theoretical part, the focus is on investigating the behavior of materials under different loads, and in the laboratory part, the model is compared with reality. The common goal of all studies conducted on this phenomenon in a wide range of disciplines is to reduce or eliminate its negative effects. In order to understand the concepts of shear band mechanics, a lot of research has been done in the field of soil mechanics [1-5]. However, the phenomenon of strain localization is one of the topics that has always been of interest to many researchers in the theoretical, numerical and experimental fields of the mechanics of grain materials [1, 6-15].

Kodicherla et al. [16] used the discrete element method (DEM) to simulate the direct shear test in PFC 2D software to investigate the micromechanical behavior of grain samples with different internal friction angle of different bindings. They showed that if the internal friction angle of the particles increased, the maximum point of the internal friction angle increased. Also, because the coordination number of all samples is greater than 3, the structure of the samples is stable. In addition, the coordination number for all samples is reduced during shearing at a low rate until a stable state is reached.

2. Calibration of micro parameters

Based on the formulation of DEM, three micro parameters including elastic modulus (E), tangential friction angle (μ), and rolling friction angle (μ_r) are required to perform a DEM simulation. In the present study, these parameters were selected based on a calibration with the results of direct shear experiments on Fontainebleau sand. Figure 1 compares the PSD curve of the assembly adopted in the DEM model and the Fontainebleau sand [17]. In order to reduce computational effort, particles with smaller diameters than d_{10} in the DEM model have been omitted [18].

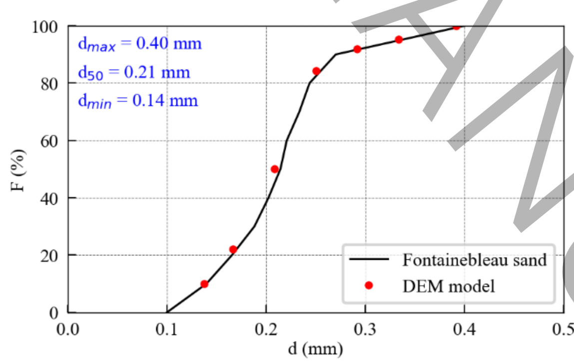

Figure 1: Comparison of particle size distributions for DEM model and Fontainebleau sand

In the calibration, first, a parametric study including a series of numerical direct shear test with DEM was performed. In these experiments, a shear box with dimensions of 50×100 mm was filled with 115723 circular particles, with the size of the diameter of the particles changing in the range of 0.14 to 0.40 mm as seen in Figure 1. It was also assumed that the shape of the particles is round corners, which were simulated in a circular shape due to the experiment in a two-dimensional environment. The dimensions of the shear box were selected based on the recommendations made in the research of Wang and Gutierrez [19]. In addition, as shown in Figure 2, 10 rigid walls were used in PFC 2D software to make this box.

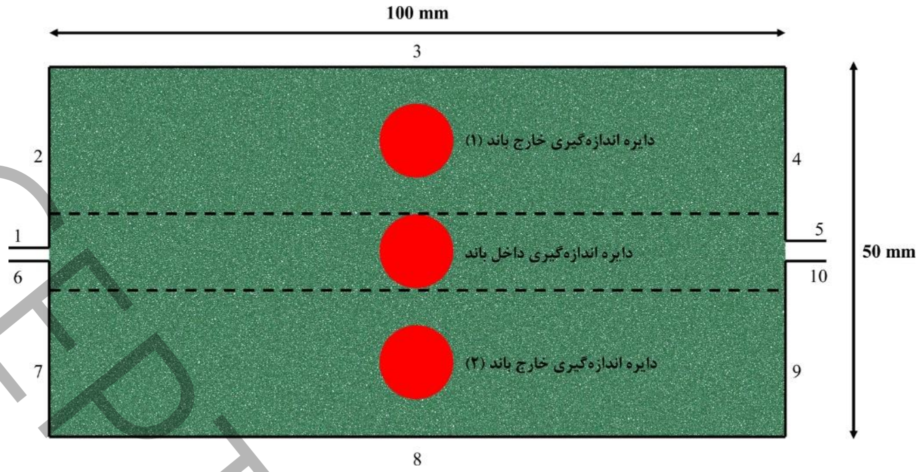

Figure 2: A schematic of the direct shear box simulated in PFC 2D

3. Discussion and results

In order to compare the behavior of dense soils inside and outside the shear band, nine direct shear tests were performed with three void ratios of 0.198 (very dense soil), 0.225 (moderate dense soil) and 0.242 (slightly dense soil) and three confining pressures of 50, 100 and 200 kPa. It is worth noting that from now on, very, medium, and slightly dense soils are abbreviated as VD, MD, and SD.

3.1. Volumetric Strain Changes

Figure 3 shows volumetric strain curves for three soil samples under different loads. The general trend of the path of volumetric strain is the same for all three samples: first the samples enter a contraction process and then they start to increase in volume and show dilation behavior. As it can be concluded from Figure 3, with increasing vertical stress, the samples experience more volume reduction compared to each other, in fact, with increasing vertical stress, the samples show more contractive behavior.

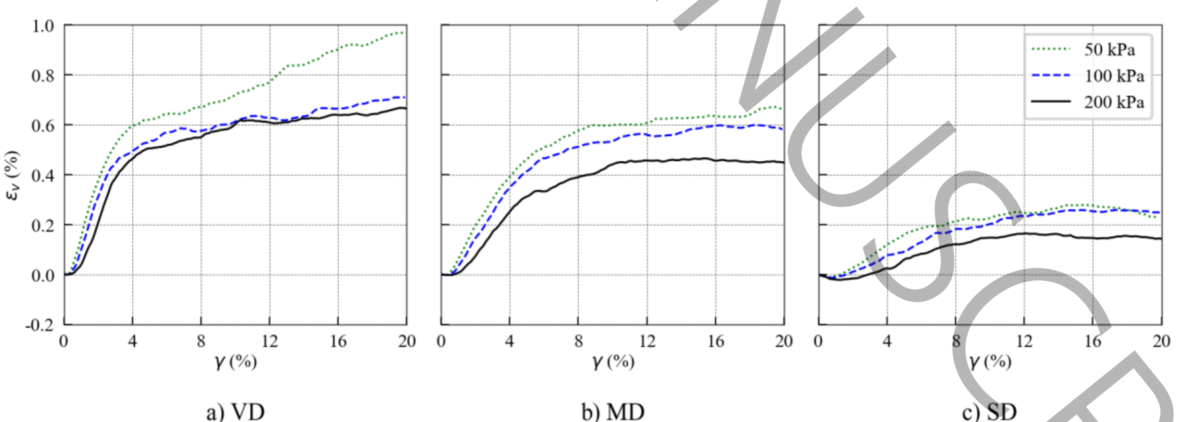

Figure 3: Variations of volumetric strain versus shear strain for soils a) VD, b) MD, and c) SD

3.2. Comparison of coordination number variations inside and outside the shear band

Figure 4 shows the changes in the coordination number inside and outside the shear band for different samples. As can be seen, the initial coordination number increases at the beginning of the test with increasing vertical stress and soil compaction, which is expected. For example, for 100 kPa vertical stress, by changing the soil type from SD to VD, the initial coordination number increases from 2.9 to 3.5 (22%).

At the end of the test, the average coordination numbers for very dense soil, medium dense soil, and slightly dense soils were 2.7 (3.3), 2.7 (2.9) and 2.7 (2.8). Therefore, by decreasing soil compaction, the difference between the coordination inside and outside the shear band decreased from about 19% for very dense soil to about 3% for slightly dense soil. Also, the coordination number inside the shear band at the end of the test, regardless of soil type, was about 2.7.

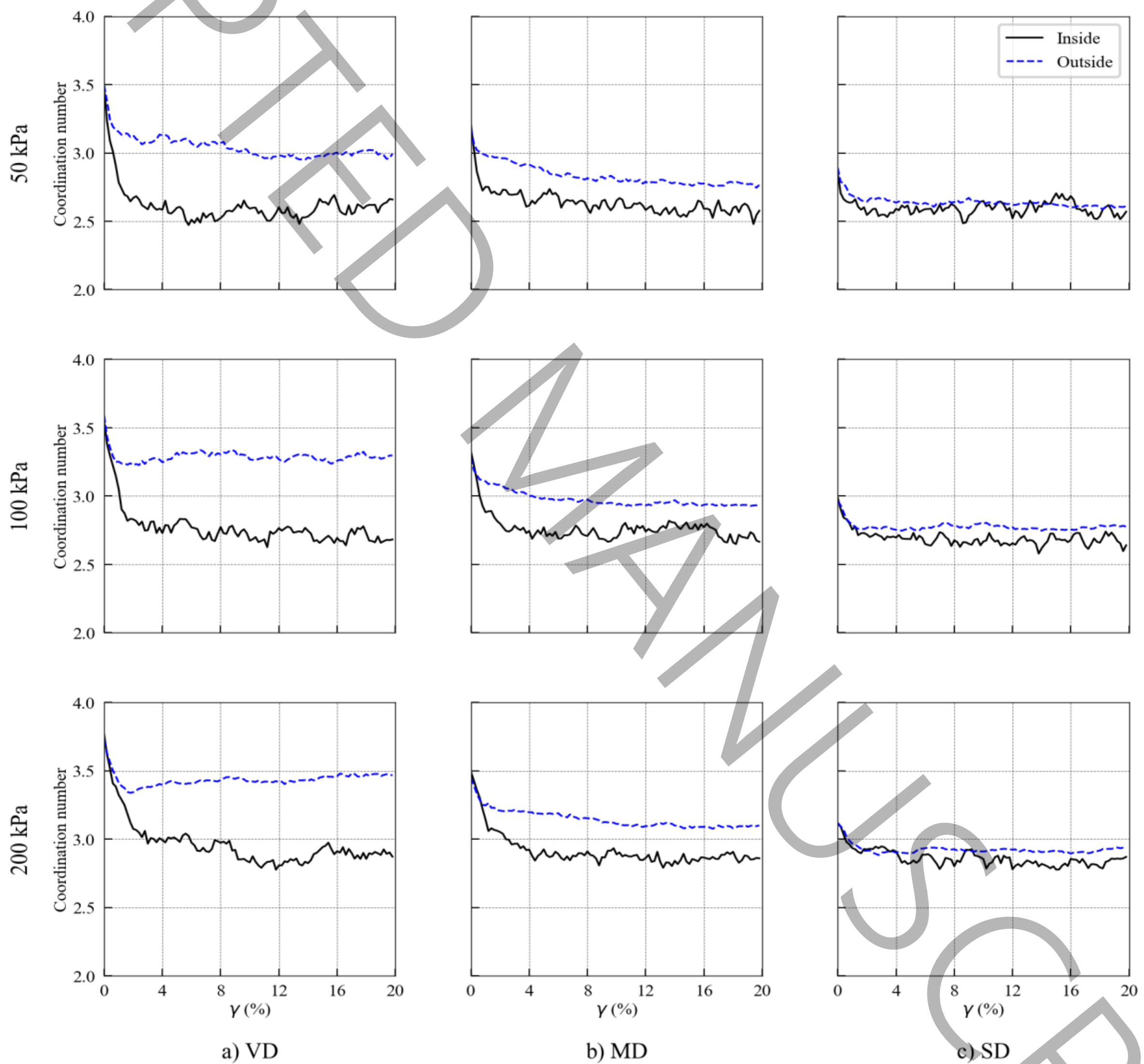

Figure 4: Variations of coordination number inside and outside of the shear band for soils a) VD, b) MD, and c) SD

4. Conclusion

In the present study, the behavior of dense granular soils inside and outside the shear band was simulated in a direct shear test using a two-dimensional discrete element method in PFC2D software. First, the micro parameters were calibrated by simulating a direct shear test on the Fontainebleau sand and comparing its results with the experimental one. Then, a parametric study was performed by performing 9 direct shear tests on three types of soils with different void ratios (very dense soil, medium dense soil, and slightly dense soil) and three different vertical stresses (50, 100 and 200 kPa). In this parametric study, quantities including shear stress, porosity, coordination number, particle rotation and plastic energy between the particles inside and outside the shear band were measured and compared during the tests.

5. References

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