Study on Opening between Shear Boxes using DEM Simulation

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ABSTRACT

The slope failure so far has been occurred due to the heavy rainfall, and induced losses of a human life and properties. In order to prevent these damages, the measurement and the evaluation for the strength characteristics of the ground such as the shear strength and the angle of internal friction should be required. The direct shear test (DST) which is one of testing methods for this has been generally used, and has several experimental limitations. In particular, it should be recognized that there is no the standard of the opening size between the shear boxes in the DST, and the strength characteristics can vary according to the opening size. Thus, Kim et al. (2012) suggested that the opening size is determined based on the Threshold-Line. In this study, the Threshold-Line (TL) proposed by Kim et al. (2012) was examined through the distinct element method (DEM) simulation. As a result, the shear behaviors in the DEM simulation are similar to the experimental results by Kim et al. (2012). Through the results of the DEM simulation, it can be confirmed that the TL can be a standard for the opening size in the DST.

Keywords: direct shear test, opening size, DEM simulation, Threshold-Line

1 INTRODUCTION

The direct shear test (DST) has commonly been carried out in analysis for practical engineering in order to obtain the shear strength parameters or study the behaviors of shear strength and deformation in some soil samples. The results of the DST are mainly affected by the following three factors; a) direct shear apparatus type, b) specimen size (scale effect), and c) opening size between upper and lower shear boxes. In particular, among the three factors, the opening size between upper and lower shear boxes has a profound effect on the shear behavior in the DST.

If the setting of the opening size between shear boxes is not set in the DST, an exaggerated dilatancy or the stress concentration on the shear plane would be occurred. In order to improve this, the shearing process in the DST has been performed with setting of the opening between shear boxes (Shibuya et al., 1997). But, it should be recognized that there is no the definite standard on the opening size between the shear boxes.

Kim et al. (2012) studied the effect of the opening between the shear boxes on the shear behavior in the DST (Height= 20 mm x Diameter= 60 mm) under a constant pressure condition using seven types of granular material. They reported that the magnitude of shear strength and dilatancy decreases due to the outflow of sample with an increase in the opening. They proposed the notion of the Threshold Point (T.P) in terms of the relationship between opening size and angle of internal friction (Fig. 1). The T.P is defined as the intersection point between the tangent of the initial part and the tangent of the decreasing part. That is, the T.P defines the magnitude of opening size at which the angle of internal friction drops abruptly. Subsequently, The Threshold-Line (TL) is defined in the relationship between the magnitude of T. P. and the mean particle size (Fig. 2). If setting the opening size on the basis of the TL in the DST, it would be possible to obtain the reasonable angle of internal friction without the outflow of sample during shearing. Therefore, it could be expected that the TL which implies the maximum opening size without the outflow of sample offers a guideline for an adequate opening size in the DST.

For the validity of the TL in this study, the TL is examined using the distinct element method (DEM) simulation. The shear behaviors according to the opening sizes of 0.0, 0.2, 0.5, 1.0, 2.0, 3.0, and 4.0 mm between shear boxes in the DEM simulation are compared to the experimental results. The variation of magnitude of the T.P is examined according to the fine and gravel grain contents.
2 DEM SIMULATION FOR DIRECT SHEAR TEST

2.1 Distinct element method

The distinct element method (DEM) was originally introduced by Cundall (1971) for the analysis of rock-mechanics problems and then applied to particle media by Cundall and Strack (1979). The DEM as a general particle-flow model provides a simulation on the mechanical behavior of a particle assemblage comprised of a collection of arbitrarily shaped individual particles under static and dynamic (i.e., flowing) conditions. In the DEM analysis, simple dynamic models (generally, the Voigt model and Coulomb’s friction rule) are introduced at contact points and contacting surfaces between the spherical particles with the assumption that the particles are rigid. An independent equation of motion at every element is solved forwardly in the time domain, and interactions between particles and deformation of particle aggregates are traced. The merit of this method is that it is easy to obtain necessary output data such as stress, strain, and rotation angle of some disk particles, and the setting of boundary conditions.

2.2 DEM Simulation of the DST

The DEM simulation on the DST in this study was performed using the three-dimensional PFC Program (PFC-3D) (ITASCA, 1995). The DEM simulation are comprised of 3 steps. In the first step, the specimen mold of the direct shear apparatus are made with walls, and then the balls (i.e., soil particle) are created according to each condition inside the specimen mold. In the second step, the consolidation process is performed under the normal stress of 300 kPa. In the last step, before the shearing process, the opening sizes of 0.0, 0.2, 0.5, 1.0, 2.0, 3.0, and 4.0 mm between shear boxes are set. The shearing process is performed with the shear rate of 0.1 m/sec to the shear displacement of 4.0 mm under the constant pressure condition. The material parameters

![Fig. 1. Notion of the Threshold Point (T.P) (After Kim et al., 2012).](image1)

![Fig. 2. The definition of Threshold-Line (TL) (After Kim et al., 2012).](image2)

![Fig. 3. The definition of the particle size distribution curve of a standard line (A material) used in the DEM simulation.](image3)

![Fig. 4. The particle size distribution curves of A, B, C, and D materials.](image4)

Table 1. Material parameters used in the simulation analysis.

| Parameters                              | Value          |
|-----------------------------------------|----------------|
| Normal Stiffness of particles (kn)      | 1.0×10^8 N/m   |
| Shear Stiffness of particles (ks)       | 2.5×10^5 N/m   |
| Normal Stiffness of axial walls (kn)    | 1.0×10^6 N/m   |
| Normal Stiffness of lateral walls (kn)  | 1.0×10^6 N/m   |
| Shear Stiffness of walls (ks)           | 0.0 N/m        |
| Friction Coefficient between particles   | 0.5            |
| Friction Coefficient between particles   | 0.0            |
| and wall                                |                |
| Density of particles (kg/m^3)           | 2600           |
| Local Damping Coefficient               | 0.7            |
used in the DEM simulation analysis summarized in Table 1.

2.3 Modelling of specimen
The size of each specimen in the DEM simulation is 60 mm in diameter and 20 mm in height as in the experimental specimen. The particle size distribution curve of specimen is set as 7 times as much as that of Toyoura sand (soil density: 2.64, mean particle size: 0.161 mm) which is a standard sand in Japan because of the capacity of the computer calculation (Fig. 3). This particle size distribution curve is defined as a standard line (A material), and then the particle size distribution curves (B, C, and D materials) defined as 1/2, 1/3, and 1/4 times for a slope of A material with the fixity of the mean grain size ($D_{50}$) are used in the DEM simulation (Fig. 4). This would make it possible to verify the shear behavior according to the variation of the fine and gravel grain contents. Thus, the variation of magnitude of the T.P can be observed on the several patterns of the particle size distribution curve.

The range of the particle size in the DEM simulation is defined from 0.5 mm to 2.0 mm. Here, the definition of 0.5 mm is to prevent the excessive increase of the particle number related to the computer calculation, and the definition of 2.0 mm is because that the soils below the grain size of 2.0 mm was used in the laboratory test. Thus, the percent finer of each material is summarized in Table 1. The particle numbers of each material are as follows: A material: 46,370, B material: 95,822, C material: 110,558, D material: 118,233. The initial void ratio of specimen is 0.818.

3 DEM SIMULATION RESULT OF THE DST

The shape after the completion of the shearing process in the DEM simulation of the DST is shown in Fig. 5 (A material: slope=1.0, opening size 0.0 mm). Figures 6 and 7 shows the results of the shear behavior according to the opening sizes of 0.0, 0.2, 0.5, 1.0, 2.0, 3.0, and 4.0 mm between shear boxes (A, B materials). In the relationship between the horizontal displacement and the shear stress, the shear strength increases sharply
at an initial shear step, and the peak shear strengths are occurred before the horizontal displacement of 1.0 mm. As shown, it is found that as the opening size increases, the shear strength decreases. In the relationship between the horizontal and vertical displacements, all of the results shows a dilative behavior. It is found that as the opening size increases, a dilatancy decreases. These results of the DEM simulation are similar to those of the experimental test by Kim et al. (2012). Thus, the reproducibility of the DEM simulation to the DST can be confirmed. The Threshold Point (T.P) in the relationship between opening size and angle of internal friction is concluded as shown Fig. 1. Figure 8 shows the decision process of the T.P of 1.81 mm for A material. Each T.Ps are as follows: B and C material: 1.72 mm, D material: 1.67 mm. Figure 9 shows the relationship between the mean particle size and the magnitude of the T.P. The solid line indicates the TL from experimental test by Kim et al. (2012). The magnitude of the T.P for the \(d_{50}\) of 0.89 mm in the TL is 1.80 mm. As shown, it is found that the results of T.Ps of each material are placed on the TL, and the maximum difference between the TL and the T.Ps of each material is 0.13 mm. Thus, it can be concluded that because there is no the variation of magnitude of the T.Ps according to the fine and gravel grain contents through the results of the DEM simulation on the DST, the TL is valid as a standard for the opening between shear boxes.

4 CONCLUSIONS

The validity of the TL as a standard for the opening between shear boxes in this study was examined using the DEM simulation. The results of the T.P in the DEM simulation according to the opening sizes of 0.0, 0.2, 0.5, 1.0, 2.0, 3.0, and 4.0 mm between shear boxes, and the fine and gravel grain contents were compared to the TL. The conclusions could be summarized as follows:

(1) The shear behaviors of the DST in the DEM simulation were similar to those of the experimental test by Kim et al. (2012). Thus, the reproducibility of the DEM simulation to the DST could be confirmed. It can be said that the study on the opening between shear boxes in the DST using the DEM simulation is valid.

(2) It was found that the results of T.Ps of each material are placed on the TL, and the maximum difference between the TL and the T.Ps of each material is just 0.14 mm. Thus, it could be concluded that because there is no the variation of magnitude of the T.Ps according to the fine and gravel grain contents, the TL is valid as a standard for the opening between shear boxes in the DST.

(3) For the securement of more objectivity on the TL, the additional DEM simulation using the smaller mean particle size than 1.25 mm might need.

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