Evaluation of arching effect in 3-dimensional trap-door problem with X-ray CT and DEM

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１．Introduction

Arching effect is a universal phenomena taking place in granular materials and among them in soils. The arching mechanisms have been widely studied by means of the trap-door problem. Trap-door problem has been investigated experimentally and theoretically by many authors[1]. However, the difficulty of observing the mechanisms occurring during trap-door tests performed in other conditions than plane strain conditions made that experimental trap-door problem in 3-dimensions were not investigated. The purpose of this study is to conduct experimental trap-door tests in the active mode and in 3-dimensions. These tests were conducted using X-ray CT, with a square shaped trap-door, and experimental results were compared to numerical results obtained with the Discrete Element Method (DEM). The exact conditions of the experimental tests were reproduced with the numerical model: model size, granular material characteristics and testing process.

２．Methods

Experiments

Fig.1 shows an acryl cylindrical container. This container had an inside diameter of 240mm and was supported by a horizontal steel plate under which the trap-door displacement device was placed. The trap-door hole (40mm×40mm) was created in the acryl bottom plate, placed inside the container and laying on the steel plate. The steel plate was fixed on the displacement control device. The granular layers were composed on glass beads of diameter, 6±0.2mm as shown in Photo1. The density of these glass beads is γ_g=2.52g/cm^3. The minimal and maximal void ratios were measured as following: e_{min}=0.562 and e_{max}=0.661. Trap-door tests were performed on granular layers with a void ratio equal to e_{min}. After the preparation of the glass beads sample in the container, the whole container was placed and fixed on the turn-table of the scanner. For the CT scanning, the specimen was scanned with a 1mm attenuation width of x-ray beam. The total number of voxel in each CT image obtained was 2048×2048, so that the size of a single voxel of the CT image was equal to 73.2×73.2(μm) in plane and with 1000μm in height. The specimen was scanned in different states corresponding to different displacement steps: δ=0mm (initial state), δ=2mm, δ=5mm and δ=10mm.

Discrete Element Method

The DEM used here is based on the molecular dynamics[2], and the software used here is called SDEC. The rigidity of the contact is modeled by allowing particles to overlap at their contact point without any deformation of the particle itself. In order to evaluate the dispersion of the results obtained with numerical analysis, 3-dimensional trap-door tests were performed in the same testing conditions. Contact parameters were set by fitting the response of the glass beads to a triaxial compression test.

３．Comparison of X-ray CT and DEM results

The evolution of the force on the trap-door as the trap-door moved downward is given on the Fig.2 for experimental and numerical results and the vertical error bars represent the standard deviation obtained at the measurement point for each series of test made in similar condition. The evolution of the force on the trap-door is very similar for the experimental tests and for the numerical analysis: as soon as the trap-door is moved downward until δ=0.1mm, the force on the trap-door decreased suddenly from its initial value 75% of decrease for experimental results and 80% of decrease in the numerical results. The phase of force decrease continue until a trap-door displacement δ=2.0mm. The minimal force on the trap-door is then very similar for both methods: 0.22N for the experimental tests and 0.26N for the numerical tests. Then, as the trap-door displacement increases (δ>2.0mm), the force on the trap-door starts to increase until the end of the test. For δ=5.0mm and δ=10.0mm, experimental and numerical results are very similar. However for δ=20.0mm, a difference can be noticed between the two results: the force on the trap-door was smaller in the experimental tests than in the numerical analysis. It means that the load transfers in the granular layer are more efficient in the experimental conditions.

As the trap-door is moved downward, the granular material progressively expands above the trap-door. This expansion process starts at the vicinity of the trap-door at the bottom of the granular layer and propagates towards the top surface of granular layer, as the trap-door displacement increases. A 3-dimensional reconstruction of the failure zone was made from the series of horizontal cross sections. The 3-dimensional views are displayed in Fig.3 and allowed to calculate the volume of the granular

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material affected by the trap-door displacement. The disturbed zones extracted from experimental results and from numerical results are found to be very similar in shape but also in volume (see Fig.3). This good agreement can be obtained for all values of the trap-door displacement values δ =2, 5, and 10mm.

４．Conclusions

A comparative study of the trap-door problem in non-plane strain conditions but 3-dimensions conditions was conducted involving experimental tests and DEM modeling. The use of X-ray CT was very efficient for observing the local phenomena occurring in the glass beads layer in 3-dimensions. In parallel, a numerical modeling of the experimental model test was developed using Discrete Element Method. The numerical analysis reproduced exactly the tested material of glass beads.

References

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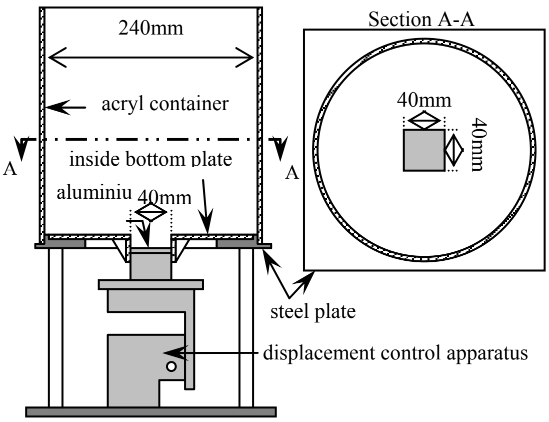

Fig.1. Configuration of trap-door apparatus

Photo 1. Trap-door apparatus

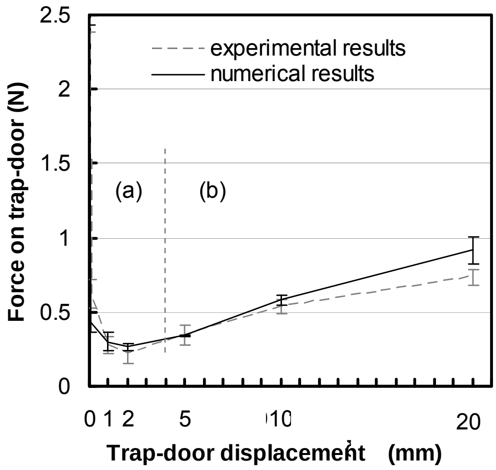

Fig.2. Force-displacment relationship

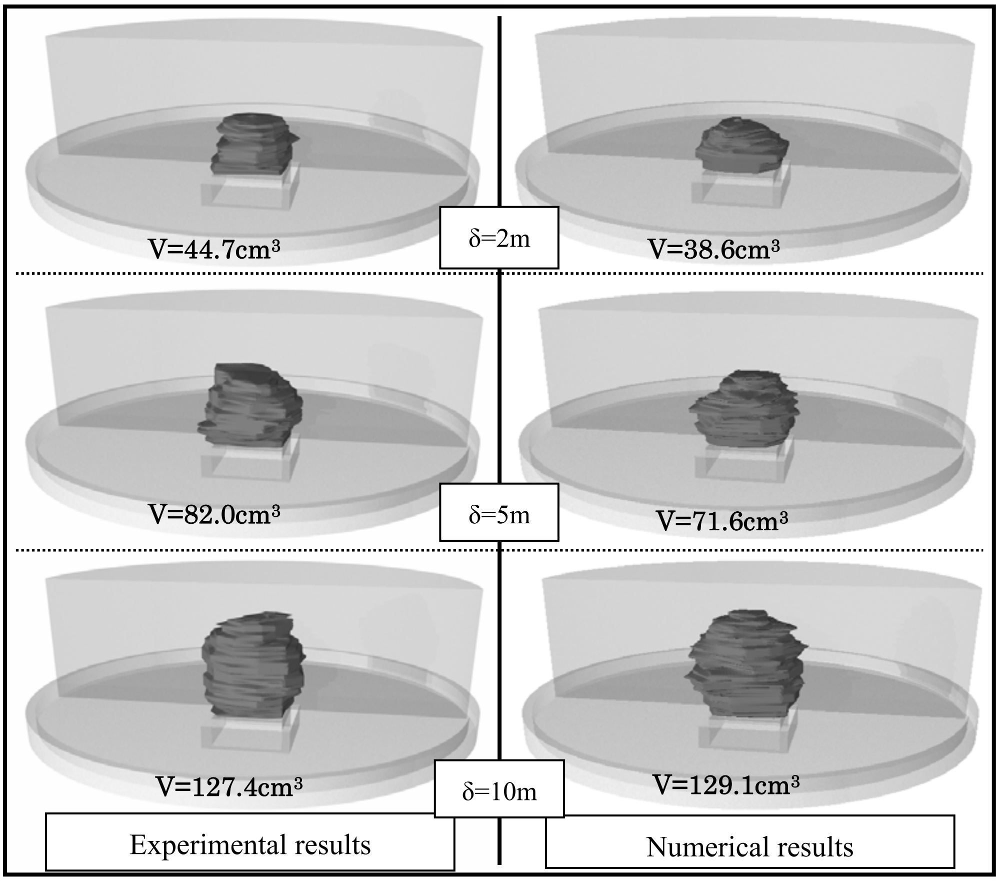

Fig.3. 3-dimensional view of the disturbed area for different displacement steps of the trap-door