LAT/PSC Test for Microscopic Observation of Three-Dimensional Granular Fabric

by

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1. INTRODUCTION

A granular material with a zero or weak bond among particles never behaves like a continuous medium. Thus, in order to understand its fundamental behavior, it is necessary to study dynamic changes in the interior granular fabric during deformation. With keeping this objective in mind, Konagai et al. (1992, 1994, 1998)[1), 2), 3)] developed a new experimental method, Laser-Aided Tomography (LAT), which is capable of visualizing an interlocking structure of fine to coarse particles in a three-dimensional model. In LAT experiments, particles made by crushing a block of optical glass are arranged to make a structure model, as a heap, in a water tank filled with a liquid having a refractive index equal to that of glass. Glass particles, when immersed in this liquid, are invisible because they have the same refractive index. However, all the particles start illuminating at their surfaces when an intense laser-light sheet (LLS) is applied to the model. This is because the crushed surface of glass has slightly different optical properties from the intact glass. By scanning the model with LLS, we can visualize particles in three-dimensions.

LAT itself does not allow for detecting a stress state in a three-dimensional model. However, if the method is applied to such conventional geotechnical tests as Plane-Strain Compression Test (PSC test) and Triaxial compression test, one will be able to discuss the overall behavior of a granular assemblage with clear boundary conditions as well as microscopic parameters provided. This paper describes a new PSC test with the LAT technique implemented.

2. LAT/PSC TESTING SETUP

Figure 1 shows the setup of the LAT/PSC testing device. The structure of the device is basically identical to that of a conventional device. Glass grains are piled up in a mold assembled in rectangle on the pedestal of the testing device to prepare a specimen wrapped up in a rubber membrane. One side of the membrane however is cut out, and the four sides of the rectangular opening are pinched in a pair of acrylic plates serving as a window for observing the interior granular fabric. The specimen is eventually mounted on a transparent acrylic pedestal that

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allows an intense laser light sheet (LLS) to be transmitted through it. The void of specimen is then filled with carbon dioxide that easily dissolves in the mixture of silicone oils for LAT experiments. Silicon oils are mixed such that the refractive index of the mixture becomes identical to that of the glass. The liquid is then vacuum-pumped to remove air or gas from it. The above procedure allows the specimen to be highly saturated with few air bubbles entrapped in it. A flat mirror was put beneath the pedestal at an angle of 45° with respect to the light path from the laser. This mirror, reflecting the light from the laser right upon the specimen, moves back and forth in the direction of the specimen's depth, allowing the specimen to be thoroughly scanned.

Grass grains were initially prepared by crushing optical glass blocks. This method however produces very angular grains which shapes have little in common with those of natural sands and gravels. Therefore, the crushed grains were ground by using a ball mill. A 2D projection of a grain shape can be described in terms of the radial distance r from a point on the perimeter to the center of gravity of the grain's projection. This r is a function of θ in the polar coordinate, and is given by:

$$r(\theta) = \frac{b_0}{2} + \sum_{k=1}^{\infty} \{a_k \sin k\theta + b_k \cos k\theta\} \quad (1)$$

where, k is the number of ups and downs of the grain's surface. Fourier amplitude spectra c_k ($= \sqrt{a_k^{\ 2} + b_k^{\ 2}}$) of a ground glass grain are shown for different times of grinding (**Figure 2**). It is clear from this figure that the shape of the grain becomes more similar to that of a natural grain as the time of grinding increases.

3. EXPERIMENTS

An assemblage of glass grains having a representative size of 6 mm was sheared under a confining pressure of 30 kPa. **Figures 3** and **4** show respectively the variations of deviator stress and volumetric strain with respect to axial strain. It is noted in **Figure 3** that a stick and slip phenomenon becomes more pronounced as the axial strain increases, the phenomenon seems to be accompanied by a steep increase of the assemblage volume (**Figure 4**). This noticeable dilation is due to the development of a thick shear band, which is strongly affected by the sizes of grains making up the assemblage.

Figure 5 shows a visualized cross-section of the specimen. From this picture, the void ratio is calculated to be 0.76. This value is larger than 0.68, the void ratio obtained from a conventional method in which the effect of membrane penetration is not taken into account.

As has been mentioned, scanning the specimen with the laser-light sheet allows 3D image of grain's shape to be visualized. The specimen was scanned at a regular interval of 1 mm, and the obtained 3D image of some arbitrarily chosen grains in the interior of the specimen is shown in

Figure 6a. After the specimen was sheared, the grains were pushed down, and moved away from one another (**Figure 6b**). This deformation is accompanied by rotations of grains. As the axial strain of the specimen increases, the grains become more and mode sidelong-oriented

4. SUMMARY

A new visualization technique, Laser-Aided Tomography (LAT) enables us to observe individual grain's behavior in the interior of a granular structure model. The method has been continuously improved since it first was worked out in 1994, and with the enhanced capability of the method and its relevant techniques, LAT was applied to a conventional Plane Strain Compression (PSC) test. Though the realized setup for the testing is basically identical to that for a conventional PSC test, some new contrivances allowed for observation of each grains shape and motion in the interior granular fabric as well as the observation of overall behaviors of the granular assemblage.

ACKNOWLEDGMENT

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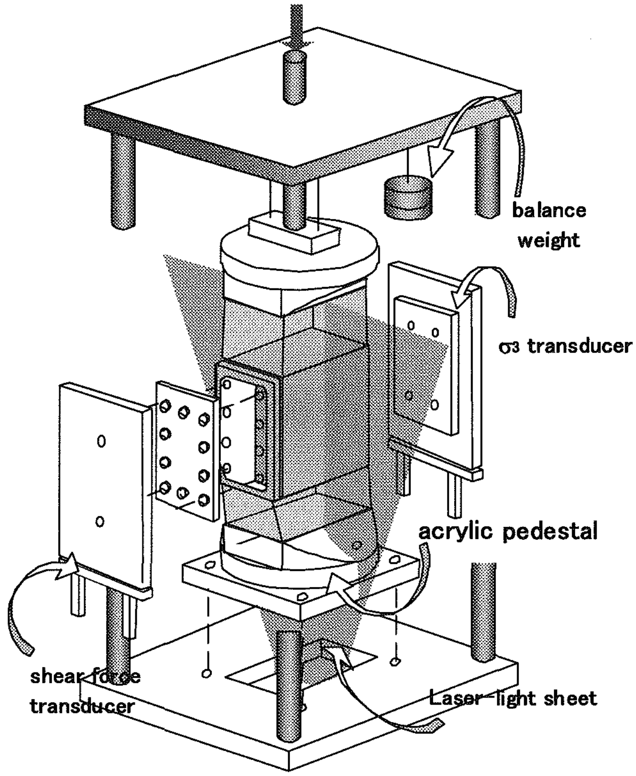


Figure 1 LAT/PSC testing setup

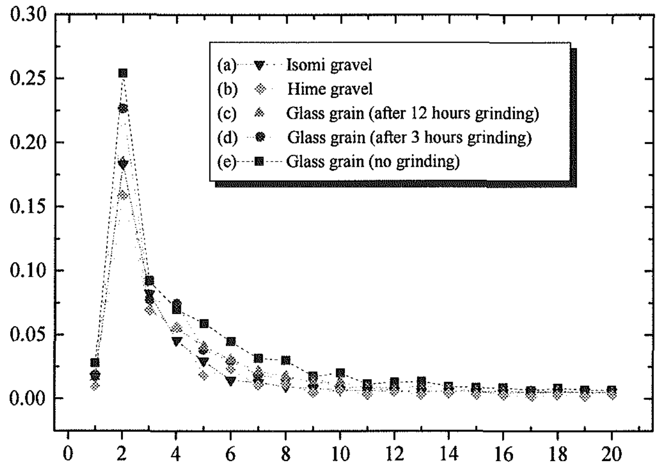


Figure 2 Fourier spectrum c_k

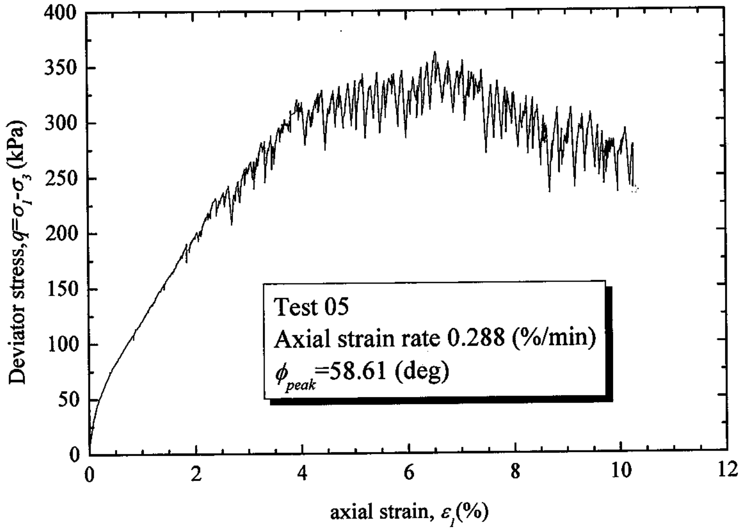


Figure 3 Deviator stress - axial strain relationship

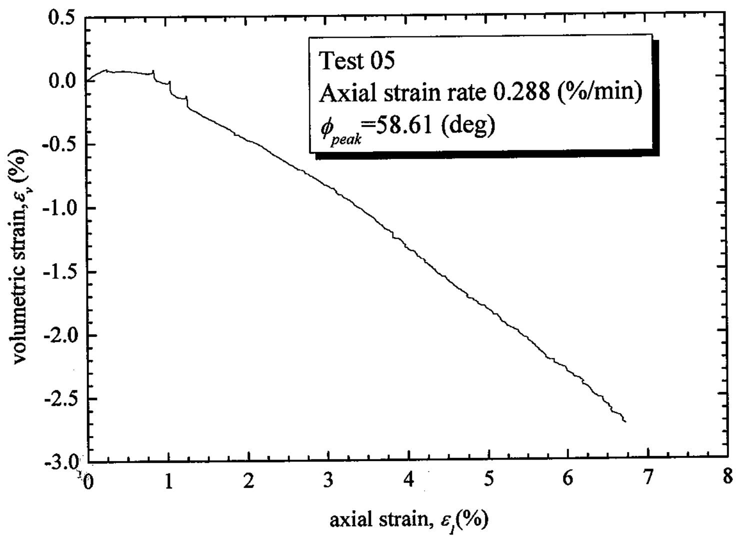
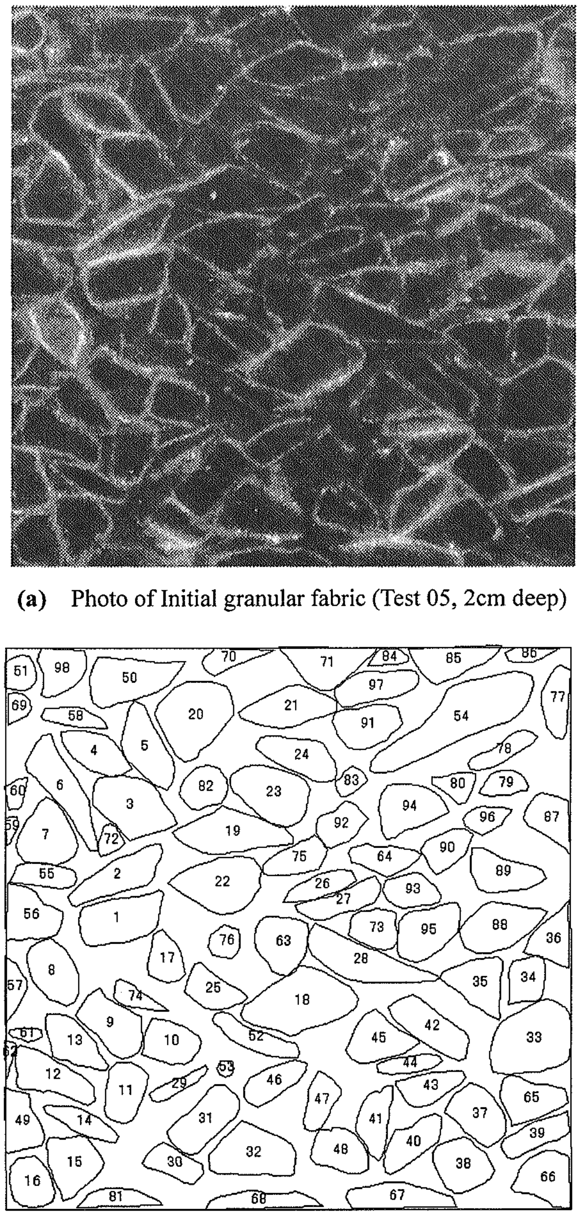


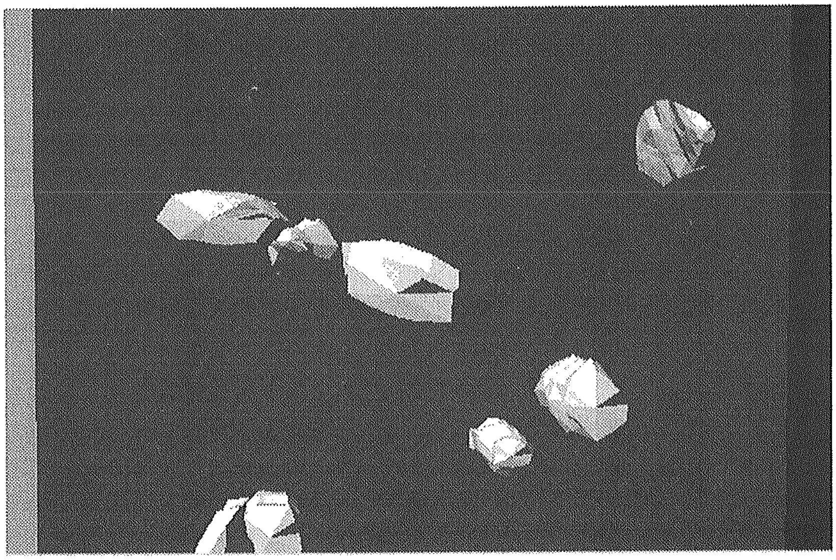
Figure 4 Variation of volumetric strain with axial strain



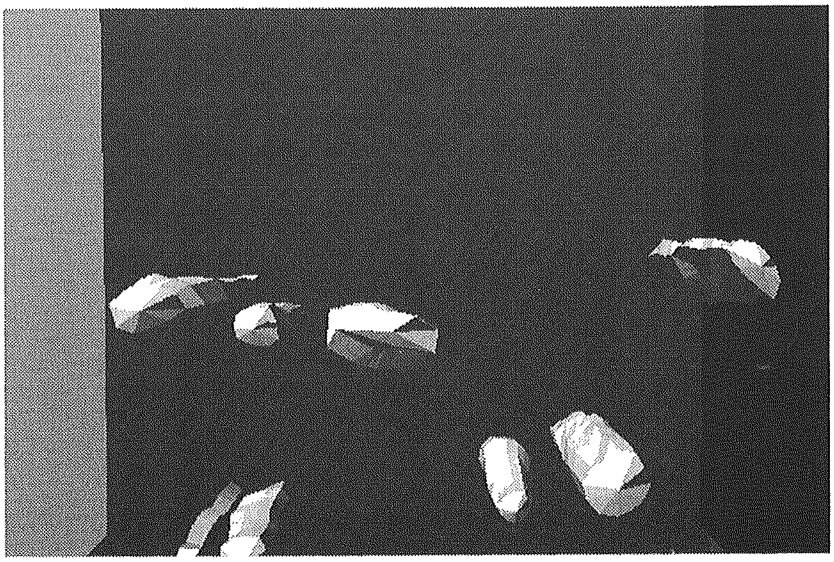
(a) Photo of Initial granular fabric (Test 05, 2cm deep)

(b) Detected perimeters

Figure 5 Visualized cross-section of specimen



(a) Before shearing



(b) After shearing

Figure 6 3D image of interior grains (Test 05)