Digital Image Measurement System for Soil Specimens in Triaxial Tests

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Abstract. In order to measure the deformation distribution over the entire surface of soil specimens in triaxial tests, a digital image technique is developed by use of a complementary metal-oxide-semiconductor (CMOS) camera and two mirrors to obtain the deformation field and the strain field of the whole surface of the specimen. Two sets of circular light-emitting diode (LED) lights are placed on the top and the bottom of the pressure chamber. A shading box seals the camera and the plate glass in front of the chamber to ensure an unchanged lighting environment. The process of data processing involves the error check, the expanding and the splicing of the images, and the calculation of the strain in each element. The measurement precision of the strain is approximately $10^{-4} \sim 10^{-5}$. And then, the application of this digital image processing technique is introduced in the study of shear band problem, membrane embedding problem, the heterogeneous soil, the end contact and end constraint, and so on. At last, based on the digital image measurement system, a series of geotechnical test instruments have been developed, including: (1) Advanced triaxial compression test apparatus; (2) Bidirectional dynamic triaxial apparatus; (3) High pressure triaxial compression apparatus; (4) Plane strain compression apparatus; (5) Unsaturated soil triaxial compression apparatus; (6) Frozen soil triaxial apparatus; (7) Asphalt concrete stress-strain apparatus; (8) Hydrate triaxial apparatus; (9) Soft material testing machine.

Keywords: Digital image measurement system · Deformation field
Measurement precision · Geotechnical test instruments

1 Measurement of the Deformation Distribution over the Entire Surface of the Specimen

The digital image technique is applied to deformation measurements on the surface of the specimen. In this approach, a complementary metal-oxide-semiconductor (CMOS) camera and two mirrors are used to capture images of the entire surface of the specimen. The specimen is wrapped in a black rubber membrane, on which white squares are printed, i.e., the surface of the specimen is meshed, and the nodes of the black and white grid on the images can be recognized using a sub-pixel corner

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detector algorithm. The hardware of the measurement system is composed of a redesigned pressure cell, the CMOS camera, a camera bracket and a shading box (shown in Fig. 1). The coordinates of the element nodes on the entire surface of the specimen are recorded during the test. The recorded data are processed in five steps [1, 2].

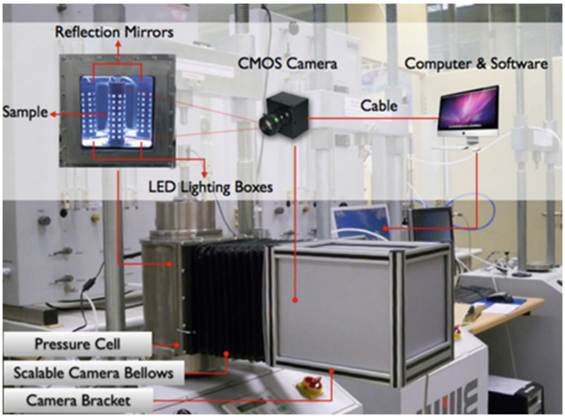


Fig. 1. Hardware of the measurement system.

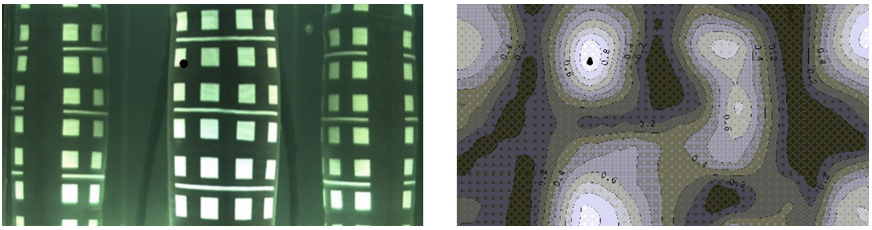
To confirm the reliability of the deformation measurement results, the measurement precision was estimated by comparing the strain measurement results from the digital image system with that from the strain gauges and comparing the volume change results with that of the drainpipe. The measurement precision of the strain is approximately $10^{-4} \sim 10^{-5}$.

2 Application of This Digital Image Processing Technique

The application of this digital image processing technique is introduced in the study of shear band problem, membrane embedding problem, the heterogeneous soil, the end contact and end constraint, the constitutive model, and so on.

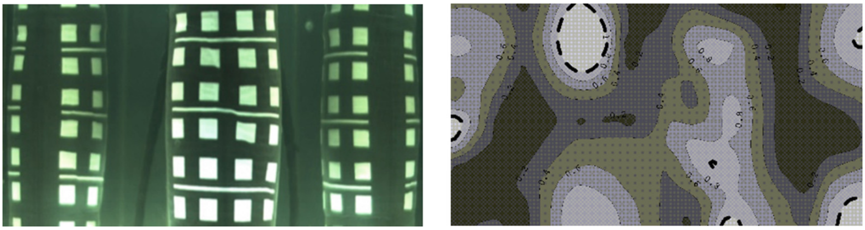
2.1 Shear Band Problem

The deformation distribution over the entire surface of the specimen is obtained by digital image measurements during triaxial testing. The strain distribution is derived from the measured deformation, and the stress distribution is then calculated based on the strain, Young's modulus and Poisson's ratio. Furthermore, the stress level S of any point on the surface of the specimen is evaluated. Figures 2, 3 and 4 show that the shear band began at a point, then expanded gradually, and become the penetrated shear band.



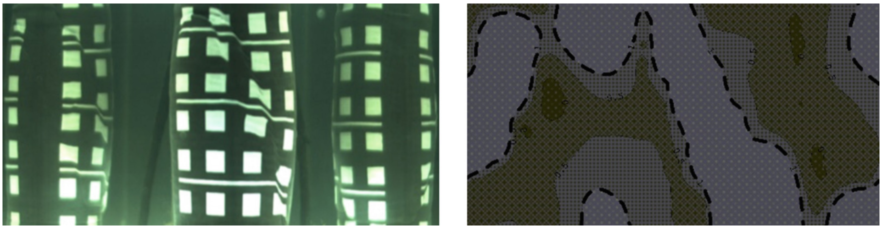
(a) Image of the specimen (b) stress level contours

Fig. 2. Image of the specimen and stress level contours in the pre-failure state.



(a) Image of the specimen (b) stress level contours

Fig. 3. Image of the specimen and stress level contours in the in-failure state.



(a) Image of the specimen (b) stress level contours

Fig. 4. Image of the specimen and stress level contours in the post-failure state.

2.2 Membrane Embedding Problem

The problem of membrane embedding can be studied quantitatively based on digital image system. The relation between the membrane embedding and its mainly influence factor, such as σ3, d50, as shown in Fig. 5. The formula of membrane embedding volume is put forward.

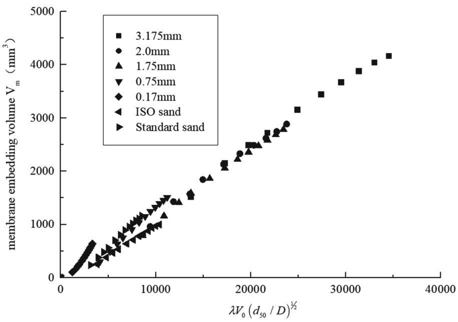


Fig. 5. Membrane embedding volume and $\lambda V_0 (d_{50} / D)^{1/2}$.

2.3 Heterogeneous Soil

A systematic study on the mechanical properties of the layered soil specimen under different conditions can be conducted. By comparing different test results from the single soil specimen and the layered soil specimen, the effect of the layered specimen on the deformation and the shear strength of the single soil specimen can be obtained.

2.4 End Contact and End Constraint

Based on qualitative analysis of local deformation characteristics, strain non-uniformity coefficient is defined and calculated, this, quantitative comparisons are then given out for local deformations along specimen height.

3 A Series of Geotechnical Test Instruments Based on the Digital Image Measurement System

Based on the digital image measurement system, a series of geotechnical test instruments have been developed, including: (1) Advanced triaxial compression test apparatus; (2) Bidirectional dynamic triaxial apparatus; (3) High pressure triaxial compression apparatus; (4) Plane strain compression apparatus; (5) Unsaturated soil triaxial compression apparatus; (6) Frozen soil tri-axial apparatus; (7) Asphalt concrete stress-strain apparatus; (8) Hydrate tri-axial apparatus; (9) Soft material testing machine.

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