Development of new triaxial compression test apparatus for geomaterials on industrial X-ray CT scanner

Dévéloppement d'un nouvel appareil d'essai de compression triaxial pour les géomatériaux monté sur un scanner industriel CT à rayon-X

J.Otani & T.Mukunoki – *Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan*
M.Yoshimura – *Fukuoka Prefectural Government, Fukuoka, Japan*

ABSTRACT: A new triaxial compression apparatus is developed on the purpose of the use of industrial X-ray CT scanner. A series of nondestructive tests using X-ray CT scanner are conducted consecutively during triaxial compression without moving out this new apparatus from the shield room in the system of the scanner. Based on those test results, the developed apparatus gives fairly reasonable results as a triaxial compression test apparatus and the progressive failure with progressing strain localization is visualized using CT images. Finally, it is concluded that the proposed test apparatus makes the characterization of the failure possible in the soil without any destructions.

RÉSUMÉ: Un nouvel appareil de compression triaxiale a été développé dans le but de l'emploi du scanner industriel CT à rayons X. Une sèrie d'essais nondestructifs utilisant le scanner CT à rayon X a été conduit consécutivement durant la compression triaxiale sans sortir ce nouvel appareil du compartiment protecteur contenu dans le systéme du scanner. En se basant sur les résultats de ces essais, l'appareil développé donne des résultats raisonnables comme un appareil d'essai de compression triaxiale et la rupture progressive avec la localisation du front des deformations est visualisée en utilisant les images CT. Enfin, il est conclu que l'appareil d'essai proposé permet la caractérisation de la rupture dans le sol sans aucune destruction.

1 INTRODUCTION

It has been discussed that a failure mechanism of the ground or soils is related to its local deformation or so called "strain localization" of the soils. Desrues et al. (1996) used X-ray CT scanner in geotechnical engineering but their machine was the medical use, so that their results were not enough to discuss quantitative point of view. Authors have characterized the failure in the soils more quantitative sense using industrial X-ray CT scanner, in which the voltage of x-ray tube is much higher than that of medical one (Otani et al., 2000). However, the specimen had to be moved after every scanning from the shield room because of the luck of special apparatus for this X-ray CT scanner. Besides, more realistic stress condition such as triaxial compression should be expected.

The purpose of this paper is to develop a new triaxial compression test apparatus for the industrial X-ray CT scanner and the progressive failure with strain localization in the soil under triaxial compression is characterized using this new apparatus.

2 NEW TRIAXIAL COMPRESSION TEST APPARATUS

A system of industrial X-ray CT scanner is shown in Fig.1. Here, in order to obtain the reliable results by scanning, compression test should be conducted on the specimen table in the shield room as shown in Fig.1 and besides, all the operations have to be conducted from outside of this room. A new triaxial compression test apparatus for the industrial X-ray CT scanner is developed under those conditions. Figure 2 shows a new triaxial compression test apparatus developed in this study. The highlights of this apparatus are summarized as follows:

1) In order to set this apparatus on the specimen table in the shield room, in which this table moves transversely and rotationally during scanning of the specimen, this apparatus should be light weight which is maximum of 1000N made of duralumin mainly and compact size enough to conduct on this specimen table.
2) The applied load is reacted by only pressure cell wall made of acryl and is counteracted in the apparatus, so that the self-weight of the apparatus is only applied on the specimen table of the X-ray CT scanner.
3) In order to scan the specimen horizontally during triaxial compression, it should be no obstacles such as steel bars around the compression cell. This is because the CT images are interrupted by those materials.
4) All the operations for this apparatus are conducted using personal computer from outside of the shield room and the whole process of the loadings is memorized.
5) The loading is stopped during scanning of the specimen, in which the scanning time of each one cross sectional image takes about 5 minutes.
6) As shown in Fig.2, all the equipments for measurements with their leads put on the top of this apparatus, so that the images are not interrupted by those equipments.

3 VERIFICATION

First of all, the loading system was verified using dummy specimen made of spring. The size of this specimen was the diameter of 50mm and the height of 100mm. The spring constant of the specimen was 82.9N/mm. The test using this apparatus was conducted under strain control, so that the input velocity of applied displacement and the value of load transfer were checked with the results of testing. Figure 3 shows the confirmation of the velocity of applied displacement while Figure 4 shows the load-displacement relationship. Here, in order to check the accuracy of the results, the loading test was conducted five times. For the compression test in the CT scanner, the loading has to be stopped in order to scan the specimen. Thus, it is noted that this loading was stopped at the strain levels of 3mm and 6mm for 30min during compression. All the results show the error of less than 1%, so that it is considered that the loading system is well checked quantitatively. Therefore, it is confirmed that the loading system produces the reliable results and the reappearance of the results is also proved.

The accuracy of the test results was also examined by comparing with those by conventional compression test apparatus. The consolidated undrained (CU) test was conducted using Ariake clay, which has been known as one of soft clay deposited around Ariake Bay in Kyushu, Japan. Figure 5 shows the comparison between two results of stress-stain relationship. Each test was conducted twice in order to check the accuracy. Both results are fairly close and the effectiveness of the proposed apparatus is verified.

4 TEST PROCEDURE

A series of nondestructive tests using X-ray CT scanner were conducted during triaxial compression at the strain levels of initial, 3, 6, 9, 12, and 15% without moving out the new apparatus from the CT room (Yoshimura, 2000). The soil specimen used in this test was Toyoura Sand whose size was 50mm diameter and 100mm height with the density of 1.5 t/m^3. The triaxial compression test was conducted under CD (Consolidated Drained) condition and several test cases in terms of different confining pressure were conducted (Case 1: 24.9 kPa; Case 2: 49.1 kPa and Case 3: 73.6kPa). The test procedure is summarized as follows:

1) After consolidating the specimen under the same pressure as the confining pressure, the initial condition of soil specimen was scanned before applying the compression.
2) The specimen was compressed under strain control and is unloaded at the strain levels of 3%. Here, in order to take the effect of stress relaxation, the specimen was unloaded until the deviator stress is zero. Then, the nondestructive test using X-ray CT scanner was conducted. After finish scanning, the specimen was reloaded until the strain level of 6%. Here, the total number of cross sections was 5, which are the locations of the heights of 10, 25, 40, 55, and 70 mm from the bottom of the specimen.
3)The same process of above step 2) was continued until the strain level of 15% in every 3% strain.

The result of CT scanning is spatial distribution of so called "CT-value" and those are the representative values for the material density. CT images are also obtained using those values, which are presented with shaded gray or black color for low density or white color for high density with total of 256 levels.

5 RESULTS AND DISCUSSION

Figure 6 shows the result of stress-strain relationship with volumetric strain for Case 2. The meanings of step A, step B, step C, step D, and step E in the figure indicate the locations of the strain levels 3, 6, 9, 12 and 15 % respectively where the CT scanning was conducted. There is a peak stress at the strain level of around 7 % and it is realized that the volume of the specimen decreases at the strain level from initial to the stage of 3 % and increases afterwards. As realized easily, the total behavior is the cyclic one and is nothing different with those of conventional apparatus. Thus the usefulness of this proposed apparatus can be confirmed.

Figure 7 shows the cross sectional images of each strain level at five cross sections for Case 2. The relatively dark area in the image is the area of low density. As realized from those images at the initial condition, there is a dark area around the center in some of the cross sections and this reason is that the specimen is not homogeneous due to insufficient saturation. Meanwhile, the other type of the area of low density appears in the images from step B at the height of 10 mm. This can be considered to be the area of strain localization. It is easily observed from this figure that the local shear banding starts from the bottom of the specimen at the strain level of step B which is the right before the peak stress, although the shear band can not be observed from outside of the specimen. The shape of this local shear band in the cross section is the same as that of circumference of the specimen at the bottom of the specimen and this strain localization propagates upwards towards the top of the specimen as the strain increases. It is also observed that the total failure surface as a result of progressing the local ones appears after the peak stress condition, which is the strain level of step D.

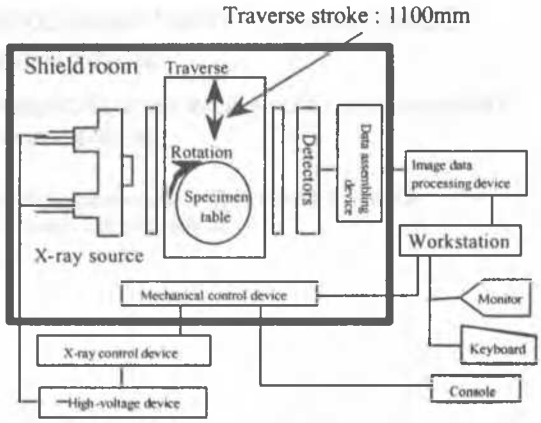


Figure 1. System of Industrial X-ray CT scanner.

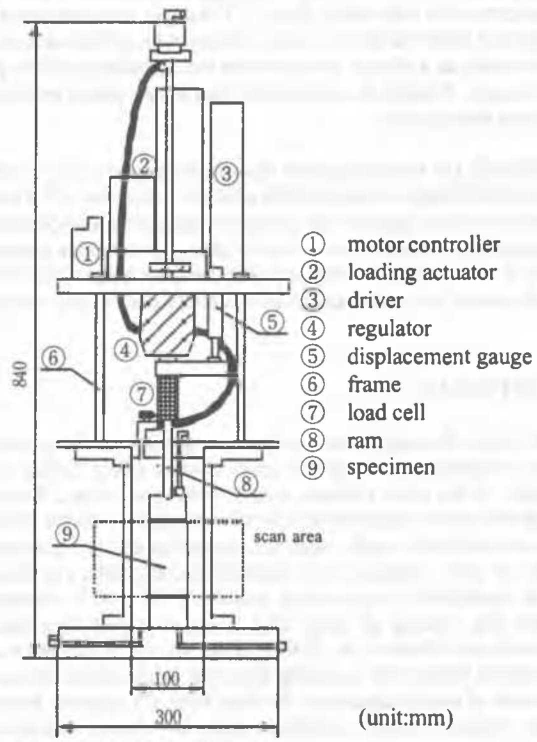


Figure 2. New test apparatus.

Figure 8 shows the distribution of the CT-value for every strain levels (from initial to step E) at the cross section of the height, 25 mm for half cross section in the specimen. As realized from this figure, the density at around the location of 15 mm from the center decreases locally as the strain level increases and this phenomenon shows the progress of the shear band in the cross section. Here, it is interesting to note that the start of the decrease of the density at that area is observed at even the strain level of step B although the CT image shown in Fig.7 (at 25 mm with step B) did not show any localization in that cross section. Thus, more precise discussion on the progress of the shear band could be possible using the distribution of CT-value in the specimen. Figure 9 shows one of examples of vertical cross-sectional images at both initial and the end of test. As easily realized, the area of low density around the top of the specimen is the origin of shear banding but the progress of local shear banding is interrupted by another failure surface at the end of the test as shown in Fig.9(b). Figure 10 shows the graphical images of the total failure surface for two cases (Case 1 and Case 2) at the end of the test, which is the strain level of step E. These results were obtained using the data of the six cross sectional images using computer graphic software. It is easily realized that

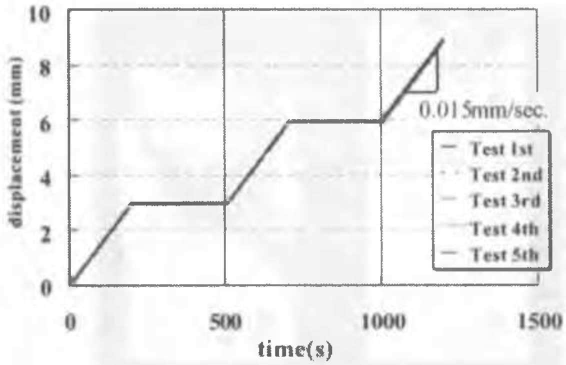


Figure 3. Verification of loading system (velocity of the loading).

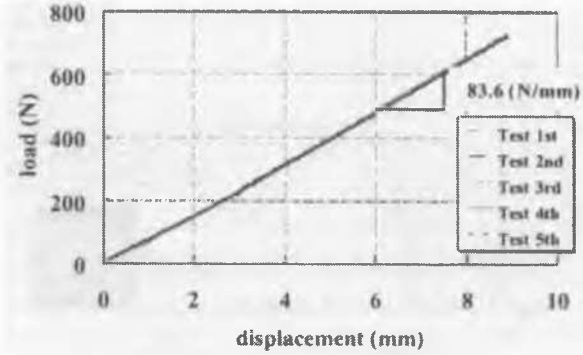


Figure 4. Verification of loading system. (load-displacement relationship).

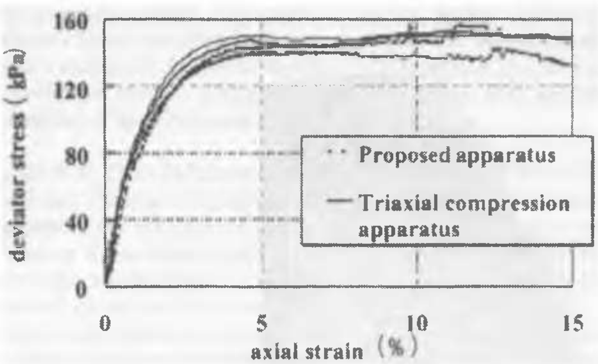


Figure 5. Comparison with conventional triaxial compression apparatus.

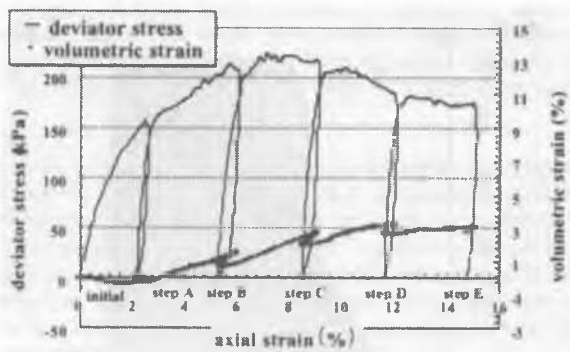


Figure 6. Stress – strain relationship with volume change.

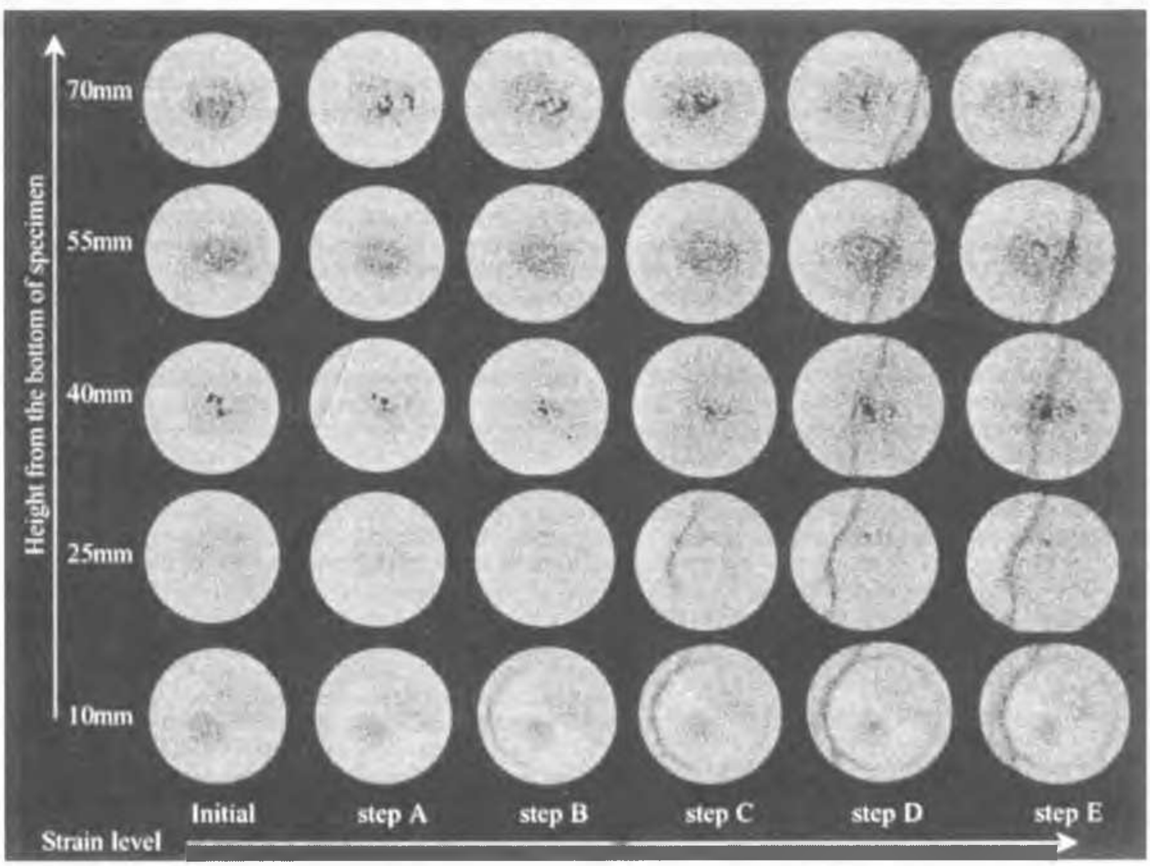


Figure 7. Cross sectional images of the specimen for Case 2.

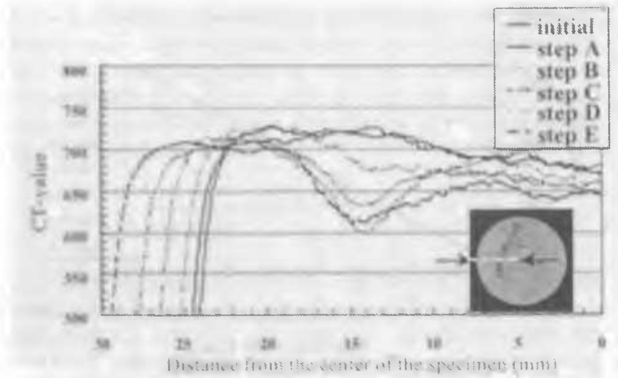
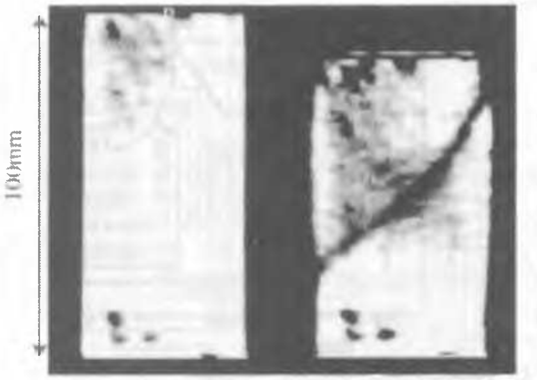
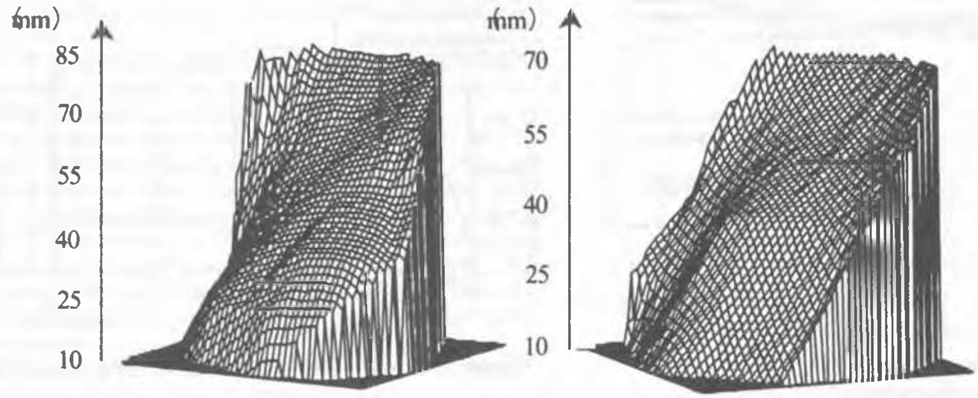


Figure 8. Distribution of CT-value for half cross section at the height of 25mm for Case 2.



(a) initial (b) step E

Figure 9. Vertical cross sectional images for Case 3.



(a) Case 1 (b) Case 2

Figure 10. Graphical images of failure surface.

the shape of the failure surface is clearly reconstructed and this is not plane surface but the complicated curved surface. It is interesting to note that the shapes of total failure surface at the cross section of both top and bottom of the specimen are the same as those of the circumference of the specimen. It can be considered that this is because the shape of the specimen is deeply involved.

6 CONCLUSIONS

A triaxial compression test apparatus for the industrial X-ray CT scanner was newly developed and the progressive failure with strain localization in the soil was characterized without any destruction using this new apparatus.

Finally, it is concluded that the progressive failure in the soil could be precisely discussed without any destruction in three dimension using industrial X-ray CT scanner and the newly developed triaxial apparatus made it possible. It is also confirmed that the possibility of the other applications of this apparatus could be highly expected.

AKNOWLEDGEMENT

The system of industrial X-ray CT scanner used in this study is a property of the group of Rock Engineering at the Department of Civil and Environmental Engineering, Kumamoto University, Japan. The authors would like to express their gratitude to Prof. Yuzo Obara and Prof. Katsuhiko Sugawara who gave us the opportunity to use this valuable apparatus.

REFERENCES

Desrues,J., Chambon,R., Mokuni,M. and Mazerolle,F. 1996. *Void ratio evolution inside shear bands in triaxial sand specimens studied by computed tomography*, Geotechnique: 46:3, pp.529-546.

Otani, J., Mukunoki,T. and Obara,Y., 2000. *Application of X-ray CT Method for Characterization of Failure in Soils*, Soils and Foundations Vol.40, No.2, pp.111-118.

Yoshimura,M., 2000. *Development of new triaxial compression apparatus for X-ray CT scanner and visualization of progressive failure in soils*, Master Thesis, Graduate School of Science and Technology, Kumamoto University (in Japanese).