

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Stress-strain behaviour of overconsolidated clay under plane strain condition

Miftahul Fauziah

Department of Civil Engineering,
Curtin University of Technology, WA, Australia

Hamid Nikraz
Department of Civil Engineering,
Curtin University of Technology, WA, Australia

Keywords: plane strain, triaxial, overconsolidated clay

ABSTRACT

The present modelling of soil failure in common usage tend to view the stress-strain behaviour of soil based on principles of continuum mechanics. The behaviour of soil is routinely interpreted from triaxial testing; whereas, testing of soil using the biaxial device would be more useful information, as more geotechnical problems basically occur in these situations. A new biaxial compression device has been used to investigate the stress-strain behaviour of overconsolidated clay. The plane strain apparatus, which was used in this study, is a modification of the conventional triaxial apparatus. Cell pressure from the triaxial compression test and a rigid loading platen are used to apply the minor (σ_3) and major (σ_1) principle stresses, respectively, to the clay specimen. The specimen is mounted inside the device, which fully restrains any out-of-plane deformation by the use of a pair of rigid Perspex wall. Some results of the testing are presented and compared with the known soil mechanical model. The device has been able to provide test results that are reasonably consistent with known soil behaviour.

1 INTRODUCTION

The failure of soil is an important basis of its mechanical behaviour. Experimental tests to determine constitutive behaviour of soil are based on the premise that the specimen deforms uniformly in spite of the fact that laboratory evidence of localization phenomena has existed for some time. The occurrence of such failure zones, therefore, affects the experimental techniques as well as the numerical implementation of the constitutive equations of soil.

Routine soil testing mainly using triaxial apparatus is carried out to obtain its mechanical properties in the laboratory. However, field problems involving geotechnical structures are often plane strain situations and hence data obtained from triaxial testing would not apply. It would be more appropriate using data from biaxial compression testing. Mochizuki et al. (1993) reported that when soil is tested under plane strain conditions, it, in general, exhibits a higher compressive strength and lower axial strain. Plane strain testing of soil was performed firstly by Kjellman (1936). Hambly and Roscoe (1969) who adopt this testing device found the "corner junction" problem. Wood (1958) and Cornforth (1964) proposed a long rectangular specimen for ease of controlling the plane strain condition. However, inaccuracy in the measurements of stresses and strains caused by the friction force arising from axial loading surface was found by Finn et.al.(1968), Lee (1970) and Marach et.al (1981) when they adopted this method. A plane strain test device using a rectangular sample of 84 mm x 76 mm x 53 mm was developed by Green (1971). However, Bishop (1981) pointed out that Green's method, which had the σ_2 loading surface suspended by wires, could not perform as expected. Most of the plane strain apparatus (Green and Reades, 1975; Mochizuki et.al., 1993; Drescher, 1990; Han and Vardoulakis, 1991; Viggiani et.al., 1994) had the common feature of using rigid walls and tie-rods to impose a zero strain boundary condition in one of the principle axes. This method was found to be satisfactory, and friction between the rigid wall and test specimen could be adequately mitigated. Taylor (1941), Rowe and Barden (1964), Lee and Seed (1964) and Bishop and Green (1965) found that if the aspect ratio (height to width) was bigger than 2, the effect of loading platen friction and the restraint of loading frame would be negligible.

The present study deals with the strain-stress of overconsolidated clay specimens by the use of biaxial compression device, although the fracture characteristics of brittle clay may also be determined by this test apparatus. Details of the apparatus, specimen preparation and data evaluation are presented in the following discussion. Some results of the testing will be compared with the known soil mechanical concept.

2 BIAXIAL COMPRESSION TEST

2.1 Testing apparatus

The testing apparatus used in this study was a modification of the conventional triaxial apparatus. The biaxial arrangement is placed in a cell, with the height of 300 mm, 200 mm internal diameter and 30 mm wall thickness. A specimen of initial width of 36 mm, height of 72 mm, and thickness of 72 mm, so that the aspect ratio is 2, is placed on the base pedestal where it is restrained laterally by two rigid Perspex plates to restrain its out-of plane movement. All biaxial surfaces which are in contact with the specimen are lubricated to offset the likelihood of scratching and reduced friction. The cell is filled with water to enable the specimen to be pressurized laterally by the use of the pressure generator for applying confining pressure.

A 5 kN capacity of submersible load cell is used to measure the axial load of the specimen. The axial displacements of the test specimen are measured by 35- mm range LVDT (Linear Vertical Displacement Transducer) attached on top of the top cover of the cell. For the purposed of measuring the applied cell pressure, back pressure and pore pressure of the specimen three pore pressure transducers were used and mounted to the base plate of the cell. The global volume change of the water-saturated soil specimens are monitored by an automatic volume change unit which is connected to the back-pressure line.

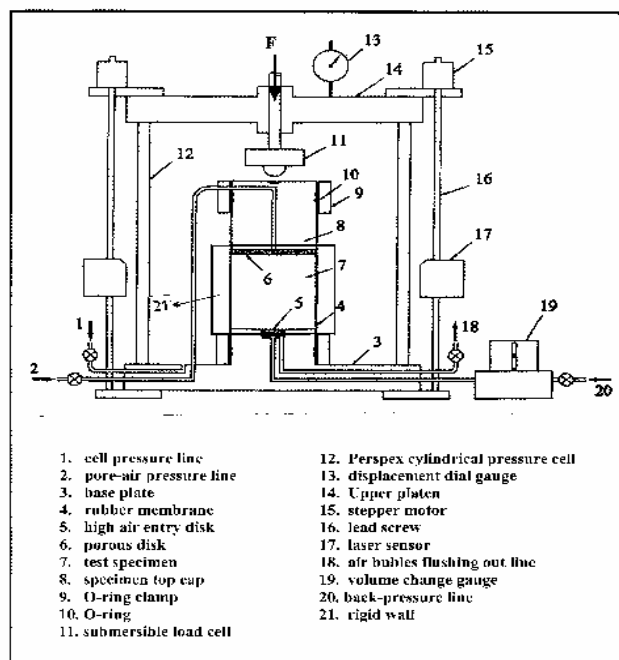


Figure 1 : Schematic diagram of the biaxial device

To record the displacement, loads, pressure and volume change reading a data acquisition system consisting of data logger and a set of microcomputer were used. A package software is used to

convert digital bit data from the ADU (Analogue digital Unit) to engineering units based on the calibration of the relevant measuring unit, which was done before running the plane strain test. A schematic diagram of the biaxial device used in this study is shown in Figure 1. The difference between triaxial and biaxial apparatus is that the specimen for biaxial test is restrained laterally by two rigid perspex plates, which make $\varepsilon_2=0$. Therefore, only major (σ_1) and minor (σ_3) principal stresses acting on the soil specimen.

2.2 Specimen preparation

Plane strain experiments have been performed on remoulded kaolin clay specimens. The source of clay used in this study was kaolin clay, with a specific gravity $G_s = 2.6$, Liquid Limit $LL = 53.5\%$ and plastic limit $PL = 30.76\%$.

It took a few weeks to complete the preparation of soil specimens. Initially, a kaolin clay sample was slurried to a uniform consistency of $1\frac{1}{2}$ times its liquid limit using an electrical soil mixer. A steel cylindrical mould with the height of 600 mm and 150 mm in diameter was used to consolidate the slurry using a hydraulic tester in over a period of one to two weeks which the maximum of 300 kPa was applied in three stages. Two circular perspexes were placed at both ends of the slurry in the mould to apply the pressure evenly to the slurry. The slurry was allowed to consolidate by its own weight and small pressure was applied to prevent the slurry being squeezed out between the circular perspexes and the mould. A higher vertical pressure was applied when there was no further settlement change. Once consolidated, the soil was extruded from the mould into lubricated formers. Following this, the specimen and the former were wrapped in a plastic film sheeting after sealing both their faces with liquid wax, and then left in the dehumidifier for at least 2 days until it is tested.

2.3 Tests procedures

The standard procedure either for consolidated-drained test (CD) and consolidated-undrained test (CU) triaxial testing was applied before the biaxial compression test was carried out (Head, 1986). Firstly, the specimen was saturated until the B-value of the specimen reached the value of 0.95-0.98; then it was consolidated by applying a back pressure of 300 kPa and the maximum of 700 kPa effective consolidation pressure, and followed by unloading process to reach the desire OCR in three stages. The specimen was then sheared by elevating the base of the confining pressure cell at a constant velocity of 0.04 mm/m for drained test (CD) and 0.08 mm/m for undrained test (CU). The specimen is loaded axially with the drainage line opened for CD specimen and closed for CU specimen. The Data were recorded at 5 minute interval and it was terminated at the axial strain of about 20 % or sooner. The primary data acquisition comprised the axial load, axial displacement, pore pressure, applied cell pressure, and volume change. From these data, the axial stress (σ_1), axial Strain (ε_1), deviatoric stress, (q), effective mean normal stress (p'), and other quantities of the following graphs have been determined.

3 TEST RESULTS AND DISCUSSION

The typical result given by two CD specimens, and two CU specimens, there were OCR20CD, OCR8CD, OCR16CU and OCR4CU for specimen with the value OCR of 20, 8, 16, and 4 respectively, will be discussed in the following discourse.

The strain softening response of the two specimens in the drained test are showed in Figure 2. The stress increases monotonically up to about 5.5 % and 7.8 % axial strain for OCR20CD and OCR8CD, respectively. A reduction in the shear strength after they reached peak stresses followed by strain softening to reach the critical state is the typical behaviour of overconsolidated clay when it is sheared. Compared to the specimen with the OCR of 8, the specimen with the OCR of 20 has lower stress because it was sheared under the lower confining pressure. Figure 3 shows the volumetric strain with axial strain of the drained specimens. The compressive volumetric strains are taken as positive. The tendency in plane strain test seems to be compressive volume change. Similar observations have been reported elsewhere (Mochizuki et.al., 1993; Lo et.al., 2000).

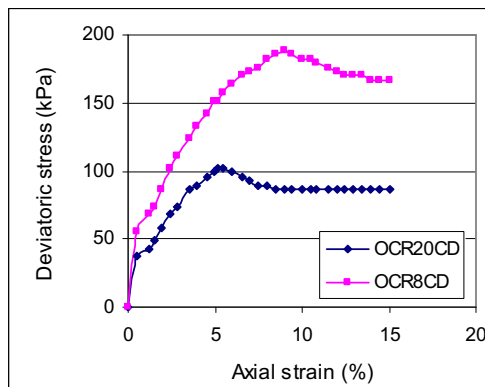


Figure 2: Stress-strain behaviour (CD test)

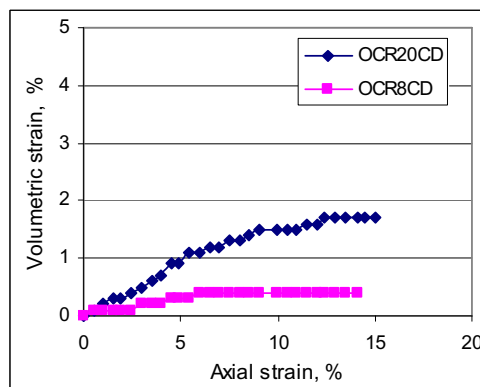


Figure 3: Volume change (CD test)

The stress-strain behaviour of CU specimens can be seen in Figure 4. Similar to the stress-strain of CD test on Figure 2, because of the lower confining pressure when sheared, the specimen with higher OCR (OCR16CU) has lower stress than the lower OCR specimen (OCR4CU). The maximum deviatoric stress of the specimens was reached on the value of about 7.4 % and 7.8 % axial strain for OCR16UD and OCR4UD, respectively. Changes in excess pore pressure against axial strain are depicted in Figure 5. The response of the specimens in undrained tests of the present study seems to be consistent with the findings of Atkinson and Richardson (1987). The results are fairly typical for specimen of heavily overconsolidated clay subjected to undrained compression.

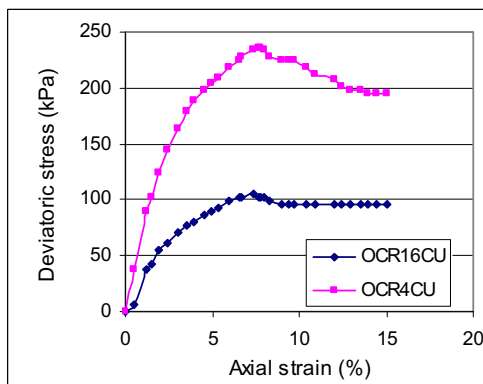


Figure 4: Stress-strain behaviour (CU test)

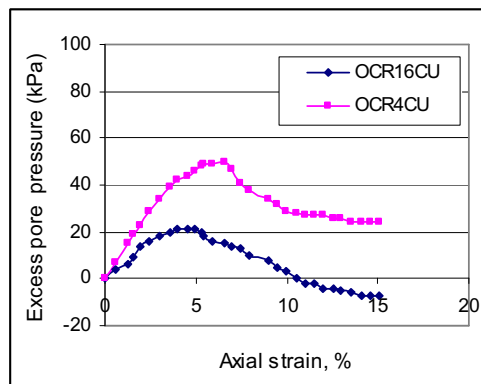


Figure 5: Excess pore pressure changes (CU test)

The stress path of the plane strain compression test is depicted in Figure 6. For drain loading condition, the specimen yields on the Hvorslev surface, where it reaches a peak shear stress and thereafter starts to dilate and soften, finally attaining the critical state. The result of this study seems to be consistent with the known mechanical concept which was founded by Hvorslev and reinvestigated by Parry in 1960 (in Atkinson and Bransby, 1982).

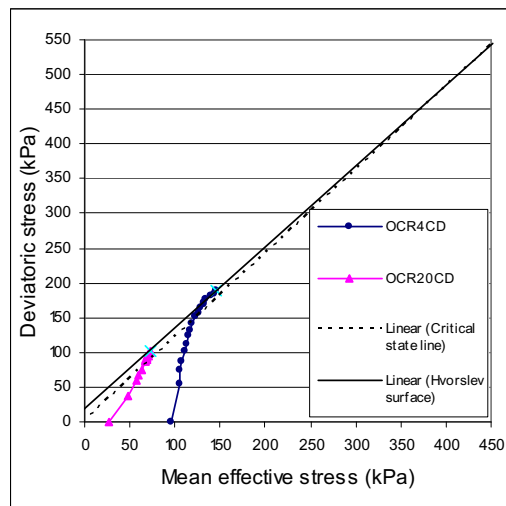


Figure 6: Stress path of drained specimens

4 CONCLUSIONS

The biaxial compression apparatus used in this study for the purpose of conducting plane strain tests has been able to provide test results that are in accordance with generally observed behaviour and known soil behaviour. Failure behaviour of overconsolidated specimens on the Hvorslev surface is shown in the test results.

ACKNOWLEDGEMENTS

We would like to thank all those involved in the project, especially to Associate Professor Kwang Wei Lo and Dr. Min Min Zhao for valuable advice and supports and Mr. Pontjo Utomo and Mr. Paisar Syakur, both research students at Curtin University of Technology, for their assistance, commitment and care.

REFERENCES

- Atkinson, J.H. and Bransby, P.L.(1982). *The mechanics of soils : an introduction to critical state soil mechanics*. McGraw-Hill, New York
- Atkinson, J.H. and Richardson,D.(1987). *The effect of local drainage in shear in shear zones on the undrained strength of overconsolidated clay*. Geotechnique, 37 (3), 393-403
- Bishop, A.W.and Green, G.E.(1965). *The influence of end restraint on the compression strength of cohesionless soil*. Geotechnique, Vol.15, No.3, pp.243-266
- Cornforth, C.N.(1964). *Some experiment on the influence of strain conditions on the strength of soil*. Geotechnique, Vol.14, No.2, pp.143-167
- Drescher, A., Vardoulakis, I. and Han, C.(1990). *A biaxial apparatus for testing soils*. Geotechnical Testing Journal, GTJODJ, Vol.13, pp.226-234
- Finn, W.D.L., Wade, N.H. and Lee, K.L.(1968). *Volume change in triaxial and plane strain tests*. ASCE, No.SM6, December, pp.297-308
- Hambly, E.C. and Roscoe, K.H.(1969), Observation and prediction of stresses and strains during plane strain of "wet" clays.7th ICSMFE, Mexico, Vol.2, pp.173-181

- Han, C. and Drescher, A.,(1993). *Shear bands in biaxial tests on dry coarse sand. Soils and Foundations*. Japanese Society of Soil Mechanics and Foundation Engineering, Vol.33, No.1, pp.118-132
- Han, C and Vardoulakis, I.G.(1991). *Plane strain compression experiments on water-saturated fine-grained sand*. Geotechnique, Vol. 41, No.1, pp.49-78
- Head, K.H.(1986). *Manual of Soil Laboratory Testing*. Vol 3, Pentech Press, London
- Green, G.E. and Reades, D.W.(1975). *Boundary conditions, anisotropy and sample shape effects on the stress-strain behaviour of sand in triaxial compression and plain strain*. Geotechnique, Vol.25, No.2, pp.333-356
- Kjellman, W. (1936). *Report on apparatus for consummate investigation of the mechanical properties of soils*. 1st ICSMFE, Cambridge, Vol.2, pp.16-20
- Lee, K.L.(1970). *Comparison of plane strain and triaxial tests of sand*. *Journal of the Soil Mechanics and Foundation Division*. ASCE, Vol.96, May, No. SM3
- Lee, K.L. and Seed, H.B.(1964). *Discussion on use of free end in triaxial testing on clays*. ASCE, Vol.91, No.SM 6, November, pp.173-177
- Lo, K.W., Mita, K.A., and Tamiselvan, T.(2000). *Plane Strain Testing of Overconsolidated Clay*, Research Report, Department of Civil Engineering, National University of Singapore
- Mochizuki, A., Min, C. and Takahashi, S.A (1993). *A method for plane strain testing of sand*. *Journal of Japanese Geotechnical Society*, No.475, pp.99-107
- Marach, N.D., Duncan, J.m., Chan, C.K. and Seed, H.B.(1981). *Plane strain testing of sand, laboratory shear strength of soil*. ASTM STP 740, pp.294-302
- Roscoe, K.H. and Burland, J.B.(1968). *On the originalized stress-strain behaviour of wet clay*. *Eng.Plasticity*. Cambridge Univ. Press, pp.535-609
- Rowe, P.W. and Barden, L. (1964). *Importance of Free Ends in Triaxial Testing*. ASCE, Vol.90, No.SMI, January, pp.1-27
- Viggiani, G., Finno, R.J. and Harris, W.W.(1994). *Experimental Observations of strain localisation in plane strain compression of a stiff clay*. In *Localisation and Bifurcation Theory for Soils and Rocks*, Chambon et.al., Eds., Balkema, Rotterdam, pp.189-198