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# A Hydraulic Servo-Controlled Cyclic Simple Shear Device

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SUMMARY: This paper describes a newly developed simple shear device. The device utilizes a servo-controlled hydraulic loading system and a personal computer to automate the whole test. It is a modified version of the NGI simple shear device. Various types of stress and strain controlled constant volume simple shear tests were performed to evaluate the device's capabilities. Results suggest good reliability and versatility in the performance of the equipment.

## 1. INTRODUCTION

The prediction of soil behaviour frequently necessitates laboratory tests to obtain basic soil parameters and the accuracy of any form of numerical analysis will depend on the soil parameters used. Determination of the soil parameters will require the laboratory tests to model closely in-situ loading conditions. In certain engineering applications where simple shear behaviour is expected, it will be convenient to model the site situation using the direct simple shear (DSS) apparatus. For example, the shaft resistance of piles or the foundation beneath an offshore platform will normally involve a simple shear state of stress. The DSS apparatus is one of the few pieces of laboratory equipment that models these in-situ conditions acceptably.

## 2. EXISTING SIMPLE SHEAR DEVICES

Various simple shear devices have been developed over the past three decades. The two most common types are the Cambridge University and the Norwegian Geotechnical Institute (NGI) Simple Shear devices. In the Cambridge design, a cuboidal sample (100 mm by 100 mm by 20 mm high) is sheared with its lateral deformation restricted by rigid hinged metallic walls. For the NGI device, a round specimen 80 mm diameter by 20 mm high is laterally confined by using a wire reinforced rubber membrane. Both devices have been modified to perform cyclic tests. Other less common simple shear devices exist. Franke et al. (1979) developed a system whereby zero lateral strain is achieved through an automatic measuring and regulating system. Casagrande (1976) used a "gyratory apparatus" where a cylindrical sample is enclosed in a rubber membrane and supported by a flat spring to prevent lateral strains. As the tests were conducted in a pressure chamber, both apparatus allowed for back pressures and pore pressures could be monitored directly. None of the simple shear devices mentioned can successfully apply complementary shear stresses on the vertical face normal to the plane of deformation, consequently some degree of non-uniformity of shear and vertical stresses can be expected.

There are two main types of simple shear test. Firstly, the constant normal load test, in which a fixed normal load is applied and maintained during shear. The specimen is allowed to dilate or collapse and water is permitted to drain from the specimen through porous discs in the loading platens. The other test is the constant volume test. The height of the specimen is kept constant and as lateral deformation is prevented the volume is kept constant also. The reduction or increase in vertical stress required to maintain constant volume is considered to be equal to the pore water pressure that would have developed in an undrained test. Recent comparative studies by Dyvik et al. (1987) of truly undrained and constant volume tests in the NGI device showed good agreement between actual and derived equivalent pore water pressures.

## 3. DESCRIPTION OF EQUIPMENT

### 3.1 Mechanics of Simple Shear Application

In the DSS test a soil specimen is consolidated under Ko conditions and a shear displacement is applied in the horizontal direction only. The stress and strain condition achieved during the experiment is illustrated in Fig. (1a). The ideal simple shear stress and strain field is illustrated in Fig. (1b). Lack of complementary shear stresses $\tau_{yx}$ during test implies non-uniformity of stress and strain fields as equilibrium conditions must be satisfied. This non-uniformity of stress field for the direct simple shear equipment has been studied and critically commented on by several authors (eg. Airy & Wood [1987], Saada & Townsend [1981]). Various experimental studies were conducted to investigate this non-uniformity of shear stresses (eg. Budhu [1984], Vucetic & Lacasse [1982]). Finite element analysis results were reported to evaluate the degree of non-uniformity of stresses (eg. Budhu & Britto [1987], Lucks et al. [1972]). Lucks et al. (1972) showed by elastic finite element analysis that 70% of the sample was uniformly stressed. Recently, Budhu & Britto (1987) reported that good quality results can be obtained from DSS tests by using carefully prepared samples and taking measurements over the sample core. Vucetic & Lacasse (1982) conducted an experimental investigation of soil specimens at different height to diameter ratios and concluded that the non-uniformities do not affect measured soil behaviour significantly. Finn (1985) reported that the cross anisotropy of soils results in a more uniform deformation field and increasing the diameter to height ratio produces more uniform conditions. The problems have not been resolved fully and the topic is the subject of active research.

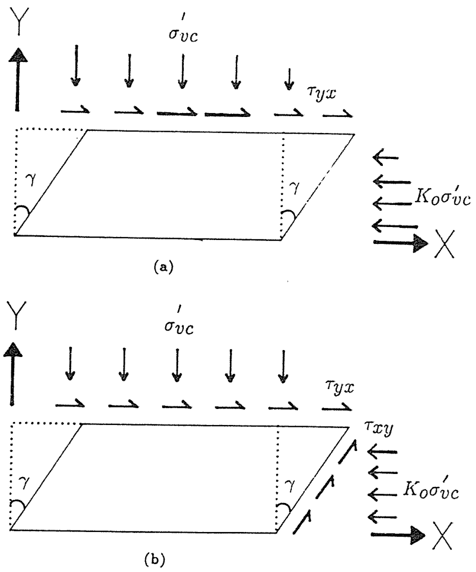


Fig. 1 Stress and strain fields (a) in simple shear device (b) ideal simple shear

3.2 Automated Cyclic Simple Shear

A schematic of the cyclic simple shear device is given in Fig. 2. The equipment is a modification of the NGI simple shear apparatus. A round specimen (A) 80 mm diameter by 20 mm high is confined in a wire reinforced rubber membrane and a shear distortion applied. The key components of the device are an electro-hydraulic servo controlled loading system for normal and shear stresses, equipment for data acquisition and a personal computer for test control.

The main advantage of the system lies with its flexibility of application. Various loading conditions can be applied and the system is capable of performing the following types of test:

- static strain/stress controlled test for a wide range of strain/stress rates.
- cyclic strain/stress controlled test at specified amplitude and frequency (0.001 hz to 1 khz can be applied). Waveforms of sine, triangular or square shape are available.
- cyclic tests with any desired increasing or decreasing rate of strain/stress with the cyclic loading superimposed.
- transient loading test
- programmed loading according to the field variable loading being simulated.

The above tests are limited only by the capacities of the actuators, the resolution of system control and response time of the whole system. Controls apply to both the vertical and horizontal loads and deformations.

The loading system comprises two low friction servo controlled actuators [B]. Hydraulic operation was preferred to pneumatic as it was felt that system response and incompressibility were of primary importance. The actuators are powered by a hydraulic pump which can supply a constant pressure up to 20 MPa with a delivery of 26 l/min. The maximum force that can be applied is 6.6 kN. The servo valve (C) controls the actuator in proportion to any electrical signal supplied to the servo controller either in force or displacement control mode. The loading system works on a closed loop feedback principle. Feedback signals are supplied either from the DCDT (D) or the S-beam load cell (E). Appropriate signal conditioning of the transducer outputs is required. A signal generator delivers 3 types of waveform viz. sine, triangular, square from 0.001 hz to greater than 1 khz.

Hardware used for data acquisition includes an IBM-compatible personal computer (PC) and a high speed 12 bit analog to digital (adc) board that resides in the PC. The adc board serves as an interface between the personal computer and system transducers and load cells. It consists of 8 differential ended adc channels, 2 digital I/O (input/output) channels and 2 dac (digital to analog channels. Outputs from transducers are connected to a screw terminal panel that is connected to the back of the PC. Control to better than 0.4 N load and 0.01 mm is possible with the equipment. The maximum sampling rate of the adc card is 13.7 khz per channel throughput. This should be adequate for most soil laboratory work. In the present system only 4 channels of adc are being used. The digital 1/0 channels are used as triggers to start the test. Each of the 2 dac channels is used to control an actuator. Any kind of signal can be digitised and sent to the servo controller through the dac to obtain loads and displacements. Commercial software packages are used to facilitate the use of data acquisition hardware. Access to realtime clocks to set the sampling rates and the desired channels to sample and store the data to diskfile can be greatly simplified by employing these packages. Such a package was used to program and automate the system. Chart recorders and digital visual displays are used as back up data acquisition.

The PC peripherals include a dot matrix printer for rough plots. A 20 Mbyte hard disk and a 60 Mbyte tape disk drive store the large amount of data

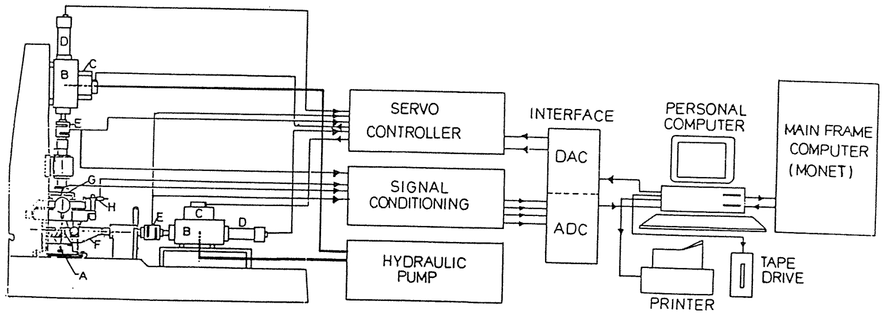


Fig. 2 Schematic of the Direct Simple Shear Device

generated by cyclic tests. The PC is also connected to the University main frame computer, MONET (Monash University Computer Network), so that the full power of the main frame computer can be exploited. The experimental results in this paper were uploaded to the main frame host computer and plotting packages used to obtain high quality laser plots.

## 4. TEST PROCEDURE

All test results reported were conducted on undisturbed samples of lower Yarra Delta (LYD) clay, Melbourne. The specimens were taken by a 90 mm piston sampler at 10 m depth. The specimens have the following average properties: unified soil classification, CH; unit weight, 15.1 kN/m$^3$; natural water content 63%; liquid limit, 100%; plasticity index, 56; clay fraction, 95%; organic content 4-6% (Donald et al. 1976). All the specimens were re-consolidated to the in-situ effective vertical stress. For normally consolidated LYD clay, Ko = 0.75, (Anantasech 1985).

## 5. TEST PROCEDURE

Each sample was prepared in the manner outlined in the NGI specimen preparation procedure. The LYD clay pore water contains a high concentration of salt, about twice that of sea water. 45 gm/l of Sodium Chloride is added to the water used to saturate the specimen to minimise osmotic effects that may cause break down of the clay particle structure. The specimen is consolidated using double incremental steps in three stages viz. $p_o/4, p_o/2, p_o$, to return the clay to its in-situ normally consolidated condition. The vertical actuator is in the force control loop during consolidation. Consolidation proceeds until the specimen stabilises when no further significant vertical height change can be observed. The vertical actuator is switched to the position loop prior to shearing. Special attention has to be given to matching the input signal and the vertical actuator lvdt feedback signal of the position loop before switching, to ensure no movement of the vertical actuator. The shearing phase commences according to the desired type of test while the sample is maintained at a constant height, as the vertical actuator is in the position loop. Computer software has been written to automate the whole process as well as maintaining constant volume, while allowing for apparatus compressibility.

## 6. TEST RESULTS

To illustrate the performance of the DSS apparatus 3 constant volume tests were conducted in the strain and stress control modes.

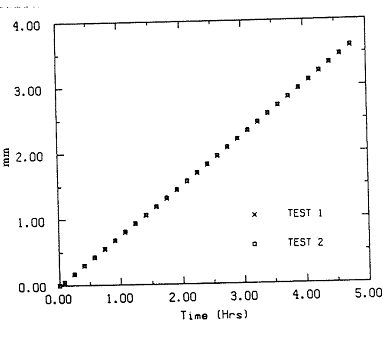


Fig. 3 Horizontal movement of actuator under static strain control

Tests 1 and 2 are static strain controlled tests at 0.0127 mm/min deformation rate. For the cyclic stress control test (Test 3), a cyclic two way loading of 68% of the peak shear stress was applied at 1 hz.

Tests 1 and 2 were conducted to check the validity and repeatability of the test. Fig. 3 illustrates the response of the horizontal movement throughout the tests. The plot indicates excellent linearity and repeatability of the actuator movement. The results of the strain controlled tests are plotted together and compared with one obtained by Anantasech (1984). Fig. 4 shows the normalised plots of shear stress vs shear strain and pore water pressure vs shear strain. Fig. 5 is the effective stress path plot.

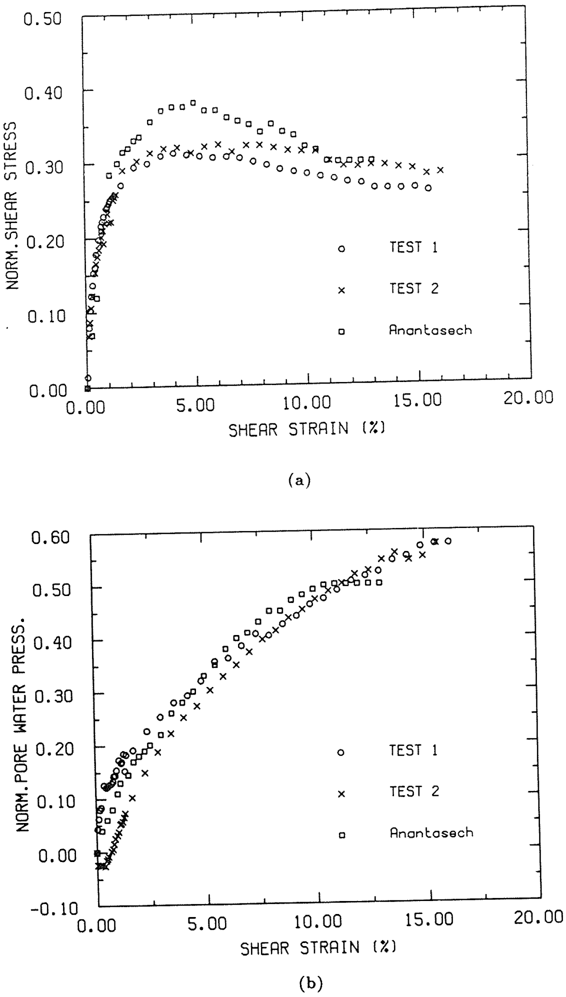


Fig. 4 (a) Normalised shear stress vs shear strains (b) Normalised pore water pressures vs shear strains

The initial moduli for Tests 1 and 2 show very good agreement up to 5% strain where the peak stress occurs. The result obtained by Anantasech showed higher strength as the sample tested was from a different depth and from a different part of the site. Nevertheless the general behavior of the results shows similar behaviour. This tends to confirm the validity and repeatability of the testing equipment, at least for tests of moderate duration. The response of the loadcells and lvdt for Test 3 are shown in Fig. 6. The actual data collected are shown on the plots. They indicate good response of the loading system and proper working of the data acquisition system. Figs. 7 and 8 summarise the behaviour of the specimen under stress controlled cyclic testing.

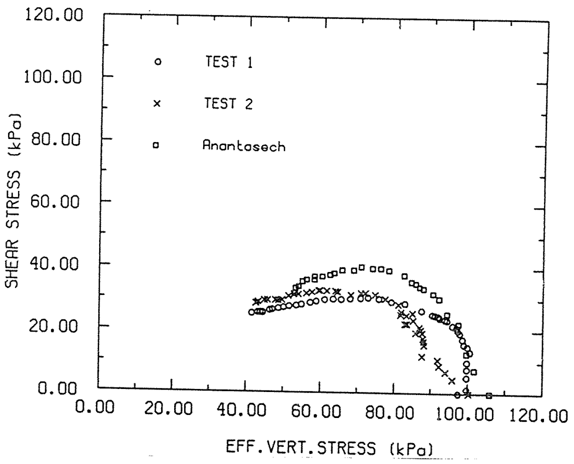


Fig. 5 Average shear stress vs effective vertical stress

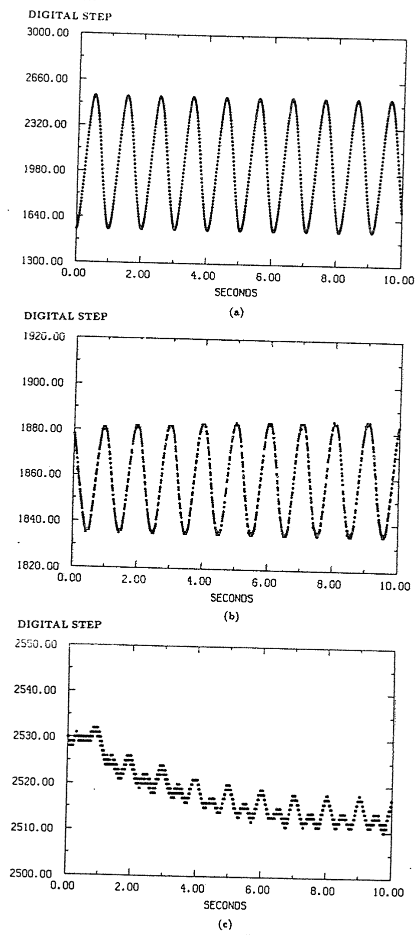


Fig. 6 Typical response during cyclic stress control test (a) Horizontal load (b) Horizontal displacement (c) Vertical load

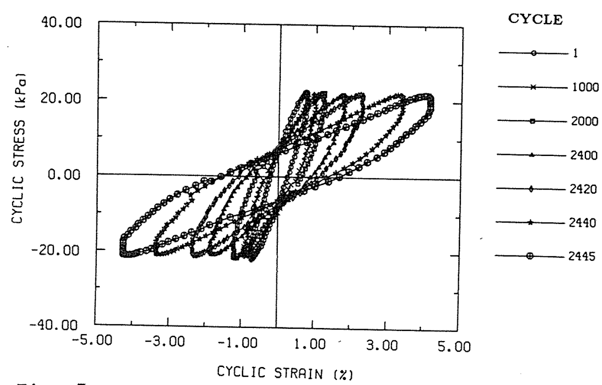


Fig. 7 Cyclic stress vs cyclic strain for stress control tests

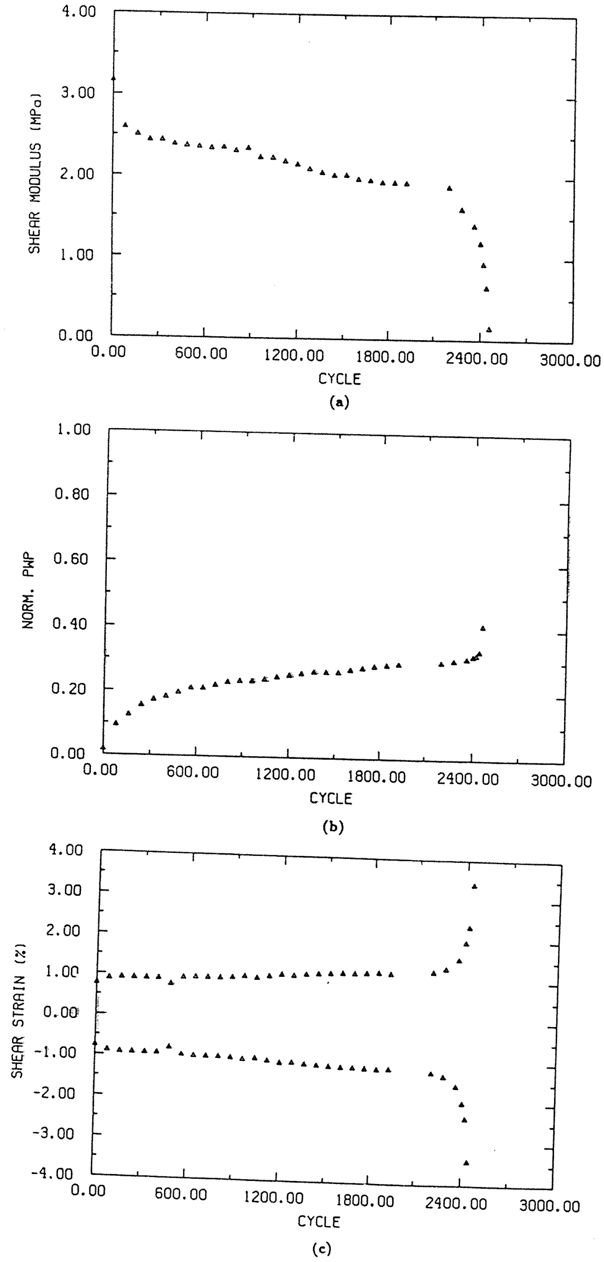


Fig. 8 Typical behaviour of sample under cyclic stress control (a) shear modulus (b) average pore pressure (c) cyclic strain

The dynamic shear modulus is seen to decrease with increasing number of cycles, liquefaction occurring after 2445 cycles with a corresponding increase in pore water pressure and increase in cyclic strain.

## 7. CONCLUSION

A versatile cyclic simple shear device is described. It utilizes a hydraulic servo control system that enables any kind of loading waveform to be simulated accurately in the laboratory. A personal computer automates the test, allowing the execution of long duration tests reliably and accurately without supervision. Preliminary test results indicate good response of the device in both strain and stress control modes and the functioning of the data acquisition system has been verified. Further improvement of the existing device will be made. A pressure chamber is to be incorporated to allow for truly undrained tests and direct measurement of the pore water pressures. A more elaborate insrumentation is under consideration for measuring normal and shear stresses over the central core of the specimen.

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