Development of Data Acquisition System for Consolidated Undrained Triaxial Test

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Abstract. Consolidated Undrained (CU) triaxial test is a common laboratory test used in practice for determining effective and total shear strength parameters of soil. This paper reported works carried out to develop a data acquisition system for a self-assembled triaxial machine. The developed system was capable of acquiring signals from the installed sensors (i.e. pressure transducer, load cell, LVDT), interpreting and presenting the data in real-time graphs. In addition, the study highlighted the advantages of performing double vacuuming method to saturate the soil specimen. The saturation can be obtained quicker and at a significantly lower cell pressure compared to the conventional stepwise increment of back pressure and cell pressure method.

Keywords: Triaxial test, residual soil, double vacuuming, effective stress, shear strength.

1. Introduction

Consolidated undrained (CU) triaxial test is a common laboratory test used for determining shear strength parameters of soil in practice. The CU triaxial test offers several advantages over direct shear test such as controllable drainage and stress conditions and measurable volume change [1]. The CU triaxial test with pore-water pressure measurement enables both the effective and total shear strength parameters (c', ϕ' and cu, ϕ_u) to be obtained, which makes it a popular test in practice. However, extra care should be given when selecting an appropriate triaxial test (e.g. Unconsolidated Undrained or Consolidated Undrained or Consolidated Drained) for a project as the selected test should replicate the actual soil conditions of the site.

For typical long term analyses, even though Consolidated Drained (CD) triaxial test may be more representative of the actual soil behaviors, the CU triaxial test with pore-water pressure measurement is normally preferred in practice due to its shorter shearing duration. Numerous researchers found that the effective shear strength parameters obtained from the CU test can be correlated well with those of CD test by applying a reduction factor of approximately 0.9 [2, 3]. The procedures of conducting the CU triaxial have been well documented in ASTM D4767-11 [4] and BS1377-Part 8 [5]. An operator is required to monitor and control the saturation, consolidation and shearing stages of the test which may span over several days. The testing time can be even longer when dealing with clayey soil with extremely low permeability, particularly during saturation stage. The main objective of the saturation stage is to ensure that all the voids of specimen to be fully filled with water without causing undesirable prestressing and swelling of the specimen. This process attempts to replicate a similar condition to that of actual field soil by saturating the soil followed by consolidation process in order to achieve equilibrium in a drained state under a known effective consolidation stress.

Recent advancement in computing and electronic technologies have seen introduction of fully automated triaxial test systems that can significantly shorten the testing duration of the CU triaxial test. The changing from one stage to another can be performed automatically without operation and monitoring of the operator. However, such system is considerably costly. Based on current practice in Malaysia, the soil saturation process of CU triaxial test is carried out by alternating the increase of back pressure and cell pressure. This normally results in an extremely high cell pressure. Eventually, the triaxial cell and other fittings of the triaxial machine need to be designed to sustain a considerably high pressure. Another drawback from the practice is that the high back pressure upon completion of saturation may destroy the soil structures and results in unrealistic testing results.

This study aims to improve the data acquisition and testing procedures of a self-assembled CU triaxial test machine. The detailed procedures of developing the data acquisition system are presented. In addition, the saturation duration of the soil specimen is shortened by adopting double-vacuuming method.

2. Materials and Methods

2.1 Soil Specimen

The soil specimen used in the present study was a typical tropical residual soil extracted from a site at Shah Alam, Selangor. The in-situ water content of the residual soil ranged from 19% to 22%, and the in-situ density was about 1.4 to 1.5 g/cm3. From the results of compaction test, the maximum dry density was 1.68 g/cm3 corresponding to the optimum moisture content of 19.6%. Based on Unified Soil Classification System (USCS), the soil was classified as Silty SAND.

2.2 Triaxial Test Setup

Fig. 1 shows the schematic diagram of the CU triaxial test setup while Fig. 2 shows the photograph of the actual setup. The instruments assembled in the present study have a similar setup with those typical CU triaxial tests, except that 2 units of convums were placed at the inlets of cell pressure and back pressure, respectively.

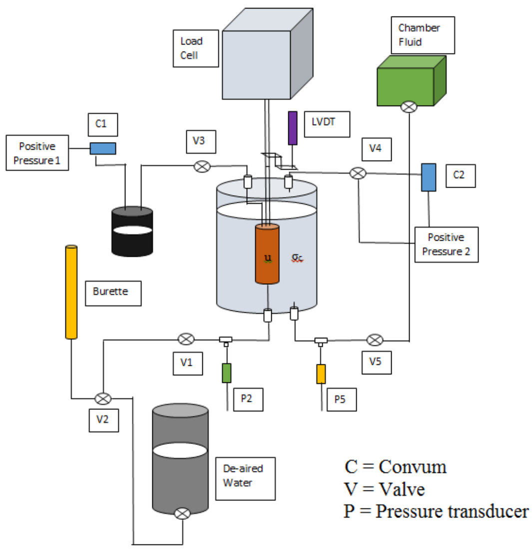

Figure 1. Schematic diagram of the Consolidated Undrained Triaxial setup.

Figure 2. Photograph of the actual Consolidated Undrained Triaxial setup.

Convum (Fig. 3) is a device used to convert positive pressure into negative pressure. In this study, double vacuuming method was used for saturating the specimen. The convum was required to generate negative pressure / suction in the cell and back pressure line. Calibration was required to obtain a correlation between the supplied positive pressure and the generated suction. Other sensors of the triaxial machine consisted of load cell for measuring the load increment during shearing, linear differential transformer (LVDT) for displacement measurement, and pressure transducer for measuring pressures in cell chamber and soil specimen.

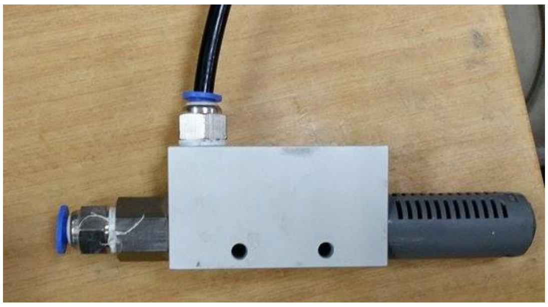

Figure 3. Convum installed at cell pressure and back pressure inlets.

3. Development of Data Acquisition System

All the sensors of the triaxial setup were connected to a connector box that consisted of 9 channels with 1.8V as a bridge excitation voltage. All the sensors used were of strain gauge type. This means that any physical changes during measurement will cause the strain gauges within the sensors to deform and generate an output voltage proportional to the strain. Each channel has two wires as output voltage terminals which have to be wired to the data logger to read the voltage.

The data logger used in the present study was Graphtec's midi LOGGER GL220. It consisted of 10 isolated channels which can measure and read the voltage from 0-50V, depending to the user's choice of amplitude range. Each sensor has a pair of output voltage terminals from the connector box, to be connected into the input terminals of a channel in the data logger. The data logger has instrument driver and software which were available online for connecting the data logger to a computer via a USB cable.

A set of programs or Virtual Instruments (VI) were written using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) to bridge the communications between sensors, data logger and computer. LabVIEW is a system design software from National Instrument. In the present study, the developed program consisted of a main VI which configured the data logger with the sensors, and several sub-VIs for performing different data analysis tasks during different stages of triaxial test. In the main VI, data from the sensor channels were written into a global variable. Global variable can be imagined as a container that allows sharing of data of several items among several VIs, but under the same LabVIEW project. In the sub-VIs, the global variable will retrieve these data for specific processes. A sample of the developed program interface is shown in Fig. 4.

3.1 Saturation Stage
During saturation stage. Skempton's pore water pressure parameter (B value) was monitored. Several real-time graphs were developed in the sub-VI to monitor the changes of pore-water pressure and B value with time, as well as correlation between cell pressure and pore-water pressure.

3.2 Consolidation Stage
During consolidation stage, water was drained out from the sample. The volume of water drained from the sample is important to determine the degree of consolidation. A sub-VI was developed to present the volume change with time.

3.3 Shearing Stage
During shearing stage, a real time stress-strain curve was displayed in this VI to monitor and identify the failure point of the specimen.

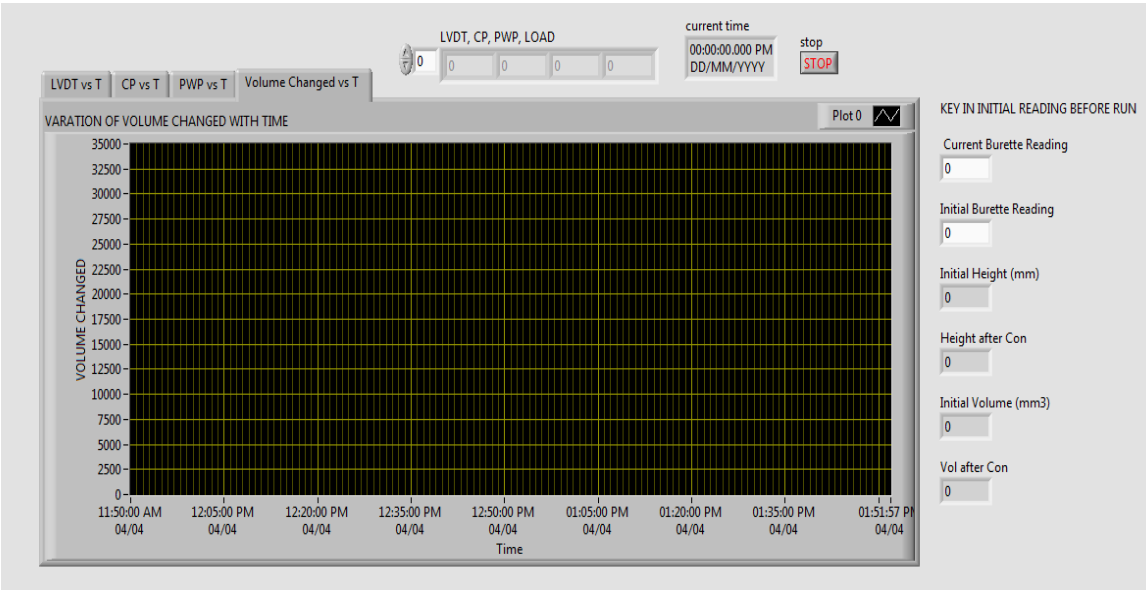

Figure 4. Interface of developed program.

4. Saturation by Double Vacuuming
Double vacuuming saturation method [6] was adopted in the present study. This method has been widely practiced in Japan. Two convums were used to perform the vacuuming process, i.e. one was used to vacuum the air in the specimen, while another was used to vacuum the air in the cell chamber. The difference in pressure between the specimen and the cell chamber was maintained at 20kPa, as detailed in Table 1.The pressures at each increment step were maintained for 5 minutes

Table 1. Cell and specimen pressures during double vacuuming saturation.

Step	Specimen pressure, *u* (kPa)	Cell pressure, σ_3 (kPa)
1	-10	0
2	-20	0
3	-30	-10
4	-40	-20
5	-50	-30
6	-60	-40
7	-70	-50
8	-80	-60
9	-90	-70

Upon applying the last step of negative pressures, the pressures were maintained for at least 30 minutes to achieve an equilibrium condition. Subsequently, de-aired water was introduced into the specimen. The water was allowed to flush through the specimen until the collected volume of water was about twice the specimen volume to ensure that all the voids had been filled with water. The entire process took about an hour.

The specimen was then subjected to Skempton's B test. The cell pressure was increased at an interval of 20 kPa until 120 kPa. The back pressure was applied accordingly to maintain the effective stress at 20 kPa. The cell pressure was then increased by an additional 100 kPa to monitor the increase of pore-water pressure. All the specimens successfully achieved Skempton's B coefficient of 0.95 or greater. By adopting the double vacuuming method, the specimen can be saturated quicker and easier compared to the conventional stepwise increment of back pressure and cell pressure. The entire saturation process was completed within 3 hours. More importantly, the final cell pressure upon completion of saturation can be maintained low (within 300 kPa). The subsequent procedures of conducting the consolidation and shearing stages were similar to that of typical CU triaxial test

5. Results

Fig. 5 shows the volume change against root time, deviator stress against strain, Mohr-Coulomb failure envelope at total stress, Mohr-Coulomb failure at effective stress obtained from the present CU triaxial test. The total shear strength parameters obtained were c = 16.5 kPa and ϕ = 22.5o, while the effective shear strength parameters were c' = 4 kPa and ϕ' = 31o. These parameters show good agreement with the testing results on similar residual soil reported by previous researchers [3].

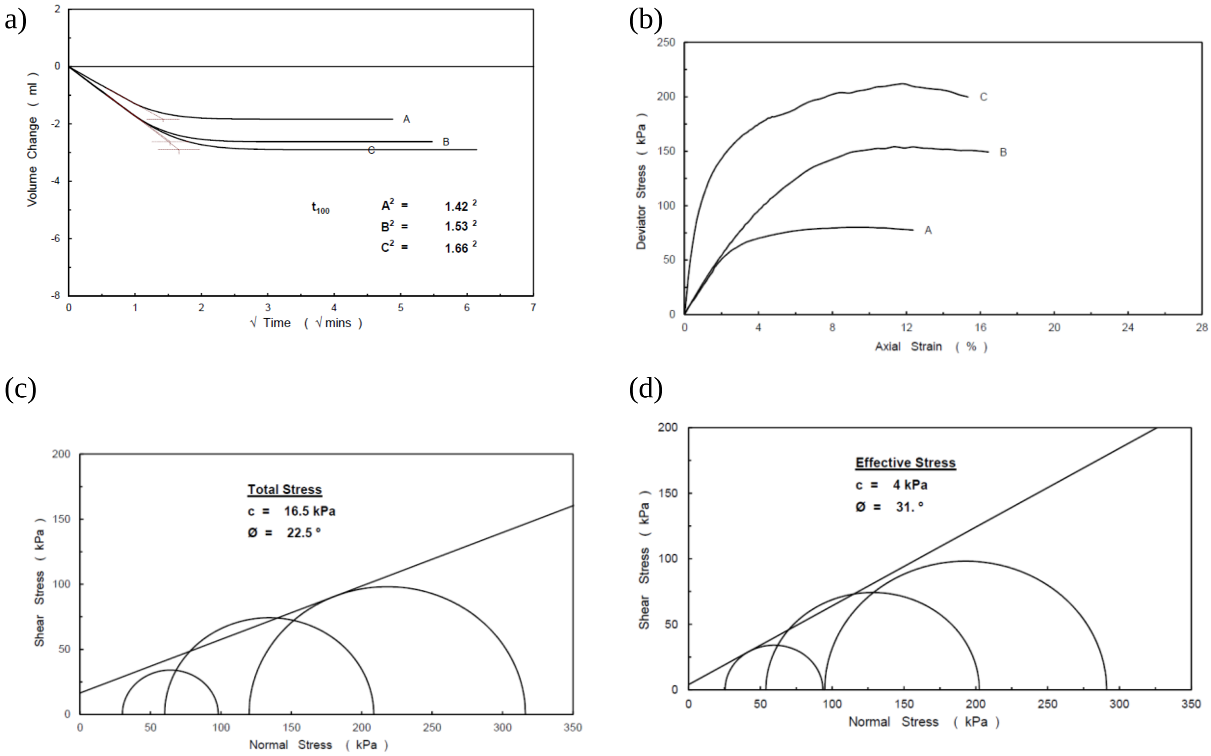

Figure 5. (a) Volume change Vs Root time, (b) Deviator stress Vs strain, (c) Mohr-Coulomb failure envelope at total stress, (d) Mohr-Coulomb failure at effective stress.

6. Conclusion & Discussion

This paper reported works carried out in the geotechnical laboratory of Universiti Tunku Abdul Rahman on developing a data acquisition system for a self-assembled Consolidated Undrained triaxial machine. The developed system was capable of acquiring signals from the installed sensors (i.e. pressure transducer, laod cell, LVDT), storage of the data, and presenting the data in real-time graphs. These features were useful for monitoring the measuring parameters at different stages of the CU triaxial test.

In addition, the study highlighted the advantages of performing double vacuuming method during saturation stage of the CU triaxial test. The saturation can be obtained quicker (within 3 hours) and at a significantly lower cell pressure compared to the conventional staging up back pressure and cell pressure method. The shear strength parameters of the residual soil obtained from the present study showed good agreement with the results reported by previous researchers.

Acknowledgement

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