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Behavior of Residual Soil with High Silt Content Under Low Frequency Cyclic Loading Using Modified Direct Simple Shear Apparatus

(Tingkah Laku Sisa Tanah dengan Kandungan Lendir Tinggi Di Bawah Beban Berulang Berfrekuensi Rendah Menggunakan Alat Ricih Sederhana Langsung yang Diubahsuai)

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ABSTRACT

This paper presents the experimental work on typical Malaysian silty residual soils in order to evaluate fundamental soil properties in particular its stiffness under low frequency cyclic loading. There has been very little information on local silty residual soils which is very important for local geotechnical design purposes. Lack of such information contributes to the dependency of foreign soil data which might not be representative of local silty residual soils. This study departs from the basis of there have been verified evidences that we are not spared from seismic activity in Malaysia. Hence, it would be misleading if we were to exclude soil properties under cyclic loading for design purposes in Malaysia. This research revolves around the development of simplified device to evaluate the stress-strain behaviour of soils under simple shear strain conditions. The cyclic loading test results on Malaysian sedimentary residual soil sample exhibit increase of drained shear stiffness, GSTIF and gained strength after 30 cycles indicating cyclic hardening behaviour. It is evident that magnitudes of cyclic load and cyclic displacement influences the rate of soil volume change. Nevertheless, the densification of soil samples due to increment of cycles caused reduction in volume change. It is foreseen that the obtained parameters could assist in the practical geotechnical engineering problems related to cyclic conditions.

Keywords: Cyclic; simple shear; loading; shear stiffness

ABSTRAK

Makalah ini menghuraikan modifikasi alat ricih mudah yang diubah suai untuk mampu melakukan ujian siklik yang berfrekuensi rendah. Dalam kerja lapangan yang sebenar, kita mungkin mengalami situasi berkaitan dengan pembebanan siklik. Di waktu tertentu, pembebanan seperti ini sering diabaikan kerana rekaan reka bentuk yang sederhana. Kajian pada sedekad yang lalu, telah membuktikan bahawa terdapat banyak kes yang berkaitan dengan pergerakan atau aktiviti gempa di Malaysia. Oleh itu, kepentingan tanah di bawah pembebanan siklik untuk tujuan rekabentuk adalah tidak wajar diabaikan. Kajian ini dimulakan untuk modifikasi alat yang dipermudahkan untuk untuk menguji sampel tanah dalam keadaan siklik. Setelah berjaya menguji sampel tanah sedimen di Malaysia, didapati bahawa peningkatan kekukuhan ricih GSTIF dan kekuatan meningkat pada kitaran yang ke-30. Kadar perubahan isipadu tanah meningkat dengan peningkatan magnitud beban siklik dan anjakan siklik. Walau bagaimanapun, kadar isipadu menurun dengan peningkatan bilangan kitaran kerana kepadatan sampel tanah. Diharapkan parameter yang diperoleh dapat membantu dalam merancang infrastruktur yang meliputi keadaan siklik.

Kata kunci: Kitaran; ricih mudah; pembebanan; kekukuhan ricih

INTRODUCTION

Simple shear condition in soil mechanics refers to a state whereby the soil sample undergoes shear stress on the top and bottom surface of the sample without any shear stress induced on the lateral sides of the sample. Quite a number of infrastructures such as dams or reinforced slopes have very large lengths compared with their other dimensions (Xu et al. 2020; Kumruzzaman & Yin 2012; Li et al. 2014). Many cases involving stability of embankments and cuts for roads and strip footings eventually represent a plane strain condition whereby we could not observe any deformation taking place in the direction at right angles to the displacement (Zhao 2017; Terzaghi et al. 1996). The deformation of soils in many ground situations conversely, may be related to simple shear deformation (Szypcio 2017; Budhu 2010). The simple shear apparatus enables soil specimens to be tested in which the major principal stress axis rotates during shear while the specimen is kept under a condition of plane strain. During earthquakes, soil layers' experience cyclic shear stresses with different amplitudes and frequencies which will lead to cyclic deformations. Certain types of soils are also exposed to low frequency cyclic loads due to periodic drainage and recharge of groundwater (Zhang et al. 2017; Liu et al. 2013). These deformations are going to affect structures located on these layers and may cause severe damages. Moreover, the variation in the stress-strain and strength properties of soil layers during cyclic loading raised the concern on the stability of related infrastructures (Huang et al. 2019; Kalinowska & Malgorzata 2015; Indraratna et al. 2015). Consequently, evaluation of soil properties under cyclic loading has been of interest to geotechnical engineers. There has been very little information on local sedimentary residual soils properties under cyclic loading which is very important for local geotechnical design purposes. Lack of such information contributes to the dependency of foreign soil data which might not be representative of local sedimentary residual soils.

The aim of this paper is to present results of an experimental investigation performed using modified direct simple shear apparatus (70 mm circular sample) to study the characteristics of a residual soil with high silt content under one-way cyclic load-control test. The preparation procedures of direct simple shear testing samples and the extra measures taken during the preparation and experimental stages will be discussed in this paper. All the tests were carried out using a modified computer-controlled direct simple shear apparatus.

SOIL CHARACTERISTICS

The soil used for the series of tests were sandy clayey silt from Universiti Tenaga Nasional (UNITEN) campus. The university, located between Bandar Baru Bangi and Kajang, is underlain by sedimentary residual soils. The soils generally consist of sandy clayey silt, sandy silty clay, silty sand, and clayey silt. However, only the sandy clayey silt from the first four metres of the profile is used as the test material. The samples were tested in a reconstituted form, rather than in a natural state. Sandy clayey silt was chosen for two reasons. Firstly, it was considered an additional effort of substantial significance to study this type of soil, as the conducted literature study shows that previous researchers in Malaysia were concentrating on granitic residual soil, peat, soft, and marine clay. Secondly, the location of the university on the sandy clayey silt ground provides easy and continuous acquisition of samples. The basic properties of the highly silted sedimentary residual soil are given in Table 1.

TABLE 1. Basic properties of the sedimentary residual soil with high silt content

Parameters	Symbol	Value
Specific gravity	Gs	2.66
Sand fraction (%)		9
Silt fraction (%)		74
Clay fraction (%)		17
Liquid limit (%)	LL	42
Plastic limit (%)	PL	11
Plasticity index (%)	PI	31
Activity	A	1.8
Maximum dry density (Mg/m3)	γd (max)	1.72
Optimum moisture content (%)	Wopt	17.6
Minimum dry density (Mg/m3)	γd (min)	0.93
Coefficient of permeability (mm/s)	k	5.24 x 10-5

AUTOMATED SIMPLE SHEAR TESTING SYSTEM

In this research work, a modified computer controlled simple shear testing apparatus was used. It has its own data logging system. The original testing apparatus is only meant to perform manual static testing. Some modification works in collaboration with GDS UK Limited finally enables the whole system to be fully computer automated.

The details of this apparatus and data logging system are described in the following section. The automated simple shear testing system comprises of five main components, namely simple shear testing apparatus, communication port, DIO control box, RS232 multiplexer, and data acquisition pad as shown in Figure 1. The existing simple shear apparatus is only intended for manual testing purposes. Some extra modifications were carried out to enable the system to be fully computer controlled. Even though the apparatus does not have inbuilt computer control via RS232 port, it is possible to have complete computer control as many simple shear machines have manual control of start, stop, and change direction. The velocity is set via the machine's gears. GDS DIO control box is wired into the existing system, allowing the PC (communication port) to then control the start, stop, and change direction. With this box in place, the user can turn an existing manual machine into a complete PC controlled system with the ability to run tests up to particular strains set by the user, continuous reversal for residual strength tests, and setting user safety limits to protect the apparatus.

The GDS 8 Channel Serial Data Acquisition Pad, which is generally referred to as the serial pad is used for data acquisition purposes. Vertical and horizontal transducers are connected to the serial pad to obtain strain control. Two load cells meant for vertical and shear stress measurement are attached to the pad to obtain load control.

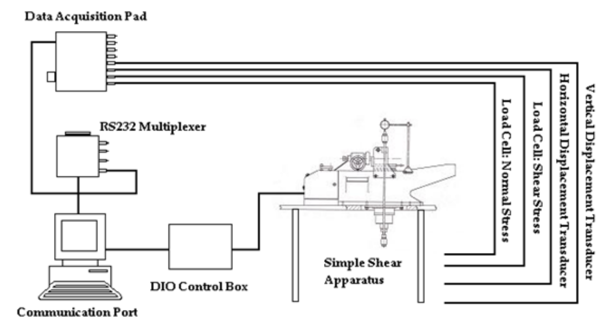

FIGURE 1. Basic layout of automated simple shear testing system

TESTING METHODOLOGY

The soil samples used for this experimental study was dried continuously using industrial oven. Then, sieving was conducted to ensure only particles less than 2 mm were used throughout this testing. A rubber membrane encased by a stack of metal washers was mounted on the 70 mm circular platen of the apparatus. This is followed by spraying of the soil particles at a predetermined height which ensures uniform density between each sample. It is important to ensure that we maintain the standard dry density between 1.05 g/cm^3 – 1.42 g/cm^3. Some minimal tappings with low force were carried out on the external body of the metal washers to minimize voids. After saturating the sample at an appropriate pressure head, the consolidation clamp was installed slowly to avoid any deformation on the sample. The vertical consolidation pressure is then applied for a reasonable duration until it reaches equilibrium conditions in the sample. Extra measures were taken by tightening clamp screws in the testing system to avoid any slack that would contribute to erroneous experimental results. Any slack in the drive system can be eliminated by disengaging the clutch and hand winding. The testing procedures and data acquisition were performed by using a computer software and data acquisition system. The applied normal stress in the tests varied from 23 kPa to 100 kPa. Upon completion of the primary consolidation, the sample was sheared at the rate of 0.24 mm/minute up to a maximum horizontal strain of 16 %.

RESULTS

Figure 2 illustrates the behaviour of silty residual soil under one-way cyclic loading. The soil specimen was initially overburdened with a normal stress of 100 kPa. Using the maximum shear stress obtained from static loading test, the specimen was subjected to 100% of the maximum shear stress for 30 cycles (N=30) before it was brought to static failure. The hysteresis loop moves forward as number of cycle increases. The soil specimen seems to get denser as number of cycle increases, N. At the end of this cyclic loading test, the soil specimen was statically sheared to failure and it was found that the soil specimen strength increased by 24%. This behaviour was attributed by the densification process that took place in this drained test. A clearer picture of the hysteresis loops for N=1, 5, 10, 20, and 30 can be seen in Figure 3. It was evident that in this drained test with constant cyclic stress amplitude, the amplitude of shear strain decreases gradually as the cycles proceed. In many engineering works, such as roads and dams, the soil is compacted to increase its stability. However, natural phenomena such as earthquake can produce a tendency to compaction (densification). Densification increases with increment in strain amplitudes and increment in number of cycles (Liu 2014). It could be observed that large vertical displacement occurs in the first five cycles. From the study, the shear stiffness, *GSTIF* of the silty residual soil increases as number of cycles increases. The summary of this result is tabulated in Table 2.

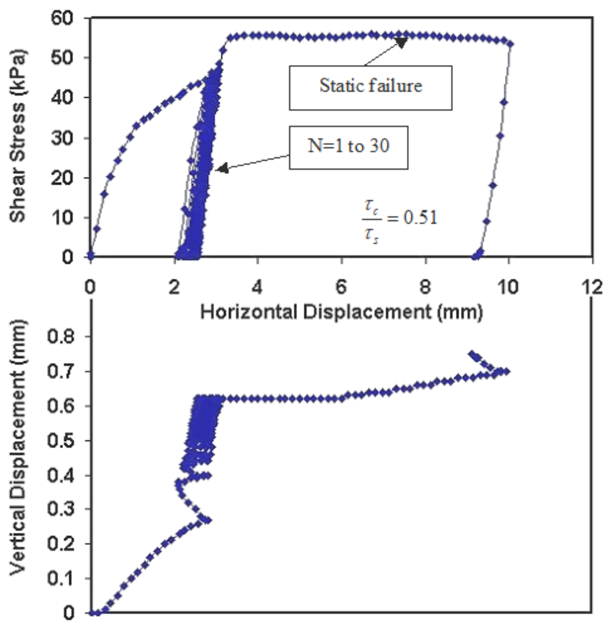

FIGURE 2. One-way cyclic load-control test

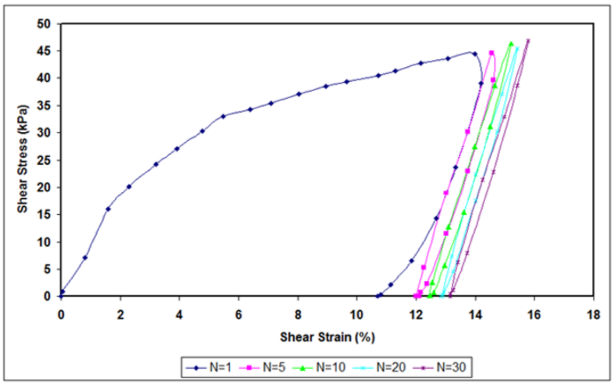

FIGURE 3. Shear stress versus shear strain graph for selected loops

TABLE 2. Shear stiffness obtained at selected number of cycles

N	1	5	10	20	30
Shear Stiffness, GSTIF (MPa)	0.89	1.51	1.56	1.78	1.80

CONCLUSION

It is found that for the Malaysian sedimentary residual soil, the shear stiffness, GSTIF, increases as the confining or normal stress increases under direct shear conditions. The cyclic loading results from direct simple shear tests indicate that drained shear stiffness, GSTIF, increases as the number of cycles increases. In order to determine the relevant geotechnical parameters in a design situation, laboratory tests should simulate the in-situ loading conditions as closely as possible. The direct simple shear test is capable to simulate the plane strain condition beneath the spread footing and is suitable for soil-structure interface testing. Since there is very limited test data available on the behaviour of Malaysian sedimentary residual soil under cyclic loading hence there is clear need for further research work on this subject.

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DECLARATION OF COMPETING INTEREST

None

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