Saturated Shear Strength Behavior of Granitic Residual Soil Grade VI

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ABSTRACT

Tropical residual soils are widespread in Malaysia due to its location in a hot and humid tropical region. More than 75% of the land area in Peninsular Malaysia is occupied by residual soil that formed by the weathering process of granitic, sedimentary and metasedimentary (metamorphic) rocks. Since the feature of tropical residual soil is prominent in engineering construction work such as highway cut-slopes, dam site excavations and is also widely used as construction fill materials for highway embankments, earth dam, and fill-platforms for housing development, the properties and the behavior of the residual soils needs to be investigated. The main difficulty of the residual soils is associated with rainfall distribution and the effect of the infiltration of the surface run off on the earth. This is due to the slope failure cases on residual soil in the tropics are triggered by the infiltration of the surface run off that occurs during heavy rainstorm that caused damages and deaths. In this study, the shear strength characteristics of residual soil were assessed using consolidated drained (CD) triaxial tests for saturated soil specimens. Curve Surface Shear Strength Envelope Model (CSSEM) was used to interpret the test results. The test results shows that the failure envelope forms a non-linear shape at low stress levels that shows the soils exhibits drop in shear strength as effective stress approaches zero in saturated specimens. This is mean that shear strength vanished drastically as the soil gets closer to the ground surface and when it is wetted by the infiltrated water. Furthermore the application of Curve Surface Shear Strength Envelope Model (CSSEM) is useful to avoid the problem of overestimating and under estimating of shear strength behavior.

Keywords: *Shear strength, residual soils, Curve Surface Shear Strength Envelope Model (CSSEM)*

Introduction

Malaysia in a tropical climate region that experiences heat and humidity all year round are experiencing the high rate of weathering process. It is one of the countries in the world where the residual soil covered more than 75% of the country's land area. According to McCarthy (1993), residual soils are those formed from rock or the accumulation of organic material and remain at the place where they are formed. Generally, in Malaysia, the type of residual granite soil is reddish in colour, which is from a laterite type of soil (Fookes, 1986). Since there have been many uses of tropical residual soils in engineering construction, the properties and the behaviour of these residual soils needs to be investigated. The shear-strength characteristics of residual soils are the most important elements that need analyses in many cases. Many geotechnical problems such as bearing capacity, lateral earth pressure and slope stability are related to the shear-strength of a soil. The landslide occurrences of granitic residual soil slopes are uncontrolled in Malaysia and the tropical region. Most of the slope failures are caused by the infiltration of rainwater into a slope. Studies by Brand et al. (1984), F.C. Dai & C.F. Lee (2000) and Rahardjo et al. (2001) all confirmed that antecedent rainfall induced slope failure when the rainwater infiltrated into a slope and caused an adverse effect on its stability. Infiltration of surface run-off into a slope affects the distribution of moisture in the soil and subsequently decreases its strength when the soil is wetted (Rahardjo & Fredlund, 1991; Rahardjo et al., 2007). Wetted soils have relatively lower shear-strength in comparison to fairly dry soil (Fredlund et al., 1978; Escario and Saez, 1986; Rahardjo et al., 1995; Rahardjo et al., 2004; Melinda et al., 2004).

Since the failure is close to the slope surface, the effective stress along the slip plane must be on the low stress levels (< 100 kPa). The shear-strength behaviour on the lower effective stress range is recognized as non-linear with respect to net stress and suction (Md. Noor & Anderson, 2006). This non-linear and steep drop in shear-strength as suction approaches zero is suspected to be the primary governing factor for the shallow type of slope failure. However, this type of attribute is not incorporated in analysis when the shear strength model of Terzaghi (1936) and Fredlund et al. (1978) are applied since these models considered linear shear strength behaviour relative to effective stress. Therefore, the true shear-strength behaviour of the tropical residual soil in saturated conditions needs to be investigated to understand the characteristics of the soils.

Methodology

Soil samples and preparation of remolded specimens

The disturbed sample of granitic residual soil for this study was taken from Bukit Rawang Putra, Selangor. The pictures of the disturbed sampling work and oven dried test material are shown in Figure 1, 2 and 3 respectively. The soil was reddish in colour. Through the particle size distribution curve as shown in Figure 4, the residual soil tested was classified as well graded silty SAND according to the British Standard of Soil Classification.

Figure 1: Sampling of disturbed sample

Figure 2: Sampling of disturbed sample

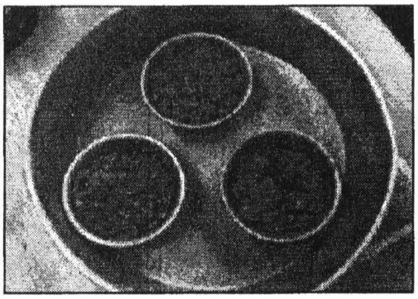

Figure 3: Oven dried samples for testing

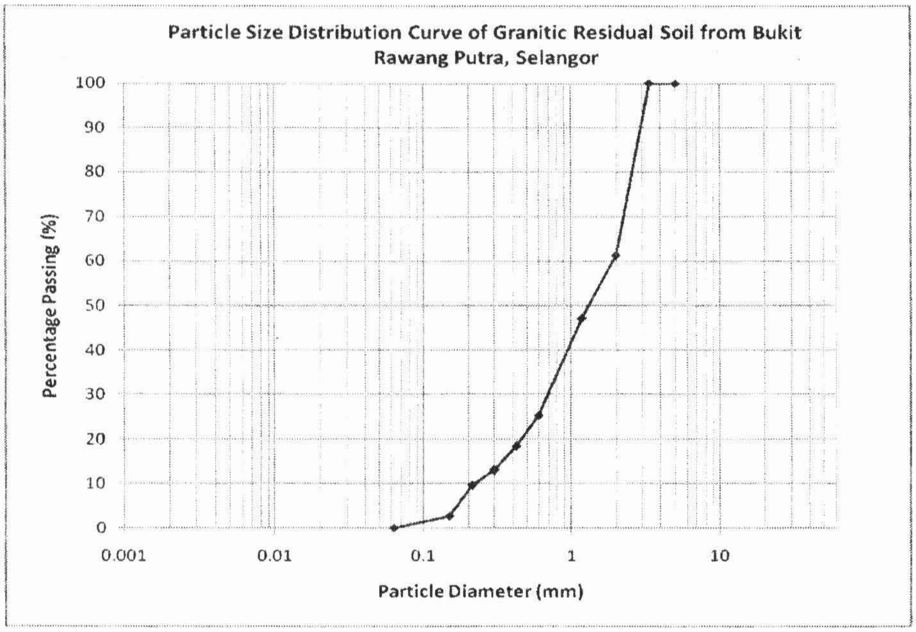

Figure 4: Particle size distribution curve of the test material i.e. granitic residual soil grade VI.

The remoulded cylindrical triaxial specimens were prepared by stamping 25 times uniformly for every layer of 20 mm thick oven dried soil, using a 1cm diameter steel rod. The same weight of dry soil (115gm) for saturated soil was used for every specimen. These are the steps taken in order to achieve identical specimens for every test. The specimens were 50 mm in diameter and 100 mm high. The stamping of a specimen in a split mould is shown in Figure 5 and the ready remoulded dry specimen with the mould removed is shown in Figure 6. The specimen stood by applying vacuum through the back pressure line and the vacuum was removed once the specimen was subjected to cell pressure of 15 kPa. Then the cell cylinder was installed and clamped together by tightening the tie bars as shown in Figure 7.

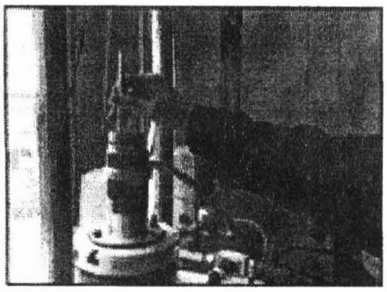

Figure 5: Soil sample was placed in the membrane and mould by stamping each spoonful of soil.

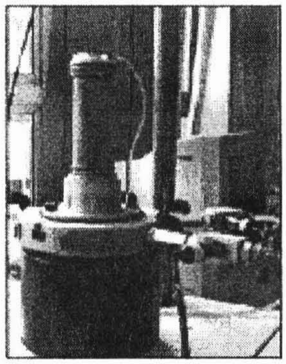

Figure 6: The vacuum was released and the specimen mould was removed.

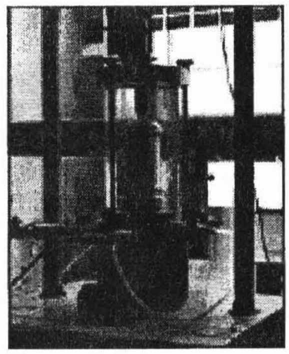

Figure 7: The cell cylinder was installed and clamped together by tightening the tie bars.

Consolidated drained triaxial tests

Soil specimens were loaded to failure under three (3) different effective stresses which were; 50kPa, 100kPa and 200kPa. The test was carried out in the triaxial apparatus on specimens in the form of cylinders whose height was approximately equal to twice their diameter. The diameter used for testing was 38mm with a 76mm height.

The cell was filled with fluid, usually distilled water. The fluid is allowed to flow into the bottom of the cell and then up through the valve located in the top plate. The goal was to fill the cell with fluid without trapping any air within the cell. After setting the apparatus, it was continued with saturation stage, where the objective of the saturation process is to fill all the voids within the soil specimen with water, without producing undesirable pre-stressing of the specimen or allowing the soil to swell.

After the equalisation stage where soil is fully saturated, each specimen was consolidated isotropically where the fluid in the triaxial cell applied the same pressure in all directions to the soil specimen. This stage continued until the soil specimen had equilibrated under the initial effective confining pressure.

After the consolidation stage, the soil specimen underwent the shearing process; in this stage load was applied to the loading piston so that it just slowly moved down and barely came into contact with the specimen cap. The pore pressure was constant throughout the soil specimen during the drained shearing. The triaxial test was sheared at a strain rate of 0.03 mm/min. Since the usual procedure was to shear the soil specimen to an axial strain of at least 20 per cent, the shearing portion of the triaxial test took about 13 hours.

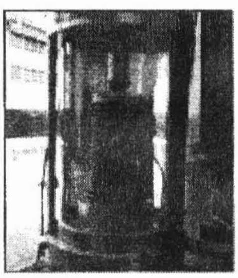

Figure 8: During the saturation and consolidation stage

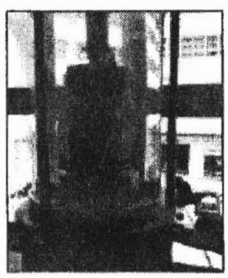

Figure 9: Shearing stage

Results and Discussion

The consolidation curves are shown in Figure 10 that the 100% consolidation was achieved at 43 minutes. Figure 11 shows the relationship between principal stress difference (σ1-σ3), or deviator stress, and the axial strain during the shearing stage from the triaxial test under consolidated drained conditions and effective stresses of 50kPa, 100kPa, and 200kPa. The results show an increase in shear-strength up to a peak value and then a reduction in shear-strength. Figure 11 shows a well-defined peak type of stress-strain curves which is the characteristic of a dense specimen. This was achieved through the stamping effort applied in the preparation of the specimens.

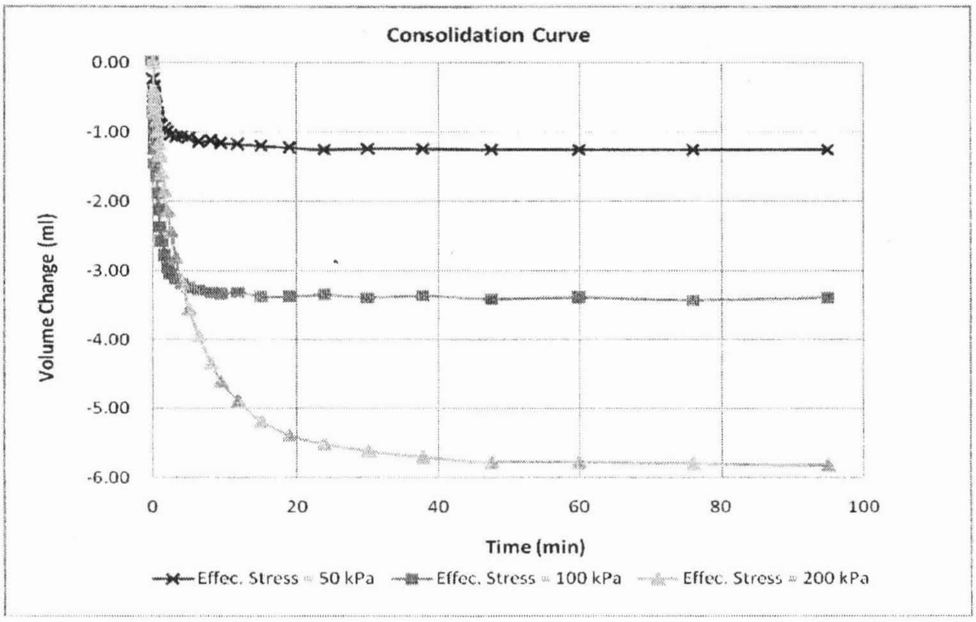

Figure 10: Consolidation curve during the consolidation state on saturated granitic residual soil

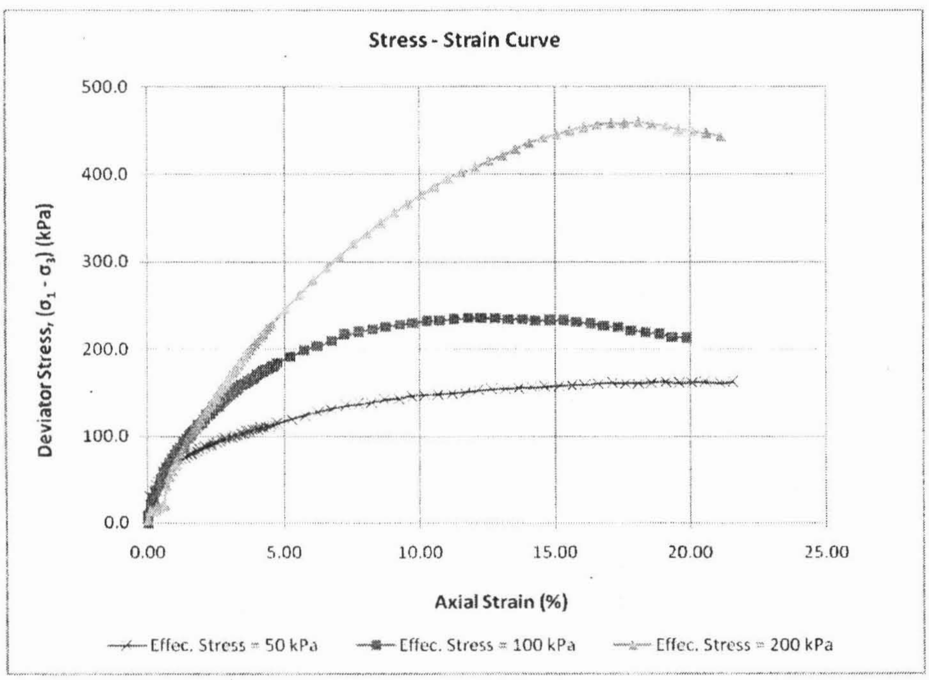

Figure 11: Stress behaviour relative to % axial strain during shearing stage (Stress – Strain Curve) on saturated granitic residual soil.

Shear Strength Envelope of the soil sample

The data at failure during the shearing stage for the three triaxial tests is summarized in Table 1. The Mohr circles and the Mohr-Coulomb envelope are plotted in Figure 12.

Table 1: The data for the shearing stage of the consolidated drained triaxial tests at failure.

Targeted effective stress (kPa)	Cell pressure (kPa)	Pore water pressure (kPa)	Maximum deviator stress, q (kPa)	σ_3'	σ_1'= (q+σ_3')
50	450	394.50	146.60	55.5	202.1
100	500	395.60	245.40	104.4	349.80
200	600	396.80	430.20	203.20	633.40

The shear-strength parameters at saturation according to the model are as follows;

i) Transition effective stress, = 315 kPa

ii) Transition shear-strength, τ_t = 188 kPa

iii) Minimum friction angle at failure, $\phi'_{\min_f}$ = 24.5°

The envelope passed through the origin indicating the absence of cohesion. This was due to the un-cementing between particles, because the cement was destroyed when the soil was remoulded. The failure envelope indicated that the shear-strength behaviour was non-linear at low effective stress. In other words shear-strength dropped steeply as effective stress approached zero.

The model was able to characterise exactly the non-linear shear strength behaviour relative to effective stress of the test material except for the smallest Mohr circle which was a test at effective stress 50 kPa. This Mohr circle was smaller in relation to the curved-surface envelope. Nevertheless, it indicated that the shear strength is diminishing towards zero with effective stress. Apparently, the presence of silt in the material did not provide any effect of cohesion on the strength. After all even for silt soil itself, there have been reports that they bear no cohesion like the Avonmouth and London clays as reported by Bishop (1966) and Tanjung Bin soft clay (Zaibullah, 2008). The presence of particle adhesion in clay silt soils derived from the attraction of the cations and ions presence in their structural framework may provide tensile resistance but would not provide any strength in relation to shear especially in the direction in line with the dispersed structure (Budhu, 2007).

Thence the anticipated characteristic of steep drop in shear strength as effective stress approached zero was exhibited by the soil. The traditional practice of adopting the best straight line like the dotted line envelope in Figure 12 would over-estimate on the high stress levels. The latter can be very risky when applied in high retaining walls or deep excavation in the soil tvpe considered.

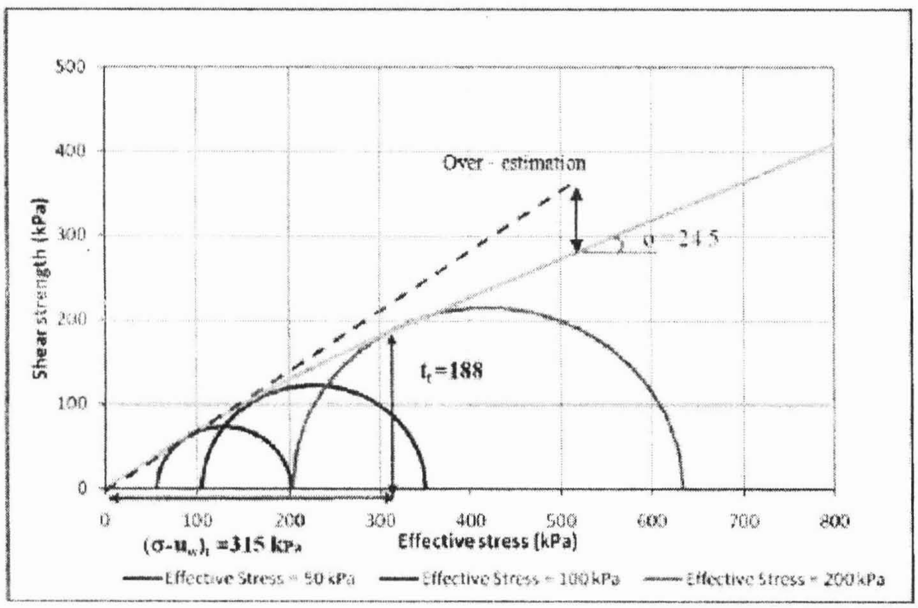

Figure 12: Curvilinear shear-strength envelope of saturated specimen of Bukit Rawang Putra granitic residual soil

Conclusions

The experimental test on the saturated specimens provided information on the shear strength behavior of saturated compacted granitic residual soil. The following conclusions can be drawn from this study;

The shape of the failure envelope of Rawang, granitic residual soil grade 6 can be defined as a curvilinear type according to the curved-surface envelope soil shear-strength model (CSESSM) of Md. Noor and Anderson (2006).

The shear-strength reduced drastically as the soil gets closer to the ground surface and when it was wetted by infiltrated water that do exhibit steep drop in shear strength as effective stress approaches zero. These are suspected to be the important attributes that govern the shallow type of slope failures.

The application of the linear type of envelope would over estimate shear-strength on the high stress levels, and this would create complexity in understanding their behavior.

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