The effect of soaking on shear strength of a Malaysian granitic residual soil

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Abstract. Shear strength plays a significant role in controlling the stability of geotechnical constructions. Any reduction in shear strength can cause costly damages and risk the human life. Tropical countries are covered by residual soils and clay is the content of many soils in these regions. The shear strength of clay diminishes when it starts to absorb water and soaked. In this study the effect of soaking on the shear strength of a Malaysian granitic residual soil was examined by conducting a series of consolidation drained triaxial tests. The results show a reduction in shear strength while the soil was soaked.

1. Introduction

Shear strength plays a significant role in geotechnical problems. The stability of slopes, embankments, foundations, backfills strongly depend on the shear strength of the soil materials involved [1]. The soil mechanic theory is very complex since it involves saturated and unsaturated soil mechanism. The soil shear strength is very important factor that influence the slope stability and govern the landslide behaviour [5].

However, when the soil is in unsaturated condition, two independent stress state variables that governed the soil shear strength, known as net stress and suction [2]. In any reduction in shear strength can cause costly damages and risk the human life. Shear strength of a soil depends on stress state variables and pore water pressure is one of the most key factors in controlling the shear strength. The pore water pressure can be negative (unsaturated condition) or positive (fully saturated condition). The negative pore-water pressure or knowing as suction, it tends to pull (gather) the soil particles together and increase the strength while the positive pore-water pressure tends to push the soil particles separately and reduce the strength. It can be concluded that water can perform as silent or weak agent to destabilize or stabilize the geotechnical constructions.

In tropical countries like Malaysia which covered by residual soil, clay is the content of many soils. In residual soil clays acts as the cementing agent between the granular particles and has a significant influence on the shear strength of residual soils. In Malaysian granitic residual soils, clay may contain more the 52% of the soil particles [9] which is derived from the weathering of feldspar in the parent rock.

Moreover in Malaysia the highland soil shear strength is affected due to infiltration of rainfall. More crucial the effect of infiltration which reduces the suction and automatically reduces shear strength that governing the slope stability in hilly area of Malaysia. However when some slope failure
occurred sometimes after rainfall has stopped, it needs a further explanation in theory and experimental besides the macro effect of infiltration on shear strength. This type of phenomena known as “delayed failure” [4].

Figure 1: JKR probe for soil testing and GPS to check the location by using coordinate system.

Meanwhile in Figure 1, the site study on slope location at Tanah Rata Cameron Highland, Pahang, Malaysia where the spatial GPS coordinate is: N040 28.23.00, E1010 23.02 and the altitude: 1475 meters (Projection: WGS84). The district faced many slope failures due to rainfall and during the site visit to this topographically hilly area ecology that new/fresh and old scar can be seen and analyzed clearly.

For shear strength of clay diminishes when it starts to absorb water in surrounding [6]. This phenomenon is a serious case and happens in shallow depth where the confining pressure is less. On surface (exposed to atmospheric) it is very critical where clay mineralogy have space to expand while soaking the water. Even though the geotechnical understand when clay absorbs water it becomes softer or weaker as its microscopic structure changes, but this aspect of strength change is less discussed and incorporated in relation to stability analysis. The aim of this study is to examine the effect of soaking on the shear strength of a Malaysian granitic residual soil. The shear of the tested soil was obtained at fully saturated condition and also after soaking the soil samples for 7, 21 and 28 days by applying the Curved-Surface Envelop shear strength model of Md. Noor and Anderson [8]. The roles of soaking in controlling the shear strength have been discussed.

2. Materials and methodology
In Malaysia many highlands have faced are series of slope failure. This rapid occurrence happen after the highland area was rapidly develop with highway, road, residential area and more agriculture land acquired due to food demand.

In Figure 2, the map of Peninsular Malaysia that occupied on granitic residual soils that behave the decreases in shear strength due to soaking time (rainfall phenomena). The worst case when this highland received the high intensity of rainfall all the year.
Figure 2. Digitized maps of distribution of tropical residual soils in Peninsular Malaysia.

The Tanah Rata Cameron Highland, Pahang Malaysia soil was taken for particle soil sample (PSD) test known as dry sieving method according to British Standard 1377: Part 2:1990, Test 9.3. The soils pass through the sieves that were arranged with the largest at the top down to the smallest and were shaken using mechanical motor sieving shaker powered by electricity. The PSD experimental was manipulated to range the soil classification. From the results, the soil was classified as Granitic Residual Soils Type IV (Gravelly Silt Soil). It contains of 44% Gravel, 18.66 Sand, 36.47 Silt, and 0.87 Clay, as a plotted graph in Figure 3.
Figure 3. The results of Particle Size Distribution (PSD) for Granitic Residual Soil Type VI from Cameron Highland, Pahang, Malaysia.

The series of shear strength test is quantified through the tests (consolidated drain triaxial tests) [3]. A series of four multistage consolidation drained triaxial test have been done on the granitic residual soil grade VI undisturbed samples collected from the investigated cut slope at Tanah Rata Cameron Highland, Pahang Malaysia.

All soils sample must undergo shear test used triaxial machine located at Advance Geotechnical Laboratory in UiTM Shah Alam and Pulau Pinang. The full set-up of Triaxial machine for this experimental as in Figure 4. The first sample was saturated and after B value was achieved, it consolidated and sheared under targeted effective stresses of 50, 100, 200, 300 and 400. The second sample was saturated first and then left for soaking for 7 days. After 7 days soaking the sample consolidated and sheared under same effective stress of 50, 100, 200, 300 and 400 kPa. The same procedure was applied on third and fourth samples, but they left for soaking for 21 and 28 days respectively. In each test the stress-strain curves and the maximum deviator stress during the sharing was obtained.
3. Results and discussion
The maximum deviator stress for each sample in different effective stresses has been obtained from the shearing stage. Besides that, the Mohr circles and curvi-linear shear strength envelopes [8] have been drawn based on Curved-Surface Envelope Extended Mohr Coulomb Shear Strength Model (CSE Model). The application of curvi-linear shear strength envelope was applied in this experimental for results interpretation of cohesion and phi-angle that governed factors to soil shear strength. The attribute of the non-linearity of the envelope at low stress levels is believed to be very significant in governing the shallow type of failure [7]. Figures 5 to 8 are presenting the shear strength envelopes for the tested soil in saturation condition and 7, 21 and 28 days soaking respectively. The shear strength parameters for each specimen are highlighted in the Figures below.
Figure 5. The shear strength envelope under saturated condition.

Figure 6. The shear strength envelope under saturated condition after 7 days soaking.
The result shows a reduction in shear strength when soil is soaked. From graphs that shown clearly in Figures 5 to 8, it can be seen $\phi$ (phi angle) is $20^\circ$ for fully saturated condition and it drops to $17^\circ$, $15^\circ$ and $13^\circ$ after being soaked for 7, 21 and 28 days (0-672 hours) respectively. This is indicated by the lowering of the shear strength envelopes shown in Figures as the period of soaking increases. The longer the period of soaking the lower will be the shear strength envelope. The results as in Figure 9 and Table 1 indicated the influence of shear strength due to the intermediate period of soaking can be interpolated as significant reduction in shear strength was observed after 28
days soaking. This is to determine how the shear strength is being reduced within the period of soaking. A maximum period of soaking of 28 days was selected in order to simulate a worse scenario considering a prolong period of rainfall for 28 days which resulted in infiltration and soaking processes.

These phenomena can be correlated to the explanation for the causes of slope failure when the slope is subjected to prolong duration of rainfall. The long period of rain resulted in a deeper infiltration of rainwater into the slope. And when the clay mineral in the soil matrix is in contact with the infiltrated rainwater, the clay will start absorbing the water. The longer the absorption of the water will resulted in reducing the shear strength as demonstrated in Figure 9.

The clay in the soil matrix acts as the binder for the coarse particles. And as the binder softened due to soaking effect the overall strength of the soil matrix reduces. This is indicated by the lowering of the shear strength envelopes shown in Figure 9 as the period of soaking increases. The longer the period of soaking the lower will be the shear strength envelope.

Moreover, the shear strength of the soil diminishes when the clay mineral in the soil matrix is in contact by water. The clay starts absorbing the water while soaking. The longer absorption of the water will result in more reduction in the shear strength which can make the soil unstable. Then, the clay in the soil matrix acts as the binder for the coarse particles. And as the binder softened due to soaking effect the overall strength of the soil matrix reduces.

In another factor, this is anticipated to be influenced by the effect of changes within the clay micro-structure when it is in a prolong content with water, where the clay platelets change to fatter and softer especially when water is absorbed [10]. It is commonly understood that its soil physical properties change from high plasticity change to form low plasticity and finally reaches liquid state when moisture content continuously increases. This research will quantify the shear strength reduction when the clay micro-structure changes with increasing moisture content.

The soaking effect is due to the intermediate period of soaking can be interpolated in calculation Factor of Safety (FOS) to determine the slope stability during preliminary and post construction.

![Figure 9](image-url)

*Figure 9.* The super-impose of all the shear strength envelopes for soaking period of 0, 7, 21 and 28 days.
Table 1. Comparison of soil shear strength with respect to soaking period of time for granitic residual soil type IV, the soil sample from Cameron Highland of Malaysia.

| Samples | Time of soaking hour | Phi Angle (Φ) |
|---------|----------------------|---------------|
| Soaking Sample I (Granitic Residual Soil Type IV) | 0/0 day | 20° |
| Soaking Sample II (Granitic Residual Soil Type IV) | 168/7 days | 17° |
| Soaking Sample III (Granitic Residual Soil Type IV) | 504/21 days | 15° |
| Soaking Sample IV (Granitic Residual Soil Type IV) | 672/28 days | 13° |

4. Conclusion
In conclusion, the study confirmed the effect of soaking on reduction of shear strength for Malaysian granitic residual soil. The value of $\phi'$ drops from 20° to 13° as the specimen was soaked for 28 days. It is suggested to incorporate the effect of soaking on the influence of shear strength in to stability analysis, especially in tropical countries which covered by residual soils and are facing with long period of rainfall.

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