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Degradation of Curvi-linear Shear Strength Envelope at Failure Due to Soaking Effect

Abdul Samad Abdul Rahman, Mohd Jamaludin Md Noor, Ismacahyadi Bagus Mohd Jais and Mohd Raizamzamani Md Zain
Institute for Infrastructure Engineering and Sustainable (IIESM),
Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

Abstract: Causes of slope failures to occur normally by the water infiltration. That is the common factor that triggered slope to fail in tropical countries. When water infiltrates into the soil, the magnitude of suction diminishes and in thus, the shear strength also reduces. At zero suction the shear strength envelope correspond to the shear strength at saturation which is commonly thought as the lowest shear strength. Analysis proved that many slopes are still stable even though being infiltrated to the failure depth and this has puzzled the engineers of how the slope has failed. This study will substantiate that the lowest shear strength is not the shear strength at saturation. The shear strength envelope is further lowered when the soil constituent is soaked within certain period of time. This has been the common triggering factor in slope failure caused by rainfall infiltration that never being incorporated in slope stability analysis and design. A laboratory test was conducted for granitic residual soil in consolidated drained triaxial test for unsoaked and soaked for 14 days and will be presented with respect to shear strength effect and stability analysis applying linear and non-linear failure envelope have been conducted and compared.

Key words: Consolidated drained, unsoaked, soaked, infiltration, consolidated drained triaxial test, rainfall infiltration

INTRODUCTION

The main purpose of this research is to study the soaking effect of a specimen in 14 days and compare with unsoaked of the control specimen. This type of soil shear strength behaviour is very important for the shallow mode of slope failure especially on the low stress levels which are the relevant stresses for the shallow mode of failure, the model can replicate exactly the curve shape of the envelope without any over-estimation of strength. In addition when water infiltrates the slope it exhibits a steep drop in shear strength which is very relevant for the infiltration type of failure.

Residual soil is formed in-situ by the process of chemical weathering on rock and this process develops most readily under humid tropical condition. The infiltration of water into the soil somehow reduces the soil strength and to a certain limit it will cause the slope to fail. This was realized when the cut slopes that has been standing safely for quite some time suddenly fail during or shortly after a heavy rainfall.

In the partially saturated soil the presence of pellicular water in the soil pores causes the soil to be in the state of suction/tension due to the act of surface tension. As the soil moisture increases due to infiltration this state of suction/tension reduces and consequently decreases the soil strength. The strength reaches the lowest when the soil is fully saturated. In triaxial tests, normally the samples are saturated prior to testing. Therefore, the soil parameters obtained from these tests are lower and are not actually representative of the unsaturated soils in the field.

Fredlund *et al*. (1978) introduced the shear strength formula of soil by taking into account the effect of soil matric suction. Matric suction is a variable which is directly related to moisture content. This equation is the first to characterise strength base on moisture content. Apparently it shows that strength increases as the soil dries out, i.e. when suction increases. Later, Noor and Anderson (2006) introduced curved-surface envelope soil shear strength model which can replicate exactly the non-linear shear strength behaviour on the low stress levels and very significant for the modelling of shallow landslides.

The curved-surface envelope soil shear strength model of Noor and Anderson (2006) is able to replicate

Corresponding Author: Abdul Samad Abdul Rahman, Institute for Infrastructure Engineering and Sustainable (IIESM), Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia

exactly the shear strength behaviour at any net stress and suction. The non-linear behaviour at low net stress and low suction is very relevant for governing the behaviour of shallow landslide (Duncan and Wright, 2005). In other words when not applying the true soil shear strength in the stability analysis, the resulted stability factor is not realistic and can be misleading. Most of the time, the application of the linear type of soil shear strength models with cohesion intercept would over-estimate strength on the low stress levels. That is why it is very important to apply the true shear strength behaviour in any slope design (Noor and Hadi, 2010).

The characteristics of the non-linear behaviour of shear strength at low net stress and low suction indicates there are a steep drop in shear strength as the depth of the soil approaches the surface and a steep drop in shear strength when the soil is wetted, respectively. These are very important attributes for the shear strength that is mobilised along the sliding surface in shallow landslide (<5 m deep) triggered by surface water infiltration.

Thus, in order to fully utilise these curved-surface envelope shear strength equations, a special triaxial apparatus which can control the pore air and water pressure has to be used, so that, the partial saturation is maintained while the test is carried out for unsaturated specimens. The curvi-linear shear strength variation with respect to effective stress can be obtained using the conventional consolidated drained triaxial test on saturated specimens. And this has to be interpreted with no cohesion intercept on the shear strength vertical axis. This can be easily interpreted using the curved-surface envelope shear strength equations of Noor and Anderson (2006).

The research of Jiang *et al*. (2003), Baker (2004), Noor and Hadi (2010) and substantiated that the application of linear envelope with some value of cohesion would over-estimate strength at low stress levels thereby explain why the FOS for the above case is greater than unity (i.e., 1.16) for the analysis that applied the linear envelope. Moreover the application of the non-linear failure envelope with zero cohesion has also produced FOS of greater than unity (i.e., 1.14). Then how would the slope has failed?

This is where the hidden aspect of slope stability became relevant in analysis of slope failure. This is about soil shear strength and the hidden aspect is the effect of soaking on soil shear strength which was revealed (Noor and Hadi, 2010). The research of Noor and Hadi (2010) has quantified that the soaking has further lowered

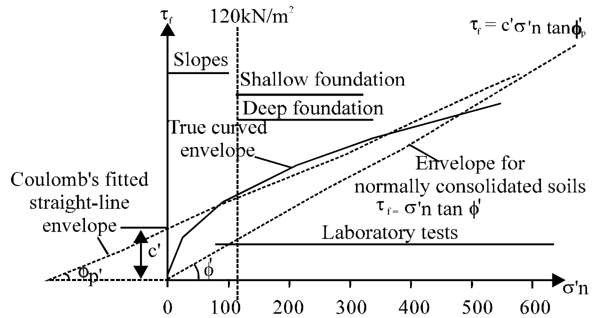

Fig. 1: True curved failure envelope

the shear strength of soil to even lower than the shear strength at saturation. The incorporation of the effect of soaking in the analysis would let the failure to be understood. The effect of soaking at the site has been proven by the existence of caladium plants that grew at the toe of the slope to indicate the abundance of water collected there. It is suspected that the water came from an excessive infiltration at the top of the slope. The infiltration has penetrated to a depth of 10 m deep and has soaked the soil to that extent and this cannot be a short term process. The infiltration must have been going on for quite a period of time prior to the failure which must be long enough for the caladium plants to grow.

Geotechnical engineers are accustomed with the linear shear strength model of. This is just a simplified or an idealized model representing a true complex non-linear behaviour. The application of the linear shear strength behaviour at the high stress range would represent the right shear strength but at low stress range there would be an over-estimation. There has been many reports that the shear strength envelopes of soils are non-linear at low stress levels relative to effective stress like the reports by Charles and Watts (1980). Hence, the application of the linear envelope with a value of cohesion would certainly over-estimate strength at low stress levels (Jiang *et al*., 2003). Figure 1 shows the relevancy of applying the non-linear failure envelope to avoid over-estimation of shear strength for cases of shallow slope failure where the activated stresses along the failure slip plane are <120 kN/m^2.

Besides, the concern about the importance of the non-linear failure envelope at low stress levels has started earlier by the introduction of the non-linear equation by Mello (1977). Later, Noor and Anderson (2006) have introduced another non-linear equation that can make a better replication of the true non-linear shear strength behaviour at low stress levels for saturated soil condition.

MATERIALS AND METHODS

This research was conducted to determine the effect of shear strength using granitic residual soil grade V due to soaking effect. The specimens were soaked into water for at least 14 days in the triaxial machine. In order to determine the effective friction angles of the specimens, about 4 stages of applied effective stress was carried out. Each effective stress consists of 50, 100, 200 and 300 kPa (different of cell pressures and back pressures) takes about 14 days and total all together to complete the test of soaking is about 56 days (about 2 months). During the soaking process in order to make sure that water is in soaking condition, reading of Volume Change Unit (V.C.U.) is vital where each day the volume of water in cubic centimeter, cc will be taken and recorded. Changes in V.C.U. reading will shows that the water is in soaking condition thus the soaking process is currently running.

The soil was taken at an area in Kuala Kubu Baharu and identified as igneous parent rock from previous research papers. The soil were collected using shovel at the depth of 500 mm from original ground surface and right after that, the samples bought to Advance Soil Laboratory Lab., UiTM for testing. To determine the shear strength of the soil, a triaxial consolidated drained test will be carried out. Also, to soaked the specimens with water will be carried out using the same triaxial machine. Figure 2 shows the exact location where samples were collected at Kuala Kubu Baharu, Selangor.

In order to execute the soaking test, each of the specimen will carried out using single stage of effective stress which consists of 4 stages of 50, 100, 200 and 300 kP in effective stress in triaxial machine. It means that in order to define the effective stress values it is the different in cell pressure and back pressure. After that, the soaking process will be done in the triaxial machine for 14 days for each stage. After the soaking process complete, then it will continue with consolidation process and right after that, the shearing process will take place.

During the shearing process, the rate of shearing will be applied slowly as 0.001 mm/min to make sure during shear, the drained water passing through the specimens are not affected and thus, can compromise the results of the findings. The soaking process can be achieved in cell bodies by allowing back pressure and cell pressure flowing through which a value of 50 kPa will be applied to the cell pressure and 45 kPa will be applied to back pressure. Thus, the different of 5 kPa will be the soaking value of the sample allowing through for the desired time. Sample will be under soaking process for the desired time where all the microstructures of the sample are being saturated.

Fig. 2: Location of samples at Kuala Kubu Baharu, Selangor

RESULTS AND DISCUSSION

Table 1 shows the findings of effective shear strength parameters using curvi-linear shear strength envelope for unsoaked and soaked 14 days specimens. Result shows that there are slightly decreasing in shear strength between unsoaked and soaked specimens where in unsoaked specimen, the effective internal friction angle, • ’ was 33° while for the specimen that been soaked for 14 days was 19°. It’s mean that there is a significant reduction in effective friction angle for unsoaked compared to soaked specimens for 14 days by 14°. With reflect in term of effective shear strength of the soil properties, the differences in 14° of unsoaked and soaked specimens would give a numerous effect especially in designing stages.

In addition, to determine the effective shear strength of the specimens, the graph of deviator stress against axial strain in percentage must be plotted as shown in Fig. 3. After that, in order to determine the true effective shear strength of the specimens, it must incorporates the curvi-linear shear strength envelope as shown in Fig. 4.

While in Fig. 5, it is shows that the graph of deviator stress against axial strain for soaked 14 days specimens. Notes that when specimens were soaked into the water for at least 14 days, the shear strength decrease rapidly as shown in Table 1. It is also will results in lowering the effective shear strength when incorporates the curvi-linear shear strength envelope as shown in Fig. 6.

Figure 7 shows the summarized of deviator stress against axial strain for unsoaked and soaked 14 days specimens at single stage of 50, 100, 200 and 300 kPa applied stress. Noted that the value of deviator stress at soaked 14 days specimens were at lower part when compare to unsoaked specimens. It shows that water have significant effect on the soil structures when soaked. It would decrease the effective shear strength of the

Table 1: Summary of shear strength parameters

		Condition of failure			Shear strength parameters		
Description	Effective stress (kPa)	DS (kPa)	PWP (kPa)	CP (kPa)	• ’ kPa	$•_t$ kPa	$(• -U_w)_t$ kPa
Unsoaked	50	144	437	501	33°	80	120
	100	280	437	550			
	200	488	444	650			
	300	646	478	750			
Soaked for 14 days	50	124	460	500	19°	64	900
	100	203	436	550			
	200	306	425	650			
	300	368	460	750			

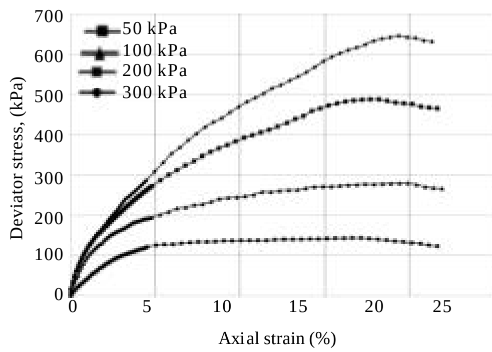

Fig. 3: Stress-strain for unsoaked specimens at 50, 100, 200 and 300 kPa applied stress

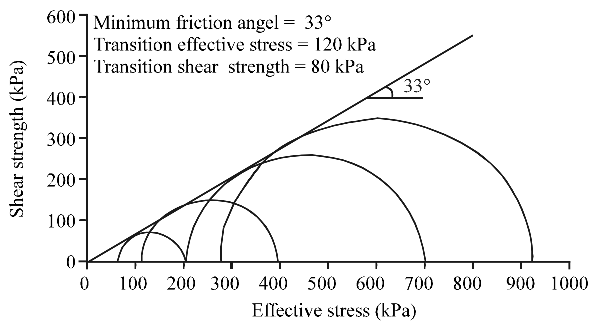

Fig. 4: Curvi-linear shear strength envelope for unsoaked specimens; Granitic residual soil grade V MOHR failure envelope for unsoaked specimens

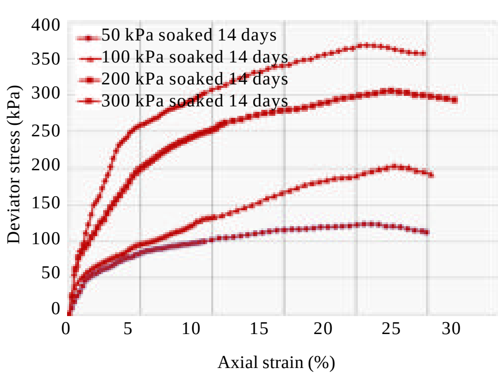

Fig. 5: Stress-strain for soaked 14 days specimens at 50, 100, 200 and 300 kPa applied stress

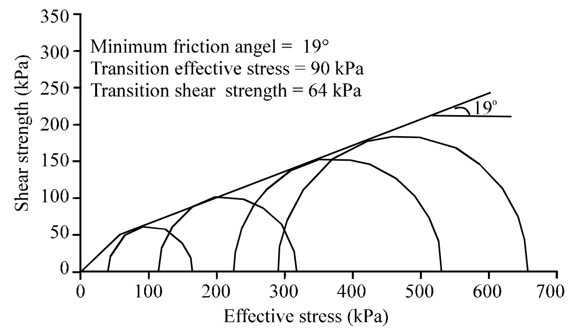

Fig. 6: Curvi-linear shear strength envelope for soaked 14 days specimens; Granitic residual soil grade V MOHR failure envelope for soaked 14 days specimens

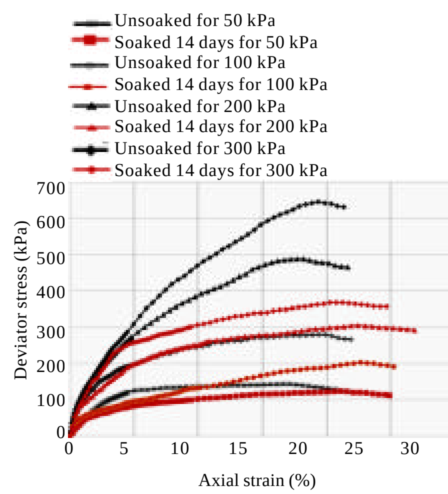

Fig. 7: Combined stress-strain for unsoaked and soaked 14 days specimens at 50, 100, 200 and 300kPa applied stress

specimens when compared to unsoaked specimens up to 20 kPa in terms of maximum deviator stress at 50 kPa effective stress. For 100 kPa effective stress, the different was about 77 kPa while in 200 kPa effective stress was 182 kPa and last but not least for 300 kPa effective stress, the different was 278 kPa. In order to determine the effective shear stress of unsoaked and soaked 14 days specimens

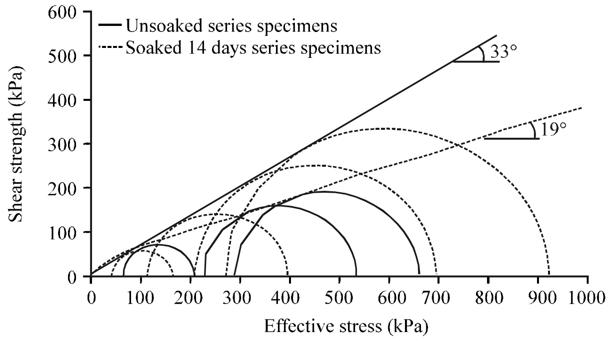

Fig. 8: Curvi-linear shear strength envelope for unsoaked and soaked 14 days specimens; Granitic residual soil grade V-summaries of MOHR failure envelope for unsoaked and soaked 14 days specimens

in terms of effective friction angles then it must incorporates the curvi-linear shear strength envelope for both of them as shown in Fig. 8. In Fig. 8. it found that the different of effective shear strength was at 14°. Due to soaking effect, there was a great significant reduction in shear strength of the specimens. Basically, it shows that during soaking, the micro structures of the soil expand and bulging in thus reduce the bonding between the soil molecules. By that it will slowly decrease the shear strength of the soil and lastly the soil will tend to failures.

CONCLUSION

When water infiltrates into soil structures it will tend to weaken the bonding between soil skeleton. Thus, the strengthen of the soil will deduce rapidly based on how long the soil being soaked. Time of soaking will be the main factor that contribute to the soil failures. It can be shown in the results where during the specimens being soaked for 14 days continuously, the shear strength reduce in term of effective frivtion angle by 14°. If the soil is been soaked into water, the shear strength will be decreasing tremendously and it will further decrease with time when the soil is too long soaked into water. The process of soaking the specimens in the triaxial involved complex processes and it takes a very long times. During soaking process, each specimen was soaked for about 2 weeks and to complete all the process, it will takes about 2 months of soaking process. Findings reveals that the shear strength in soil will decline when the soil is soaked with water and will keep declining with time. This finding also reveals that the slope failures normally occurs during or right after the rainfall. That is the most reasonable reason why slope failure are because of soil is being soaked into water for too long by water infiltration from rainfall intensity.

RECOMMENDATIONS

As a recommendation in order to obtain more accurate results and interpretation of the shear strength of the soil, a longer soaking period might be the best option since previous results shows that shear strength of soil is keep decreasing with time if the sample is being soaking for too long.

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