

THRESHOLD VALUES OF SHEAR STRENGTH PARAMETERS OF SOILS TAKEN FROM SLOPE FAILURES AND STABLE SLOPES IN MALAYSIA

¹Damanhuri Jamalludin, ²Fauziah Ahmad, ³Roslan Zainal Abidin

¹School of Civil Engineering, Universiti Sains Malaysia, Penang, Malaysia

²School of Civil Engineering, Universiti Sains Malaysia, Penang, Malaysia

³Infrastrucutre University Kuala Lumpur, Kajang, Selangor, Malaysia

Abstract- The reduction of shear strength parameters of the soil in the slopes as well as the reduction of suction as the soil become saturated during prolonged rainy seasons are the two main causes of slope failures in Malaysian residual soils. In this study, a total of 227 shear strength parameters were obtained from 29 slope failures in Penang Island and Baling. Both locations are located in Northern Malaysia. In addition, 35 shear strength parameters were also obtained from 10 stable slopes, also at the same locations. Disturbed soil samples were taken at a depth of 100mm from the existing ground surface. Field bulk density tests were carried out at all the location where soil samples were taken. The field bulk density results were later used to re-compact the soil for the consolidated drained shear box tests to be carried out in laboratory. The objective of the research is to determine the threshold values of the effective shear strength parameters of soil taken from both the slope failures and stable slopes. The threshold values of the effective shear strength parameters of the soil slopes were determined after comparing the effective soil shear strength parameters taken from slope failures and stable slopes. It was found that, the threshold value for the effective cohesion c' was 0.0 kN/m^2 while the threshold value of effective friction angle θ' was 23.2° .

Keywords - Consolidated Drained Shear Box Test; Slope Failure: Stable Slopes: Effective Cohesion; Effective Friction Angle

I. INTRODUCTION

In Malaysia, slope failures usually occur during the rainy season especially during the months of October to January every year. The two main factors causing slope failures are the reduction of shear strength parameters of the soil slopes and the reduction of suction as the soil become saturated during prolonged rainy season. Slope failure is defined as the movements of a large volume of sediments and rock materials down slope under the action of gravity as mentioned by [13]. Stable slope is a slope which is still standing until now and does not show any sign of failure. Shallow slope failure is a slope failure where the depth is between 3 - 5m and occurring above the slope toe as explained by [13, 14].

Many slopes designed by experienced geotechnical design engineers failed as described by [1, 11] in which more than 15 slope failures occurred during the construction of the newly cut slopes along the new road from Pos Selim in Perak to Lojing in Pahang. One of the slope failures along this road was studied by [12] upon the request of Public Works Department of Malaysia, after 10 slope failures occurring to this particular cut slope at CH 23+800. The main reason is due to the usage of higher value of effective shear strength parameters during the design stage since soil investigation (SI) could not detect the relict joints as well as the slope is passing through a treacherous instable geological setting zone as explained by [16]. Only nominal numbers of SI were conducted since they are expensive unless it is necessary to conduct more SI due to the area is prone to slope failure

occurrences. The higher value of effective shear strength parameters were not downgraded or reduced during the construction stage since during the mapping works of the cut slopes were done, relict joints were not detected as the cutting of slopes progressed downwards. Relict joints are discontinuities that are inherited from their parent rocks as the rocks decomposed into residual soils. These discontinuities are in the form of bedding planes, foliation planes, joints, fault planes etc. Relict joints will form planes of weakness in the slope mass since they have much lower effective shear strength parameters as described by [16]. They also readily allow groundwater to flow through them. The objective of the research is to determine the threshold (minimum) values of the effective shear strength parameters of soil taken from both the slope failures and stable slopes.

One dimensional consolidation tests were used to determine the slow shearing rate to be used in the CD shear box tests, and these were based on [8]. The procedures to conduct consolidated drained (CD) shear box tests were based on [3, 10]. Reference [4] conducted a study on the variation of shear strength parameters of residual soils and concluded that the shear strength parameters of the soil are highly variable and increases in strength as it goes deeper into the soil. Reference [12] conducted shear box tests on soil samples taken from the most troublesome cut slope failure in Malaysia. The slope is about 240.0 m high and about 1.5 km width with the average slope angle of 40.0 degrees. Reference [18] mentioned that this is the highest and biggest cut slope ever built in Malaysia is also responsible for the delay of the completion of the road by more than 4 years. The

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parent rock of the slope consists of well foliated with almost perpendicular joints, locally faulted schist. Once the highly fractured schist is weathered, all the foliations and its perpendicular joints will become relict joints within the weak weathered soil. From the results of the shear box tests, reference [12] found that the range of the residual friction angle the weak weathered schist is between 23.0 – 42.0°.

II. GEOLOGY

Reference [19] stressed that residual soils are formed from the weathering of parent rocks and they remain in-situ where they are formed. The properties of residual soils depend strongly on the weathering conditions and features of the parent materials. The distribution of tropical residual soils is closely related to the distribution of the various parent rock types in Malaysia. Reference [9] had produced a simplified geological map for Peninsular Malaysia as shown in Fig. 1. It also shows the distribution of the three major classes of soils widely found in Malaysia. As described by [17], the 3 types of soils commonly found in Peninsular Malaysia are granitic residual soil, sedimentary including meta-sedimentary residual soil and coastal alluvium formation. As explained by [20], granite rock which is part of igneous rock, is widely found in Malaysia while sedimentary rocks mostly found in Malaysia are mudstone, sandstone, shale and schist. Fig.1 also shows the study areas of slope failures and stable slopes in Penang and Baling. Fig. 2 and Fig. 3 show the locations of slope failures and stable slopes selected in Baling and Penang respectively.

III. SOILS SAMPLING AND FIELD TESTS

A total of 227 shear strength parameters were obtained from 29 slope failures in Penang Island and Baling. In addition, 35 shear strength parameters were also obtained from 10 stable slopes, also at the same locations. Soil sampling points taken at the slope failures and stable slopes are shown in Fig. 4 and Fig. 5 respectively. A slope failure area includes the failed section, the un-failed section next to the failed one as well as the slope crest and slope toe. Disturbed soil samples were taken at depth of 100mm from the existing ground surface at both the slope failure and stable slope locations. Once they were retrieved from the ground, they were immediately placed in two layers of plastic bags to prevent moisture loss. Field bulk density tests were also carried out at all the locations where soil samples were taken.

IV. TESTING PROGRAM

Field bulk density tests were carried out at all soil sampling points. The actual field bulk density was used to re-compact the soil specimen into the shear box. Shear tests were conducted on 60 x 60 x 26 mm soil specimens. The specimen preparations and procedures to conduct CD shear box tests were based on [3, 8]. Soil specimens were submerged in water for about 30 minutes until water seeped towards the soil surface. Since the residual soil is a porous material as explained by [2], water quickly seeped into the very permeable residual soil. The soil specimen was consolidated until all consolidation settlements were completed. Once they were completed, the soil specimen will be sheared until failure using a slow shearing rate of 0.179 mm/min. The procedures to determine the slow shearing rate of the CD

shear box tests were based on [3, 5, 8]. Since the average height of the slope failure and stable slopes in Baling and

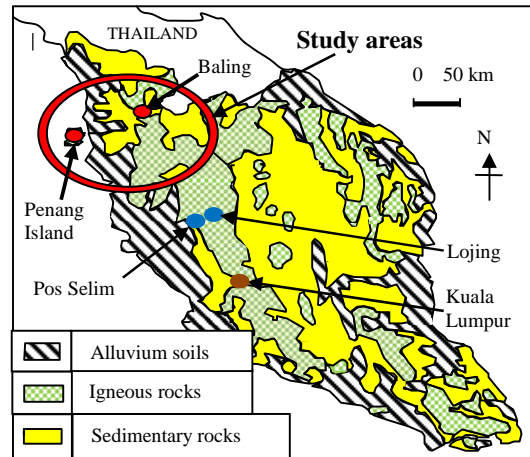


Fig. 1 Simplified geology map of study area (Simplified geology map after [9]).

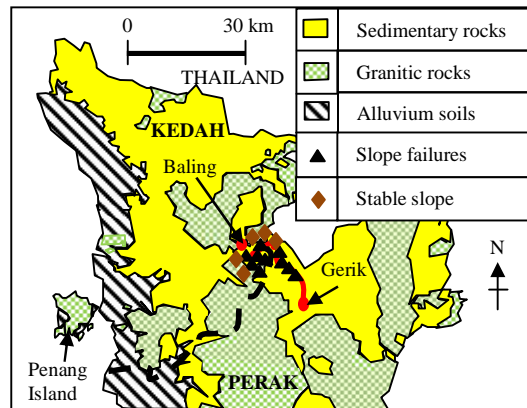


Fig. 2 Slope failures and stable slopes in Baling.

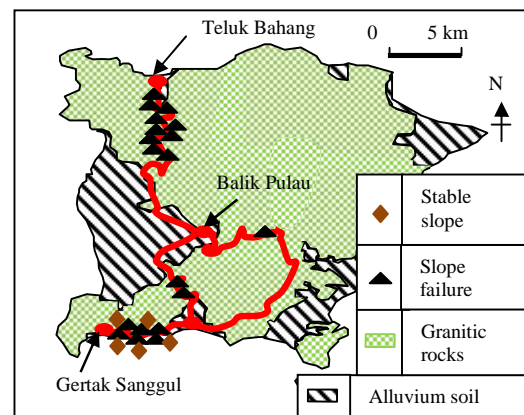


Fig. 3 Slope failures and stable slopes in Penang Island.

Penang is 6m, normal stresses used in the CD shear box tests were 20.0, 45.0 and 90.0 kN/m².

V. SHEAR STRENGTH PARAMETERS

From Table 1, lower values and ranges of shear strength parameters are observed at stable slopes as compare to at slope failures due to the weakest soil at the slope surface is displaced and moved down the slope as the slope failed. At failed slopes, soil samples were taken at the slightly stronger soil. The weaker soil at the slope surface of stable slope is still there, thus giving slightly lower value and ranges of shear strength parameters at stable slopes. Soil samples were taken at depth of 100mm from the existing ground level. As explained by [4], the soil strength increases as the soil goes deeper into the residual soils.

TABLE 1 RANGES OF SHEAR STRENGTH PARAMETERS AT FAILED AND STABLE SLOPES

Soil types	Shear strength parameter	Range in slope failures	Range in stable slope
Residual soils	c' (kN/m ²)	0.20-59.40	0.20-36.20
	ϕ'^0	8.60-65.80	3.20-44.40

VI. THRESHOLD VALUES

The average normal stress of 51.7 kN/m² was used to calculate the shear strength of soil taken from slope failures and stable slopes where the shear strength of soil is given by (1).

$$\tau_f = c' + \sigma' \tan \phi' \tag{1}$$

Where: τ_f is the soil shear strength, c' is the effective cohesion, σ' is the average effective normal stress and ϕ' is the effective friction angle of the soil. Fig. 6 and Fig. 7 show the effective cohesion versus soil shear strength and effective friction angle versus soil shear strength respectively for soils taken from slope failures and stable slopes, both in Penang and Baling. It can be seen from Fig. 6 and Fig. 7, the soil shear strength are highly variable as explained by [4]. In Fig. 6 and Fig. 7, when the curves of the slope failure crossed the curves of the stable slope, threshold values of the effective cohesion and effective friction angle are obtained respectively. The threshold value of effective cohesion $c' = 0.0$ kN/m² while the threshold value of effective friction angle $\phi' = 23.2^\circ$.

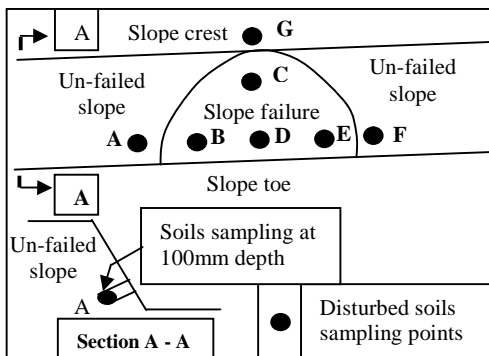


Fig. 4 Locations of soil sampling points at slope failure.

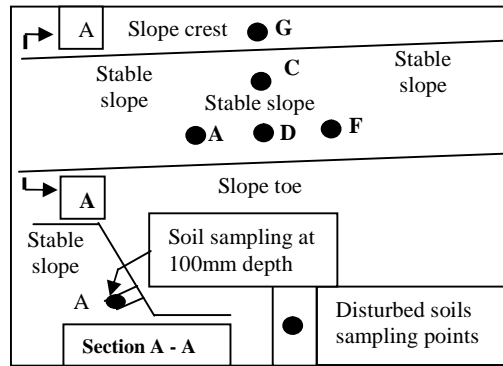


Fig. 5 Locations of soil sampling point at stable slope.

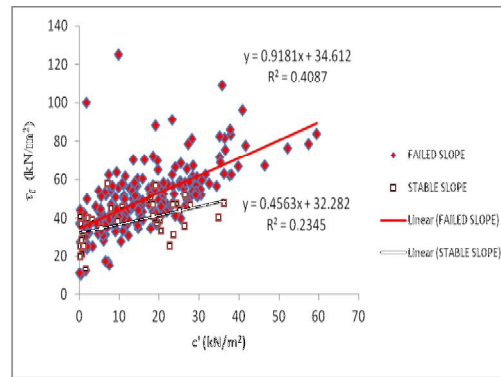


Fig. 6 To determine the threshold value of effective cohesion.

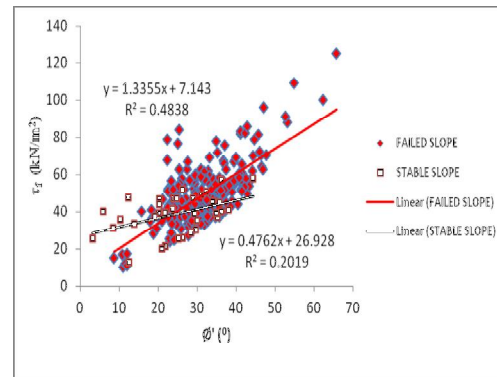


Fig. 7 To determine the threshold value of effective friction angle.

VII. SLOPE W ANALYSIS

By using the threshold values of the shear strength parameters and also by using the typical un-failed cross-sections of slopes for both in granitic and sedimentary residual soils (Fig. 8), the typical SLOPW W analysis output is obtained as in Fig. 9. The output in Fig. 9 shows a shallow slope failure since failure plane is above the slope toe where this type of failure was selected in this study. The SLOPW W analysis was using Morgenstern-Price method.

As explained by [7, 15], Morgenstern-Price method is one of the most accurate methods to analyse the stability of slope. It was observed from Table 2 that the values of Factor of Safety (FOS) were less than 1, for slope with water table at ground surface. When the water table is at the ground level, the soil is fully submerged and this condition is the most critical stability condition of a slope.

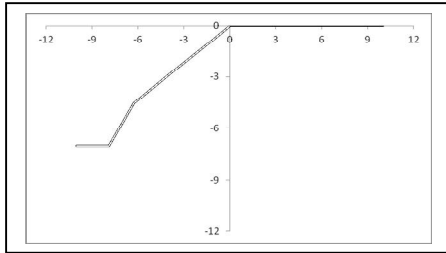


Fig. 8 Typical cross section of the un-failed slope in granitic residual soil

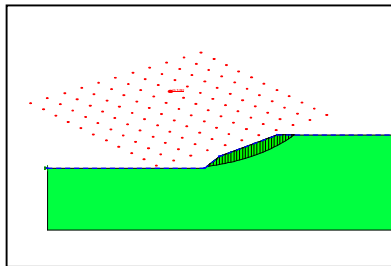


Fig. 9 Typical SLOPE W analysis output using the un-failed slope in granitic residual soil.

TABLE 2 RESULTS OF SLOPE W ANALYSIS BASED ON UN-FAILED SLOPE CROSS SECTIONS

Residual soil type	Avg. slope height (m)	Avg. slope angle (°)	c' (kN/m ²)	Ø' (°)	FOS
Granitic	7.0	44.0	0.0	23.2	0.1
Sedimentary	5.4	48.5	0.0	23.2	0.1

VIII. DISCUSSIONS

The threshold values of the effective shear strength parameters of the soil slopes are determined after comparing the effective soil shear strength parameters taken from slope failures and stable slopes. The threshold value obtained for the effective cohesion $c' = 0.0 \text{ kN/m}^2$ while the threshold value for the effective friction angle $\phi' = 23.2^\circ$. The effective cohesion $c' = 0.0 \text{ kN/m}^2$ which is in accordance with the view of [6] who only recommended the used of $c' = 0.0 \text{ kN/m}^2$ unless there are significant test results to obtain the other representative values. The threshold value of the effective friction angle $\phi' = 23.2^\circ$ and this value is almost the same as the minimum value of residual friction angle of 23.0° found by [12]. By using the threshold values of the shear strength parameters and using the typical un-failed cross-sections for both in granitic and sedimentary residual soils, SLOPW analysis was carried out. It was found that, the values of factor of safety were less than 1, for slope with

water table at ground surface. The water table at the ground surface is the most critical slope stability condition of a slope.

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