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EFFECTIVE SHEAR STRENGTH PARAMETERS OF SOIL SAMPLES TAKEN FROM SLOPE FAILURE ALONG THE KULIM – BALING ROAD

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ABSTRACT

Slope failures always occur in Malaysia especially during the monsoon seasons between October and January every year causing fatalities and damages to properties. The main factors causing the slope failure to occur are reduction of the shear strength parameters and loss of negative suction due to saturation of the slope. The objective of this study is to determine the effective shear strength parameters of the soil taken at slope failure using consolidation drain (CD) shear box and also to determine the factor of safety using SLOPE/W software. The soil samples were tested under submerged condition. The minimum value of effective shear strength parameters obtained from the CD shear box tests were c' = 0 kN/m^2 and ø' = 47.3^0 while the maximum value of c' = 30.2 kN/m^2 and ø' = 35.6 ^{0}. The FOS varied from 0.377 to 0.749 with minimum value of factor of safety was 0.377. When using SLOPE/W software on a stable slope cross section having minimum value of effective shear strength parameters, the minimum value of factor of safety was less than 1 indicating that the slope had already failed.

Keywords: CD Shear Box; Factor of Safety; Effective Shear Strength Parameters; Slope Failure; SLOPE/W software.

1. INTRODUCTION

Slope failures were movements of rock or debris materials down the slopes under the pull of gravity as defined by Md. Noor (2011). The study area selected was situated along Kulim – Baling road and was within the sedimentary residual soil. When sedimentary rocks were completely decomposed by weathering for millions of years, they became sedimentary residual soils. Among the main causes of slope failures are lack of proper drainage system on the slope surface, high ground water table in the slope body, complicated weathering profiles

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and reduction in negative suction. The heavy rainfall in Malaysia is the main triggering factors causing instability problems related to the residual soil slopes as mentioned by Kassim et al. (2006). In this study, CD shear box test will be conducted to obtain the effective shear strength parameters of the soil obtained from the slope failure zone. By using a stable slope cross section together with minimum values of effective shear strength parameters in SLOPE/W software, the minimum FOS was found. Stable slopes were the slopes on both sides of the failed slope.

2. LITERATURE REVIEW

2.1 General

Jamalludin (2016) conducted a study on the variations of effective shear strength parameters as well as the basic soil properties of soil taken from granitic residual soil in Penang and sedimentary residual soil along Baling - Gerik road. Disturbed soil samples were taken from slope failures at depth of 100 mm below the exiting level. More than 200 effective shear strength parameters data were obtained from 30 slope failures. He found that the variation of effective shear strength parameters was in the form of normal distribution, where the mean and lower bound values of the effective shear strength parameters were obtained. This study is a continuation of the study carried by Jamalludin (2016) and Jamalludin et al. (2012) but it focuses on the variations of effective shear strength parameters in slope failure within the sedimentary residual soil along Kulim – Baling road. Only man - made cut slopes were involved in this study. Due to time constrain, only 5 soil samples managed to be tested out of a total number of 56 samples.

Brenner et al. (1997) conducted a study on the variation of soil shear strength of residual soil by using vane shear, undrained unconsolidated triaxial and shear box tests at varying depths. The scattered results were obtained with shear strength increasing with depth i.e. shear strength increases with depth where less weathering occur to the residual soils as they go deeper. Jamalludin (2016) also found that the shear strength parameters not only vary in horizontal direction along sample locations but also in vertical directions as the soil the soil goes deeper. Jamalludin (2016) also found that even though the soil samples were taken from slope failures, few extremely high values of effective shear strength parameters were found. The effective shear strength parameters of residual soils were invariably anisotropic, non-homogeneous and dynamic in nature as confirmed by Neoh and Alimat (2002).

2.2 CD Shear box

The shearing of CD shear box test should not start until all the consolidation settlements due to applied normal loads have stopped. Shear force is applied so slowly that no pore water pressure developed in the samples (i.e. preventing the formation of excess pore water pressure in the soil sample). Drainage is allowed at all time. There was a continuous reduction of moisture content of the soil during both the consolidation and shearing stages. The test was analogous to the consolidated isotropically drained triaxial test. The shear strength parameters are in terms of drained stresses which were almost equal to effective stresses as mentioned by Head (1994). Water was placed around the sample to soak the soil before consolidation and shearing tests were carried out. The soak condition of soil was the normal soil condition prior to failure after prolonged rainfall.

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The effective shear strength parameters of soil can be determined using triaxial or shear box tests following the procedures explained in BS 1377: Part 8 (1990) and ASTM D 3080 (1998). CD shear box tests can also be used to determine the effective shear strength parameters of soil samples as specified in Head (1994) and ASTM D 3080 (1998). The procedures to determine the slow shearing rate of CD shear box tests using consolidation tests were based on Head (1994) and ASTM D 3080 (1998). CD shear box tests will produce drained shear strength parameters namely, c_d and $ø_d$.

2.3 Effective Shear Strength Parameters

Effective shear strength has two components which are effective cohesion and effective friction angle. The effective cohesive element attract particles together because the effective cohesive resulting from inter-particulate forces. Effective cohesion ‘c'’ is sensitive to water and pore water chemistry. Under small restrain, the effective cohesive resistance will develop to the maximum value and decrease as the strain increase. The effective frictional elements are derived from inter-granular contact and will not develop to the maximum value if it did not reach a significant amount of strain. The internal friction angle is represented as ‘ø’’.

In this study, CD shear box test was used in determining the effective shear strength parameter. In this test, the normal stresses and corresponding values of peak shear strength obtained from number of tests and plotted on graph from which the shear strength parameters were determined (Braja 2005). The concepts of determining shear strength parameters are adopted from Mohr- Coulomb Failure Criteria.

2.4 Factor of Safety (FOS)

By using the stable slope cross section next to the failed slope together with the lowest values of effective shear strength parameters in SLOPE/W software, the FOS is determined as in equation 1.

$$\text{FOS} = \frac{c' + \sigma' \tan Ø'}{\tau_{\text{required}}} \qquad (1)$$

where, c’ = Effective cohesion
ø’ = Effective friction angle

2.5 Significant of Factor of Safety

Theoretically, the slope is considered safe if the shearing resistance available along the considered slip surface is more than distributing forces. The stable slope is estimated to have FOS higher than one (FOS > 1.0). However, the slope is considered unsafe when the factor of safety is less than one (FOS < 1.0). When designing a new cut slope, the minimum value of FOS must be greater than 1.5 based on JKR (2015).

According to Whitlow, (2004), when deciding the minimum factor of safety for a particular problem a number of factors have to be considered. They are:

i. The consequences of the event that is being factored against, example: slip of an embankment or cutting.
ii. The numerical effect on the FOS value of variations in the parameters involved.

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iii. The reliability of the measures or assumed values of the parameters involved.
iv. The economics of the problem.

2.6 SLOPE/W Software

This method assumes that Coulomb's failure criterion is valid and a failure surface is assumed. Because of variations in stresses along the trial slip surface, the slip mass is considered as a series of slices. Although there are many methods to analyze slope stability, GCO (1984) and Duncan and Wright (2005) stated that Morgenstern and Price method of limit equilibrium will produce the most accurate FOS where the procedures are applicable to virtually all slope geometries and soil profiles. In this study Morgenstern and Price method was used to analyze the slope. By using a minimum value of the effective shear strength parameters on stable slope cross section, the lowest FOS can be obtained. The FOS obtained from SLOPE/W software must be less than 1 because the slope had already failed.

3. METHODOLOGY

3.1 Location of Slope Failure

The slope failure selected in this study is located along Kulim – Baling road as shown in Figure 1.

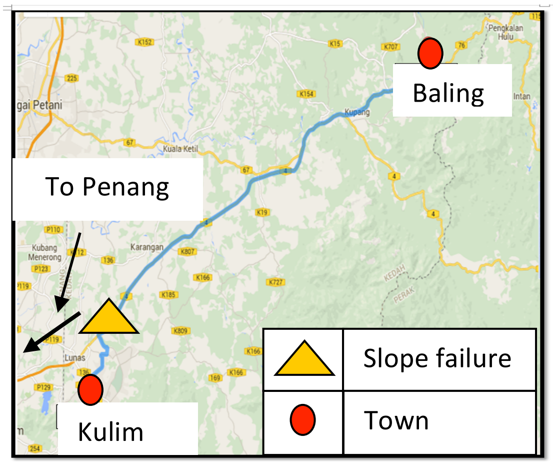

Figure 1: Location of slope failure selected

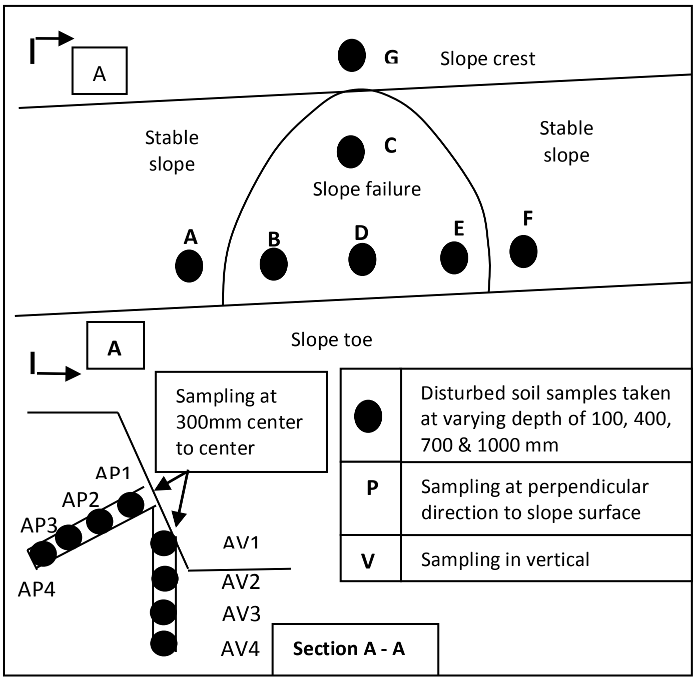

Figure 2: Locations of soil samplings at slope failure zone. Soil samples were taken at varying depths of 100, 400, 700 & 1000mm in both vertical and perpendicular directions.

3.2 Soil sampling and Field Tests Conducted

The disturbed soil samplings are shown in Figure 2. Seven sampling points were selected. At each sampling point, 8 soil samples were collected whereby 4 samples were in vertical direction while another 4 soil samples were collected in perpendicular direction to the slope surface. At both directions, the soil samples were collected at depths of 100, 400, 700 and 1000mm from slope failure surface. Due to limited time, only 5 samples namely BP1, CP1, DP1, EP1 and FP1 were tested from a total of 56 soil samples collected. Soil samples tested in this study were collected at a depth of 100mm in a perpendicular direction to the existing slope surface.

Field bulk density tests were carried all location where soil samples were collected. The soil was removed from bulk sampler into tray so the bulk sampler could be reused. The soil from the tray was placed into three layers of plastic bags to prevent moisture loss and the bags were labelled. The results of field bulk density were used to re-compact the disturbed soil into the shear box. Survey work was also carried out across the slope failure as well as along the 2 stable slopes on either sides of the slope failure in order to determine the slope geometry.

3.3 Shear Box Test

Knowing the field bulk density result, the mass of soil required to fill the shear box was determined. The mass of soil was re-compacted into the shear box. Prior to filling the shear box, a bottom porous plate was placed. Then, the shear box is submerged with water for about 45 minutes. Once soaked, the soil was consolidated. Consolidation test was considered completed once there were no more vertical displacements. Once consolidation was completed, the soil sample was shear using slow shearing rate. The slow shearing used for the CD shear box tests was 0.179 mm /minute as reported by Jamalludin et al. (2014).

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4. RESULTS AND DISCUSSIONS

4.1 Shear Strength Parameters

Figure 3 shows the typical graphs of shear stress versus horizontal displacement obtained from the CD shear box tests. From Figure 3, the maximum stresses can be obtained to plot normal stress versus shear stress graph in order to get the shear strength parameters of the soil.

Normal
stress (kPa)

Figure 3: Graph of horizontal shear stress versus displacement

Figure 4 shows the graph of shear stress versus normal stress. The shear stress is the maximum shear stress obtained from shear stress versus horizontal displacement as in Figure 3. From Figure 4, equation y = 0.7478x + 30.2 can be generated from the graph. From the generated equation, shear strength parameters can be obtained. The friction angle was obtained by using the gradient from the generated equation, meanwhile cohesion was the value of y-intercept from the generated equation. The values of effective shear strength parameters, the results shown in Table 1. The effective shear strength parameters were highly variable where c’ varies from 0 to 30.2 kN/m^2 while ø’ varies from 22.8 to 47.3^0. This observation was in line with Brenner et al. (1997) where the shear strength parameters of residual soil were highly variable.

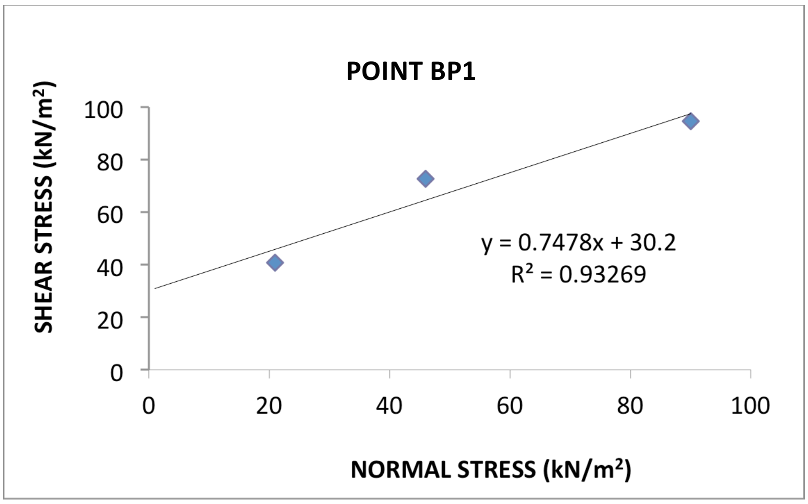

Figure 4: Typical graph of shear stress at failure, τ_f (kN/m^2).versus normal stress, σ (kN/m^2) applied

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Table 1: Shear strength Parameters and Factor of Safety (FOS)

Samples reference no.	c' kN/m^2	ø' (^{0})	FOS
BP1	30.2	35.6	0.749
CP1	0.0	47.3	0.377
DP1	16.8	41.8	0.653
EP1	8.7	46.6	0.514
FP1	26.5	22.8	0.573

4.2 SLOPE/W Output

Figure 5 shows the SLOPE/W software output where minimum value of FOS was obtained. The SLOPE/W output was using the stable cross section of slope and the shear strength parameters. Water table was considered at the surface of the slope where the slope was assumed to be fully saturated. Table 1 shows the shear strength parameters and FOS obtained. When using the effective shear strength parameters of c'= 0 kN/m^2, ø'= 47.3^0, minimum FOS equal to 0.377 was obtained. The FOS varied from 0.377 to 0.749. However all the FOS in Table 1 are less than 1. Since the FOS < 1, it confirmed that the slope had already failed as what occurred at site.

From Table 1 there are only 5 data of effective shear strength parameters and all the output of SLOPE/W were less than one with soil sample CP1 giving the lowest FOS. This research is at its initial stage where only 5 data out of 56 data were available. When all the 56 data are available, it is expected that extremely high shear strength parameters will be obtained giving FOS > 1. As observed by Jamalludin (2016) even though the soil samples were taken from slope failures, few extremely high values of effective shear strength parameters were found giving the FOS > 1 when analyzed using SLOPE/W software. Due to saturation and loss of negative suction, there was a reduction in values of the effective shear strength parameters. The effective shear strength parameters were not constant and they were in dynamic in nature of as explained by Neoh and Alimat (2002). If any portion of a stable slope having low effective shear strength parameters with FOS < 1, it will trigger the failure. Once the slope cracked and soil stated to move downwards, more rain water will enter the failure zone causing more saturation and loss of more negative suction. Erosion will further cause the slope to fail and become larger. Slope failure has generally occurred after heavy rainfall as described by Morgenstern (2007).

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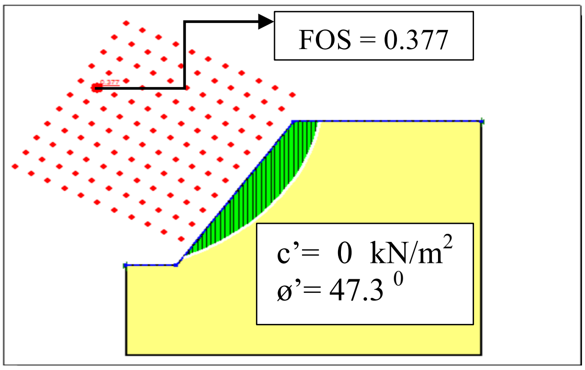

Figure 5: Typical SLOPE/W output using minimum value of effective shear strength parameters.

5. CONCLUSION

The effective shear strength parameters of residual soil are not constant and they are highly variable. From this research, significant information about the sedimentary residual soils along the Kulim-Baling road was obtained. The conclusion that can be made from this study is the effective shear strength parameters of soil taken from slope failure were obtained from CD shear box tests. The effective cohesion, c' varied from 0 kN/m² to 30 kN/m² while effective friction angle, ø' varied from 20 ^{0} to 40 ^{0}. The FOS varies from 0.377 to 0.745 by using SLOPE/W software using minimum value of shear strength parameters of c'= 0 kN/m², ø'= 47.3 ^{0} on stable slope cross section, the minimum FOS obtained was 0.377 which was less than 1. When the FOS < 1, it confirmed the minimum values of effective shear strength parameters where the slope had already failed at site.

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