COMPARISON OF PROPOSED SLOPE FAILURE ANALYSIS AT LATAR EXPRESSWAY SELANGOR WITH PREVIOUS CRITERIA AND INDUSTRIAL STUDY

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ABSTRACT: *Slope failure is not necessarily related to the shear strength alone, the liquid limit and dry density in particular are useful indicators in determining the cause for slope failure. Soil samples were collected from the failed slope and the neighboring stable slope at KM13.2 LATAR Expressway, Selangor Peninsular Malaysia and their moisture properties are analyzed against established criteria from previous studies. It was revealed that the slope may have failed due to low liquid limit after checking against criteria of Denisov and also due to low shear strength parameters i.e. internal friction angle. However, evaluation on the maximum dry density of the failed slope sample has revealed that it is a suitable slope material thus the slope has not failed due to low maximum dry density.*

Keywords: Slope Failure, Liquid Limit, Dry Density, Shear Strength, Internal Friction Angle

1. INTRODUCTION

Prior researches have indicated that heavy rainfall has consistently been identified as the main cause to slope instability [1]. Effect of water is highly significant in slope stability study, a research by [2] has stated that the strength of slope is highly dependent on the moisture content, especially in slopes containing clayey materials. The study slope which has failed in 2012 is located at KM 13.2 westbound of LATAR Expressway with a height of approximately 25 meters and width of 3 meters. An interview session with the Resident Engineer has revealed that the leading cause of failure was identified to be the poor maintenance of the existing drain. The surrounding drain channels were heavily silted hence induced growth of vegetation which if found in excess is an obstruction to water flow, this is highly undesirable especially in case of heavy rain. Reduction in drain effective depth was significant resulting in consequent reduction in drainage capacity. During heavy raining seasons where water inflows are high, the silted drains could not discharge at design flow rate which has caused overflow and saturating the slope consequently adding up to its weight. The weight of the overlying soil became an excess burden to the underlying plane reducing the shear strength due to excessive moisture content; the top plane eventually slipped causing a landslide. Only a part of the slope has failed and the other remained stable with no sign of failure.

2. LITERATURE REVIEW

A landslide study near Simpang Pulai – Lojing highway was conducted by [3] in which 5 Direct Shear Tests were carried out on 4 failed slope samples in Engineering Geology Laboratory of Leeds University, UK. The shear strength parameters of weak and strong samples were obtained and compared. The internal friction angle for weak and strong samples were determined to be about 23° and 42° respectively. Reference [4] has conducted an extensive research in attempt to determine the failure threshold in terms of shear strength whereby a set of 227 shear strength parameters were obtained from 29 failed slopes in Penang Island and Baling and another set of 35 shear strength parameter were obtained from 10 stable slopes within the same said location. The samples were disturbed and were taken 100 mm from the existing ground surface. Shear strengths were determined via Consolidated Drained Direct Shear Tests. Both sets of shear strength parameters were compared to find a common pattern. It was concluded that the failure threshold for soil cohesion and angle of internal friction were found to be 0 kN/m^2 and 23.2° respectively i.e. shear strength parameters lower than the said threshold are deemed as weak. In terms of slope geometry, reference [5] stated that 30° to 45° of internal friction angle is frequently prescribed for construction of clayey soil slopes, but to achieve stability, slope angle should be less than 20°. Reference [6] suggested that there is a connection between soil liquid limit and its stability based on the argument of Denisov (1953). It was suggested that if the moisture content upon saturation exceeds the liquid limit, the soil should collapse and densify under its own weight. In another report, the dry density of soil is closely linked to its collapsibility as stated in [7]. Reference [5] has suggested that soil maybe collapsible based on the dry density, if it is less than 1.28 g/cm^3, the soil is liable to significant collapse and if the dry density exceeds 1.44 g/cm^3, it has small chance of collapsing while the collapsibility is transitional in between. Reference [8] suggested that soils with higher dry density tend to have lower collapsibility. It was determined that soil with dry density above 1.5 g/cm^3 has an obvious small chance of collapsibility, the value somewhat agrees with Clevenger's. A range of collapsible dry density between 1.14 g/cm^3 – 1.69 g/cm^3 was suggested by [7]. Reference [9] suggested the use of liquid limit and dry density to distinguish between collapsible and non-collapsible soil. A graph with function of the soil's maximum dry density and its liquid limit is used, a soil is considered non-collapsible if it lies in the upper region of the line otherwise it is considered as collapsible soil.

3. EXPERIMENT PROGRAM

All laboratory test procedures were performed according to ASTM standards based on procedures outlined by [15]. 1 to 2 kg of disturbed bulk samples were obtained at depth of 15 cm to 30 cm (weathered top soils were removed) with hoe and hand shovel from the crest and middle of the failed and stable slopes and were transported to the laboratory in sealed black plastic bags and kept at room temperature with no sun exposure. Water Content Determination Test, Atterberg's Limit Test, Compaction

Test and Shear Box Test were performed using 3 different samples from each bulk for every test.

4. RESULTS & DISCUSSION

4.1 Atterberg's Limits and Maximum Dry Density of Soil Samples

The liquid limit (LL) for soil samples of the failed slope was found to be lower than the samples of stable slope i.e. 41 and 53 respectively as shown in Figure 1 and 2. The samples from failed slope also show more reduction in liquid limit with increasing blow count as compared to stable slope samples i.e. steeper slope gradient. Cross-referencing the results with theory and criteria of Denisov for connection between liquid limit and slope stability indicates that soil at stable slope is more resistant to collapse than the soil at failed slope. Higher liquid limit means the stable slope is more capable in absorbing water before it enters liquid state and this capability is lesser for soil in failed slope whereby less water may be absorbed by the failed slope before it saturates and enters liquid state. Both failed and stable slopes were subjected to the same volume of overflow from the congested interceptor drain, it is possible that the overflow was enough to increase the water content of the failed slope to its liquid limit, saturating and destabilizing it but it was not enough to destabilize the stable slope due to its capability of retaining more water. The strength of stable slope may have reduced but not to the extent of flowing which has happened to the failed slope. In this case, the link between Liquid Limit of soil and its stability in slopes are justified and may be used as an indicator to slope stability. In reference with site condition, it was observed that the failure plane lies at the slope crest beneath the interceptor drain as highlighted in Figure 3; the hypothesis which states that water overflow has caused the failure is justified. Prolonged rain has caused overflow and saturated the slope crest until the water content of soil along the failure plane reached liquid limit which turned the slope into fluid state and reduced its shear strength i.e. slope resisting force. The slope eventually failed when its resisting force could no longer sustain the driving force due to increment in its self-weight as it saturates.

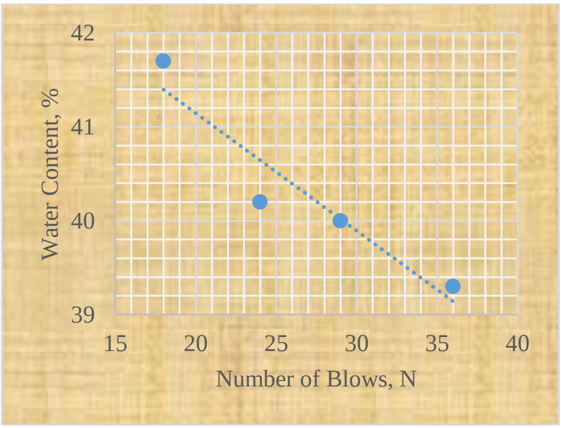

Fig. 1: Liquid Limit Plot – Failed Slope sample.

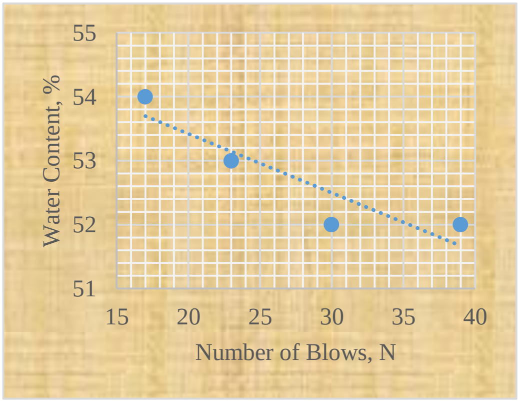

Fig. 2: Liquid Limit Plot – Stable Slope

Fig. 1: Failure Plane beneath Slope Crest

The Plastic Limit (PL) of soil samples at the failed slope was found to be lower than the soil samples at the stable slope i.e. 28 and 34 respectively. This indicates that the failed slope will turn from its solid state into plastic state at lesser water content than the stable slope. Soils with high silt and clay content are generally stronger at solid state but may become significantly weak upon wetting.

High level of silt content was found in the failed slope samples thus its strength is sufficient if kept dry but may reduce significantly upon high water penetration, although this may not have happened if the drainage system was maintained as instructed in [11]. The Plasticity Index (PI) of soil samples at the failed and stable slopes are 13 and 19 respectively. Higher plasticity index indicates that the soil is less permeable as stated by [13] thus it can be deduced that the stable slope is less susceptible to rain penetration making it more resistant to saturation.

In terms of compaction strength, the samples from the failed slope achieved a maximum dry density of 1.7 g/cm^3 at 15% water content, it exceeded the maximum dry density of 1.6 g/cm^3 at 13% water content for sample from the stable slope as shown in Figure 4. The results from literature review were used as base reference for evaluation which is summarized in Table 1. Both samples passed the Clevenger's and Yue's criteria, however the stable slope samples have shown higher collapse potential than the failed slope samples when tested against criteria of Chen et. al., however in reality the soil at failed slope did not prevail.

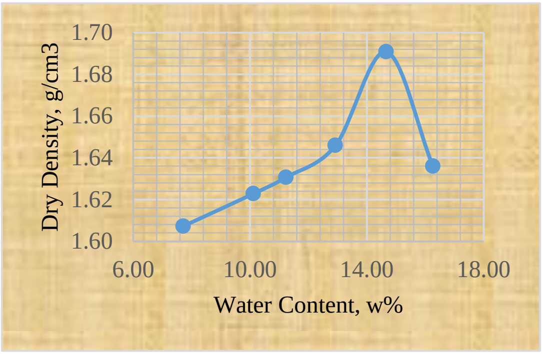

Fig. 2: Maximum Dry Density – Failed Slope

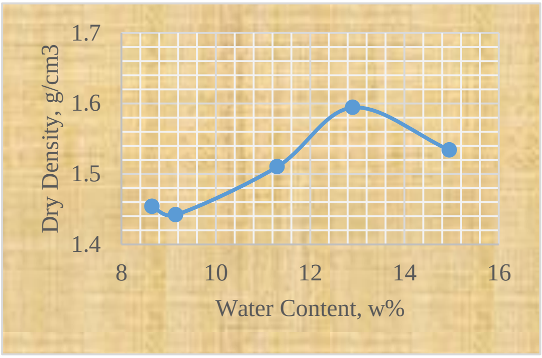

Fig. 5: Maximum Dry Density – Stable Slope samples.

Table 1: Criteria for failed and stable slope samples

	Clevenger (1985)	Yue (1996)	Chen et. al. (2006)
Criteria for Stability	1.44 g/cm^3	1.5 g/cm^3	1.69 g/cm^3
Failed Slope	Pass	Pass	Borderline Pass
Stable Slope	Pass	Pass	Fail

4.2 Liquid Limit, Maximum Dry Density & Gibbs's Criterion

Both samples were checked against criterion of collapsibility [9]. The liquid limit and corresponding maximum dry density of both samples were plotted on Gibb's chart. It was revealed that both samples lie within the non-collapsible soil region as shown in Figure 6 which means both soils are resistant to collapse. Approximating the distance of each soil coordinates to the line of division reveals that soil at the stable slope is indeed stronger, this is because its coordinates is further away from the division line which is marked by a longer yellow line as shown in Figure 7. In other words, soil is stronger as the liquid limit and dry density increases.

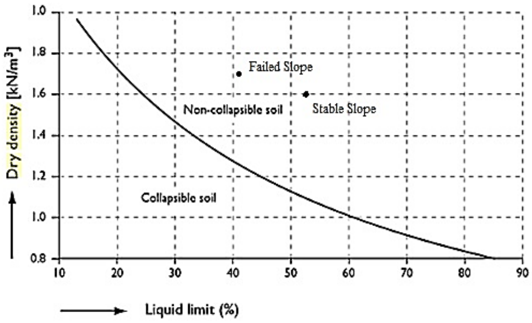

Fig. 6: Plot on Gibb's Chart – Failed & Stable Slope Samples

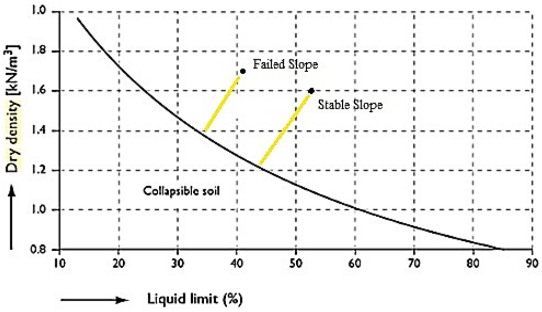

Fig. 7: Plot Distance from Division Line

In terms of maximum dry density, both slopes samples are proven strong and it may be deduced that the slope did not fail due to low maximum dry density.

4.3 Shear Strength Parameters

Direct Shear Test was conducted on 3 specimens from each bulk sample whereby 3 different loads were constantly applied while the specimens were sheared to failure. The shear stresses at failure were recorded and plotted against the corresponding normal stresses which exhibit a linear pattern as shown in Figure 8 and 9 below.

Table 2: Direct Shear Test results – Failed and Stable Slope Samples

Test No.	Sample Type	Normal Load (kg)	Normal Stress (kN/m^2)	Shear Stress (kN/m^2)
1	Failed	4.5	12.26	9.1
	Stable			10.0
2	Failed	9.0	24.53	17.5
	Stable			18.3
3	Failed	18.0	49.05	27.0
	Stable			38.0

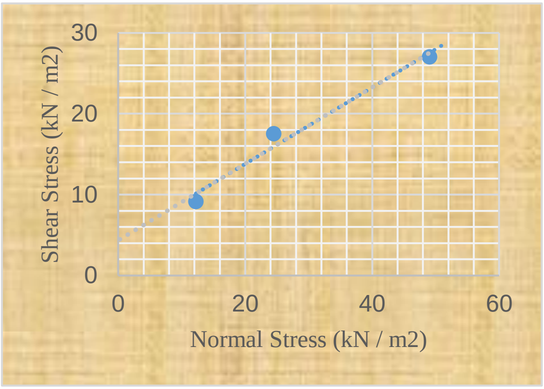

Fig. 8: Shear strength plot for failed slope sample

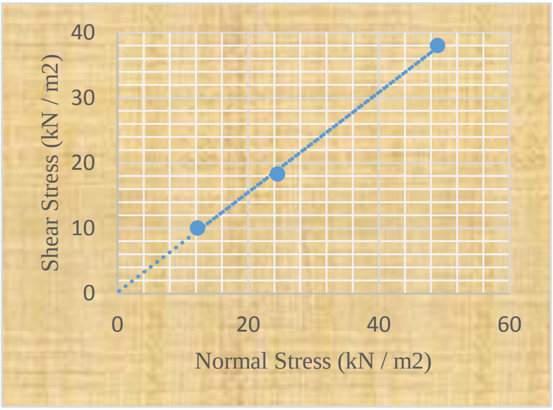

Fig. 9: Shear strength plot for failed slope sample

The cohesion and internal friction angle of each slope sample are obtained from the shear strength plots. Cohesion of 4.35 kN/m^2 and internal friction angle of 25.3° were obtained for the failed slope sample while the stable slope sample exhibit cohesion of 0.15 kN/m^2 and internal friction angle of 37.5°.

Table 3: Shear Strength Parameters – Failed & Stable Slope Samples

Sample Type	**Cohesion, *c* (kN/m^2)**	**Internal Friction Angle (°)**
Failed Slope	4.35	25.3
Stable Slope	0.15	37.5

Cross – referencing the laboratory – based Direct Shear Test results with the data from [3] reveals that the internal friction angle of the sample from failed slope i.e. 25.3° is at near concurrence with the value of their weak soil sample i.e. 23° and the internal friction angle of the sample from stable slope is closer to the value of their strong soil sample i.e. 42°. The internal friction angle for sample of the failed slope is also in accordance with the failure threshold value determined by [4] i.e. 23.2°. Based on the cross – referencing outcome, it can be deduced that the slope has failed due to low internal friction angle. Cross-referencing the test data with the angle outlined by [5] reveals that both slopes are susceptible to failure since both slopes have internal friction angles that exceed Bell's criterion, however this criterion is debatable because a slope will remain stable as far as its angle is concerned as long as it does not exceed its failure angle i.e. a slope with angle of 25° will not fail if the internal friction angle of soil at failure which makes up the slope is 50°.

4.4 Evaluation of Laboratory Performance

The failed slope was professionally tested for its shear strength by a multinational engineering company [14] in 2012 i.e. the same year when the slope collapsed and the report was procured for comparison. The shear strength parameters of the failed slope from the report were compared with the laboratory – based Direct Shear test results in order to assess the laboratory performance in terms of accuracy of results. Note shall be taken that the shear strength parameters were the only results made available by [14] thus evaluation of laboratory performance was limited to shear strength test only, evaluation of the other tests were not possible.

Table 4: Comparison of Shear Strength Parameters of Failed Slope Samples between [14] and Laboratory Test

	Cohesion (kN / m^2)	**Internal Friction Angle (°)**
Stability Analysis Report (2012)	5.00	30.00
Laboratory Direct Shear Test (2015)	4.35	25.30
Difference	0.65	4.70

The difference is marginal in cohesion and measurable in internal friction angle. Among possible contributing factors for the difference is difference in sampling method, shear strength parameters reported by [14] were obtained from undisturbed in-situ samples in contrast with laboratory Direct Shear Test which was performed on disturbed bulk samples. Another factor is time difference between both tests whereby the samples for laboratory test were obtained 3 years after the failure event where the soil might no longer represent the condition when it failed. Despite this, the difference is within the acceptable range as shear strength parameters of a slope are usually presented in ranges rather than absolute values.

5. CONCLUSION

Evidence has shown that one of the reasons causing the slope failure was low liquid limit. The slope crest was saturated due to overflow from congested interceptor drain which has steadily increased the slope weight and reduced its strength concurrently, this results in increment of the driving force and reduction of the resisting force. The water content kept on increasing until it exceeded the failed slope soil's liquid limit and consequently collapsed. In terms of maximum dry density, both samples are in the non – collapsible soil category therefore both soils are suitable slope materials as far as collapsibility is concerned. However, analyzing both properties together i.e. maximum dry density and liquid limit has revealed that soil sample of the failed slope has higher chance of collapsibility as compared to the stable slope which may be deduced as its factor of failure. Evidence has further shown that low internal friction angle of soil sample of the failed slope has also become a contributing factor for its failure. Comparing the shear strength parameters obtained in the laboratory with the shear strength parameters on the same slope obtained by world established engineering company indicates good laboratory performance in terms of results accuracy.

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