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Physical Analysis Work for Slope Stability at Shah Alam, Selangor

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ABSTRACT. Slope stability analysis is performed to assess the equilibrium conditions and the safe design of a human-made or natural slope to find the endangered areas. Investigation of potential failure and determination of the slope sensitivity with regard to safety, reliability and economics were parts of this study. Ground anchor is designed to support a structure in this study. Ground anchor were implemented at the Mechanically Stabilized Earth (MSE) wall along Anak Persiaran Jubli Perak to overcome the further cracking of pavement parking, concrete deck and building of the Apartments. A result from the laboratory testing of soil sample such as index test and shear strength test were applied to the Slope/W software with regard to the ground anchors that were implemented. The ground anchors were implemented to increase the value of the factor of safety (FOS) of the MSE Wall. The value of the factor of safety (FOS) before implementing the ground anchor was 0.800 and after the ground anchor was implemented the value increase to 1.555. The increase percentage of factor of safety by implementing on stability of slope was 94.38%.

1. Introduction

In the midst of modern constructions, a lot of construction activities can contribute to the unwanted event such as landslides, flood and so on. This project will discuss more on a slope failure at the chosen case study somewhere in Shah Alam, Selangor which is at construction on apartments. The study area for the project will cover on the retaining wall built by Jabatan Pengairan & Saliran (JPS) along Anak Sg Damansara. The site can be accessed through Federal Highway by taking a detour to Persiaran Jubli Perak. It is approximately 6.1 km to the South East direction from Shah Alam, Selangor. The project will present a detailed assessment on the site based on the available information obtained throughout the dissertation period such as soil investigation, several instrumentation monitoring and also w/slope analysis.

Based on the data obtained, cracking on concrete deck has worsened after the construction of the Green MSE Wall by Jabatan Pengairan & Saliran (JPS) along its riverbank of Anak Sg Damansara in 2012. The concrete deck has experienced severe cracking and it is observed tilted towards the river. The data was collected by means of Engineering Survey, Instrumentation Monitoring, Soil Investigation, and field and laboratory works. All of the data made available and collected were used to carry out engineering analysis by using w/slope analysis to find explanations for the slope problems.

In short, for the concrete deck, cracking was detected prior to the construction of JPS MSE Wall and the cracking has become more severe after the completion of JPS MSE Wall. This appears to be related to the large ground deformation recorded during and after the construction of the JPS MSE

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Wall by inclinometers and later confirmed by Finite Element Analysis (FEA). In terms of remedial works, Ground Anchor will be adopted to the slope facing Persiaran Jubli Perak to improve its slope stability.

2. Literature Review

2.1 Slope Stability Then and Now

Geotechnical engineering method for slopes have been changed since the first ASCE conference on performance and stability of embankments and slopes in 1966, mostly because computers have changed in certain aspects of geotechnical engineering and geo-construction. Availability of the new tools for shear strength evaluation, computation, communication, construction, and monitoring have improved the way we work, the need for the judgment and the value of experience have not diminished. Computer programs for slope stability analysis have been created and developed which can perform analyses and provide results in figures in very little time. However, results should not be accepted at face value. They should be checked thoroughly. Because the computer programs now available are so complex, it is virtually impossible to check the results using hand calculations. The only feasible way of checking the results is by using a second computer program to analyse the problem [1]

2.2. Limit Equilibrium Analysis

Limit equilibrium have been best tested and developed in actual case histories. The limit equilibrium theory is briefly presented along with the discussion on difficulties occurred in finding the best solution for the factor of safety [2]. The limit equilibrium (LE) approach has been used to analyse slopes since 1930's [3]. The used of a number of differing analysis methods depending on the type of problem (non-circular versus circular) to be solved and the required accuracy of the result [4]. The first method adopted for undertaking LE analysis was the Swedish or Fellenius circle method. The method was applied to the circular slip surfaces and leads to significant underestimation of the FoS and is now rarely used [5]. Bishop developed a revised method for undertaking circular slip analysis which improved the accuracy of the resultant FoS. The method required an iterative procedure to solve and it was suited to computer methods where this could be automated. Bishop's methods are still routinely used in slope stability analysis software until now [6].

2.3. *Limit Equilibrium Software*

Limit equilibrium analysis have been in use widely in geotechnical engineering for a long time and are now used in geotechnical engineering practice. Modern graphical software tools have made it possible to gain the best understanding of the inner numerical details of the method. A closer look at the details reveals that the limit equilibrium method of slices has some serious limitations [7].

2.4. Slope Failure

A phenomenon when a slope collapses abruptly due to weakened self -retain of the earth under the influence of a rainfall or an earthquake are called slope failure. The sudden collapse of slope which caused many people fail to escape from it if it occurs near a residential area, thus resulting in a higher rate of fatalities. Slope Failures are characteristics by a sudden failure of the slope resulting in transport of debris downhill by sliding, rolling, falling, and slumping. The slope stability analyses in geotechnical engineering have followed closely the developments in soil and rock mechanics. Slopes either occur naturally or are made by humans. Slope stability problems have been faced throughout history when men and women or nature has disrupted the delicate balance of natural soil slopes. Furthermore, the increasing demand for engineered cut and fill slopes on construction projects has only increased the need to understand analytical methods, investigative tools, and stabilization methods to solve slope stability problems [8].

2.5. Ground Anchor
Ground anchor is a structural element installed in soil or rock which is used to transfer an applied tensile load into the ground. The ground anchors, are installed in grout filled drill holes. Grouted ground anchors are also referred to as “tiebacks”. The basic components of a grouted ground anchor include the free stressing length, anchorage which is unbonded and bond length. The anchorage is the combination system of trumpet, bearing plate and anchor head that is capable of transferring the pre-stressing force from the pre-stressing steel whether a bar or a strand to the ground surface or the supported structure [8].

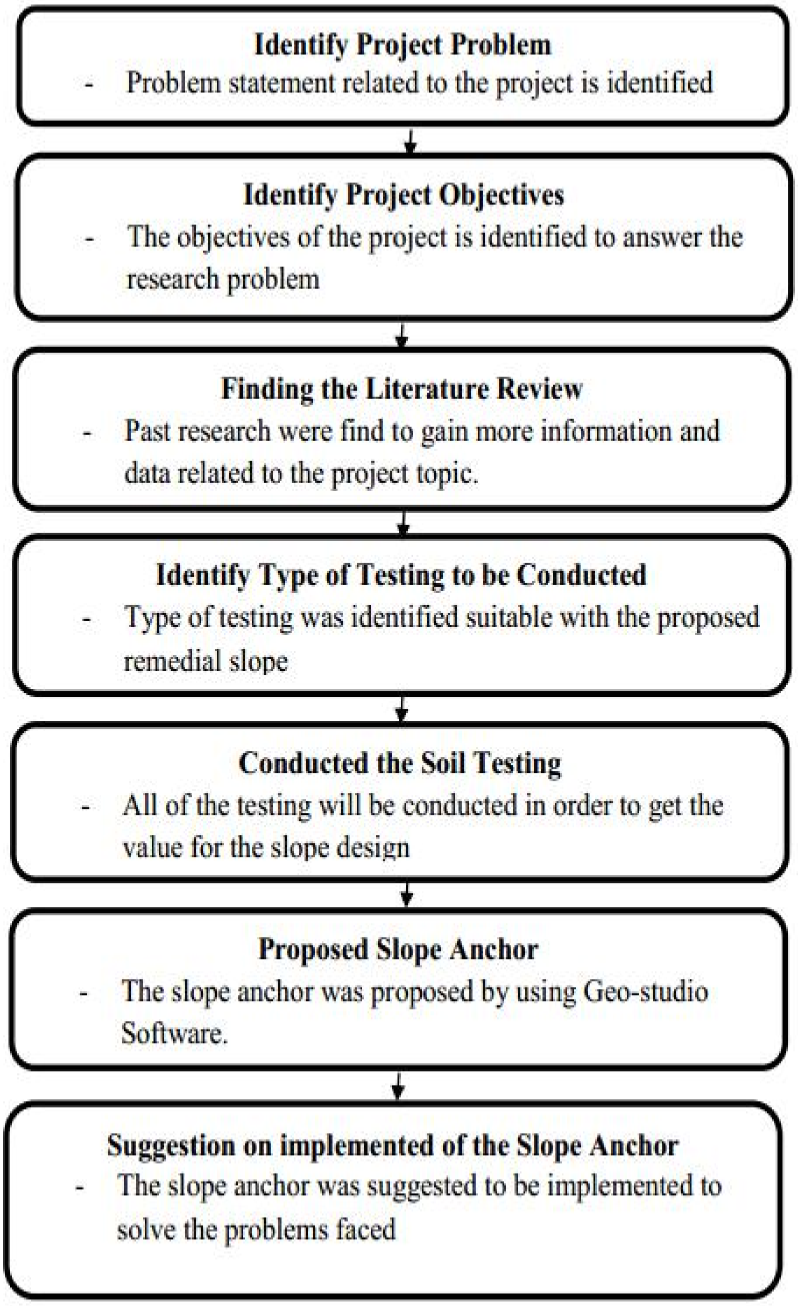
3. Methodology


Figure 1. Flow Chart of Research Stages.

4. Analysis
According to BS1377: Part1-6

4.1 Soil Classification System
The results from the Atterberg Limit were adopted in British Soil Classification System to determine the soil type. The subsoil in the site area is generally sandy silt/ clay and sandy clay. Table 4.1 shows the British Soil Classification System (BSCS) for the boreholes taken at the site from 3 m to 3.5 m depth of soil profile.

Table 4.1. British Soil Classification System for Borehole 1.

SM No.	Att. Limit (%)			Particle Size Distribution (%)				Soil Description	
	Liquid Limit	Plastic Limit	Plasticity Index	Clay	Silt	Sand	Gravel		
1				10	24	44	22	SF	Very Silty/ Clayey SANDS
2	32	14	18	5	15	65	15	SCL	Very Clayey Sand of Low Plasticity
3	43	22	21	24	34	19	23	CIG	Gravelly CLAY of Inter. Plasticity
4				7	23	37	33	SF	Very Silty/ Clayey SANDS
5				33	35	16	16	F	SILTS and CLAYS
6				8	26	36	30	SF	Very Silty/ Clayey SANDS
7				3	22	48	27	SF	Very Silty/ Clayey SANDS
8				8	26	42	24	SF	Very Silty/ Clayey SANDS
9	43	23	20	22	32	28	18	CIS	Sandy CLAY of Inter. Plasticity
10	38	19	19	12	35	29	24	CIS	Sandy CLAY of Inter. Plasticity
11				14	32	36	18	FS	Sandy SILTS/ CLAYS

4.2 Consolidated Undrained Triaxial Test (CIU)
This test is to obtain effective shear strength parameters such as effective cohesion, c' and effective friction angle, Ø. The CIU tests were carried out on disturbed samples at various depths of the subsoil layer ranging from 6.0 m to 19.0 m below the existing ground. The data obtained from this test will be used in designing the slope in Geo-Studio software. The effective stress parameters are shown in Table 4.2.

Table 4.2. Summary of Consolidated Undrained Triaxial Test.

BH No.	Sample No.	Depth (mbgl)	Bulk Density, (kN/ m^3)	Dry Density, (kN/ m^3)	Effective Cohesion, c' (kPa)	Effective Shear Angle, Ø'(°)
BH 1	UD 1	6.00	14.28	9.84	5	25
	UD 2	10.00	13.19	6.79	4	20

Based on the table above, there were two undisturbed sample taken at borehole 1 labelled as UD1 and UD 2 which varies in value after CIU have been conducted. The variation of the result obtained was due to the different depth of the sample being taken. The value of bulk density, dry density, effective cohesion and effective shear angle for UD2 is lower than the value of UD 1.

4.3 One Dimensional Consolidation Test

The value of the compression ration $C_c/(1+e_0)$ ranges from about 0.117 to 0.226. The summary of the above results are shown in Table 4.3.

Table 4.3. Summary of One Dimensional Consolidation Test.

BH	Depth (m)	Bulk Density, (kN/ m^3)	Unit Weight, (kN/ m^3)	Void Ratio, e_0	p_c, (kPa)	Compression Index, Cc	Compressible, Cc/ (1+e_0)	Over consolidated Ration, (OCR)
BH1/UD1	6.0	1.450	14.22	0.60	31.0	0.501	0.192	1.17
BH1/UD2	10.0	1.939	19.02	0.94	45.0	0.636	0.216	0.49

Based on the table above, there were two undisturbed sample taken at borehole 1 labelled as BH1/UD1 and BH1/UD2. From the table, it can be concluded that when the depth increase, the value for all of the parameters being observed increased except for the over consolidated ration resulted to decrease.

4.4 Slope Stability Analysis

The height for slopes along Persiaran Jubli Perak are ranging from 3.0 m to 5.0 m with slope angle ranging from 21˚ to 37˚. The stability of this slope were assessed by utilizing a well-accepted geotechnical programme Slope/w. The targeted Safety Factor (FOS) based on the current Selangor state guidelines is 1.4 and 1.2 for permanent slope and temporary slope respectively. Thus, the complicated soil settings on site have to be presented by a simple model in the analysis to ease computation. Soil layering was carried out according to the stiffness of the soil based on SPT N obtained in boreholes. Mohr Coulomb soil model was used to represent the simplified soil settings on the site with representative Effective Stress (drained) soil parameters. Effective Stress (drained) parameters adopted in the slope stability analyses were tabulated in Table 4.4. Ground water table regime was established according to standpipe readings. Furthermore, slope stability analysis using Slope/w is assuming a plane strain condition where the 3 dimensional effects of the slope is not taken into account. Slopes FOS were determined by using Morgenstern- Price theory coupled with Auto-Locate and Entry-Exit slip circle locating method whenever suitable

Table 4.4. Parameters Adopted in Slope Stability Analysis.

Layer	Soil Description	SPT N	Unit Weight, ɣ (kN/m^3)	Cohesion, c' (kPa)	Friction Angle, Ø (˚)
1	Soft Silty CLAY	0-8	14.3	3	25
2	Firm Silty CLAY	10-20	18.0	4	30

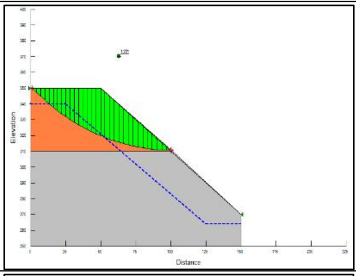
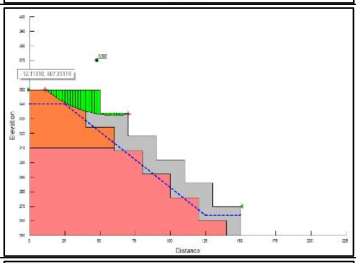
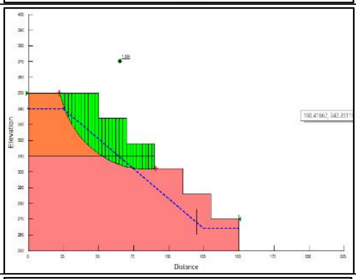
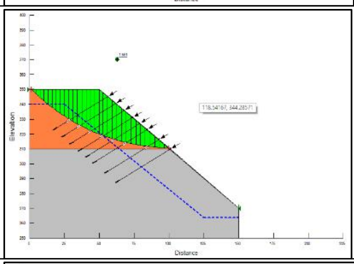
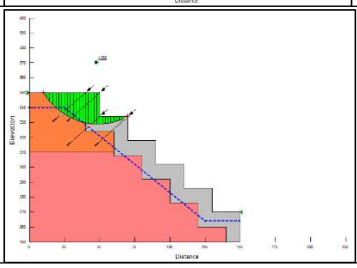
A slope stability analyses have been carried out which comprising a slope along Persiaran Jubli Perak. Summary of the analysis results were tabulated in Table 4.5.

Table 4.5. Summary on Slope Stability results.

Section	Location	FOS	Remark
R	Persiaran Jubli Perak	1.309	< 1.4

Based on the analysis results, slope at Persiaran Jubli Perak are having FOS lesser than the required statutory value of 1.4. Slope stability improvement is proposed.

Table 4.6. Summarization of the W/Slope Analysis.

Figure	FOS	Type of Slope	Unit Weight, γ	Cohesion, c’	Friction Angle, Ø
	1.201	Original Slope	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25° Firm Silty CLAY: 30°
	0.800	Original Slope + MSE Wall	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25° Firm Silty CLAY: 30°
	1.035	Modification to the Original Slope	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25° Firm Silty CLAY: 30°
	1.551	Ground Anchor	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25° Firm Silty CLAY: 30°
	1.555	MSE Wall + Ground Anchor	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25° Firm Silty CLAY: 30°

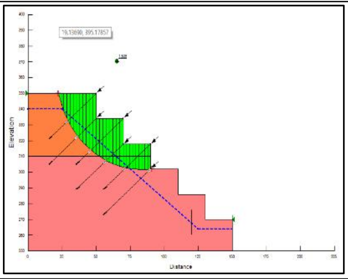
	1.535	Modified Slope + Ground Anchor	Soft Silty CLAY 14.3 kN Firm Silty CLAY: 18 kN	Soft Silty CLAY 3 kN Firm Silty CLAY: 4 kN	Soft Silty CLAY 25˚ Firm Silty CLAY: 30˚

Table 4.6 shows the summarization of the W/Slope analysis that give the value of safety factor for each of the slope remedial proposed. The parameters being discussed were the factor of safety (FOS) of the slope, type of slope remedial, unit weight, ɣ, cohesion, c' and the friction angle, Ø. Based on Table 4.6, it can be justify that the value for the safety factor for each slope varies from one and another. The parameters that were being kept constant were unit weight, ɣ, cohesion, c' and the friction angle, Ø which the value for the two layers that are soft silty clay was 114.3 kN, 3 kN and 25˚ while the value for the firm silty clay was 18 kN, 4 kN and 30˚ in correlation to the constant parameters stated before. The original slope was already failed which resulted to the cracking to the pavement deck at Indahria apartments, it can be prove through w/slope analysis which stated that the value of safety factor for the original slope is 1.201 which is decreased in value compared to the global safety factor that is 1.5. The original slope was considered slope failure based on the w/slope analysis. When a Green MSE Wall is added for the w/slope analysis, the safety factor value decrease from 1.201 to 0.800. This proved that, the Green MSE Wall was not only failed but also cause more severe parking at the pavement parking at Indahria apartment.

Besides, in this project, the original slope were compare between the modified slope and the Green MSE Wall. Even though the modified slope failed but the value of the safety factor for the modified slope is slightly higher than the Green MSE Wall which was 1.035. Compared to the Green MSE Wall, the modified slope should be implemented due to the cost effectiveness and the value for the safety factor which is slightly higher. The first, second and third slopes gave the value of safety factor less than 1.5 which can be considered as slope failure. Therefore, an immediate remedial works should be taken place in order to prevent more severe cracking at the pavement parking and slope failure on the case study area. The ground anchor was being analysed by using w/slope under three different conditions, as suggested are:

a) Installation of the ground anchor directly to the original slope
b) Installation of the ground anchor directly to the Green MSE Wall
c) Installation of the ground anchor after a slope modification has been made

By referring Table 4.6, the fourth, fifth and sixth slope are all slope with the proposed ground anchor. Based on the w/slope analysis, the slope before the ground anchor was proposed have the safety factor more than global safety factor that is 1.5. It can be concluded that when the ground anchor was proposed to the three slope which were failed before, the value of the safety factor for each of the slope increased. Hence, all of the three slope failure can be prevented after the ground anchor was proposed to each of the discussed slope. As being shown in Table 4.6, there were three remedial works that was suggested which are the original slope with the ground anchor, the Green MSE Wall with the ground anchor and finally the modified slope with the ground anchor. The purpose of the slope being analysed was that to make a comparison which one of the three slope remedial was the most suitable method that should be implemented at the study area. The safety factor for each of the slope remedial were 1.551, 1.555 and 1.535 respectively which were suitable to be implemented. Based on the result obtained, the most suitable method to be implemented is ground anchor due to the economical consideration.

5. Conclusion

The project has explained the slope stability analysis for slope along Persiaran Jubli Perak with accordance to the two main objectives derived**.** It can be concluded that the detail data and information of the site investigation were from the test being conducted. The data and information obtained from the test are shear strength, engineering parameters of the soil, consolidation and type of soil which is clay. From the test being conducted, the value of unit weight, ɣ, cohesion, c' and friction angle, Ø were also determined. It also can be concluded that the cause of the slope failure at the case study are because of the construction of the MSE Wall built by Jabatan Pengairan dan Saliran (JPS) in 2012. The proposed slope remedial that is ground anchor was made by using w/slope. The value of the unit weight, ɣ, cohesion, c' and friction angle, Ø were applied to the software to obtain the value of the safety factor. Thus from the software, it can be concluded that ground anchor can increased the value of the safety factor from 0.800 to 1.555. The increase percentage of factor of safety by implementing on stability of slope was 94.38%. Based on the study being conducted for the purpose of completing project, slope stability analysis were very important to be carried out in order to know the probable cause of failures thus the following recommendations are made.

The slope stability analysis along Persiaran Jubli Perak obtained FOS less than 1.4. Thus the slope strengthening works is recommended to be implemented for this slopes. The detail site investigation should be conducted in order to obtain necessary data and information which to be used as the parameters in proposing the slope remedial works. Besides, the data are also very important to determine the probable cause of failure of the slope. Lastly, the most suitable method of analysis is by using the geo studio software which used the data obtain from the SI report. The slope will be design with accordance to the suitability of the area of study. The slope design by the designer and gave the value of the safety factor that determine whether the slope design by the designer is suitable to be proposed or vice versa.

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