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# STABILISATION ANALYSIS OF SLOPE ON BAUXITE MINING AREA

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## ABSTRACT

Unexpected slope failure has the potential to the most costly form of failure as it leads to safety issues (loss of life) and sometime required time consuming remediation. A work over survey of on TNB substation at Kg Padang, Kuantan revealed a significant movement and failure of a slope within vicinity of excavation works. Ground investigation was conducted to establish information within underlying strata consists of GRAVEL and clayey SILT with traces of sandy which dominantly from residual soil. Laboratory testing and soil investigation are gather as an input parameter to propose a slope and analysis for stabilization. The analysis of slope stabilization reduced the hazard of further work involving cutting and trimming on mining area. Sensitivity study for angle of slope is to address the most effective and suitable for maximize extracting bauxite ore. Reducing slope gradient with improved site drainage to ensured safety for TNB substation was implementing as a remedial works from this study.

**Keywords:** instability of slope, site investigation, residual soil, slope stabilization.

## INTRODUCTION

For many year to come, slope failure has the potential to the most costly form of failure as it leads to safety issues (loss of life) and sometime require expensive and time consuming remediation (e.g. train derailment). According to Glendinning *et al.* (2009) slope failure can be caused by sudden increases in pore water pressure or gradual progressive failure and can be translational (i.e. shallow) or deep.

In term to be considered as a safe condition, slope stability analyses have become a common analytical tool for assessing the factor of safety of slopes (Krahn, 2004). Consequently, information and data from study area were used in specifying method of geotechnical slope analysis to determine slope safety. The use of limiting equilibrium method of slices is sufficient in most slope problem, where the aim is to determine the values of factor of safety as performance indicator compared to the finite element method (Fredlund and Rahardjo, 1993; Chowdhury *et al.*, 2010). Finding the critical failure surface is the heart of this problem and its corresponding (minimum) factor of safety (FOS).

This study was carried out at proposed slope located near Kg Padang at Kuantan, Pahang Darul Makmur. The construction of slope will consider the proper safety awareness for the excavation works involving bauxite ore.

The situation has seriously concerned by the TNB Pahang as they have to find and determined the most suitable and effective way to design and analysis the cutting slope. The most importance is to secure electricity substation from any hazard contributed by bauxite excavation. This slope assessment present the finding from the desk study of the available information such as subsurface investigation (SI) report by M/S Get Services as well as the observations from the site visit.

The main objective of the study is to identify the source or the cause of failure on cutting slope after excavation works and to recommend the most suitable or appropriated of slope specifications and mitigation measures to overcome the problem. The objectives are stated as determination of the sub-surface and geological formation and present findings of the failure investigations. The proposed slopes were analysis with various remedial options to address the slope stabilisation.

## METHODOLOGY

The inclusive assessment has been conducted starting from 10th February 2015 to 14th February 2015. The detail site investigation which includes soil investigation (BS 5930, 1999) and laboratory testing BS 1377: Part 1-9, 1990) was completed on 5th March 2015.

### Desk Study

Previous reports, related documents (Hutchison and Tan, 2009) and historical data have been reviewed (Hutchinson, 2007) comprehended and digested to understand more about the study area.

### Fieldwork and Data Collection

In order to assess and to evaluate the slopes, these are the essential technical assessments that have been executed as been reported by Kelly *et al.* (2008). Detail ground topographical survey including soil investigation study such as borehole and sampling with related to laboratory testing on the soil samples.

### Soil Investigation Study

The soil investigation works was carried out from 10th February 2015 and completed on 13th February 2015. About four (4) nos of borehole have been carried out on site. The soil investigation works was carried out to obtain the subsurface profiles as summarized in Table-1 and input geotechnical parameters in order to determine and find the very closest probable cause of failure on site.

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**Table-1.** The depth of all boreholes drilled can be summarized as follows.

| Time / Date | Borehole number (BH) | Ground Water Level (m) | Depth of termination (m) |
|---|---|---|---|
| 6.00 pm / 11th Feb 2015 | BH-1 | 4.35 | 6.00 |
| 9.00 am / 12th Feb2015 | BH-1 | 6.15 | 22.74 |

One borehole, which is BH-1 was sunk on the top of the slope beside approximately 20 m from TNB tower as show in Figure-1. Ground water level was measure during the soil investigation works in these areas. The detailed *in-situ* properties can be referred to Table-3.

**Figure-1.** Drilling rig operated on top of the slope.

**Laboratory Analysis**

Samples collection from site investigation consists of undisturbed sample (thin wall tube) and disturbed sample (SPT sample) to executed laboratory tests. Laboratory analyses were carried out to classify the soil samples and determine the effective shear strength. It is important to ensure that testing was carried out on samples that truly represent the materials at the site. For this purpose, full and accurate descriptions of all samples were tested are record.

Representative of the mass behavior of the ground at the site, the laboratory tests should be supplemented by appropriate field tests. Results are summarized together with soil investigation works as shows in Table-2 and 3.

## ENGINEERING GEOLOGY AND GEOTECHNICAL DATA ANALYSIS

All data collected especially the subsurface related information were analyzed to understand the most probable cause and mechanism of failure of the slopes as to identify the Factor of Safety (FOS).

A series of technical assessments have been executed in order to obtain as much geotechnical information as can be provided and those are as elaborated below.

**Subsurface Profile**

Interpretation from borelogs and engineering geological information find that subsurface can be interpreted as the complete weathering profile of the residual soil, as shown throughout BH-1 with either the residual soil (Grade VI) sampled at the top, as the strata getting harder (Grade V to IV) as boreholes gone deeper towards the (Grade II to III) weather rock shale.

GRAVEL and clayey SILT with traces of sandy are dominantly from residual soil is stiff to hard with SPT values range from 14 to 43 blows/30cm. The thickness varies from 1.5 m to 4.5 m. This follow by a highly to completely weathered soil of hard to dense sandy SILT and silty SAND with some weathered shale fragment with SPT values reaching 50 blows/33 cm. The thickness varies from 1.5 to 4.0 m. The final layer mainly comprise of hard layer of SILT as summarized in Table-2.

**Table-2.** Boreholes data from soil investigation works that have been executed at the study area.

| Strata | Thickness (m) | | SPT Values (Blows/ ft) | Color | Description |
|---|---|---|---|---|---|
| | min | max | | | |
| Residual Soil | 7.00 | 9.00 | 4 - 43 | Dark Brown to Reddish | Sandy or gravelly SILT |
| Highly to Completely Weathered Soil | 9.50 | 24.50 | 50 | Light to medium grey | SILT or Sandy SILT with traces of gravels. |

**Description of Each Categorized Layer**

**Residual Soil (Grade VI)**

The top layer of weathering profile is the residual soil (grade VI) which is origin from the weathering process of Shale rocks. The sample was Dark brown to medium grey in color.

The SPT value ranges from 4 to 43-blows/33 cm, showing a consistency of firm to stiff sandy SILT layer

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with some weathered gravels. The maximum thicknesses are 4.0 m.

**Highly to Completely Weathered Soil (Grade V to IV)**

The samples were multicolored; Dark brown to Medium grey. The SPT reaching 50 blows/30 cm showing a relative density of hard sandy SILT layer with some gravels and dense sandy SILT. The thickness is varies from 1.5 m to 4.5 m.

**Geotechnical Analysis**

Theoretical slope stability and engineering analyses were performed to study the consequences of failure, the cause of failure and the likely failure mechanism. Recommendation and remedial works are based on the findings of geotechnical and engineering geological analysis. The purpose of these analyses was is to evaluate the potential instability of the slopes in the area.

**Soil Parameter Adopted**

The test results were collected based on location and soil type. As is the case in any geotechnical engineering study, engineering judgment and local experience are necessary inputs. The engineering practice of ignoring the cohesive strength of fill material in the engineering analyses is adopted. This is because a substantial amount of the cohesion in the soil would have been destroyed during sample remoulding. Considering the case when the ground becomes fully saturated during intense rainy seasons the saturated densities are adopted in the engineering analyses to stimulate critical stability related conditions. The selected soil parameters for analysis are summarized in Table-3.

**Table-3.** Selected soil parameters for analysis.

| Soil Strata | Saturated Bulk Density $\gamma_{sat}$ | Effective Cohesion c'(kN/m$^2$) | Effective Angle Friction $\phi$' (degrees) |
|---|---|---|---|
| Gravelly SILT (Layer 1) | 18 | 6 | 30 |
| Sandy SILT/CLAY (Layer 2) | 18 | 7 | 26 |
| SILT (Layer 3) | 19 | 10 | 35 |

**STABILITY ANALYSIS**

**Safety Factor**

Slope stability analyses for cut slopes were carried out using a well-established computer programmed 'SLOPE\W' developed by GEOSTUDIO. The programmed utilized simplified analysis or modified Bishop method, Janbu method and Morgenstern-Price method.

**Slope Stabilisation Analysis**

The proposed cross section was identified and analyzed to determine the localized and overall stability of the existing and proposed remedial works. Soil profile then interpolated along these sections. Slope stability analysis considers the site conditions and soil properties gathered from soil investigation and laboratory testing.

Result of stability analysis for the slope profile together with subsoil parameters used for each of the slope section was design to achieve FOS > 1.40. The slopes were analyses in order to find the most suitable and effective design as shows in Figure-3, 5, and 6 respectively. The sensitivity analysis was carried out in two conditions: slope at 60 degree and at 45 degree angle in every section (section 1, 2 and 3) as presented in Figure-2 to 7, respectively.

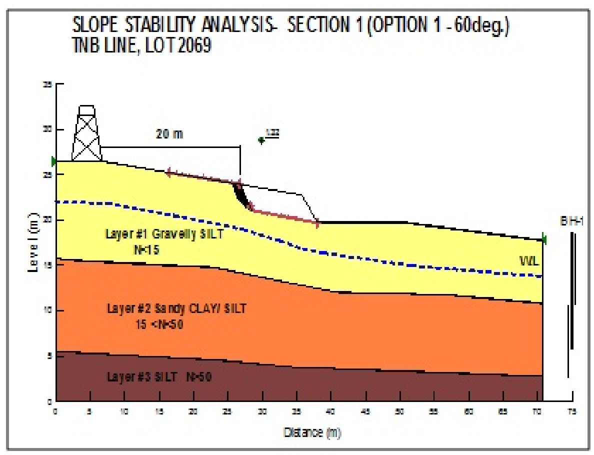


**Figure-2.** SLOPE\W analysis of section 1 on 60 degree slope angle.

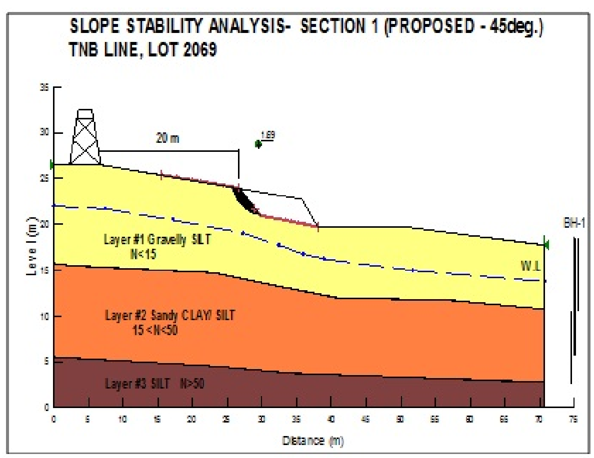


**Figure-3.** SLOPE\W analysis of section 1 on 45 degree slope angle.

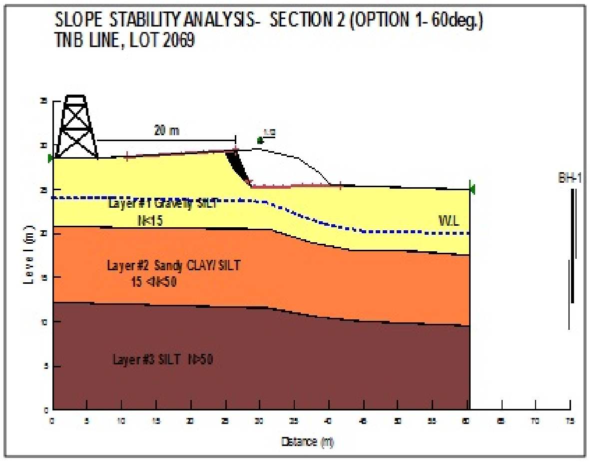


**Figure-4.** SLOPE\W analysis of section 2 on 60 degree slope angle.

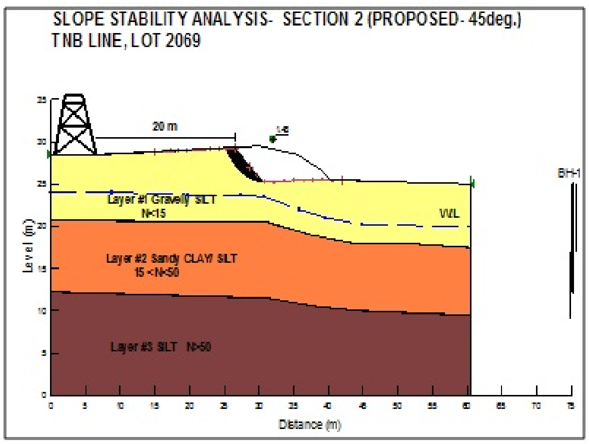


**Figure-5.** SLOPE\W analysis of section 2 on 45 degree slope angle.

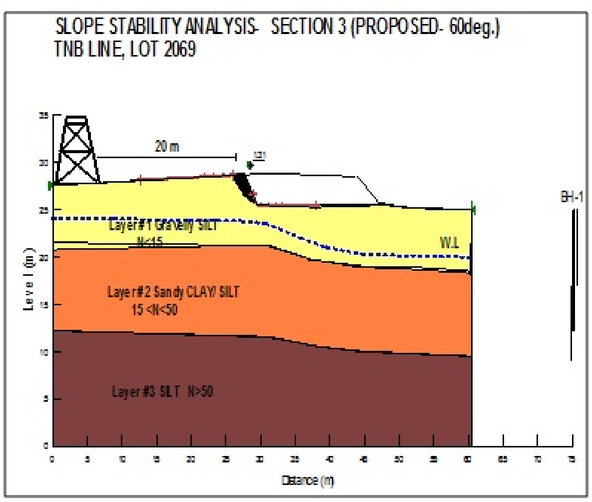


**Figure-6.** SLOPE\W analysis of section 3 on 60 degree slope angle.

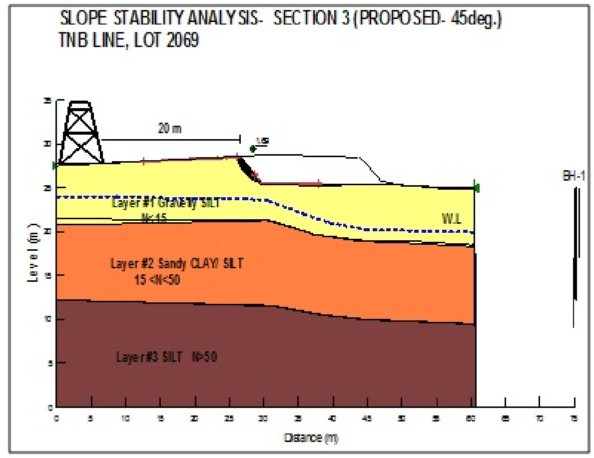


**Figure-7.** SLOPE\W analysis of section 3 on 45 degree slope angle.

Based on the analysis the stability of the factor of safety the proposed of 45 degree on all section of slope is categorized a suitable for construction. Thus, slope with proposed of 45 degree are minimum recommended for factor of safety as shown in Table-4.

**Table-4.** Summary of stability analysis.

| SECTION | Factor of Safety | Remarks |
|---|---|---|
| Slope Section 1 | 1.32 | Proposed of 60 degree slope |
| Slope Section 1 | 1.69 | Proposed of 45 degree slope |
| Slope Section 2 | 1.13 | Proposed of 60 degree slope |
| Slope Section 2 | 1.48 | Proposed of 45 degree slope |
| Slope Section 3 | 1.31 | Proposed of 60 degree slope |
| Slope Section 3 | 1.69 | Proposed of 45 degree slope |

## CONCLUSIONS AND RECOMMENDATIONS

The site investigation conducted together with analysis of slope stability in the study area finds the key finding of the study. Reducing the angle of slope to explore the most suitable angle is one of the solutions in the construction of cutting slope to prevent any contribution of failure. The effective angle of cutting was determined to produce a maximum quantity of bauxite ore. A part from that, observation due to the above infiltration of surface water into the ground resulted in increase in negative pore water pressure. The above phenomena also resulted in weakening of the fill material on upper portion of the slope.

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The slopes need to be effectively and efficiently treated to ensured safety for TNB substation, by implementing the recommendations remedial works from this study. The remedial works shall take into account all aspects such as stability of the overall and localized slope together with overall drainage systems.

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