JOURNAL OF SUSTAINABLE UNDERGROUND EXPLORATION
e-ISSN: 2821-2851

J-SUE

Vol. 3 No. 2 (2023) 1-6
https://publisher.uthm.edu.my/ojs/index.php/j-sue

Back Analysis and Potential Remedial Approach for Failure Slope at Bukit Nanas, Kuala Lumpur

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DOI: https://doi.org/10.30880/jsue.2023.03.02.001

Article Info

Received: 05 October 2023
Accepted: 18 December 2023
Available online: 24 December 2023

Keywords

Failure, remedial work, slope stability, Bukit Nanas, SLOPE/W, soil nailing and FOS

Abstract

This study aims to validate the design parameters and stability of the slopes failure and propose acceptable remedial work by assessing the slope stability in Bukit Nanas, center of Kuala Lumpur. The slopes' height is around 40 and 60 m with the gradient around 30°-45°. A total of 7 boreholes were carried out and the pertinent engineering properties were analyzed from laboratory testing and back analysis (in situ test). An established computer program SLOPE/W was used to carry out slope stability analysis. The analysis method adopted was Morgenstern-Price's Method. Based on the result of the field investigation and numerical analysis, the model of lowest factor of safety (FOS) that evaluated from the existing slope in critical section were selected and recommended for remedial work. Two options of remedial slope design have been proposed. The first option is soil nailing with grid beam and proposed drain while the second option is hybrid anchor with grid beam and proposed drain. Both options are used to improve the slope stability, but the first option had been chosen as higher FOS and more efficient option. This remedial approach based on the main cause of slope failure in Malaysia can applied as reference in future slope remedial design.

1. Introduction

Based on landslide forensic statistical data from Slope Engineering Branch Malaysia, there are about 57% of slope failure were happen due to human factor, whereas 29% were ascribed to physical factor and 14% was caused by various geological factors. Based on the data, most of the slope failure were occurred at manmade slopes. Besides, the extreme climatic - heavy rainfall, in combination with other physical and geological factors such as slope angle, slope height, geological formation, type of slope vegetation, water content, and overloading will influence the soil slope stability and then cause the slope failure [1]. The increasing rainfall intensity changes the shear stress condition of the slope due to the increasing of groundwater table of the slope. The soil becomes saturated with water and decrease the shear strength of soil slope. The sudden changes in geometry, external force and loss of shear strength will make the stable slope become unstable [2]. Different soil types and different slope characteristics have various effects on slope stability [1]. In recent years, there has been rapid development in computational methods, high-speed and low-cost software and hardware design in this field as they are more widely used than manual methods. Various software is available to analyze the slopes stabilization by calculating the factor of safety. Despite several numerical inconsistencies and computational difficulties to locate the critical slip may occur due to the geological properties, the limit equilibrium method (LEM) has been commonly used approach due to its simplicity and accuracy [3].

Slope stability analysis is the process of calculating and assessing how much stress a particular slope can manage before failing and performed to assess the slope design and equilibrium conditions. The occurrence of slope failure annually causes damage to live and properties from time to time make the public safety is threatened directly. Thus, the immediately remediation should be commenced. The aim of this study is to determine the factor of safety and propose a safety slope at Bukit Nanas, center of Kuala Lumpur. The objectives of this project are mainly to validate the design parameters and stability of the slopes failure and modelling it based on the SLOPE/W programmed and propose the appropriate remedial method on investigated slope by ascertaining the design parameters and stability of the failure slopes based on the SLOPE/W programmed. Based on this study, the acceptable remedial approach based on weather and slope condition in Malaysia can be as reference in future slope remedial design. This case study of slope failure was located at Bukit Nanas, center of Kuala Lumpur which happened on the 7th May 2013 and causing nine vehicles had been buried and massive traffic jam due to main road closure. Fig. 1 shows the location of slope failure in the topography map.

Fig. 1 *Site location (Topography Map)*

2. Literature Review

In order to justify the above-mentioned problems, some literature reviews related to the slope failure issues in Malaysia and theory of slope stability analysis were written. The findings and arguments by researchers provide better understanding to overall study on the general knowledge on landslide, slope failure and slope stability analysis in this chapter. According to Mukhlisin et al. [4], more than 100 hill slopes had been identified by Malaysian Public Works Department (PWD) as risky for possible landslides. Table 1 below summarizes several landslide tragedies happened in the past few years. Most of landslide in Malaysia can be concluded due to the relative amount of water in the soil surrounding the slope because most of the vital landslide occurred during monsoon season which supported by [4]. Normally, slope failure cases in Malaysia occurred under combinations of few triggering factors as well such as design errors or construction errors and vegetation coverage.

Table 1 *Landslide occurred in Malaysia (2013-2018)*

Date	Location	Description
4th January 2013	Putra Heights	Landslide buries 7 vehicles.
11th Novermber 2015	Kuala Lumpur – Karak Expressway	Landslide blocked highway.
February 2016	Puncak Borneo area, Sarawak	194 minor landslides and embankment failures.
26th November 2016	Serendah, Selangor	Landslide due to swift flow of underground water buried vehicles and about 4 residents evacuated.
21st October 2017	Tanjung Bungah, Penang	Landslide killed 11 workers.
14th October 2018	Cameron Highland	Landslide after heavy rains killed 3 people.
19th October 2018	Bukit Kukus (Construction site)	Landslide after rains killed 9 workers.

Basically, slope failure occurs when the shear stress developed in the soil body is greater than the shear resistance of the soil. Main driving force in gravity while resisting forces depends on cohesion(c) and internal friction (φ) based on Terzaghi's theory. Limit equilibrium method (LEM) is the common methods widely used by the geotechnical engineers. Varies analysis methods are developed based on LEM, including circular method, non-circular method and Method of Slices. Most of the slope stability analyses methods are statically indeterminate and the assumptions about the distribution of internal forces acting on them are required to solve this redundancy. However, the assumptions are different for each limit equilibrium method. The factor of safety is initiated by application of force and moment equilibrium. The static limit equilibrium methods have 2 different approaches which are Single Free Body Procedures and Method of Slices. In the Single Free Body Procedures, the soil diagram is considered in equilibrium and a single free body diagram is assumed for the entire soil diagram. Bishop, Janbu, Fellinius, Morgenstern's Price are popular methods because factor of safety value can be quickly calculated for most slip surfaces [2]. Hence, different of slip surface have different of factor of safety generally. In order to ensure obtaining the minimum of factor of safety, complete and iterative search for the critical slip surface is required [5].

The changing in factors of safety of slopes depend on shear strengths applied with time and loads acting on slopes. The factor of safety, FOS against slope instability may increase or decrease depend on several different conditions reflecting different stages in the life of a slope because of weathering and erosion along the lifetime of the slope [5]. Based on NYSDOT Geotechnical Design Manual, the required data for slope stability analysis of soil slope are soil profile, slope geometry, and soil shear strength. Soil profiles show the detail assessment of soil stratigraphy while slope geometry is the basic data required for slope stability analysis and can be derived from field survey. Soil shear strength is used for limit equilibrium method to calculate factor of safety (FOS).

Stability of a slope can be evaluated by manually or a computer analysis after determining the slope geometry and subsoil conditions of a slope. The main objectives of a slope stability analysis are preventing slope failure by calculating the factor of safety of the slope and validating the failure mechanism which provide necessary information for the remedial design if the slope failure happen. Stability of a slope is usually analyzed by limit equilibrium method and applied by computing the factor of safety of the critical slip surface. The factor of safety is defined as the ratio between the shear strength and the shear stress that required to achieve the equilibrium of the slope. Theoretically, slope will be considered as stable when factor of safety above 1.0. However, the level of stability is rarely considered acceptable except when the factor of safety is significantly greater than 1.0 in practically. Thus, most of the cases show typical minimum factor of safety is about 1.5 for long term loading condition and 1.3 for temporary slope or end of construction condition.

SLOPE/W is a programme software from GeoStudio. It is usually used to identify factor of slope failure by simulating both mobilized shear stress and total shear resistance along the slope surface in software. SLOPE/W then computes a local stability factor for each slice and each slice formulated in terms of moment and force equilibrium factor of safety equations. Morgenstern-Price method is best example that satisfies both force and moment equilibrium. This general formulation makes it easy to compute the factor of safety for a variety of methods and to readily understand the relationships and differences among all the methods [6]. In the SLOPE/W software, the interslice functions available are constant, halfsine, clipped-sine, trapezoidal and data-point specified. The advantages of Morgenstern–Price method are deliberate shear and normal interslice forces, satisfies the moment and force equilibrium, and allows for diversity of user-selected interslice force function [5].

3. Methodology

This project is validating the design parameters and stability of the slope's failure and proposes acceptable remedial work at Bukit Nanas. The methodology of this study case includes the steps taken to achieve the objectives and result of the study. The data consists of soil investigation report is a second data which is gathered from one related journal. The method to collect data from the condition of slope failure in this chapter consists of surface and subsurface investigation. The field work has been carried out by Ikram Center Engineering Service. Field work is surface investigation involves desk study, site reconnaissance and detailed engineering survey. Based on the surface investigation, the length of slope is 410m and 35m-60m height with 30°-45° slopes' angle. Subsurface investigations were applied to obtain information data of the physical properties of soil of the study area. The subsurface exploration involves in-situ test and laboratory tests. It includes the SPT test, JKR test and essential laboratory test. The data finally applied in SLOPE/W and the framework of SLOPE/W used was limit equilibrium framework and methods of the Morgenstern-Price during simulation. The flow chart containing steps to complete the study shown in Fig. 2.

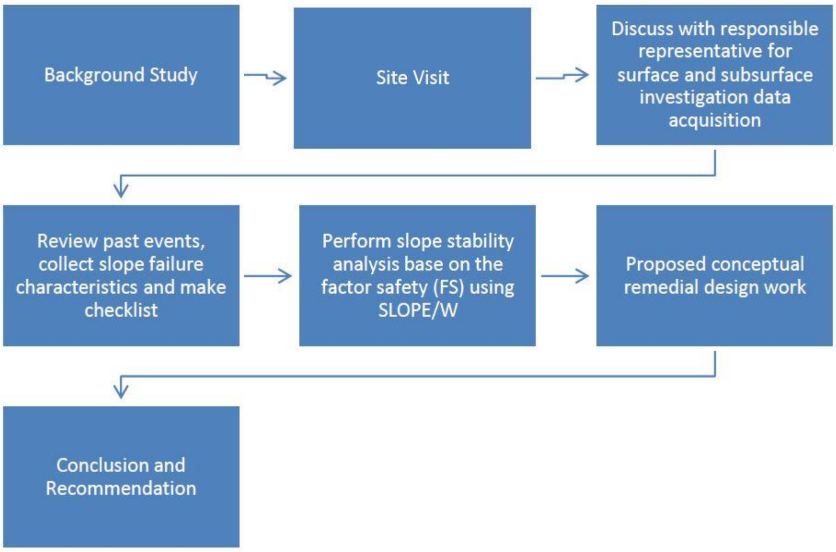


Fig. 2 *Flowchart of the study*

4. Data and Analysis

The soil strength parameters were identified based on back-analysis, laboratory tests and engineer judgment. Compared with the laboratory test and back analysis as well as assisting with consideration of engineering judgment, table 2 shows the adopted soil parameters applied in the analysis. The main soil material was sandy silt with partially gravel. The different colours represent the different layer with different SPT-N, friction angle and cohesion to increase the accuracy of simulation in the analysis when using SLOPE/W programme. Based on the 2 cross sections selected, cross section A-A was less than 1 (0.995) while FOS of cross section D-D was slightly more than 1(1.074). Hence, cross section A-A was considered as more critical section compared with the cross-section D-D and it has been used as the simulation for remedial measurement. Fig. 3 shows the initial slope model analysis of cross section A.

Table 2 *The main regional soil strength parameter*

Soil type	Laboratory Test			Back Analysis			Applied Values			Colour
	γ (kN/m³)	c' (kPa)	φ' (°)	γ (kN/m³)	c' (kPa)	φ' (°)	γ (kN/m³)	c' (kPa)	φ' (°)	
Soft 0-10				17.0	3	29	17.0	3	29	
Firm 11-20	19.0	7	31	19.0	5	30	19.0	6	30.5	
Stiff 20-41				19.5	7	32	19.5	7	32	
Hard >50				20.0	10	35	20.0	10	35	

Based on the slope stability analysis of investigated slope failure, there were 2 options of recommendation of remedial work design proposed as reinforcement method in order to improve the stability of investigated slope.

- Option 1: Slope stabilization using soil nailing with grid beam and proposed drain.
- Option 2: Slope stabilization using hybrid anchor with grid beam and proposed drain.

Based on Guideline for Slope Design of JKR (2010), both options are qualified but option 1 chosen as proposed remedial work design because it had higher FOS which is equal to 1.577, while FOS of option 2 equal to 1.567. Besides, soil nailing has less earthworks required, and lower risk taken during the construction period. Table 3 shown the summary of both recommended remedial work design. Fig. 4(a) and fig. 4(b) shown the simulation of both remedial work designs that applied in SLOPE/W. The potential sliding segment will be tied down by the nail shaft to the interior stable ground. The tension in the nail shaft will provide a long-term stress effectively to the slope surface.

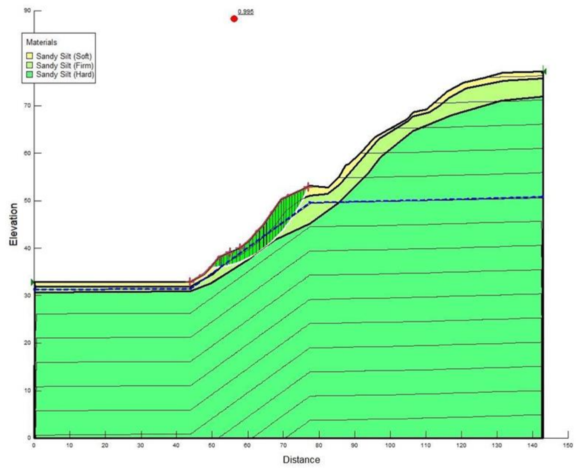
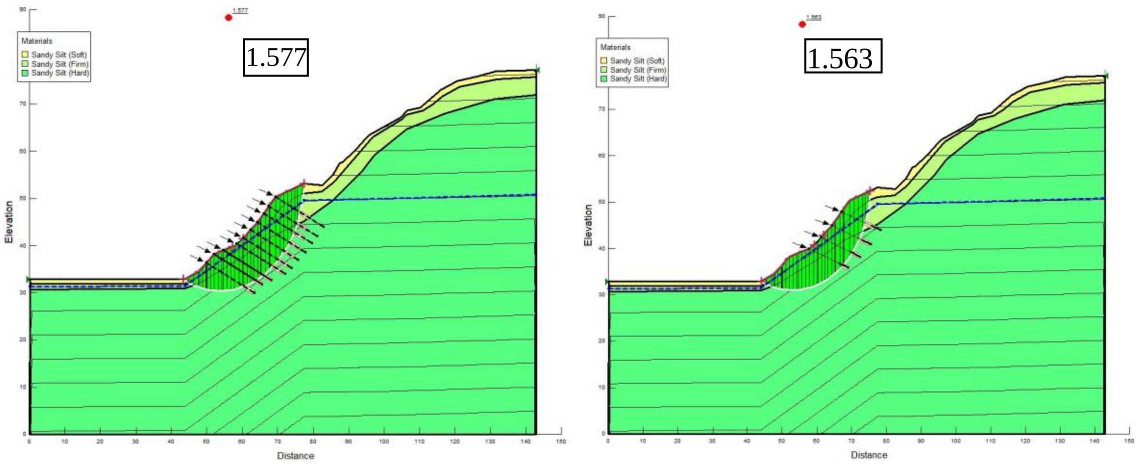


Fig. 3 *Slope stability analysis for cross section A-A*

Table 3 *Summary of recommended remedial work design*

Option	Slope Erosion Protection	Slope Strengthening	FOS
Soil Nailing	Grid Beam	• 10 layers of T25 Soil Nail • Spacing – 2.0m x 2.0m • Length – 15m (each layer)	1.577
Hybrid Anchor	Grid Beam	• layers of Hybrid Anchor • Spacing – 3.0m x 3.0m • Length – 12m (each layer)	1.563



(a) **(b)**

Fig. 4 *Remedial analysis for (a) Soil nailing; (b) Hybrid anchor*

5. Conclusion and Discussion

From the result, soil of investigated slope classified as sandy silt and gravelly silt, option 1 which is remedial work design of soil nailing with grid beam and proposed drain is more recommended for remedial slope design of the slope failure at Bukit Nanas, Kuala Lumpur due to the result (1.577) and the performing as remedial work that suitable applied in Malaysia. Extreme climate of heavy rainfall needs to consider as main factor in the slope stability analysis as well. For further observation, instrumentation monitoring work like inclinometer and piezometer need to be installed and monitored from time to time. Besides, nearby slope location also recommended to do investigation to avoid the incident of slope failure happening.

Acknowledgement

Completion of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia via Grant Tier 1 (Vot Q349).

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Lim Kit Siang, Siti Azela Mazlan;* ***data collection:*** *Dayang Zulaika Abang Hasbollah, Mohd Firdaus Md Dan;* ***draft manuscript preparation;*** *Muhammad Aminuddin Khalid, Noor Hakim Basri, Melvern Goh. All authors reviewed the results and approved the final version of the manuscript.*

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