INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 13 NO. 1 (2022) 39-49

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Climatic Influence on Slope Failure: A Case Study at Kem Terendak, Melaka

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DOI: https://doi.org/10.30880/ijscet.2022.13.01.004
Received 13 March 2022; Accepted 19 March 2022; Available online 16 May 2022

Abstract: Slope failure or landslide is always ascribing to the slope sculptures in the hilly area. The trend of people building a structure on a hilly area has resulted in slope cutting works being carried out aggressively and, at the same time, has increased the risk of landslides. Most of the community lacks understanding regarding slope care and maintenance, which adds to the slope suffering. One of the factors contributing to slope failure is rainfall. The rainfall-runoff to the slope erodes the turfed and topsoil particles from the slope surface. When the slope surface is exposing to extreme weather, then the slope failure will occur. These failures pose a significant engineering hazard, necessitating urgent repair work and planning in many areas. All failures that occur will require expensive repairing costs. Therefore, this study is carried out to model the rainfall-induced slope failure occurrence at Kem Terendak, Melaka. This study utilises a simulation of slope stability analysis by limit equilibrium, Slope/W 2012 and finite element software for simulating groundwater flow in saturated steady-state situations, Seep/W 2012 in order to analyse the stability of the slope with the influence of climate. Through those analysis, one can understand the causes and mechanisms of the landslide. At the same time, the factors that influence the occurrence of failures can be identified and appropriate action can be taken to reduce or even eliminate the root cause of slope failures. In addition, effective and efficient slope repair methods can be proposed with optimal cost.

Keywords: Slope failure, landslides, rainfall–runoff, limit equilibrium software, slope stability analysis

1. Introduction

In the past two decades in Malaysia, the growth of hillside has been growing fast. Sustainable development planning and achievement are essential for drainage, flux, erosion, sedimentation and slope stability management in such an environment. Malaysia is exposed to high intensity and rainstorms more often than other industrialised nations and thus calls for more rigorous, structural or non-structural, control methods to cope with the issues. Thus, hillside development typically generates more extraordinary flash floods to downstream communities and water (MetMalaysia, 2020). The tendency of the landslide occurrence in Malaysia is growing gradually (Akter et al., 2019). The recent increase in landslides has led researchers to make it an essential topic of study. Observations also found that the main factor in

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landslides' occurrence in Malaysia is prolonged heavy rains in hillside areas. Muaz et al. (2020) recognized that rainfall is the primary trigger of landslide occurrence, and have to determine the relative importance of high-intensity rainfall and antecedent rainfall and how they may alter the pattern of the rainfall threshold.

The rainfall threshold that triggers landslides was investigated using satellite remote estimations to predict potential landslides in Ulu Kelang, Selangor (Ya'Acob et al., 2018). Roslee et al. (2017) examined the geomorphology of landslide areas along the Karak highway that connects Genting Sempah and Bentong. The physical relief of this research region is mainly flat to undulating and somewhat 19 rough to steep, with an elevation range of 0 to 1317 metres. Abdullah et al. (2019) determine the geomorphology of soil erosion on landslides in the agricultural land, Cameron Highlands. Debris avalanches, flows or run off are significant in mountainous regions, distinguished by their very high velocities. In Kundasang, Sabah, Sharir et al. (2018) examines the effect of topographical factors on landslide zones via the use of a GIS-based empirical model. National Slope Master Plan (NSMP) indicates that slope failure mainly occurred in hilly areas, contributing 55% to other locations such as rivers, mines, and coastal areas (refer Figure 1). The root cause of the failure is high and prolonged heavy downpour intensity, which is climatic inducing, especially during the monsoon season. Water is a significant effect on slope stability as in Malaysia, the cumulative rainfall every year is very high. The safe and stable slope can drain water out well from the slope. Indeed, the increasingly steep slope and the slow rate of outflow of water will cause dangerous conditions to the slope. Depending on the soil saturated permeability and rainfall intensity, shallow slope failure initiates under rainfall infiltration depending on the slope geometry and contour. The soaked of the soil is one of the most critical variables in determining the range of rainfall intensities. The presence of slope failure is possible when the downpour event intensity is greater than the infiltration capacity at the saturated state because matrix suction completely disappears during the infiltration stage. Thus, the slope failure is encountered during the infiltration stage (Jabatan Kerja Raya, 2009).

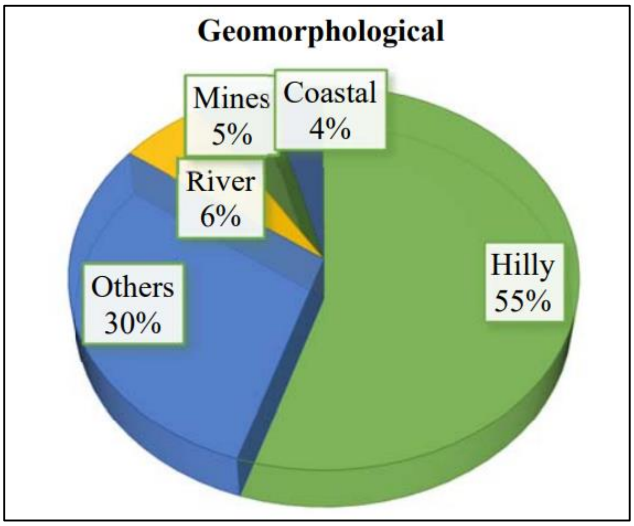

Fig. 1 - Geomorphological of landslides (Jabatan Kerja Raya, 2009)

In case of triggering factor comparison, in Malaysia, rainfall is a significant element compared to the others, with triggering factor of 58%, and the principal reason for triggering is a rainfall of 2550 mm annually (refer Figure 2). The load change contributes to 35% in the Malaysia area, after rainfall (Kazmi et al., 2016). The terrible disaster occurred in Penang Hill on September 2013, when thirteen landslides record after severe rain. It was said that three landslides at KM2.1, KM2.5 and KM4.0, where the ground collapsed massively. It was also stated that weak slurry run off and soil erosion were the causes behind the landslide, adding that soft ground may have led the tree to collapse and the ground with it owing to persistent heavy rains. Fortunately, no fatalities were present, but the cost of the remediation work increased to RM 1 million due to the landslides.

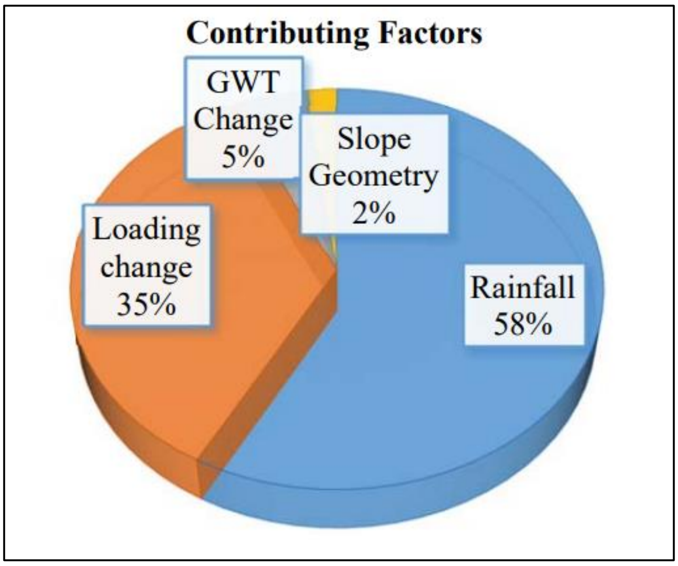

Fig. 2 - Physical factors contributing of Malaysia landslides (Kazmi et al., 2016)

The slope failure can be due to nature, and highly progressive demand for luxurious accommodation needs the construction works to be done at the hillside. Unfortunately, inadequate planning, supervising, and maintaining the hillside development area will become a disaster, not to the resident but also the people surrounding. The failures pose a significant engineering danger, necessitating corrective work and planning constraints in many locations. The proper consideration and techniques must adapt during the designing processes. The unknown and unease to predict the failures make it worse, and so the design should first ensure to be effective. Safe and well standard of procedure for the hillside construction can avoidance the catastrophic sequences. Therefore, this study will simulate the geology and climatology factors that influence the slope failures.

1.2 Background of Terendak Beach

The Terendak Beach, Melaka, located approximately 23.5 km away from Melaka City Centre. It is a military camp, namely Kem Terendak, built in 1964, which houses the Army Rapid Deployment Force, and equips with Rumah Keluarga Angkatan Tentera (RKAT), housing facilities. On the 1st April 2019, a landslide has occurred in the RKAT area housed an executive bungalow at the top of the slope in Kem Terendak, Melaka.

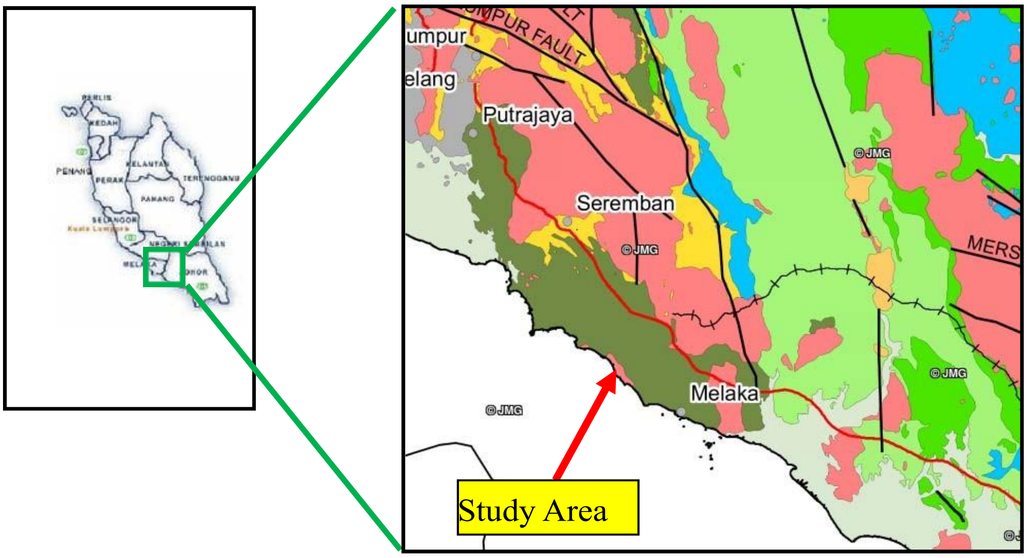

Fig. 3 - The study area location in Melaka

Figure 3 shows the location of the study area in Melaka. The original geology of the study area is an igneous rock consisting of intrusive rocks, mainly granite with minor granodiorite. Intrusive rock is an igneous rock with coarse grains (Intrusive Rock, n.d.).

Fig. 4 - View of the slope

The study area is a high slope located on the coaster of Kem Terendak, Melaka. The geometry of the landslide is a high slope measuring 21 m high, 50 m wide, and at an angle of 30°. The slope area housed an executive bungalow at the top of the slope, while the bottom of the slope was an exclusive picnic area. The slope is a single-flight slope without any terrace—the entire surface covers with cow grass without trees. There are reinforced concrete stairs on the side of the landslide area used as a path to walk down to the slope's toe (refer to Figure 4). The soil was eroded and slide down within to about 1 m onto the ground, debris from the failed slope accumulated with rill erosions created for water discharging (refer to Figure 5). Landslides also damaged the reinforced concrete stairs to go down the hill and were no longer safe to use.

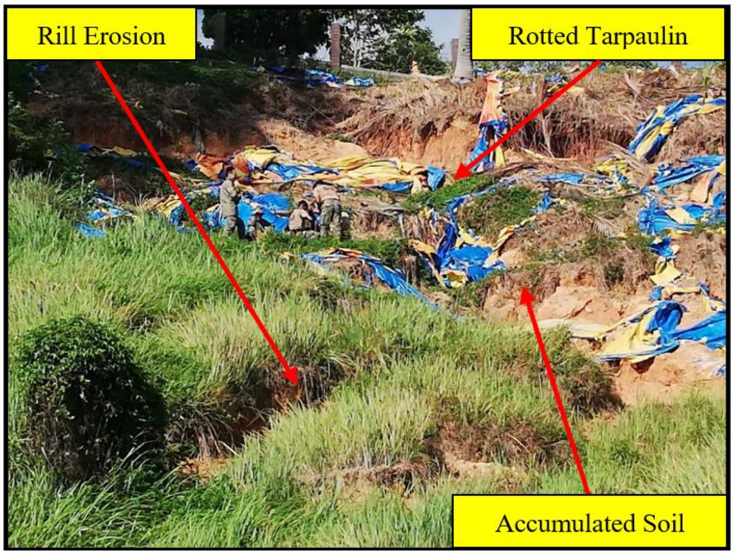

Fig. 5 - The slope condition after landslide

This study aims to associate with a set of objectives or targets intended to accomplish by completing the research. The goals are to simulate the original geometric modelling of the landslide and get the pre–failure safety factor by using Slope/W 2012. Next, to evaluate the factors triggering landslides and get the post–failure safety factor of the slope by using Seep/W 2012 and Slope/W 2012. On top of that, this study proposes and recommend the practical and safe slope stability works. SLOPE/W 2012 uses limit equilibrium method to simulate diverse soil types, complicated stratigraphic and slip surface geometry, and changing pore-water pressure conditions. While Seep/W 2012 is a finite element software for simulating groundwater flow in saturated steady-state situations with ground surface atmospheric interaction. To better understand the site's geological constitution, previous soil investigation reports and engineering survey plans were studied. The soil investigation report includes three boreholes drilled between 5 to 16 March 2020 and twelve locations of the mackintosh probe test. This study explains the climatic influencing of slope failure by computing the Factor of Safety of failed slope by using the Seep/W 2012 and Slope/W 2012 software.

2. Methodology

The techniques and processes used to accomplish the study's goals refer to as methodology. The main research activities divide into the following four steps:

2.2 Data Collection

This study begins with collecting data from field studies that land surveyors and site investigation contractors had carried out. The data taken are information on slope geometry, drainage system and any defects on the slope surface. The location of the collapsed slope is about 70 meters from the shore. The top of the slope built an executive bungalow, and the flight and toe of the slope is a grassy plain. Slopes project lengthwise to the left and right of the landslide area. However, it is only in those locations that landslides occur. The distance of the bungalow to the collapsed slope is only 15 m. Grass plants are covering the entire slope of the area. There is no slope drainage either at the top or at the bottom of the slope. In general, the existing slope is good and shows no signs of erosion. Through observations, no water supply pipes or sewage crossed the slope area. Table 1 below shows the coordinates of slope geometric.

Table 1 - Summaries of slope geometric coordinates

Layer Type	Coordinates
Upper Soil Layer	(0,32), (7,32), (21,22) and (0,22)
Middle Soil Layer	(0,22), (21,22), (44,12) and (0,12)
Lower Soil Layer	(0,12), (44,12), (52,11), (59,10), (69,10), (69,0) and (0,0)

2.3 Subsurface Determination

This step involves identifying information such as slope profile, soil strata and soil engineering characteristics. In addition, groundwater level information will also determine during this stage. The above information will extract from laboratory test reports on soil samples that the site investigation contractor had carried out.

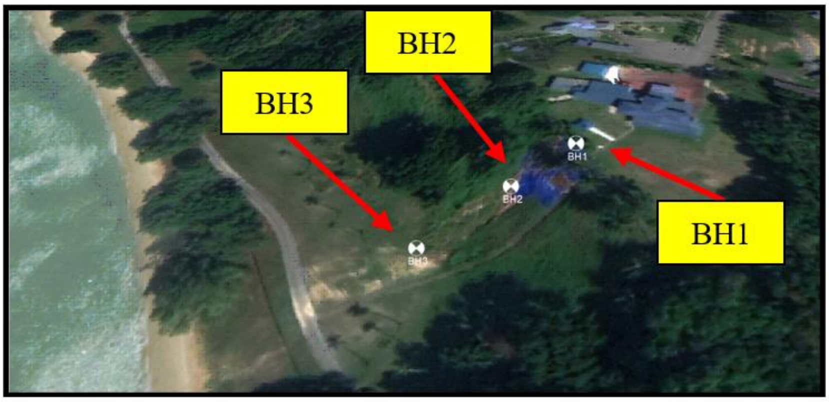

Fig. 6 - Location of borehole test

The subsurface profiles and conditions beneath the landslide area infer from the soil investigation report completed mid of April 2020 by an appointed site investigation contractor. One cross-section consists of Borehole 1, 2 and 3 were developing across the landslide area (refer to Figure 6). To furnish the analysis, the soil information encountered from the bore log will table into the group for ease of reference (refer to Tables 2 until 5).

Table 2 - Summaries of subsurface parameters

	BH 1	BH 2	BH 3
Soil Type	Overburden	Overburden	Overburden
SPT	<15	<15	<15
Soil Model	Mohr–Coulomb	Mohr–Coulomb	Mohr–Coulomb
Unit Weight (kN/m³)	17.9	18.0	18.3
Cohesion (kPa)	50	5	15
Phi (°)	31	33	34

Table 3 - Summaries of groundwater level

	BH1	BH2	BH3
Groundwater Level (m)	6.3	6.3	6.3

Table 4 - Summaries of material input for Seep/W 2012

Material	Value
Saturated Water Content	0.5 m³/m³
Sample Material	Silty Sand
Saturated K_x	1×10^{-6}
Residual Water Content	0.05 m³/m³

Table 5 - Summaries of piezometric line coordinates

Layer Type	Coordinates
Piezometric Line	(0,26), (7,26), (21,16), (44,6) and (69,6)

2.4 Climatic of Malaysia

Malaysia has a humid climate throughout the year. Malaysia's average daily temperature ranges between 21°C to 32°C. Malaysia's climate is often affected by winds from the Indian Ocean (Southwest Monsoon, May to September) and the South China Sea (North-Eastern Monsoon - November to March). It receives about 80% of its annual rainfall, which ranges between 2000mm and 2500mm (MyGOV - Malaysia Information Climate, n.d.). Between mid-October and the end of March, the rainy season, or monsoon season, affects the eastern half of the peninsular climate. Since the weather is often highly harsh during these months, this is not the ideal time to visit certain areas of Malaysia. For example, certain tropical islands (Perhentian, Redang, and Tioman) shut down during the rainy season, and visitors are not transported to the islands. Melaka is part of the state in Malaysia. Location Melaka is on the southwest coast of Peninsular Malaysia, as well as opposite Sumatra. Monsoon winds are not disturbing because the estuary is protected from the wind and blocked by Sumatra soil. Of course, the weather in Melaka is similar to the Peninsula, experiencing hot and humid, tropical, all year round. A study on the weather in Melaka in 2019 has been carried out, and the pattern of weather, including temperature, rain, wind, humidity and sunlight, is as follows:

Table 6 - Melaka monthly climate averages for 2019 (Melaka, Melaka, Malaysia Weather Averages, World Weather Online, n.d.)

Month	**Jan '19**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan '20**
Max & Min Temperature (°C)	31 25	32 25	32 26	32 27	32 27	30 27	30 26	30 26	30 26	30 26	30 25	29 24	30 24
Average Rainfall (mm)	178	102	190	237	242	276	174	128	114	199	243	176	144

Average Rainfall Indicator (mm)	290	185	276	301	254	180	172	197	200	277	466	384	290
Rainy Days (day)	25	16	27	29	29	30	28	29	22	31	28	27	29
Wind Gust and Max. Speed (km/h)	24.5 20.7	20.7 19	17.4 15.8	15.1 13.7	16.9 15.1	16.5 14.8	16.6 14.8	17.5 15.9	17.9 14.9	14.8 13.5	16.5 13.7	23.6 18.7	20.6 17.1
Humidity (%)	75	73	72	74	73	77	76	75	74	74	78	80	78

From Table 6, it can conclude that the weather conditions in March and April 2019, months of the landslide occurrence, are as usual in the previous year. Besides, rainfall measures for March and April onwards are higher than the previous month of February 2019 rainfall recorded. Therefore, it can conclude that prolonged heavy rainfall is the cause of landslides in the study area.

2.5 Geometry and Simulation

All information such as slope geometric, soil profile, soil engineering characteristics and piezometric line will analyse in the Seep/W 2012 and Slope/W 2012 software. The analysis will unravel the value of Factor of Safety on slopes that have failed in three conditions, stable state water, rising groundwater and wetting front (refer to Figures 7 and 8).

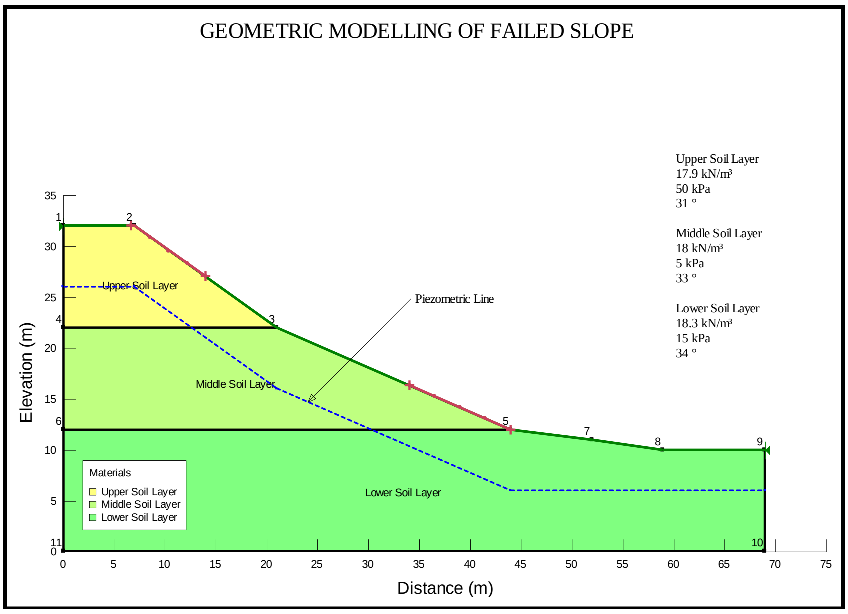

Fig. 7 - Slope modelling in Slope/W 2012

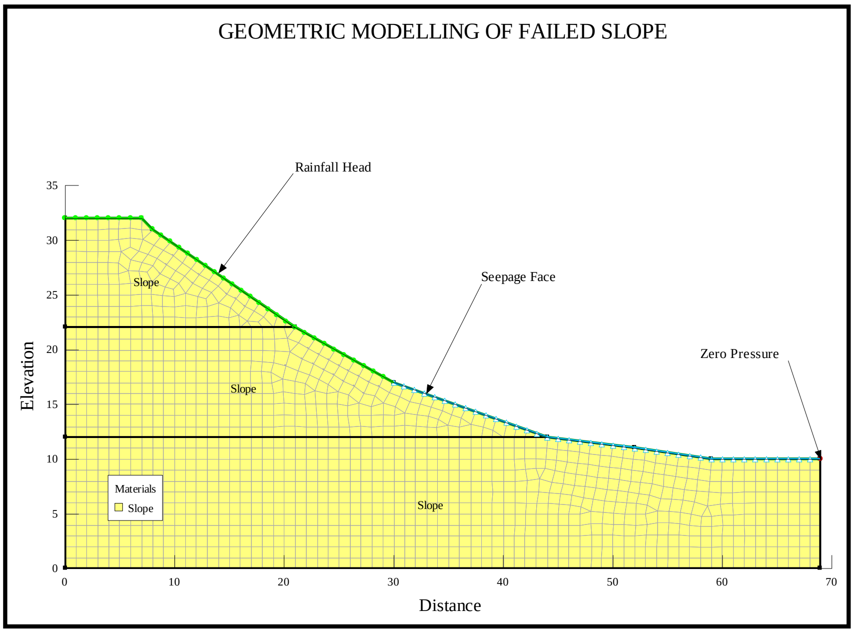

Fig. 8 - Slope modelling in Seep/W 2012

3. Results and Discussions

The slope stability analysis was conducted based on the shear strength parameters from soil investigation. The most critical cross-sections have been selected to find the most critical potential slip circle. The primary purpose of the stability analyses is to perform a back analyses study based on the original profile of failed slope to predict the soil shear strength when a failure occurs. The simulation results are shown in Figures 9 until 12.

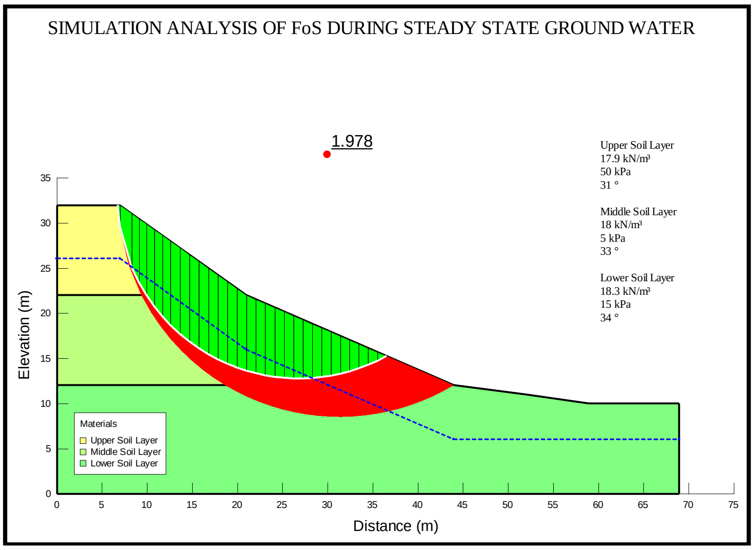

Fig. 9 - Simulation result FoS for steady state of groundwater

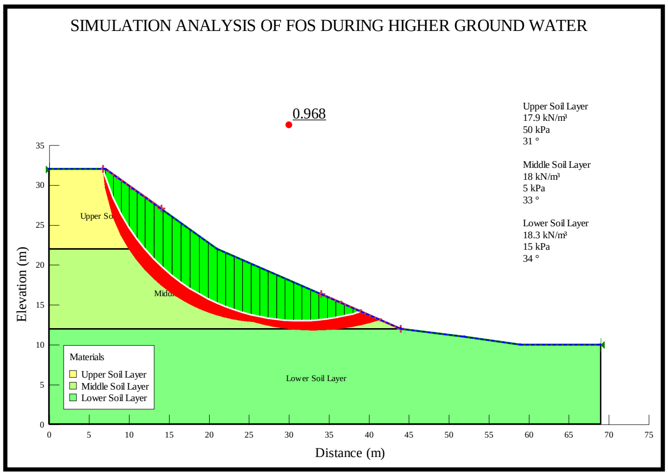

Fig. 10 - Simulation result FoS for rising of groundwater

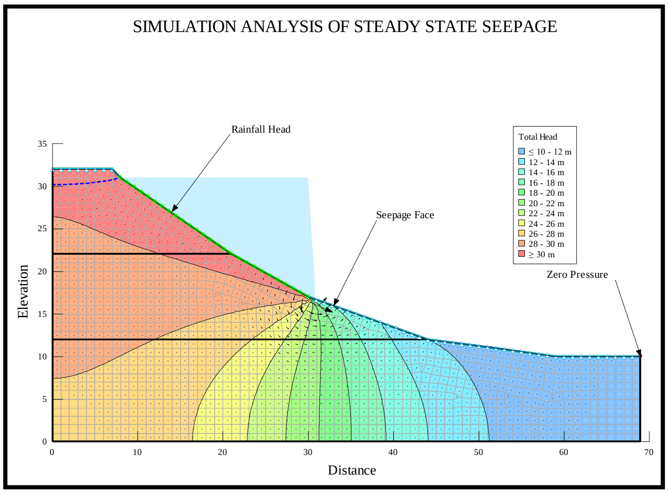

Fig. 11 - Simulation result of total head analysis during rainfall

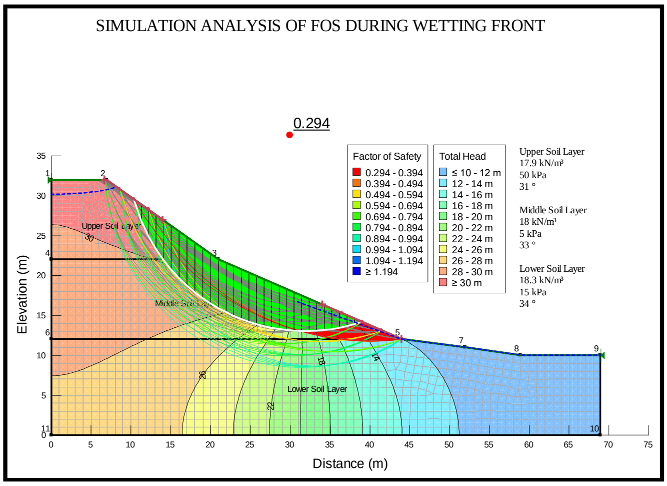

Fig. 12 - Simulation result FoS during rainfall–runoff

Analysis of landslides done through three ways, namely analysis when the groundwater level is at a depth of 6.3m from surface, groundwater level is at the same level as the slope surface (rising of groundwater), and the assumption of landslide happened during heavy rainfall. The soil suction was assumed linear at 10° during the simulation analysis.

Table 7 - Summaries of result of slope stability analysis

Condition	Factor of Safety	Remarks
Pre–Failure Slope Profile	1.978	Safe
Groundwater level increase to the same level of slope flight surface (piezometric line level increase 6.3m to the slope surface)	0.968	Failed
Slope wetting front due to rainfall–runoff infiltration (>5 m into the slope)	0.294	Failed

The results in Table 7 show that the slope failed during water changes, either increasing groundwater or rainfall–runoff infiltration. As shown in the site investigation report, the analysis process can assume that the groundwater level was relatively high (6.3 m). At the same time, heavy rains during the monsoon season have battered the study area, causing high water infiltration into the slope and accumulated without having much time to drain out, causing the slope to become the wetting front. The findings of this study showed that the slope stability is determined by soil characteristics, infiltration flow, and preceding moisture conditions. It was found that saturated hydraulic conductivity and infiltration intensity exert the most influence on stability, which is consistent with the findings reported. Additionally, this research established that the relative location of the hydraulic conductivity function in relation to the infiltration flow is critical. The pore-water pressure behind the wetting may become constant throughout infiltration. Pore-water pressure behind the wetting front is proportional to the amount of the infiltration flux in relation to the hydraulic conductivity function.

Based on slope stability analyses done, the proposal for remedial works considers strengthening the slope at Kem Terendak, Melaka, as below.

1. Existing high slopes can improve by cutting to a gentle slope angle to achieve the required factor of safety.

2. Proper slope drainage system must be proposed at the new remedial slope to prevent the water from flowing from the existing building, allowing slope flight.

3. Berm come with drain need to be built at every 6 m high slope to shorten the flowing down of water. The surface runoff will accumulate at the berm faster than the original slope and flow down 20 m to the toe of the slope.

4. If any, slope strengthening with soil nail can be proposed by installed at a minimum of 9 m nail through the hard bedding soil.

3. Conclusion

The following conclusions are made based on the findings of result and assessment:

1. The study has characterised the soil properties from the soil investigation report. The groundwater level of 6.3m is too high for a slope with a height of 21m. During a heavy downpour, the rainwater that seeps into the soil will increase the water level in the soil quickly. In addition, the low SPT value (less than 15 blows/feet) at a level of 6m in the soil accelerates the occurrence of slope geological changes. Continuous monitoring of groundwater level using piezometer and inclinometer to monitor slope movement must carry out to observe the condition of the existing slope until the slope stabilize.

2. The study is simulating the original geological model of the slope by using Seep/W 2012 and Slope/W 2012. The value of the safety factor reached is high, which is more than 1.5. These pre-failure results indicate that the slope is stable as long as external factors such as climatology and geological processes such as erosion do not disrupt the stability of the original slope.

3. The study is evaluating the probable causes of slope failure. The stability analyses indicated that the calculated factors of safety are inadequate based on rainfall infiltration assessment. The leading cause of failures was the infiltration of surface runoff into the slope flight before reaching the slope's toe. The factor of safety against global stability is not stable which is below the required safety factor of 1.4.

4. Based on on-site the investigation results and geotechnical analysis, the study strongly recommends that the stability of all existing slopes be further investigated and strengthen. In this case, the factor safety of the slope falls below the safety requirements whereby slope strengthening work must carry out immediately such as correct slope geometry reconstruction and the use of geosynthetics.

Acknowledgement

The authors would like to thanks the UiTM Shah Alam for giving the opportunity to conduct this research.

References

Abdullah, A. F., Aimrun, W., Nasidi, N. M., Hazari, K., Sidek, L. M., & Selamat, Z. (2019). Modelling erosion and landslides induced by farming activities at Hilly Areas, Cameron Highlands, Malaysia. Jurnal Teknologi, 81(6), 195–204. https://doi.org/10.11113/jt.v81.13795.

Akter, A., Noor, M. J. M. M., Goto, M., Khanam, S., Parvez, A., & Rasheduzzaman, M. (2019). Landslide Disaster in Malaysia: An Overview. International Journal of Innovative Research and Development, 8(6). https://doi.org/10.24940/ijird/2019/v8/i6/jun19058.

Intrusive Rock. (n.d.). https://www.britannica.com/science/intrusive-rock

Jabatan Kerja Raya. (2009). National Slope Master Plan.

Kazmi, D., Qasim, S., Harahap, I. S. ., Baharom, S., Imran, M., & Moin, S. (2016). A Study on the Contributing Factors of Major Landslides in Malaysia. Civil Engineering Journal, 2(12), 669–678. https://doi.org/10.28991/cej-2016-00000066.

Melaka, Melaka, Malaysia Weather Averages | Monthly Average High and Low Temperature | Average Precipitation and Rainfall days | World Weather Online. (n.d.). Retrieved 25 July 2021, from https://www.worldweatheronline.com/melaka-weather-averages/melaka/my.aspx.

MetMalaysia: Iklim Malaysia. (2020). In MetMalaysia (pp. 2–5). www.met.gov.my/home%0D.

Muaz Abu Mansor Maturidi, A., Kasim, N., Abu Taib, K., Nur Aifa Binti Wan Azahar, W., & Husain Husain, N. M. (2020). Rainfall-Induced Landslides in Cameron Highland Area, Malaysia. IOP Conference Series: Materials Science and Engineering, 917(1). https://doi.org/10.1088/1757-899X/917/1/012019.

MyGOV - Malaysia Information | Climate. (n.d.). Retrieved 25 July 2021, from https://www.malaysia.gov.my/portal/content/144.

Roslee, R., Mickey, A. C., Simon, N., & Norhisham, M. N. (2017). Landslide susceptibility analysis lsa using weighted overlay method wom along the genting sempah to bentong highway pahang. Malaysian Journal Geosciences, 1(2), 13–19. https://doi.org/10.26480/mjg.02.2017.13.19.

Sharir, K., Simon, N., & Roslee, R. (2018). The influence of landslides parameters contributing to runout zones using GIS-based empirical model in Kundasang, Sabah. ASM Science Journal, 11(Special Issue 3), 254–266. https://doi.org/10.32802/asmscj.2020.657.

Ya'Acob, N., Tajudin, N., Yusof, A. L., Ali, D. M., & Sarnin, S. S. (2018). Rainfall thresholds for possible landslide occurrence in Ulu Kelang, Selangor, Malaysia using TRMM satellite precipitation estimates. *IOP Conference Series: Earth and Environmental Science*, *169*(1). https://doi.org/10.1088/1755-1315/169/1/012112.