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GEORISK DESIGN APPROACH FOR SUSTAINABLE DEVELOPMENT ON MOUNTAINOUS TERRAIN

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Abstract
Residential on or near mountainous terrain is becoming a popular life style partly owing to deficiency in flat land. However, it is subjected to risk of slope instability and slope hazards. Studies reported that slope hazards are commonly triggered by monsoon rain, human activities, deforestation or design and construction challenges. Slope hazard is identified as one of the frequent natural disasters that leads to fatalities and economic loss. Record shows that the past slope hazards in Malaysia had killed more than 500 peoples for the last forty years where the estimated economic loss is about 2.5 billion Malaysia Ringgit. This paper introduces the georisk and reliability design approach to predict the sustainability of development on or near mountainous terrains. A field study was conducted on fifty two slopes to identify the most frequent factor that trigger slope instability. Parameters such as slope geology, mode of slope failure, slope geometry, slope distress, rainfall, and drainage system and slope stabilization techniquewere studied. Further parametric study was carried out to determine the internal instability factor of slope failure.

Keywords: Georisk, Slope failure, Instability factor.

1. Introduction

Slope failures have been identified as one of the most frequent natural disaster disasters that can lead to great loss in property and life. Studied by Azami S. M (2009), showed that georisk of slope failure has been a worldwide geohazard and don't have any solution to ensure zero risk to slope failure. One of the factors that trigger the slope failures is rainfall. The intensity of rainfall in Malaysia is very high and hence, the slope is easily exposed to erosion and landslide. According to Ismail F et al. (2006), Malaysia's is among the highest that received rain with average rate of annual rainfall is about 2500mm and experienced high humidity. Moreover, some slope failures happened in slopes with no slope protection, while, some happened in slopes which had already been protected by slope stabilization measures such as soil nailing, gabion, retaining wall, vegetation cover and others. Hence, the problem here is why do slope failures happen only in some slopes but not in the others areas. It would be interest to find out the georisk factors that create the slope failures, why slope failures happen and when will the slope failures will happen. To deal with the problem that was stated earlier, the concept of risk reliability study is beneficial useful to study the cause of slope failure probability. Therefore, this paper will introduce a process for evaluating the probability of slope failures in Malaysia. The objectives of this paper are: (1) to identify the georisk factors of slope failure through case study and (2) to determine the reliability of slope design that can contribute to the slope instability.

2. Principle of Slope Design

There are three main category of slopes i.e. natural slope, fully engineered slope and partially engineered slope. Partially engineered slope can be a cut slope or filled slope. The slope material may range from competent rock slope, weathered rock slope, stiff soil slope to soil slope. There are many empirical methods of slope design however each has its assumption and limitation as established by the researcher. In principle the empirical methods is determining the ratio of resisting slope forces against the driving slope forces named as factor of safety. Despite all the theoretical, mathematical formulation and complex software to address the range of parameters contributed to the resisting and driving forces in concluding the safest factor of slope stability, the slope continues to fail for whatever known or unknown reasons. In Malaysia, the principle of slope design are followed the recommendation by Geotechnical Manual for Slopes (GEO) of Hong Kong, with some modification to suite the local condition (Gue and Wong, 2009). As suggested by GEO (2000), the design criteria should start with survey data, site investigation and engineering geology mapping. For the geometry of the slope, 4V:1H and 3V:1H are the optimum design geometry used for rock slope design while soil slope are design using 1V:1H to 1V:1.5H and the maximum berm height are 6m height and 2m width wide for easy maintenance. The adopted slope angle are depends on the results of analysis and design of the strength parameter and the groundwater levels while the maximum number of berm shall be limited to 6 berm and other solution such as tunnel, soil nailing, retaining wall etc shall be considered if design required more than 6 berm. Moreover, the minimum factor of safety applied for cut slope should be greater than 1.3 to 1.5 depending on the type of slope protection.

2.1 Slope Risk Design Approach

Due to the instability of the slope are still questionable, the paradigm shift in predicting of slope against failure are increased continuously. In Malaysia, many studied has conducted reduce the risk from slope failure. As described by Gue and Wong (2009), GEO suggested to applied the different values of Factor of safety (FOS) in different risk element. The large value up to 1.5 factor of safety are used for slope in high population area and 1.3 value are used for slope at low population area. Westen (1994) suggested the risk analysis of slope failure usually depends on the scale of map to determine the suitable analysis to used. Statistical analysis approach also suggested by Luzi and Pergalani (1996) and founded that it suitable to be used for region scale map due to the model incorporates the computation of the frequency of the slope failure. In other studies Lacasse & Nadim (2006) and Shien K.N (2005) founded deterministic approach such as FOS and probabilistic approach, First-Order Second-Moment and Monte-Carlo Simulation are suitable for the large scale study area or specific slopes. However, Youssef et al. (2003) introduced the slope rating system that suitable to used in large scale, small scale or specific slope. In Malaysia the slope rating system are begin in 1996. Studied by Jamaludin S. et al. (2004), most of the slope risk management work in Malaysia carried out by Public Work Department (PWD). According to Azami, S. M (2009) the slope rating system is the important criteria to classified the level of the risk and suggested rating system is suitable for the early warning system.

3. Methodology

The methodology is divided into three main part of data analysis. Firstly, data analysis by using raw fieldwork data. The data from the fieldwork study are analysed to produce the graphical representation on the most favourable condition of slope instability. The statistical technique are used for secondary data analysis. Existing SPSS 16.0 software are used for statistical analysis. This analysis are the further data analysis from the preliminary data analysis in first part. This statistical analysis are used to convert the qualitative data of the fieldwork study into the quantitative data and presented in the statistical statue. The final stage of data analysis are analysed the data using established SLOPE/W Software. This stage is to analysis the internal factors of slope instability such as the value of cohesion, friction and the present of the water table. This study selected Selangor and Perak as the site locations. Forty nine (49) cut and natural slopes were selected and the fieldwork was carried out between June 2010 until June 2011. The site locations were 19 sites from Jalan Batu Arang, Puncak Alam, 15 sites form Jalan Kajang, Dengkil, Selangor and 15 sites from Jalan Parit, Perak. The selection of the location was based on the latest occurrence of slope failure, easy access, discussion with supervisor and support from the National Slope Master Plan by the Public Work Department (PWD) which the statistics showed the highest cases of slope failure in these two states. The Mineral and Geosciences Department Malaysia (2000) stated that the geology of a site locations is classified as sedimentary rocks or carboniferous formation.

4. Result and Analysis

4.1 Mode of failure

Generally there are three main types of slope failure which are fall, slide and flow. For the slope that layered by sedimentary formation, six (6) modes of failure that contributed to the main failure were identified. The most favorable mode of failure in this study was raveling which had twenty (20) cases, followed by erosion at eleven (11) cases, compound failure at eight (8) cases, complex failure at seven (7) cases, composite wedge failure at two (2) cases and one (1) case for planar failure as shown in Figure 1. The most favorable mode of failure in this study was raveling of the slope as shown in Plate 1. Raveling process means the soil and rock are easily decomposes by water, wind or climate. It happened due to the weathering process of slope materials where the weathering grade is between III to V. Raveling of the slope materials is due to heavy rainfall that deteriorate the slope surface. In Malaysia the wet and dry weather are frequently the triggering factor that contributed to the raveling of the slope materials. Moreover, raveling process also complicated in estimating the probability of failure surface due to the combination of soft rock and hard soil materials. This statement is support by Mohamed. Z (2004) that stated the weathering grade between grade III to V has always been not fully understood due to rock soil characteristic.

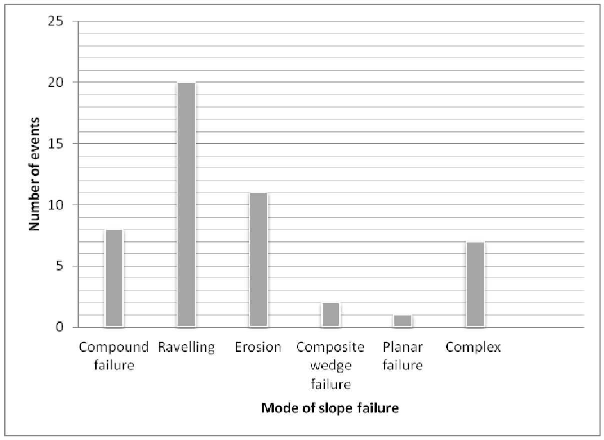

Figure 1: Mode of failure on forty nine (49) sedimentary slope

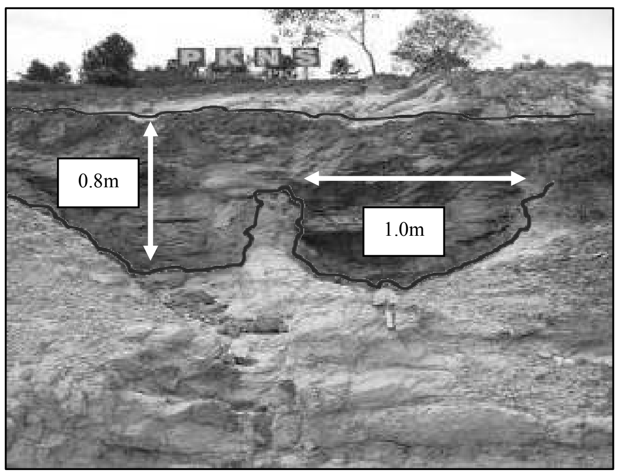

Plate 1: Raveling of the slope

4.2 Geological Risk

Site geology is classified into three categories. The categories are the type of slope materials, rock mass lithology and weathering grade. Most of the slope materials are in rock to soil state, namely 32 rock and soil materials and 17 soils. The lithology of site location is underlain by sedimentary formation and the weathering grade of site location is shown on Figure 4. From Figure 4, the highest is weathering Grade V which is 24 cases, followed by Grade VI with 17 cases, Grade IV with 8 cases, and Grade II with 1 case. Grade V of weathering is known as complete decomposed rock. Weathering process in this study happened due to climatic changes that affected the sedimentary formation. This statement is supported by rainfall data from the Malaysia Meteorology Department as shown in Figure 5. Rainfall data amount from 2001 to 2009 showed that the highest yearly rainfall was at Hospital Batu Gajah Station with 3375.3mm. Meanwhile, Sg Buluh Estate Station received 2438.9mm of rainfall. Rainfall data from 2001 until 2009 showed that the rainfall amount both increased and decreased. This process proved that the site location has been exposed to wet and dry weather for the past 10 years. The exposure of wet and dry weather will highly support the weathering process. This is because if more water is available, more chemical processes can proceed and if temperatures are warm, the chemical weathering process can proceed very fast.

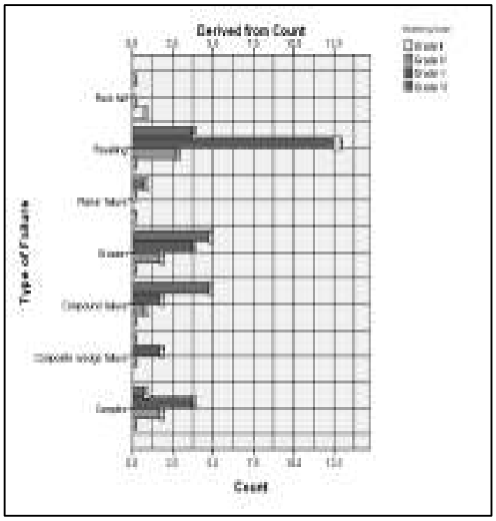

Figure 4: Graph on weathering grade and mode of failure of sedimentary formation

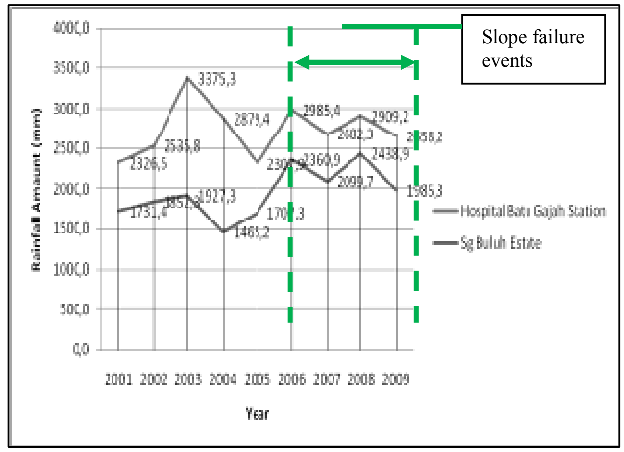

Figure 5: Yearly rainfall amount and slope failure events

4.3 *Reliability of slope design*

The test of normality conducted to identify the normality of the data. As shown in Figure 6, for the slope height the value are normal distribution due to the dots fall very close to the linear line. Only two dots fall away from linear line, so there are two values are departure from normality. For the slope angle only one dots are fall away from the normality of the data as shown in Figure 7.

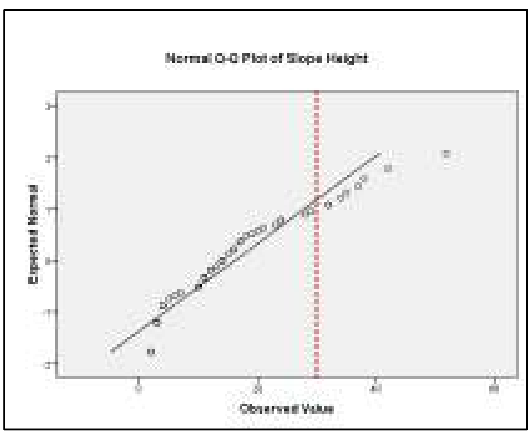

Figure 6: Normal Q-Q plot of slope height

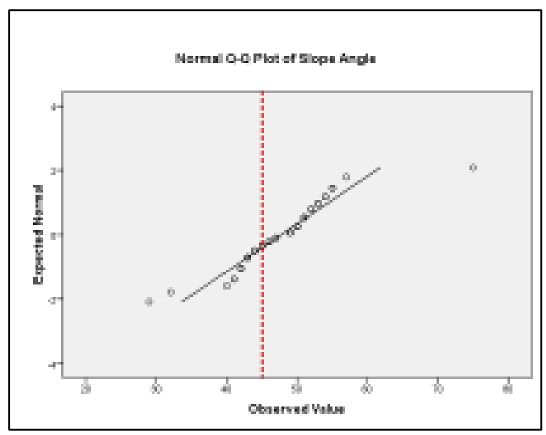

Figure 7: Normal Q-Q plot of slope angle

Based on the result, the percentages of slope failed more than 30 meter which is 50% is high than slope less than 30 meter which is 26.7%, so it can be concluded that, the height of the slope affect the probability of slope failure. Slope with more than 30 meter height are more percentages to fail compare to slope less than 30 meter height. Based on the Table 4.10, slope with angle less than 45 degree are 22 cases and slope with more than 45 degree are 30 cases. For slope below than 45 degree, 7 cases from 22 cases identified as failed slope. For the slope more than 45 degree angle, 10 cases from 20 cases are identified as failed. Moreover, the percentages of slope failed for slope more than 45 degree are slightly higher than slope less than 45 degree angle with different 1.5% only.

Forty nine (49) slopes also analysis to compare the mean score for each instability factors. Based on the Table 1, nine out of eleven instability factors bring a large effect to slope instability, one bring moderate effect and two bring a small effect. Based on the result, drainage structural have a high eta squared value which are 0.37 so it can concluded that drainage structural are the main factor that effect the slope instability. Based on the site observation, most of the drainage structural are in severe condition. Drainage structural are the main part of the slope design, without proper drainage structure the slope will not be able to cater the water into the toe of the slopes. This study founded that the majority of the drainage structure has been cracked and covered by soil debris and wild plant. The moderate effect in this study are slope angle with 0.03 eta squared value. This results show that slope angle are not the major factors of slope instability. The small effect in this study are weathering grade, with 0.000012 eta squared value.

Table 1 : Eta squared values for slope instability factor

Instability factors	Eta Squared	Effect size
Drainage Structural	0.37	Large effect
Surface Materials	0.35	Large effect
Erosion	0.34	Large effect
Slope Surface	0.30	Large effect
Water Seepages	0.27	Large effect
Drainage Services	0.20	Large effect
Slope Height	0.19	Large effect
Slope Materials	0.15	Large effect
Slope Angle	0.03	Moderate effect
Slope Stabilisation	0.008	Small effect
Weathering Grade	0.000012	Small effect

This study show that in sedimentary formation, weathering grade bring the small effect to slope instability. The range of weathering grade for this study are from grade IV to grade VI only. So it can be concluded that slope failure can be happen at any weathering grade from grade IV to grade VI. In conclusion, results from independent-samples t-test identified that drainage structure are the main factors that affect the instability of the slopes, if rating from drainage structure are high risk, the slopes known as high slope instability. Moreover, for weathering grade it can be concluded that low or high instability slopes not effect by change of weathering grade.

To analysis the changing of safety factor, the parametric study are conducted to analyses the changing of shear strength parameters of the two modeled slope. The slope are modeled with the water table and without the water table. The critical slip surface is illustrated in Figure 8. The results of the analysis are shown in Table 2 and Table 3.

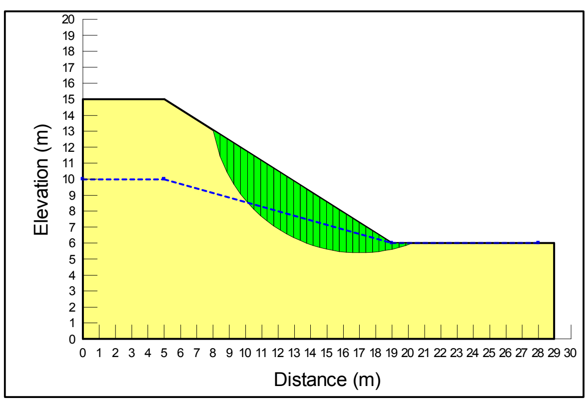

Figure 8: Yearly rainfall amount and slope failure events

Table 2: Results on changing of effective cohesion (c')

No	Soil Parameters	Case A1 - Slope without water table		Case B1 - Slope with water table		Different percentages of Case B1 over Case A1 (%)
		Calculated Factor of Safety (FOS)	Different percentage of safety factor over previous try (%)	Calculated Factor of Safety (FOS)	Different percentage of safety factor over previous try (%)	

i	c' = 2.0kPa Ø = 24	1.097	-	0.929	-	15.31
ii	c' = 1.5kPa Ø = 24°	1.052	4.10	0.894	3.77	15.02
iii	c' = 1.0kPa Ø = 24°	1.007	4.28	0.858	4.03	14.80

Based on the result in Table 2, the factor of safety are slightly decrease when the effective cohesion gradually decrease from 2.0kPa to 1.0kPa. For the slope without water table, the different percentage of safety factor over the previous trial show that the decreasing factor of safety are about 4% from the previous value. Moreover, for slope with water table, the different percentage of safety factor over the previous try show 3% to 4% difference for their factor of safety. Meanwhile, for the slope with water table, excessive different safety factor with 14% to 15% are identified compare to slope without water table.

Table 3: Results on changing of effective friction angle (Ø)

No	Soil Parameters	Case A2 - Slope without water table		Case B2 - Slope with water table		Different percentages of Case B2 over Case A2 (%)
		Calculated Factor of Safety (FOS)	Different percentage of safety factor over previous try (%)	Calculated Factor of Safety (FOS)	Different percentage of safety factor over previous try (%)	
i	c' = 2.0kPa Ø = 24	1.184	-	1.004	-	15.20
ii	c' = 1.5kPa Ø = 24°	1.097	7.34	0.929	7.47	15.31
iii	c' = 1.0kPa Ø = 24°	1.014	7.57	0.853	8.18	15.88

The results on effective friction angle are shown in Table 3. Based on the results, greater different in factor of safety founded when effective friction angle is decreased consecutively from 22° to 26°. The percentage safety factor for case A2 and case B2 over the previous trial show that 7% to 8% of the factor of safety are decreased when the friction angle decrease. The different percentage of case B2 over case A2 identified about 15% of the decreasing factor of safety means that the slope with the water table are more likely to failed compare to slope without water table.

5. Conclusion

Sedimentary cut slopes in tropical environment most common mode of failures are found to be twenty (20) cases of slope face raveling, eleven (11) cases slope face erosion, eight (8) cases of compound failure, seven (7) cases of complex failure, two (2) cases of composite wedge failure and one (1) case of planar failure.

The georisk factor contributed to low slope instability are the type of slope materials weathering grade and the rise and fall rainfall intensity. From the forty nine (49) sedimentary cut-slope analysed, 32 slopes geology range from rock to soil slope, and 17 are soil slopes. Tropical weathering grade is the determining factor whether the cut slope is rock, soil or rock-soil slope (Mohamed Z, 2004). The weathering grade classification concluded that 24 slopes are of Grade V, 17 slopes of Grade VI and 8 slopes are of Grade IV. The rise and fall intensity rainfall with maximum 3375.3mm and minimum 1465.2mm per year are the major factors causes the deterioration of slope face and increased the water table.

The slope height more than 30 meter are concluded have the 50% probability to failed compare to slope with less than 30 meter had only 27.3% probability to failed. The different percentage are 22.7%. For slope angle, the percentages of slope failed for slope more than 45 degree are slightly higher than slope less than 45 degree angle with different 1.5% only. From the parametric study, it can be concluded that the probability of the slope failure are increased 15% with the availability of the water table.

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