IDENTIFICATION OF SLOPE FAILURE USING 2-D RESISTIVITY METHOD

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Abstract - A study has been conducted to analyze the slope failures features and the factors that contribute to the landslide occurrence at Restu, Saujana and Tekun (RST) Complex, USM by using the 2-D resistivity method. Five survey lines were conducted with 100 m length and 2.5 m minimum electrode spacing. The data obtained were transferred into the computer for further processing and was presented in 2-D resistivity inversion model via Res2Dinv and Surfer v11.0 software. The inversion models convey the subsurface structure on each line in which was represented by the resistivity values. The range of resistivity values were determined and classified into three classes for interpretation. The saturated zones, weathered granite and fresh granite were classified with range values of 1-400 Ωm, 1500-5000 Ωm and greater than 5000 Ωm respectively. The saturated zones may compose of alluvium in which commonly consist of clay, silt and sand. Other features such as presence of boulders was indicated by isolated high resistivity values, boulders overlie saturated zone and presence of fracture were also determined as indicated by the resistivity variations of the inversion models. These features can be the influence to trigger the landslide event in the early stages. Apart from precipitation as a major factor of the phenomenon, slope angle can also be one of the important factors to be aware to determine slope stability. Precipitation can affect the soil strength and texture while the slope angle can determine slope's class of landslide risk. This study area has been classified of having higher risk of landslide event.

Index Terms - landslide, saturated, slope failure, 2-D resistivity

INTRODUCTION

As observed from the view of infrastructure and buildings, Malaysia could be seen as a growing and developing country. This will eventually be involving more infrastructures to be built together with its upgrowing development in the future. Along with advancing geophysical technologies, favorable conditions are necessary to meet the requirements for land development for future country growth. However, to sustain the balance between development and the nature, the view from the engineering and environmental aspects was also important. Nevertheless, in obtaining favorable and appropriate conditions for constructions, there will be difficulty and challenges as landslides activities which is one of the concerns as the disaster increased [1]. To minimizing any future natural disasters events, it is necessary to consider and investigate the targeted area which will be conducting any construction beforehand for safety and sustaining nature purposes. The subsurface in Malaysia is known with its homogeneous characteristics in which this could be reflects to the significant effect of climate change due to increasing sea levels and rainfall, flood risks and extreme droughts. Presence of boulders and rainfall amount which reflects the slope conditions are often relatable to the landslide events [2]. Geophysical methods are mainly used to study the complex subsurface of the Earth. This includes seismic, 2-D resistivity, magnetic, ground penetrating radar (GPR) and gravity survey method. Meanwhile, the study of the subsurface from the view of engineering and environment aspects is known as geotechnical studies. As different method has its own specialization of certain study findings, by correlate suitable findings and data between geophysics and engineering, this will contribute to reducing cost, time and enhance the results outcome. Suitable selection of geophysical method has to base on the project objective and targets together with site conditions for a great result. For example, by using 2-D resistivity method, identifications of boulders' locations, bedrock depth, presence of overburden materials, saturated zones, earth work related to the leachate migration, groundwater sources and contamination, cavity, sinkhole and other can be obtained [3-4].

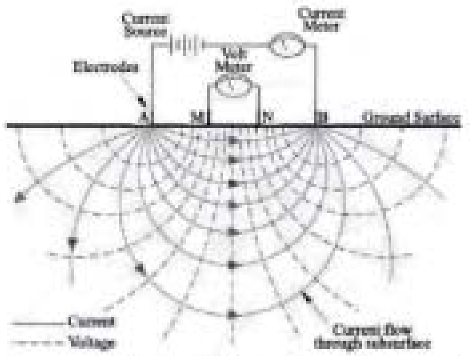

Figure 1 Electrical resistivity configurations overview [6].

Generally, current will be injected into the earth through current electrode which was remarks by C1 and C2 at point A and B respectively in Fig. 1. The potential difference between a pair of potential electrode which were represent by P1 and P2, at point M and N respectively are measured, [5].

2-D resistivity consists of four common types of electrode arrangement which are Wenner-Schlumberger, Pole-Dipole, Dipole-Dipole and Pole-Pole. Wenner-Schlumberger array has strong signal strength and sensitive to vertical variation and less to horizontal but it has relatively poor horizontal coverage with increasing electrode spacing. For pole-dipole array, it has good horizontal coverage and sensitive to vertical structure but has lower resolution compared to Wenner-Schlumberger eventhough it has deeper depth of penetration.

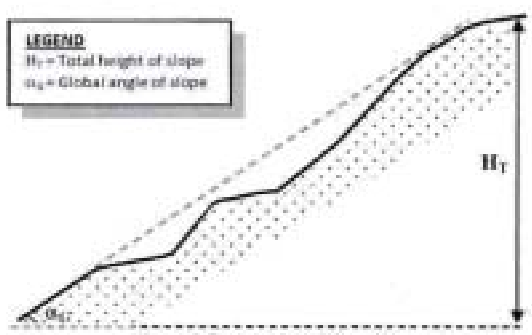

Figure 2 Geometries of slope [7].

From geotechnical aspects, the slope angle and height played one of crucial factor in determining the slope stability which is shown in Fig. 2 and its descriptions in Table 1 [7]. Based on Table 1, slopes with certain angles and height will fall under certain class and it can either be in class 1 which has low risk of landslide occurrence, class 2 which has medium risk of landslide occurrence or it also may be classified under class 3 which has higher risk of landslide occurrence.

Table 1 Classification of risk of landslide event.

Class	Description
1 - Low risk	For slopes either natural or manmade, in the site or adjacent to the site not belonging to Class 2 or Class 3
2 – Medium risk	For slopes either natural or manmade, in the site or adjacent to the site where : $6\ m \le H_T \le 15\ m$ and $\alpha_G \ge 27^\circ$ or $H_T \ge 15\ m$ and $19^\circ \le \alpha_G \le 27^\circ$
3 – Higher risk	For slope either natural or manmade, in the site or adjacent to the site where : $H_T \ge 15\ m$ and $\alpha_G \ge 27^\circ$

II. STUDY AREA

Penang, Malaysia mainly composed of granitic rocks and alluvium that commonly consists of clay silt and sand as referred to geology map of Penang [1]. The study area was located at RST, Universiti Sains Malaysia (USM), Penang (Fig. 3) with coordinate of N 5.35634 E 100.2886.

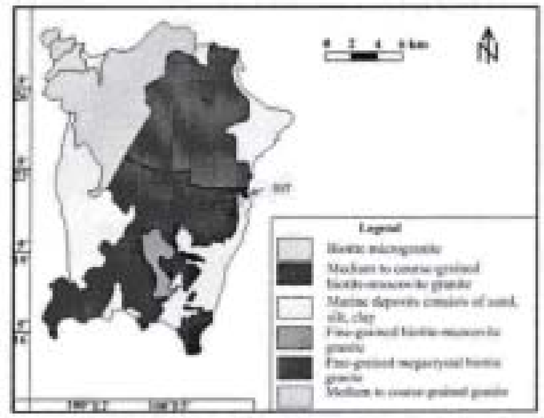

Figure 3 The geological map of Penang Island including the geology of USM [8].

III. METHODOLOGY

Five survey lines (labelled as RST01-RST05) which are marked in yellow colored line were conducted at Restu, Saujana and Tekun (RST) Complex with minimum electrode spacing of 2.5 m of 100 m length. The array used for this research is Pole-Dipole that was conducted at all survey lines except for RST01 which used Wenner-Schlumberger array due to the limitation of the cable (Fig. 4).

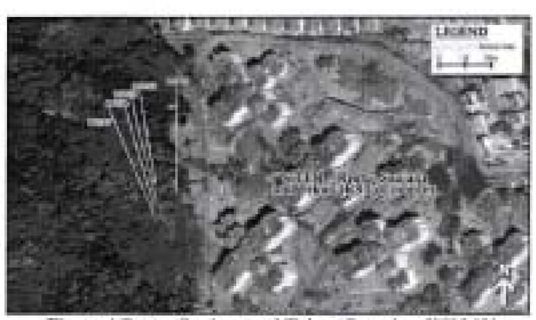

Figure 4 Restu, Saujana and Tekun Complex, USM [9].

IV. RESULTS AND DISCUSSION

The scale of resistivity values was classified based on their corresponding zones and composition as tabulated in Table 2.

Fig 5. shows the 2-D resistivity inversion model of RST01. For the first survey line which was denoted as RST01 exhibit the presence of a boulder which was identified with the value of 3000-6000 Ωm. Saturated zones were also found at RST01 with the resistivity value range of 1-400 Ωm. Fracture were determined which remarked by the dashed line indicating the high contrast of resistivity values [13-14].

Table 2 Scale classifications

Zones	Compositions	Resistivity values
Saturated zones	Saturated clay and silts [10]	1-100 Ωm
	Dry clay and silts [11]	100-500 Ωm
	Sand [10]	500- 1500 Ωm
Weathered granite	Weathered granite	1500-5000 Ωm
Fresh granite	Fresh granite [12]	> 5000 Ωm

Figure 5 Inversion model of 2-D resistivity, RST01.

The following survey lines (a) RST02, (b) RST03 and (c) RST04 shows the similarity of subsurface structures (Fig. 6). There was presence of boulders in which may compose of granitic features that was indicated by values of >3000 Ωm [15]. Saturated zones were also determined with low resistivity values of 1-400 Ωm [16]. A saturated zone was located just beside the boulder as shown in RST03. Survey line of RST02 exhibit the presence of floaters indicated by the curved dashed line [17]. These features found may be the triggering factors of landslide event. High contrast of resistivity lows and high indicates the presence of fracture that was marked with the dashed line.

Based on Fig. 7 which referring to the last survey line, RST05, there were presences of high resistivity region with the value of 5000-10000 Ωm at depth of 18-46 m that may indicate fresh granite. There was also presence of fracture and saturated zone with the value of 1-400 Ωm at the depth of 16-22 m.

Proceeding to Fig. 8, as the survey lines were arranged according to increasing elevation from RST01 up to RST05. The high resistivity region in survey lines of RST02, RST03, RST04 and RST05 were observed. Due to the high resistivity values and large in size, the zones were determined as part of fresh granite fragments. The high resistivity regions are also known with it low conductivity characterization which reflect good quality of rocks. It also could be part of landslide bedrock [18-19]. These features may be correlated from one to another as the survey lines were conducted parallelly.

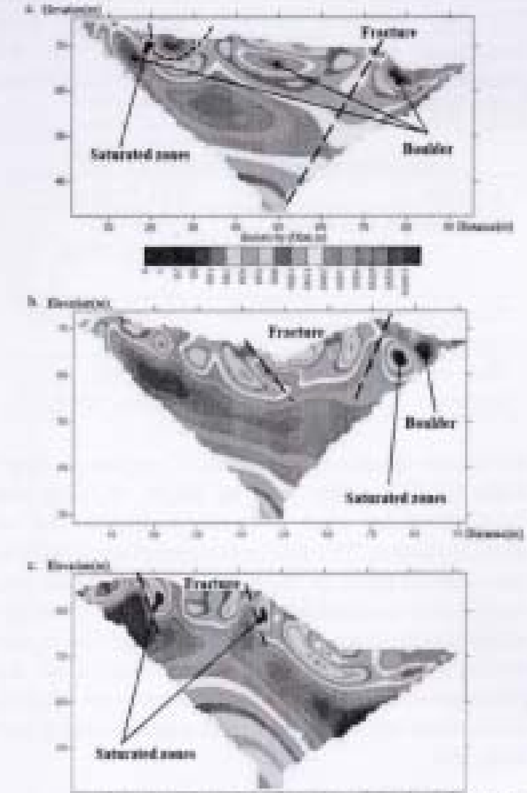

Figure 6 Inversion model of 2-D resistivity, (a) RST02, (b) RST03 and c) RST04.

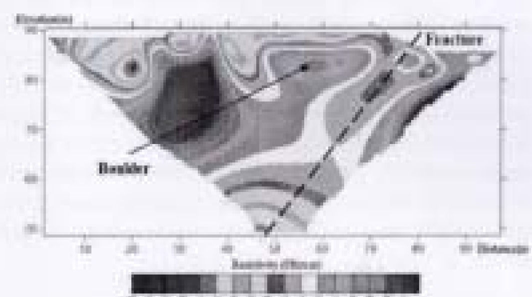

Figure 7 Inversion model of 2-D resistivity, RST05.

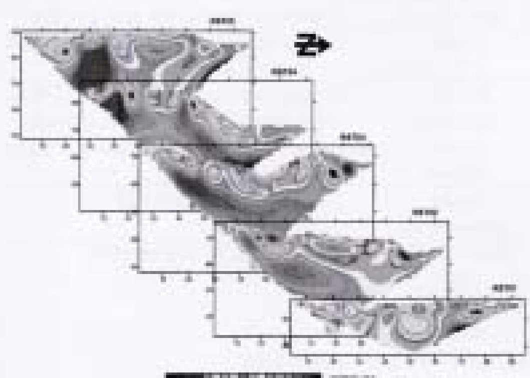

Figure 8 Inversion model of all survey lines at RST, Penang.

The 2-D resistivity method which was done throughout the survey was compared with the geotechnical aspects, specifically on slope angle and height and precipitation record.

Table 3 Details of geotechnical aspects at RST.

Criteria	RST Complex
Slope angle and height	Angle : 30° Height : 76 m
Class of risk for landslide event	Class 3 – Higher risk
Sum of precipitation (Month)	17.28 mm (January 2016)

As mention in table 3, slope of RST Complex has slope angle of 30° together with its height of 76 m was classified under class 3 possesses higher risk of landslide events. The sum of the precipitation records was obtained based on the month that the survey was conducted to compare how precipitation can affect the subsurface structure. From the table stated above, this site recorded small amount of precipitation on the particular month of survey. This reflects to the small in size and less amounts of saturated zones located at that study area.

CONCLUSION

The 2-D resistivity survey lines were carried out in order to identify the subsurface characteristic of slope failure. The application of both geophysical and geotechnical methods which were conducted at RST provided useful information for identification of slope failure and the results obtained may be useful for future slope instability investigation. The results which were obtained in the term subsurface features, slope angle and height and precipitations were compiled and shown in Table 4.

Table 4 Summary of slope at RST, Penang

Criteria	Details
Type of soil	Presence of clay, silt and granite
Zones	consist saturated zones, weathered granite and fresh granite.
Factor cause to slope failure	Presence of saturated zone (1-400 Ωm), fracture, highly weathered granite, boulders and floaters (>3000 Ωm).
Slope steepness	Slope angle : 30°
Class of risk for landslide event	Class 3 – Higher risk

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