Jurnal
Teknologi

Full Paper

SLOPE FAILURE INVESTIGATION USING ELECTRICAL RESISTIVITY PROFILING

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Article history
Received
7 June 2015
Received in revised form
5 September 2015
Accepted
8 December 2015

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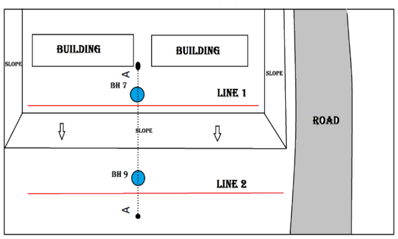
Graphical abstract



Abstract

This study elaborates on the destructive and non-destructive test methods in investigation of slope failure. Borehole method is the conventional destructive test method which commonly used to investigate the slope failure. Due to the sensitivity of the slope failure, the non-destructive investigation was conducted using electrical resistivity method. Both methods were used to investigate the slope failure area and to obtain the engineering properties of the study area. Field resistivity test was carried out using ABEM Terrameter SAS400 instrument for resistivity profiling. Borehole drilling works were conducted to provide bore log data. The results of resistivity are illustrated in imaging profile and engineering properties such as soil classifications, moisture content, soil hardness and SPT N-value were analysed from the laboratory tests. In order to develop the relationships of both resistivity and engineering properties, a comparison between soil hardness and resistivity value was determined. The findings of this study show that both methods are reliable to investigate the slope failure via sub-surface profile and engineering properties.

Keywords: Resistivity imaging, SPT, N-value, engineering properties, slope failure

1.0 INTRODUCTION

Slope failure area is very sensitive zone; all the investigation works at the slope failure area must not be destructive to prevent the failure becomes worst. The method of site investigation of slope failure usually used borehole to determine the soil profile. This method is usually involves of heavy machineries that drills the hole into the soil and this drilling activity may destruct the slope failure area. Moreover it consumes a higher cost and more time to conduct the drilling investigation. In order to overcome the aforementioned problems, the application of electrical resistivity imaging (ERI) method is utilized. This method is a new approach in site investigation works in hazardous zones. It is an ideal method to minimize the destruction on soil compared to other tests such as drilling and penetration test (Standard Penetration Test, SPT). In addition, the resistivity method covers a large area and provides continuous information of the soil profile whilst the borehole only collects a series of discrete data. By having a continuous image of soil profile, the numbers of boreholes could be minimized and thus, the total cost of the project could be effectively reduced. In light of this, small borehole logs are needed to validate the resistivity image and to obtain the engineering properties.

The present study was mainly focused on determining the soil profile using ERI method at a slope failure area. The soil profile of resistivity image was then compared to borehole profile and the relationship between the resistivity values and the engineering properties of soil were developed

2.0 ELECTRICAL RESISTIVITY IMAGING

2.1 Concept and Principle

Resistivity (ρ) is geometrically-independent quantity indicated by Eq. 2.1:

$$\rho = \frac{RA}{L} \qquad (1)$$

where R is resistance, A is cross sectional area and L is the length of the two points of electrodes. The soil resistivity measurements on field are normally made by injecting current into the ground through two current electrodes, and measuring the resulting voltage difference at two potential electrodes. From the current and voltage values, apparent resistivity (ρ_a) value is calculated. Eq. 2.2 shows the common Eq. for the apparent current.

$$\rho a = k\frac{V}{I} \qquad (2.2)$$

$$\rho a = kR \qquad (2.3)$$

where, ρ_a is apparent resistivity, k is the geometric coefficient, and R is the proportional of voltage, V, to current, I, as simplified in Eq. 2.3.

ERI method aims to determine the sub-surface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the sub-surface could be estimated [1]. Variations in the resistivity of sub-surface materials are mostly a function of lithology. The resistivity variations within the sub-surface could be associated with different materials. Each material normally has its own value of resistivity.

2.2 Previous Studies

Some previous studies have been conducted to investigate the slope failure by using resistivity method. Siti and Bujang [2] applied electrical resistivity imaging technique in slope stability study in Banding Island, Perak. In this study, detailed field resistivity imaging was carried out on four lines along the eastern and western part of Banding Island. The inferred lithological depth section based on the electrical properties clearly differentiates between the different types of rock. Each value of the resistivity represents the type of the material under laid the soil. The research of application of electrical resistivity imaging technique in slope stability study of granitic residual soil in Cameron Highlands, Pahang was conducted by Lau [3]. In the study, the electrical resistivity imaging technique was used in the assessment of ultimate shear strength (USS) and the dynamic cone penetration resistance (DPCR) of residual soil derived from weathering product of granitic rock. The depth and lateral extent of possible slip surface of sloping ground in main range granite especially on the cut slope, bordering the federal road in Cameron Highlands was identified.

3.0 METHODOLOGY

With regards of soil profiling, the methodology of field measurement for resistivity imaging and borehole logging are needed. The boreholes drilling were carried out earlier than resistivity tests, thus the alignment of resistivity lines were proposed based on the location of borehole points (see, Figure 1). Figure 2 shows the side view of the failure area which shows the different of heights with respect to BH7 and BH9 is 8.36m.

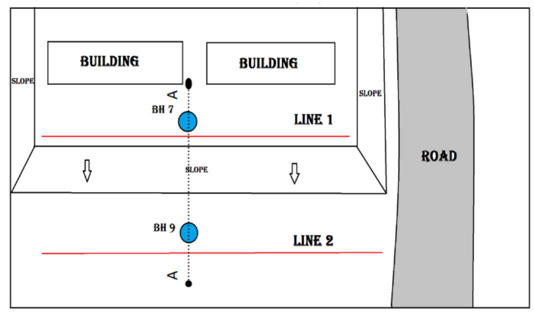


Figure 1 Plan view of the resistivity lines and borehole points arrangement

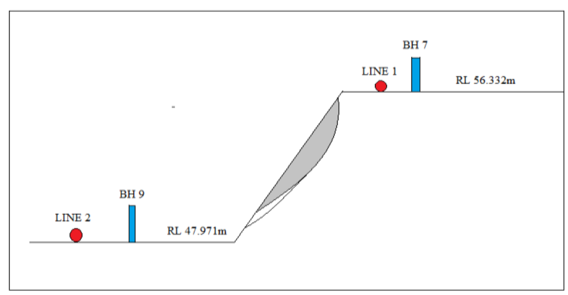


Figure 2 Side view of failure area, resistivity line and boreholes point

3.1 Electrical Resistivity Imaging Measurement

Two resistivity tests were conducted on landslide area at different slopes as shown in Figure 2. The alignments of the resistivity lines passed through borehole points. Protocol of the resistivity method used is Wenner 32 SX array. It is very suitable due to the capability of the array that able to travel up to 35m depth for 5m electrode spacing. The electrical resistivity measurement was carried out using the ABEM SAS 4000 Terrameter, and an electrode selector ES 10-64 which was connected to two multicore cables. A total of 41 stainless steel electrodes were pinned to the ground in a straight line with constant spacing and connected to 41 '*take out*' of the multi-core cables.

The main unit SAS 4000 Terrameter and Lund electrode selector ES 10-64 for resistivity recording apparatus were located at the centre of the line.

The recorded digital resistivity data was then converted to resistivity images. This process used RES2D Inversion program [4]. From these resistivity images, the soil profiles were interpreted based on resistivity value [5].

3.2 Boreholes Drilling

Boreholes drilling are conducted to determine the soil properties. Five boreholes were drilled at different locations of the slope failure area. However, only two numbers of boreholes were chosen due to the significant data observed. The BH7 and BH 9 were chosen which located near to the resistivity survey lines as in Figure 2.

4.0 RESULTS AND ANALYSIS

4.1 Resistivity Images

Results of electrical resistivity imaging surveys are presented In Figure 3 and Figure 4, respectively. The 2D resistivity images of the study area represent the soil layers underneath the cable line. Each of the colours represents the different resistivity value. The value of the resistivity image could be referred to the resistivity index [5]. The resistivity value is remarked by inverse model resistivity colours.

The resistivity image of line 1 shows that the sub-surface consists of low resistivity value with below 200ohm.m interpreted as low stiffness or loose soil. Very low resistivity (< 30ohm.m) is depicted from the depth of 12 m and below which can be interpreted as saturated soil. The saturated zone represented by blue colour is due to soil having high moisture content that reduced the resistivity value. This is the area where the slope failure was occurred.

The resistivity image of line 2 shows that the sub-surface dominantly consists of high resistivity value which is more than 400ohm.m. Consequently, the soil could be classified as stiff soil or hard material such as rock. This area is located along the toe of the slope.

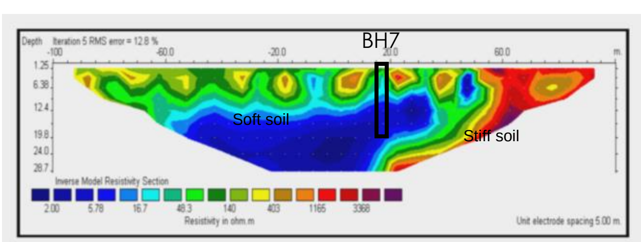


Figure 3 Resistivity image of Line 1

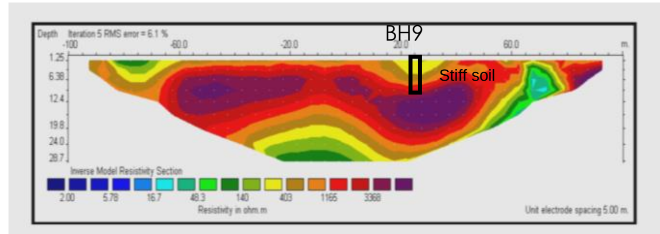


Figure 4 Resistivity Image of Line 2

4.2 Soil Properties

The engineering properties of soils were obtained from the laboratory tests and bore logs such as soil classification, STP N-value and types of soils according to depth were identified. Figure 5 shows the soil bore logs profile for BH 7 and BH 9.

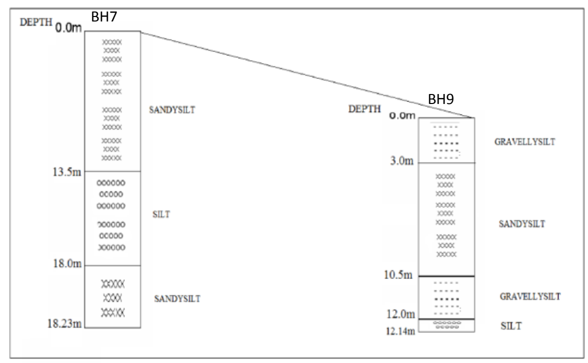


Figure 5 Generalized soil profile for cross section A-A' of BH7 and BH9

Table 1 Soil classifications of BH7 and BH9

Borehole No.	BH7					BH9			
Depth of borehole (m)	1.5	3.5	9.0	16.5	Av	3.0	6.0	9.5	Av
Clay < 0.002mm (%)	15	13	25	30	21	21	20	21	21
Silt0 002-0.063mm (%)	26	42	52	59	45	61	40	46	49
Sand 0.0063-2 mm (%)	43	26	12	21	26	18	40	29	29
Gravel (%)	16	19	11	0	9	0	0	4	1.3

Table 2 Soil moisture content on the slope between BH7 and BH9

Sample	1	2	3	Average
Moisture content (%)	41.1	45.5	46.1	44.27

Table 3 SPT,N-Value of BH7

Cumulative depth	Material description	SPT N-Value
0 – 1.5	Top soil: Brown molted red slightly sandy SILT	0
1.5 – 3.0	Soft brown slightly gravelly sandy SILT of high plasticity	3
3.0 – 3.45	Stiff brown slightly gravelly sandy SILT	10
3.45 – 4.5	Brownish yellow slightly gravelly slightly sandy SILT of high plasticity	13
4.5 – 6.0	Stiff brownish yellow slightly sandy SILT	16
6.0 – 9.0	Very stiff brownish yellow mottled red slightly sandy SILT	28
9.0 – 10.5	Hard yellow striped brown red grey slightly gravelly slightly sandy Silt of high plasticity	43
10.5 – 12.0	Hard yellow striped brown red grey slightly sandy silt	37
12.0 – 13.5	Hard grey striped brown purple slightly sandy silt	50
13.5 – 15.0	Hard yellowish brown mottled purple silt	50
15.0 – 16.5	Hard light brown mottled purple silt	50
16.5 – 18.0	Hard yellowish brown slightly sandy silt of high plasticity	50
18.0 – 18.3	Hard yellowish brown sandy silt	50

Table 4 SPT, N-Value of BH9

Cumulative depth	Material description	SPT N-Value
0 – 1.5	Top soil: Greyish brown slightly sandy slightly gravelly SILT	0
1.5 – 3.0	Very stiff grey slightly sandy slightly gravelly SILT	20
3.0 – 3.45	Grey slightly sandy SILT of intermediate plasticity	50
3.45 – 4.5	Hard brownish grey sandy SILT	50
4.5 – 6.0	Hard brownish grey sandy SILT of intermediate plasticity	50
6.0 – 9.0	Hard brownish grey sandy SILT	50
9.0 – 10.5	hard brownish grey sandy SILT	50
10.5 – 12.0	Hard grey slightly gravelly slightly sandy SILT of intermediate plasticity	50

According to Table 1, BH7 and BH9 consist of high silt content with 45% and 49%, respectively. Samples taken from failure area consist of high moisture content of 44.27% in average as shown in Table 2. The hardness of soil could be seen in Table 3. Table 4 shows the results of SPT N-Value with depth and different soil hardness. SPT N-Value is higher on depth above 9 m and 3 m for BH7 and BH9, respectively.

4.3 Comparison of Resistivity and Soil Hardness Values

A comparison of the resistivity and soil hardness was drawn as in Table 5. It shows that the resistivity value increases with the increment of soil hardness and SPT N-value.

Table 5 Classification of soil hardness based on SPT N- and resistivity values

Soil hardness	SPT N-Value	Resistivity value (Ω.m)
Soft	0-3	0-20
Stiff	3-30	20-100
Very stiff	30-50	100-400
Hard	>50	>400

5.0 DISCUSSIONS

In this study, the borehole profiling, resistivity images, resistivity and SPT N- values are presented using borehole logging and electrical resistivity imaging methods at the slope failure area.

The resistivity image of line 1 has lower resistivity value than line 2 due to the resistivity profile of failure area. This failure area has high moisture content of with 44.27%. Base on Table 3, the material is classified as soft to stiff soil with SPT N-value less than 50 from the depth of 0m to 9m. By comparing the resistivity image in line 2, we conclude that the high resistivity value obtains from the toe of the slope. This area consists of hard soil as shown in Table 4 which SPT N- value is more than 50 blows for the depth of penetration above 3m.

Therefore resistivity imaging method could be used as an investigating method to detect the slope failure area. It is also a reliable method in determining the causes of the slope failure. The moisture content has been identified as the main cause of the slope failure.

6.0 CONCLUSION

The slope failure investigation was conducted using electrical resistivity imaging as a non-destructive method and borehole drilling as a destructive method in this study.

Correspondingly, the results show a good agreement between the resistivity and bore log profiles. In light of this, the sub-surface with high resistivity values are inter-related to the hard soil as well as the low resistivity value which fit to the soft soil material. The saturated zone with high moisture content gives a significant influence on the resistivity value which caused the failure of the slope.

Conclusively, resistivity imaging method could be implemented in investigating the failure of long slope area with minimum number of borehole drilling. A reliable result on using both destructive and non-destructive methods has been obtained throughout this study.

Acknowledgement

The author would like to give an endless gratitude to institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA for the supports given in completing this study.

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