Mapping on Slope Seepage Problem using Electrical Resistivity Imaging (ERI)

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Abstract. The stability of slope may influenced by several factors such as its geomaterial properties, geometry and environmental factors. Problematic slope due to seepage phenomenon will influenced the slope strength thus promoting to its failure. In the past, slope seepage mapping suffer from several limitation due to cost, time and data coverage. Conventional engineering tools to detect or mapped the seepage on slope experienced those problems involving large and high elevation of slope design. As a result, this study introduced geophysical tools for slope seepage mapping based on electrical resistivity method. Two spread lines of electrical resistivity imaging were performed on the slope crest using ABEM SAS 4000 equipment. Data acquisition configuration was based on long and short arrangement, schlumberger array and 2.5 m of equal electrode spacing interval. Raw data obtained from data acquisition was analyzed using RES2DINV software. Both of the resistivity results show that the slope studied consists of three different anomalies representing top soil (200 – 1000 Ωm), perched water (10 – 100 Ωm) and hard/dry layer (> 200 Ωm). It was found that seepage problem on slope studied was derived from perched water zones with electrical resistivity value of 10 – 100 Ωm. Perched water zone has been detected at 6 m depth from the ground level with varying thickness at 5 m and over. Resistivity results have shown some good similarity output with reference to borehole data, geological map and site observation thus verified the resistivity results interpretation. Hence, this study has shown that the electrical resistivity imaging was applicable in slope seepage mapping which consider efficient in term of cost, time, data coverage and sustainability.
1. Introduction

Generally, soil slope was constructed based on natural or engineered civil engineering structure. Stability of slope was commonly determined by the equilibrium between shear stress and shear strength. Slope stability was relative to its geometry, geomaterial properties and external factors such as weathering, seismic activity, etc. [1] has detail up regarding factors that influence the slope stability namely support removal, overloading, transitorily effect, removal of underlying material, lateral pressure increment, nature of materials, weathering, pore pressure influences and structure changes. Specifically on water influences, continuous seepage of water from slopes may reduce the slope stability thus contributing to the slope failure. Water in slopes can be originated from surface and subsurface thru rainfall, groundwater and piping or drainage system failure. Conventional method of subsurface water detection and monitoring was based on standpipe piezometer. Standpipe piezometer was designed specifically for monitoring seepage, groundwater and pore-water pressure for slope stability evaluation. As reported by [2], standpipe piezometer can measure in-situ permeability of surrounding soil slope to determine seepage permeability calculations, detection of permeable zones and capability of geomaterials to accept remedial grouting. From past experienced, detection of seepage in soil slope experienced several limitation due to cost, time and data coverage. Installation of standpipe piezometer is quite tedious and require borehole thus consider expensive and time consuming. Borehole method will increase site damageability due to its destructive drilling process during the field measurement [3]. Moreover, standpipe piezometer only obtained seepage data specifically at its actual installation point in one dimensional (1-D) perspectives thus consider limited in data coverage. Large number of standpipe piezometer is required to obtain detail seepage data particularly at large sites thus increased the cost of the projects. Based on those scenario and constraints, conventional method in soil slope seepage mapping needs to be supported by alternative technique in order to produced comprehensive data which efficient in term of cost, time, data coverage and sustainability. As a result, the solutions to these challenges will require multidisciplinary research across the social and physical sciences and engineering [4].

In recent years, geophysical method has increasingly popular adopted in engineering and environmental studies. Basically, geophysics used to studying an earth using physics principles. Common physics principles used in geophysical method were resistivity, wave, density, magnetic susceptibility, etc. Those physics principles were used to geophysical equipment invention namely electrical resistivity, seismic, gravity, magnetic, etc. Geophysical method has widely known due to its economic, fast, large data coverage and sustainable for our environment. Geophysical method was able to map the subsurface data based on two dimensional (2-D) and three dimensional (3-D) perspectives rapidly thus consider economic when working at large sites. In the past, the application of electrical resistivity was increasingly used by engineers in SI works especially when dealing in a difficult site and due to its high efficiency of cost and operational time [5]. Moreover, the nature of indirect or surface technique (non-destructive method) used in geophysical data acquisition has contribute benefit with our environment particularly in reducing site damageability thus sustainable to our environment [6]. According to [7], geophysical method offers the chance to overcome some of the problems inherent in more conventional ground investigation techniques. Nowadays, electrical resistivity imaging (ERI) has greatly being improved in term of survey coverage, field measurement, processing techniques thus applicable to resolve complex geological structure compared to the previous sounding approach [8]. The technology of electrical resistivity method is easily mobile and fast [9]. According to [10], [11], [12] and [13], geophysical method such as the electrical resistivity can be practically adopted to determine the internal distribution of materials within a slope, identifying sliding surface geometry, water effect on slope, landslide material physical properties and mass movement. As a result, this study performed a field ERI to investigate the problematic subsurface profile with particular reference to soil slope seepage thus demonstrated the ERI prospect as a promising alternative tool in slope seepage mapping.
2. Materials and Methods

2.1 Study area and geologic setting

Study area was located at Kuantan, Pahang Malaysia. Localize topographic of studied area consist of flat, sloppy and undulating ground topography. The general geology of Malaysia has been well documented by Mineral and Geoscience Department Malaysia [14]. According to Figure 1, bedrock of the studied area was derived from volcanic rock in the era of Quaternary. Possible bedrock at study area was basalt. Localize geology of Kuantan area has been studied by Fitch [15]. According to [15], Kuantan area has been underlain by basalt which overlies and surrounds the granitic rock formation (grey porphyritic and non-porphyritic) at north and northwest of Kuantan and expand over sequence of Late Palaeozoic sedimentary volcanic rocks. Generally, the characteristics of basalt were black to greenish-black, vesicular, olivine-bearing rocks with columnar joints. Nowadays, basaltic rock along the coastal areas and towards the south in the environments of Kuantan river has been covered and widespread by alluvium. In relation to Kuantan geology, study area was located near to the Kuantan river which located on basaltic bedrock. According to the nearest existing borehole data (BH1-BH3), subsurface profile in study area consists of thick residual soils with deep bedrock. Residual soils derived from basaltic rock consist of clayey SILT, silty CLAY, sandy SILT, silty SAND with some gravel. Shallow strata (0 – 12 m depth) have been dominated by clayey SILT and sandy SILT while deeper strata have been dominated by clayey SILT, sandy CLAY, sandy SILT and gravel. SPT (N) value at shallow depth (0 – 12 m) founds to be inconsistent from soft-firm-stiff-very stiff (SPT (N) = 2 – 16). Then, stiffness consistency of soil layers at depth of 12 m and over was founds to be consistent from stiff-very stiff-hard (SPT (N) = 8 – 50). All boreholes has been terminated due to the repetitive hard layers (at least 5 times of SPT (N) = 50). Based on the physical mineralogy observation, weathered basaltic rocks have produced the developments of soil blanket and bauxite material within the existing residual soils. Approaching the ground level, residual soils composed of bauxite forms moderately hard, porous masses and commonly brick-red in colour [16]. During site observation, shallow depth of residual soil layers consists of weak and porous soil strata permitting the overflow water seepage which clearly visible in study area.

![Figure 1. Location and geology of the study area [14].](image-url)
2.2 Electrical resistivity method

Electrical resistivity imaging (ERI) was performed using the ABEM Terrameter SAS 4000, combined with ES 10-64 electrode selector. Two (2) lines of electrical resistivity were performed across the problematic study area. Testing configuration was based on Schlumberger array using four (4) resistivity land cables, sixty one (61) numbers of electrode and sixty four (64) numbers of jumper cable. Equal electrode spacing of 2.5 m was used for all 61 electrodes producing total electrical resistivity survey length of 200 m. The survey traverses were oriented west to east (Spread line 1 and 2) direction. Field arrangement and spread line alignment of the electrical resistivity imaging was given in Figure 2 and 3. Schlumberger array was used during the data acquisition since it able to provide dense near-surface cover of resistivity data. As reported by [17], the array provides a good vertical resolution and can give a clear image of groundwater and sand-clay boundaries as horizontal structures. Furthermore, greater depth of subsurface profiles within limited spaced area was able to be fulfilled using schlumberger array. Raw data obtained from data acquisition were firstly being processed using commercialize RES2DINV software of [18] to provide an inverse model that approximates the actual subsurface structure. The inversion algorithm of RES2DINV was used to process the data, as proposed by [19] in order to obtain the 2-D resistivity section.

Figure 2. Field arrangement of electrical resistivity imaging (ERI).

Figure 3. Electrical resistivity imaging (ERI) field arrangement performed at study area [20].
3. Results and Discussions

3.1 Electrical Resistivity Tomography (ERT)

The electrical resistivity survey for spread line 1 was located on the top of the slope crest while spread line 2 was located slightly lowers (2 – 3 meters or 1 number of berm heights) from the slope crest which aligned in west-east direction as shown in Figure 2. ERT for Spread Line 1 and 2: West – east alignment was performed using rolled along technique (2.5 m of equal electrode spacing) with total length of 200 m as shown in Figure 4 and 5. The penetration depth obtained was up to 35 m based on mixture of undulating and flat ground level presents at site. Generally, the ERT sections (Figure 4 and 5) obtained from the resistivity survey has revealed three types of materials namely soft layer/permeable soil with water: residual soil with highly conductive geomaterials (10 – 100 Ωm), residual soils: permeable-semi permeable to dry residual soil (1 – 150 Ωm) and dense/hard soil to weathered volcanic rocks (> 1500 Ωm).

Based on Figure 4 and 5, it was found that soil profile has been dominated by residual soils with different degree of saturation and dense/hard soil to weathered volcanic rock. Generally, this profile can be categorized into three (3) zones representing thin layer of loose to dense residual soils with moist to dry condition (200 – 1000 Ωm), residual soils with saturated condition (10 – 100 Ωm) and thick layer of dense and hard material with moist to dry condition (> 200 Ωm). Due to undulation condition, thickness of each zones was varied at 0 – 5 m (First zone), 1 – 15 m (Second zone: saturated zone) and 12 m and over (Third zone). As reported by [21] and [22], geophysical methods are unable to stand alone in order to provide solutions to any particular problems. Hence, verification of resistivity interpretation was performed by nearest available borehole data, resistivity standard values for earth materials and geological map. Moreover, site observation and mapping also indicate the resistivity results and interpretation was in good agreement thus verified the interpretation and judgment of ERT.

Based on Figure 4 and 5, soil layer with saturated condition (10 – 100 Ωm) was located at second layer beneath thin residual soil with moist to dry condition. According to Figure 4 and 5, depth (y) of resistivity center point to saturated zone head was found to be nearly 5-6 m and nearly 4 m respectively. Based on site observation, overflow seepage zone can be clearly seen at nearly 6-7 m (spread line 1) and 4 m (spread line 2) depth (y) from the center of the resistivity lines ground level (at horizontal distance, x = 100 m) thus verified the resistivity interpretation. According to [23], resistivity value for surface waters in sediments was 10 – 100 Ωm thus verified the interpretations of ERT (Figure 2). According to [24], low electrical resistivity value (ERV) will indicate the existing of the weak zone, which may contain high water content or highly conductive materials. As a result, it is possible to think that weak zone of subsurface geomaterials in natural slope is likely to show a low resistivity value due to the high conductive zone which commonly contained water [25]. According to [26], reduction of ERV may relate to increased water content that would lower the ERV of sheared materials. The nearest available borehole data has revealed that this area consists of thick soil layers from clay, silt, sand and gravel. Shallow layer (0 – 12 m) was a mixture of clay, silt and sand while deeper layer compose of clay, silt, sand and gravel. According to [1] and [27], resistivity values of clay, silt, sand and gravel was varied at 1 – 5000 Ωm thus verified the interpretation of ERT (Figure 4) in term of soil layer and its composition. Theoretically, geomaterials conductivity was highly influenced by degree of saturation. For example, wet and saturated soil may experience high electrical conductivity thus producing low resistivity value while dry materials poses low electrical conductivity thus increased the resistivity value. As reported by [28], pore fluid and grain matrix of geomaterials was able to highly influenced the resistivity value. Based on [29-32], fluctuation of basic physical properties of soil such as grain size fraction, moisture content and density can largely influenced the geomaterials resistivity value. Other than geomaterials physical and chemical properties influences, resistivity value also was influenced by geometry factor of array. [5] and [33-34] has reported that resistivity value can be varied due to the different types of array performed during the data acquisition since each array has its own geometry factor, k in calculating resistivity value.
Figure 4. Electrical resistivity tomography (ERT) for spread line 1 (West-East direction).
Figure 5. Electrical resistivity tomography (ERT) for spread line 2 (West-East direction).
4. Conclusion
The problematic slope profile due to seepage problem was successfully being investigated using electrical resistivity imaging (ERI). Based on ERT analyzed, problematic slope due to the overflow seepage problem was detected at depth of 6 - 7 meter (spread line 1) and 4 meter (spread line 2) from ground level of center of the resistivity line 1 and 2 respectively. The geometry and electrical resistivity anomaly distribution has been determined by analyzing ERI data obtained along the seepage zones and the result has shown a good correlation with physical mapping. This finding has proved that this approach was applicable to detect slope seepage in order to assist the conventional method. ERI was successfully mapped the slope seepage which able to extend the surface information observed during the physical mapping. The mechanics and physical characteristics of slope seepage can be easily recognized. The determination of shape and depth of the subsurface weak material which promote the slope instability are easier and cheaper than with the conventional standpipe piezometer method. The information from the ERI was useful as a decision making regarding the most suitable rehabilitation and mitigation approach which may applied afterward. This geophysical method is suitable for our sustainable slope seepage assessment since its ability to reduce time, cost and compliment others conventional method especially by its 2-D surface technique of investigation.

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