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Interpretation of 2D Resistivity with Engineering Characterisation of Subsurface Exploration in Nusajaya Johor, Malaysia

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Abstract. 2-D resistivity technique and pole-dipole array with spacing of 2 m electrode and total spacing of 80 m were adopted to map and characterize the shallow subsurface in a sedimentary area at Nusajaya, Johor. Geological field mapping and laboratory testing were conducted to determine weathering grades. Res2Dinv software was used to generate the inversion model resistivity. The result shows sandstone contains iron mineral (30-1000ohm-m) and weathered sandstone (500-1000 ohm-m). The lowest layer represents sandstone and siltstone with the highest range from 1500 through 5000 ohm-m. The weathering grade IV and V of sandstone in the actual profile indicates the range from 30 to 1000 ohm-m, whereas grade II and III in ground mass matched the highest range. Overall, the increase of weathering grade influenced both the physical properties and strength of rocks.

1. Introduction

Subsurface exploration in engineering projects require a comprehensive geotechnical assessment in determining the site behaviour, depth to bedrock, overburden materials and near surface structures such as sinkholes, cavities, voids, faults and boulders. It can be divided into direct assessment and indirect assessment. Direct assessment such as geotechnical and geological techniques can be applied simultaneously with indirect assessment like geophysical method in order to ease the process of subsurface exploration with low cost and effective method. Since geophysics in civil engineering is an application of the principles of geophysics and methods to measure the subsurface characteristics and properties, the techniques were used to establish ground profile for the engineering and development purposes. Behaviour of subsurface in weathered rock mass is complex dependent upon numerous aspects. In addition, the weathered rock mass in tropical region has very thick profile more than 50 m [1]. Some deterioration and weathering can be seen at unweathered to slightly weathered rocks that located near the ground surface or along fractures². Furthermore, due to the differences of climate environment where heavy rain pours conditions, wide variation of temperature and high humidity along the year especially in Malaysia, the weathering grades and zone beneath ground surface is difficult to be evaluated and identified. Therefore, the understanding of the nature of rock type and its weathering profile is crucial and very significant in site investigation processes. This study focus on sedimentary area where the occurrence of discontinuity such as bedding thickness, folding, foliation



and the inhomogeneity of rocks can manipulate its physical and mechanical properties.

2. Regional Geology

The field studies are done at SiLC (Southern Industrial and Logistics Clusters) Nusajaya Johor which located at south-western tip of Peninsular Malaysia. The survey area is underlain by sedimentary rock consists of sandstones, siltstones, clay and shale. Quartz mineral normally forms as the main component in many rock types. Somehow, granitic parentage of the materials does contain imperative amounts of feldspar in some places. Materials undergo leaching and weathered to clay. In places thin beds of clay are found intercalated with the sand. For the most part the sand is of white, cream, buff, or pale-yellow colour, with only minor dark-brown to black variations. Generally the colour index is directly related to the clay content, whether this is due to the presence of organic matter or to iron staining. The dark-brown to black colours could be due to the presence of organic matter, or may possibly be a result of leaching and redeposition of oxides of iron, alumina at lower levels³.

3. Methodology

This study was carried out at an outcrop in Southern Industrial Logistic Cluster (SiLC) Nusajaya, Johor consisted of sandstone and siltstone. Weathering classification of each type of materials is determined based on Figure 1 which was established by Ibrahim Komoo [1]. Samples were collected and brought back to laboratory for measuring the parameters such as moisture content, density, point load test, slake durability and hardness in accordance to ISRM [4]. Grain size classification was conducted based on British Standard Methods of Test for Soils for Civil Engineering Purposes [5] as in Table 1. Electrical resistivity method was applied in the field to evaluate the geological data and the geophysical interpretation. Table 2 shows the resistivity value of some common rocks and soils⁵.

Table 1. Grain size classification [5].

Description	Size (mm)	Recognition	Equivalent Soil Type	Equivalent Rock Type
Very Grained	< 0.06	Individual grains cannot be seen with a hand lens	Clays & Silts	Claystone & Siltstone
Fine Grained	0.06 – 0.2	Just visible as individual grains under hand lens	Fine sand	Sandstone
Medium Grained	0.2 – 0.6	Grains clearly visible under hand lens, just visible to naked eye	Medium sand	Sandstone
Coarse Grained	0.6 – 2.0	Grains clearly visible to naked eye	Coarse sand	Sandstone
Very Coarse Grained	>2.0	Grains measurable	Gravel	Conglomerate

Table 2. Resistivity values of common rocks and soil materials [6].

Material	Resistivity (ohm-m)
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	$8 - 4 \times 10^3$
Shale	$20 - 2 \times 10^3$
Limestone	$50 - 4 \times 10^3$
Granite	5000 to 1,000,000

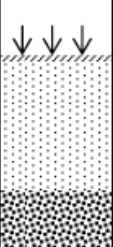
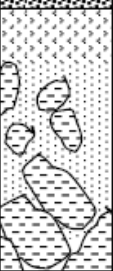
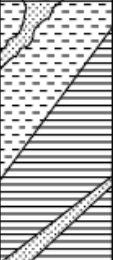



Classification	Weathering Zone	Log	Description
Residual Soil	VI		Upper Soil All rock materials changed into soil. No texture or rock mass structure preserved. Homogenic.
Completely Weathered	V Vc Vb Va		Zone is rich in Iron Concretion. Unclear texture, less than 25% preserved fabric. Preserved structure. Whole materials changed to soil. Stained. Whole Materials changed into soil. Reddish color, Stained with original material 25-75% fabrics are preserved. Materials disintegrate in water or crushable by hand.
Highly Weathered	IV IVb IVa		Materials changed into soil preserving original color and textures. >75% preserved texture, easy to disintegrate in water and crushable by hand. Slaking. Material is in transition to IVb condition. Texture & structure intact. Small fragments formed when crush in hand or immerse in water. Geology Hammer does not rebound
Moderately Weathered	III		Color changes in all earth materials (original color increases). Whole texture & structure of rock mass unchanged. Edges of rock material are hard to break by hand. Schmidt Hammer average value is less than 30. Geology Hammer rebounds by hit but does not rings, discontinuity filled with iron oxide.
Slightly Weathered	II		Slightly changes of color in material. Most materials are still fresh. Changes of color on discontinuity clearly exceed 1cm. Schmidt Hammer average value is more than 30. Geology Hammer rebounds and rings. Discontinuity spacing is filled with iron oxides.
Fresh Rocks	I		No changes of forms or color in earth materials. Slightly or no iron stains in discontinuity spacing. Geology Hammer rebounds and rings on hit.

Figure 1. Weathering profile classification of rock mass [1].

In this study, 2-D resistivity imaging method is deployed in order to gain continuous and precise information of subsurface in different representative geological situations, and for evaluating the behaviour by the interpretation methods. Outcrop of the site are compared to the 2D profiling to gain the subsurface structures in natural geological environments. The data obtains from resistivity method are combined with the analysis of geotechnical site evaluation and some laboratory data. Throughout the study, 2-D profiling with Pole-dipole array [7] is adopted for this study due to the good horizontal and vertical resolution in as carried out by Nordiana et al.[8]. Pole-Dipole array are used in this study because it has comparatively good horizontal coverage, significantly higher signal strength compared with the dipole-dipole array and it is not as sensitive to telluric noise as the pole-pole array. Different from other common arrays, the pole-dipole array is an asymmetrical array (Figure 2a) and over symmetrical structures the apparent resistivity anomalies in the resistivity section are asymmetrical. In some situations, the asymmetry in the measured apparent resistivity values might influence the model obtained after inversion. One method to eliminate the effect of this asymmetry is to repeat the measurements with the electrodes arranged in the reverse manner (Figure 2b). By combining the measurements with the “forward” and “reverse” pole-dipole arrays, any bias in the model due to the asymmetrical nature of this array would be removed.

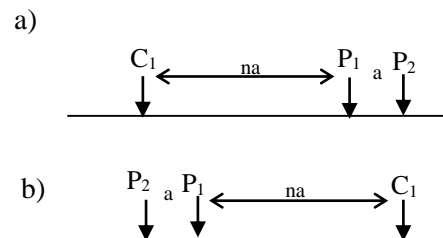


Figure 2. Arrangement of resistivity technique: a) pole-dipole, and b) reverse pole-dipole [6].

Results from the laboratory tests were analysed and their relation with the weathering grade and 2-D profiling result were established. 2D resistivity survey was conducted using ABEM SAS4000 Terrameter with ES10-64C selector, smart cables with 5m takeouts and stainless steel electrodes. A survey line was conducted at the study area. The survey used Pole-dipole array with 2 m spacing between electrodes. After the data acquisition, the processing was done using Res2Dinv software. The measured data was inverted to resistivity image to simplify the interpretation of the result. Some gridding and contouring was done to the data based on actual site condition. Subsurface outcrop was map by using Surfer software.

4. Result and Discussion

The result of weathering grade is presented with inversion resistivity profile (Figure 3) trends South-North direction to a length of 80 m and imaging depths of 15m. The interpretation of the resistivity image was corresponded to the actual rock mass profile. It was found that the ground mass was classified from grade II to grade V sandstone and grade III siltstones, which was from moderately to completely weathered materials. This weathering classification was indicated by in situ observation on the mass. The grain size and mass hardness was done and the results are tabulated below (Table 3). The result shows increase value of 6-30 MPa with decrease weathering grade.

The inversion model resistivity displays upper part as sandstone contains iron mineral (30-250 ohm-m) and weathered sandstone (500-1000 ohm-m) alternately. The lower part of the layer represents sandstone and siltstone exhibit high resistivity values of 1500-5000 ohm-m. The range from 30- 1000 ohm-m correspond to the grade IVa, IVb and V of sandstone in the actual profile as shown in Figure 3.

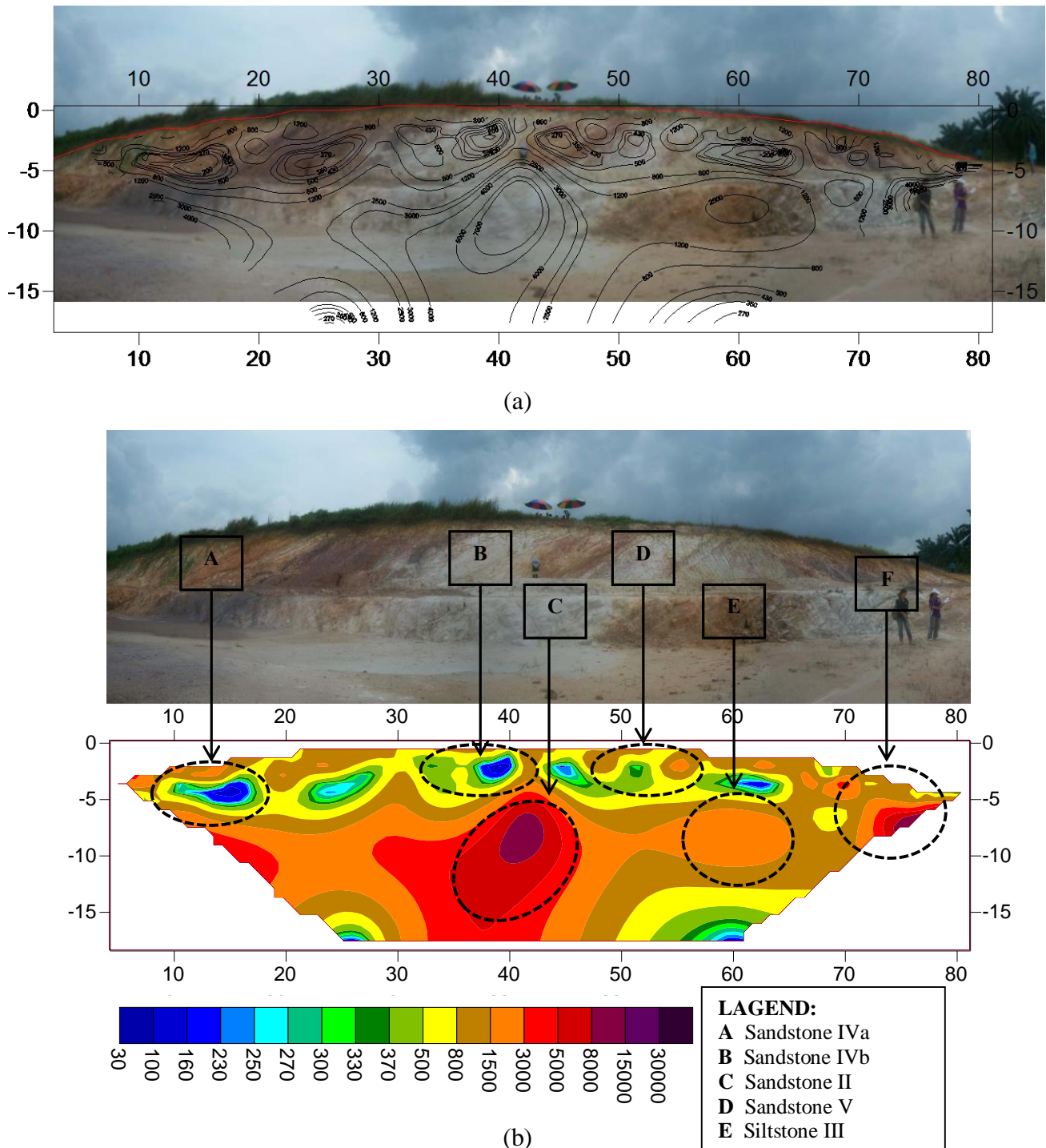


Figure 3. Result from resistivity analysis: a) Outcrop of study area with inversion model resistivity at Nusajaya, Johor, and b) correlation between resistivity value and rock types.

Meanwhile, the high range of the resistivity value matched the material with weathering grade II and III in ground mass. The data show wide range of value was because the ground mass comprises of different type of rock. The results somehow have shown a good agreement, whereby the resistivity profile and actual ground mass profile matched each other.

Table 3. Summary result of weathering grades and laboratory test.

Weathering Grade	Grain Size	Water Content (%)	Dry Density (g/cm ³)	Schmidt Hammer (MPa)	Point Load I _{s(50)}	Slake Durability Id ₂ (%)
Sandstone II	Fine	0.19	2.24	30	4.726	90.67
Sandstone III	Fine	0.33	2.19	24	3.552	87.73
Sandstone IVa	Medium	2.05	2.13	14	2.146	57.40
Sandstone IVb	Medium	2.72	2.05	14	1.858	45.32
Sandstone V	Fine	9.63	2.32	6	0.765	29.04
Siltstone III	Very Fine	3.45	2.54	8	1.543	38.65

From the laboratory testing, the average value of each test was recorded. The dry density of each sample is not drastically different in the range of 2.05-2.54 kg/m³. Schmidt hardness, point load strength and slake durability displays decrease value of increase weathering grade. The deterioration of most physical properties was associated with the increase number of weathering grade.

5. Conclusion

The ground mass have been characterised by resistivity interpretation result and laboratory data. Clearly, the relationship between weathering grade and their properties are vital in order to predict the performance of the subsurface material. The interpretation of the resistivity result can ease the process of site investigation in civil engineering works.

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