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Application of Geoelectrical Resistivity Imaging for Site Investigation

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Abstract

Two dimensional geoelectrical resistivity imaging has the ability to image the subsurface by analysing the resistivity distribution within the earth. It provides general information on subsurface geological strata and the depth to the bedrock below the lines of traverse. The resistivity imaging surveys carried out basically measures and maps the resistivity of subsurface materials. The resistivity anomalies may indicate the presence of geological features, which may introduce geotechnical hazards in an area planned for development. This paper briefly describes some results of geoelectrical resistivity imaging surveys to assist in understanding the underground conditions at three development sites in Malaysia. The surveys were conducted using the ABEM SAS300C terrameter with LUND ES464 electrode selector system. The resistivity imaging surveys in these studies were used to investigate the occurrence of sinkholes and cavities in the limestone bedrock, to help in delineating the bedrock profile at the development sites and to characterise the weathering profile of a quartz mica schist slope cut at km 67 of the east west highway, north of Peninsular Malaysia.

Aplikasi Imej Kerintangan Geoelektrik Untuk Penyiasatan Tapak

Abstrak

Imej kerintangan geoelektrik dua dimensi berupaya menggambarkan subpermukaan melalui penganalisisan sebaran kerintangan dalam bumi. Ia memberikan maklumat asas tentang jujukan geologi subpermukaan dan kedalaman lapisan batuan yang berada di bawah rentasan. Survei imej kerintangan dilakukan untuk mengukur dan memetakan kerintangan bahan subpermukaan. Anomali kerintangan boleh mengenalpasti kehadiran fitur geologi yang boleh menyebabkan bencana geoteknikal di dalam kawasan pembangunan. Kertaskerja ini mengulas sedikit hasil tinjauan imej kerintangan geoelektrik yang digunakan untuk memahami keadaan bawah permukaan di tiga kawasan pembangunan di Malaysia. Tinjauan ini dilakukan mengunakan ABEM SAS300C terrameter dengan LUND ES464 sistem pemilih elektrod. Tinjauan imej kerintangan dalam kajian ini digunakan untuk menyiasat kehadiran lubang benam dan kaviti dalam batu kapur untuk mengambarkan profil batuan dasar kawasan pembangunan dan untuk mengelaskan profil luluhawa potongan cerun syis kuarza mika di km 67 Lebuhraya Timur-Barat, Utara Semenanjung Malaysia.

INTRODUCTION

Geoelectrical resistivity methods were developed in the early twentieth century but have been more widely used since the 1970s. These techniques are used extensively in the search for suitable ground water sources and also to monitor types of groundwater pollution. In engineering surveys the technique is used to detect underground cavities, faults and fissures, mineshatfs etc. and in archaeology for mapping out the areal distribution of buried foundations of ancient building (Reynolds, 1997).

The geoelectrical resistivity techniques are both non-invasive and non-destructive. These techniques can be deployed rapidly and cost effectively, and have the ability to locate significant subsurface geological structures (Griffith and Barker, 1993). This paper describes some results of resistivity imaging surveys conducted to delineate subsurface topography and geological structures of limestone bedrock as well as to characterise the weathering profile of a quartz mica schist slope cut at km 67 of the east west highway, north of Peninsular Malaysia.

MATERIAL AND METHOD

The resistivity method basically calculates the resistivity distribution of the subsurface materials. Table 1 shows the resistivity and conductivity values of some typical rocks, soils and water (Keller and Frischknecht, 1966 and Daniels and Alberty, 1966).

Igneous and metamorphic rocks normally have high resistivity values. The resistivity is mainly dependent on the degree of fracturing which are commonly filled with groundwater. The greater the degree of fracturing, the lower is the resistivity value of the rock. Sedimentary rocks on the other hand, generally have higher porosities than igneous and metamorphic rocks, so they usually have lower

Table 1: Resistivity and conductivity values of rocks, soils and water.

Material	Resistivity (ohm-m)	Conductivity (ohm-m) $^{-1}$
Igneous and Metamorphic Rocks		
Granite	$5 \times 10^3 - 10^6$	$10^{-6} - 2 \times 10^{-4}$
Basalt	$10^3 - 10^6$	$10^{-6} - 10^{-3}$
Slate	$6 \times 10^2 - 4 \times 10^7$	$2.5 \times 10^{-8} - 1.7 \times 10^{-3}$
Marble	$10^2 - 2.5 \times 10^8$	$4 \times 10^{-9} - 10^{-2}$
Quartzite	$10^2 - 2 \times 10^8$	$5 \times 10^{-9} - 10^{-2}$
Hornfels	$8 \times 10^3 - 6 \times 10^7$	$1.7 \times 10^{-8} - 1.3 \times 10^{-4}$
Sedimentary Rocks		
Sandstone	$8 - 4 \times 10^3$	$2.5 \times 10^{-4} - 0.125$
Shale	$20 - 2 \times 10^3$	$5 \times 10^{-4} - 0.05$
Marls	3 - 70	$1.4 \times 10^{-2} - 0.3$
Limestone	$50 - 4 \times 10^2$	$2.5 \times 10^{-3} - 0.02$
Soils and water		
Clay	1 -100	0.01 - 1
Alluvium	10 - 800	$1.25 \times 10^{-3} - 0.1$
Groundwater (fresh)	10 - 100	0.01 – 0.1
Sea water	0.15	6.7

resistivity values especially when saturated with groundwater.

Wet soils and fresh groundwater generally have low resistivity values. The resistivity of fresh groundwater depends on the concentration of dissolved salts. It varies from 10 to 100 Ωm, which is well above the resistivity of saline water that has very low resistivity (< 1 Ωm) due to the high salt content.

The geoelectrical imaging survey was carried out using the ABEM SAS300C terrameter and an electrode selector ES464, which are connected to a total of 60 electrodes laid out in a straight line with constant spacing via ABEM Lund multicore cables. A computer-controlled system was used to automatically select the active electrodes used for each measurement (Griffiths *et al.*, 1990). The data collected was interpreted using a 2D inversion programme (Loke and Barker, 1996).

The resistivity imaging surveys were conducted at three development sites . The first site is at an old police quarters of Bau, Sarawak, which was abandoned due to the problem of subsidence over limestone bedrock. The resistivity imaging survey at the second site was to investigate the profile of limestone bedrock at the construction project site of a proposed Public Park near Gunung Lang, Ipoh, Perak. The main objective was to determine whether the piles for the site foundation are actually lying on stable limestone bedrock. The resistivity survey at the third site was used to characterise the weathering profile of a quartz mica schist slope cut at km 67 of the east west highway, north of Peninsular Malaysia.

RESULTS AND DISCUSSIONS

Figure 1 shows a map of the police quarters and location of the resistivity imaging lines. The resistivity inverse models (Figure 2) show that the limestone has relatively high resistivity values (200-600 Ωm) with several anomalous zones of low resistivity. These low resistivity zones are interpreted to be associated with shallow cavities and sinkholes in the bedrock, which have caused subsidence problems in the study area. The resistivity sections generally indicate that the limestone in the area under investigation is partly cavernous in nature and is saturated with groundwater (1-100 Ωm).

The interpretation of the resistivity profile for the second site was based on borehole data, which shows that the depth of the limestone bedrock at the resistivity station is about 6.0m below surface. The interpreted resistivity inverse model indicates a distinct boundary at the depth of about 6.0m between the top of the limestone bedrock and the alluvial sediment above it (Figure 3). The soft sediment, which covers the limestone bedrock has low resistivity values ranging from 2.0 ohm.m to 181 ohm.m. Relatively high resistivity values (>181 Ωm) for the lower layer of the resistivity section is interpreted to be the weathered fractured limestone bedrock. A regular and almost horizontal resistivity contour was observed in the section suggesting that the topography of the bedrock along the resistivity line is relatively flat. Field observation at the site shows that the driven piles in the area has resulted in almost similar lengths (15 feet) along the surveyed line, which confirms

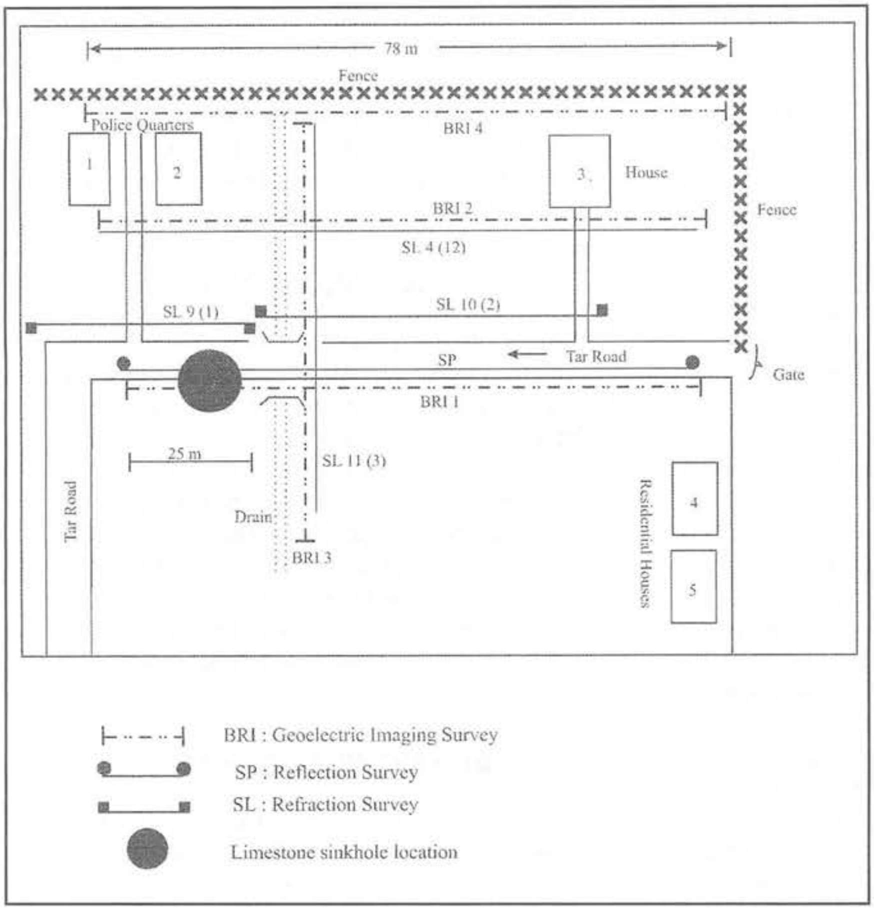

Figure 1: Map showing the locations of resistivity imaging lines at the police quarters area of Bau, Sarawak.

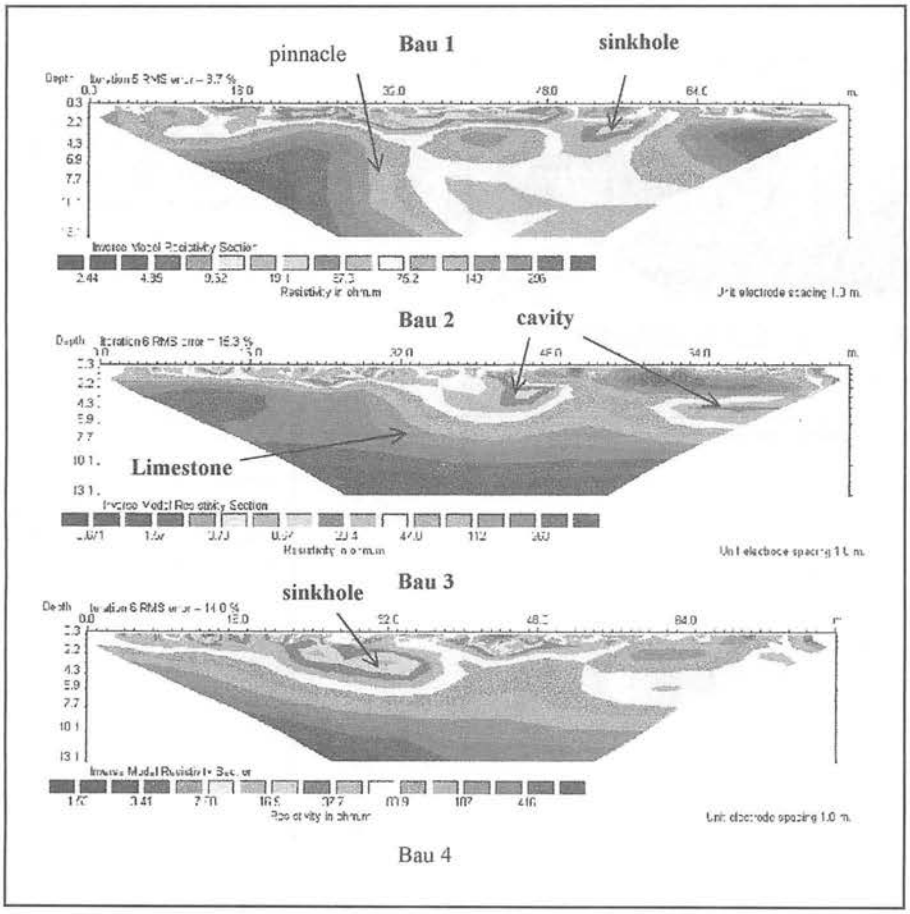

Figure 2: Resistivity inverse models showing locations of sinkhole and cavity.

that the limestone bedrock has regular or flat surface bedrock.

The geoelectrical resistivity imaging was performed to characterise the weathering profile of a quartz mica schist slope cut at km 67 of the east-west highway, north of Peninsular Malaysia. The geoelectrical resistivities of the rock mass were measured along several terraces of the slope cut. Subsurface variation of the measured resistivities were used to establish qualitative correlation between these parameters with the weathering grade of the rock mass, which was established based on the weathering index of the International Association of Engineering Geology and the Environment (IAEG, 1981).

The weathering profile of the quartz mica schist slope cut is shown in Figure 4. Figure 5 shows the resistivity inverse models for the sections along terrace 7 and 4, which includes weathered rock mass from index 1 to 5. The bulk resistivity of index 6 weathering profile gives values ranging from 200 Ωm to 1300 Ωm, whereas for index 4 and 5, the resistivity values appear to be high (1500 Ωm to 5000 Ωm). Moderately weathered rock of index 3 has resistivity values ranging from 5000 ohm.m to 8000 Ωm. Index 1 and 2 which represents the fresh rock could be correlated with a very high range of resistivity values (>8000 Ωm). However, certain sections of the slope face of the fresh rock were observed to be more fractured, which explains the occurrence of localised regions with relatively low resistivities. This zone of low resistivity is possibly associated with the fractured part of the rock mass with significant water accumulation. The results show that the geoelectrical resistivities could be used to map different grades of weathered rock mass and other geological structures related to a slope cut problem. The data can be used for rock characterization and for the development of new methods to keep pace with the increasingly difficult nature of slope cut failure problem.

CONCLUSIONS

Results of the resistivity studies indicate that the imaging technique can be successfully used to map subsurface geological structures of limestone bedrock at development sites. The imaging technique can also become more useful if the measured parameters could be correlated with geotechnical parameters and changes in those parameters can be estimated by the proper combinations of field procedures. Nevertheless, the complexity of subsurface geological structures within the limestone bedrock requires an integrated approach of investigation where drilling and careful application of suitable geophysical techniques are necessary.

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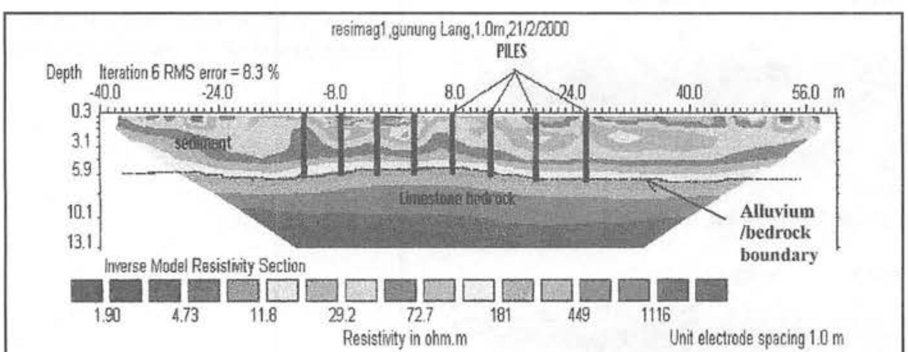

Figure 3: Resistivity inverse model showing location of piles resting on a regular and almost flat subsurface topography of limestone bedrock.

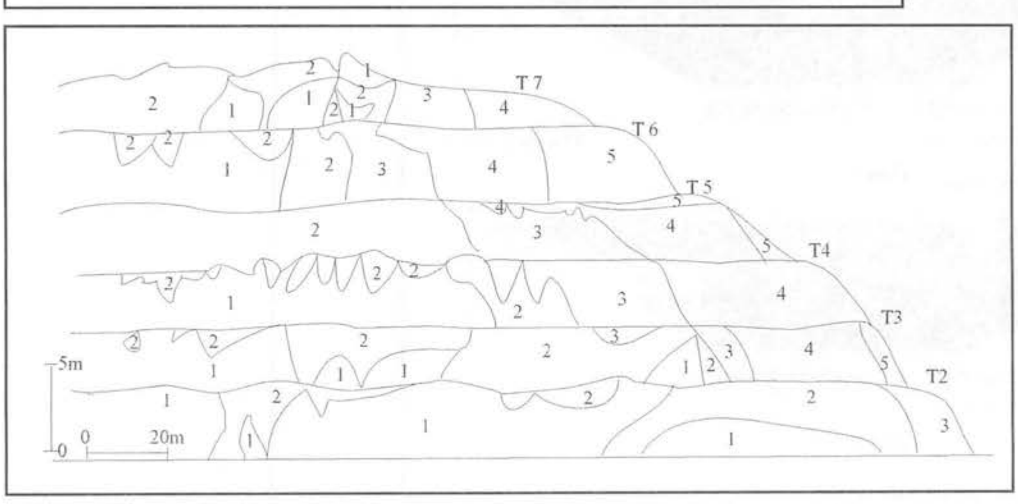

Figure 4: Weathering profile index of quartz mica schist slope cut at km 67, Grik-Jeli highway, Perak.

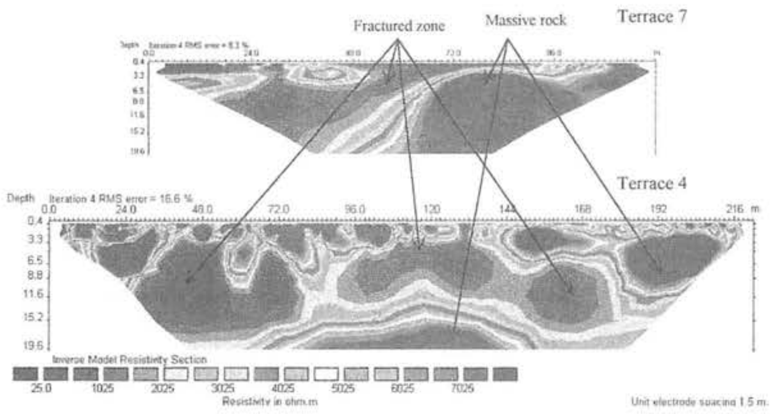

Figure 5 : Inverse model resistivity sections showing distribution of true resistivity with depth for terrace 4 and 7.

Figure 5: Inverse model resistivity sections showing distribution of true resistivity with depth for terrace 4 and 7.

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