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In situ measurement of geoelectrical resistivity in relation to weathering profile of a sedimentary rock mass at Lubuk Paku, Pahang: A case study

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Abstract: 2-D geoelectrical resistivity imaging using the Wenner configuration was conducted to investigate the weathering profile of a sedimentary rock cut slope at Lubuk Paku, Pahang. The rock which belongs to the Tembeling Formation was cut into three terraces and it consists of, from bottom to top, thick layers of basal conglomerate, massive pebbly sandstone and highly weathered shale. The resistivity imaging results show that the rock cut slope can be characterised into several zones of low, moderately low, moderately high and high resistivities. The low resistivity zone which has resistivity values ranging from 150 to 500 Ωm is associated with the residual soil with high water content. It is classified as grade VI according to the IAEG (1981) weathering index with an average layer thickness of about 1.8 m. A moderately low resistivity zone with weathering index of grade V shows resistivity values ranging from 650 to 800 Ωm. This layer appears to have low water content and its thickness varies from 1.1 to 1.7 m. Weathered rock material of grade IV shows resistivity values ranging from 800 to 1200 Ωm. A zone of moderately high resistivity is represented by the weathered rock mass of grade III. The resistivity value for this particular zone is relatively high and ranges from 1232 to 2000 Ωm. This zone is dominated by a slightly weathered layer of pebbly sandstone. A slightly weathered rock of grade II represents the high resistivity zone with values ranging from 2000 to 3000 Ωm. This zone is correlated well with the massive and solid rocks of basal conglomerate and pebbly sandstone. The results of the present study illustrate empirically that the geoelectrical resistivity values decrease as the weathering grades of the rock material increase. The presence of discontinuities and fractures in the rock mass appears to have lowered the overall resistivity of the rock mass. This empirical correlation could be used to map zones of different grades of weathered sedimentary rock mass and to study other subsurface geological structures related to slope cuts.

Abstrak: Survei pengimejan keberintangan geoelektrik dengan menggunakan susunatur Wenner telah dijalankan untuk mengkaji profil luluhawa potongan cerun batuan sedimen di Lubuk Paku, Pahang. Cerun batuan sedimen Formasi Tembeling ini telah dipotong kepada tiga teres dan batuan ini, dari bawah ke atas, terdiri daripada lapisan batuan konglomerat basal, batu pasir berpebel massif dan syal terluluhawa. Imej keberintangan yang dihasilkan menunjukkan jasad batuan di cerun kajian boleh dikategorikan kepada zon keberintangan rendah, sederhana rendah, sederhana tinggi dan tinggi. Zon keberintangan rendah yang berjulat daripada 150 hingga 500 Ωm. adalah berasosiasi dengan tanah baki sedimen yang lembab. Tanah ini dikelaskan sebagai bahan bergred VI mengikut pengelasan IAEG (1981) dengan ketebalan purata 1.8 m. Zon berkeberintangan sederhana rendah yang diwakili oleh bahan bergred V menunjukkan julat keberintangan 650 - 800 Ωm. Lapisan ini mempunyai ketebalan sekitar 1.1 ke 1.7 m dan kurang mengandungi air. Bahan terluluhawa bergred IV mempunyai nilai keberintangan daripada 800 ke 1200 Ωm. Zon berkerintangan sederhana tinggi diwakili oleh bahan bergred III. Nilai keberintangan bahan ini relatif tinggi dengan julat 1232 ke 2000 Ωm. Zon ini didominasi oleh lapisan batu pasir berpebel yang sedikit terluluhawa. Jasad batuan gred II yang sedikit terluluhawa mewakili zon berkeberintangan tinggi dengan julat daripada 2000-3000 Ωm. Zon ini boleh dikorelasikan dengan jelas terhadap batuan dasar konglomerat serta batu pasir massif. Hasil kajian yang diperolehi menunjukkan secara empirikal bahawa nilai keberintangan geoelektrik menurun dengan kenaikan gred luluhawa jasad batuan. Kehadiran fitur ketakselanjaran dan retakan juga didapati merendahkan keseluruhan nilai keberintangan dalam jasad batuan. Korelasi empirical yang diperolehi ini boleh digunakan untuk pemetaan zon-zon gred luluhawa batuan sedimen dan mengkaji struktur geologi bawah permukaan yang berkaitan dengan cerun potongan.

INTRODUCTION

Rapid developments of computer and electronic-based technologies have encouraged the application of several geophysical techniques for civil engineering works. These techniques are able to give extensive coverage of a site for relatively low cost, enabling details of subsurface structure to be established prior to the use of conventional borehole drilling. Drilling is rather expensive and only gives information for a particular point or location. Information between the boreholes is merely based on interpolation and lithological correlation.

Two-dimensional (2-D) geoelectrical resistivity imaging is a geophysical technique recently developed to investigate areas of complex geology where the use of resistivity sounding and profiling is inadequate (Griffiths and Barker, 1993). The imaging surveys can give results that are more accurate than any other geophysical survey. The seismic method for example can map an undulating interface well, but will have difficulty (without using advanced data processing techniques) in mapping discrete bodies such as boulders. Abdul Rahim Samsudin *et al.* (1999) had successfully studied the weathering profile of a metamorphic rock cut slope at km 67 of the Grik - Jeli highway, using the 2-D resistivity imaging and seismic refraction techniques. The resistivity technique was also used to investigate the subsurface structure of karstic limestone in the Bau area, Sarawak (Abdul Rahim Samsudin *et al.*, 2000) and to detect subsurface boulders of granite (Mohd Nawawi Mohd Nordin and Agnelo Alphonse, 2000).

This paper describes the results of the resistivity imaging surveys conducted to study the characteristics of the 2D subsurface resistivity images in relation to the weathering profile of a sedimentary rock cut slope located at the Maran - Lubuk Paku road, Pahang. The sedimentary rock is classified as the Tembeling Formation of Jurassic age and it consists of, from bottom to top, thick layers of basal conglomerate, massive pebbly sandstone and highly weathered shale. Detailed geology of the study area can be found in reports by Hamzah Yunus (1976), Abd Rashid Ahmad (1985) and Wong (1997).

MATERIAL AND METHODS

The weathering characterisation of the sedimentary rock cut slope was studied based on the International Association of Engineering Geology's (IAEG, 1981) weathering index . Profiles showing distribution of rock mass with different weathering grades were established for all the three terraces investigated. These profiles were then used to obtain empirical correlation with the corresponding geoelectrical resistivity sections measured along the same terraces.

The resistivity survey was carried out with an ABEM SAS300C resistivity meter and LUND ES464 electrode selector system. Measurement of ground resistivity involves passing an electrical current into the ground using a pair of steel electrodes and measuring the resulting potential difference within the subsurface using a second pair of electrodes. These are normally placed between the current electrodes. Unlike conventional resistivity sounding and lateral profiling surveys, 2-D resistivity imaging is a fully automated technique that uses a linear array of up to 80 electrodes connected by a multicore cable. The current and potential electrode pairs are switched automatically using a laptop computer and control module (ES464) connected to ground resistivity meter (SAS300C) that provides the output current. In this way a profile of resistivity against depth ('pseudosection') is built up along the survey line. Data were collected by automatically profiling along the line at different electrode separations. The computer initially keeps the spacing between the electrodes fixed and moves the pairs along the line until the last electrode is reached. The spacing is then increased by the minimum electrode separation (the physical distance between electrodes which remains fixed throughout the survey) and the process repeated in order to provide an increased depth of investigation.

The maximum depth of investigation is determined by the spacing between the electrodes and the number of electrodes in the array. For a 80 electrode array with an electrode spacing of 1.5 m this depth is approximately 18 m. However, as the spacing between the active electrodes is increased, fewer and fewer points are collected at each 'depth level'. A 'roll-along' technique of investigation was also employed in order to build up a longer pseudosection. The raw data is initially converted to apparent resistivity values using a geometric factor that is determined by the type of electrode configuration used. Once converted the data is modelled using a least squares inversion programme (Loke and Barker, 1995) in order to calculate a true resistivity versus depth pseudosection.

RESULTS AND DISCUSSION

Detailed field observation shows that slightly fresh rock materials are mainly found at the lower terrace of the cut slope (Terrace 2 and 3) and they are classified as Grade II, Grade III and Grade IV. The soil materials of grade V and VI are mostly found at the top terrace (Terrace 4) of the slope.

A total of three resistivity lines (i.e. one line for each terrace) were established. Resistivity coverage for the top terrace (Terrace 4) is about 60 m wide and for the middle terrace (Terrace 3), the maximum length of the resistivity section is 100 m. The lowest terrace (Terrace 2) has the longest resistivity line with a total coverage length of 140 m.

Terrace 2

The weathering profile of the rock mass section at Terrace 2 and its relationship with its corresponding resistivity inverse section is shown in Figure 1. In general the resistivity section shows good correlation with the corresponding weathering profile. The zone of high resistivity (>2000 Ωm) correlates well with the exposed rock mass of grade II. A moderately high resistivity (1740 Ωm – 2000 Ωm) is associated with that of grade III material. A thin layer of grade IV material with resistivity ranging from 932 Ωm to 1740 Ωm occupies the top part of the terrace. The wide range of resistivity values is interpreted as being due to the heterogeneous nature of the rocks and the presence of discontinuity structures in the rock mass. Grade V soil material shows relatively low resistivity values which range from 143 Ωm to 900 Ωm.

Terrace 3

This terrace has zones of weathered rock material of grade II, grade III, grade IV and grade V (Figure 2). Grade II material is represented by a high resistivity anomaly of

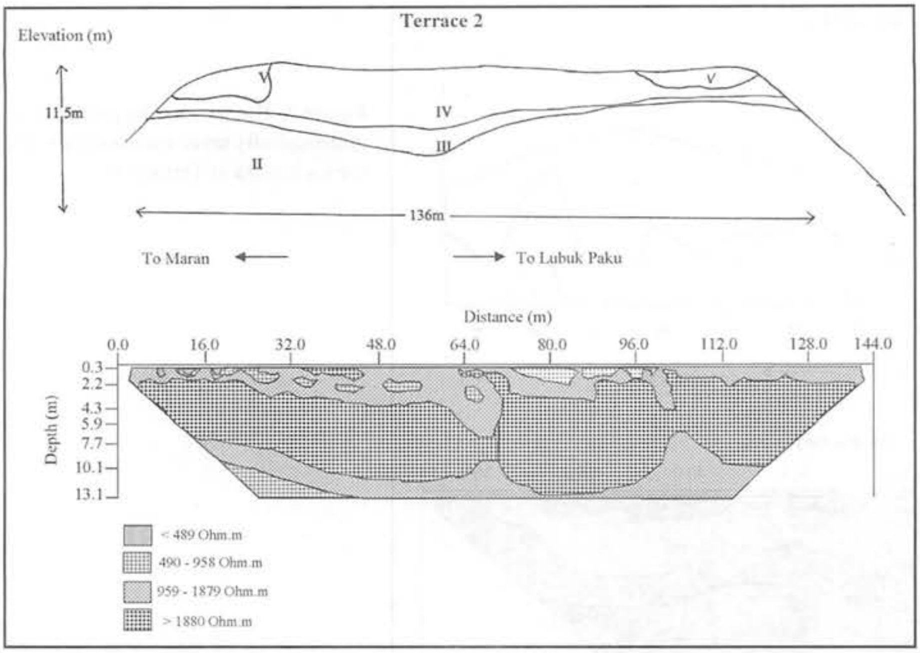

Figure 1. The weathering profile (top) and resistivity inverse section (bottom) for rock mass at Terrace 2

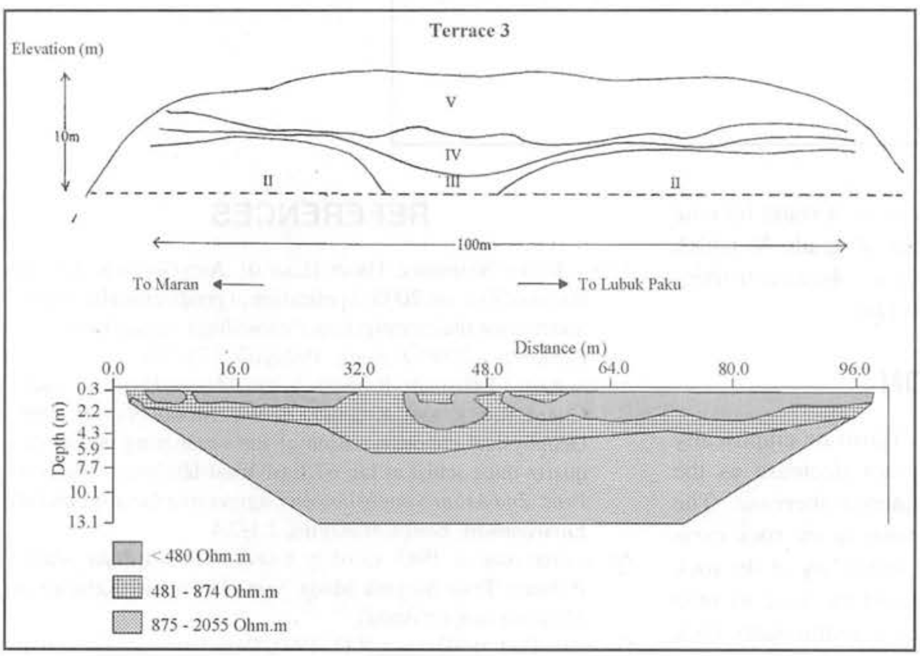

Figure 2. The weathering profile (top) and resistivity inverse section (bottom) for rock mass at Terrace 3

over 1600 Ωm. The high resistivity value suggests that the rock mass at this terrace has low porosity. This is shown by the presence of joints or cracks which are commonly tight with narrow openings. However the dark brown coloured material of grade III has relatively low resistivity values which range from 800 Ωm to 1600 Ωm.

The weathered zone of grade IV rock material has much lower resistivity values ranging from 600 Ωm to 800 Ωm. The medium joint openings in the rock have allowed the movement of surface water into the rock, thus reducing the resistivity values of the rock material. The soil material of grade V is mostly covered by plants and it shows much lower values of resistivity compared to those of grade IV.

Terrace 4

This terrace is represented mostly by the residual soil material of grade VI with resistivity values ranging from 150 Ωm to 500 Ωm. The low range of resistivity values is probably due to the high clay content and porosity of the soil material. Some isolated high resistivity anomalies are also observed in the upper part of the resistivity section which is believed to be associated with the presence of pebbles and rock fragments in the soil bedding. Relatively high resistivity values of more than 700 Ωm were obtained for layering underneath the soil material which is interpreted to be the weathered rock material of grade IV (Figure 3). This layered rock material has many joints with opening of

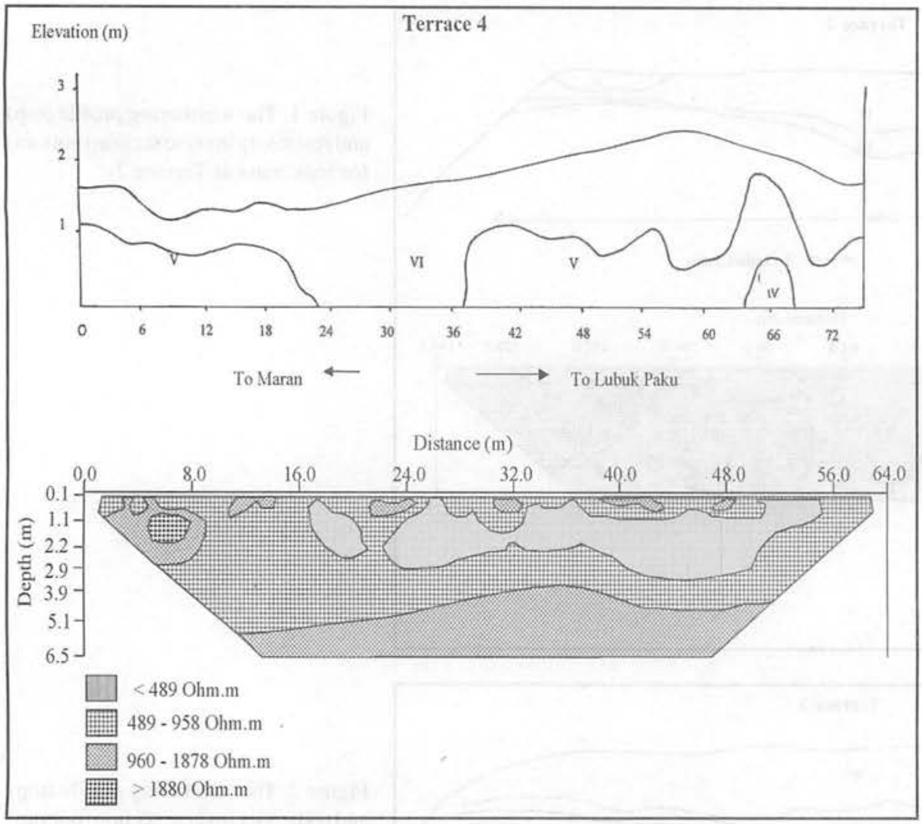

Figure 3. The weathering profile (top) and resistivity inverse section (bottom) for rock mass at Terrace 4

up to 3 cm wide which enables movement of water into the rock mass. Weathered rock material of grade V which located on the top left section of the terrace shows resistivity values ranging from 650 Ωm to 800 Ωm.

CONCLUSION

The results of the present study illustrate empirically that the geoelectrical resistivity values decrease as the weathering grades of the rock material increase. The presence of discontinuities and fractures in the rock mass appears to have lowered the overall resistivity of the rock mass. This empirical correlation could be used to map zones of different grades of weathered sedimentary rock mass and to study other subsurface geological structures related to slope cuts. The study can also become more useful if the measured resistivity could be correlated with other in situ geotechnical parameters of the rock. The resistivity data can be used for geotechnical rock characterization and it has the potential to be developed as a new tool in dealing with the difficult nature of the slope cut failure problem.

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