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2-D ELECTRICAL RESISTIVITY TOMOGRAPH (ERT) & INDUCED POLARISATION (IP) SURVEY ON DETECTION OF KARST FEATURES AND CONNECTIVITY OF SOLUTION CHANNELS

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ABSTRACT
The presence of naturally formed voids/cavities and solutioning channels in the subsurface karstic limestones can cause severe problems in civil/geotechnical engineering and mining projects. Peninsular Malaysia has various types of karstic limestone, sinkholes, solutioning cavities and channels. To effectively appraise the karstic formation, electrical resistivity and induced polarisation techniques have been proven a cost-effective solution for investigating subsurface bedrock profile, solution channels and its connectivity. A case study using 2-D electrical resistivity tomography and induced polarisation survey for a limestone quarry site is used to illustrate the successful application in identify the location of the karst features. Data processing has been carried out taking into consideration of the collective response of resistivity and induced polarization (IP)/chargeability that helps in interpreting subsurface strata, seepage path in the upper alluvial deposits, location of porous/jointed limestone rock mass or/and karst features with potential seepage flow, and the infilling condition of the joints and voids.

Introduction

This case study is an existing limestone mining quarry located at Perak State of Malaysia. Geology of this mining location is Kinta Limestone Formation with Devonian to Permian age. Kinta Limestone Formation consists of limestone bedrock with karstic features. However, the mining site location has a layer of alluvial overburden (predominantly is sandy deposits from the earlier days of mining activities and, also the natural river deposits) with varies thickness overlying the bedrock of Kinta Limestone Formation. The limestone rock mass with inherent joint sets can easily be dissolved by the weak acidic groundwater circulating through the joint sets (Friend, 2002) and gradually developing into solution channels with different diameter and shape that can convey water with remarkable quantity in the solutioned rock mass. With the continuous mining operation, downward quarry pit excavation will expose these solution channels on steeply formed rock bench surface which provide an exit boundary for the hydrogeological regime storing significant amount of water within the rock mass into the mining pit. There is high potential that the connectivity of these solution channel networks linking to external water bodies, likes ponds and river stream that can supply rapid recharge of the water. Any beaches of the connected channel networks to the mining pit can be disastrous and very disruptive to the mining operation and production. As such, the detection of the hazardous karstic features is of paramount importance to ensure continuous safe operation and, also taking measures to control the pumping costs in keeping the operational pit in a reasonable dry working condition.

Detection of solution channels and cavity location in this case study site has adopted 2-D Electrical Resistivity Tomography (ERT) Survey with the view of good contrast of resistivity among the overburden soils, limestone rock mass and the infilled or empty karstic features with both possibilities of dry and saturated conditions. The survey lines around the developed pit boundary and across the pit section are shown in Figure 1. Once any unfavourable karst features with potential hazards is identified, necessary treatments and measures can then be explored to mitigate the hazards.

Method

The 2-D ERT/IP Survey method at the mining site was conducted by using dipole-dipole array to detect potential seepage path within the alluvial deposits, subsurface solution channels and bedrock profile. An example is shown in Figure 2; the resistivity and chargeability profile show there is a water saturation zone (dark blue colour) at distance about 147m from the starting point from the resistivity line. This low resistivity zone can be interpreted as cavity in the limestone with the limestone bedrock is very shallow in depth because the saturation zone is very near bedrock surface. The shallow limestone bedrock and cavity at the location is confirmed by borehole test (BH11) carried out at the location. The borehole (Figure 3) shows the low resistivity zone (dark blue colour) is cavity with sandy soil infilling and the bedrock is just about 1.50m from ground surface.

The 2-D ERT survey method also can use to estimate the bedrock level. Figure 4 shows the resistivity profile of Line 9 where two different units (alluvium and limestone rock) is accurately be interpreted. Overburden layer in survey line, Line 9 has a thickness of 1m to 10m. The resistivity range is 75 Ωm to 5000 Ωm and the chargeability is 0.5 msec to 14 msec. A higher resistivity can be seen at the start of the survey line and is suspected due to the topographic changes and the unpaved road material which increases the contact resistance of the electrodes. Thick alluvium can be observed at site at the middle and end of survey line. In limestone unit, the resistivity range generally falls between 800 Ωm and 5000 Ωm depending on porosity, fracture, weathering, the infill in the pore spaces of the limestone, and chargeability range is 0.5 msec to 12 msec. Higher chargeability in limestone may be due to existence of chargeable material (clayey material) in porous space or joints of limestone. The boundary between overburden and limestone body in survey line, Line 9, is well demarcated with the correlation of resistivity values in borehole data of BH9. Borehole BH9 was drilled at about CH360m from the start of survey line. In borehole BH9, limestone is encountered at depth of 14.60m. the borehole data supports and proves that the resistivity data acquired is appropriate.

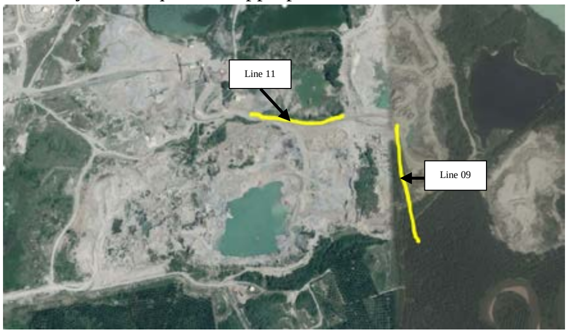


Figure 1: *Google Map shows resistivity surveyed lines*

Conclusions

With the understanding of good contrast of resistivity characteristics in the concerned medium and its surrounding materials, 2-D Electrical Resistivity Tomography (ERT) Survey has been proven a good investigation method with intuitive and confident interpretation of the subsurface structures especially identification of bedrock level and solution channels within the limestone rock mass. Two main geological materials, namely the alluvial deposits and the underlying limestone, are distinctly differentiable based on the resistivity and chargeability profiles. The resistivity value of alluvium unit, which highly depends on the clay content and water saturation, generally ranges from less than 10 Ωm up to 800 Ωm. The alluvium is found to form the overburden overlying limestone, or as in-filled sediments in the solution channels in the limestone. Second geological unit is limestone, which has resistivity range of 800 Ωm to more than 5000 Ωm. The resistivity range of limestone depends on the porosity, fracturing, weathering and the material infilling the pore spaces or joints in the limestone. In the limestone, clay in-filled channels can be clearly identified. This is indicated by the lower resistivity and higher chargeability zones within the normally higher resistivity of more than 1500 Ωm. However, if the cavity size is too small (limit by the electrode spacing, thus the survey resolution), then detection of smaller karst features in limestone will be very challenging unless the electrode spacing can be reduced with increasing resolution with some practical limit.

Acknowledgements

The authors would like to extend his sincere appreciation to geophysical survey for conducting the 2-D ERT/IP survey and provide good interpreted subsurface conditions with calibration to boreholes.

References

Friend, Sandra (2002). Sinkholes. Pineapple Press Inc., 95 p.

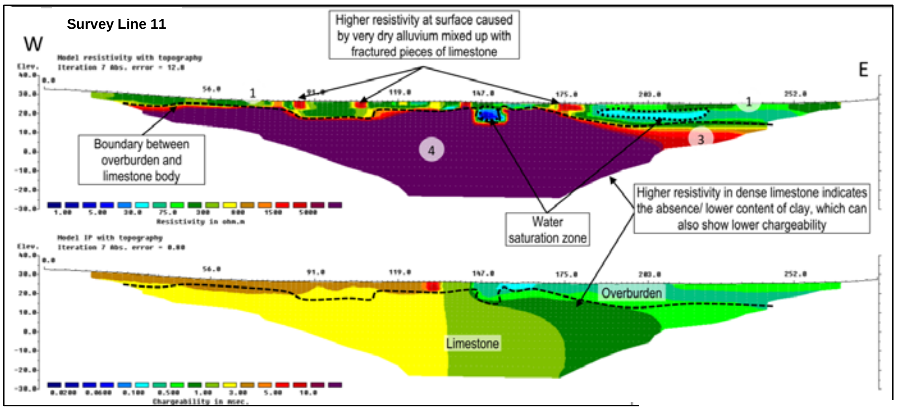
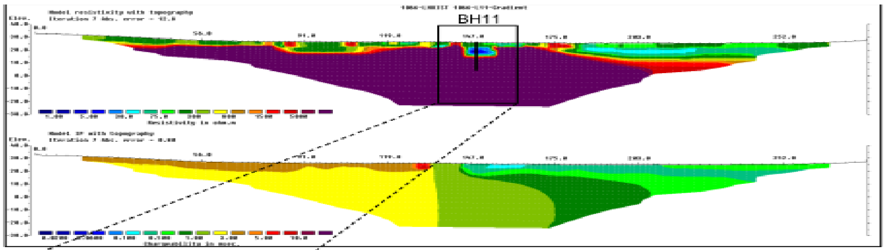
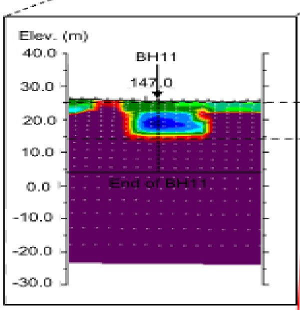


Figure 2: *Resistivity and chargeability of survey line*





Borehole 11 (BH 11)

Depth (m)	Sample No.	Description / (CR,RQD)
0 – 1.50	-	Topsoil
1.50 – 2.00	C1	LIMESTONE (100%, 46%)
3.00 – 3.45	D1	Sandy CLAY
4.50 – 5.20	UD1	Sandy CLAY
6.00 – 6.45	D2	Silty SAND
7.50 – 7.95	D3	Silty SAND
9.00 – 9.45	D4	Silty SAND
10.50 – 10.95	D5	Sandy SILT
12.00 – 12.45	D6	Sandy SILT
12.60 – 14.10	C2	LIMESTONE (100%, 83 %)
14.10 – 15.60	C3	LIMESTONE (100%, 80%)
15.60 – 17.10	C4	LIMESTONE (100%, 80%)
17.10 – 18.60	C5	LIMESTONE (100%, 83%)
18.60 – 20.10	C6	LIMESTONE (100%, 87%)
20.10 – 21.60	C7	LIMESTONE (100%, 95%)
21.60 – 22.60	C8	LIMESTONE (100%, 60%)
End of BH 11 at depth 22.60 m		

Low resistivty at depth ~3.0m to ~12.6m across BH11 is due to clay, sand and silt materials in-filled the cavity. The cavity is believed to contain high water saturation.

Figure 3: *Shallow cavity detected by resistivity survey confirmed by borehole*

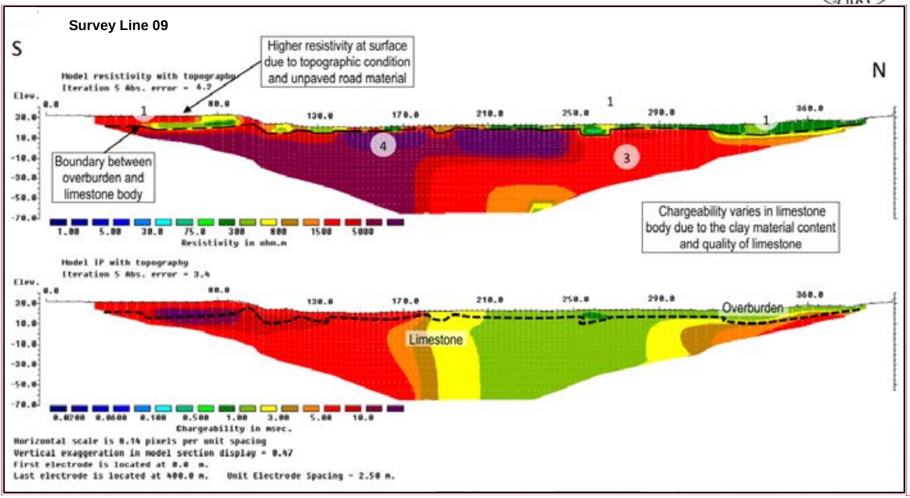
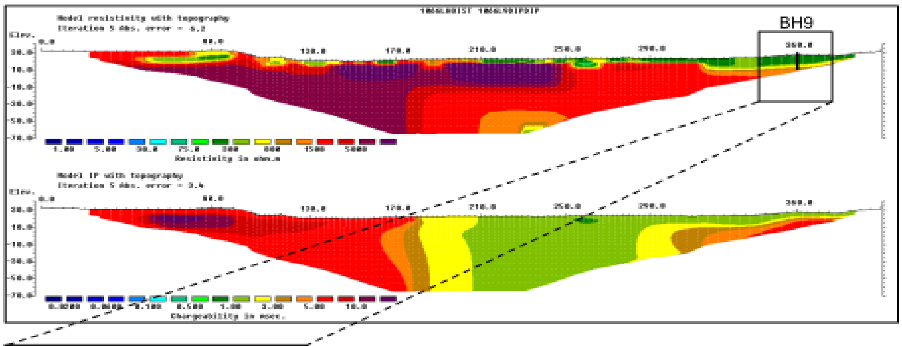
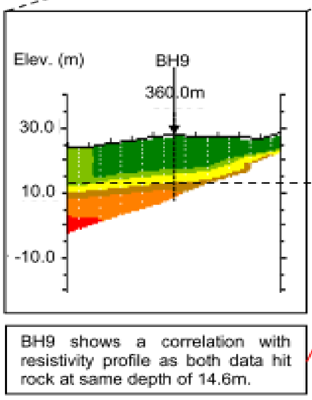


Figure 4: *ERT detected limestone bedrock level*





Borehole 9 (BH 9)

Depth (m)	Sample No.	Description / (CR,RQD)
1.50 – 1.95	D1	Sandy SILT with some gravels
3.00 – 3.45	D2	Clayey SAND
4.50 – 4.95	-	No sample recovery
6.00 – 6.45	D3	Sandy CLAY
7.50 – 7.95	D4	Clayey SAND
9.00 – 9.45	D5	Clayey SAND
10.50 – 10.95	D6	GRAVEL
12.00 – 12.45	D7	Clayey SAND
13.50 – 13.95	D7	No sample recovery
14.60 – 15.10	C1	LIMESTONE (100%, 70%)
15.10 – 17.60	C2	LIMESTONE (100%, 63%)
17.60 – 19.10	C3	LIMESTONE (100%, 61%)
19.10 – 20.60	C4	LIMESTONE (100%, 57%)
20.60 – 21.10	C5	LIMESTONE (100%, 45%)
21.10 – 23.60	C6	LIMESTONE (100%, 67%)
23.60 – 24.60	C7	LIMESTONE (100%, 62%)
End of BH 9 at depth 24.60 m. 2D resistivity profile is limited up to ~20.0 m depth only.		

Figure 5: *Borehole confirms the bedrock depth at about 14.60m*

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