# THE APPLICATION OF 2-D ELECTRICAL RESISTIVITY AND SEISMIC REFRACTION METHODS IN EVALUATING SUBSURFACE PROFILE AT TROPICALLY KARSTIC TERRAIN

# ПРИМЕНЕНИЕ МЕТОДОВ 2-D ЭЛЕКТРИЧЕСКОГО СОПРОТИВЛЕНИЯ И СЕЙСМИЧЕСКОГО ПРЕЛОМЛЕНИЯ ПРИ ОЦЕНКЕ ПРИПОВЕРХНОСТНОГО РАЗРЕЗА ЗАКАРСТОВАННЫХ УЧАСТКОВ В ТРОПИКАХ

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*Limestone is a sedimentary rock composed primarily of the great variety of mineral calcite ($CaCO_3$). The design of foundation in limestone areas always emit problems to geotechnical engineers due to the karstic features of limestone such as steeply bedrock, boulders, cavities, etc. In Malaysia, more than 800 karsts can be found scattered across the Eastern (Sabah and Sarawak) and Western (Peninsular Malaysia) regions. Hence, careful planning and execution of the works at this highly irregular karstic ground condition are important starting from preliminary to detailed investigation, analysis to design stage and up to construction stage where the continuous feedback is necessary for the satisfactory performance of the foundations. Even though logging of boreholes has been used to determine the characteristic of the subsurface in karst limestone, it is only provides information at a discrete location and not valid for vast area. Therefore, the uses of surface geophysical methods not only speed but cost effective of deriving aerially distributed information on the subsurface geology. Thus, this paper covered the study of the application of 2-D electrical resistivity and seismic refraction methods to the effect of subsurface profile as well as the depth to bedrock in karst limestone area in Tapah, Perak, Malaysia with the conjunction of borehole to refine the data. The data has been interpreted by Res2Dinv software for resistivity survey and SeisOptPicker and SeisOpt2D software for seismic refraction survey. The results indicate that seismic refraction gives a better result to determine the depth of bedrock, inversely, electrical resistivity more reliable to characterize the types of the rock. Thus, the evidence for this analysis is given and the methods used for this study is explained.*

*Известняк осадочная горная порода, состоящая в основном из большого разнообразия минерала кальцита ($CaCO_3$). Конструкция фундамента в известняковых районах всегда создают проблему для геотехнических инженеров в связи с карстовыми особенностями известняка, таких как круто падающие коренные породы, валуны, полости и т.д. В Малайзии, более 800 карстовых образований разбросаны по всей Восточной (Сабах и Саравак) и Западной (полуостров Малайзия) областях. Следовательно, тщательное планирование и выполнение работ на этом весьма неравномерном карстовом грунте является важной отправной точкой предварительное детальное исследование, анализ на стадии проектирования и до стадии строительства, где непрерывная обратная связь является необходимым для удовлетворительного выполнения фундаментов. Даже использование каротажа скважин, для определения характеристик геологической среды из закарстованого известняка, дает информацию только для дискретного участка и не распространяется на обширную территорию. Таким образом, использование поверхностных геофизических методов не только ускоряет процесс, но экономически эффективно для получения пространственно распределенную информацию о геологическом строении. Таким образом, эта статья отражает результаты изучения с применением методов 2-D электрического сопротивления и сейсмической рефракции к составлению приповерхностного профиля, а также определения глубины залегания коренных пород в закарстованных известняках в областях Тапах, Перак Малайзии с использованием скважины для уточнения данных. Данные были интерпретированы с использованием программного обеспечения RES2DINV для обследования сопротивления и SeisOptPicker и SeisOpt2D для сейсморазведки преломления. Результаты показывают, что метод сейсмического преломления дает лучший результат при определении глубин залегания коренных пород, наоборот, метод электрического сопротивления более надежен для характеристики скальных типов пород. Таким образом, здесь приводится результаты, полученные при использовании вышесказанных методов, их анализ и интерпретация.*

## 1. INTRODUCTION

Limestone karsts are defined as sedimentary rock outcrops made up primarily of calcium carbonate which were formed millions of years ago by calcium-rich organisms under the sea, but were uplifted relatively recently by tectonic events (Reuben et al., 2008). In Malaysia, more than 800 karsts can be found scattered across the Eastern (Sabah and Sarawak) and Western (Peninsular Malaysia) regions (Lim and Kiew, 1997 and Price, 2001). However, latest findings in Peninsular Malaysia according to Hareyani et al. (2011) limestone caves extensively outcrop in the northen half of Peninsular Malaysia such as in Langkawi Islands, northern Perlis, Kinta Valley in Perak and Klang Valley in Kuala Lumpur.

According to Yeap et. al. (1993), the karstification process happen beneath a permeable layer of sediment that was later eroded to expose the karstic formations to the air before later being buried once again under alluvium.However, karstic formation existing in limestone always emit problems which occasionally causes death, injury and extensive damages.

Even though logging of boreholes has been used by most engineers to determine the characteristic of the subsurface in karst limestone during preliminary stage, but it is only provides information at a discrete location and not valid for vast area. Therefore, the details subsurface investigations by using geophysical methods are important due to speed and cost effective of deriving aerially distributed information on the subsurface geology. Some of the geophysical method which can assist civil engineering works also is still rarely understood due to its limitation of applications. Thus, this paper provide a study on the application between 2-D electrical resistivity and seismic refraction surveys on delineating subsurface profile at limestone karst area which resistivity surveying can be used very efficiently at shallow target, but for deeper target seismic method can be very useful. (Franjo et. al., 2001).

The study is mainly to evaluate and compare the accuracy of the results between two geophysical methods of the subsurface profile in limestone karst formation which are represented by the following specific objectives;

I. To identify the strata and subsurface features by geophysical instruments.

II. To investigate the suitability of 2-D electrical resistivity and seismic refraction method in determining the depth of rock head in karstic terrain.

III. To correlate the geophysical survey results with geotechnical data derived from borehole data.

In this study, the assessments of survey area are mainly at the existing borehole location which later can be correlated with borehole data. The subsurface profile was assessed by geophysical testing which are 2-D electrical resistivity and seismic refraction methods to obtain their apparent resistivity and time travel of mineralogy of rock.

## 2. LITERATURE REVIEW

Electrical resistivity method is designed to yield information on formations or bodies having anomalous electric conductivity ( Dobrin, 1988 ). This also mentioned by Kearey et al. (2002) that resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground and in the detection of three-dimensional bodies of anomalous electric conductivity.

The purpose of electrical resistivity is to determine the resistivity distribution on the subsurface materials. Artificially generated electric current are supplied to the ground surface and the resulting potential differences are measured. It measures how strong a material opposes the flow of electric current. The lower of the resistivity value indicates that a material has higher conductivity.

The variation of potential differences in homogeneous ground gives information of subsurface heterogeneity and its electrical properties (Kearey et al., 2002). Basically, direct currents or low frequency alternating current is used to determine the electrical properties of the subsurface.The two-dimensions (2-D) direct current method has been described by previous researchers on their study (Figure 1).

In electrical resistivity method, the better the electrical contrast or heterogeneity, the better the detection. Kearey et al. (2002) stated that the electrical resistivity is the most function for the variability of soil physical properties.

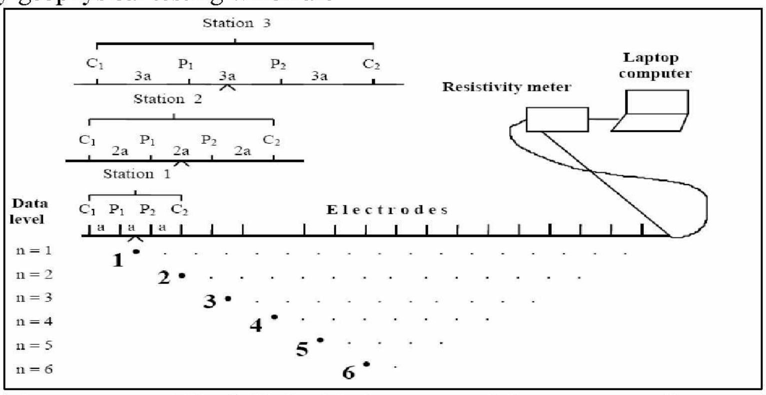



***Figure 1*****:** Multi-electrode arrangement for 2-D electrical survey and the sequence of measurement used to build up a pseudo-section (Loke, 1997)

Seismic surveying is based on the stress and strain concept. It utilize the principal of elastic waves travelling with different velocities at different formation of the Earth Kearey et al. (2002). The velocity of the seismic waves are determined by Elastic Moduli and the densities of materials through which they travel.

In seismic refraction, acoustic energy is supplied to the ground surface by an energy source as a sledgehammer impacting to a metallic plate, weight drop or explosive charge during the seismic refraction survey. The acoustic waves propagates through the subsurface of the ground at varies velocities dependant on the elastic properties of the material through which they travel. When the waves reach at the interface where the velocity is change significantly, some of waves is reflected back to the surface and some is transmitted into the lower layer where the velocity at the lower layer is higher than upper layer (Figure 2). A portion of energy also is critically refracted along the interface. Critically, refracted wavs travel along the interface at the velocity of the lower layer and continually refract energy back to the surface. The receiver then record the incoming refracted and reflected waves (Redpath, 1973) and the time-distance plots of these first arrival are interpreted to derive information on the depth to refraction interfaces. Table 1 shows the differences of values of seismic refraction and resistivity for common rocks and materials from previous research-es, Telford and Sheriff (1984).

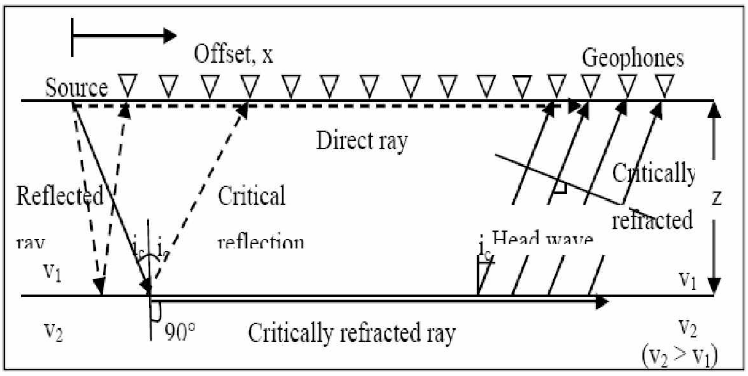



***Figure 2***: Ray path diagram showing the respective paths for direct, reflected and refracted rays

***Table 1***: Resistivity and velocity of some common rocks and minerals (Telford and Sheriff, 1984)

| **Material** | **Seismic (m/s)** | **Resistivity (Ohm-m)** |
|---|---|---|
| ***Igneous/ Metamorphic*** | | |
| Granite | 4580-5800 | 5 x$10^3$ - $10^8$ |
| Weathered granite | 305-610 | 1-$10^2$ |
| Basalt | 5400-6400 | $10^3$ – $10^6$ |
| Quartz | | $10^3$ – 2 x $10^6$ |
| Marble | | $10^2$ – 2.5 x $10^8$ |
| Schist | | 20 – 104 |
| ***Sediments*** | | |
| Sandstone | 1830-3970 | 8-4 x $10^3$ |
| Conglomerate | | 2 x$10^3$ – $10^4$ |
| Shale | 2750-4270 | 20 – 2 x $10^3$ |
| Limestone | 2140-6100 | 50 – 4 x $10^2$ |
| ***Unconsolidated sediment*** | | |
| Clay | 915-2750 | 1-100 |
| Alluvium | 500-2000 | 10-800 |
| Marl | | 1-70 |
| Clay (wet) | | 20 |
| ***Groundwater*** | | |
| Fresh water | 1430-1680 | 10-100 |
| Salt water | 1460-1530 | 0.2 |

## 3. METHODOLOGY

The study area is located in Tapah, Perak with coor-dinates of 4.20° North and 101.26° East.

### 3.1 Geological Features and Survey Area

It is Devonian-Silurian age which consists of limestone, phyllite and slate and also schist, phylilite, slate amd minor sandstone. In general, tapah is predominantly by intrusive rock of granite. However, this study was carried out at the buried limestone which located towards Northwest direction of Tapah. The surface of survey area consists of alluvium layer. In addition, the survey location is mostly for rearing the buffalo. Besides, it has hilly terrain and valley area with some existing water channels and ponds

### 3.2 Data Acquisition

Data acquisition is the process of collection and conversion of raw datas to the expected results. It capture large number of data points and analysis the data in a small time scale. Therefore, in this study, 2-D resistivity method and seismic refraction method has been chosen as the best data acquisition under karstic formation for the accurate interpretation and anomaly resolution.There are two survey lines located at Tapah which one for 2-D resistivity line and another one for seismic refraction line (Figure 3). Prior to the survey, the site investigation has been conducted in order to get the best place for the better interpretation.


***Figure 3***: Location of survey lines for 2-D resistivity (yellow) and seismic refraction (pink) (Google Earth, 2010)

For 2-D electrical resistivity, there is only one survey line has been carried out at Tapah, Perak namely TP01 which is directed to West-East.The equipment used during this survey consisted of ABEM SAS4000 Terrameter, Electrod Selector 10-64C, electrode cables with 5 m takeouts and stainless steel electrodes. The length of resistivity survey line was 400m which consists only one spread. The electrode array configuration used in this survey was Wenner Schlumberger (WS) protocol. As the cable length is only 100m, hence it is required four cables to get 400m length. This four cable was considered as one spread or single spread. This single spread consists of 41 electrodes and nominally spaced 5m apart for a maximum total spread length is 100 m. The total takeouts for 400m length is 41 instead of 44 (include short and long readings). This is because, the sharing electrode has been used for selected electrodes such as last electrode for cable 1 sharing with first electrode of cable 2. It is same goes to cable 2&3 and 3&4. This procedure is important to get continue readings within 400m length. The input current used as minimum 2mA to a maximum 20mA.

The raw datas recorded from terrameter has been transferred to the computer for the data processing and analysis using Res2Dinv software. The output of Res2Dinv is an inverse model resistivity which presents contour colors of resistivity values. From the inversion model, the different subsurface material has been delineated with different resistivity values which has been discussed further in discussion section.

For seismic refraction survey, to get better interpretation between resistivity and seismic data, the seismic survey line namely TP02 was made on the same place as resistivity line. The location of seismic line was at the center of resistivity survey line at 57.5m distance to the East and West direction. The survey was conducted using ABEM Terraloc MK8Plus, 28Hz vertival geophones, two refraction cable with 12-foot takeouts, a weight drop and aluminium striker plate. The length of TP02 survey line is 115m with ± 80 m offset. The survey used 24 geophones for one spread in a straight line to acquire layer beneath the ground. There is only one spread has been made for this survey. The 24 geophones were connected with two rolls of seismic cables which has 12 channels to the receiver system, ABEM Terraloc MK8Plus. The geophones interval was 5 m. There are only nine shot points has been made to acquire the data of the survey area which includes; offset (-80m), offset (-60m), mid of geophone 1-2, 6-7, 12-13, 18-19, 23-24, offset (+60m) and offset (+80m). Stacking has been done at each shot points with weight drop.

The raw datas taken from the stacking has been stored in the Seismograph 24.Ch, ABEM Terraloc MK8Plus and analyzed by SeisOptPicker and SeisOpt2D software for the result interpretation. SeisOptPicker to obtain the reciprocal travel time curve and SeisOpt2D to determine the elevation and velocity of subsurface materials from SeisOptPicker output.

## 4. RESULTS AND DISCUSSION

### 4.1 Inversion Model of Resistivity

Generally, the section shows 3 major zones of low, medium and high resistivity value which can be found at certain section of the cross sectional area. The low resistivity zone can be detected at the top part of the section until 10 m beneath the survey line at 170-400 m spread (Figure 4 (a)). This section can be visualised by the blue colour and marked in the figure. The low-medium resistivity zone also can be detected at spread 155 m and 255 m at the depth of 25 m from the ground surface (Figure 4 (b)). From the profile, this particular structure has rounded shape of 10 and 20 m diameter respectively.

The medium resistivity zone was encountered at the depth of more than 22.5 m below the ground surface along the spread line (Figure 4 (c)). Meanwhile,the higher resistivity zone was detected at 50-225 m spread line (Figure 4 (d)). This pattern can be visualized near to the ground surface until the depth of 10 m. At spread line distance of about 200 m, a high resistivity zone structure can be found at depth greater than 60 m (Figure 4 (e)).

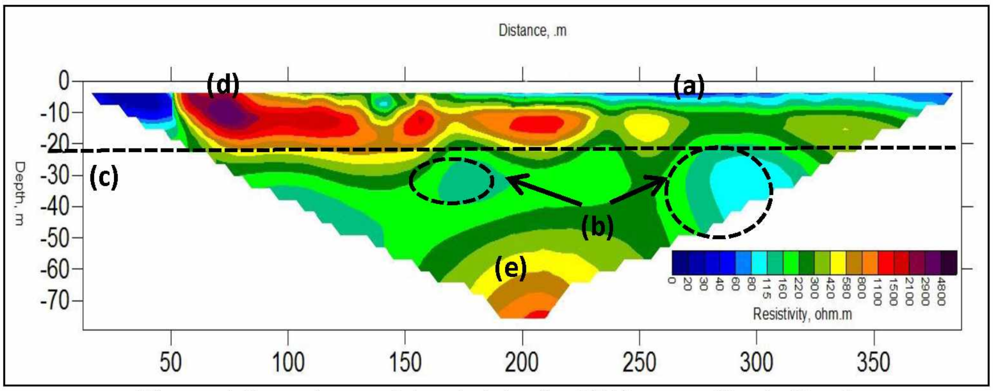



***Figure 4***: Inversion model resistivity for TP01 survey line in Tapah

### 4.2 Seismic Section of Velocity Gradient

Figure 5 shows the final seismic section of velocity gradient at surveyed area. The result shows three distinct layers of velocity present beneath the survey area. The first layer range of 0-400ms$^{-1}$ located at depth 0-2 m (Figure 5 (a)). The second layer with velocity of 400-2600ms$^{-1}$ was sensed at the depth of 2 m to 31 m (Figure 5 (b)). However, there are blurred area of low velocity value at the depth of 25 m which depicted at the similar location of low resistivity value in the resistivity survey result (Figure 5 (c)). Further interpretation, the higher velocity zone of greater than 2700ms$^{-1}$ can be clearly mapped at the depth of greater than 32 m (Figure 5 (d)).

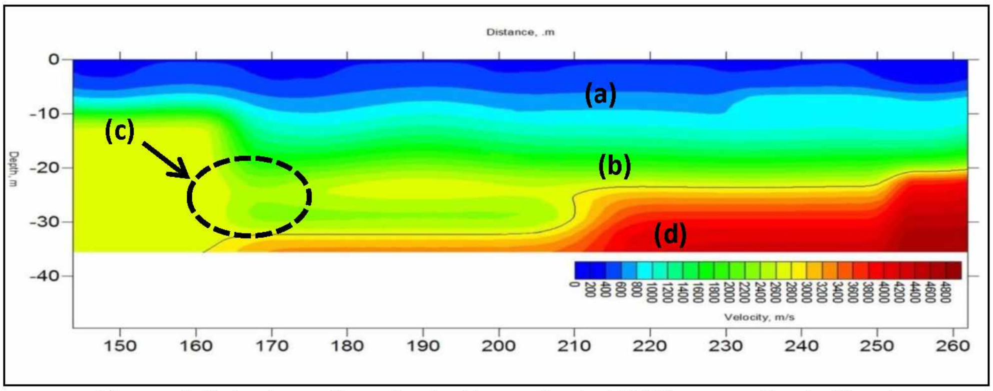
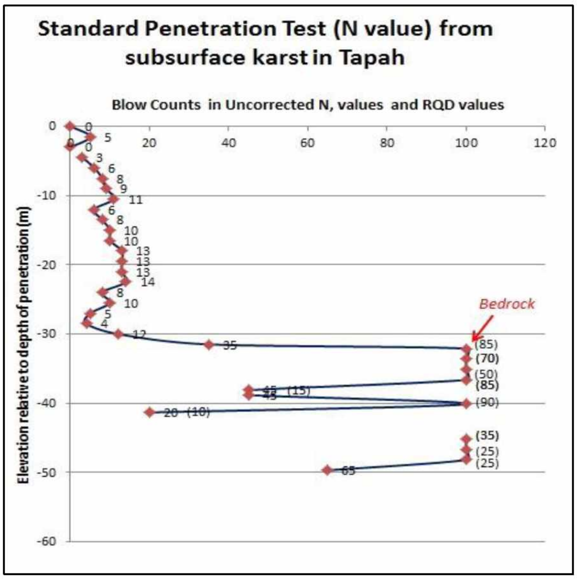



***Figure 5***: Seismic section of velocity gradient at TP02 survey line in Tapah

### 4.3 Correlation with Borehole Log

The collection of borehole record, BH08 used in this study was based on the rotary wash drilling and logging carried out previously by a private geotechnical companyon October 2013. The details of the borehole results are shown in Figure 6 and 7. Based on borehole data, the depth of bedrock is encountered at 32.12 m below the ground surface with SPT and RQD values of 100% and 85% respectively (Figure 6 and Table 2).

From the borehole result, generally the site is underlain by soft to stiff (sandy silt, silty clay, clayey silt and sandy clay) and loose to dense (silty sand and sandy gravel) of soil profile. These soil types has low SPT value (N) of less than 14. The borehole data also revealed that a bedrock can be found at 32.12 m depth and cavities are found at 38.81 m and 41.97 m below the ground level with space of less than 3.2 m. The data also can be summarized as the limestone bedrock is underlain by various type of soils known as alluvial soils of up to 32 m depth (Figure 7) with ground water level of 6.2 m. This was considered as fully developed void or karst in limestone which revealed no recovery of the core. Thus, this finding prove a study from previous researchers (Yeap et. al., 1993; Mohd Shafeea and Ibrahim Komoo, 2004) that the presence of subsurface karst was buried under alluvial layer.




* ( ) represent RQD value
*Figure 6*: SPT (N value) and RQD (%) of subsurface profile from BH08

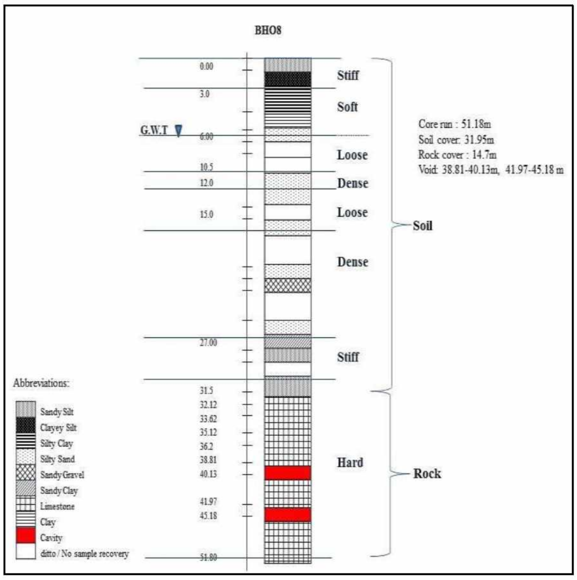



*Figure 7* : Details of rock cores of BH08

However, to understand the quality of the rock mass or limestone, the log BH08 was then re-analysed to re-assess the SPT and RQD value so that the quality of the ground can be determined. Using the values obtained, the ground is re-classified into four different quality of rock mass ranging from good, fair, poor and very poor rock (Table 2). The higher RQD value represents a good limestone otherwise a lower value is considered as very poor quality or "highly weathered" limestone which is thus expected to contain cavity or karst. It explains that the weathering has opened up discontinuities and hence gives a great potential to contain well developed small scale karst within the rock mass. Based on the re-analysis, the highly weathered limestone was measured at RQD value <25%.

*Table 2*: Rock classification of Borehole Log, BH08 based on RQD(Bieniawski, 1989)

| Classification | Description | RQD (%) | Depth (m) |
|---|---|---|---|
| Good Rock | **Slightly Fractured** to **Moderately Fractured** and Slightly Weathering Limestone | 75-90 | 32.12-33.62<br>33.62-35.12<br>36.62-38.12<br>40.13-41.33 |
| Fair Rock | **Highly Fractured** and Moderately Weathering Limestone | 50-75 | 35.12-36.62 |
| Poor Rock | **Lightly Fractured** and Moderately Weathering Limestone | 25-50 | 45.18-46.68 |
| Very Poor Rock | **Totally Fractured** and Highly Weathering Limestone | <25 | 38.12-38.81<br>41.3341.97<br>46.68-49.68<br>49.68-51.18 |

### 4.3.1 Correlation Inversion Model Resistivity with Borehole Data

The SPT and RQD values from borehole data, BH08 was overlapped at the pseudosection to evaluate the accuracy of the resistivity datas. Figure 8 and Figure 9 shows the combination of inversion model resistivity (TP01) with borehole data (BH08) at Tapah. It has been explained in the previous section that there are three zones formation; low (0-100Ωm), medium (160-400Ωm) and high resistivity zone (500-4000Ωm) which has been interpreted as top soil, limestone and weathered limestone respectively based on Telford and Sheriff (1984). The resistivity interpretation seems accurate with the correlation of borehole data where the characteristic of the soils has been determined. At the first layer, the low resistivity value is predominantly made up of top soil with depth generally less than 2 m which form the overburden.

As depth penetration increases, the resistivity values also increases ranging from 160-400Ωm at depth greater than 22.5 m beneath the survey area. This layer was considered as hard layer. Based on the geological condition of site, the hard layer or bedrock is limestone. According to borehole data, rock head was encountered at depth 32 m with resistivity value of 181.32Ωm. Thus, it is signifies with Telford and Sheriff (1984) that rock head encountered at lower resistivity ranging 50 to 400Ωm with higher RQD. However, based on inversion model of resistivity result, the depth of rock head was assumed to be at 28.5 m depth with resistivity value

195.62Ωm. Therefore, it can be summarized that, the accuracy of the result is 5 m deviation from the actual of borehole data.

It has different interpretation with higher resistivity zone at this survey area. The higher resistivity value ranging of 500-4000Ωm (“red” to “purple” colors) with sudden lower resistivity of 420-500Ωm in between are not considered as bedrock or hard layer, but it represents as alluvium soils or “weathered limestone” which consists a mixture of sand and clay. This is occurred due to the weathering process of limestone which turn into sand. Sand has slightly higher resistivity value than clay as the porosity in sand is higher than clay which allows water goes through it without accumulating it. This layer can be detected at depth 0-10 m and greater than 60 m below the ground surface.

In term of cavity detection, resistivity method was not able to sense the ‘empty’ structure due to the wide electrode spacing. The electrode spacing used in this survey was 5 m which it can only detect the cavity at minimum gap of 3 m. This is because generally the measurement of resistivity only taken at depth 0.6 times of electrode spacing.

Therefore, the accuracy of the result was measureddue to effectiveness of the method in delineating the subsurface profile and depth of bedrock of survey area was shown in Table 3 to Table 5.

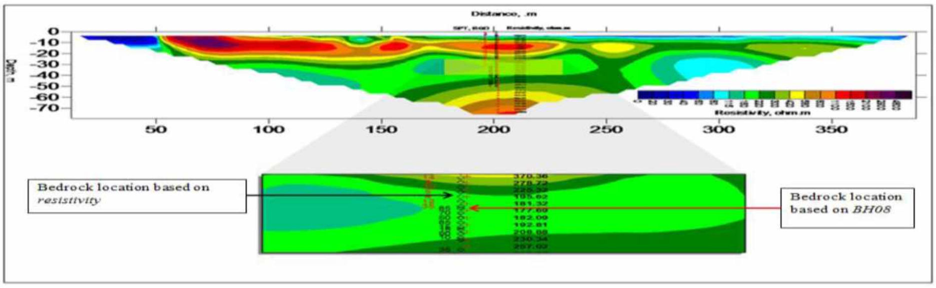



***Figure 8***: The combination of inversion model resistivity (TP01) and borehole in Tapah

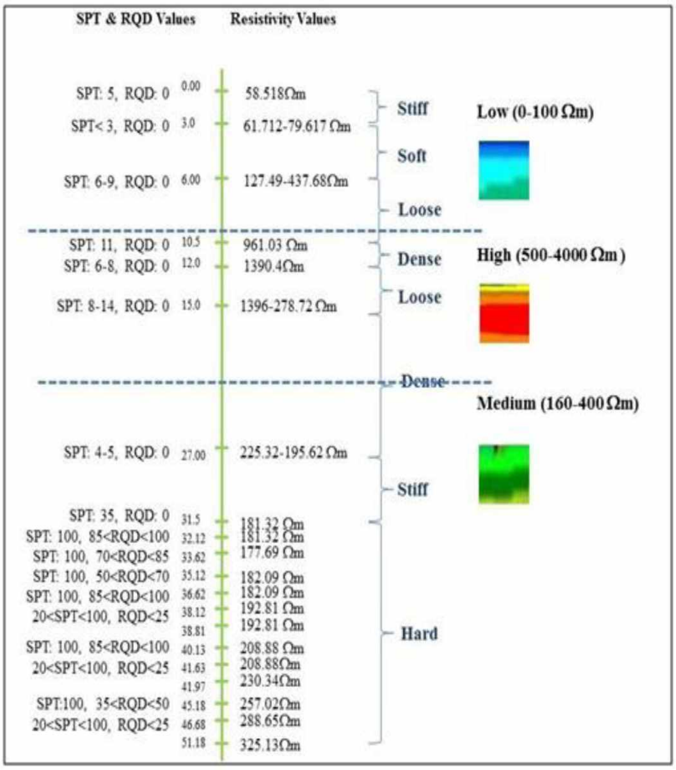



***Figure 9*** : Resistivity values correlate with SPT and RQD values

***Table 3***: Summary of resistivity values based on characteristic of soils

| **Characteristic of Soils** | **Findings** | **Borehole (as reference)** | **Literature (Telford and Sheriff, 1984)** |
|---|---|---|---|
| Top Soil | 0-100 Ωm | <127 Ωm | 1-100 Ωm |
| Alluvium | 500-4000 Ωm | 438-1396 Ωm | 10-800 Ωm |
| Hard rock (Limestone) | 160-400 Ωm | 177-325 Ωm | 50-400 Ωm |

***Table 4***: Summary of resistivity values due to cavity detection

| **Depth of Cavity** | **Findings** | **Borehole (as reference)** | **Literature (Telford and Sheriff, 1984)** |
|---|---|---|---|
| 38.81 m | - | - | Low resistivity than rock mass |
| 41.97 m | - | - | Low resistivity than rock mass |

***Table 5***: Summary of resistivity values based on depth of bedrock

| | **Depth of bedrock** | **Resistivity Value** |
|---|---|---|
| Findings | 28.5 m | 195.65 Ωm |
| Borehole (as reference) | 32 m | 181.32 Ωm |

**4.3.2 Correlation Between Seismic And Borehole Data**

The same approach has been made for seismic refraction result. The output of seismic data (TP02) has been overlaid with borehole data (BH08) to get better correlation (Figure 10 and Figure 11). According to borehole data, seismic results was successful in delineate the characteristic of subsoil of the survey area where three layers formation with seismic velocities ranging from 0-400ms$^{-1}$,400-2600ms$^{-1}$ and >2600ms$^{-1}$ has same interpretation as per borehole logs. It is satisfied with borehole data where the first layer ranging of 0-400ms$^{-1}$ indicates as top soil with depth <2m while for the second layer consists of unconsolidated sediment with velocity is 400-2600ms$^{-1}$. This layer indicates the presence of alluvium with depth extend from 2 m to 31 m.

Further interpretation of seismic for the third layer, the velocity >2700ms$^{-1}$ is assumed to be a rock head or bedrock. This assumption has been made due to the increasing velocity of wave travel from one medium to another with lower to higher velocities. It can be said that the limestone become harder or the density become higher as the wave travel with increasing in depth. The depth of rock head encountered from seismic interpretation are similar with borehole data where the bedrock happens at depth in between 31.875 m to 33.75 m with the velocity ranging from 2728ms$^{-1}$ to 3103ms$^{-1}$.

However, in term of cavity detection, seismic refraction failed to detect the cavity due to limited depth penetration. In this study, length of seismic survey line was 115 m where the depth of penetration based on “rule of thumb” for WS protocol was 1/3 times of total survey length. Hence, seismic refraction only covered depth of up to 38.33 m where it exclude the location of cavities which occurred at depth of 38.18 m and 41.97 m as recorded in borehole data.

In summary, the accuracy of the seismic result due to the effectiveness of method in delineating the subsurface profile and depth to bedrock of survey area can be summarized in Table 6 to Table 8.

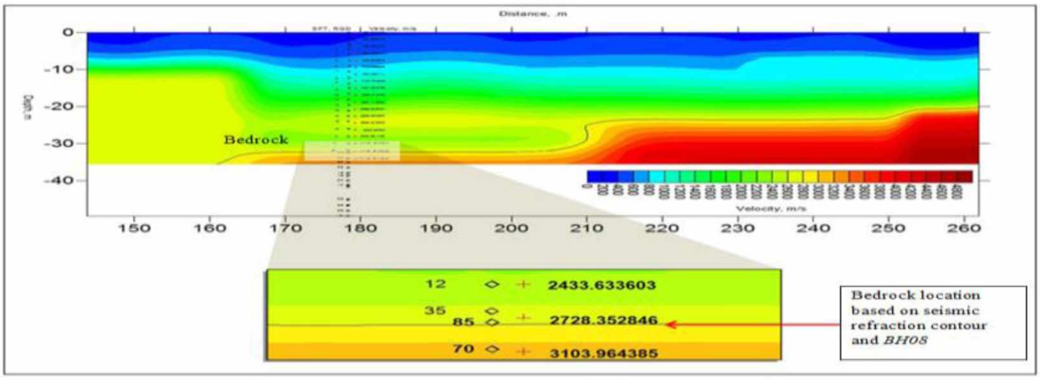



***Figure 10***: The combination of seismic section (TP02) and borehole in Tapah

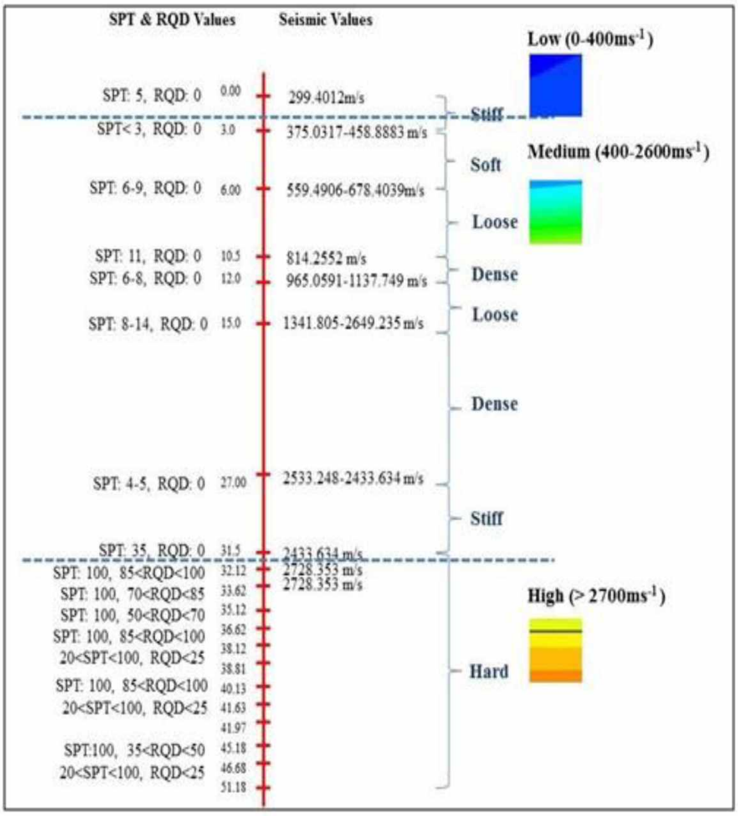



***Figure 11***: Seismic values correlate with SPT and RQD values

***Table 6***: Summary of velocity values based on characteristic of soils

| **Characteristic of Soils** | **Findings** | **Borehole (as reference)** | **Literature (Telford and Sheriff, 1984)** |
|---|---|---|---|
| Top Soil | 0-400 $ms^{-1}$ | <300 $ms^{-1}$ | 915-2750 $ms^{-1}$ |
| Alluvium | 400-2600 $ms^{-1}$ | 375-2649 $ms^{-1}$ | 500-2000 $ms^{-1}$ |
| Hard rock (Limestone) | >2600 $ms^{-1}$ | >2728 $ms^{-1}$ | 2140-6100 $ms^{-1}$ |

***Table 7***: Summary of velocity values due to cavity detection

| **Depth of Cavity** | **Findings** | **Borehole (as reference)** | **Literature (Telford and Sheriff, 1984)** |
|---|---|---|---|
| 38.81 m | - | - | Low velocity than rock mass |
| 41.97 m | - | - | Low velocity than rock mass |

***Table 8***: Summary of velocity values based on depth of bedrock

| | **Depth of bedrock** | **Velocity Value** |
|---|---|---|
| Findings | 31.875 m to 33.75 m | 2728-3103 $ms^{-1}$ |
| Borehole (as reference) | 32 m | 2728 – 3103 $ms^{-1}$ |

## 5. CONCLUSION

From the results and data interpretation that has been discussed in previous section, four conclusions can be inferred;

I. The characteristic of rock mass can be determined and clearly described by 2-D electrical resistivity method at shallow depth as compared to seismic refraction method when correlated with borehole data. The 2-D resistivity result is not only matched with the borehole data but also could describe the quality of rock mass encountered (with RQD value).

II. The 2-D electrical resistivity and seismic refraction methods can be utilized to detect rock head or depth to the bedrock. However, seismic refraction is more effective where it provides an accurate interpretation of bedrock location according to the borehole log as compared with 2-D electrical resistivity because seismic refraction sensitive to the mechanical properties of earth materials and are relatively insensitive to chemical makeup of both the earth materials and their contained fluid.

III. The 2-D electrical resistivity and seismic refraction results has been correlated with some geotechnical properties and found there is a slightly variation at the top soil layer between two methods. Resistivity results shows similar data as per borehole but not for seismic. Hence, this findings proved with the previous study by Franjo et. al. (2001) that resistivity surveying can be used very efficiently at shallow target, but for deeper target seismic method can be very useful.

IV. Both methods are able to detect cavity in karst terrain with low resistivity and low velocity values. However, for this study, the cavity cannot be seen at the specific depth as per borehole log location. This is due to the limitation of both methods which are electrode spacing and length of the survey line for resistivity and seismic method respectively. Modification on the electrode spacing and the length of spread line need to be adjusted accordingly.

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