Integration of Resistivity and Seismic Data to Determine the Cavity at Teluk Apau, Langkawi: An Evaluation

Rasyikin Roslan, Rohayu Che Omar, Intan nor Zuliana Baharuddin, Warishah Abdul Wahab, Faten Syaira Buslima

Abstract: ***A geo-environmental evaluation to build and maintain the transmission tower often requires a large amount of spatial information to determine foundation and slope stability. Geo-electrical or resistivity measurements are capable of managing large amounts of spatially related information, enabling various layers of data to be integrated.These geophysical methods are readily available can assist engineering geologist and geotechnical engineers in obtaining the material properties and boundaries of sub-surface materials.Multi-criteria analyses are carried out to assess the development suitability of the transmission tower's geo-environment based on properly measured and weighted variables. It is demonstrated that Geo-electrical or resistivity measurements have high functionality for geo-environmental assessments.***

Keywords: ***Geo-Electrical, Resistivity Measurement, Transmission Towers, Pole Tower.***

I. INTRODUCTION

In the case of electrical supply in Malaysia, transmission towerswere built from North to South through various land use and topography. There are cases where the towers werebuilt in the landslide area and have very limited access (Hazwani et al. 2016). Due to concerns on the stability of these transmission towers and the natural hazards that come with it, it is very important to monitor these towers. Therefore, when planning and carrying out remedial interventions intended to protect the environment, proper consideration must be given to the geo-environment.Technologically, Geo-electrical or resistivity measurements have been done for a long time for foundation and slope stability studies (Bogoslovsky and Ogilvy 1977; Stotzner 1974).

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Rasyikin Roslan, Institute of Energy Infrastructure, Universiti Tenaga Nasional,43000 Kajang, Malaysia

Rohayu Che Omar*, Institute of Energy Infrastructure, Universiti Tenaga, Nasional,43000 Kajang, Malaysia

Intan Nor Zuliana Baharuddin, Institute of Energy Infrastructure, Universiti Tenaga Nasional,43000 Kajang, Malaysia

WarishahAbdulWahab, Institute of Energy Infrastructure, Universiti Tenaga Nasional,43000 Kajang, Malaysia

FatenSyairaBuslima, Institute of Energy Infrastructure, Universiti Tenaga Nasional,43000 Kajang, Malaysia

The restriction was that the interpretation of the measurements was mathematically highly complicated and that only standard situations could be solved, normally with the help of standard graphs. In recent years, the availability of technology with cheaper cost has made geophysical surveys more easily done by non-specialists. However, interpretations for slope stability analysis are yet to become more reliable and accurate with the integration of various geophysical methods. Despite the variation of geophysical techniques required for the analysis, the costs to operate the tests are considerably cheaper. Still, regrettably, geophysical methods are seldom used and often only boreholes or soundings are made to investigate the sub-surface. The geophysical methods described are readily available and are helpful to the engineering geologist and geotechnical engineer in obtaining the material properties and boundaries of sub-surface materials (Hack. R 2000).

In this paper, Geo-electrical or resistivity measurements are used to dosoil investigation in the area of TelukApauto verify whether a standard transmission tower can be built or ifa pole tower is to be used instead. Furthermore, the geo-environment must be duly taken into account during the development of the transmission tower lines, including natural hazards such as landslides. This evaluation incorporates the following information: topography, geology, groundwater conditions, and geologic hazards. Multi-criteria analysis is performed to evaluate the development suitability of the geo-environment in the area.

A) Study Area

For future expansion, the energy provider addeda new transmission line along the existing transmission line at Langkawi Island, Kedah. The transmission line starts from theTelukApau area, which is the nearest location to connect a transmission line between Langkawi Island and Peninsular Malaysia.

Soil investigation on that area needs to be done to verify whether a standard transmission tower can be built or if a pole tower is to be used instead. Geophysics surveysusing resistivity imaging and seismic refraction were conducted in the study area. The purpose of this field investigation is to provide information onthe subsurface soil layers at Tower 22 of the new transmission line at Langkawi Island, Kedah. In addition to that, this survey is used to determine the location and depth of the cavity within the tower area.

Due to limitations of site topography, both geophysics surveys only extended up to 30 meters in length. The orientations of survey lines are shown in Fig. 1.

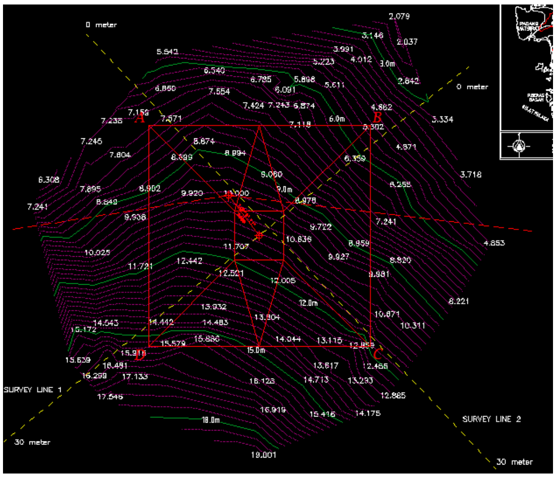

Fig. 1 Resistivity Survey Lines at T22 TelukApau, Langkawi Island

As observed in the geological map of Langkawi Island specifically at TelukApau (Fig. 2), the site area is mainly constituted with schist, phyllite, slate, and limestone. There is also a high possibility of the existence of marine and continental deposits; clay, silt, sand and peat with minor gravel towards the sea area.

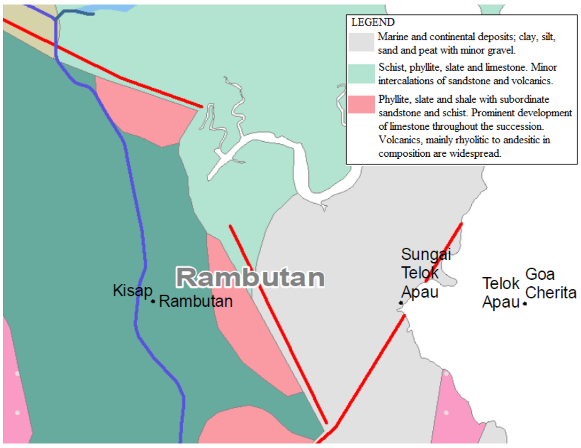

Fig. 2 Site Topology

II. METHODOLOGY

2D Resistivity Survey Concepts

Measurements of geo-electric or resistivity are based on the difference in resistivity between distinct materials on the subsurface.Such trials use several electrodes in a direct row with a constant spacing (usually 25 to 100). The amount of which the products on the sub-surface effect the evaluated ability depends on the distance between the electrodes, the set used, the fluid positioned on the floor, and the measuring instrument sensitivity. The method can be used for vertical and for horizontal profiling. For vertical profiling the spacing between the electrodes is increased with regular steps while the center of the array is fixed, hence for horizontal profiling, the array of potential electrodes and current electrodes is moved over the surface. Deeper materials will influence the potential on the potential electrodes if the distance between the electrodes is larger or if the current is larger.

A computer-controlled system is then used to automatically select the active electrodes for each measure (Griffith & Barker, 1993). Various electrode arrays are possible in resistivity surveys (Fig. 3). The maximum sensitivity of all arrays is obtained near the measuring electrodes.

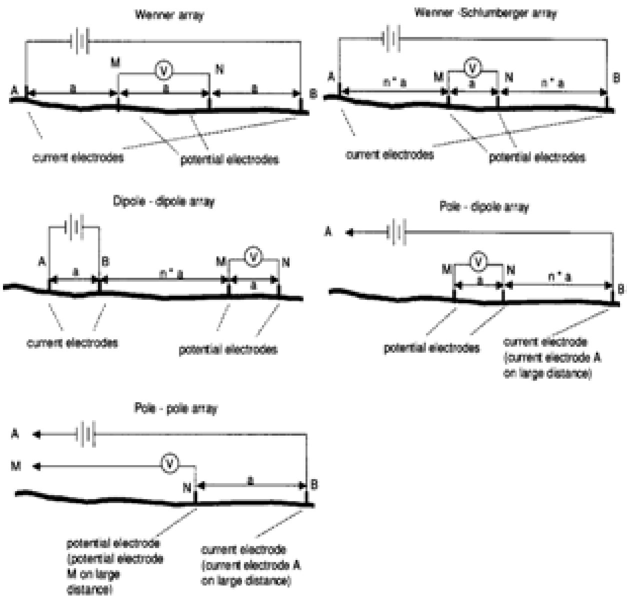

Fig. 3Various arrays for current and potential electrodes

Interpretation of 2D Resistivity Survey

The resistivity method measures the resistivity distribution of the subsurface materials. The measurement is based on the resistivity and conductivity values of some of the typical rocks and soil materials prepared by Telford et al., (1990) and Vogelsang(1994).

The results from the resistivity test will be compared to the standard values in the table above. As an example, the results of the geo-electrical resistivity images recorded at the site appears red in color, meaning that it belongs to granite in a wet condition whereby the resistivity would be 4400 ohm-m.

Field Work Procedure

Wenner-Schlumberger Array is used in this study area using the arrangement carried out with a multi-electrode resistivity meter system (ABEM SAS4000 system) as the layout shows in Figure 1. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo-section are shown in Fig. 4.

Fig. 4 The arrangement of electrodes for a 2-D electrical survey and the sequence of measurement used to build up a pseudo section

The spacing of 0.75 meters was used for both survey lines based on the survey lines based on the Wenner-Schlumberger Array. The maximum depths of investigation for the survey were almost 8 meters for Survey Line 1 and barely 7 meters for Survey Line 2 due to the topography and limitation of workspace in the study area. The total length for both survey lines is 30 meters. In principle, the data recorded is translated into a geo-resistivity image represented by a default color code. Each color code represents the resistant index (ohm-m) of the earth minerals, density, and porosity (as an indirect result) as well as the presence of the least resistant mineral. The depth of the geo-resistivity images recorded depends on the spacing of the electrodes and length of survey as in Fig. 4. The longer the survey line, the deeper theimages that can be recorded.

Site Investigation using Seismic Refraction Survey

Seismic techniques are focused on the measurement of an elastic wave (also: seismic, shockwave, or sound object) traveling through the sub-surface.Refraction seismic studies have been the standard tool for geotechnical work for years. However, state-of-the-art computerized seismographs for use in geotechnical work handle 24 or more channels each connected to one geophone and, hence, measure the signal of many geophones in one round. This reduces the number of sources necessary, but more importantly, has opened up the option to do seismic reflection surveys in geotechnical work with relatively low costs. A problem often encountered is the frequency content of the source signal.

The seismograph compiles and processes geophone output information in the form of traces of time. The basic elements of a seismic trace are the direct wave, the reflected wave, and the critically refracted wave. Wave refraction takes place at surface interfaces where the lower layer's seismic velocity is higher than the upper layer's velocity. Usually, this condition applies in near-surface site investigations where soil or fill overlies bedrock. Direct waves are the first seismic waves to reach geophone positions near the seismic source. However, the first arrivals shift to refracted clouds over a critical distance from the origin due to the refracted clouds ' faster relative velocity. Interpretation processes require precise estimation of first deliveries at each geophone position from the moment traces registered.Seismic refraction is based on the first arrival of a signal that travels through a layer with a higher velocity. The topsoil has velocity V 1 and the slightly weathered rock mass velocity V 2. The angle θis given by:

$$\sin(\theta) = \frac{V1}{V2}. \qquad (1)$$

The thickness of the residual soil layer can be calculated easily from Figure 1 and Equation (2).

$$\text{depth} = \frac{1}{2}\frac{V1^{*}t_i}{\cos(\arcsin(V1/V2))}, \qquad (2)$$

Where$t_i$is the intercept time (see graph Figure 1b).

For an inclined plane boundary, the survey should be repeated with the source position at the opposite end of the geophone spread (Figure 8). If the inclination between boundary and surface is relatively small, the velocities and depth become:

$$\frac{1}{V2} \approx \frac{1}{2}\left(\frac{1}{V\text{down}} + \frac{1}{V\text{up}}\right) \qquad (3)$$
$$ti_{\text{down}} = \frac{2z_{\text{down}}}{V1}\cos(\theta) \quad ti_{\text{up}} = \frac{2z_{\text{up}}}{V1}\cos(\theta),$$

Where, z_{down}, $z_{up}$are the depths below down-dip and up-dip source point, respectively.

Interpretation techniques are applied to the first arrival times to calculate the seismic velocities of the layers and the depths of individual refracting interfaces. The interfaces are correlated with real physical boundaries in the ground, such as the soil-bedrock interface and other lithological boundaries, to produce a model of the subsurface ground structure. The final interpretation is presented in a format that is easily understood by engineers.

Interpretation of Seismic Refraction Survey

In this study, the interpretation methods using traditional layered interpretation represented by the intercept-time method (ITM) by Rucker (2000) are considered. Both techniques provide seismic velocity, typically determined as part of the analysis outcomes from the first arrival of the compression wave (p-wave).There are many other techniques of interpretation available and are used in the field of geophysics.The physics of the seismic refraction method prevents straight, onward detection and interpretation of lower velocity layers or zones underlying higher velocity layers. In this case, at the interface between layers of distinct velocities, the propagation of refracted seismic energy goes downward rather than upward, and the required assumptions for ordinary interpretations are violated.

Field Work Procedure

Seismic refraction survey techniques are used to determine the thickness of underlying strata, depth to the water table (groundwater) and bedrock surfaces and uses sound waves to determine the thickness and extent of aquifer (water) materials.

The principle of seismic refraction is founded on the fact that sound waves travel at different velocities through different earth materials such as dry (unsaturated) sand and gravel, wet (saturated) sand and gravel, and bedrock. The denser the material, the faster the waves travel through it. As in resistivity surveys, seismic tests were done for two lines with a length of approximately 30 meters. Spacing between geophones was set at 1 meter with 7 points of impact from hammer towards the plastic plate to obtain proper readings.

III. RESULTS AND DISCUSSION

2D Resistivity Survey

Survey Line 1

The length of Line 1 is 30 meters. A unit electrode spacing of 0.75 meters was used which gave a maximum depth of investigation of about 8 meters. There are three different resistivity layers observed in Fig.5.

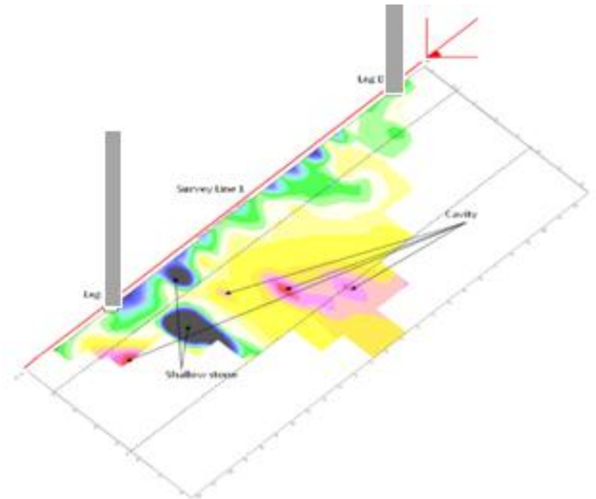

Fig.5Resistivity Image of Survey Line 1 at Tower 22 at 45° slope

The first layer is a region witha resistivity between 611 - 5337 ohm-m, which can be interpreted as unconsolidated soil and weathered material. The second layer is a region with 6579 to 12328 ohm-m of resistivity, which can be interpreted as medium-grade weathered limestone. The third region has a resistivity value of more than 12328 ohm-m, which may be interpreted as limestone bedrock. Results from 2D imaging shown in Figure 9 attributes to the following:-

1)Most of the upper layer between 0 to 2 meters of depth consists of weathered limestone with a resistivity of up to 3500 ohm.m.

2)There are a sign of cavities at 4 different locations along survey line 1 which are:-

- At 5 meters length of depth 2.5 meters and below (*extent of cavity depth is uncertain due to limitation of survey line length*)
- At 12.5 meters length of depth in between 2.8 to 3.5 meters.
- At 14.5 meters length of depth in between 4 to 5 meters.
- At 16.5 meters length of depth in between 5.5 to 6 meters.

3)Shallow stones detected at 2 locations along survey line 1 were distinguished by their resistivity value of 1000 to 2000 ohm.m. The exact location would be:-

- At 9-10 meters length of depth in between 2 to 5 meters depth.
- At 11-12 meters length of depth in between 1 to 2 meters depth.

Survey Line 2

The length of Line 2 is 30 meters. A unit electrode spacing of 0.75 meters was used which gives a maximum depth of investigation of barely 8 meters. Fig.6 shows the section of Line 2 with 30 meters in length.

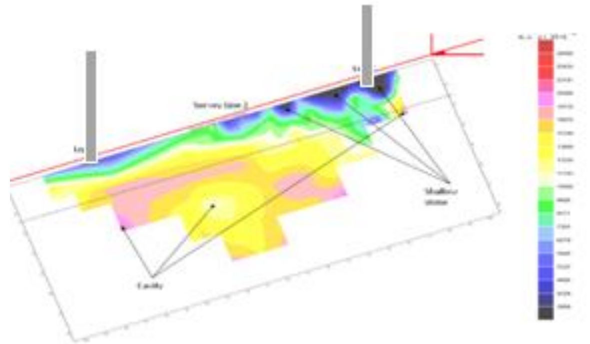

Fig. 6Resistivity Image of Survey Line 2 at Tower 22 at 20° slope

There are two different resistivity regions observed in Figure 10. The first region is a region of resistivity of 3899 to 11103 ohm-m, which may be interpreted as weathered limestone. The second region has a resistivity value of more than 16876 ohm-m, which may be interpreted as limestone bedrock. Results from 2D imaging shown in Figure 10 attributes to the following:-

1)Most of the upper layer between 0 to 2 meters depth consists of limestone with resistivity up to 3500 ohm.m.

2)There are a sign of cavities at 2 location along survey line 1 which are:-

- At 13 meters length of depth in between 4 to 5 meters.
- At 6 meters length of depth 3.5 meters and below (*extent of cavity depth is uncertain due to limitation of survey line length*)

3)Shallow stones detected at 3 locations along survey line 1 are distinguished by their resistivity value of 1000 to 2000 ohm.m. The exact location would be:-

- At 17-18 meters length of depth in between 0 to 1.5 meters depth.
- At 19-23 meters length of depth in between 0 to 2 meters depth.
- At 21 meters length of depth in between 2.5 to 3.5 meters depth.

Seismic Refraction Survey

Tables I, II and III summarize the findings of the seismic refraction survey. Three seismic layers are detected in the survey area in line 1.

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Table. 1 Summary of Seismic Refraction Results for Survey Line 1

P-wave Velocity (m/s)	Interpretation	Legend
200 - 350	Firm to Stiff or Medium Dense to Dense Overburden Material and weathered limestone, highly fractured and with clay infilling (moderate to highly – Grade 4 weathered limestone/marble)	
350 - 500	Firm to Stiff or Medium Dense to Dense Overburden Material and weathered limestone, slightly massive (less fracture) and will clay infilling at some part of join (moderate to highly – Grade 4 weathered limestone/marble)	
500 - 1500	Firm to Stiff or Medium Dense to Dense Overburden Material and weathered limestone (moderate to highly – Grade 4 weathered limestone)	

Table. 2 Summary of seismic refraction results for survey line 2

P-wave Velocity (m/s)	Interpretation	Legend
150 - 200	Weathered Material (Grade 5) with Gravel	
200 - 350	Firm to Stiff or Medium Dense to Dense Overburden Material and weathered limestone, highly fractured and with clay infilling (moderate to highly – Grade 4 weathered limestone/marble)	
350 - 500	Firm to Stiff or Medium Dense to Dense Overburden Material and weathered limestone, slightly massive (less fracture) and will clay infilling at some part of join (moderate to highly – Grade 4 weathered limestone/marble)	

Table. 3 Summary of Seismic Refraction Results

Survey Line	Velocity of first layer (ms-1)	Thickness of first layer (m)	Velocity of second layer (ms-1)	Thickness of second layer (m)	Velocity of third layer (ms-1)	Thickness of third layer (m)
1	362.0-388.0	1.8-12.8	388.0-398.0	5.6-5.7	398.0-456.0	11.4-22.5
2	182.0-191.0	3.3-11.8	191.0-212.0	3.9-5.8	221.0 above	12.3-22.9

The first layer with a velocity of 362 $ms^{-1}$to 388 ms^{-1} may represent soft unconsolidated soil and weathered material. The second layer is interpreted as medium weathered limestone bedrock with a seismic velocity in between 388 $ms^{-1}$to 398 ms^{-1}. The third layer is represented as limestone bedrock with a seismic velocity of 398 to 456 ms^{-1}. Similarly, Line 2 is divided into three sections, one with a velocity between 182 ms^{-1} to 191 ms^{-1} while the other two with velocity between 191 ms^{-1} to 212 ms^{-1} and 182 ms^{-1} to 191 ms^{-1}, respectively. The first section is interpreted as being soft unconsolidated soil and weathered material. The second layer is interpreted as being medium weathered limestone bedrock and the third layer limestone bedrock.

IV. CONCLUSION

The seismic refraction sections show three distinct seismic layers up to 30 meters. The thicknesses of all the layers are summarized in Table 7. The wide range of bedrock velocities shows that the bedrock in the area has a few grades of weathering. Cavity zones can be found at 2 m to 6 m, 10 m to 12 m and 18 to 22 m below the base of Tower 22. The resistivity sections show three different regions with low (<611 ohm-m), medium (100-5337 ohm-m) and high (> 6500 ohm-m) resistivity values. The first layer is a region of resistivity between 611-5337 ohm-m bedrock. Note the concentration of the medium resistivity value, which is a cavity zone at 2 m to 8 m in Line 1 and 2.5 m to 8 m below the base of Tower 22. All interpretations for which can be interpreted as unconsolidated soil and weathered material. The second layer is the region 6579 to 12328 ohm-m, which can be interpreted as medium grade weathered limestone. The third region has the resistivity value of more than 12328 ohm-m, which may be interpreted as limestone resistivity survey subjected to a horizontal plane position of the slope.

Based on the result of 2D resistivity and seismic refraction done along the survey line, it can be concluded that the cavity resides below the location of leg A of proposed tower area from depth 2 meter to below (3 location detected with cavity which isat 2 to 6 meters, 10 to 12 meters and 18 to 22 meters). At leg C, the underground layer beneath it consisted of shallow stones whereby the possibility of cavity residing within the area is high.

Possible cavity detected below leg C would be at depth of 2 to 6meters. For survey line 1, the encountered cavity is approximately 1 meter away from leg B starting at depth 2 to 8 meters) while shallow stone detected just below the leg. The area of leg D showed promising results whereby no cavitiesnor shallow stoneswere encountered within its area. The nearest cavity towards leg D would be at 3 meters away starting at depth of either 4 or 6 meters. Based on seismic refraction test for both survey lines, UCS values are as follows (in reference to Paulos.H&Whitley.R, 2007-Coffey Geotechnic);

- Layer 1 & 2: UCS is less than 10MPa.
- Layer 3: UCS in between 10 to 20 MPa.

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