Relationships between geophysical and geotechnical parameters focusing on a site specific results of a landslide risk area

Relaciones entre los parámetros geofísicos y geotécnicos centrados en los resultados específicos de un sitio en un área de riesgo de deslizamiento de tierra

Relações entre parâmetros geofísicos e geotécnicos com foco em resultados específicos de uma área de risco de escorregamentos

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Abstract

The population growth and extension of a settlement on a risky area have increased the impact of natural disaster. Slope failures, landslides and subsidence of foundation have been identified as the most commonly occurring natural disaster if such sensitive areas are not well monitored. On the other hand, a detailed analysis of the triggering factors is often hindered by the lack of information gathered from the field measurements. A survey investigation was performed in a possible landslide risk area, using the geotechnical, geophysical and geological mapping approaches. The geotechnical investigations included coring in order to obtain the lithological sequence and for sampling purposes. And standard penetration test (SPT) in-situ field tests of soil strength. Electrical resistivity tomography (ERT) and seismic refraction tomography investigations were executed in order to determine the hydrogeological characteristics and delineate the regions of weak and hard subsurface materials. The 2D inversion results of resistivity technique suggested the presence of a two-layer structure model. Moreover, the 'break' in the unit was apparent, indicative of the presence of weak zones, fractured zone and cracks. As also demonstrated clearly by the seismic refraction data, the depth to bedrock (a sharp boundary interface approximately at a depth of 15 m) varies, and such variation is mainly attributed due to the thickness of the overlying backfill material.

Resumen

El crecimiento de la población y la extensión de un asentamiento en un área de riesgo han aumentado el impacto de un desastre natural. Las fallas en la pendiente, los deslizamientos de tierra y el hundimiento de la fundación se han identificado como el desastre natural más frecuente si dichas áreas sensibles no están bien monitoreadas. Por otro lado, un análisis detallado de los factores desencadenantes a menudo se ve obstaculizado por la falta de información obtenida de las mediciones de campo. Se realizó una investigación en un área de riesgo de deslizamiento posible, utilizando los enfoques de mapeo geotécnico, geofísico y geológico. Las investigaciones geotécnicas incluyeron la extracción de muestras para obtener la secuencia litológica y para fines de muestreo. Tambien pruebas de penetración estándar (SPT), pruebas de campo in situ de la resistencia del suelo. La tomografía de resistividad eléctrica (ERT) y la tomografía de refracción sísmica se realizaron para determinar las características hidrogeológicas y delinear las regiones de materiales subsuperficiales débiles y duros. Los resultados de inversión 2D de la técnica de resistividad sugirieron la presencia de un modelo de estructura de dos capas. Además, la "rotura" en la unidad era aparente, indicativa de la presencia de zonas débiles, zona fracturada y grietas. Como también se demuestra claramente por los datos de refracción sísmica, la profundidad al lecho de roca (una interfaz de

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Additionally, we examined the possible correlation (if any) between geophysical parameters and geotechnical parameters to establish the quantitative estimates of a particular geotechnical parameter (e.g., soil strength) from geophysical surveys. From this study, a good relationship between electrical property (resistivity) and geotechnical property (soil strength) with the empirical equation RS= 31.733 (N60) -165.88 and regression coefficient R2=0.77 was observed. Based on the correlation between elastic property and weathering profile, we divided the subsurface materials into three zones: the first zone is classified as Residual soil with p-wave velocity (300 – 900 ms-1), the second zone is classified as highly weathered granite with p-wave velocity (900 – 1800 ms-1), and the third zone is classified as moderately weathered granite with p-wave velocity (1800 – 3000 ms-1). All geophysical and geotechnical data suggest that a fairly weak/uncompact backfill materials underlying the bedrock are likely to provide a planar surface where the landslide mass would move/be triggered.

Keywords: landslide, borehole, seismic refraction, electrical resistivity tomography, Wenner –Schlumberger, standard penetration tests.

borde afilada aproximadamente a una profundidad de 15 m) varía, y dicha variación se atribuye principalmente debido al grosor del material de relleno suprayacente. Además, examinamos la posible correlación (si existe) entre los parámetros geofísicos y los parámetros geotécnicos para establecer las estimaciones cuantitativas de un parámetro geotécnico particular (por ejemplo, la resistencia del suelo) a partir de estudios geofísicos. En este estudio, se observó una buena relación entre la propiedad eléctrica (resistividad) y la propiedad geotécnica (resistencia del suelo) con la ecuación empírica RS = 31.733 (N60) -165.88 y el coeficiente de regresión R2 = 0.77. En función de la correlación entre la propiedad elástica y el perfil de intemperie, dividimos los materiales del subsuelo en tres zonas: la primera zona se clasifica como suelo residual con velocidad de onda p (300 - 900 ms-1), la segunda zona se clasifica como altamente meteorizada el granito con velocidad de onda p (900 - 1800 ms-1), y la tercera zona se clasifica como granito moderadamente degradado con velocidad de onda p (1800 - 3000 ms-1). Todos los datos geofísicos y geotécnicos sugieren que un material de relleno bastante débil / no compacto que subyace en el lecho de roca es probable que proporcione una superficie plana donde la masa de deslizamiento de tierra se movería o se activaría.

Palabras claves: deslizamiento de tierra, perforación, refracción sísmica, tomografía de resistividad eléctrica, Wenner-Schlumberger, pruebas de penetración estándar.

Resumo

O crescimento da população e a extensão de um assentamento em uma área de risco aumentaram o impacto de um desastre natural. Falhas na encosta, desmoronamentos e subsidência da fundação foram identificados como o desastre natural mais freqüente se essas áreas sensíveis não forem bem monitoradas. Por outro lado, uma análise detalhada dos gatilhos é muitas vezes dificultada pela falta de informações obtidas a partir das medições de campo. Foi realizada uma investigação em uma área de risco de escorregamento, utilizando as abordagens de mapeamento geotécnico, geofísico e geológico. As investigações geotécnicas incluíram a extração de amostras para obter a seqüência litológica e para fins de amostragem. Também testes de penetração padrão (SPT), testes de campo in situ de resistência do solo. Tomografia por resistividade elétrica (TRE) e tomografia de refração sísmica foram realizadas para determinar as características hidrogeológicas e delinear as regiões de materiais subsuperfície fracos e duros. Os resultados da inversão 2D da técnica de resistividade sugeriram a presença de um modelo de estrutura de duas camadas. Além disso, a "quebra" na unidade era aparente, indicando a presença de áreas fracas, área fraturada e rachaduras. Como também é claramente demonstrado por dados de refração sísmica, a profundidade do leito de rocha (uma interface de borda afiada a aproximadamente uma profundidade de 15 m) varia, e essa variação é atribuída principalmente devido à espessura do material de preenchimento sobreposto. Além disso, examinou-se a correlação possível (se algum) entre os parâmetros geofísicos e geotécnica parâmetros para estabelecer estimativas quantitativas de um determinado parâmetro geotécnica (por exemplo, a resistência do solo) a partir de levantamentos geofísicos. Neste estudo, foi observada uma boa relação entre a propriedade eléctrica (resistividade) e propriedade geotécnica (resistência do solo) com as equações empíricas RS = 31,733 (N60) e -165,88 coeficiente R2 = 0,77 regressão. Dependendo da relação entre a propriedade elástica e os elementos de perfil, que divide os materiais do subsolo em três zonas: primeira zona é classificada como solo residual com velocidade de onda de cisalhamento p (300-900 ms-1), a segunda zona classificada como granito altamente resistido com velocidade de onda P (900 - 1.800 ms-1), e a terceira área é classificada como moderadamente degradada velocidade da onda de granito p (1800-3000 ms-1). Todos os dados geofísicos e geotécnicos sugerem que um material de preenchimento bastante fraco / não compacto subjacente ao leito rochoso provavelmente fornecerá uma superfície plana onde a massa de escorregamento se moveria ou se ativaria.

Palavras-chave: aterramento, perfuração, refração sísmica, tomografia de resistividade elétrica, Wenner-Schlumberger, testes de penetração padrão.

Introduction

Landslide is considered as a word-wide hazard due to its high levels of damage. In Malaysia every year during the monsoon season, the occurrence of slope failures and landslides can be observed; and after floods, slope failures and landslides have been reported as the second most destructive natural disaster (Matori et al., 2011). These landslides either cause closure of road for remediation, affect the foundation stability of building, or worse, they sometimes cause causalities and huge economic loss (Gue, 2002). However, a detailed analysis of the triggering factors is often hindered by the lack of information gathered from the field measurements (Tsai & Chen, 2010). Meanwhile, the investigations carried out in the landslide area consist of geological mapping, geotechnical parameters, and geophysical measurements.

The geotechnical investigations are performed in order to obtain the lithological sequence of the subsurface materials as well as to determine the physical parameters of subsurface materials. These physical parameters such as standard penetration test (SPT), Rock quality designations (RQD) and point load test are the important key for defining the subsurface characteristic.

Standard penetration test (SPT) is an in-situ field test of soil which presents an idea concerning the soil's shear strength and can be expressed with respect to shear strength parameters. These tests are laborious and time-consuming (Venkatasubramanian & Dhinakaran, 2011). Meanwhile, the rock quality designation (RQD) is used as a standard parameter in drill core logging to provide a quantitative estimate of rock mass quality.

Recently, the geophysical investigation has been carried out to assist the underground characteristics (McCann & Forster, 1990; Bruno & Marillier, 2000; Gallipoli et al., 2000; Hack, 2000; Mauritsch et al., 2000; Lapenna et al., 2003). Geophysical investigation has been employed in the study of landslide since the late 1970s (Bogoslovsky & Ogilvy, 1977; Caris & Van Ash, 1991; Hack, 2000; Havenith et al., 2000) to determine the landslides characteristics and provide useful information in planning the constructions in the areas prone to landslide.

This study was conducted at National Secondary School in Bukit Tinggi, Bentong. Based on a geological survey conducted by the Department of Mineral and Geosciences Pahang (JMG) in 2015, the vicinity area of a Secondary School in Bukit Tinggi, Bentong Pahang is considered as one of the natural terrain areas (weathered granite) prone to landslide hazards and should be effectively monitored to provide the forewarning of slope movements. Accordingly, the early field observations in the school compound revealed the occurrence of elongated cracks on the damaged walls, parking lot and roadside within the school premise (Terrain Resources, 2016). These indications are believed to be associated with ground movement at the vicinity of school compound and the slope/terrain instability areas.

In the present study, the data for both the seismic refraction (SR) and electrical resistivity tomography (ERT) methods were correlated with the borehole data gathered from the location of the study. The correlation achieved in the present study could assist in the determination of the signature of engineering parameters from the infield data. The attempt at linking the rock quality with seismic velocity has been performed at intervals, in the course of rock engineering and engineering geology development and integration.

This paper presents the results of correlation between two different geophysical techniques with geotechnical parameters to evaluate the subsurface conditions for the National Secondary School in Bukit Tinggi area, and the results were deeply discussed to get a comprehensive understanding of the subsurface conditions.

The study area

The study area involves an area of 10.09 acres and Located on SMK Bukit Tinggi (Figure 1b). The site is located with the coordinate of 3°21'16.95"N 101°50'24.9"E. The site itself is easy to access but the area at the west boundary is hard to access because of the steep slope and moderate vegetation (Terrain Resources., 2016).

The main topography of the site is mostly categorised as an excavated platform at the centre, and surrounded by cut and fills area within the school's boundary is based on the data collected during the construction's period. Based on the topographical survey plan provided by a licensed surveyor, the highest point of the proposed development site is approximately at 310 m of elevation and is located in the south of the study region, while the lowest point is approximately at 262 m of elevation which can be found in the eastern part of the development area.

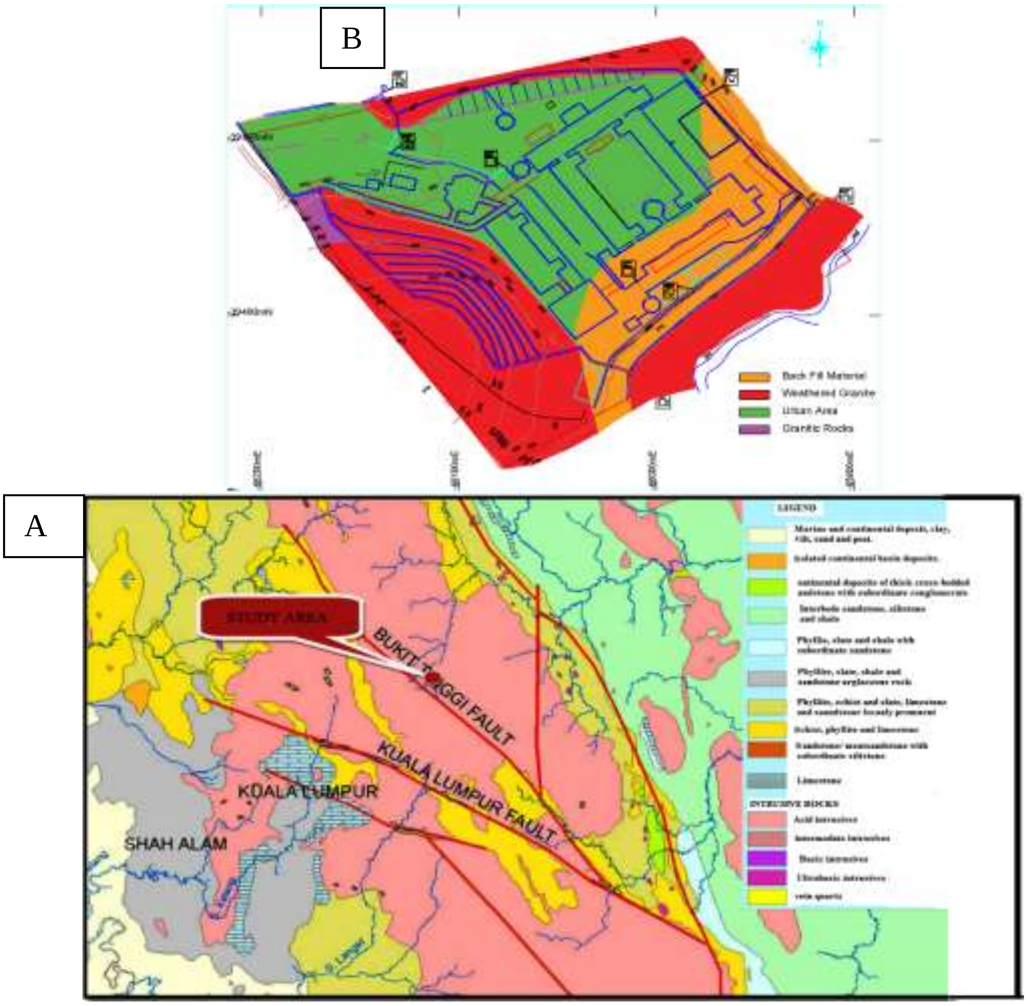

Fig. 1. (A) Schematic geological map of the focus area (modified from Mineral and geosciences department 2015). (B). Plan view of the school compound and preliminary areas of investigation using geophysics and geotechnical (modified and based on Terrain resources, 2016).

The areas of study include the south-western side of Pahang as well as to the east of the main range of Peninsular Malaysia. The geology of the study area is summarized in the simplified map shown in Figure 1a.

The geology of the site essentially consists of granite. The granite rocks consist of highly porphyritic and very coarse-grained biotite granite, medium porphyritic coarse-grained biotite granite, porphyritic medium coarse-grained biotite granite, and non-porphyritic fine-grained biotite granite. Also, the granite boulders have been observed along the school border.

There is not much of outcrop observed along the study area. The site has been mostly covered by the weathered granite and backfills material. The terrain has undergone weathering to form residual soils of varying thickness. The texture of the zone is reddish brown consisting of silty sand that covers the surface of the entire area.

Tectonically, the area is controlled by the Bukit Tinggi Fault which is considered an active strike-slip fault zone with a substantial component of dip-slip. This fault is typified by mylonite zones, fault breccias and large quartz veins. The sub-horizontal to moderately inclined stretching lineation in the mylonites alongside the fault zone denotes that it is fault kinematic studies on the mylonites implies that the early ductile movement had a dextral sense of shear (Ng, 1994). However, at Kuala Kelawang and along the Karak Highway, it was shown that the movements were sinistral (Zaiton Haron, 2002).

Investigation methods

In carrying out site investigation, some of the data acquired include borehole coring, standard penetration test (SPT) value and rock quality designation (RQD) values. Seismic refraction (SR) and electrical resistivity tomography (ERT) methods are carried out in addition to these tests on the site. Five of ERT profiles were carried out using a Schlumberger quadrupole configuration so that a better resolution of the geological units near the ground surface can be attained. Meanwhile, six SR profiles were conducted with a total profile length of 115 m in order to confirm the resistivity assumption and correlate with other data.

Geotechnical methods

A total of four boreholes were drilled in the selected area by using the wash boring machine, which provides power rotation of drilling bit and removal cutting by circulation of fluid. These boreholes were terminated when reaching 30 meters. The size of these holes was 100 mm in diameter and rock coring was carried out in accordance ASTM 2113.

SPT-N-values

Standard Penetration Tests were performed utilizing a split barrel sampler and a self-tripping hammer of approved design. The value of the N was reported with the number of blow counts for each 75mm penetration of the sampling tube. For the first 150mm penetration (the seating drive), the blow counts which do not contribute the value of N were also included.

There are numerous factors other than the hammer type that are affecting the N value. Relevantly, many authors have proposed the correction factors to account for factors including the drill stem's length and type, the type of anvil, the blow rate, the usage of liners or borehole fluid and the hammer type. The corrected SPT values N (60) are computable from the field measured Nf from the general equation (excluding the corrections made to overburden) (Aggour & Radding, 2001) shown below:

$$N(60) = N_f \; n1 \; n2 \; n3 \; n4 \; n5 \; n6 \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: n1 denotes the energy correction factor
n2 denotes the rod length correction factor
n3 denotes the liner correction factor
n4 denotes the borehole diameter correction factor
n5 denotes the anvil correction factor
n6 denotes the blow count frequency correction factor

In this study, the table employed in Aggour and Radding (2001) was used, and following the field conditions and soil type, the average values of correction factors are as follows: n1 = 1.67, n2 = 1.0, n3 = 1.0, n4 = 1.0, n5 = 0.7, n6 = 1.0).

Rock Quality Designation (RQD)

The rock quality designation is employed as a standard parameter in drill core logging to provide a quantitative estimate of rock mass quality. The classification of RQD values and Rock mass quality is displayed in Table 1. A total of four core samples were made as a description for furnishing good information concerning the quality of the underground rocks in the study area.

Table1. Rock Mass Classification from RQD Index (Deere et al., 1967)

RQD	Rock mass quality
< 25%	very poor
25% - 50%	poor
50% - 75%	fair
75% - 90%	good
90% - 100%	excellent

Results and discussion

The results of RQD data were obtained from four boreholes correlated with depth as shown in Figure 3 below.

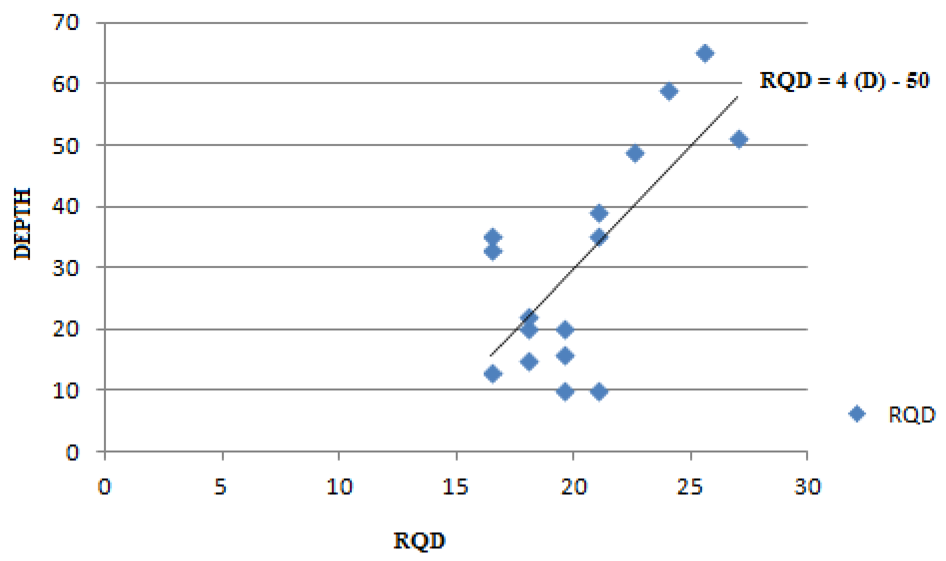

Fig. 2. The relationship between RQD and depth in the study area.

As shown in this figure, the relationships between RQD and depth are below the ground surface. Here, it can be noticed that the depth of RQD samples ranges between 16.5 – 28 meters below the ground surface and the value of RQD ranges between 10 and 63.

The relationship between RQD and depth is expressed as the following equation:

$$RQD = 4^{*} (D) - 50.449$$

Where: RQD is rock quality designation value, and D is the depth of the sample.

Following this equation on the rock mass quality, the rocks in the study area with a depth less than 25 meters are classified as poor to very poor rocks. Accordingly, Table 2 summaries the geological classification.

Table 2. The Geological Classification of Rocks in the Study Area

DEPTH	RQD	GEOLOGICAL CLASSIFICATION
<15 M	-	VERY POOR
15-23 M	LESS THAN 50	POOR
> 23	50- 75	FAIR

Correlation between geotechnical parameters and geophysical results.

In the environmental study has evidenced the countless physical parameters to be taken into account prior to making a crucial decision for civil construction. The aforementioned physical parameters are integral in denoting their behaviour which is affected by time and changes in condition. Accordingly, in the present study, the data for the SR and ERT are correlated with the borehole data gathered from the region under study. Notably, soils have complicated in-situ behaviour considering that the behavior is highly impacted by many factors. Hence, in order to have the right comprehension, these soils need to be analyzed using geophysics and geotechnical engineering skills, in addition to using other related disciplines such as geology, geomorphology, climatology and other earth and atmosphere associated sciences (Bery & R. Saad, 2012).

The SR employed in this study encompasses 4 seismic lines comprising 4 borehole datasets. As can be viewed in Table 3, the correlation between P-wave velocities (VP) and granitic rocks can show the level of weathering of the rock layer of weathered granite rock mass in peninsular Malaysia as presented in RafiqulIslam and Zaw Win (2005).

Table 3. Weathered granite rock mass classification in peninsular Malaysia. (Source: Extracted and adapted from Islamic Rofiqul@ Zaw Win 2005).

Weathered Grade	P Wave Velocity (ms^{-1})	Explanation
VI and V	300-900	Residual soil and overall weathered
IV	900-1500	Highlyweathered
III	1500-2500	Moderatelyweathered
II	2500-4000	Slightlyweathered
I	4000-6000	Freshrock

Profile line 1 (SR1):

The results of the seismic refraction survey in profile line 1 present 3 zone. From the recorded Vp velocity, the range of Vp is from 300 to 900 m/s consisting of residual soils and completely weathered granite. This zone is classified as a zone of weathering grade VI to V and the thickness was varied from 0 to 15.5 meters from the surface. Zone 2 is underneath of zone 1. Consist of high weathered granitic rocks (grade IV). The recorded Vp velocities ranged from 900 to 1800 m/s. This zone begins at a depth of 15.5 meters from the surface and the thickness ranges from 4 to 5meters. The third zone consists of weathered granitic rocks of medium-grade III with a Vp velocity of 1800-3000 m/s and has a thickness of 4-6 meters (Figure 4).

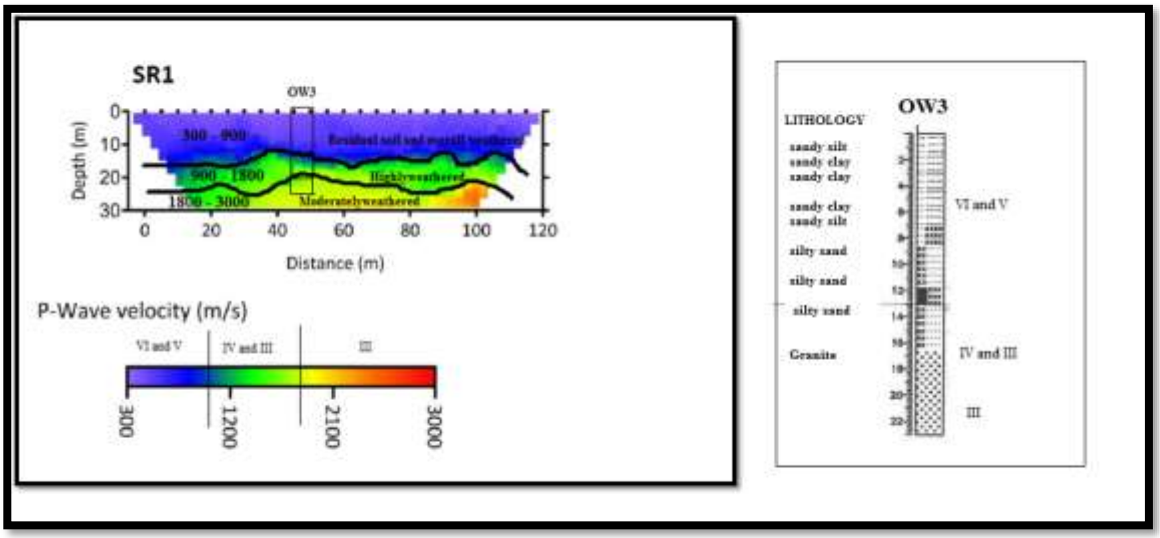

Fig. 3. The Correlation between SR Line 1 and borehole OW3

Profile line 2 (SR2)

Profile 2 presents 2 zones. The range of Vp is from 300 to 900 m/s consisting of residual soils and completely weathered granite. This zone is classified as a zone of weathering grade VI to V and the thickness was varied from 0 to 11 meters from the surface. Zone 2 is underneath of zone 1 and consists of high weathered granitic rocks and classified as a zone of weathering grade IV. The recorded Vp velocities ranged from 900 to 800 m/s. This zone begins at a depth of 11 meters from the surface and the thickness ranges from 14 to 15 meters (Figure 5).

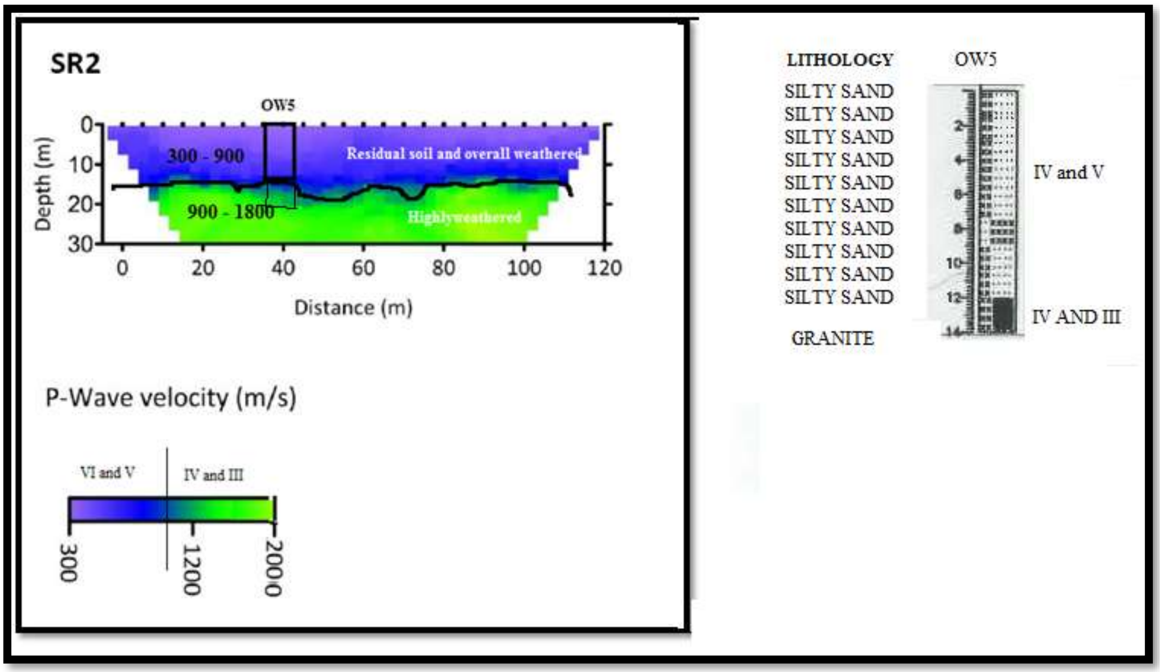

Fig. 4. The correlation between SR Line 2 and borehole OW5.

Profile line 3 (SR3)

The study of seismic refraction survey in profile line 3 found the 3 zones (Figure 6). From the recorded Vp velocity, the range of Vp is from 300 to 900 m/s consisting of residual soils and completely weathered granite. This zone is classified as a zone of weathering grade VI to V and the thickness was varied from 13 to 15 meters from the surface. Zone 2 is underneath of zone 1 and it consists of high weathered granitic rocks (Grade IV). The recorded Vp velocities ranged from 900 to 1800 m/s. This zone begins at a depth of 13 meters from the surface and the thickness ranges from 7 to 10 meters. The third zone consists of weathered granitic rocks of medium-grade III with a Vp velocity of 1800-3000 m/s and has a thickness of 10 - 12 meters.

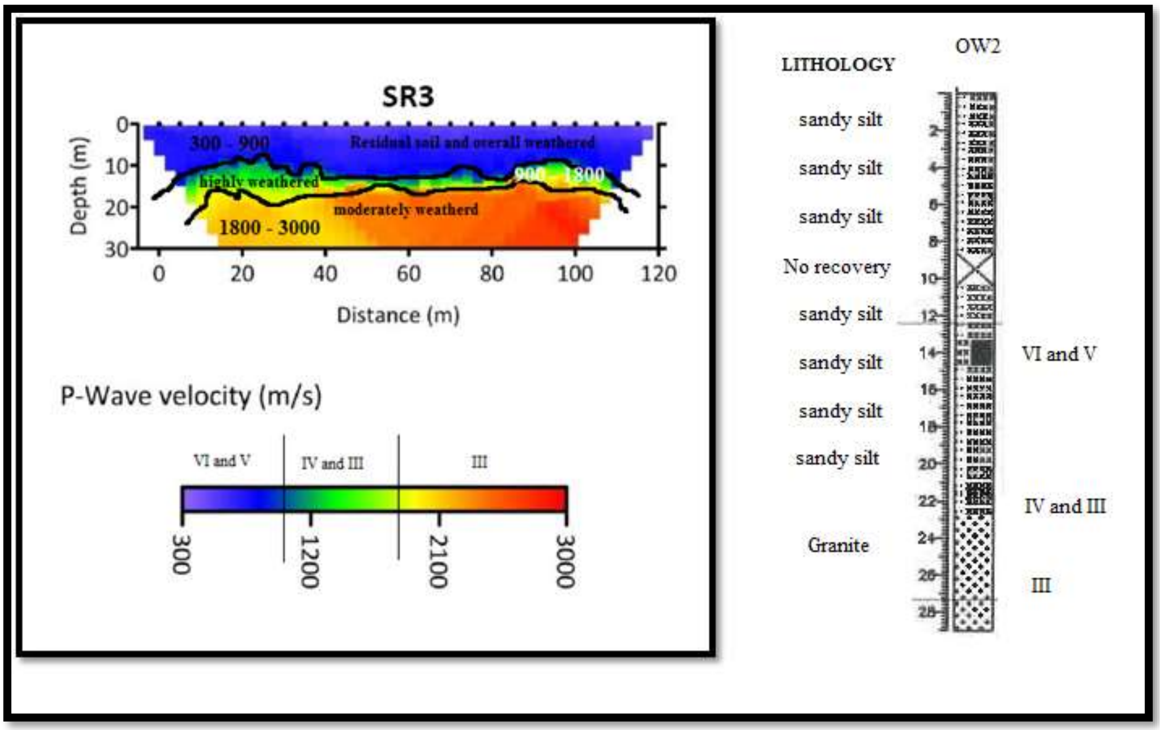

Fig. 5. The correlation between SR Line 3 and borehole OW2

Profile line 4 (SR4)

Profile 2 presents 2 zones. The range of Vp is from 300 to 900 m/s consisting of residual soils and completely weathered granite. This zone is classified as a zone of weathering grade VI to V and the thickness was varied from 16 to 18 meters from the surface. Zone 2 is underneath of zone 1 and consists of high weathered granitic rocks (Grade IV). The recorded Vp velocities ranged from 900 to 1800 m/s. This zone begins at a depth of 16 meters from the surface and the thickness ranges from 14 and 15 meters.

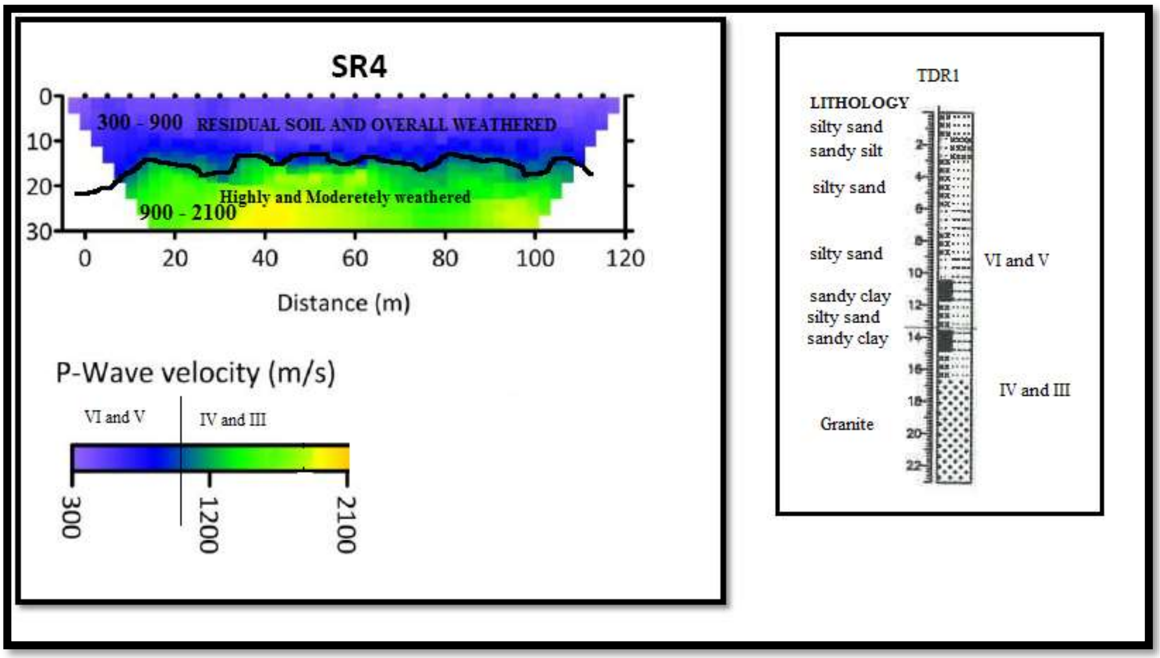

Fig. 6. The correlation between SR Line 4 and borehole TDR1

Weathering Zone Interpretation

Vp velocity in the field is heavily influenced by many factors such as the existence of cracks and squats (particularly in granitic rocks), porosity and groundwater conditions. Many of the weathered zones layer and recorded for each line based on the velocity, and the Vp survey showed decreasing weathering grade of rock depth albeit the incomplete grade sequence. Thus, with reference to the results obtained, grade VI residual soil and weathered rock are of severe grades V at the very top or surface layer exposed. Grade VI residual soil has a velocity Vp less than 400 m/s while the Vp velocity of grade V ranged from 300 to 900 m/s.

In summary, the relationship between Vp values obtained and the grade of weathering in each area of study can be summarized as in Table 3.

Table 5. The Relationship between P Wave Velocity and Rock Weathering Grade Obtained in the Study Area

GEOLOGICAL CLASSIFICATION	P- WAVE VELOCITY ms-1	WEATHER GRADE
Residual soil and overall weathered	300 – 900	VI and V
Highly weathered	900 – 1800	IV and III
Moderately weathered	1800 – 3000	III

Correlation between ERT and SPT values

ERT and SPT have been carried out at the location (figure 8) in order to make a correlation between the apparent resistivity of soil and the number of blow counts (N 60 values) obtained from SPT data. These correlations show the worth of the ERT method in the geotechnical investigation, which, as opposed to the other geotechnical method, is economic, professional and less time-consuming. In this study, the results of the combined correlation between SPT from four borehole and resistivity values with respect to depth are shown in Table 6. The relationship between ERT and corrected SPT are compared in Figure 9.

Table 6. The Results of Value of SPT and ERT with Respect to the Depth

N60	RES	Depth
6	99	1.5
10	100	3
7	58	4.5
6	33	6
10	60	7.5
12	170	9
6	80	1.5
8	139	3
8	75	4.5
11	81	6
9	142	7.5
10	103	9
14	260	11
15	335	12.5
13	230	14
15	350	15.5
16	450	15.5

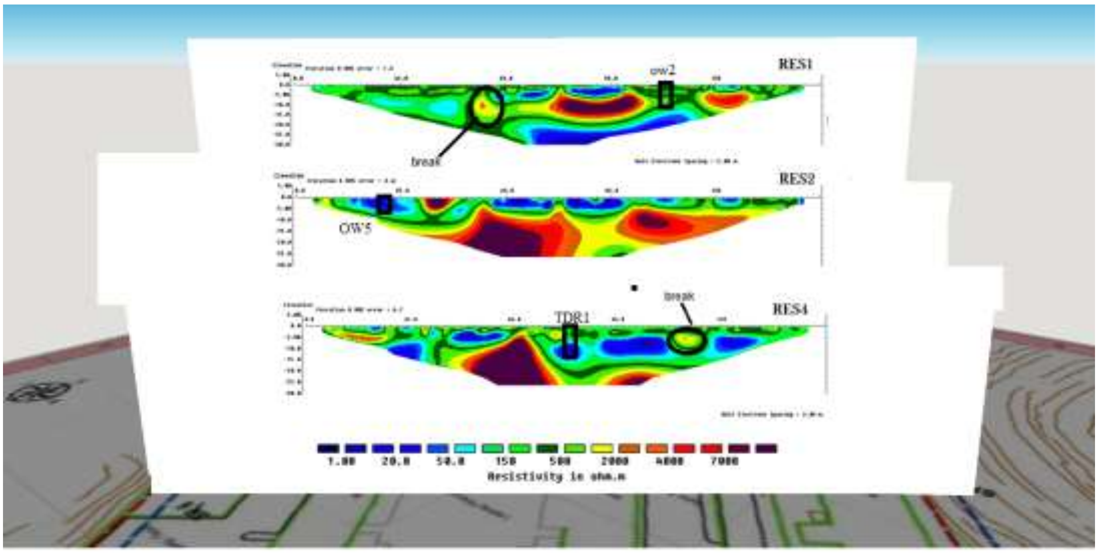

Fig. 7. The inversion results of the ERT and SPT location.

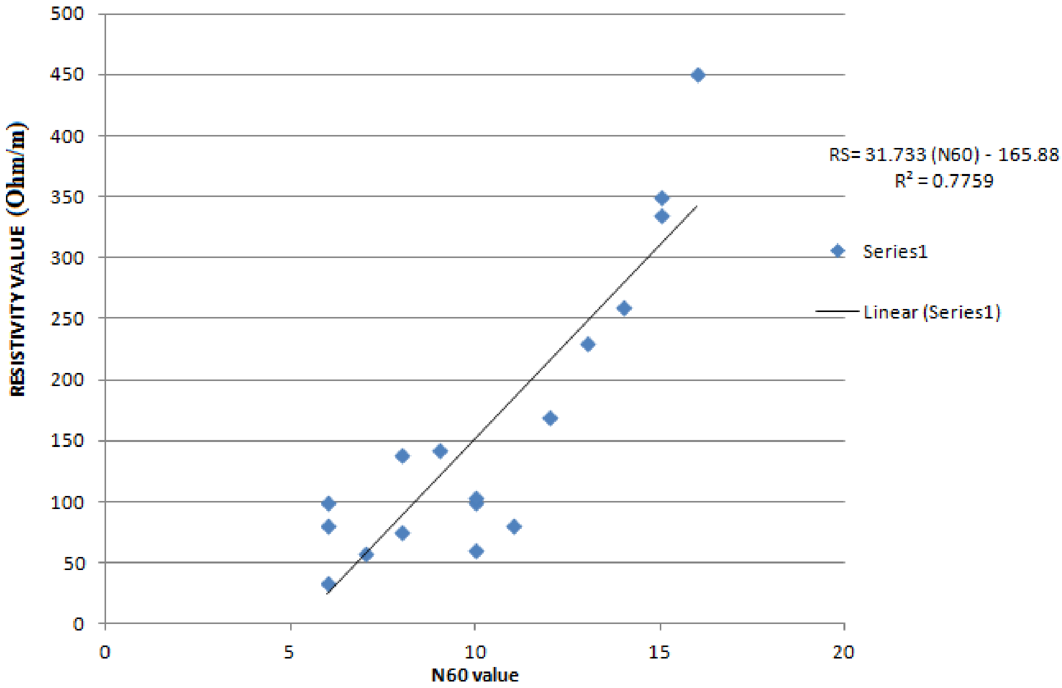

Fig. 8. The relationship between ERT and SPT in the Study Area.

ERT values range between 33 and 450 Ωm, which are considered as a conductive zone. The conductive zone is indicative of clay-rich material or higher sand and/or gravel composition. Also, the corrected SPT values range between 6 and 15 which is considered soft to the very soft soil. As observed in Figure 8, a good correlation between these two parameters with (R2=0.77) and a linear relationship between SPT and ERT with the empirical equation RS= 31.733 (N60) - 165.88 can be applied in the Bukit Tinggi area.

Conclusion

The correlation of geophysical data with geotechnical parameters was carried out at National Secondary School in Bukit Tinggi in Bentong Pahang for the Bukit Tinggi area. These correlations have afforded useful information for future correlation study. RQD correlation indicates that there are three zones in the study area and the depth below 23 m underground is considered a weak zone. Also, the SR lines and borehole data confirm that, and provide a good interpretation for the subsurface condition of the study area. Therefore, with reference to the results obtained, the study area consists of three zones according to weathered grade and classified as: grade VI residual soil and weathered rock are severe grades V at the very top or surface layer exposed. Grade IV and III Highly weathered has a velocity Vp less than 900-1800 m/s and the Vp velocity of grade III ranged from 1800 and 3000 m/s. The ERT data show a good relationship between SPT and ERT with the empirical equation RS= 31.733 (N60) -165.88 that can be applied in the Bukit Tinggi area.

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