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CORRELATION BETWEEN SEISMIC REFRACTION AND BOREHOLE DATA FOR SUBSURFACE EVALUATION

Edy Tonnizam Mohamad, Mohd Nur Asmawisham Alel*, Nurul Farahain Masdi

Geoengineering and Geohazard Research Group, Department Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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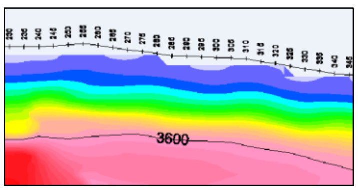
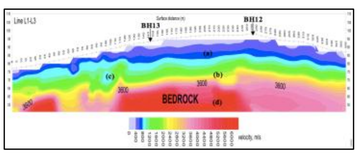
*Corresponding author
alel@utm.my

Graphical abstract





Abstract

In conventional way, investigation of the subsurface parameter is determined from boreholes data. However, the information retrieved from a bore log only provides information at a discrete location. Geophysical method such as seismic refraction has been routinely used to compliment the 'missing' boreholes information as it offers continuous information along the survey line. This paper presents the relationship between seismic refraction method and borehole logging in a granitic area at Ulu Tiram, Johor. Three lines of seismic survey were carried out to assess the subsurface for quarry development. Two boreholes were drilled along the seismic line in the effort to find relationship between information gathered from those methods. The seismic survey results are evaluated along with SPT and RQD information. Results for the correlation of seismic refraction survey and borehole data can be used for better subsurface characteristics exploration between boreholes besides providing data rapidly at a relatively low cost and give benefits in terms of work time.

Keywords: Subsurface; boreholes; seismic refraction; correlation

Abstrak

Dalam kaedah biasa, penyiasatan parameter subpermukaan ialah ditentukan melalui data lubang jara. Walau bagaimanapun, maklumat yang diambil dari data lubang jara hanya memberikanmakluat lubang jara yang berada di lokasi yang terhad. Kaedah geofizik seperti pembiasan seismik telah secara rutin digunakan untuk penambahbaikan maklumat subpermukaan tanah kerana ia memberi maklumat yang berterusan sepanjang garis penyiasatan. Kertas kerja ini membentangkan hubungan antara kaedah pembiasan seismik dan lubang jara di kawasan batu granit di Ulu Tiram, Johor. Tiga peringkat kajian seismik telah dijalankan untuk menilai permukaan bawah tanah bagi tujuan pembangunan kuari di kawasan tersebut. Dua lubang jara telah digerudi berhampiran dengan garisan seismic bagi digunakan untuk mencari hubungan antara kedua-dua kaedah ini. Keputusan daripada kajian seismik telah dinilai melalui maklumat SPT dan RQD. Keputusan daripada kolerasi kajian pembiasan seismik dan lubang jara boleh digunakan untuk mendapatkan penerokaan subpermukaan yang lebih baik disamping menyediakan keputusan yang cepat pada harga yang rendah dan memberi manfaat dari segi masa kerja.

Kata kunci: Subpermukaan; lubang jara; pembiasan seismik; kolerasi

1.0 INTRODUCTION

In site investigation work, the subsurface characteristic is mainly determined from a borehole data. On the other hand, surface seismic refraction survey claimed that this method could also helps in determining the subsurface profile and has been routinely used to supplement the borehole data. Its application has been used in studying the shallow subsurface for a variety of applications, such as engineering problem, geotechnical evaluations, environment studies, hydrogeological investigation and others. Often, the seismic refraction method are used as a preliminary phase in understanding the general overview of a site prior planning for a more detailed boring program.

The study is carried out to evaluate and compare the result of seismic refraction survey and borehole logging data in a granitic area, which are represented by the following objectives;

(i) To evaluate the subsurface profile through seismic refraction method
(ii) To investigate the suitability of seismic refraction method in determining the depth of bed rock
(iii) To compare the information provided by the seismic refraction with borehole method in evaluating shallow subsurface.

The conventional method of investigating the subsurface profile by using drilling boreholes relatively is more expensive and provides information only at discrete location. There has been increased interest recently in the use of geophysical surveying for the subsurface exploration although sometimes prone to ambiguities of interpretation, it provides a very cost effective and less time consuming by means of deriving really distributed information on subsurface geology [1]. In general, geophysical exploration methods used to determine the distributions of physical properties at depths that reflect the local subsurface geology.

2.0 LITERATURE REVIEW

Seismic surveying is based on the stress and strain concept. When the stress applied to an elastic medium, the energy imparted to the Earth will be transmitted to the form of elastic waves and propagate through or on the surface of the Earth which is known as seismic waves. There are two categories of seismic waves; body waves and surface waves. Body waves are elastic waves that propagate through the internal medium but surface waves propagate along the surface medium. Virtually, in exploration surveys, surface waves are a form of noise and the consideration is only to the body waves.

Seismic body waves can be subdivided into two waves; Longitudinal or P-waves and Transverse or S-waves. P-waves propagate by compressional and dilational uniaxial strain in the direction of wave travel. But S-waves propagate by a pure shear strain in a direction perpendicular to the direction of wave travel. In history of seismic surveying, most survey has used only compressional waves due to it simplifies the survey technique in two approaches [2]. Firstly, the detectors of seismic survey only record the vertical ground motion and insensitive to the horizontal motion of S-waves. Secondly, it easy to recognize since the higher velocity of P-waves always reach a detectors before any related S-waves (V_s<V_p).

It utilizes the principal of elastic waves travelling with different velocities at different formation of the Earth [2]. The velocity of the seismic waves is determined by Elastic Moduli and the densities of materials through which they travel.

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 dependent 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 1). A portion of energy also is critically refracted along the interface. Critically, refracted wave travel along the interface at the velocity of the lower layer and continually refract energy back to the surface. The receiver then records the incoming refracted and reflected waves [3] and the time-distance plots of this 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 researches [4].

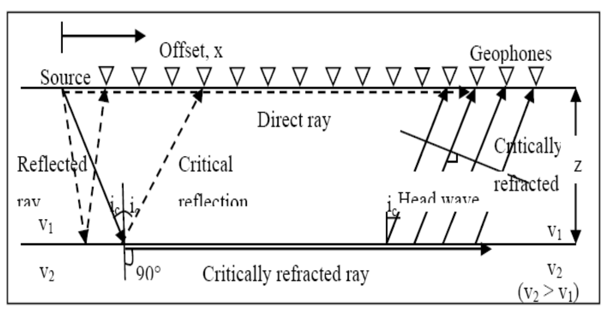


Figure 1 Ray path diagram showing the respective paths for direct, reflected and refracted rays [3]

Boreholes drilling are the conventional method in obtaining soil and rock profile. Constructing boreholes requires specialized knowledge and technical expertise in decision-making tool to assist in making cost-effective choices between borehole drilling methods. In general, there are two methods used for obtaining information on subsurface condition of the ground that are trial pits and soil boring [5]. A number of tools are available for soil exploration. Therefore, careful judgment is important on the tools type appropriate for a given project. Once a suitable site has been selected and borehole drilling decided on, the proper drilling method must be chosen. The position, depth, and number of boreholes should be determined before starting the site exploration. The outcome from the investigation that is the soil or rock profile will be represented by borehole log. Additional, beside the description of the drilled material (bore log), the results of the standard penetration test (SPT) are used as the quantitative measure of the subsurface characteristics.

Table 1 Resistivity and velocity of some common rocks and minerals [4]

Materials	Seismic (m/s)	Resistivity (Ohm-m)
Igneous/ Metamorphic		
Granite	4580-5800	5×10^3 - 10^8
Weathered granite	305-610	1-10^2
Basalt	5400-6400	10^3 – 10^6
Quartz		10^3 – 2×10^6
Marble		10^2 – 2.5×10^8
Schist		20 – 10^4
Sediments		
Sandstone	1830-3970	8-4×10^3
Conglomerate		2×10^3 – 10^4
Shale	2750-4270	20 – 2×10^3
Limestone	2140-6100	50 – 4×10^2
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

3.0 METHODOLOGY

3.1 The Study Area and Geological Setting

The survey area is located at Ulu Tiram, about 17 km from Johor Bahru town towards Kota Tinggi. The coordinate of the study area is 1.636462° latitude and 103.800115° longitude (Figure 2). The study area is planted with palm oil with very rugged ground surface. The geology of the site as indicated by the Geology Map [6] is underlaid by Permian-Jurassic age of intrusive rock, mainly granite (Figure 3). Through walk about survey at the site, it is confirmed that the rock type underlaid is medium-coarse grained granite.

Figure 2 Location of the survey area in Ulu Tiram, Johor

3.2 Data Acquisition

Seismic refraction method has been chosen as the geophysical method employed in this study. Three survey lines with length of 115 m each were laid namely L1, L2 and L3 (Figure 4).

The seismic refraction survey has been carried out using a 24-channel seismography and 5 m geophone spacing. A 6.5kg sledgehammer has been used as the vibration source.

With 24 geophones at 5 m interval, a seismic spread is 115 m long for each line. The location of seismic line (L1, L2 and L3) was made on the same place as existing borehole position.

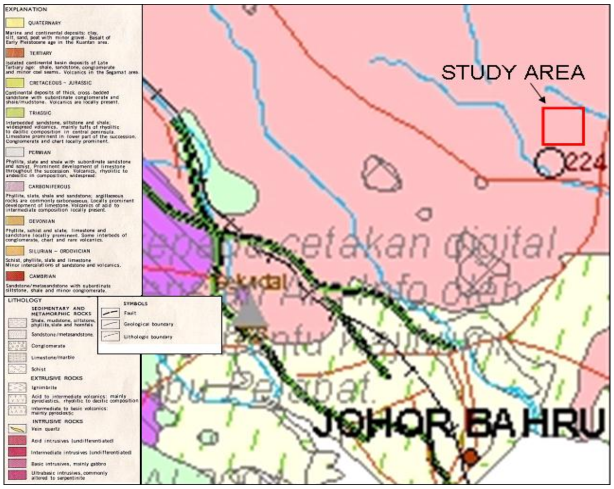


Figure 3 Geology of the study area, Ulu Tiram, Johor [6]

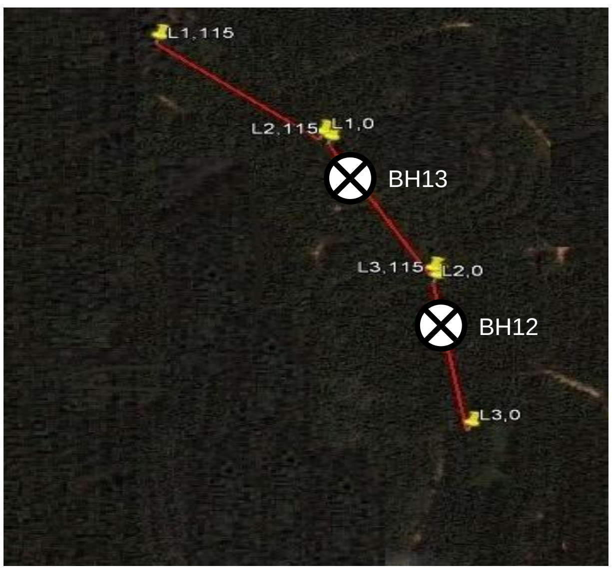


Figure 4 Location of survey lines for seismic refraction (red) and existing borehole (white)

The decision on the existing boreholes position a quite difficult as the study area consists of planted palm oil. Hence, BH12 and BH13 have been chosen to correlate with seismic results, as these borehole positions are not disturbed by presence plant. Also, there are only 7 shot points for each spread has been made to acquire the data of the survey area. Stacking has been done at each shot points with weight drop.

The raw data taken from the stacking has been stored in the 24-channel seismograph, ABEM Terrolac MK8Plus and analyzed by using Firstprix and Gremix 15 software for the result interpretation.

3.3 Borehole Survey

Borehole information was obtained from a site investigation record as performed in 2013. The borehole information is given by the company's representative for our study. The locations of the drilled boreholes were marked and at these locations, seismic refraction lines were tested.

4.0 RESULTS AND DISCUSSION

4.1 Seismic Section of Velocity Gradient

Figure 5 shows the final seismic section of velocity gradient at surveyed area. Generally the study area consists of overburden zone with velocity of <3600 m/s. The result shows three distinct layers of velocity present beneath the survey area. The first layer shows topsoil or highly weathered granite with velocity value range of 0-400ms^{-1} located at depth 0-10 m (Figure 5 (a)). The second layer with velocity of 400-3200 ms^{-1} was sensed at the depth of 5 m to 30 m (Figure 5 (b)). However, there is grey area of low velocity value at the depth of 27 m in the second layer (Figure 5 (c)). Further interpretation, the higher velocity zone of greater than 3300 ms^{-1} can be clearly mapped at the depth of greater than 30 m (Figure 5 (d)).

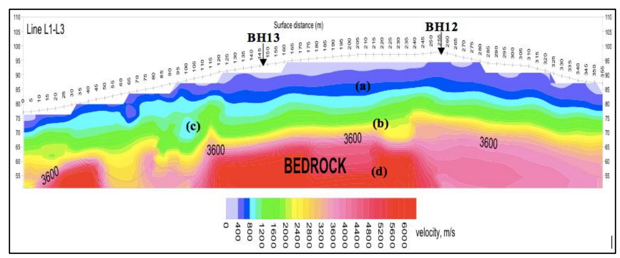


Figure 5 Seismic section of velocity gradient at L1-L3 survey line in Ulu Tiram (Johor)

4.2 Seismic Section of Velocity Gradient

The collection of borehole record, BH12 and BH13 used in this study was based on the rotary wash drilling and logging carried out previously by a private geotechnical company. The details of the borehole results are shown in Figure 6. The borehole was situated on the survey line, L2 and L3 at the distance 148 m and 254 m from the starting point L1. Based on the borehole data, the depth of rockhead is encountered below the ground surface at 26 m and 32.5 m and matched the seismic velocity value 3600 m/s. The SPT and RQD values also shown respectively.

Generally, the uppermost layer with thickness of less than 0.7m is referred to as top soil. From the borehole result in BH12, the site is underline by soil with relative density is medium stiff to very stiff (silty clay, clayey silt) soil profile refers to the penetration resistance and soil properties based on SPT [7]. The SPT reached 50 at depth 30m, which is shown that hard layer is found but it is not bedrock. Soil profile in BH13 is slightly similar as BH12, which has relative density of stiff to very stiff (clayey silt, silty clay, and clayey silt) and hard layer found at depth of 23.7 m. The SPT values generally increases gradually until N=50. However, Figure 7 shows the SPT number decrease at depth 21 to 22.95 m and increase sharply to N=50 at 23.7 m.

This indicates an extreme changes in properties of the subsurface but the change is not obvious in the bore log description. Therefore, the data can be summarized as the granite bedrock which underlain by clay type soil.

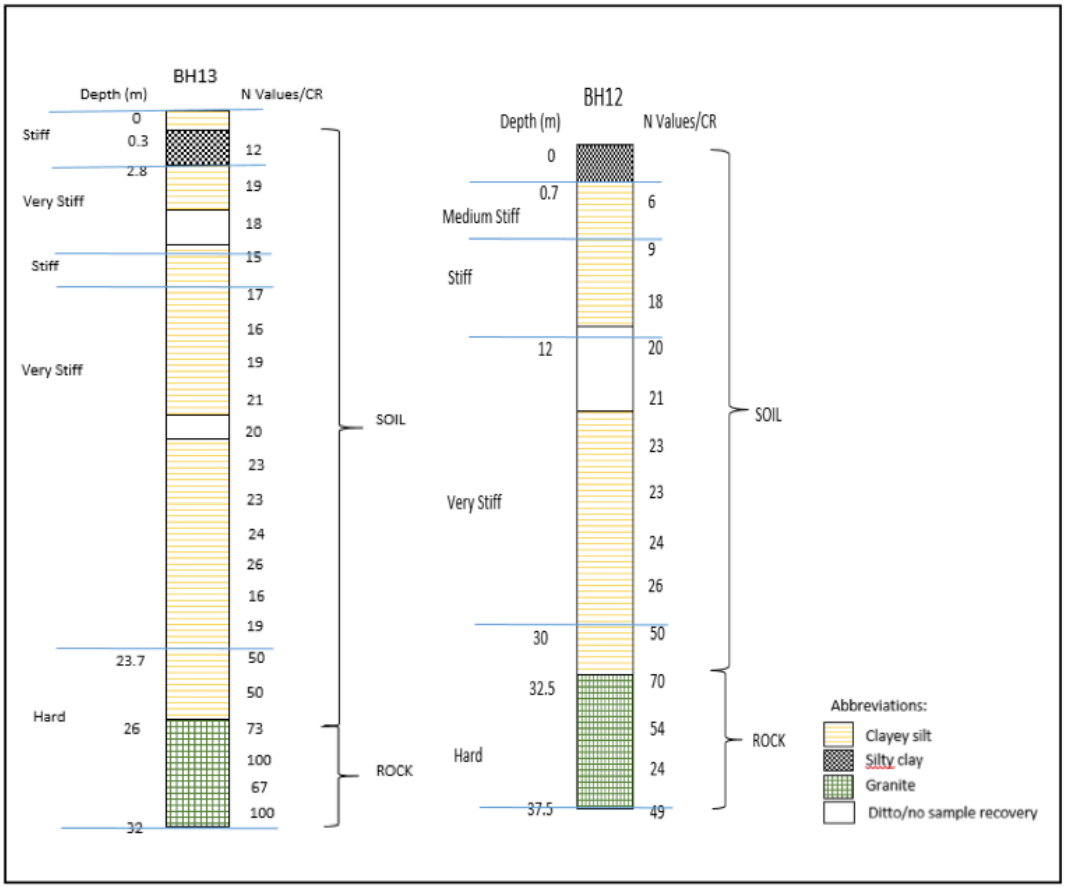


Figure 6 Details of rock cores of BH13 and BH12

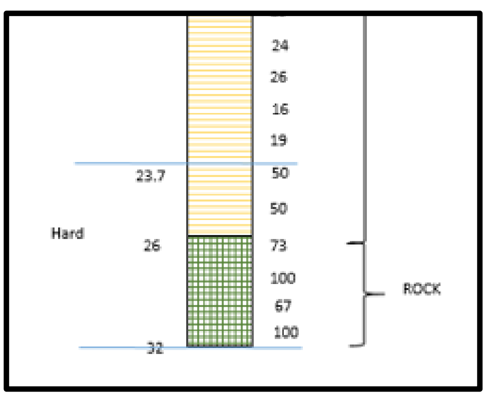


Figure 7 Details of BH13 bore log

However, to understand the quality of the rock mass or granite, the bore log BH12 and BH13 was then re-analysed and re-assess from SPT and RQD value so that the quality of the ground can be determined. Using the values obtained, the ground is classified into four different quality of rock mass ranging from good, fair, poor and very poor rock (Table 2). The higher RQD value represents good granite otherwise a lower value is considered as very poor rock quality (highly weathered), which is thus expected to contain cavity or karst. From the observations in bore log BH13, the RQD values are 73%, 100%, 67% and 100% which can be classified as good and fair rock quality. On the other side, RQD values in BH12 is lower compare to BH13, which the rock quality is in the ranking of fair to poor.

4.3 Correlation Between Seismic And Borehole Data

Boreholes (BH12 and BH13) is overlain on the depth profile in order to assist in calibrating the output seismic data (L1-L3) and provide an indication of the level of better correlation along the survey line as shown in Figure 6. The combination of seismic line and boreholes (BH12 and BH13) has been analyzed separately for better results interpretation.

Table 2 Rock classification of Borehole Log, BH12 and BH13 based on RQD [1]

Classification	Descriptions	RQD (%)
Excellent	Very slightly fractured	90-100
Good Rock	Slightly Fractured to Moderately Fractured and Slightly Weathering	75-90
Fair Rock	Highly Fractured and Moderately Weathering	50-75
Poor Rock	Lightly Fractured and Moderately	25-50
Very Poor Rock	Totally Fractured and highly weathering	<25

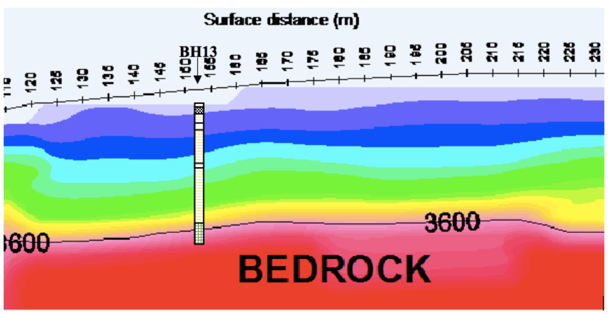


Figure 8 The combination of seismic section (L2) and BH13 in Ulu Tiram

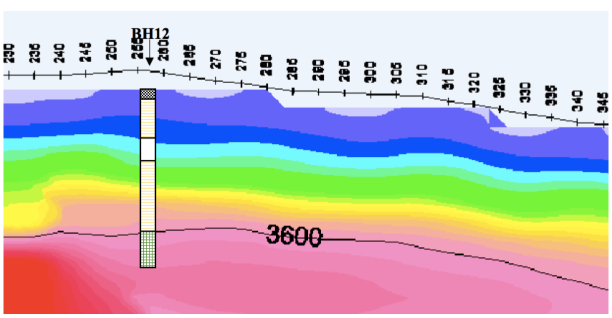


Figure 9 The combination of seismic section (L3) and BH12 in Ulu Tiram

Figure 8 shows the combination of seismic section L2 and borehole (BH13) in distance 115m. Location of borehole is between 30-35 m in L2. According to borehole data in BH13, seismic results was successful in delineating the characteristics of subsoil of the survey area where three layers formation with seismic velocities ranging from 0-400 ms^{-1}, 400-3200 ms^{-1} and > 3200 ms^{-1} has same interpretation as borehole log. It agree with borehole data where the first layer ranging from 0-400ms^{-1} indicate as top soil with depth < 0.3 m while for the second layer consists of weathered sandstone with N values ranging between 19-26. Third layer N>50 consider it as sandstone or granite bedrock with velocity > 3200ms^{-1}. The higher N values will reflect the rock hardness increment. With the RQD values (73, 100, 67 and 100%) from borehole data, it compile with the higher velocity from seismic, which indicates the bedrock of granite is presence at depth 26 m.

The same approach has been made for combination of seismic section (L3) and BH12 (Figure 9). Location of borehole is between 25-30 m in L3. According to borehole data in BH12, it is satisfied with seismic velocity where the first layer ranging from 0-400m/s indicate as top soil with depth < 0.7 m while for the second layer consists of weathered sandstone with N values 6-26. Third layer N>50 consider it as sandstone/granite bedrock with velocity >3200 m/s. In BH12, the RQD values are 70, 54, 24 and 49% indicates that the rock quality is fair to poor.

The depth of rock head encountered from seismic is similar with boreholes data where the bedrock happens at depth in between 31.5m to 37.50m. 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 the relationship between p-wave velocity, N values and relative density (Table 3 and Table 4).

Table 3 Relationship between p-wave velocity, N value and relative density in BH12

Velocity (m/s)	N values	Relative density
0-400	6-18	Stiff
400-2800	20-26	Very Stiff
>3200	>50	Hard

Table 4 Relationship between p-wave velocity, N value and relative density in BH13

Velocity (m/s)	N values	Relative density
0-400	12-15	Stiff
400-2800	17-26	Very Stiff
>3200	>50	Hard

5.0 CONCLUSION

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

1. Using the borehole logging method, the head of bedrock is determined using the standard penetration test value N=50 as found in boreholes data. However, this hard layer is not necessarily the bedrock. Thus the seismic refraction method, which enables determination of the bedrock, is an essential compliment.
2. The characteristics of rock mass can be determined and clearly described by seismic refraction at shallow depth when correlated with borehole data. However, seismic refraction could not describe the quality of rock mass as compared to information from borelog (RQD value).
3. In the seismic refraction, the velocity subsurface division does not provide the subsurface quantitative data directly. The comparison to the SPT and bore log values allows the seismic result to be equated to the quantitative values.
4. As the formation of granite always prefer for quarry exploitation, hence it is suggested to carry out the geophysical exploration at the area rather than straight forward depiction by borehole drilling. This is important to speed the project progress in site investigation stage especially at the wide area and complex geology formation. Both methods would compliment the information, thus a more comprehensive evaluation can be made.

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