Rippability assessment of weathered granite rock mass using seismic velocity and graphical method

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Abstract

Seismic refraction methods and Electrical Resistivity Tomography (ERT) are commonly used as geophysical methods for rock mass characterization and ground subsurface for excavation assessment. In this study, this method was used in the BJ Kota Tinggi Quarry, Johor to evaluate the characteristics of granite and geological features and perspective zones for excavatability. There are two (2) seismic and two (2) electric resistivity surveys were performed at this site with 69m and 80m respectively. The seismic data were processed using SeisOptPicker and SeisOpt2D software. Resistivity data were interpreted and analyzed by using the software RES2DINV. Materials with seismic velocities greater than 2000 m/s show no ripping. While a low resistivity value is obtained due to fracture zones found in harder rocks that have been filled by water or clay minerals. This seismic velocity profile is then compared with the Rippability Chart by Caterpillar using the smallest ripper D8R, to obtain the rippability of the rock. While the evaluation of excavatability is carried out using the graphical method Pettifer and Fookes (1994), consider discontinuity spacing and point load index ($I_{S(50)}$). The results show that the research that can be carried out is ripping, more economical and suitable for use at this site.

1. Introduction

Excavatability is defined as the ability to select the most effective surface excavation method for excavating rock and rock mass that ultimately results in smaller, manageable rock sizes. The main methods involved in the surface excavation are digging, ripping and blasting. (Tsiambaos & Saroglou, 2010; Mohamad et al., 2005; Mohamad et al. 2019). Direct digging and ripping are referred to as a mechanical excavation method, while digging is defined as the process of cutting rock material with a penetration blade and then putting the result into a bucket (Hadjigeorgiou & Poulin, 1998). While ripping refers to loosening the soil by dragging one or more steel tynes of a bulldozer. This method is suitable for excavations involving weak blast rocks but too strong to be removed by an excavator. Ripping is an economical method of breaking soft rock masses to remove fragmented material (F.G.Bell, 2008). The mechanical excavation method provides more advantages compared to the blasting method. It is safer, environment-friendly and has minimum ground disturbance, uniform muck size, selective excavation capability, continuous operation, and higher production rates in complex ground conditions (Bilgin et al., 2014). While blasting is the most common method to break rocks and produce a fragment size distribution, explosives and other methods have a similar and very strong force. However, it has an environmental impact such as ground vibration, airblast, dust, fumes and flyrock (Mohamad et al., 2013). The ripping is usually inexpensive compared to blasting but it is rather challenging to decide the need for ripping on a particular rock and estimate excavation cost.

In tropical countries like Malaysia, there is a problem of disputes in excavation work involving weathered rock, especially for moderately weathered to highly weathered rock. Before starting excavation work, it is a practice of engineering and geology in this country to carry out methods such as geophysics to provide a solution to these difficulties and disputes. Although geological and geotechnical assessment methods are the best in obtaining rock mass and rock material properties, geophysical methods such as resistivity and seismic refraction methods are alternative methods for determining bedrock depth and are very useful. This includes defining the terms hard mass, rock mass and complex rock characteristics. This situation may result from the engineer being not familiar with the technique and the interpretation of the results is quite challenging to understand and can be disputed. Nevertheless, it is seen that surface excavation performance can be improved with geophysical methods, with a combination of geological and geotechnical mapping methods. Therefore, by implementing the geophysical methods with conventional methods, the site investigation problems can be reduced. However, the cost and variation order (VO) faced by the government on earthwork is bound to be the highest compared to other VO. This has caused many losses to the government and delays in many projects.

Seismic refraction is a very good site investigation method and is suitable for implementation at the initial investigation stage, which is before starting a construction project. This is because seismic velocity depends on several rock mass qualities including weathering, density, porosity, strength and overall rock mass characteristics. (Olona et. al, 2010) compared geophysical methods with traditional methods, and found that geophysics can provide a good characterization, especially for the heterogeneous rocks in the area. It was well explained that spacing, orientation, condition of discontinuities and the other essential parameters used in describing rock masses specifically for surface excavation. Although the rock engineering properties are relatively complicated to determine, it still needs attempts to assess the required rock properties and provide reliable value in solving problems related to rock engineering. In addition, geophysics provides other detailed information such as cavities, dissolution features in carbonate rocks and boulders, and locating possible potential groundwater accumulation (Al-Garni et al., 2002; Saad & Mohamad, 2016; Azrief Azahar et al., 2019), as well as can provide volumetric measurements and subsurface conditions (Mehidi et al., 2019). The seismic refraction survey can produce stratigraphy, geomaterials features, and subsurface information in two-dimensional (2D) (Hazreek et al., 2013). At present, there are many other benefits of using geophysics and it is widely used for engineering purposes and so on. (Haryati et al., 2019) has studied overburdened material on top of a fresh rock in the quarry area which will be removed for its material. Therefore, the seismic refraction method has been used to obtain the profile and depth of the rock before removing the thick overburden.

Currently, the study conducted by (Muztaza et al., 2022) has shown that geophysical methods are very essential to be carried out in earthworks to obtain more economical and effective cost and time. They use the seismic refraction method to assess excavations in the site area before developing the area into a quarry. Therefore, through tomography 2D the subsurface layer is obtained and subsequently, the estimated volume of rippability can be determined. Accordingly, the excavatability of the site studied had been determined with minimal time and cost. Likewise, the study conducted by (Kausarian et al., 2014) conducted the seismic refraction method in several locations in the granite quarry area. From the studies made, Vp shows a certain range of velocities even if the rock mass of the same type is at the same depth. This indicates several factors such as inhomogeneous rock layers due to the non-uniform content and distribution of rock minerals. In granite rocks, there are also issues such as porosity, groundwater conditions, and also the existence of cracks in the rock mass. Vp shows a decreasing trend as the weathering grade decreases in the deeper parts even though the grade sequences are incomplete. Then, the suitable excavation method for the quarry is determined by using the Caterpillar seismic velocity chart.

Generally, the evaluation of surface excavation can be divided into grading, graphical method and approximation by seismic velocity. Seismic methods are widely used in rock excavation, but the accurate result cannot be obtained by this method alone. This is because several factors are not taken into account in this method. For example, embedded boulders and massive formations consisting of large blocks or very soft rocks are undetectable, often occurring in sedimentary, igneous, and metamorphic rocks such as basalt, gabbro, and granite (Weaver, 1975). Besides, this seismic method is also undetectable on abrasive rock potential. (Hadjigeorgiou & Poulin, 1998) have provided a good summary of the possible sources of errors in the seismic velocity of the data that result in misleading estimates.

In 1958, Caterpillar developed a chart related to seismic velocity and rock type, whether the rock is rippable, marginal and unrippable for each bulldozer model. Seismic velocity values for the marginal to non-rippable category are higher for larger-size dozers. Komatsu has also produced a performance chart for each of its dozers, as has Caterpillar which also shows rippable, marginal and non-rippable velocity zones for various rocks. (Macgregor et al., 1994) commented that the Caterpillar ripper performance chart is the most widely used method. It is complete for every bulldozer model, even though Komatsu has also produced charts for each bulldozer model. They suggested that the Caterpillar chart is too optimistic by predicting rock mass should be ripped economically, while in reality, it is difficult to achieve its production value. (Koczanowski et al., 1991) also commented that the Caterpillar chart is highly dependent on seismic velocity, and contributes to unpredictable efficiency predictions when certain conditions such as boulder formation, thin layers, or water tables are within the depth to rip.

The indirect method is a method that is commonly carried out by using the seismic refraction method, referring to the standard table shown in the Caterpillar Performance Handbook 2017. Caterpillar Tractor Company (2001) has proposed the use of seismic velocity charts on the ripper performance. Caterpillar made a comparison of the wave velocities for several case studies that used their equipment, finding that there were good indications of ripper performance. Through this chart, rippability is measured qualitatively and quantitatively in terms of rippability i.e rippable, marginal, and/or non-rippable, as well as a rating scale from 0 to 100. The physical principle used in determining rippability is that seismic waves move faster in rocks that have a higher density, on the contrary, in a less consolidated rock mass. The study conducted by (Mohamad et al., 2011) on sedimentary rocks also commented that Caterpillar charts only provide information related to seismic velocity whereas other factors such as discontinuity spacing and strength affect the excavation of the sedimentary rocks were carried out in this study. Rock masses that have a lower wave velocity are more easily ripped. Currently, many researchers have used it in studies related to the usage of geophysics method in surface excavation (Ismail et al., 2018; Aziman et al., 2019; Muztaza et al., 2022; Akingboye & Bery, 2022; Jug et al., 2020; Ndiaye et al., 2020). Most scholars support the idea that other parameters affect surface excavation performance other than the seismic velocity method. This includes geomechanical parameters of the rock mass, machine parameters and rock material parameters

The first serious discussions and analyses of geological factors influencing surface excavation emerged during the 1970s. (Weaver, 1975) defined rock type, seismic wave velocity, rock hardness, rock weathering, rock structure and rock fabric. The researchers also argued that although the assessment of rippability can be obtained through seismic wave velocities, the geological condition is still crucial as a guide for engineers and geologists to face troubles that may arise. Therefore, the assessment of rippability chart/ graph to be proposed is advised to consider each of these factors, which is beneficial for estimating the cost and method of excavation. Similarly (J.Smith,1987) described several factors that are significant in evaluating rippability other than seismic velocity. Among them depend on the type, structure, and weathering of rocks, as well as rock fabric. This statement is agreed by (Bozdag,1988), in addition, suggests that production requirements, mine geometry and excavating machinery are significant for rippability. (Macgregor et al.,1994) conducted a study using ripping and geological databases for bedded and non-bedded rock to determine the factors affecting the ripping productivity of bulldozers. The factors that influence productivity are uncontrolled rock compression strength, weathering rate, seismic velocity, roughness, joint strength, bedding spacing in unripped rock and bulldozer mass. This selection is necessary to produce effective excavation and optimum production. The study conducted by (R. N. Singh et al.,1987) studies the effect of rock mass characteristics on ripper performance and ripper selection process based on its function, which produced the correlation between the tractor ripper's design capabilities and performance.

Rock excavation assessments conducted in the past have been critically studied, using various approaches and methods. Recently, there is an increase in the amount of literature on excavation assessments in tropical countries (Liang, 2016, Mohamad et al., 2017, Ismail et al., 2018a, Mohamed et al., 2006, Tating et al., 2015, Md Dan et al., 2016a, Alavi Nezhad Khalil Abad et al., 2014, Siti Norsalkini, 2019, Mohamad, Abad, et al., 2011a). Comparison between assessments completed by considering various factors such as rock type, geological, geotechnical and geophysics parameters, excavation methods, machine characteristics, etc. However, there are differences between the accessor. Together these studies provide important insights into the factors affecting excavatability in a tropical region, it is important to consider producing an excavation classification system that takes into account technological factors that are always appropriate and rapidly increasing. As developing technology is increasing in our country, there is an urgent need for reliable and simplified excavation assessments to consider the unique factors in a tropical region. Therefore, a study needs to be conducted to carry out rippability assessment in tropical regions using both seismic velocity and graphical methods

2. Site description and geological background

The study area is located in the industrial area of Bukit Waha, Kota Tinggi, Johor. Figure 1 shows outcrops conditions with weathered rocks and boulders visible in several zones. The topography in this area is undulating with hills and covered with vegetation. The geographical condition near the quarry is an oil palm plantation. From the observation, the topographies of the areas showed that it was a mountainous area with undulating topography. However, there is a main road namely Jalan Bukit Aping -Kangkar Papan that connected Kota Tinggi to Bandar Penawar, Johor. Through observation, this area consists of boulders of various sizes ranging from 1.5 m to 5.0 m that are covered by residual soil. It can be seen that the presence of rocks and soil formation in different weathering zone at the study site. In general, the weathering process has fragmented the granite rock mass into various grades of weathering in this area. Excavation works involving igneous rocks such as granite are usually associated with the occurrence of boulders in tropical areas. Some researchers were found to have done studies on rock weathering on granite (Md Dan et al., 2015; Md Dan Azlan et al., 2020; Mohd Firdaus Md Dan et al., 2016). However, the discussion about the relationship between size and shape, as well as the distance of the rock from the bedrock where it was formed is rarely studied and well-understood in Malaysia (Muztaza et al., 2013). Therefore, these boulders can be defined as unique physical characteristics that are affected by the weathering process and should be considered as one of the important parameters in engineering design.

The area consists of acid intrusive rocks that consist of granite that are excavated for quarry purposes. The lithology of the studied site consists of plutonic igneous rock from Muntahak Pluton (Cobbing et al., 1986). Granitic rock in this area can be classified as medium-grained granite. Most of the rocks are medium to coarse-grained, with colors ranging from pinkish gray to almost pink. The Muntahak Mountain area is largely underlain by fine to coarse-grained granite, gray and pink. Overall, the granite in this area consists of quartz, plagioclase and k-felspar. Sometimes there is also the presence of minerals such as biotite and hornblende. The general geology of the BJ Granit Quarry, Kota Tinggi is shown in Fig. 2.

3. Methodology

This study involves field and laboratory work. The field study includes outcrop inspections, geological and geomechanical mapping, in-situ testing and 4 geophysical survey lines. The results of field and laboratory studies in the studied area are explained in this section.

3.1 Field work

A geophysical survey of two (2) lines of electrical resistivity tomography (ERT) and two (2) lines of seismic refraction surveys were conducted at BJ Granit Quarry, Kota Tinggi. The aim is to obtain subsurface strata profiling for rock mass assessment. In this case, the ERT with Gradient array and seismic refraction line surveys were conducted to achieve the subsurface profiling maximum at 20-meter depth. Figure 3 illustrates the profile lines at BJ Granit, respectively. This study was conducted in the quarry area located in Bukit Waha Quarry, Kota Tinggi where the quarry is a granite quarry. The position of the BJ quarry on the map is located at a Longitude of 1.7614910 and a Latitude of 104.0520930. Lithology in quarries is a type of granite. The surveyed locations are the slopes of the quarry outcrop which are named RL01, RL02, SR01 and SR02 as shown in Fig. 3. The study was conducted on the quarry outcrop when it was inactive and not operating at that time. Location of resistivity line based on longitude and latitude of global positioning system (GPS) using the portable Garmin 6800. The accuracy was taken from the satellite signal at horizontally 3 to 4 meters. All two (2) geophysical surveys at BJ Granit Quarry, Kota Tinggi was recorded in Table 1.

Table 1 Coordinate of the seismic refraction survey lines in the study area

Line	Start	End	Length of Profile (m)		
	Northing, N (00 00’ 00”)	Easting, E (00 00’ 00”)	Northing, N (00 00’ 00”)	Easting, E (00 00’ 00”)	
SR 01	1 45’ 37.79”N	104 2’ 44.00”E	1 45’ 35.56”	104 2’ 43.63”	69
SR 02	1 45’ 34.06” N	104 2’ 42.44”E	1 45’ 33.94”	104 2’ 44.69”	69
RL 01	1 45’ 37.84” N	104 2’ 44.10”E	1 45’ 35.27”	104 2’ 43.70”	80
RL 02	1 45’ 34.02” N	104 2’ 42.24”E	1 45’ 35.86”	104 2’ 44.83”	80

3.1.1 Seismic Refraction

There are three major components used in seismic refraction surveys which include sources (energy or wave source), receiver (geophones and cables) and data logger or seismograph. The source of the seismic survey is a 7 kg of sledgehammer where hammering was done on a striker plate. For detectors, 24 channel of vertical geophone and ABEM Terraloc MK-6 seismograph was used for the recorder. The geophones were connected to the seismograph by two-unit geophone cables with a maximum length of a 115-meter survey line. For data acquisition, there were a pair of reels of geophone cable and each reel consists of 12 geophones connector points. During the setup of the geophone cable, the cable was in a linear or straight line to have optimum results during recording. The geophones should be placed on a clear area and approximately level with the ground. The seismograph was placed at the center of the geophone spread line. Figure 4 shows the seismic refraction equipment arrangement of geophone spread lines. The offset points were 15-meter distance to the left and right of the survey line while the spacing of each geophone was set to 5-meter between each other. A 5 kg sledgehammer was used as a seismic source by striking vertically on a metal plate at a specific location (Fig. 4).

Striking the metal plate generated the seismic source (Fig. 5). Vibration from other activities such as moving vehicles, vibrating machines, or any movement that generates vibration around the surroundings should be kept minimal. The reason was to obtain more accurate and consistent data without any disturbance. The shot point location was taken at offset and intervals of 1st and 2nd, 6th and 7th, 12th and 13th, 18th and 19th, and 23rd and 24th geophones. Figure 6 shows the location of a shot point.

The raw data of seismic refraction were processed with Optim Software to generate the model of a subsurface soil profile. Two Optim Software were used which include SeisOptPicker and SeisOpt@2D. This process started by directly removing the DC for noise reduction. Then, the first arrival of the P-wave that moves to the geophone as a receiver was selected using SeisOptPicker 1.5 software. All velocity and thickness values for each point were entered into this software, and then overall views of the entire segment were obtained. Later, the curve pattern of the graph was edited. Next, the data was imported into SeisOpt2D to obtain a 2D seismic refraction profile. Finally, the processed data was imported into the Surfer 8 software to get a detailed interpretation and understanding.

3.1.2 Electrical resistivity tomography (ERT)

Computer-controlled data acquisition systems consist of resistivity instruments, computers, switching units, electrode labels, various connectors and electrodes. The equipment used for the electrical resistivity survey was 1 unit of ABEM Terrameter, LS2, 4 units of Multipurpose Cable, cable connector and others. It is recommended to measure the distance between the first electrode positions by following the planned profile line. The schematic diagram of the electrode cable arrangement is shown in Fig. 7. Figure 8 shows an arrangement of the ERT method conducted on-site.

The ERT program was used to process the converted raw data in the extension of the DAT format. Upon field survey, the resistance measurements were reduced to true resistivity values by the inversion of the apparent resistivity process. ERT used a least-squares inversion scheme to determine the appropriate resistivity value so that the calculated apparent resistivity values agree with the measured values. The inversion process was carried out to obtain three types of resistivity sections, which consist of calculating apparent resistivity, measured apparent resistivity, and inverse model resistivity.

Table 2 and Table 3 show the resistivity values of common rocks, soil materials and chemicals. The resistivity of these rocks was greatly dependent on the degree of fracturing and the percentage of the fractures filled with groundwater. Sedimentary rocks which are porous and have higher water content, normally have lower resistivity values. Wet soils and fresh groundwater have even lower resistivity values. Clayey soil normally has a lower resistivity value than sandy soil. However, note the overlap in the resistivity values of the different classes of rocks and soils. This is because the resistivity of a particular rock and soil sample depends on many factors such as the porosity, the degree of water saturation and the concentration of dissolved salts.

Table 2
Resistivity values of common rocks and soil materials (Keller and Frischknecht, 1966)

Material	Resistivity (ohm-m)
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	$8–4 \times 10^3$
Shale	$20–2 \times 10^3$
Limestone	$50–4 \times 10^3$
Granite	5000 to 1,000,000

Table 3
Resistivity values of some types of waters (Keller and Frischknecht,1966)

Type of Water	Resistivity (ohm -m)
Precipitation	30–1000
Surface water, in areas of igneous rock	30–500
Surface water, in areas of sedimentary rock	10–100
Groundwater, in areas of igneous rock	30–150
Groundwater, in areas of sedimentary rock	> 1
Sea water	≈ 0.2
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (max. salt content 0.25%)	> 0.65

3.2 Laboratory Test

3.2.1 Point Load Test

A total of 50 rock samples were taken from the excavated materials during the trial excavation at the sites. These samples were tested using a point load tester apparatus to obtain point load strength values for rocks with various degrees of weathering. The dimensions of the rock samples were measured using a measuring tape and recorded using the test form. A load was applied to the rock sample until it fails and the load was recorded. This test assesses the resistance load of the sample strength placed between two loading cones or bits that could adjust to grip. A correction factor (F) is applied to the uncorrected point load strength (I_s) equation as follows:

$$I_s = \frac{P}{{D_e}^2}$$

$$I_{s(50)} = F \times I_s$$

where P is the failure load (N) and ${D_e}^2$ is 4A/π which is the equivalent diameter of lump sample.

where $F = (D_e/50)^{0.45}$.

3.2.2 Moisture Content

Two techniques were conducted to determine the moisture content of collected samples. The first technique was to put the sample in the dryer oven for 14 days. Then, the mass of each dry sample was measured. All 10 cores which consisted of small and large test core samples were weighed. The sample was positioned in water for every one-minute interval. Later, samples were removed and weighed. Immersion time varied between five to thirty minutes. The second method was to determine moisture content by placing fully saturated samples in a drying oven and weighing the mass of the samples at a predetermined interval. The moisture content could be obtained by using this equation:

$$w = \frac{Mcms - Mcds}{Mcds - Mc} x100 = \frac{Mw}{Ms} x100$$

where *w* is water content (%), *Mcms* is the mass of the container and moist specimen (g), *Mc* is the mass of container (g), *Mw* is the mass of water (g) and *Ms* is the mass of oven-dry specimen (g). To obtain the effect of moisture content on rock strength, a point load test was performed on the samples following Mohamad et al. (2015a) who conducted a moisture content test with soaking periods of 15, 30 and 60 minutes.

3.2.3 Slake Durability Test

A provided sample consisted of ten spherical-shaped rock lumps, each with 40–60 g in weight. The corner of the sample was rounded during preparation to a maximum size of less than 3mm. Thus, the total mass of the sample was between 450g and 550g. The sample was positioned in a clean barrel and dried until a persistent mass was observed at 105 C. Usually, the sample would take between two and six hours in the oven. First, the drum plus mass (A) was recorded. Next, the lid was changed, and the drum was mounted on the trough and attached to the motor. The through was filled with slaking fluid and tap water with a temperature of 20 C up to 20mm below the drum axis. The drum was then rotated up to 200 rotations in 10 minutes with an accuracy of 0.5 min. Next, the drum was detached from the trough. At the same time, the lid from the drum was removed. Then, the weight of the drum and the dried sample was further dried until the mass remained constant at a temperature of 105 C. Subsequently, the mass of the drum and cooled retained portion of the sample (B) after the first cycle was measured. The same process was repeated. Afterward, the drum plus a retained amount of the sample mass after the second cycle was recorded as C. Finally, a mass of a brushed clean drum was recorded as D.

Based on the above test, concise recommendations were made with ten sample specimens. In short, the samples were dried in the oven. Then, they were rotated in a slake durability drum in partially soaked condition for 10 minutes. The drum was then removed and dried at 105 C for 16 hours. Next, the weight of the retained specimen was recorded. The slake durability indices could be defined using the following equations:

$$I_{d1} = \frac{B - D}{A - D} x100$$

$$I_{d2} = \frac{C - D}{A - D} x100$$

where I_{d1} is the initial slake durability index (%), I_{d2} is the slake durability index for the second cycle (%), *A* is the mass of the drum plus oven-dried sample before the first cycle (g), *B* is the mass of drum plus oven dried specimen retained after the first cycle (g), *C* is the mass of drum plus oven dried specimen retained after the second cycle (g) and *D* is the mass of drum and oven dried sample retained after the cycle (g).

While conducting the test, more refined products passed through the net and entered the water bath. The slake durability index, I_{d1} was the initial dry weight percentage in the drum. This test aimed to accelerate the weathering process to the maximum by combining the slaking and sieving processes. Factors that influence the test results are utilized tools, samples' nature, pre-treatment of samples, slaking period and liquid slaking properties (Franklin and Chandra, 1972).

4. Results and Discussion

A seismic refraction survey was done to get the subsurface profile in this area. This survey aims to obtain a subsurface mapping of geomaterials and their relation with rippability purposes. Figures 9 and 10 show the results of two seismic refraction lines namely, SR01 and SR02 and resistivity lines namely, RL01 and RL02 respectively. For SR01 (Fig. 9), the area generally can be classified as completely weathered (grade V) to highly weathered (grade IV) granite rock with a thickness of 22 meters underground. Seismic velocity (Primary velocity, Vp) shows values between 650 to 950m/s at 0 to 5m depth, and followed by 1000 to 1800m/s at 5 to 15m depth, and followed by 1900 to 2700m/s at 15m to 20m depth. The P-wave velocity ranges from 650 m/sec to 2700 m/sec and is interpreted as rippable to the marginal layer.

As shown in Fig. 10, RL01 shows a 25m deep subsurface indicating dry and hard subsurface that can be correlated as a bedrock. This layer shows a high resistivity value of 1000 ohm.m to 4000 ohm.m. However, a certain area along with RL01 displays low to medium resistivity values of 30 ohm.m to 500 ohm.m. This indicates the existence of a water pathway/infiltration in the fractured weathered rock and storage of water which reduced the resistivity value. The first zone is the upper layer with resistivity < 1000 ohm-m. The second zone is a cracked granite bedrock with a resistivity value > 4000 ohm.m and a depth of 60 to 75m.

Figure 11 shows that along SR02, the layers of rippable and marginal are much more distinguishable. The rippable layer of 350 m/sec occurs at 0 meters. But the rippable layer shows 1650m/sec at a distance of 69 meters. The seismic velocity (principal velocity, Vp) shows values between 350 to 800 m/s at a depth of 0 to 2m, followed by 850 to 1650m/s at a depth of 2m to 5m, with 1700 to 2000 m/s at a depth of 5m to 8m, and followed by 2050 to 2650 m/s at a depth of 8m to 13m. A layer of non-rippable is much clearer starting from 7-meter deep indicating fresh (Grade I) granite bedrock. While for RL02 (Fig. 12), the area is illustrated as dry and hard subsurface because the resistivity values are more than 1000 ohm.m. Several areas with a resistivity of less than 1000 ohm.m with a depth of 2m are considered to have low to medium resistivity values. This area is interpreted as the existence of a water pathway/ infiltration in the fractured weathered rock that allows water to be stored.

Seismic refraction results of both SR01 and SR02 show layers of rippable to marginal while RL01 and RL02 portray generally high resistivity values. The ERT results deduce the presence of bedrock but the SR results are more homogenous showing evidence of weathered bedrock. The resistivity contour value is adjusted based on geological conditions that match the resistivity range based on the color difference. According to (M. M. Nordiana et al., 2013), igneous rocks usually give a higher resistivity value compared to other rock types as there are cracks in weathered granite rocks. These cracks are usually filled by groundwater since the water level in Malaysia is shallow. This situation gives a factor to the resistivity value. Table 3 shows the resistivity values range adopted in this study interpretation. Classification of granite rippability for interpretation in the study area is based on a seismic refraction test conducted by (Mohamad et al., 2010).

The purpose of these surveys is to evaluate the rock mass by correlating two geophysical methods i.e., seismic refraction and electrical resistivity of tomography methods. Based on the surveys, the results between seismic velocity and resistivity value show a variation in rock mass assessment. Thus, they are complex to be correlated with each other. Besides, the results of ERT and seismic refraction do not tally with each other. The main reason for the disparities in results is the difference in parameters utilized for both surveys. In general, the seismic refraction method records p-wave (compressive wave) which is the speed of p-wave propagation that is influenced by material stiffness. Thus, the stiffness between soil and rock can be differentiated based on their seismic p-wave velocity. On the other hand, the electrical resistivity method measures the voltage potential differences after the current has been injected into the underground. Resistivity value obtained from field measurement is affected by porosity, the concentration of fluid in fractured (saturation) and fluid resistivity according to Archie's law. Thus, it is challenging to interpret either soil or rock in the saturated subsurface due to the domination of water resistivity. The presence of water highly influences the assessment of rock mass in the ERT result which creates more uncertainty to interpret the data (refer to Table 4). For instance, the existence of a water pathway/infiltration in the fractured rock causes the study area to have low resistivity values and misleads the bedrock to be interpreted as soil layers such as clay or sand.

Table 4 Resistivity value interpretation

Resistivity Value (Ω m)	Legends	Interpretation
1-300	0.00 5.00 30.0 60.0 100 300	Zone of soil/ fractured rock with the presence of water/ perched water
>500	500 1000 4000	Zone of rock/ soil of dry or less saturated with water

Table 5 shows the comparison between previous research and the current study on seismic values and weathering grades. In general, seismic values lower than 1000 m/s represent Grades V and VI. Yet, in certain cases, it can be higher up to 3000 m/s. Grade IV ranges from 1000 to 2000 m/s while Grade III from 2000 to 3000 m/s. Next, seismic values of 3000 to 4000 represent Grade II and more than 4000 m/s represent fresh rock. However, the values can differ for each study area. Validation of results using secondary data such as boreholes helps in interpretation. Hence, the correlation of the borehole (if present) is important. However, due to the lack of borehole data on this site, the values of the seismic survey can be validated using data from (Sjogren et al., 1979; Mohd Akip Tan, 2020; Santi, 2006) and (Kausarian et al., 2014). The seismic value for Grade III at this excavation area is more than 1650 m/s. In addition, Grades III and IV are represented by seismic velocities between 1650 and 2000 m/s. Also, extremely weathered residual soil is represented by values from 350 to 650 m/s.

Table 5
Comparison between previous research and current study on seismic values and weathering grade

Grade	Sjogren & Sandberg (1979)		Islam. R (2005)		Santi (2006)		Husnul Kausarian et al. (2014)	This Study
VI	Filled with soil and completely crushed rock	< 3000	Residual soil and overall weathered	200–800	Residual soil	300–900	500–1000	350–800
V					Completely weathered			650–950
IV	Highly fractured rock	< 4000	Highly weathered	800–1500	Highly weathered	900–1500	1000–2000	1000–2000
III	Strongly – moderately jointed rock masses	4000–4400	Moderately weathered	1500–2500	Moderately weathered	1500–2500	1500–3000	1900–2700
II	Slightly – moderately jointed rock masses	4500–5000	Slightly weathered	2500–4000	Slightly weathered	2500–4000	2500–4000	-
I	Massive rock mass	> 5000	Fresh rock	4000–5600	Fresh rock	4000–6000	3050–5500	

Table 6 shows a summary of previous research on resistivity values and weathering grades. In general, resistivity values lower than 1000 Ωm represent Grade V and VI. Next, Grade III and IV ranges from 1000 to 5000 Ωm. Fresh rock is represented by resistivity values of more than 5000 Ωm. The resistivity value for Grade III and IV are represented by resistivity values lower than 100 Ωm. Also, extremely weathered residual soil is represented by values from 1000 to 4000 Ωm. In addition, the resistivity value for grade V is 500 Ωm. The higher value at the surface could be due to heavy rain because resistivity is highly influenced by moisture content. The resistivity values were validated using data from (Olona et al., 2010) and (Awang et al., 2016)

Table 6
Summary of previous research on resistivity values and weathering grade

Grade	Javier Olona et al. (2010)		Haryati Awang et al. (2016)		This Study	
I	Fresh rock	800–3125	Low-weathered to fresh granite	> 5000		
II						
III	Granite fully or partially weathered to soil	66–800	Medium weathered granite	1000–5000	Medium weathered granite	1000–4000
IV						
V	Granite converted to sandy soil		Residual soil, highly weathered granite, or fractured rock container with water	< 1000	Highly weathered granite or fractured rock granite	500
VI						

5. Laboratory Test

Laboratory testing results are presented in the following section below, which is a point load test, uniaxial compressive stress, slaking index and moisture content. A point load test was carried out on rock samples to classify them based on strength (Fig. 13). Granite shows a good correlation with weathering, however, there are several different conditions on moderately weathered granite rocks. Granite for class III showed a relatively large mean difference of 4.20 MPa which is 3.03 MPa, this condition may be due to the transition that occurs between Class III and Class IV. For grade IV weathering granite, the value of $I_{s(50)}$ ranges from 0.83 to 1.84 MPa, with a mean of 1.17 MPa. While granite weathering grade V shows a very small value of $I_{s(50)}$ which is 0.04 to 0.41 MPa, with a mean of 0.25MPa. The $I_{s(50)}$ values for slightly weathered and moderately weathered rocks show decreased values with low standard deviation rates. This shows that the strength index value is more uniform and the strength variation is less for more weathered rocks such as highly weathered and completely weathered. This situation is agreed by a study conducted by (Tating et al., 2014).

Since the weathering grade for each site is high, UCS is difficult to perform due to sample preparation factors. Samples that have been tested to obtain the UCS value are very difficult to conduct for weathered rocks, but the strength index is easily related to the UCS by multiplying the Point Load Index by 24 (T. N. Singh et al., 2012)(Kaya & Karaman, 2016). This study used a conversion factor of $24I_{S(50)}$ for igneous rocks. Using conversion factors for various types of rocks gives results that are very easy, and effective and can save time. However, its use should be used properly to obtain the appropriate value. Based on the UCS results, the maximum value is 72.72 MPa, which indicates high strength. While the lowest value recorded is 6.05 MPa, which indicates low strength. Overall rock material is between low strength and high strength. Therefore, a ripper may be required to rip some rock material when it is located in a high-strength area.

For granite rocks which are known as hard and intact rocks, this slaking test only has a significant effect on weathered granite grades IV and V. In fresh and slightly weathered samples, it can be seen that there are no clay minerals. However, clay minerals begin to appear on rocks located in the slightly weathered to a completely weathered zone. This situation shows that the original mineral decomposition of granite has experienced a relatively high decomposition in weathered granite in zones located in zones IV and V. The findings of this granite are in line with the study conducted by (Momeni et al., 2017)(Heidari et al., 2013). Therefore, the hardness of the minerals found in these rocks affects the level of durability of granite.

Similarly, the value of slaking index Id_2 shows a decreasing value when the grade of weathering increases. In the second cycle, the sample for grade V weathering shows a range and mean value of 0, which is a sample that has experienced destruction. This result is in line with the research carried out by several researchers namely (E.Arel & A.Tugrul, 2001) (Ceryan, 2008). It can be seen that this sudden decrease eventually tends to decrease to zero value. All the rocks studied at the various sites showed a dramatic reduction in their slake resistance with increasing weathering grade (Mohamad et al., 2015).

Test results show rock moisture content increases, ($I_{S(50)}$) decreases for all weathering grades. On the other hand, moisture absorption increased significantly in class III samples by 4.55 percent, with rock strength values from 2.17 to 4.20 MPa. At the same time, Grade IV shows a moisture content of 6.97 percent and rock strength ranging from 0.83 to 1.84 MPa. At this stage of weathering, it is found that rock minerals have turned into clay. Grade V shows a significant moisture absorption index and strength of 8.11 percent and 0.04 to 0.41 MPa respectively. The significant reduction in strength is due to the increase in clay minerals found in weathered granite. Panels 2 and 3, consisting of Grade IV and Grade V show the clay minerals produced. This indicates that weathering has affected the granite mineralogy of this area. The results obtained are in line with the study conducted by (Yin et al., 2017). Moisture content is an important parameter because it affects the strength of the rock, so it needs to be taken into account.

A summary of the results from the laboratory testing, mainly the uniaxial compressive strength and point load index, is shown in Table 7. The properties of the rock layer underneath can be categorized as strong, moderately strong, and moderately weak materials. The rocks were categorized according to layers and their properties based on a laboratory test.

Table 7
Summary result of joint spacing and laboratory test for all weathering grades

Weathering Grade	Point Load Index ($I_{S(50)}$)	Uniaxial Compressive Strength (MPa)	Slake Durability I_{d2} (%)	Moisture Content (%)
Grade III	4.27	72.72	81.43	4.55
Grade IV	3.03	28.0	0	6.97
Grade V	1.17	6.05	0	8.11

6. Excavatability Assessment for Indirect Method

Excavatability assessment in the study area is obtained by using the rippability chart provided in the Handbook of Ripping by Caterpillar (Caterpillar Inc., 2000). Based on Caterpillar's chart for D8 as shown in Fig. 14, the materials are rippable when seismic velocity is < 1700 m/s and marginal velocity 2000m/s while they are non-rippable when seismic velocity is > 2000m/s. Therefore, the material needs to be addressed with the drill and blast method. Although blasting cost is more expensive than the excavation method, evaluation using this method is more reliable and applicable in these circumstances (Mohamad et al., 2010; Ismail et al., 2018). Based on Caterpillar's chart for D9, the materials are rippable when seismic velocity is < 2000 m/s and marginal velocity 2400m/s while they are non-rippable when seismic velocity is > 2400m/s. As can be seen, when the seismic velocity is more than 2000 m/s, the D8 tractor is not enough, a bigger tractor will be needed. In this situation, the D9 tractor is also suggested to be used for ripping work.

Apart from the evaluation of the seismic velocity method, the excavation method can also be predicted quickly with a low cost by using graphical methods such as Pettifer and Fookes (1994). This method is easy to use because it only uses two important geotechnical characteristics influencing a rock excavatability, that is discontinuity spacing and point load index value, without focusing on rock type. Thus, site assessment of excavatability was carried out using the recommended chart of Pettifer and Fookes (1994). This evaluation method is not focusing any rock type. This graph is divided into easy digging, Easy Ripping (D6/D7), Hard Ripping (D8), Very Hard Ripping (D9), Extremely hard ripping (D11 or hydraulic breaking) and blasting required. Data results for this study as shown from joint spacing and point load index, show very hard ripping (D9), hard ripping (D8) and hard digging, as shown in Fig. 15.

For granite weathering grades III and IV, it is quite difficult to make a comparison in terms of mass properties and boundaries through visual inspection. It was found that materials in this grade are greatly influenced by the connection distance and the value of the strength point load index. The material found in Panel I which consists of grade III has a higher point load index and larger joint spacing. While the material in Panel II and Panel III has a lower joint spacing, falls in a hard zone and is easy to rip. Although the seismic velocity obtained from geophysical tests is a useful tool in obtaining a quick method of excavatability, there are some limitations such as undetected the presence of joints accurately. Likewise with the presence of boulders in a rock mass. As reported by (Smith, 1986), the presence of boulders is difficult to detect if found in easily ripped rock material. This is because the seismic reading is in the average velocity for the rock material body, therefore this situation is to be detected.

7. Conclusion

An overview of the geological, geotechnical and geophysical aspects, the practical evaluation related to the subsurface profile is the most critical aspect in the evaluation of surface excavation. Currently, the issue that is becoming more complex in surface excavation is the condition of weathered rock that has various levels of weathering and properties. A commonly used geophysical method in determining excavatability is seismic velocity. However, apart from that, geological factors also influence and need to be considered such as rock type, rock structure, weathering, mineralogy, porosity and rock fabric. After that, marrying these two methods will succeed in producing a good interpretation and relationship between the two. Therefore, excavation performance can be obtained after taking into account the behavior of the rock mass that is unique to tropical areas, which are weathering grade, discontinuity, point load index, uniaxial compressive strength, moisture content and slaking. Therefore, this study has used and considered geological, geotechnical and geophysical parameters that affect excavation.

It is concluded that the seismic refraction method is much more reliable compared to the ERT method in evaluating the presence of rock mass in the subsurface and excavatability based on its value. Material that has a seismic velocity of more than 2000 m/s indicates non-rippable. This is because the resistivity value is influenced by the porosity, concentration of fluid in fractured (saturation) and fluid resistivity. However, both methods are highly suggested to be done simultaneously to support data interpretation for better representation of a subsurface profile to include bedrock layer, water table/ perch water and water within the fractured rock. In the context of rippability, both results of seismic refraction at BJ Granit Quarry show a clear representation of rippable and marginal layers at least 20-meter and 7-meter depth for SR01 and SR02, respectively. These layers mainly consist of residual soil, completely to a highly weathered rock which is more easily and cost-effective to excavate.

The purpose of the classification system for excavation purposes is to understand the profile and includes understanding the chemical and mechanical properties of the profile. However, the most important matter in practical classification is to determine the rock-soil interface. Where rock and soil boundaries (between Grade III and IV) are in engineering contact. In granite rocks, excavation work is simple, unlike in sedimentary rock. For example, when we said about rock heads (III and IV), where the bottom surface is composed of rock and soil, while the top part is soil and boulders, the most important thing is to carry out a geological mapping. In this case, if the boundaries (between grades III and IV) can be well defined in the field, excavation work will become easier, and minimal engineering issues to overcome. Whereas for excavations for Grade IV and V (those with more and less boulders), it can only be interpreted. Meanwhile, the upper part, namely the residual soil, can be determined easily based on changes in color and texture alone. Whereas for Grade II, there may only be cracks but no soil. Whereas for grade III there is an open up for crack and slightly weathered soil. Even though it is said to be easier than sedimentary rocks, the most important thing is to determine the boundaries for III and IV. This process often occurs with errors and mistakes. It should be reminded that granite rocks are composed of non-homogeneous materials, this rock boundary has many locations/points involved. Because of this, boundaries are rather difficult to determine on the site and so can lead to big mistakes.

The excavatability method of Pettifer and Fookes (1994) is one of the best site investigation methods done at the initial stage of construction, which is at the planning stage. This is because of the involvement of two parameters that greatly affect excavatability and make guidance to the appropriate excavatability method to be used in an area. From the determination carried out, it was found that the ripping method using D9 and D8 bulldozers is suitable for use at this site. While hard digging can be done for areas that consist of weathering grade V which is residual soil. Therefore, the findings from this method are 90% close to the method proposed through the rippability chart introduced by Caterpillar. With that, these two methods are very reliable and are encouraged to be used as a preliminary method to obtain excavatability in an area of the site. It was found that the performance of the granite rock ripper by Caterpillar showed a different range from the production performance in this study. This is due to Caterpillar not taking into account the degree of weathering, only depending on the type of rock. In addition, the study site is located in a tropical area, with a hot and rainy climate throughout the year that has a great impact on the weathering of rocks. Therefore, for this study site, it is seen that the excavation method that can be used is ripping compared to the drill and blast method. The methods obtained through these two excavatability assessments provide economic benefits and are suitable for use on this site. A bulldozer is also a machine that can be used for various purposes in earthwork and excavation.

Declarations

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Competing Interests

The authors declare that they have no conflicts of interest.

Ethics approval

The authors state that the research was conducted according to ethical standards.

Consent to participate/ publish

Not applicable.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Authors' contribution

All authors contributed to the study conception and design. Fieldworks were carried out by Eka Kusmawati Suparmanto, Edy Tonnizam Mohamad, Nordiana Mohd Muztaza, Mariatul Kiftiah Ahmad Legiman, Zuraini Zainal, Nurul Eilmy Zainuddin, Fazleen Slamat, Vynotdni Rathinasamy, Mohd Firdaus Md Dan and Azhar Abd Manan. The first draft of manuscript was written by Eka Kusmawati Suparmanto and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

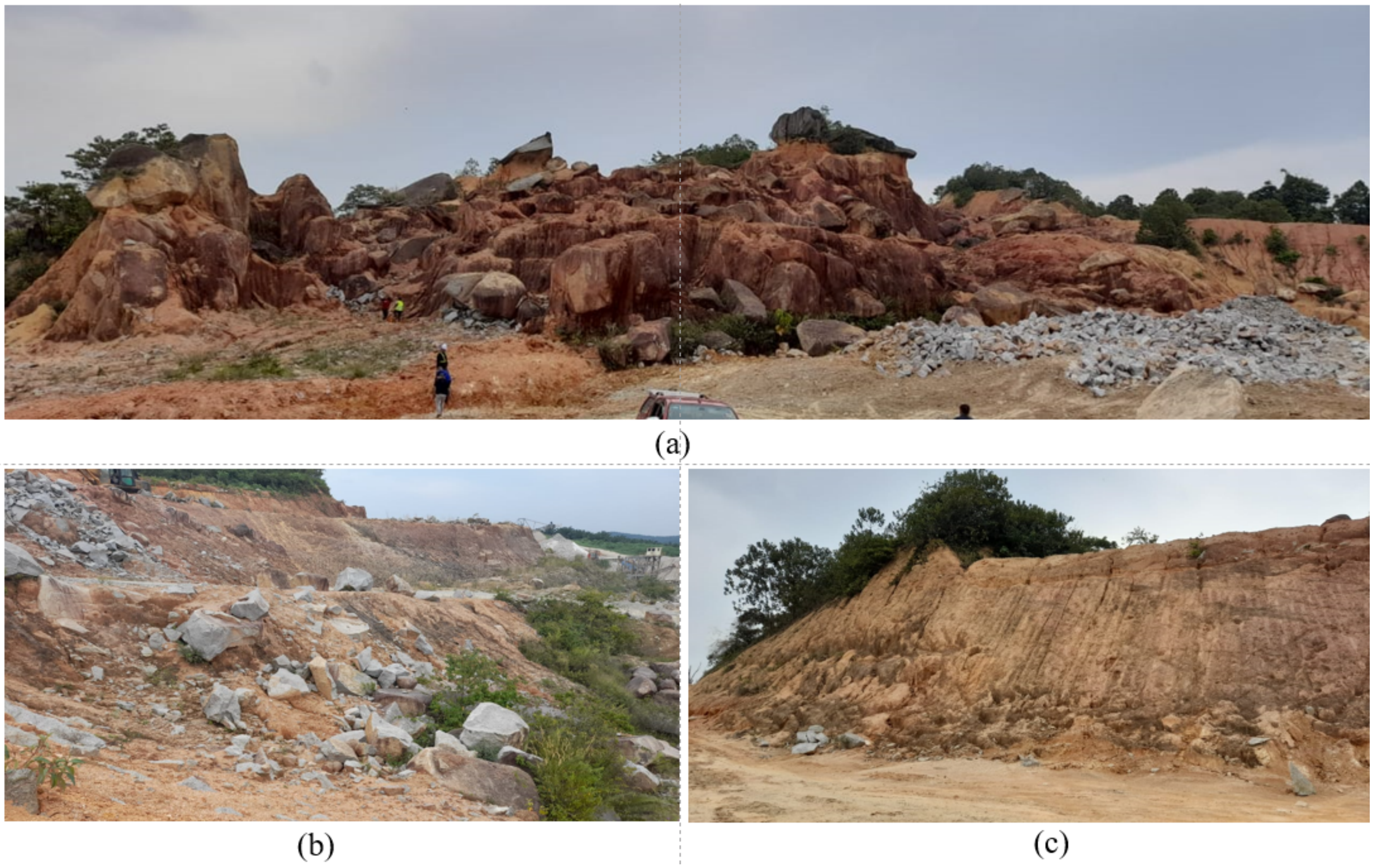

Figure 1

Overview of Site (a) Panel 1 (b) Panel 2 (c) Panel 3

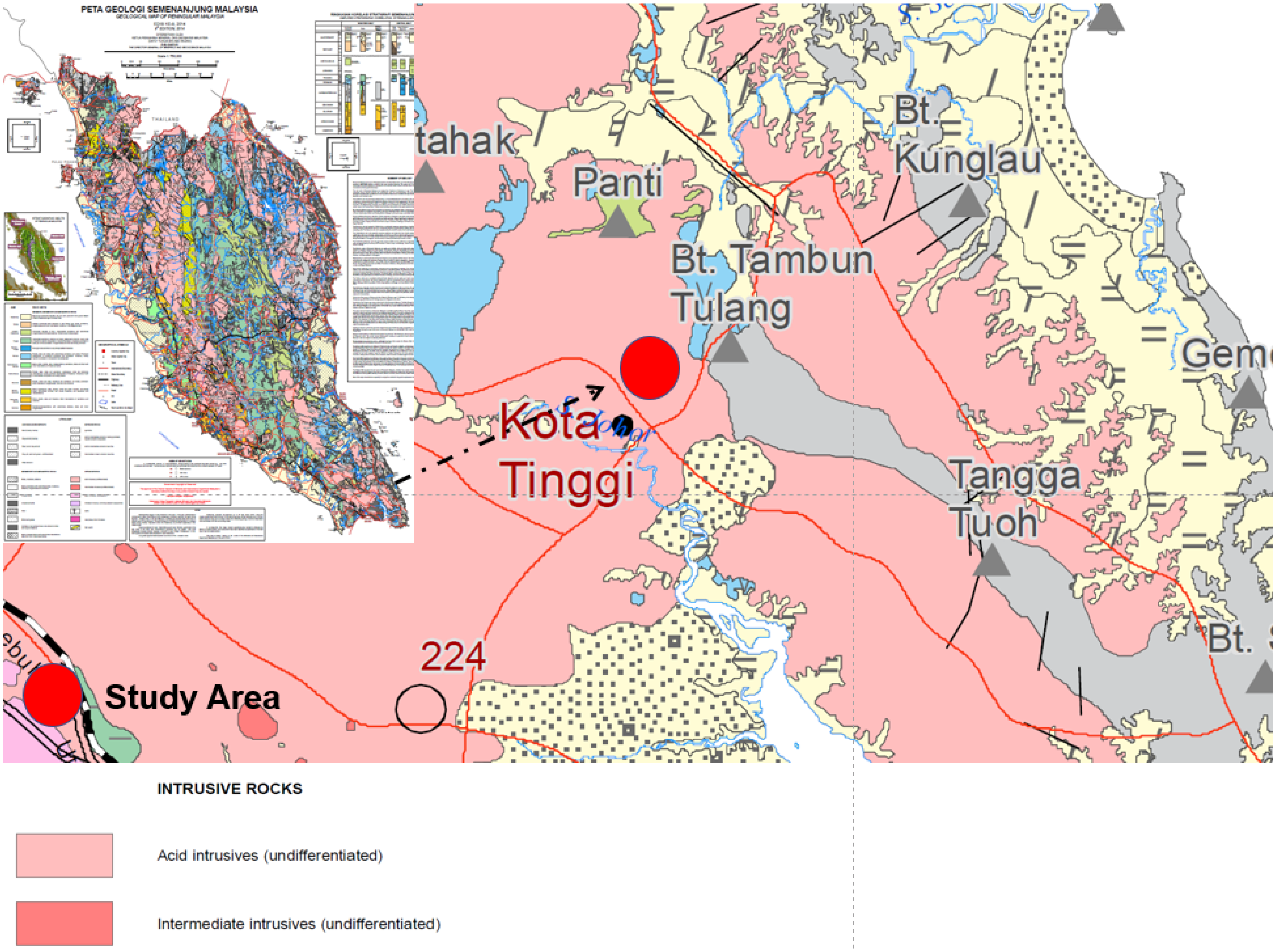

Figure 2

Geology map of BJ Granite Quarry, Kota Tinggi

Figure 3

Location of seismic survey line and 2D resistivity test

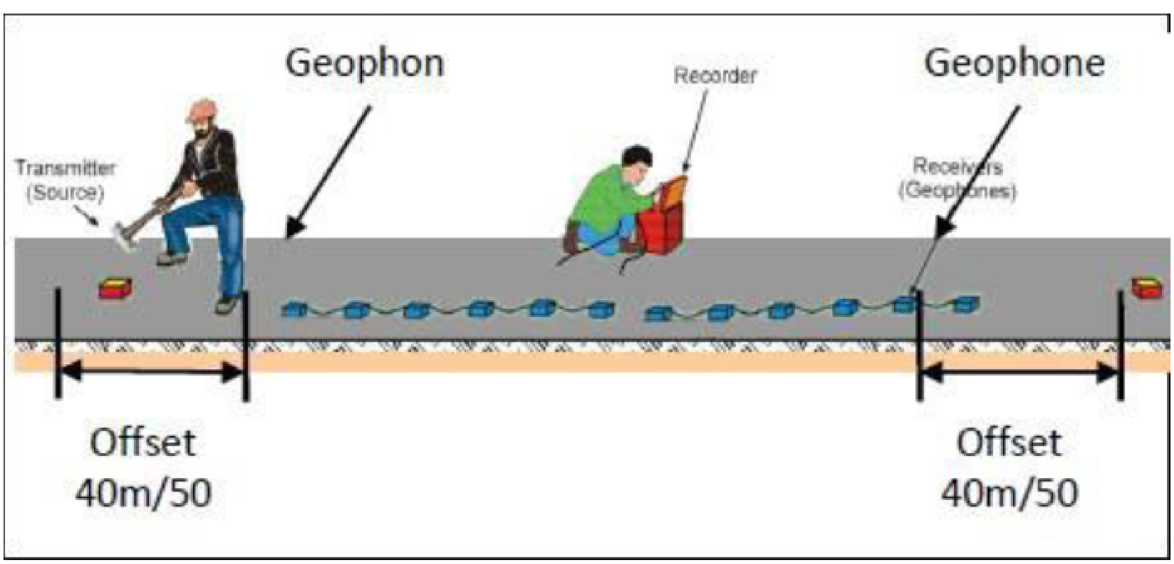

Figure 4

Seismic refraction equipment arrangement

Figure 5

Striker plate

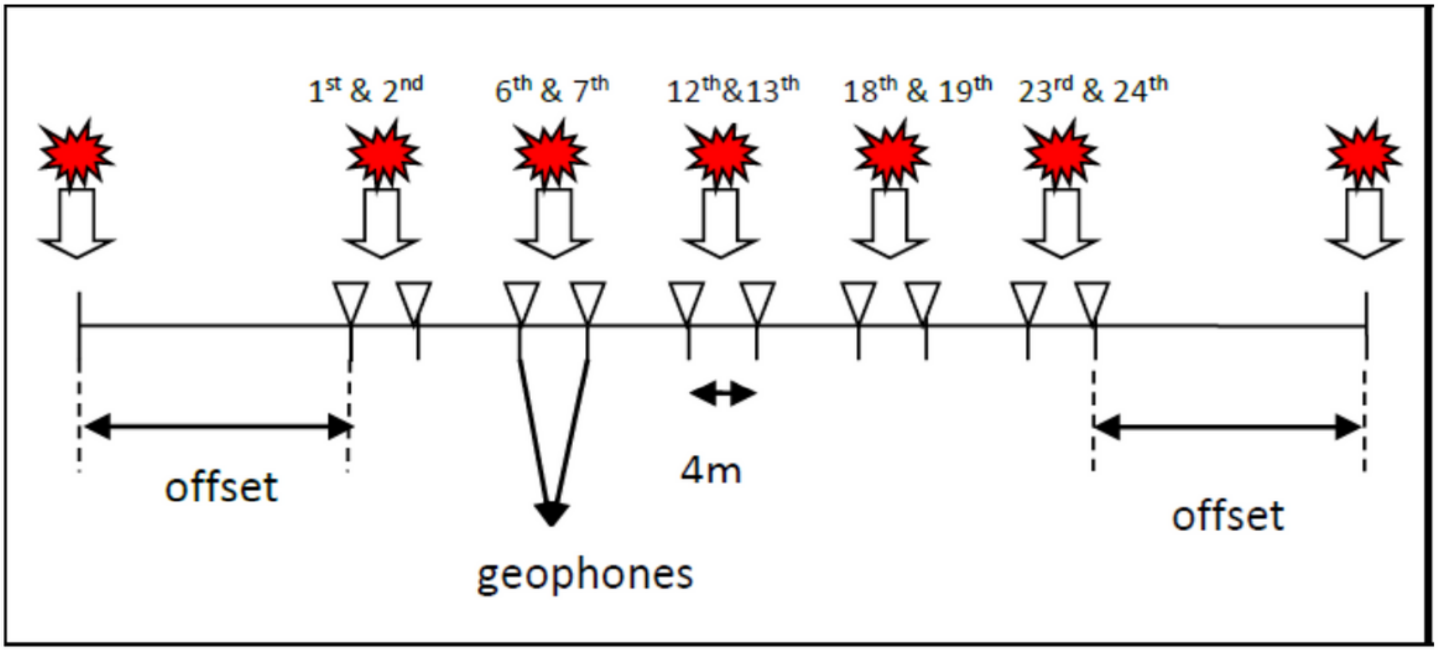

Figure 6

Location of shot point

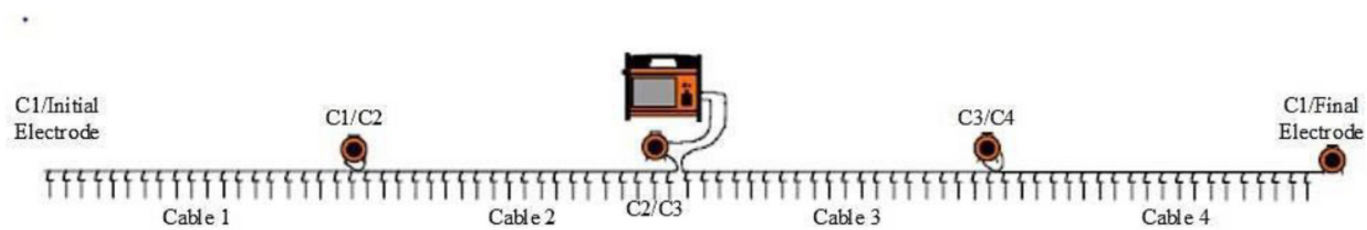

Figure 7

Electrode cable arrangement

Figure 8

Electrode cable arrangement on site

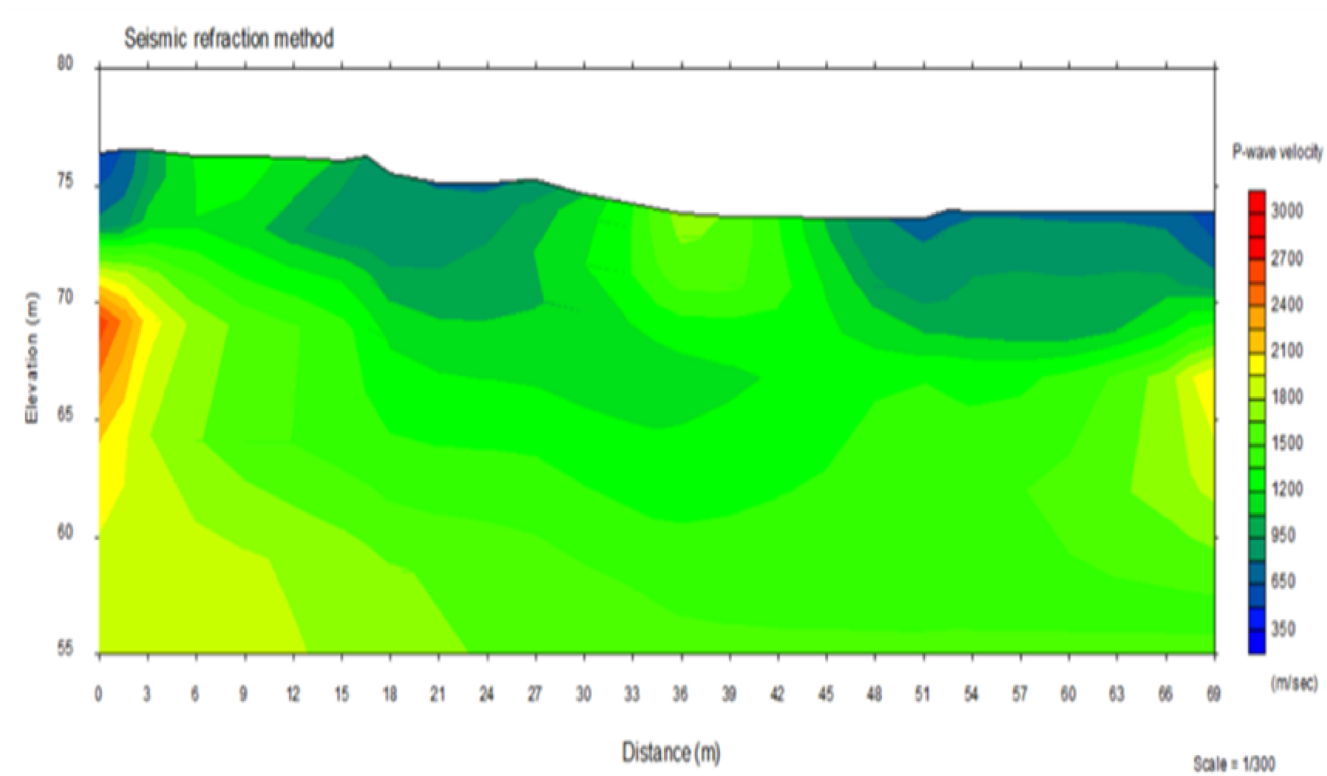

Figure 9

Seismic refraction result of SR01 at BJ Granite Quarry, Kota Tinggi

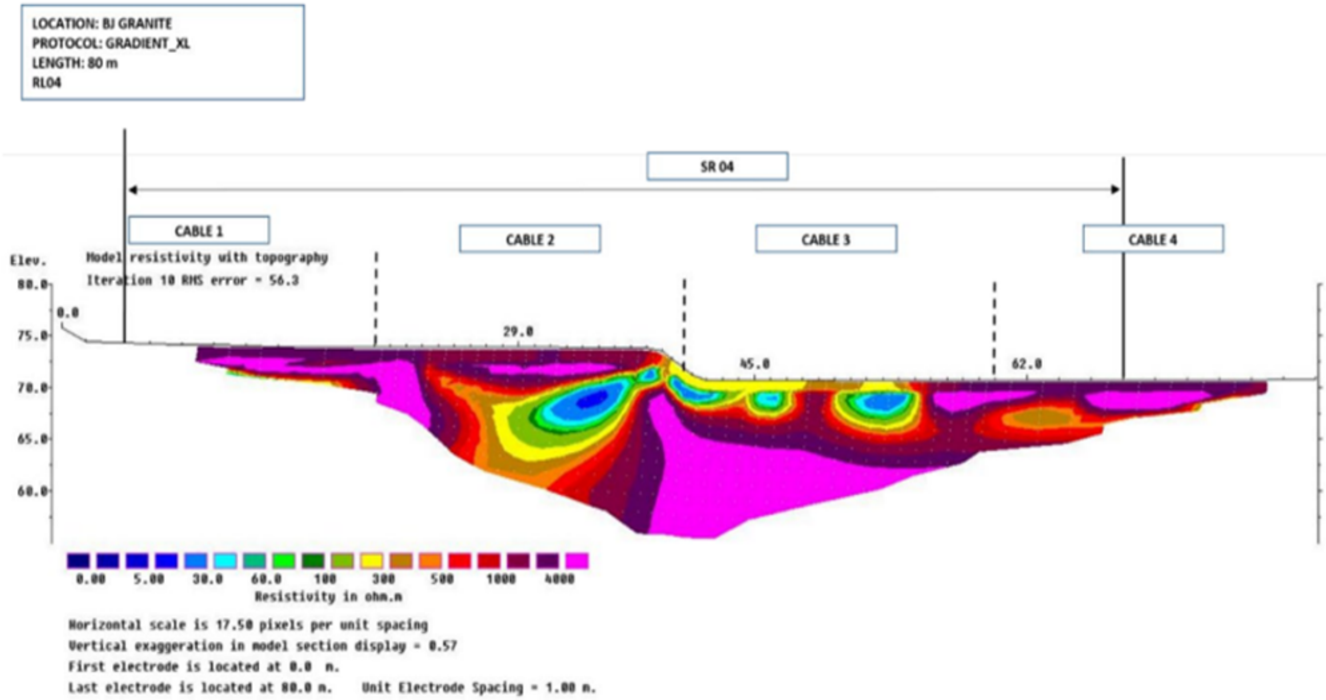

Figure 10

ERT result of RL01 at BJ Granite Quarry, Kota Tinggi

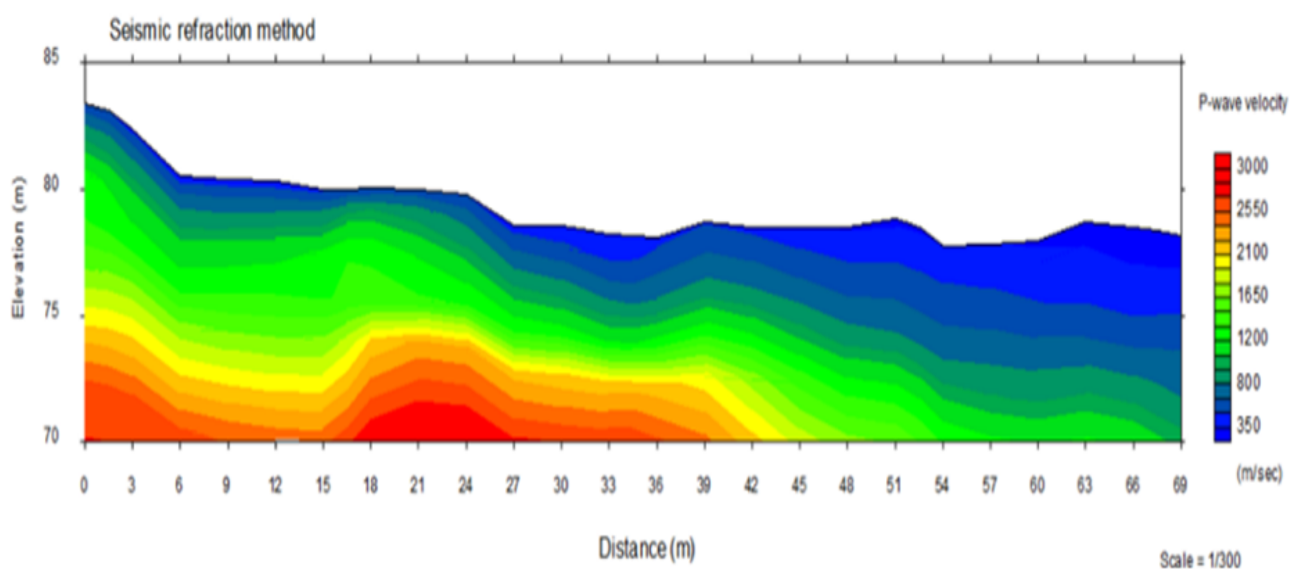

Figure 11

Seismic refraction result of SR02 at BJ Granite Quarry, Kota Tinggi

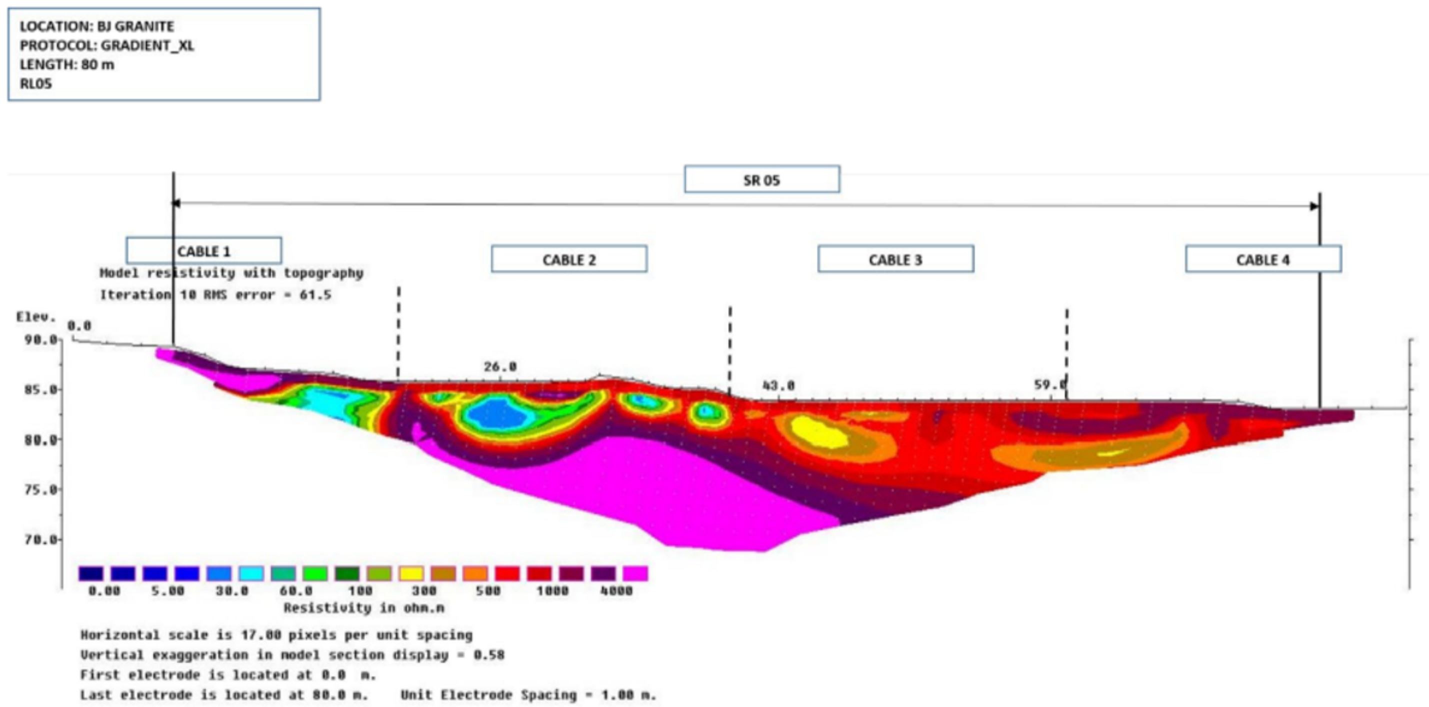

Figure 12

ERT result of RL02 at BJ Granite Quarry, Kota Tinggi

Figure 13

Point Load test conducted on granite-weathered rock

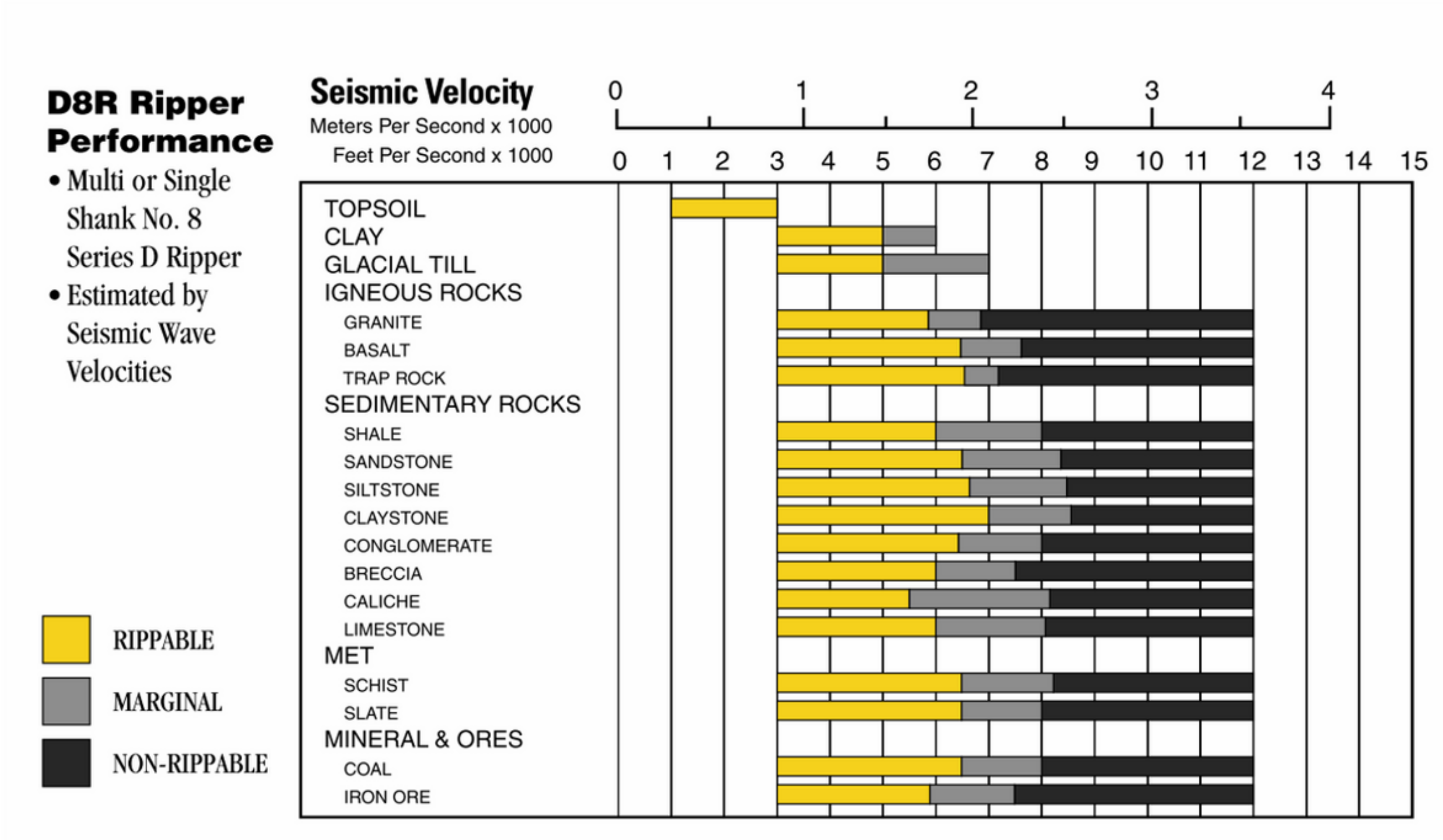

Figure 14

Rippability chart for D8 (Caterpillar, 2010))

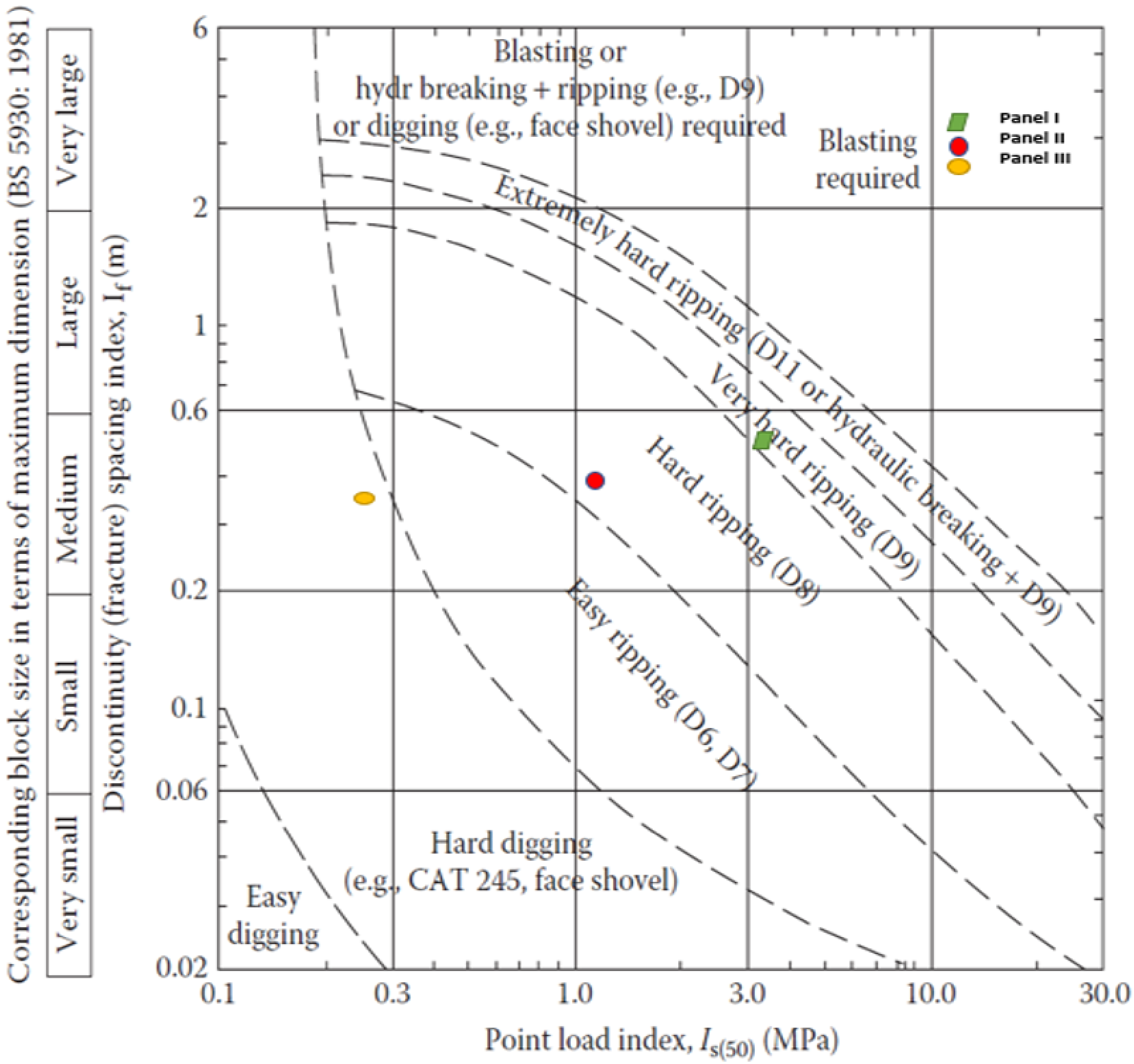

Figure 15

Excavatability Chart Pettifer and Fookes (1994)