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Seismic refraction assessment for excavatability and volume estimation in Kota Tinggi, Johor, Malaysia

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ABSTRACT

Quarry and mining management seek to understand ground excavatability. With effective assessment, earthwork could be planned to reduce unnecessary expenditure. Considering this, a study was conducted at Kota Tinggi district (Johor) to investigate the ground subsurface for excavation assessment prior to developing a quarry. Seismic refraction method was employed using 2-D tomography technique, where its output was validated using existing borehole, geological data and previous research works to achieve a comprehensive interpretation. The result shows that the area consists of three geological layers with velocity of 647–1570 m/s (1st layer), 1570–2506 m/s (2nd layer), and 2506–3647 m/s (bedrock). The two upper layers are rippable while the third layer is non-rippable. The mechanical excavation limit was estimated to be 1.4 million m^3 and 0.5 million m^3 for the 1st and 2nd layer respectively based on seismic velocity value. This indirect assessment method is fast and cost-effective in estimating the earthwork required for quarry and mining management.

1. Introduction

In quarry and mining, overburden is classified as weathered rock and soil that overlies bedrock or rock body that could be economical. Management of overburden prior to quarrying/mining is important as the overburden will be used to restore mining site (Kogel, 2009). A proper plan in stockpiling and excavation rate for a volume of overburden needs to be meticulously formulated (Health and Safety Authorities, 2020; Galera et al., 2009; Mining and Development, 2002). Quarry and mining activities typically conduct open pits, especially when profitable ore body is at shallow depths (Mossa and James, 2013). Removing of the overburden (soil, weathered/hard rock) could be executed using several types of equipment/machinery depending on stockpile distance, topography, ground characteristic and geotechnical properties of the ground layers (Zhang et al., 2013; Dey and Ramcharan, 2008; Mukhopadhyay et al., 2014; Williams, 2014; Oggeri and Ronco, 2020). To minimise risk of failure and unnecessary expenditure, information on the overburden is essential. Excavatability estimation could be divided into two methods; direct and indirect. Direct method is conducted at trial pits using accessibility equipment (dozers) for its excavatability performance. Indirect method is typically conducted only when direct method cannot be applied, where seismic refraction method is the most common (*Caterpillar performance handbook,* 2008; Basarir et al., 2004). Seismic refraction is applicable for a wide geological and geomorphology conditions (Basarir and Karpuz, 2004; Dindarloo and Siami-Irdemoosa, 2015; Ismail et al., 2010), where the result is referred to a standard table for excavation work by *Caterpillar performance handbook* (2008).

Many researchers have used seismic refraction in quarry/mining studies. Kausarian et al. (2014) conducted seismic refraction survey to characterize rock mass at a quarry. Results obtained have shown there are five zones of weathered granite, which was divided by the range of refractive wave velocity (Vp). Vp has a certain range of velocities for each layer or zone in rock mass although they are located at the same depth. This shows that the layer of rock is not homogeneous due to the non-uniform distribution of mineral content. Vp velocity in the rock mass in the field is also heavily influenced by the existence of cracks and squat (particularly in granitic rocks), porosity and ground water conditions. Many of weathered zones shown at each seismic profile based on the velocity Vp survey show decreasing weathering grade of rock with

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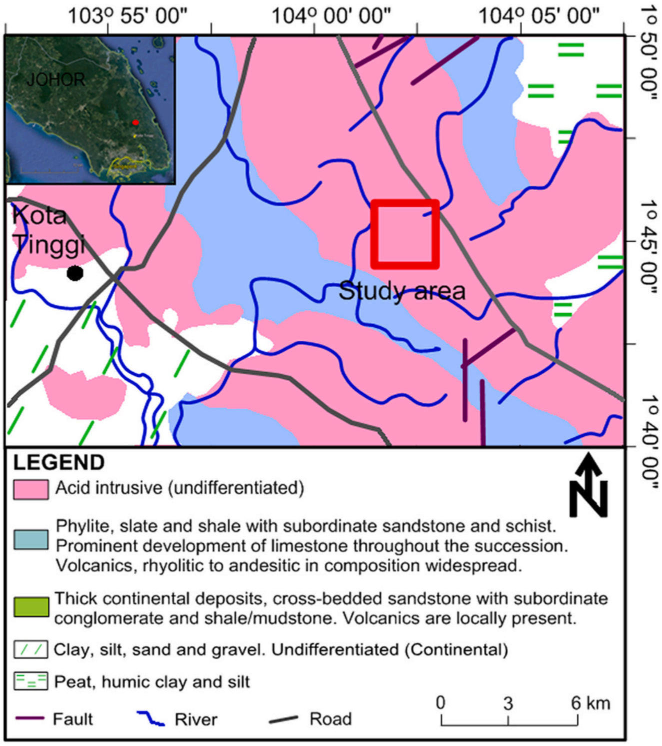


Fig. 1. Regional geology of the survey area, Kota Tinggi, Johor (Google Earth, 2016; Department of Mineral and Geoscience Malaysia, 1985).

Fig. 2. Undulating topography of the study area.

depth in incomplete grade sequence.

Seismic refraction was also applied in producing the subsurface profile of the potential quarry area (Awang et al., 2019). To identify the areas that will be actively used for economical extraction of the bedrock, overburden needs to be removed prior to production stage. Therefore, thickness and volume of overburden were determined using seismic refraction. Validation using borehole data also matches with the seismic result. This proves that seismic refraction is reliable in identifying the depth to bedrock. Their study also shows deeper granite has higher seismic velocities. The bedrock depths and seismic velocity distributions were recommended for the proposed quarry site with strict engineering measures (Sharafeldin, 2008). Fadel et al. (2016) conducted seismic refraction survey to image extent and thickness of limestone bedrock

Table 1
Coordinate of the seismic refraction survey lines at study area.

Line name	Distance (m)	Latitude (N)	Longitude (E)	UTM – Zone 48 N	
				Northing (m)	Easting (m)
P1	0	1°45′28.75”	104° 2′37.01”	194,338.14	393,622.96
	115	1°45′30.82”	104° 2′40.06”	194,401.65	393,717.24
P2	0	1°45′29.92”	104° 2′39.23”	194,374.03	393,691.58
	115	1°45′33.01”	104° 2′41.06”	194,468.89	393,748.17
P3	0	1°45′34.78”	104° 2′42.94”	194,523.21	393,806.29
	115	1°45′38.41”	104° 2′44.09”	194,634.66	393,841.88
P4	0	1°45′37.66”	104° 2′42.04”	194,611.66	393,778.53
	115	1°45′38.48”	104° 2′45.64”	194,636.78	393,889.78
P5	0	1°45′34.81”	104° 2′41.32”	194,524.16	393,756.23
	115	1°45′36.68”	104° 2′44.34”	194,581.53	393,849.58
P6	0	1°45′34.48”	104° 2′40.47”	194,514.04	393,729.96
	115	1°45′32.63”	104° 2′43.72”	194,457.18	393,830.36

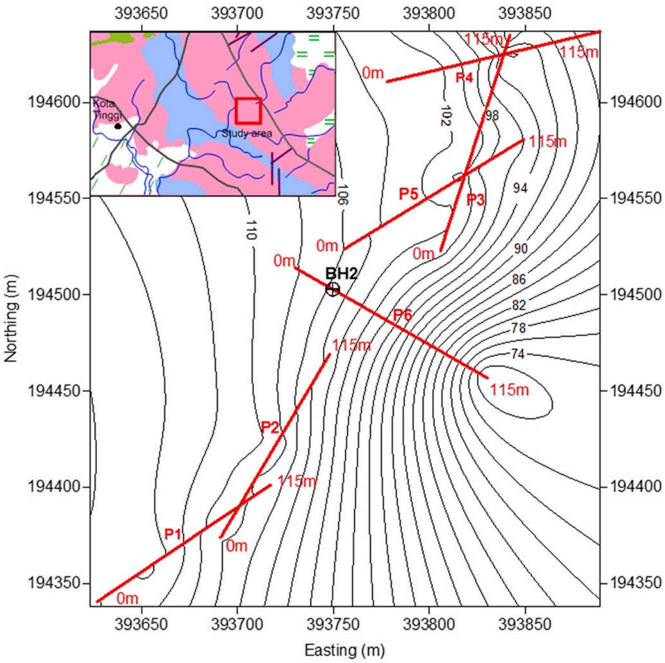


Fig. 3. Topography map of the study area with survey lines (P1 – P6) and borehole (BH2) location.

Table 2
Seismic refraction shot point locations at the study area.

Line name	Length (m)	Shot points location refer to 0 m as geophone 1 (m)
P1	115	−40, 2.5, 27.5, 57.5, 87.5, 112.5 and 147
P2	115	−35, 2.5, 27.5, 57.5, 87.5, 112.5 and 165
P3	115	−50, 2.5, 27.5, 57.5, 87.5, 112.5 and 155
P4	115	−30, 2.5, 27.5, 57.5, 87.5, 112.5 and 165
P5	115	−40, 2.5, 27.5, 57.5, 87.5, 112.5 and 133
P6	115	−40, 2.5, 27.5, 57.5, 87.5, 112.5 and 155

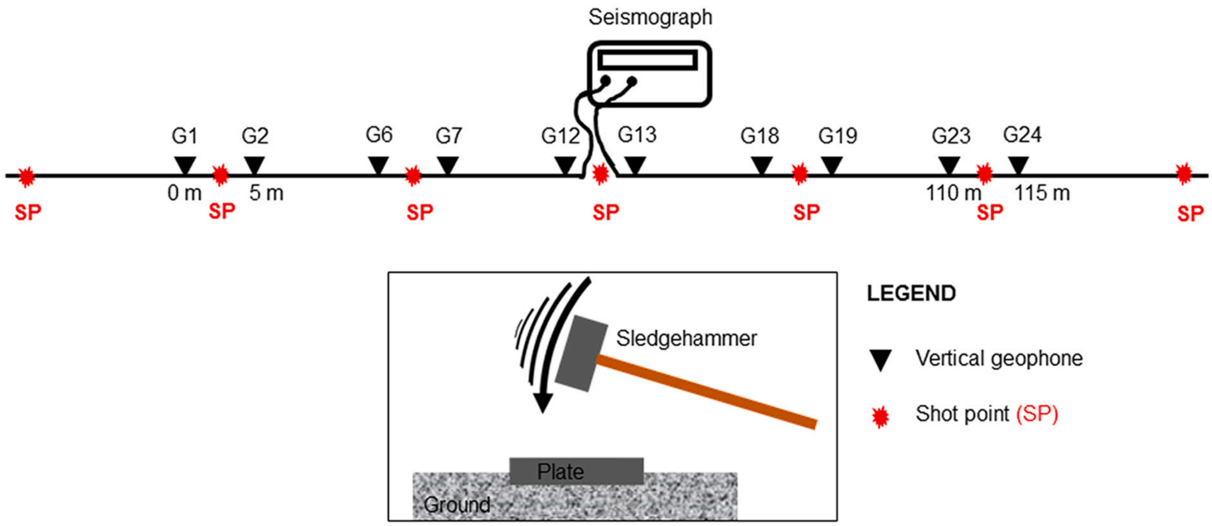
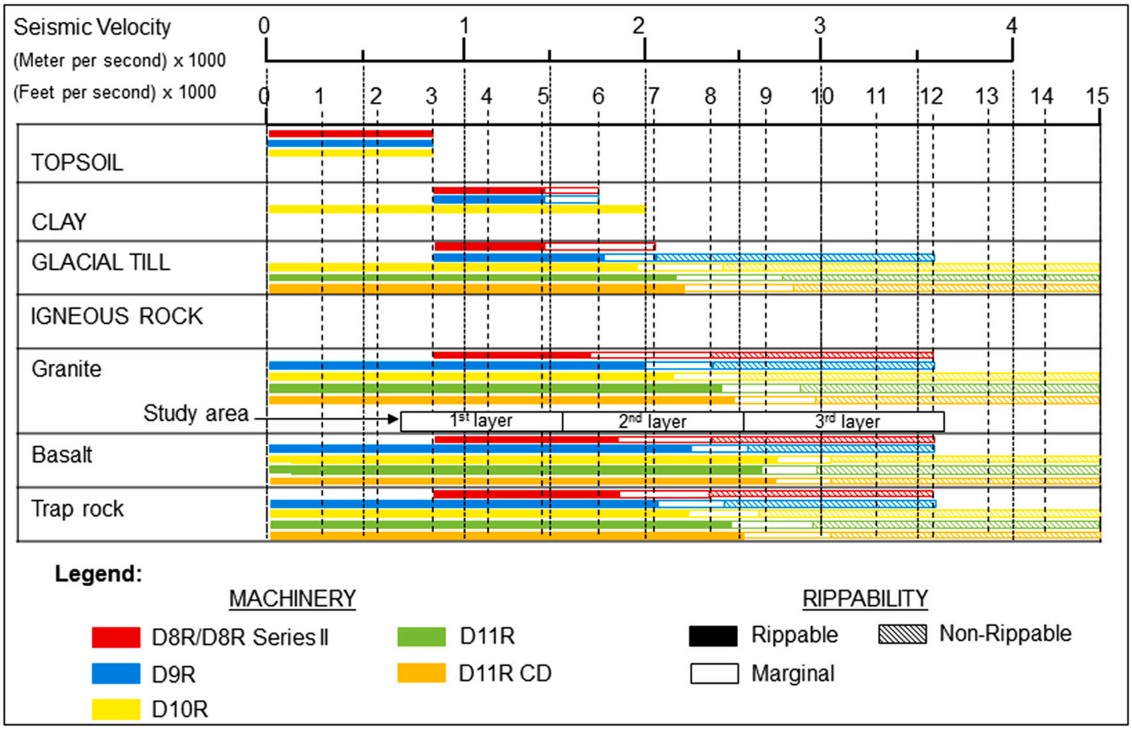


Fig. 4. Seismic source location and seismic refraction p-wave hammering technique.

Table 3
Subsurface rippability classification of the study area (*Caterpillar performance handbook*, 2008).



and overburden, including potential presence of underground seepage and soil/rock inferred strength to monitor quarry pit development.

Seismic source from quarry blasts could also be used. Quarry blasts excite seismic waves is useful in understanding how quarry blast discriminants may be transported from one region to another. An experiment in Texas with well-placed seismic stations and a cooperative blasting engineer has shed light on some of the physical mechanisms of seismic excitation at short periods (0.1–3 Hz) (McLaughlin, 2004).

Michael (2012) has determined the feasibility of constructing a new barracks building in Monterey, California using compressional-wave seismic refraction survey. It was proposed by the U.S. Geological Survey as an alternative means in investigating the depth to competent bedrock. The seismic refraction tomography models along two subparallel profiles acquired at the site indicate that rippable and non-rippable materials. The models show a transition to increasingly more consolidated material with depth.

These past researches have displayed that seismic refraction method can be applied to estimate rippability prior to excavation. Therefore, this paper discusses an application of the seismic refraction method for indirectly estimating of suitable machinery, excavatability, volume and depth to rock head for quarry management.

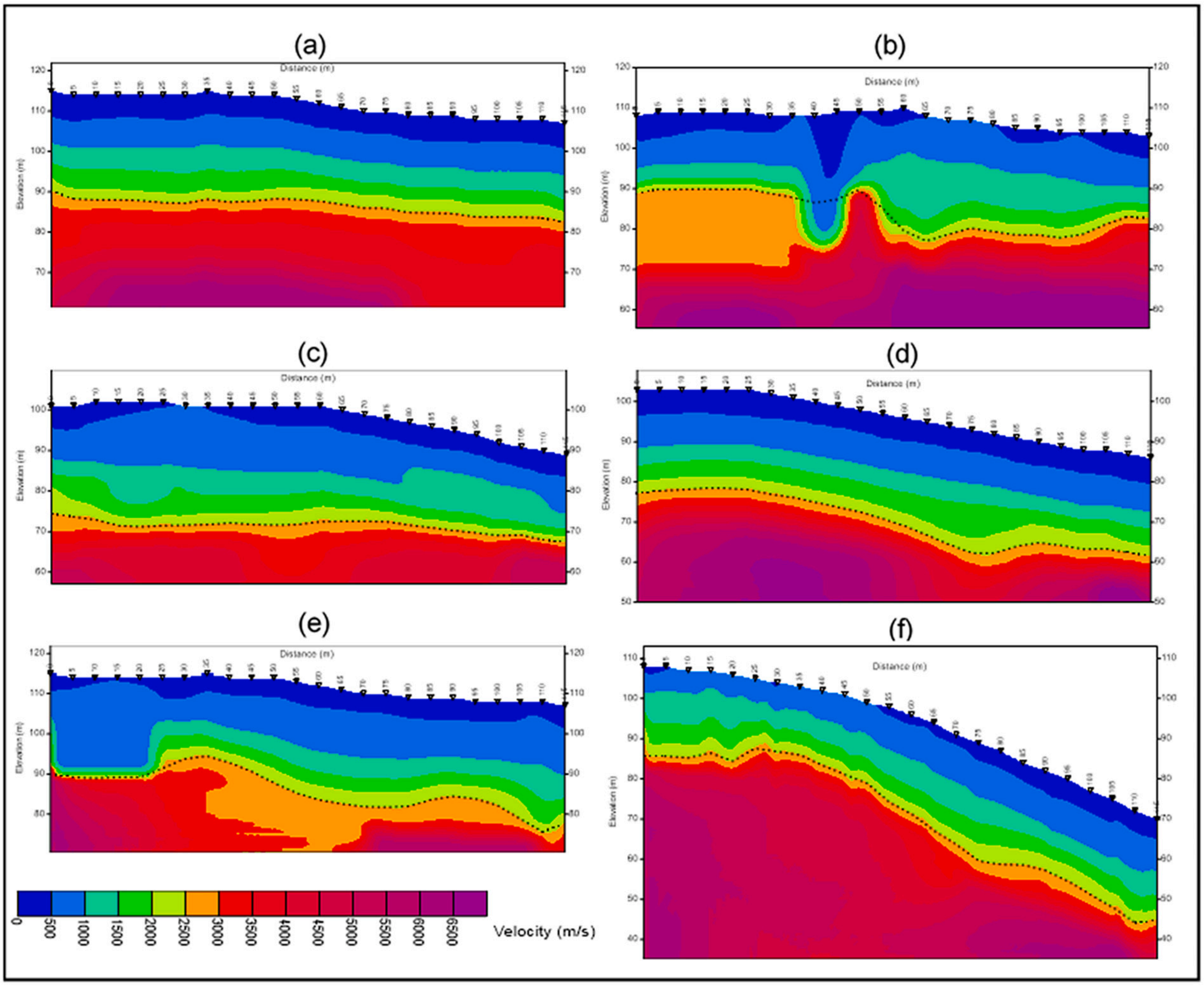


Fig. 5. 2-D seismic refraction tomography section of the study area: (a) line P1, (b) line P2, (c) line P3, (d) line P4, (e) line P5, and (f) line P6.

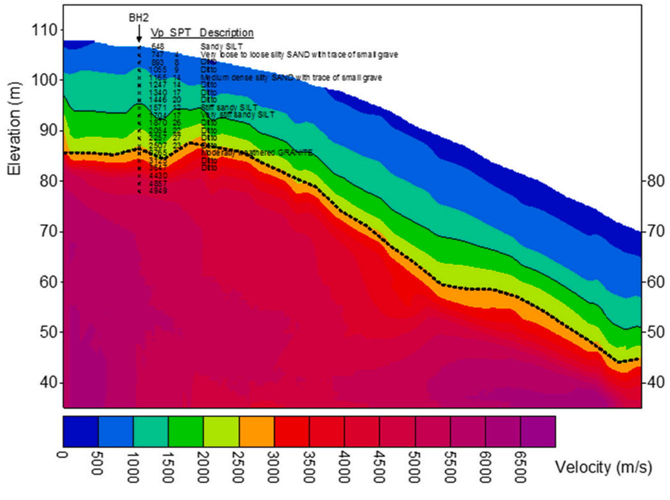


Fig. 6. Validation of subsurface using borehole BH2 with 2-D tomography of line P6.

2. Regional geology

The study area is located between Felda Sri Perani and Felda Bukit Waha, in Johor (Malaysia). It was located about 35 km from Kota Tinggi town following Jemaluang road towards North-east direction. The coordinate of the study area is from N 1° 45′ 28″ to N 1° 45′ 40″ latitude and E 104° 2′ 36″ to E 104° 2′ 47″ longitude, which covers an area of 79,470.8 m^2 (Fig. 1). The regional geology of the study area is acid intrusive (granite), and is surrounded by phyllite, slate and shale with subordinate sandstone and schist at northern and southern parts. Towards the northeast and eastern part of the study area is peat, humic clay and silt (Google Earth, 2016; Department of Mineral and Geoscience Malaysia, 1985). The study area is surrounded by five different rivers with undulating ground topography (Fig. 2).

3. Methodology

Six seismic refraction survey lines (P1 – P6), with 115 m length each line was conducted to map shallow subsurface of the study area. Borehole (BH2) was located on survey line P2 at distance of 15 m from the start (0 m). The seismic data was acquired using 24 channel seismograph ABEM TERRALOC MK8 system with 28 Hz vertical geophones that are connected to a pair of seismic cables. The geophones were firmly planted on the ground surface with a constant spacing of 5 m, using geophone spike and laid in a straight line. All geophone locations and elevations were recorded on site using GARMIN 76CSX unit with Universal Transverse Mercator (UTM) latitude/longitude function (Table 1) to produce study area topography map and survey lines (Fig. 3). A 5 kg sledgehammer was used as a seismic source by striking vertically on a metal plate at specific location (Table 2 and Fig. 4). The offset location varied in order to get accurate profile and depth imaging. The seismic data was recorded/saved by the seismograph for further processing and

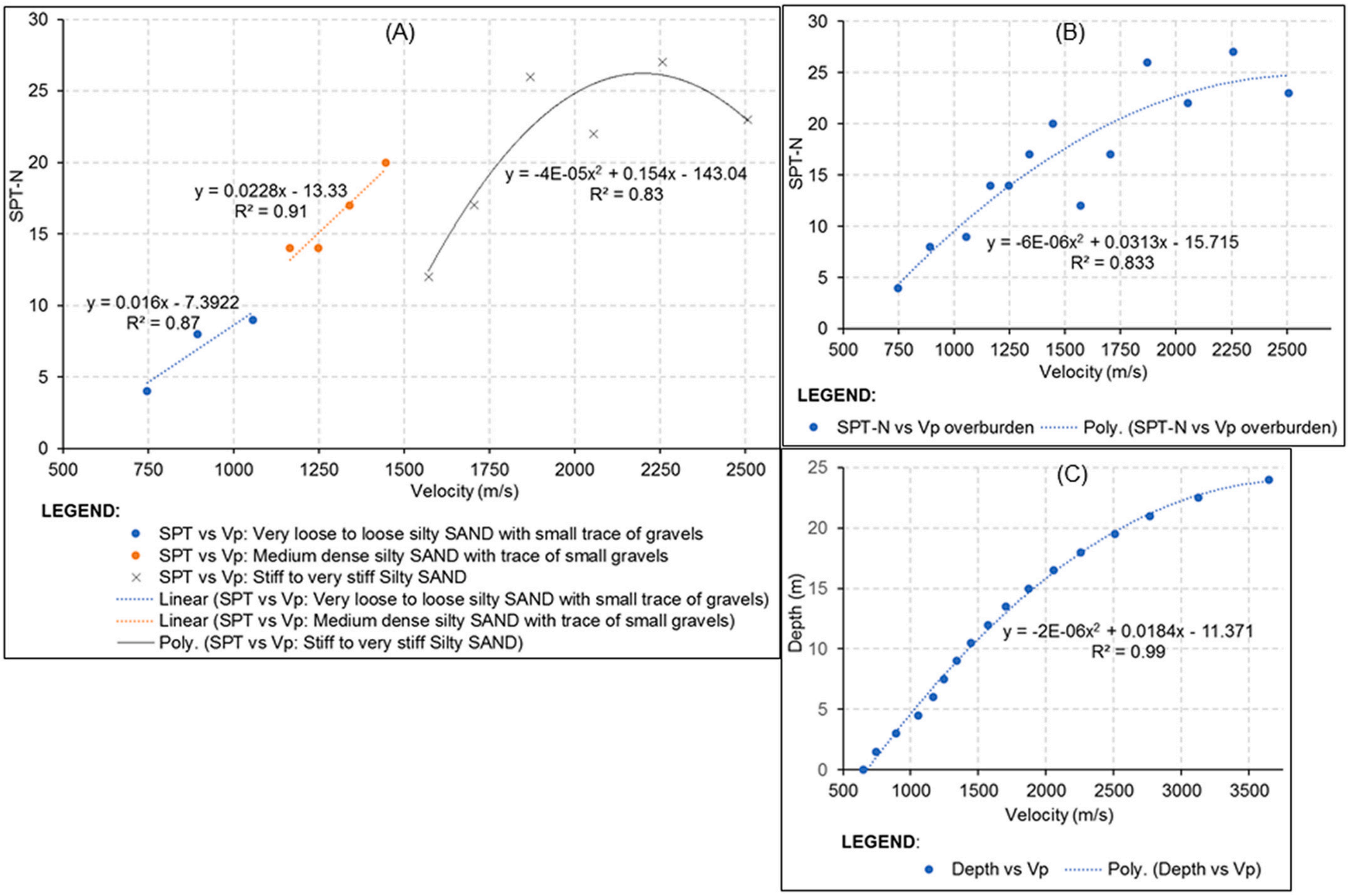


Fig. 7. Relation between SPT and depth against velocity, V for BH2: (a) SPT for each layer against V, (b) SPT for the whole sample against V, and (c) depth of samples against V.

Table 4
Rippability volume in the study area.

Upper boundary elevation (m)	Upper boundary elevation (m)	Volume (m^3)	Machine
Ground topography	1st layer	1,366,450	Minimum D9R
1st layer	2nd layer	499,756	D11R CD
Total		1,866,206	

interpretation using IXRefract, Microsoft Excel, SeisOpt@2D v6.0 and Surfer@8 software. (See Table 3.)

All seismic data were processed using IXRefract software to improve the S/N ratio. The satisfied data was saved for further processing and interpretation using SeisOpt@2D v6.0 to produce 2-D tomography section. The 2-D tomography model was generated through which the travel time was determined and the elevation data that was recorded from global positioning system (GPS) using GARMIN 76CSX unit along the profile.

Using Surfer@8 and Microsoft Excel software, the 2-D tomography sections were analysed and validated with existing borehole to identify the subsurface and estimate overburden volume by digitizing the 2-D tomography section. The borehole provides Standard Penetration Test (SPT) which was designed to provide information in the geotechnical engineering properties of soil. SPT provided the N-value and the soil description which was classified into two types; cohesive and non-cohesive. Cohesive soil was described as stiff or soft while non-cohesive soil was described as loose (Varghese, 2012). The volume is calculated based on the difference between upper and lower boundary elevation multiply by area using volume function in Surfer@8 software.

The results for 2-D profiles were combined to perform 3-D image using Surfer8 software. The volume of rippability was estimated based on combination of the 2-D models of seismic refraction. In this estimation, the locations of the first layer was identified in 2-D seismic models and digitised for further volumetric calculation. Mathematically, the volume under the function f(x,y) is defined as in Eq. (1).

$$V = \int_{x\ min}^{x\ max} \int_{y\ min}^{y\ max} f(x, y)dxdy \tag{1}$$

To identify the volume, m^3 of rippability the Universal Transverse Mercator (UTM) coordinate in meter, m unit was used with the elevation map (m unit) of the study area. It is imperative to ensure that the unit used for all parameters is the same to avoid wrong interpretations. The Kriging gridding method was used to generate the model of the subsurfaces (Zakaria, 2020). In this calculation, the isopach map was applied and generated using math function in Surfer tools, where the difference between two grid files of upper and lower was measured.

4. Results and discussion

The seismic velocities of each ground layer are importance to provide information on ground stiffness. The wave usually travels faster in denser, wet, more consolidated materials compared to loose and weathered materials. Interpreted depth-velocity models show lateral variations in both bedrock velocity and depth (Sharafeldin, 2008).

The first layer depth ranges between 13 and 15 m from the surface was characterized with velocity value of 600–1500 m/s (Fig. 5). The second layer with velocity value of 1500–2500 m/s at depth of 15 to 25

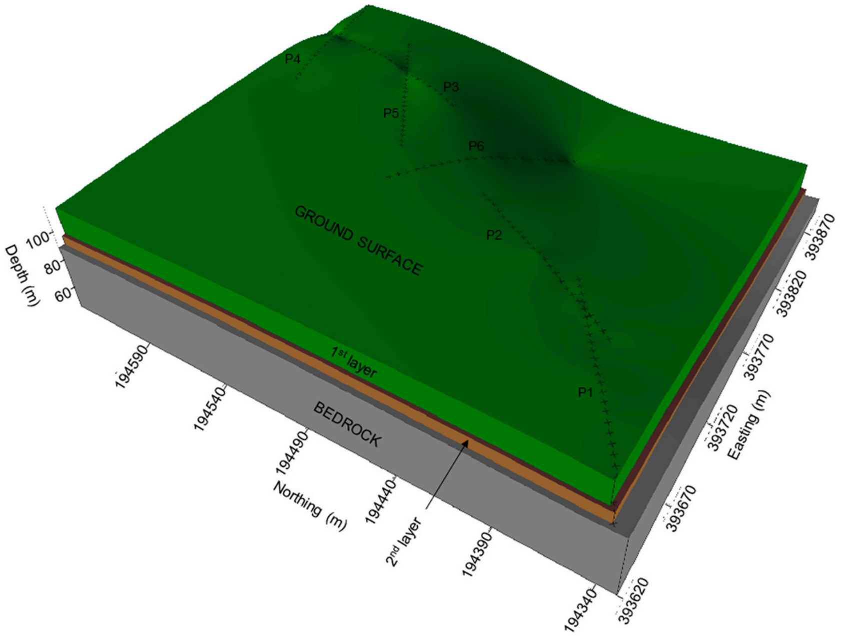


Fig. 8. 3-D view of subsurface at the study area.

m from the surface. The third layer of the site was characterized by high velocity values (> 2500 m/s) which indicates the presence of massive basement at depth > 20 m.

The 2-D tomography section of line P6 was overlaid with borehole BH2 result to validate the subsurface. The validation result shows the first layer with depth 13.5 m from ground surface was classified as medium to very loose silty sand with trace of small gravels, indicated with velocity value of 647–1570 m/s. Second layer consists of very stiff sandy silt identified at depth of 13.5–21 m from ground surface with velocity value of 1570–2506 m/s. Rock head was classified as moderately weathered granite identified at depth of ≥21 m from ground surface with velocity value of 2506–3647 m/s (Fig. 6). The denser the material the higher the seismic velocities. In most cases the seismic velocity increase with increasing the depth (Ismail et al., 2010; Awang et al., 2019; Kausarian et al., 2014).

The velocity values (V) were plotted against Standard Penetration Test (SPT) and depth for every sample of the BH2. The SPT and V for the three layers shows a strong relation with high coefficient of determination (R^2) value of 0.87, 0.91 and 0.83 respectively, while the SPT for all the sample and V show a strong relation with high coefficient of determination (R^2) value of 0.833. The relation between depth and V provides strong relation with R^2 value of 0.99 (Zaman et al., 2016) (Fig. 7). R^2 values smaller than 0.3 indicate that there is no correlation between the considered variables. However, should the R^2 value fall within the ranges of 0.3–0.5, 0.5–0.7, 0.7–0.9 and 0.9–1, the corresponding correlations are recognized as weak, moderate, strong, and very strong, respectively (Jusoh and Osman, 2017).

The results are correlated with standard table (*Caterpillar performance handbook*, 2008) and the subsurface of the study area is classified as rippable with minimum of D9R machine for the 1st layer. The 2nd layer is rippable using D11R CD machine, and third layer is non-rippable (Table 3). Rippability volume (Table 4) was calculated based on subsurface classification which 3-D view of the boundary is shows in Fig. 8.

5. Conclusion

Seismic refraction method is one of the geophysical tools commonly used to study shallow geological subsurface characteristics. Data processing with the application of tomography technique to produce 2-D section improve the result. Validation of the result is applied using secondary data such as borehole, geology, etc. assist in interpretation. The first layer was indicated as medium to very loose silty sand with trace of small gravels, with velocity value of 647–1570 m/s and rippability volume of 1,366,450 m^3. It is classified as rippable using a minimum of D9R machine. Second layer consists of very stiff sandy silt identified at depth of 13.5–21 m from ground surface with velocity value of 1570–2506 m/s and rippability volume of 499,756 m^3. It is rippable using D11R CD machine. The rock head was classified as moderately weathered granite identified at depth of ≥21 m with velocity value of 2506–3647 m/s which was classified as non-rippable. The study shows seismic refraction method can be used to evaluate geological subsurface condition and it is possible to estimate the volume of rippability for excavatability assessment of quarry and mining with minimum time and cost. Therefore, a small ripper which is D9R is sufficient to excavate the rock material. If excavation is necessary, the non- rippable section should be tackled via blasting.

CRediT authorship contribution statement

NordianaMohd Muztaza: Investigation, Data curation, Writing – review & editing. **Nur Azwin Ismail:** Investigation, Data curation, Writing – review & editing. **Edy Tonnizam Mohamad:** Validation, Supervision, Writing – review & editing. **Rosli Saad:** Conceptualization, Formal analysis, Methodology, Software, Writing – original draft. **Farid Najmi Rosli:** Investigation, Writing – review & editing. **Najmiah Rosli:** Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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