Rock Mass, Geotechnical and Rock Type Identification Using SASW and MASW Methods at Kajang Rock Quarry, Semenyih, Selangor Darul Ehsan

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ABSTRACT

Rock mass characterization study at Kajang Rock quarry was performed using Spectral Analysis of Surface Waves (SASW) and Multichannel Analysis of Surface Waves (MASW) methods. Rock Quality Designation (RQD) can be measured in the field directly. Discontinuity and processing survey methods determined from 4 locations that have been examined in this study area. Based on MASW and SASW methods, velocity of S waves (Vs) can be obtained and weathering grade of rock mass has been classified. Location 1 consists of 5 weathering zones, SASW data indicates surface wave velocity (Vs) obtained from 198 m/s to 2044 m/s, MASW (Vs) ranges obtained from <600 m/s to> 2400 m/s. Location 2 consists of 4 weathering zones, (Vs) of SASW obtained from 592 m/s to 2271 m/s and (Vs) of MASW obtained from 400 to 2000 m/s. Location 3 consists of 4 weathering zones with (Vs) of SASW obtained from 512 m/s to 2465 m/s and (Vs) of MASW obtained from 400 to >1200 m/s. Location 4 consists of 5 weathering grades with (Vs) of SASW obtained from the 200 m/s to 2040 m/s and (Vs) of MASW obtained from 300 to >2300 m/s. Rock Quality Designation (RQD) in Location 1 shown the rock quality is excellent (98.63%), in Location 2, RQD shows the rock is good (98.38%), in Location 3 RQD shows the rock is excellent (99.03%), in Location 4 RQD shows the rock is excellent (96.43%).

KEY WORDS: *Kajang Rock Quarry; SASW; MASW; RQD.*

NOMENCLATURE

SASW	Spectral Analysis of Surface Waves
MASW	Multichannel Analysis of Surface Waves
RQD	Rock Quality Designation
Vp	Velocity of P Wave
Vs	Velocity of S Wave
m/s	Meter per second
SG1,2 ...	Location survey 1,2 …
Vr	Rayleigh velocity
λ	Wavelength
Z	Depth
μ	Poison ratio
C	Constant value depends on Poison ratio
G	Shear modulus
ρ	Density

1.0 INTRODUCTION

This study area located at Kajang Rock quarry, Semenyih (Figure 1) and the quarry is a granite rock quarry (Figure 2). Kajang Rock Quarry located in the Semenyih district, Selangor. The quarry located at Longitude 02º55,261' and Latitude 101°50,376' at the north of Semenyih district. Semenyih has many parishes quarry, it is visible from many former quarries in the outskirts town area and also at the hills area of this district.

Lithology at the quarry is granitic type. The study focused on the fresh rock and weathered granite only. Position of the study area is located in the middle line of the granite pluton body, and only one type of lithology detected in this area.

Surveyed locations are slopes of a quarry outcrop which known as Terrace 2 (SG1 (Location 1) and SG2 (location 2)), Terrace 5 (SG 3 (Location 3)) and terrace 8 (SG4 (Location 4)) (Figure 3). Studies were conducted on the quarry outcrop at the inactivity, which is not operational in the short term.

Geographical condition near the quarry is oil palm plantation. However, a highway was built near the quarry, the road linked the Reko highway, Kajang, Semenyih, Kuala Lumpur and Sungai Long. These highways known as Kajang Silk Highway.

1.1 Literature Review

Ahya (2007) states that the granite at Km 14.6 of SILK highway composed by grade I and I-II and has coarse to medium texture. Ahya also find Rock Quality Designation (RQD) is 87.73%. Ser (2007) states the granite in Kajang Rock quarry consists of five types of granite, which are medium-coarse-grained porphyry granite, moderately coarse-grained granite, biotite granite, fine grain sheared white granite, clorite sheared granite. Ser centralize analysis of rock mass characterization and rock quality that found this area is starting from very low (V) to very good (I), but most are concentrated in low quality (IV) to moderate (III). Ser also states that the rock mass classification system based on RMR Bieniawski 1979, found 44% of the rock mass is in good quality (class II) and 56% of average quality (Class III). Husnul (2013) states the condition of granitic rock in this area is in good condition to be quarried.

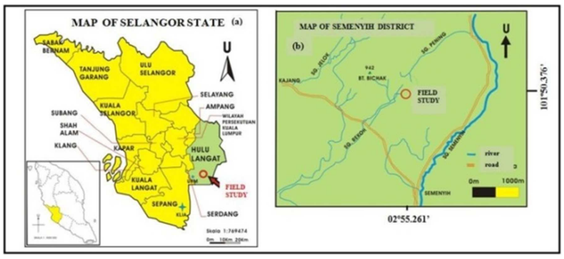


Figure 1: (a) Map of Selangor State, (b) Semenyih District Map.

Figure 2: Field study area (terrace) at Kajang Rock Quarry.

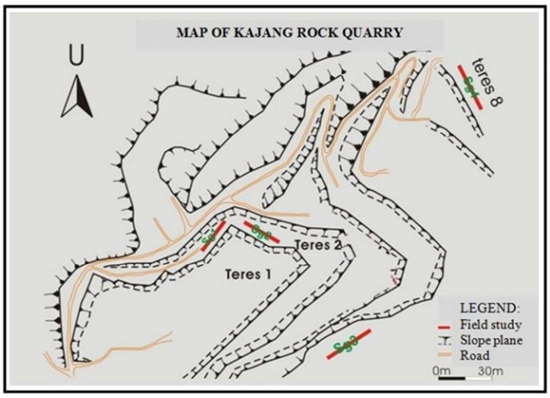


Figure 3: Plan view of field study location (Sg1, Sg2, Sg 3, Sg4), Kajang Rock Quarry, Semenyih (Modified from Ser, 2007).

2.0 OBJECTIVES

The main purpose of this study is to determine the effectiveness of SASW and MASW methods to characterize of igneous rock mass in this study area. The main objectives of this study are:

1. Characterize the granitic rocks in Kajang Rock quarry using SASW and MASW geophysical methods.
2. Determine the Rock Quality Designation (RQD) for granitic rocks using geophysical methods used in the study area.
3. Determine RQD on the discontinuity of the granite rock and rock quality indicator to compare RQD from the geophysical methods used.

3.0 METHODOLOGY

3.1 Principal of Seismic Method

SASW has been introduced since the 1980s. SASW has the advantages like this method is fast, inexpensive and nondestructive characterization studies in geotechnical and construction sites. Heisey (1982), Nazarian and Stokoe (1984), Tokimatsu et al (1991) and Mathews et al (1996) have been developed this method.

The development of the latest technique is multi-channel analysis of surface waves (MASW) where it mixes SASW and seismic reflection techniques. This technique developed in Kansas Geological Survey (Park et al 1999), can produce two-dimensional data where SASW can only produce one dimension only.

In addition to the body wave moving in an elastic medium, there is another wave that propagates in elastic media surface called surface wave. In the method of spectral analysis of surface waves (SASW), Rayleigh wave velocity is determined and reversed a shear wave velocity, Vs. Relationship between Vs and Vr as shown by equation (1-5) in elastic media.

$$Vr = f\lambda \quad (1)$$
$$Z = \lambda/2 \quad (2)$$
$$Vr = CVs \quad (3)$$
$$G = \rho Vs^2 \quad (4)$$
$$C^6 - 8C^4 + \left[3 - \frac{1-2\mu}{1-\mu}\right]C^2 + 16\left[\frac{1-2\mu}{2(1-\mu)}\right] = 0 \quad (5)$$

Where f is frequency, λ is wavelength from source to detector, Z is depth, C is constant value depends on Poison ratio, G is Shear modulus, ρ is density and μ is Poison ratio.

Deere (1964) suggests the Rock Quality Designation (RQD) as a density discontinuity parameter obtained from drill core. Deere define RQD as cumulative core length of more than 10 cm for a long drilling unit, as shown in equation (6)

$$RQD = \frac{Cumulative\ length\ of\ rock\ cores > 10cm}{Total\ length\ of\ rock\ cores} X100\% \quad (6)$$

3.2 Software and Operation Equipment

Hammer hit to the steel plate that is attached to the surface of the soil used to generate waves that will propagates in subsurface, the main wave generated is Rayleigh wave. The frequency range of Rayleigh wave has sufficient energy to be detected by the sensor by using some type of hammer that has a different weight. Rayleigh wave detection will be carried out from geophones or acceleration transducer (accelerometer) which is connected to a spectrum analyzer.

The spectrum analyzer will record data such as wave spectra and phase coherent functions in file format *.txt. The data will be displayed by using Mircosoft Excel and saved in *.txt file format. WinSASW 2.0 software was used to generate the curve of dispersion (Dispersion Curve) using that *.txt file and produce a graft of Rayleigh wave velocity (Vr) against wavelength (λ). Next, the dispersion curve inverted to be shear wave velocity (Vs) versus depth graft using WinSASW 2.0. Shear modulus or Young's modulus is calculated based on shear wave velocity (Vs) obtained from the inverse scattering income stiffness profile. The following discussion will be focused on equipment SASW in the field and several factors need to be considered to start the test SASW the choice of wave source, type of detector and the distance among the detector.

The equipment that was used for seismic studies in the area is Terraloc ABEM Mark 6, 24 geophones, two connection cables 12 buttons, hammer with many weight types, HITACHI Battery HG44-12 and battery charger, steel plates and compass to measure the direction of survey line.

Total of four line surveys were carried out with range 69 meters each. Total of 24 geophones arranged in a straight line profile with distance 3m between. Battery used to supply current and operates the equipment; ABEM Terraloc Mark 6. Each line profile has carried out seven times of emission wavelength on the relative distances specified (Table 1). The source waves generated from the hammer on a piece of steel plate with a vertical shock.

Table 1: Configuration of shock causes from the first geophone.

No. of Shock	Distance (Meter)
1	-10
2	1.5
3	6.5
4	34.5

3.3 Rock Quality Designation (RQD)

Calculation of RQD values in the field can be obtained by the discontinuity survey technique, this technique is more systematically. Based on this technique, the scanning line is made on outcrop horizontally and vertically. Vertical scan line is made in the intervening at several meters and perpendicular to the horizontal scan lines. Interval width depends on the density of the discontinuity sets to obtain the required data as shown in Figure 4.

Figure 4: Line of discontinuity in vertical scanning survey.

4.0 RESULT AND DISCUSSION

4.1 Profile of Location 1

Based on relationship between rock material with shear wave velocity (Bay 2000) (Table 2), (Vs) of Spectral Analysis of Surface Waves (SASW) profile at Location 1 (Figure 5) shows at the depth between 0-0.13 m. Vs indicates a lower value between 198 m/s - 1300 m/s, represents the existence of hard soil, mix of hard soil and granite which have experienced weathered process. At the depth 0.13 to 1.34 m shows layer of highly weathered granite with Vs ranging from 1025 to 1300 m/s, while at the depth of 1.34 to 7.15 m indicates the existence of fresh granite layer that has high Vs between 2014 m/s - 2044 m/s.

Vs of Multichannel Analysis of Surface Waves (MASW) profile at Location 1 (Figure 6) has a range of Vs from <600 - >2400 m/s with depth reached into 12 meters. Location 1 consists of 3 main zones. The first zone has Vs 400-1000 m/s with the depth of 3 m. Vs at second zone has 1000 - 2000 m/s and the thickness estimation is 7 m. Third zone has a range of Vs from 2000 to 2400 m/s, this zone was detected at the depth of 10 m below.

Table 2: relationship between rock materials with shear wave velocity

Rock Material Classification	Velocity of shear wave, Vs (m/s)
Very soft	84-107
Soft Soil	107-137
Moderately Soft Soil	137-183
Hard Soil	183-274
Very Hard Soil	274-366
Highly Wheatered Rock	366-610
Slightly Wheatered Rock	610-2743

4.2 Profile of Location 2

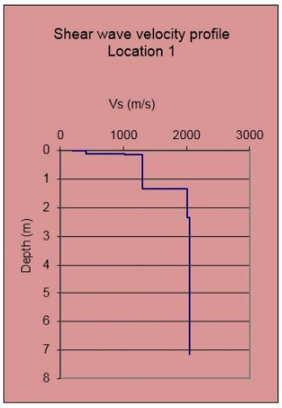
SASW profile at Location 2 (Figure 7) shows the depth between 0-0.06 m, Vs indicates between 592 m/s - 593 m/s, represents the existence of high weathered granite rocks. At the depth of 0.06 - 13.60 m indicates the existence of fresh granite layer that has high Vs between 1407 m/s - 2271 m/s.

MASW profile at Location 2 (Figure 8), has a range of Vs from 400 to 2000 m/s and the depth reached 10 m. Location 2 consists of 3 main zones, the top zone has Vs ranges from 400 - 750 m/s with 3.5 m deep. The second Zone has Vs ranges 750 - 1250 m/s and 4.5 meters deep. The third zone has Vs ranges 1250 to 2000 m/s, this zone was detected at the depth of 8 m below.

4.3 Profile of Location 3

At the depth of 0 - 0.76 m Vs indicates from 512 to 1132 m/s, represents the existence of high, medium and low weathered granite. At the depth of 0.76 - 3.94 m indicates the existence of medium weathered granite layer with Vs ranges from 1499 to 1504 m/s, fresh rock found at 3.94 - 10.94 m depth and has a high Vs between 1504 m/s - 2465 m/s. Figure 9 shows the profile of Vs at Location 3.

Figure 10 shows the profile of MASW at Location 3, has Vs ranges from 400 - >1200 m/s and reached 10 m of depth. Location 3 consists of 3 main zones. The top zone has Vs ranges 400-600 m/s with approximate depth of 4 m. Second zone has Vs ranges 600 - 1000 m/s and 4 m depth. The third zone has Vs ranges from 1000 to 1200 m/s, this zone detected at the depth of 8 m.



Depth (m)	Vs (m/s)
0.00	198
0.01	198
0.01	406
0.11	406
0.11	1025
0.12	1025
0.12	1025
0.13	1025
0.13	1300
1.34	1300
1.34	2014
2.35	2014
2.35	2044
3.75	2044
3.75	2044
5.35	2044
5.35	2044
7.15	2044
7.15	2044

Figure 5: Shear wave velocity (Vs) profile at Location 1.

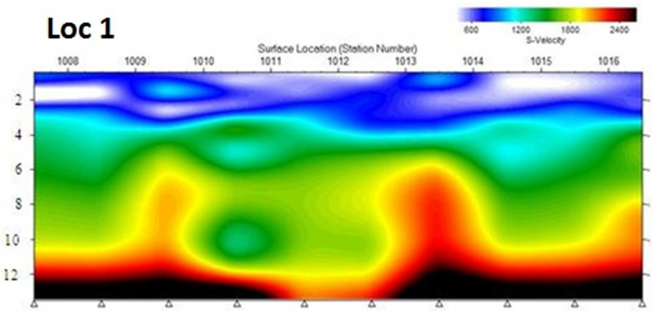
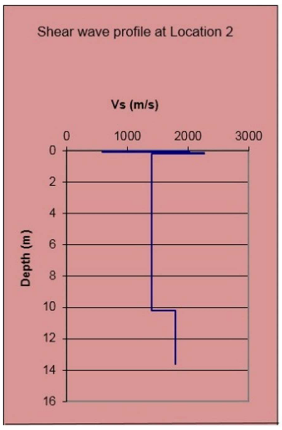


Figure 6: (Vs) MASW Profile at Location 1.



Depth (m)	Vs (m/s)
0.00	592
0.03	592
0.03	593
0.06	593
0.06	1463
0.09	1463
0.09	1918
0.11	1918
0.11	2261
0.15	2261
0.15	2271
0.20	2271
0.20	1407
10.20	1407
10.20	1798
11.80	1798
11.80	1798
13.60	1798
13.60	1798

Figure 7: Shear wave velocity (Vs) profile at Location 2.

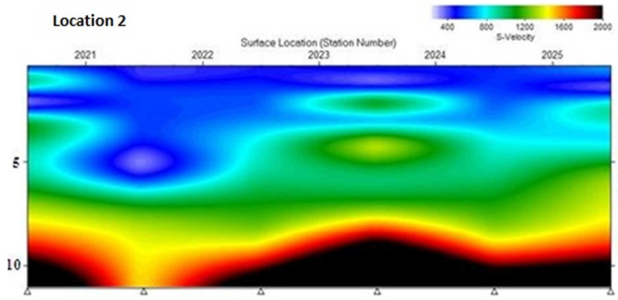
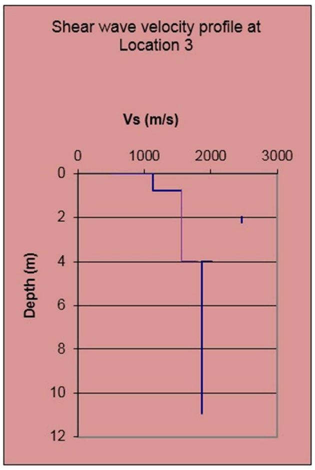


Figure 8: (Vs) MASW Profile at Location 2.



Depth (m)	Vs (m/s)
0.00	512
0.01	512
0.01	1132
0.76	1132
0.76	1499
2.61	1499
2.61	1504
3.94	1504
3.94	1871
4.94	1871
4.94	1871
6.14	1871
6.14	1871
7.54	1871
7.54	1871
9.14	1871
9.14	1871
10.94	1871

Figure 9: Shear wave velocity (Vs) profile at Location 3.

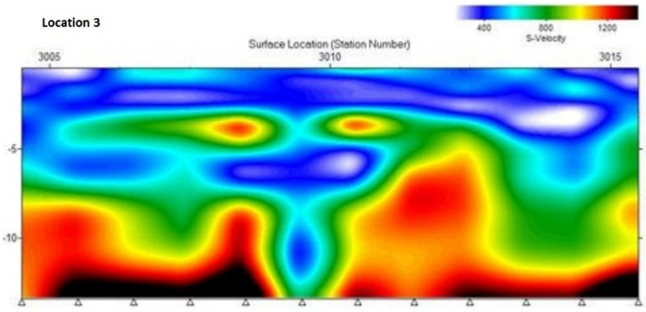
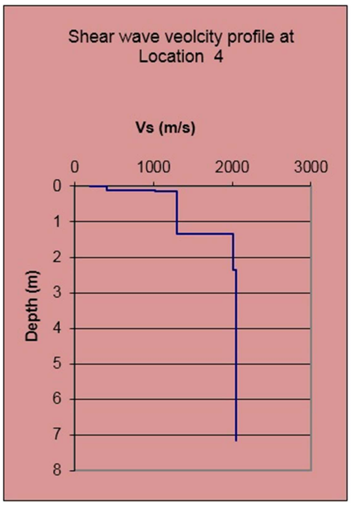


Figure 10: (Vs) MASW Profile at Location 3.

4.4 Profile of Location 4

Figure 11 shows the profile of Vs at this location. At the depth between 0 - 0.13 m Vs indicates between 200 m/s - 1320 m/s, represents the existence of hard soil, very hard soil and granitic rocks with slight/medium weathered. At the depth of 0.13 to 7.15 m, indicates the existence of fresh granite layer that has Vs between 2010 m/s - 2040 m/s.



Depth (m)	Vs (m/s)
0.00	200
0.01	200
0.01	408
0.11	408
0.11	1030
0.12	1030
0.12	1030
0.13	1030
0.13	1320
1.34	1320
1.34	2010
2.35	2014
2.35	2040
3.75	2040
3.75	2040
5.35	2040
5.35	2040
7.15	2040
7.15	2040

Figure 11: Shear wave velocity (Vs) profile at Location 4.

Figure 12 shows the profile MASW in Location 4, has a range of Vs ranges from 300 to 2300 m/s and reached 8 m depth. Location 4 consists of 3 main zones. The top zone has Vs 300 - 800 m/s with an approximate depth of 1 m. Second zone has Vs 800 - 1400 m/s with depth estimation is 4 m. The third zone has Vs ranges from 1400 to 2300 m/s, this zone is detected at the depth of 5-8 m below.

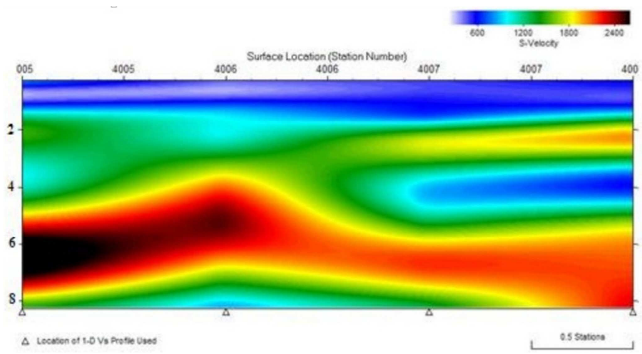


Figure 12: (Vs) MASW Profile at Location 4.

4.5 Profile of Rock Quality Designation (RQD)

To obtain more effective RQDdiscontinuity (Figure 13), a total of four discontinuity survey was conducted in the study area. RQDdiscontinuity value obtained from 98.63%, 98.38%, 99.03% and 96.43% and has very good rock mass quality standard in accordance with Deere (1968). From study location, the existence of discontinuity represented by very hard soil and weathered rock on the depth of 0.0-0.1 m. At the depth of 0.1-7.4 m, it was composed of fresh and a few weathered granite rocks.

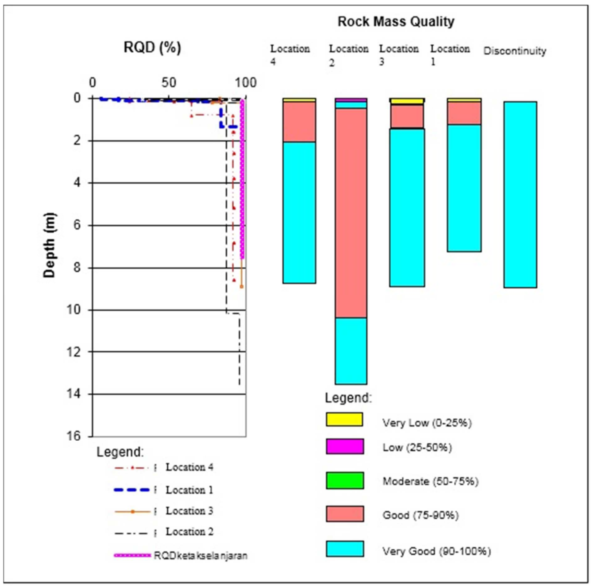


Figure 13: Rock Quality Designation (RQD) measurement at Kajang Rock Quarry.

5.0 CONCLUSION

SASW data shown the subsurface layers of this study area clearly, which consists of hard soil, very hard soil, granite rocks with slight/medium weathered (0 - 0.13 m depth), and fresh granite rock (0.13 to 7.15 m depth). The result from MASW has Vs ranges from 400-1000 m/s, found at 3 m depth and at the depth of 3 - 10 m has Vs ranges from 1000 - 2000 m/s. At the depth of 10 m below, Vs ranges from 2000 to 2400 m/s. As the average, the value of fresh granitic rocks RQD survey line is 98.63%.

Overall, Spectral Analysis of Surface Waves (SASW) and Multichannel Analysis of Surface Waves (MASW) methods helped to map the subsurface condition, especially for the granite rock area. Comparison with Rock Quality Designation (RQD) data, the differentiation is not too much, means these methods become trustable to use.

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