Rippability Assessment of Weathered Sedimentary Rock Mass using Seismic Refraction Methods

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Abstract. Rippability or ease of excavation in sedimentary rocks is a significant aspect of the preliminary work of any civil engineering project. Rippability assessment was performed in this study to select an available ripping machine to rip off earth materials using the seismic velocity chart provided by Caterpillar. The research area is located at the proposed construction site for the development of a water reservoir and related infrastructure in Kampus Pauh Putra, Universiti Malaysia Perlis. The research was aimed at obtaining seismic velocity, P-wave (Vp) using a seismic refraction method to produce a 2D tomography model. A 2D seismic model was used to delineate the layers into the velocity profile. The conventional geotechnical method of using a borehole was integrated with the seismic velocity method to provide appropriate correlation. The correlated data can be used to categorize machineries for excavation activities based on the available systematic analysis procedure to predict rock rippability. The seismic velocity profile obtained was used to interpret rock layers within the ranges labelled as rippable, marginal, and non-rippable. Based on the seismic velocity method the site can be classified into loose sandstone to moderately weathered rock. Laboratory test results shows that the site’s rock material falls between low strength and high strength. Results suggest that Caterpillar’s smallest ripper, namely, D8R, can successfully excavate materials based on the test results integration from seismic velocity method and laboratory test.

1. Introduction

Construction over sedimentary rocks in Malaysia increased over the years because of the vast development in the region. The geology of sedimentary rocks mostly comprises composites and interbedded sandstone, shale, siltstone, and limestone, making them highly variable and challenging in comparison with other rock types. The ease of excavation or the rippability of rocks is essential in designing platform levels, foundations, and other preliminary designs in civil engineering projects. These uncertainties include the selection of the excavation method, the types of machineries, and the rate of excavatability. Rippability is often qualitatively classified into three categories, namely, rippable, marginal, and non-rippable. The main concerns in construction in rock areas are the overall cost of the project, serious project delays reflected in the bill of quantities, tender, and claims that lead to the abandonment of the site in the preliminary stage. Determining the rock formation to be ripped is not an easy task, but today’s technology and experience can help ensure a reliable prediction [1] [2] [3] [4] [5].

A rock subsurface profile can be anisotropic and heterogeneous and thus requires spatial assessment of the subsurface condition. However, the use of a borehole to determine stratigraphic formation and rock parameters is not reliable because it involves a point base data set and an invasive
method that could disturb sample properties. As a complementary method, the geophysical method has been used by many practitioners to assess and characterize subsurface. Seismic refraction methods are non-invasive techniques to determine velocity profiles. These methods provide a simplified rock subsurface characterization in 2D tomography, which yields distance and depth profiles. The main objective of this research is to characterize subsurface based on seismic velocity to determine the rippability of rocks. Seismic velocity can be correlated and integrated with the borehole data to identify the properties and velocity of material. According to the assessment, the correlated data can be used to categorize machineries for excavation activities based on available systematic analysis procedure to predict the rippability of rock formation. The available ripping machineries are D8 R, D9 R, D10 R, and D11 R for the excavation system based on the velocity chart [6] [7] [8] [9].

2. Site Description and Geological Background

Study area located in the southern part of the state with two neighbouring towns, namely, Changlun and Arau, Perlis. The research area is located near the Syed Sirajuddin Areeb Putra Sports Complex, UNIMAP Kampus Pauh, Perlis. Fig. 1 (a) shows the condition of the slope with weathered rocks. The rock layers are undulating and heterogeneous, as shown in Fig. 1 (b).

![Figure 1](image1.png)

**Figure 1.** (a) Overview of site and (b) layers of rocks showing differences in weathering grade.

![Figure 2](image2.png)

**Figure 2.** Geology of Perlis and north Kedah, northwest of Peninsular Malaysia.

According to the geological map, the common outcrop strata are limestone, shale, sandstone, and siltstone, as shown in Fig. 2. The quaternary geology report indicates that the research area is situated in the Kubang Pasu formation. The Kubang Pasu formation is mainly composed of mudstone of various colors interbedded with quartz and feldspatic sandstone. In Perlis, clastic strata are
sandwiched between the Setul Group in the west (Setul boundary range) and the Chuping Hills in the east [10].

3. Field work
Field work was conducted at a construction site for the development of a water reservoir and related infrastructure in Kampus Pauh Putra, UNIMAP, Perlis. The contractor was levelling the ground for a platform to construct the water tank. Work was stopped because of variation in the bill of quantities (BQ) on the machinery for excavation. Therefore, the developer appointed a new site investigation team to assess the site. The assessment included a geophysical survey using a seismic refraction method to cover the site spatially with limited borehole. As a result of the abundant hard rock materials that could not be ripped by an excavator, a ripper was chosen before blasting was considered. During the research period, two site investigations involving invasive and non-invasive methods were conducted to establish correlation between the rock parameters of both methods. The invasive method was a rock drilling (rotary drilling) method, and the non-invasive method was seismic refraction. The location of the seismic refraction survey line and borehole point was marked in the drawing shown in Fig. 3.

![Figure 3. Location of seismic survey line and borehole on the as-built drawing.](image)

4. Methodology
Data acquisition for the seismic refraction survey utilized the GEOMETRICS Geode Ultra-Light Exploration Seismograph, which is a 24-channel seismograph with Single Geode Operating Software connected to a controller (a heavy-duty notebook). A source was created using an 8 kg sledgehammer hit on a strike plate. Geophones were distributed in a line, signals were transmitted to the seismograph via a spread cable, and 24 units of 28 Hz natural frequency of vertical geophones were used to detect body waves. Energy source was detected, amplified, and recorded. Therefore, the raw data consisted of travel times and distances. This time–distance information was then manipulated and converted into the format of velocity variations with depth. The total offset should be 3 to 5 times the depth of interest. However, this value should be balanced against the number of channels available and the required horizontal resolution.
An initial velocity model was set up, followed by the calculation of the theoretical travel times for all source and receiver pairs. The calculated travel times were subsequently compared with the observed ones. The model was modified repeatedly with an iterative method until the residuals between the calculated and observed travel times were minimized. In this research, the acquired seismic data were analysed using the software programs Pickwin (version 4.0.1.5) and Plotrea (version 2.9.1.6) from the SeisImager software package developed by Geometric Inc. Different ranges of seismic velocity indicate different types of earth material. Earth materials can be categorized according to the velocity value obtained from the seismic refraction. Researchers developed many typical propagation velocities to identify geological media. Caterpillar developed a systematic chart to indicate the rippability of a rock formation. An example of the ripping chart using a D8 R ripper is shown in Fig. 12. The results are then used to determine the rippability of a material by referring to the chart.

5. Results and discussion
The tomography inversion of the 2D seismic model provided meaningful information for delineating zones with poor layered zones, such as in weathered and transitional rock formation alteration and the depth to rock cover. The site can also be categorized into five layers according to the velocity and weathering grade, as shown in Table 1.
### Table 1. Detailed summary of five seismic layers with estimated ground conditions.

| Layer | Velocity (km/s) | Geo-materials description | Weathering Grade |
|-------|----------------|---------------------------|------------------|
| 1     | < 0.3          | Subsurface soil and much loosened ground. Very dried condition | VI               |
| 2     | 0.3-0.8        | Gravelly to clayey silty sand | VI-V             |
| 3     | 0.8 – 1.8      | Gravelly to clayey silty sand; completely weathered to highly weathered with evidence of highly fractured rock | V-IV             |
| 4     | 1.8-2.4        | Highly weathered to Moderately weathered zone         | IV-III-II        |
| 5     | >2.4           | Moderately weathered to slightly weathered zone and fresh rock | III-II-I         |

The rock profiles for the two borehole drilling activities conducted on site are plotted in Table 2. Sandstone is mostly encountered at the depth of 3.00 m within the research area, with the condition being highly fractured and weathered. A summary of the results from the laboratory testing, mainly the uniaxial compressive strength and point load index, is shown in Table 2. 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 laboratory test.

### Table 2. Lithology of rocks for borehole A2 and K2.

| Depth (m) | Velocity (km/s) | BH A2 | BH K2 |
|-----------|-----------------|-------|-------|
| 0-1.20    | D1 < 1.8        | Silt  | Gravelly silt |
| 1.20-2.70 | C1 1.8 – 2.4    | Moderately weathered and fractured Sandstone (RQD = 0-12%) | 3.00 - 4.50 |
| 2.70-4.20 | C2 > 2.4        | Weathered and fractured Limestone | 4.5 - 6.00 |
| 4.20-5.70 | C3 6.00 - 7.50  |        | Moderately Weathered and slightly fractured Sandstone (RQD = 0-16 %) |
| 5.70-7.20 | C4 7.50 - 9.00  |        |        |
| 7.20-8.70 | C5 9.00 - 10.50 |        |        |
| 8.70-10.20| C6              |        |        |
| 10.20-11.70| C7             |        |        |

### Table 3. Summary of the test results for Uniaxial Compressive Strength and Point Load Index.

| Borehole No. | Velocity (km/s) | Uniaxial Compressive Strength Test | Point Load Test |
|--------------|-----------------|-----------------------------------|------------------|
|              | Visual description | Compressive strength (MPa) | Test Results | Point Load Index (MPa) |
| BH A2-C5     | > 2.4            | Dark grey, moderately weak, LIMESTONE | 9.65 | Moderately weak | 0.76 |
| 7.20-8.70 m  |                  |                                  |                |                      |
| BH A2-C6     | > 2.4            | Pale grey, moderately strong, LIMESTONE | 27.86 | Moderately strong | 0.61 |
| 8.70 – 10.20 m|                  |                                  |                |                      |
| BH K2-C1     | 1.8 – 2.4        | Red, grey, strong, LIMESTONE | 54.41 | Strong | 1.07 |
| 3.00 – 4.50 m|                  |                                  |                |                      |
| BH K2-C4     | > 2.4            | Red, grey, strong, LIMESTONE | 87.60 | Strong | 1.32 |
| 7.50 – 9.00 m|                  |                                  |                |                      |
Correlation was made between Vp and the rock properties to make a general interpretation of rippability based on an industry standard chart and geological characteristics of the site subsurface conditions related to borehole information. As shown in the results of the borehole correlation with Line A and Line K in Fig. 5 to Fig. 8, the rippable materials extend from the surface to a maximum of 2.5 m to 5 m for both Lines A and K. This result indicates the existence of fractured limestone at the depth of 1 m to 2 m. For both three survey lines, a non-significant thickness of marginal zone material between 3–5 m exists, which indicates the interface between the rippable and non-rippable materials with P-wave velocity ranging from 1.8 km/s to 2.4 km/s. P-wave velocity > 2.4 km/s may suggest a competent bedrock with moderate to less fractured bedrock.

**Figure 5.** Borehole correlation (A2) with seismic profile of seismic refraction line A.

**Figure 6.** Borehole correlation (A2) with wave velocity with line.
Geologically, this zone may suggest a layer of weathered rocks with rock quality designation (RQD) 0%–25%, which indicates a highly fractured section of bedrock. RQD obtained from the core logging shows a value of 12%–16%, which is less than 25%. The rock material can be categorized as

![Figure 7. Borehole correlation (K2) with seismic profile of seismic refraction Line K and I.](image)

![Figure 8. Borehole correlation (K2) with P-wave velocity of Lines K and I.](image)
very poor rock. Thus, a small ripper is sufficient to rip the rock material. Based on USC, the maximum value is 87.60 MPa, which indicates high strength. The lowest value is 9.65 MPa, which indicates low strength. Overall, the rock material falls between low strength and high strength. Therefore, a ripper is necessary to rip some parts of the rock material where is high in strength.

The rippability chart given in Fig. 9 is based on the ability of Caterpillar’s smallest ripper, the D8R, to successfully excavate materials based on seismic compressional velocity or P-wave velocity, which is known as a conservative rippability classification. The chart shows that the upper bound of the rippable and marginal velocity ranges from 1.8 km/s to 2.4 km/s and that of the non-rippable > 2.4 km/s. The non-rippable section should be addressed with blasting if excavation is necessary. Blasting is expensive and costly compared with the use of a ripper, but it is used when necessary. The project cost may rise, but in most cases, the practitioner tries to avoid these situations.

![Figure 9. D8R Ripper performance chart based on seismic velocities [4].](image)

6. Conclusion
The result from this seismic velocity profile reveals lateral and vertical subsurface variability, which is in agreement with the typical geological condition of the interbedded sedimentary rocks found at the site. Boreholes should be cautiously considered in predicting geo-materials to determine the competent bedrock of rock formation and ensure an easy excavation based on the rippability chart. Additional tools, such as resistivity surveys and multichannel analyses of surface waves, can be implemented to obtain complementary subsurface information.

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