Empirical Approach in Developing Vs/Vp Ratio for Predicting S-Wave Velocity, Study Case; Sungai Batu, Kedah

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Abstract. In recognition of the difficulties in acquiring seismic refraction shear wave data and the ambiguities involved in its processing, Vs/Vp ratio for sedimentary areas of Sungai Batu have been developed and assessed in this study. Two seismic refraction survey line L1 and L2 were conducted using P- and S-wave were acquired and processed along the same line regarding study area. The resulting velocities were extracted from seismic tomography profile to compute specific ratios after linearity and correlation checks. It is found that Vs is linearly related to Vp, with coefficients of determination (R\textsuperscript{2}) of about 0.74 and 0.52 for L1 and L2 respectively. The specific ratios were computed as 0.3 and 0.4 for L1 and L2 respectively. Another data sets acquired along different lines were used to validate the ratios. The mean absolute percentage errors were calculated for both modelling and validation data sets and found that the different percentage between Vs measured and Vs calculated is 20.7\% and 22\% respectively.

1. Introduction

Several seismic studies have been carried out to investigate the relation of compressional (Vp) and shear wave (Vs) velocities at different case study. Generally, the relation between Vp and Vs velocity is expressed in term of velocity ratio (Vp/Vs). The use of velocity ratio itself has been applied for different purposes, such as lithology study, degree of saturation and consolidation determination, identifying pore fluid and predicting velocities [1]. Moreover, the ratio of Vp/Vs has become a significant parameter to interpreting the lithology structure [2]. Although, most previous works express velocity models using Vp data, fundamental interests in engineering, groundwater and environmental studies prefer the utilization of shear wave velocity (Vs) [3,4], probably for the fact that shear wave velocity is one of a significant parameter for determining stiffness of material for construction purposes [5]. There are various methods employed to measure the shear wave velocity of near-surface material such as multichannel analysis of surface wave (MASW), spectral analysis of surface wave (SASW), seismic reflection/refraction and microtremor [6]. This study employed seismic refraction method in an effort to produce Vs of the subsurface. However, there are a lot of difficulties in data acquisition and ambiguities in data processing to produce the seismic refraction tomograms applied s-wave. Based on that reason, the velocity ratio is expressed in term of Vs/Vp where the Vp models are for Vs models. To reduce time and cost needed for seismic refraction surveys, this paper discussed on finding the relationship between compressional and shear wave velocity, aimed at predicting seismic s-wave velocities using Vs/Vp ratio.
2. General geology

Sungai Batu, known as famous archeological sites at north-western of Peninsular Malaysia and recorded as marine area at first and second century [7]. It is underlain by Mahang formation which consist of two types of rock; granitic at western area and sedimentary region which is cover the rest of the area that comes from Gunung Jerai. The sedimentary rock including shale, sandstone, siltstone, orthoquartzite and homologous while the soil types are clay covered with fine sand. Followed by previous work [8], the sediment was carried by local river which is Merbok river and being established around this location (Figure 1).

![Figure 1. Geologi map of Sungai Batu area [9]](image)

3. Methodology

Generally, seismic refraction deal with elastic waves that travel into subsurface and detected by geophones that planted on top of ground surface. It will measure the travel time of wave that travel into different medium in subsurface by using physics law. The seismic data will consist of travel times of waves and distance. Based on this output, the velocity distributions and depth to individual layer can be estimated and modelled [10]. Generally, there are two type of body waves that applied on seismic refraction surveys which are compressional (P) and shear (S) wave. The difference is based on the particle motion and the propagation. P-wave, usually called primary wave since it arrives at the first place on illustrating arrival waves and has the greatest velocity. While S-wave, as known as secondary shows up after P-wave arrived [11]. On P-wave, the particles are moving in the same direction of wave propagation while on S-wave, the particles are moving or vibrating perpendicular with the wave propagation (Figure 2).

Figure 3 shows an illustration of ray path which travel into two different layers of earth and delineate the reflection and refraction occur. Wave generated from source travel at velocity $V_1$ in first
medium and hit the interface between two different medium. The wave is refracted at critical angle $\theta_c$ and propagate parallelly to the interface.

**Figure 2.** Body waves particles and waves propagation; a) P-wave, and b) S-wave

This study consists of two survey lines which are L1 and L2. Two sets of seismic cables with 24 takeout and 5 m spacing is utilize in this research. L1 is utilized to model the velocity ratio while line L2 is used to validate the velocity ratio model. Figure 4 show the survey line arrangement of L1 and L2 at Sungai Batu, Kedah with total length of 115 m.
Seismic refraction was conducted using 24 geophones as detector and ABEM MK8 seismograph as recorder. For seismic source, 25 kg weight-drop and 5 kg sledgehammer was utilized. Type of geophones are also differentiated based on wave applied. 28 Hz vertical geophones were used for seismic refraction measurements using P-wave, while 6 Hz horizontal geophones were used as detector for seismic refraction S-wave. For S-wave seismic refraction data acquisition, seismic source also changes using wooden plank which is weighted on top by vehicle to provide a good friction contact with ground surface. The wooden plank is hit at the end of both sides to generate mostly shear wave (Figure 5).

Several softwares were used to assist data processing. IXRefract software was used to filter P- and S-wave raw data. Arrival time picking for seismic refraction P-wave was assessed using Firstpix software, while Microsoft Excel and Surfer 10 software were used to assist the S-wave refraction processing. Finally, SeisOpt@2D software was employed to produce the seismic refraction tomography profile before the result are plotted in Surfer 10 software.
4. Result and Discussion

Seismic refraction tomography result with P- and S-wave of L1 are shown by Figure 6. Figure 6a indicate Vp value is ranging from 200 – 3600 m/s with depth of 26 m, while Vs are identified with value of < 1400 m/s and depth profile of 26 m as shown by Figure 6b.

![Figure 6](image6.png)

**Figure 6.** Seismic tomography profile of L1 at Sungai Batu; (a) P-wave (b) S-wave

Figure 7 show the result of line L2. From the result, velocity gained by P-wave measurement is identify with value of < 2400 m/s and depth profile of 22.6 m (Figure 7a). Afterwards, Figure 7b exhibit S-wave measurement tomography result and the velocity is identified with value of < 1200 m/s with depth of 22.6 m.

![Figure 7](image7.png)

**Figure 7.** Seismic tomography profile of L2 at Sungai Batu; (a) P-wave (b) S-wave
Velocity data distribution are extracted from seismic refraction tomography to develop empirical correlation between Vs and Vp for both study area. Figure 8 represent the relation between Vp and Vs for L1 survey line. The result indicates that the Vs is increase in increasing Vp, it is verified with strong relation expressed with $R^2 = 0.74$. The relation is considered strong according to previous work [12].

![Figure 8. Vs as a function of Vp for L1 measurement line](image)

Figure 8. vs as a function of Vp for L1 measurement line

Figure 9 shows the Vs as a function of Vp for survey line L2. It was found that the Vs was approximately linearly related to Vp with $R^2 = 0.52$, considered to be a strong correlation. Specific velocity ratios (Vs/Vp) are also computed for both measurement lines. The ratio indicates the estimation velocities for S-wave can be calculated using this value and were found to be $Vs = 0.3Vp$ for L1 and $Vs = 0.4Vp$ for L2. Weighted mean absolute percentage error for both modelling (L1) and validation (L2) data were determined as 20.7% and 22% respectively.

The $R^2$ generally explains how much variability in the dependent variable is explained by the independent variable. From Figures 8 and 9, it can be observed that up to 74 % and 52 % of variations in Vs are explained by the Vp for L1 and L2 respectively. The remaining % variability in the Vs could be explained by other factors peculiar to Vs only, such as the fluid content of the subsurface; as Vs cannot travel through liquids. The effects of common factors among both types of wave velocities such as porosity, depth, cementation, etc. had already been captured in the Vp and Vs measurements.
5. Conclusion
The empirical correlation is utilized to observe the relation between compressional (Vp) and shear wave velocity (Vs) regarding study area and found that the Vs is approximately linearly related to Vp which is expressed by strong value of determination's coefficient. Specific ratio is also calculated to predict the shear wave velocity to manage time and cost consuming, and reducing the ambiguity and difficulties of taking shear wave seismic refraction measurements. It is found that the different of measured and calculated Vs is less than 22%.

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