Preliminary study as an exploration activity for estimating in situ coal density using the correlation of seismic downhole and geology drilling

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Abstract. The need for coal is increasing every year so that coal exploration activities need to be done to maintain the availability of these materials. Exploration activities generally use the correlation of geological method (analysis) and direct measurement using the geophysical method. One of the geophysical methods used is the downhole seismic method, to determine the quality of coal hardness through several seismic parameters, namely variations in the value of the initial wave velocity (Vp & Vs) and the wave travel time (Tp & Ts). This study aims to avoid mining land clearing and environmental destruction that are misplaced. This exploration activity is carried out at six measurement points. The results showed that the density of coal in the range 1.42 - 2.05 g/cm³, while coal that is feasible to be mined has a density of 1.81 - 2.05 g/cm³ with very soft rock to very hard rock classification.

1. Introduction

The need for coal is increasing every year. Power generation is one of the industry sectors that requires a huge amount of coal. The role of coal in this sector serves as fuel to drive steam turbines as a major component of electricity generation. But behind all its benefits, coal is one of the non-renewable mining commodities, so coal exploration activities must always be carried out to maintain the availability of raw materials. Coal exploration activities often cause negative impacts on the environment, such as land destruction, pollution of water sources, degradation of the carrying capacity of the soil, and disturbing the natural habitat of certain flora and fauna [1-3].

Some careful planning steps are needed to minimize the negative impact of coal exploration on the environment, so that coal exploration activities can be better targeted and appropriate to produce quality coal [4,5]. The most commonly used coal exploration method is to combine geological analysis and direct measurement using geophysical methods. The geological analysis aims to determine the points where coal is located, but not all coal can be used, only good quality high-density coal can be used. So to overcome this, it is necessary to make direct measurements in situ where the geophysical method commonly used is the downhole seismic method [6-8].
The downhole seismic method is a passive seismic method that uses the velocity and arrival time of the P (Vp) and S (Vs) waves. P waves or compressional waves occur because of the push and pull through a medium of rock, water, and air. These waves have the direction of motion of particles that are the same as the direction of motion energy. S wave or shear wave is a slower wave than the P wave and can only propagate on hard rock. The direction of motion of the S wave-particle is perpendicular to the direction of its energy motion [9-11]. The two waves are the main parameters used in the downhole seismic method because these waves can provide detailed information related to mechanical parameters at the research location [12,13].

![Figure 1. Retrieval of data using seismic downhole.](image)

To determine straight-line slant distance (L), the following equation can be used [14].

\[
L = \left[ (E_S - E_g + D_g)^2 + X^2 \right]^{0.5}
\]

where ES is the elevation of the shear beam /vibration source (m), Eg is the elevation of the geophone (receivers) at the first measurement position (m), Dg is the depth of the geophone (receivers) (m), and X is the horizontal distance between shear beam with a borehole (m).

Meanwhile, to find the wave velocity, both P and S, use the following equation [15].

\[
V = \frac{(L_{R1} - L_{R2})}{(\Delta T_{R2-R1})}
\]

where V is the wave velocity for P (Vp) or S (Vs), LR1 is the length of the shear beam to the geophone (receiver) at the initial height, LR2 is the length of the shear beam to the geophone (receiver) at the next height, and \( \Delta T_{R2-R1} \) is the difference in the arrival time of P waves (Tp) and S (Ts) or the so-called horizontal travel between the shear beam and the borehole (m).
To determine the ground density based on variations in P wave velocity (Vp), the Gardner equation (1974) is used, which is as follows [16].

$$\rho = a V_p^m$$

Where $\rho$ is the density of a rock (g/cm$^3$), $a$ and $m$ are constants with values of 0.31 and 0.25, and VP is P wave velocity (m/s).

2. Methods
The downhole seismic method is done by hitting the vibration source (shear beam) at each geophone depth variation (receivers). In this study, the addition of depth variation of one meter was added. Seismic parameters in the form of travel time will be read by the seismograph and then stored in the Data Acquisition device. Data were collected at 6 locations of geological drilling locations spread in the study area around 32.31 hectares, namely BLC (55 m), CP (50 m), HP (55 m), NSP (45 m), P (55 m), and JL (60 m) with the aim to map locations containing coal of the desired quality, coal quality classification based on variations in seismic parameters refer to SNI 1726-2012, Handbook of Ripping by Caterpillar, and USDA Chapter 12 (Rock Material Field Classification System) [17-19]. In general, the research procedure will be explained in the following flow chart.

3. Results and discussion
The results of data processing show that the value of Vp is approximately 2 - 2.4 times the value of Vs. In addition, drilling-logs tend to show that the presence of coal can be found starting at a depth of 35
meters below ground level. Classification of coal quality determination and plot results of Vp & Vs to depth will be shown in the table and figure below.

### Table 1. Classification of coal types.

| Borehole | Vp (m/s) | Vs (m/s) | Coal’s Density (g/cm³) | Classification          |
|----------|----------|----------|------------------------|------------------------|
| BLC (55 m) | 1398 - 1720 | 645 - 780 | 36 - 50 | 1.90 - 2.00 | Very Soft Rock |
| CP (50 m) | 440 - 591 | 174 - 240 | 30 - 39 | 1.42 - 1.52 | Firm Cohesive Soil |
| HP (55 m) | 1715 - 1718 | 749 - 765 | 34 - 39 | 2.00 | Moderately Soft Rock |
| NSP (45 m) | 544 - 603 | 221 - 252 | 34 - 42 | 1.49 - 1.53 | Firm Cohesive Soil |
| P (55 m) | 1428 - 1909 | 734 - 922 | 37 - 55 | 2.00 - 2.05 | Moderately Soft Rock |
| JL (60 m) | 1548 - 2262 | 687 - 992 | 34 - 60 | 1.94 - 2.13 | Very Hard Rock |

![Graphs showing wave velocity (Vs & Vp) to depth for different boreholes](image)

**Figure 4.** Graph of wave velocity (Vs & Vp) to depth for; (a) BLC, (b) CP, (c) HP, (d) NSP, (e) P, and (f) JL

The results of geological drilling show that from the six drilling points, the distribution of coal was found to be still massive, drilling logs with coal descriptions were shown in black and the depth of the coal location varied from 35-55 meters. That results show that the greater Vp and Vs, the greater the
coal density. This affects the level of coal hardness. The greater the value of coal density, the better the quality of coal. Poor quality coal classified as Firm Cohesive Soil was found in the CP and P drill holes so it was not feasible to be mined at that location. Poor quality coal including firm cohesive soil classification with a density value of 1.42-1.53 g/cm$^3$ found in CP and P borehole so it is not suitable to be used as a location. While good coal quality with very soft rock classification until very hard rock was found at points BLC, HP, P and JL with a density value of 1.90-2.13 g/cm$^3$. A map of the recommended coal mining area is shown in the following figure.

4. Conclusion
From the research that has been done, the results show that the density of coal in the research location is in the range of 1.42 - 2.05 g/cm$^3$, while coal that is feasible to be mined has a density of 1.81 - 2.05 g/cm$^3$ with the classification of very soft rock to very hard rock. The physical explanation for this is that the greater the wave velocity $V_p$ and $V_s$ of a coal, the greater the density value. And coal density is directly proportional to the level of its hardness.

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