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Correlation of seismic velocity and mechanical properties of metasandstone from CTW-1 well, Seri Iskandar, Perak, Malaysia

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Abstract: Laboratory rock testing offers an alternative for estimation of rock mass properties through correlation of P-wave velocity and rock strength parameters for preliminary investigation in engineering geology. However, limited studies have been conducted on sedimentary rocks; e.g., sandstones and limestone in the Peninsular Malaysia. In this study, two laboratory tests using 18 metasandstone core samples obtained from CTW-1 well have been conducted to determine the correlation between P-wave velocities and uniaxial compressive strength (UCS). Measurements were conducted using ultrasonic wave pulse transmission and Schmidt rebound hammer. Rock Quality Designation (RQD) of core samples was also correlated with the P-wave velocity obtained from well log data. Four correlations were established from the results as follows; i) RQD = 99.772 (Q) + 0.2351, ii) RQD = $0.0151(V_p) + 20.353$, iii) UCS = $0.0472V_p - 144.12$ and iv) UCS = $0.064V_s - 72.31$ with regression value of 0.99, 0.87, 0.93 and 0.78 respectively. The findings show good to acceptable correlations between P-wave velocities and UCS, RQD and velocity index, Q of the rock mass. These correlations serve as an alternative for estimating rock materials and rock mass parameters, based on the P-wave velocities and velocity index, Q. Similar correlations can be established for other rock types.

Keywords: Seismic velocity, mechanical properties, metasandstone

INTRODUCTION

CTW-1 well is a 416 m vertical onshore well drilled in sedimentary rock of the Kati Formation at the UTP campus, Seri Iskandar. The lithology is mainly composed of sandstone, metasandstone and mudstone or shale interbedded with sandstone (Alkhali & Chow, 2014). Since there is lacking study to quantify the geophysical and geomechanical properties of sedimentary rocks in Peninsular Malaysia, this research therefore aims to establish a correlation between these parameters. Thus, the availability of the cores from the CTW-1 well was used to establish correlations between P-wave seismic velocity and other parameters i.e., uniaxial compressive strength (UCS), rock quality designation (RQD) and velocity index (Q). Correlation between seismic velocity and rock mechanics parameters is commonly adapted in engineering geology and preferred as it is a non-destructive method with lower cost (Goh *et al*., 2016). For instance, correlations between UCS values and sonic velocity have been widely used to predict *in situ* rock strength because these models are quick and simple to understand (Butel & Hossack, 2014).

However, there are limited studies of this correlation for sedimentary rocks as a majority of the studies are confined to igneous (granite) and metamorphic rocks (schist) (Goh *et al*., 2015; 2016). Not many studies had been performed on sedimentary rocks such as sandstone, mudstone and shale due to the unavailability of unweathered and hard rock samples that are essential for rock mechanics testing. The availability of fresh sedimentary core samples from the CTW-1 well was an opportunity that allows further study on rock physical and mechanical properties relationship for local geological reference.

METHODOLOGY

A total of 18 metasandstone core samples was used for the velocity test. The cores were taken at varying depths from the CTW-1 well. The core dimension is 6.35 cm ± 0.05 cm in diameter, and 7.62 cm ± 0.05 cm in length. To measure the P-wave velocity, a high frequency ultrasonic velocity test (at ambient conditions) was conducted using Sonic Viewer S-X equipment with a frequency of 200 kHz. The travel time of P-wave to travel from the transmitter to the receiver was obtained using the following equation:

$$\text{Velocity} = d \times t^{-1} \quad (1)$$

Where, d is the height of the core sample and t is the first (peak) arrival time of the wave. The P-wave velocity in the field is estimated from the sonic log well data, taken at similar depths as the core samples.

The uniaxial compressive strength was estimated using the rebound number R from Schmidt Hammer test. The hammer measures the rebound of a spring loaded mass impacting against the surface of a sample. UCS value was estimated using the existing formula for consolidated sandstone lithology, in this case metasandstone.

UCS = 2 * R (2) (Singh *et al.*, 1983)

The core samples selected for this test were intact (fractures were cemented), petrographically uniform and representative of the rock mass domain (Aydin, 2014).

Rock quality designation (RQD) is defined as "the percentage of intact core pieces longer than 100 mm compared to the total length of the borehole" (Deere *et al.*, 1967). It is a practical method in rock mass classification because of its simplicity and effectiveness for surface scanlines or borehole measurements (Sen, 2014). The RQD measurement followed the ASTM D 6032-01 (2006) using the formula in the following equation:

RQD = ((Sum of core pieces ≥ 100mm)/(Total length of borehole) x 100%), (3) (Deere *et al.*, 1967)

RQD can also be estimated from the ratio of V_{pf} (P-wave velocity of *in situ* rock mass) to V_{po} (P-wave velocity of the corresponding intact rock) (Liu *et al.*, 2017). The ratio of V_{field} / V_{lab} when squared is called the velocity index, Q. RQD is numerically close to the value of velocity index, Q and their rock quality as presented in Table 1.

RESULTS AND DISCUSSION

Table 2 summarizes the empirical relationship developed between P-wave velocity and UCS, RQD and Q-index parameters. The empirical formula developed a linear relationship when P-wave velocity was correlated with UCS; UCS = $0.0472V_p - 144$. The R^2 obtained from the correlation is 0.93, showing good relationship between the parameters (Figure 1). Measured rebound values ranging from 15 to 30 will deem the rock as fairly strong rock, while greater than 30 will rate the rock as strong (Wang *et al.*, 2017). The R values obtained from the Schmidt hammer test ranged from 26 to 52, this classified the rock as a fairly strong to strong rock.

Table 1: Relationship between velocity index and rock quality (Bery & Saad, 2012).

Quality Description	RQD (%)	Velocity Index $(V_F/V_L)^2$
Very poor	Less than 25	0 – 0.25
Poor	25-50	0.25 – 0.53
Fair	50-75	0.53 – 0.75
Good	75-85	0.75 – 0.85
Excellent	Over 85	Over 0.85

The lowest average value of UCS was 49 MPa while the highest was 103 MPa. This showed that the grade of the rock strength is strong to very strong (Goel, 1999), that corresponded to the high value of velocity measured in the lab, ranging from 4000 ms^{-1} to 5500 ms^{-1}. The equations were validated using different rock samples and compared with the values generated from the equations. The percentage of difference between the values is less than 5%. Hence, the equation can be acknowledged as an alternative for UCS estimation when seismic velocity is available for the specific lithology.

Figure 2 presents the correlation between P-wave velocities from field, estimated from sonic log measurement of CTW-1 well and measured RQD from borehole. A linear relationship between the parameters is developed as RQD = $0.0175(V_p) + 7.3498$, where R^2=0.801. It shows good relationship between RQD and P-wave velocity. A lower RQD values shows low core recovery or highly fractured rock material and vice versa. However, the RQD can vary significantly with the density of the specific rock type as well as its hardness (Biringen & Davie, 2013). Higher density and harder material exhibits higher RQD percentages. The metasandstone core samples used in this study had density values ranging from 2.5 – 2.7 g/cm^3. Since the hardness of the core samples as discussed was classified as strong to very strong, it is expected that the measured RQD values measured will be higher than 80 %.

The velocity index was compared with the measured RQD to determine the rock quality as well as its correlation with the lithology. The equation developed is RQD = 99.772 (Q) + 0.2351 and it is valid for P-wave velocity ranging from 4000 m/s to 5200 m/s. This equation can be used to estimate the RQD with given velocity data from field and laboratory testing as it shows an excellent relationship between the parameters, where the R^2 obtained was 0.9976. However, users need to be aware that when

Table 2: Empirical correlations developed for metasandstone.

No	Parameters	Equation	R^2	Relationship
1	UCS and P-wave velocity (lab)	UCS = $0.0472V_p - 144.12$	0.933	Excellent
2	RQD and P-wave velocity (field)	RQD = $0.0151(V_p) + 20.353$	0.801	Good
3	RQD and velocity index	RQD = 99.772 (Q) + 0.2351	0.996	Excellent

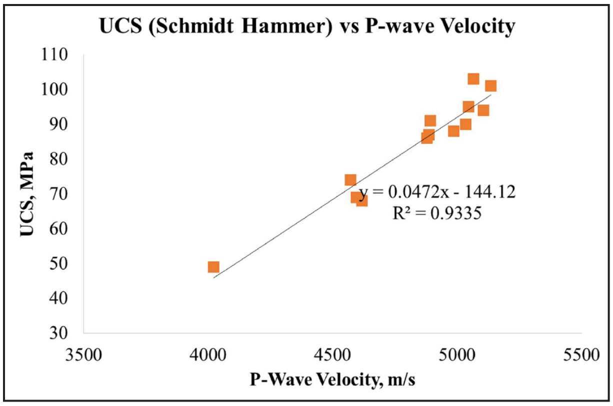

Figure 1: Relationship between laboratory P-wave velocity and average UCS.

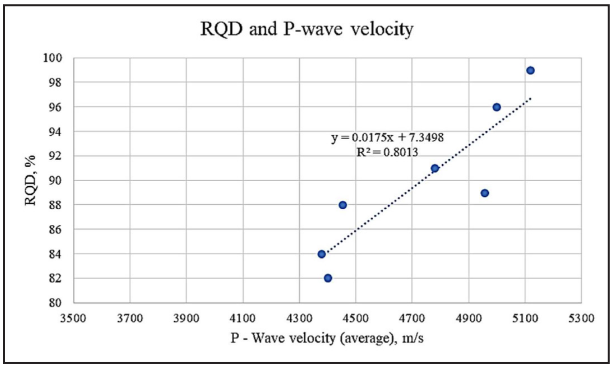

Figure 2: Relationship between field P-wave velocity and RQD.

utilizing these developed equations or those given in the literature, each estimation is only valid for a particular test condition and rock type (Kahraman & Yeken, 2008).

CONCLUSION

In conclusion, the correlations established between the P-wave velocity and other mechanical properties of the samples show good to excellent relationships. These empirical relationships can be utilised as an alternative approach to estimate the rock parameters for preliminary field investigations or, in situations where data is limited. The scope of this study only focused on metasandstone. However, it can also be extended to other rock types.

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