Study on Influence of Joint Orientation on Rock Engineering Properties for Mining and Infrastructure Design

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Abstract. Rock strength is the most important parameter for mining and infrastructure design. Accurate determination of rock strength is needed as a basis for implementing safe and economical rock engineering projects such as tunnels, open pit mines, and slope cutting for roadways. Rock is heterogeneous, anisotropic, and discontinuous materials. The discontinuities can be found as joints, faults, fissures, bedding, etc. In rock mechanics, the term of joint is generally used to represent all types of discontinuities. Joints are the planes of weakness in rock masses and can be found in various geometrical shapes, depending on past geological processes. This research briefly focuses to study the influence of joint orientation on rock strength based on UCS test. Application of this research could be recommend applying for mining and infrastructure design.

1. Introduction
Rock, in geology, is naturally agregat composed of one or more minerals and it contains numerous randomly distributed joints. In rock mechanics, the term of joints is used to refer to all kinds of discontinuities e.g., joints, faults, fissures, bedding, etc. [1]. For stability of mining and infrastructure activities such as tunnels, dam, etc, the rock strength should be determined carefully. Influence of joint on rock strength has been investigated widely by many researchers, and accordingly many significant research results have been published. Deere, (1963) was proposed Rock Quality Designation (RQD) as a rock mass classification based on the influence of joint density on rock mass conditions [2]. Brace and Byerlee (1966), conducted the uniaxial and biaxial compression test on brittle rock specimens containing a single crack [3]. Some other researchers [4], [5], [6], and [7] have been studied for the joint influence on rock strength and rock mass classification. However a large number of investigations have been devoted the mechanical behaviour of jointed rock masses, it is lack a research of influence of joint orientation on rock strength. This paper focuses on study the influence of joint orientation on rock strength based on UCS test. In addition, this paper also studies the velocity characteristic due to the joint orientations of rock.

2. Methodology
This research aims to find the influence of joint on rock strength based on UCS test. Marble as sample was taken from PT. Wutama Tri Makmur, a marble company located in Minasa Tene, Pangkep
regency (Figure 1). The marble was prepared in a cube formed with dimension of 5x5x5 cm into 7 joint orientation variant namely 0°, 15°, 30°, 45°, 60°, 75°, 90°, and a sample without joint (Figure 2). The joint orientations prepared based on loading direction in UCS test (Figure 3). Since the joints are natural formed, the ideal orientations of joint are difficult to find.

Ultrasonic Pulse Velocity (UPV) tests were conducted in every surface of samples to find the influence of joint orientation on the velocity. The cube of specimens used for UCS testing. In UCS test, the vertical loading is perpendicular to the both flat surfaces of sample.
3. Result and Discussion
The results of the research reported in this paper provide information as follows: (1) The influence of joint orientation on velocity, and (2) the influence of joint orientation on UCS obtained from the testing.

3.1. Velocity
Figure 4 shows the joint orientation on each surface. “W” surface is position on the face of sample. The joint can be seen very clearly with the direction about 0° from the top to the bottom parallel to the UCS loading direction. The joint continue to the top and bottom surface as “H” surface. Whereas, on the left and right side of the rock sample (“L” surface) there is no joint presence.

Table 1 summarizes the Ultrasonic Pulse Velocity (UPV) measurement from the marble samples. The UPV tests were conducted on every surfaces of rock samples. Figure 3 shows the presence of joint in each surfaces. Based on the measurement of velocity, when the sample has no joint the velocity seems similar more than 5,000 m/s. These conditions provide the homogeneity of the rock without joint for every direction. Figure 5 shows the average velocity for every joint directions. The rock sample without joint shows the highest velocity than the others. Based on figure 5, UPV and joint direction have a very low correlation, with $R^2$ value of 0.28. This condition explains the absence of a correlation between the influence of joint orientation and pulse velocity.

Based on the result of UPV on the face surface (W), the rock sample of Mb-1 (without joint) has high velocity about 5,363.86 m/s, however it is not the highest value. The sample with a joint direction of 60° has the highest velocity on this side which is 5,439.86 m/s within joint condition. Meanwhile on the lower side (H), the sample of MP-1-3 within a joint has the highest velocity. Whereas on the sidewall (L), the sample of Mb-1 without joint, has the highest velocity. Based on these conditions, the joint direction effect on the velocity is very difficult to know. Some things could be the cause of this, including the rock conditions within micro joints that are not detected visually or joints are filled by hard minerals.

| Sample No | Joint Orientation | Vp-W (m/s) | Vp-H (m/s) | Vp-L (m/s) | Joint Presence |
|-----------|-------------------|------------|------------|------------|----------------|
| Mb-1      | No Joint          | 5,363.86   | 5,327.53   | 5,722.22   | X X X          |
| Mp-1-1    | 0°                | 4,655.15   | 4,389.91   | 4,577.91   | O O X          |
| Mp-1-2    | 15°               | 5,020.20   | 3,163.64   | 3,364.18   | O O X          |
| Mp-1-3 | 30°  | 4,523.65 | 5,463.18 | 3,373.07 | O  | O  | X  |
|--------|------|----------|----------|----------|----|----|----|
| Mp-1-4 | 45°  | 5,087.30 | 5,174.66 | 4,978.10 | O  | O  | O  |
| Mp-1-5 | 60°  | 5,439.86 | 3,600.94 | 5,391.70 | O  | X  | O  |
| Mp-1-6 | 75°  | 4,582.30 | 3,936.48 | 3,562.24 | O  | X  | O  |
| Mp-1-7 | 90°  | 5,339.24 | 3,984.86 | 5,302.92 | O  | X  | O  |

Note:
O = presence
X = no presence
3.2. **UCS Test**

UCS tests were conducted on the rock samples with vertical loading direction to determine the compressive strength of rock, as shown in Figure 3. From the test results, it can be seen that rock sample with joint direction of 30° has the highest compressive strength (121.92 MPa) compared to other rock samples, while the rock sample with joint direction of 15° has the lowest compressive strength (62.64 MPa). The results of the UCS test shown in Table 2. Based on the results of these tests, it can be seen that the correlation between the direction of the joint and the compressive strength of the rock is very low with $R^2$ only around 0.02.

X-ray diffraction analysis was used to identify the mineral composition of the joint filled. Three samples were prepared by scraping from joint of marble rock samples. The results of analysis show that mineral filling joint consists of minerals calcite, silica, and dolomite (Figure 7). This is easy to understand because limestone composed of carbonate (calcite) minerals is dissolved so that the calcite mineral will fill the existing joint. The quartz minerals can come from the effect of intrusion which makes limestone metamorphism into marble. The calcite and quartz minerals are the relatively stable minerals and able to bind the fracture strongly [8]. This condition allows the effect of joint orientation on UPV and compressive strength of the marble rock is not indicated.
4. Conclusions
From this research, it can be concluded that the effect of joint orientation on UPV and compressive strength of the marble rock is not indicated. Joint filled by calcite and silica strengthening the joints could be a reason for this conditions. The next research focuses on characteristic of joint to answer the hesitation clearly. Some artificial joint on concrete were design to analysis the joint behaviour on UCS and UPV.
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