# EFFECT OF JOINT OPENING ON P-WAVE VELOCITY MEASUREMENT IN ANDESITE ROCK SAMPLES

Mohammad FATHOLLAHY
*PhD Student, Tarbiat Modares University, Tehran, Iran*
*mohammadfathollahy@gmail.com*

Ali UROMEIHY
*Professor, Tarbiat Modares University, Tehran, Iran*
*uromeiea@modares.ac.ir*

Mohammad Ali RIAHI
*Associate Professor, Institute of Geophysics University of Tehran, Tehran, Iran*
*mariahi@ut.ac.ir*

Mohammad BASHIRGONBADI
*Assistant Professor, Damghan University, Damghan, Iran*
*bashirgonbadi@du.ac.ir*

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## ABSTRACT

P-wave velocity measurement can be used to evaluate the rock mass quality and its soundness. Many factors influence the quality of a rock mass including the joint opening and its aperture. In this paper the effect of joint opening in Andesite rock samples were studied using an ultrasonic instrument in laboratory. The rock samples were collected at different depth of boreholes from under construction dam site. Physical and lithological properties of the samples were then determined. Also, artificial joint opening of various apertures (e.g. 0.1, 0.3, 0.5, 1, 2, 3, 5, 10, 20, and 30 mm) were made in the middle part of the samples perpendicular to their longitude axis. The transducers were attached to the both ends of the samples while applying the ultrasonic waves. The results were plotted on graphs which show a correlation between the wave velocity and the joint opening. The plots showed that the wave velocity trends for apertures smaller than 5mm were sharper than those of larger apertures. To evaluate the effect of joint opening on rock mass, velocity reduction ratio (VRR) was introduced. The VRR is defined as a ratio between wave velocity deviations of jointed rock to the wave velocity of intact rock sample ( $VRR\% = \frac{V0-V1}{V0} \times 100$ ). The VRR of a jointed rock increases with increase in the joint opening.

## INTRODUCTION

Detection of fractures in rocks is of the utmost importance because discontinuities such as fractured zones and faults seriously influence the strength of the rock masses (Sassa and Watanabe, 1995).

Ultrasonic measurement is one of the non-destructive geophysical methods commonly used by engineers working in various fields such as mining, geotechniques, civil, and underground engineering as well as oil, gas and minerals explorations (Kahraman, 2007).

Ultrasonic techniques have been used for many years in geotechnical engineering and mining science. They are employed in the field for geophysical investigations and in the laboratory for the determination of the dynamic properties of rocks (Kahraman, 2002). Since these techniques are easy and nondestructive, their application for investigation of rock properties is increasing.

There are different application areas that ultrasonic techniques have been used such as the assessment of grouting (Turk and Dearman, 1987), determining of blasting efficiencies in the rock mass (Young et al., 1985), determination of degree of weathering and fracturing (Carvalho et al., 2010), estimation of the extend of fractured zones developed around the underground openings (Hudson et al., 1980), monitoring the stability of rock structures (Kaneko et al., 1979), assessment of geotechnical properties of some rock materials (Yagiz, 2011), evaluation of geomechanical properties (Sheraz et al., 2014; Yasar and Erdogan, 2004), estimation of strength in concrete (Hobbs and Tchoketch Kebir, 2007; Trtnik et al., 2009 ), evaluation of joint anisotropy (Kano and Tsuchiya 2002), and evaluation of rock density (Gaviglio, 1989; Gardner et al., 1974 ).

Investigations have shown there are appropriate relation between the petro-physical properties of rocks and P-wave velocity (Del Rio 2006; Khandelwal and Ranjith, 2010). Generally, there are two elements that affect the rock behavior, namely intrinsic parameters e.g. mineralogy, porosity, density, water content (degree of saturation), compressive strength and fractures with their characteristics e.g. joint density, roughness, orientation, infilling. Some investigations focused specially on the cracks in the rocks attempting to understand the relation between the characteristic of P-wave velocities and the properties of the fractures. This plays a crucial role in developing a certain number of physical models, showing that the waveform, the amplitude and velocity of transmitted waves are greatly influenced, first by the manner and nature that the fractures are represented, and second by the size, number, thickness, aperture, infilling and some other properties of the fractures (Sassa and Watanabe, 1995; El Azhari, and El Amrani, 2013; Schoenberg, 1980; Fehler, 1982).

Experimental studies of Kahraman (2002) carried out on three types of rock (granite, marble and travertine) containing artificial fractures showed that P-wave velocity (Vp) decrease with increase fracture roughness coefficient (FRC). Furthermore, values of Vp rely on the hardness of the rocks, assessed by the rebound number of the Schmidt hammer (RN), and number of joint (JN). Results showed Vp decreases with increase in the number of joints; also the rocks with higher strength showed more sound velocity index (SVI) (Kahraman 2001). Investigations on the relationships between Vp and joints density (J) permitted Altindag (2005) to confirm the results of Kahraman (2001) concerning the decrease of Vp with the increase of the number of joints.

They, furthermore, highlighted a good polynomial correlation between the number of joints and the reduction rate in Vp (%) indicating that P-wave velocities are rapidly attenuated with the amplification of the joints density. The experimental studies of El Azhari and El Amrani (2013) focused on two types of building stones (Calcarenite and Marble); artificial joints created in samples and the diminution of P-wave were investigated with orientation and number of joint. The result revealed P-wave velocities undergo diminutions which the rates vary depending on the number and the plane orientation of the fractures.

Altindag (2012) reviewed previous studies and gathered all researches that had been done on sedimentary rocks and the raw data of 97 samples were subjected to statistical analysis and the relationships between P-wave velocity and physical-mechanical properties were investigated by simple and multi regression analysis.

The purpose of this study is to enhance the knowledge regarding the effect of the fractures opening on the sound velocity. Results of this study explain the effect of the opening on P-wave velocity and this will help researchers and engineers to have a real interpretation of wave transmition in rock masses. In this way, it is appropriate to determine the efficiency rate of each characteristic of fracture on P-wave velocity.

## STUDY AREA AND ROCK SAMPLES

The rock samples were selected from green Andesite units of Eosen in the North West of Iran which has been selected as a site for construction a dam with 120 meters in height, the core samples of which were taken from boreholes in the dam site around the dam axis. A large number of rock samples from different depth were studied from petrographical and petrophysical points of views in this research and previous studies in order to determine the rock type. Andesite is an igneous rock that can be classified as good from the rock engineering classification point of view (Hoek, 2000), a close view of rock masses is shown in 0.


a

b

Figure 1. Close view of subsurface (a) and surface (b) rocks

## MEASURING INSTRUMENTS

Measurements of Vp were carried out with an ultrasonic instrument (Pundit Lab / Pundit Lab+) manufactured by Proceq that complies with many standards (EN 12504-4 (Europe), ASTM C597-02 (North America), BS 1881 Part 203 (UK), ISO1920-7:2004 (International), IS13311 (India), CECS21 (China)). The device includes two transducers (a transmitter and a receiver) providing ultrasonic waves (54 kHz). According to the measurement principle, the transducers should be applied on the two parallel faces of a rock specimen having a determinate length (L) and trigger a series of ultrasound pulses. The device calculates the time interval (t) between the start and reception of the pulses. The Vp in the specimen is calculated from the simple relation (Vp = L/t) and it is expressed in m/s.

## EXPERIMENTAL WORKS

### SAMPLE PREPARATION

Sample preparation consists of selection of homogenous core samples of boreholes and cutting and smoothing their ends.

### DETERMINATION OF PHYSICAL PROPERTIES

In order to determine the physical properties of the rock, many samples as the index representatives were tested and their physical properties were calculated according to ASTM. 0 shows the physical properties of the rock samples.

Table 1. Physical properties of rock samples

| Row | Saturated density (g/cm3) | Dry density (g/cm3) | Prosity (n% ) | W% |
|---|---|---|---|---|
| 1 | 2.81 | 2.80 | 1.08 | 0.38 |
| 2 | 2.83 | 2.82 | 1.29 | 0.46 |
| 3 | 2.89 | 2.88 | 0.82 | 0.29 |
| 4 | 2.90 | 2.89 | 0.97 | 0.33 |
| 5 | 2.92 | 2.90 | 1.12 | 0.39 |
| 6 | 2.92 | 2.91 | 0.97 | 0.33 |
| 7 | 2.93 | 2.92 | 1.27 | 0.43 |
| 8 | 2.95 | 2.94 | 1.37 | 0.46 |
| 9 | 2.95 | 2.94 | 1.04 | 0.35 |
| 10 | 2.95 | 2.94 | 1.05 | 0.36 |
| 11 | 2.96 | 2.92 | 3.39 | 1.16 |
| 12 | 2.97 | 2.96 | 1.07 | 0.36 |
| 13 | 2.97 | 2.96 | 0.84 | 0.28 |
| 14 | 2.98 | 2.97 | 0.97 | 0.33 |
| 15 | 3.02 | 3.00 | 1.53 | 0.51 |
| 16 | 3.03 | 3.02 | 1.12 | 0.37 |
| 17 | 3.11 | 3.10 | 0.96 | 0.31 |

## SOUND VELOCITY TESTS

P-wave velocity were measured parallel to core axis firstly, then by cutting each sample perpendicular to the core axis generating artificial joints by a diamond saw and coupling the samples. Vp were measured at an opening of 0 mm and then in increasing opening regularly: 0.1, 0.3, 0.5, 1, 2, 3, 5, 10, 20 and 30 mm. (Figure 2). The procedure was repeated for 16 sets of samples at the laboratory condition. Measurements of Vp were performed according to the ASTM recommendation, regarding measurements of ultrasonic wave velocities in natural stones (D 2845-00) (ASTM 2000). In this regard, some precautions have been taken to ensure a better quality of measures:

Ultrasonic cuplant (part: 710 10 031, Part and Accessories of Unit, Punditlink_ENU) was applied between transducers and specimen to minimize wave loss at the interface.

Ultrasonic cuplant was applied at the opening of 0 mm, to obtain utmost connection between joint surfaces.

Figure 2. Vp mesurment on samples in laboratory

## PRESENTATION OF RESULTS

Sound velocity tests were carried out on the sets of samples (0). The results show decreases in the P-wave velocity with increase in the openings in the all sets (Figure 3).

Table 2. Results of Vp measurement on samples

| samples (set) | Opening (mm) | No Joint | 0 | 0.1 | 0.3 | 0.5 | 1 | 2 | 3 | 5 | 10 | 20 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 4278 | 3960 | 3872 | 3875 | 3913 | 3268 | 2786 | 2465 | 2425 | 2181 | 2152 | 1876 |
| 2 | | 5073 | 4733 | 4226 | 3357 | 2276 | 2172 | 2100 | 2100 | 2093 | 1856 | 1821 | 1773 |
| 3 | | 5239 | 4936 | 4768 | 4654 | 4623 | 4563 | 4358 | 2489 | 2265 | 1925 | 1922 | 1850 |
| 4 | | 5235 | 4791 | 4379 | 4354 | 3692 | 3655 | 2919 | 2240 | 2192 | 2009 | 1761 | 1505 |
| 5 | | 5418 | 5138 | 5094 | 5094 | 5080 | 5028 | 4287 | 3643 | 3563 | 2348 | 2168 | 1852 |
| 6 | | 5375 | 5305 | 5264 | 5228 | 5196 | 5183 | 5049 | 4931 | 4648 | 2766 | 2368 | 2248 |
| 7 | | 5601 | 5481 | 5475 | 5383 | 5353 | 5354 | 5089 | 4844 | 4544 | 4440 | 3497 | 2869 |
| 8 | Vp (m/s) | 5766 | 5578 | 5570 | 5444 | _ | 5242 | 5203 | 4927 | 3371 | 3144 | 2392 | 2085 |
| 9 | | 5536 | 5417 | 5291 | 5189 | 5067 | 5055 | 4789 | 4495 | 4031 | 3900 | 3860 | 1924 |
| 10 | | 5851 | 5743 | 5713 | 5691 | 5666 | 5648 | 5577 | 5483 | 4555 | 4246 | 4212 | 3921 |
| 11 | | 5811 | 5407 | 5384 | 5369 | 5343 | 5217 | 4055 | 4040 | 3977 | 3919 | 3177 | 2599 |
| 12 | | 5930 | 5714 | 5755 | 5714 | 5628 | 5574 | 5425 | 5305 | 4589 | 3611 | 3235 | 3176 |
| 13 | | 6068 | 5818 | 5721 | 5627 | 5581 | 5555 | 5460 | 4440 | 3706 | 3576 | 3453 | 2240 |
| 14 | | 6127 | 5899 | 5870 | 5861 | 5796 | 5732 | 5498 | 5498 | 5541 | 5329 | 4715 | 3572 |
| 15 | | 6222 | 6064 | 6043 | 6021 | 5964 | 5922 | 5867 | 5618 | 4308 | 3938 | 3440 | 3272 |
| 16 | | 6324 | 6183 | 6098 | 6016 | 5927 | 5755 | 5611 | 4850 | 3612 | 3713 | 2539 | 2289 |

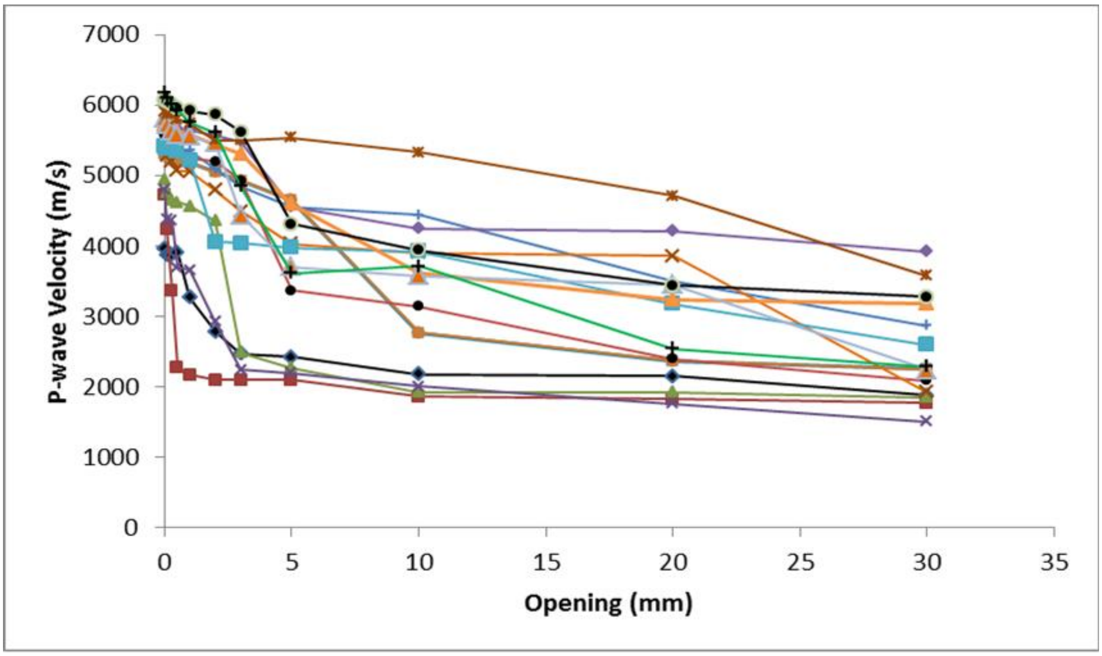


Figure 3. P-wave velocity vs. opening in different sets of samples

By comparison the P-wave velocity at different openings with original P-wave velocities in the samples, the velocity reduction ratio (VRR %) was defined. The results show VRR% increase with increasing of the opening (0 shows the VRR% in different openings and Figure 4 Shows the average VRR% versus opening in the samples).

Table 3. P-wave velocity reduction ratio (VRR%) in different openings

| samples (set) | Opening (mm) | 0 | 0.1 | 0.3 | 0.5 | 1 | 2 | 3 | 5 | 10 | 20 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VRR% | 7.4 | 9.5 | 9.4 | 8.5 | 23.6 | 34.9 | 42.4 | 43.3 | 49.0 | 49.7 | 56.1 |
| 2 | | 6.7 | 16.7 | 33.8 | 55.1 | 57.2 | 58.6 | 58.6 | 58.7 | 63.4 | 64.1 | 65.0 |
| 3 | | 5.8 | 9.0 | 11.2 | 11.8 | 12.9 | 16.8 | 52.5 | 56.8 | 63.3 | 63.3 | 64.7 |
| 4 | | 8.5 | 16.4 | 16.8 | 29.5 | 30.2 | 44.2 | 57.2 | 58.1 | 61.6 | 66.4 | 71.3 |
| 5 | | 5.2 | 6.0 | 6.0 | 6.2 | 7.2 | 20.9 | 32.8 | 34.2 | 56.7 | 60.0 | 65.8 |
| 6 | | 1.3 | 2.1 | 2.7 | 3.3 | 3.6 | 6.1 | 8.3 | 13.5 | 48.5 | 55.9 | 58.2 |
| 7 | | 2.2 | 2.3 | 3.9 | 4.4 | 4.4 | 9.1 | 13.5 | 18.9 | 20.7 | 37.6 | 48.8 |
| 8 | | 3.3 | 3.4 | 5.6 | | 9.1 | 9.8 | 14.5 | 41.5 | 45.5 | 58.5 | 63.8 |
| 9 | | 2.2 | 4.4 | 6.3 | 8.5 | 8.7 | 13.5 | 18.8 | 27.2 | 29.6 | 30.3 | 65.2 |
| 10 | | 1.9 | 2.4 | 2.7 | 3.2 | 3.5 | 4.7 | 6.3 | 22.2 | 27.4 | 28.0 | 33.0 |
| 11 | | 6.9 | 7.3 | 7.6 | 8.0 | 10.2 | 30.2 | 30.5 | 31.6 | 32.6 | 45.3 | 55.3 |
| 12 | | 3.6 | 3.0 | 3.6 | 5.1 | 6.0 | 8.5 | 10.5 | 22.6 | 39.1 | 45.4 | 46.4 |
| 13 | | 4.1 | 5.7 | 7.3 | 8.0 | 8.5 | 10.0 | 26.8 | 38.9 | 41.1 | 43.1 | 63.1 |
| 14 | | 3.7 | 4.2 | 4.3 | 5.4 | 6.4 | 10.3 | 10.3 | 9.6 | 13.0 | 23.0 | 41.7 |
| 15 | | 2.5 | 2.9 | 3.2 | 4.1 | 4.8 | 5.7 | 9.7 | 30.8 | 36.7 | 44.7 | 47.4 |
| 16 | | 2.2 | 3.6 | 4.9 | 6.3 | 9.0 | 11.3 | 23.3 | 42.9 | 41.3 | 59.9 | 63.8 |
| average of VRR% | | 4.2 | 6.2 | 8.1 | 11.2 | 12.8 | 18.4 | 26.0 | 34.4 | 41.8 | 48.5 | 56.9 |

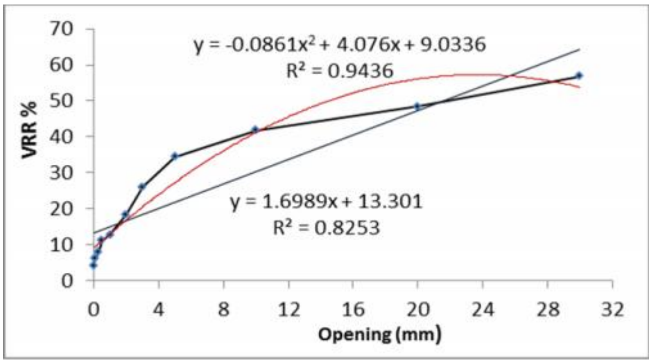


Figure 4. Average of VRR% vs. opening in different sets of samples

## EVALUATION OF THE TEST RESULTS

The results of the sound velocity tests were analyzed using the method of least square regression. The equations of the best models along with R-square were attained for each regression. The VRR% was correlated with the opening values for samples. The plots of the opening versus VRR% values are shown in Figure 4. It is seen that polynomial relationship (second degree) and linear relationship have high degrees of "$R^2$" between the VRR% and the opening values.

Table 4. Regression equations and R-square coefficients

| Regression equation | R-square ($r^2$) |
|---|---|
| $y = 1.6989x + 13.301$ | $R^2 = 0.8253$ |
| $y = -0.0861x^2 + 4.076x + 9.0336$ | $R^2 = 0.9436$ |

y = VRR% (velocity reduction) and x=opening (mm)

For the all samples the same trend is observed. The VRR% increases sharply in the first part, then shifts to a slow increase with increasing of the opening value. The regression equations and the R-square values are given in 0. Regarding the analysis, one can see there is a strong relationship between VRR% and opening values especially concerning a polynomial equation.

## CONCLUSIONS

This study was carried out on igneous (Andesite) rock types to investigate how the sound velocity varies with openings. P-wave velocities (Vp) were measured on core samples at first and then they were cut perpendicular to the core axis to create fractures artificially. By measuring P-wave velocity in different openings (0, 0.1, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30), and comparing the measured velocities at each opening value with the original velocity in sound sample, the velocity reduction ratio (VRR%) was defined.

The test results were interpreted statistically and the following conclusions are derived:

1- There are linear and polynomial relationships with high R-square (r2) between the VRR% and opening values.
2- There was an increase in VRR% with increasing in the opening values.
3- The wave velocity was strongly affected by opening in 0 – 5 mm, beyond that velocity decreases by increasing in the opening slowly.

We propose this research to be carried out on different rock types to find how the P-wave velocity varies with opening and investigate whether VRR% depends on rock type or not.

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