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Research Article

EFFECT OF JOINT INFILLING ON P-WAVE VELOCITY IN ANDESITE ROCK SAMPLES

***Mohammad Fathollahy[1], Ali Uromiehi [1], Mohammad Ali Riahi [2] and Mohammad Bashirgonbadi[3]**
[1]Department of Engineering Geology, Tarbiat Modares Modares University, Tehran, Iran
[2]Department of Geology, Institute of Geophysics, Tehran, Iran
[3]Department of Geology, University of Damghan, Damghan, Iran
**Author for Correspondence*

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 spacing, roughness, persistence, weathering, opening and filling. In this paper the effect of joint filling in andesite rock samples were studied using an ultrasonic instrument in laboratory. The rock samples were collected at depth of boreholes from under construction dam site. Physical and lithological properties of the samples were then determined. Also, artificial joint were made in the middle part of the samples perpendicular to their longitude axis. Regarding to natural joint infilling at site, the artificial joints were filled with silica at different thicknesses (1, 2 and 5 mm) to evaluate the effect of thickness, also joints were filled with gypsum at similar thicknesses to investigate the effect of filling type on sound velocity. 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 infilling thickness. 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 ($\mathrm{VRR\%} = \frac{\mathrm{V0-V1}}{\mathrm{V0}} \times 100$). The VRR% of a jointed rock increases with increase in the joint infilling thickness and this incrasing in Gypsum infilling type is sharper than Silica infilling type.

***Keywords:** P-Wave Velocity, Joint, Infilling, Andesite*

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, 2007).

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).

These 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, 2014, Yasar and Erdogan, 2004), estimation of strength in concrete (Hobbs and Tchoketch, 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 *et al.*, 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, 2007; Azhari and Amrani, 2013; Schoenberg, 1980; Fehler, 1982; Boadu and Long, 1996). Evaluation the effect of these parameters in different rocks caused in increasing of geophysical data precision.

Experimental studies of Kahraman (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 (Altindag and Guney, 2005) to confirm the results of Kahraman (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 Elazhari and El Amrani (ElAzhari and 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 (Altindag, 2012) reviewed previous studies and gather 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 investigated 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. The core samples of which were taken from boreholes in the dam site around the dam axis.

(a) (b)

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

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.

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. After that joints filled with silica at different thicknesses (1, 2, 5 mm) at each step. This process was reapeted for infilling with gypsum.

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

Sound Velocity Tests

P-wave velocity were measured on cylindrical sample of silica and gypsum and sound Andesite rock samples parallel to core axis firstly, then by cutting each Andesite sample perpendicular to the core axis generating artificial joints by a diamonded saw and coupling the samples. Vp were measured at an infilling of 1 mm and then in increasing infilling regularly 2 and 5 mm. (0). The procedure was repeated for 3 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) (ASTMA, 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.

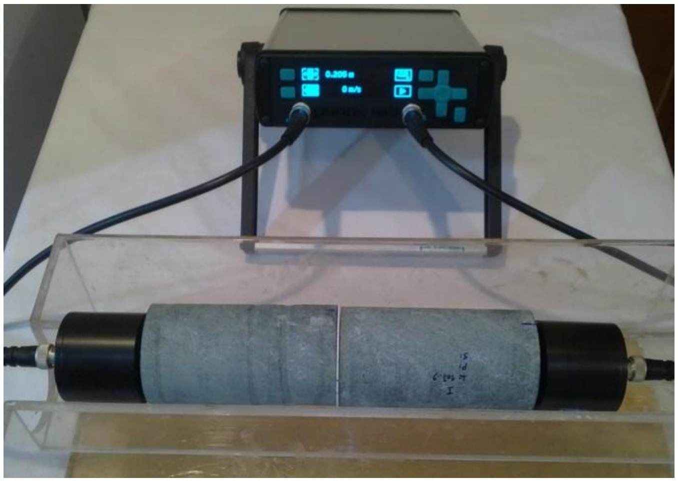

Figure 2: Vp mesurment on samples in laboratory

RESULTS AND DISCUSSION

Presentation of Results

Sound velocity tests were carried out on the set of samples (0 & 0). The results show decreases in the P-wave velocity with increase in the thickness of infilling in silica and gypsum in the all sets (0 & 0 shows P-wave velocity vs. infilling thickness in Silica & Gypsum infilling respectively.

Table 2: Results of Vp measurement on samples with Silica infilling

samples	**infilling thickness (mm)**	**total length (mm)**	**infilling type**	**infilling = 100%** Vp (m/s)	**infilling = 0%** Vp (m/s)
1,3	1	201.5	silica	5628	5304
2,4	1	201.4	silica	5564	5410
5,6	1	272.8	silica	5567	5425
1,3	2	202.5	silica	5563	5304
2,4	2	202.4	silica	5560	5410
5,6	2	273.8	silica	5554	5425
1,3	5	205.5	silica	5584	5304
2,4	5	205.4	silica	5566	5410
5,6	5	276.8	silica	5503	5425

Table 3: Results of Vp measurement on samples with Gypsum infilling

samples	**infilling thickness (mm)**	**total length (mm)**	**infilling type**	**infilling = 100% Vp (m/s)**	**filling = 0% Vp (m/s)**
1,3	1	201.5	gypsum	5193	5304
2,4	1	201.4	gypsum	5399	5410
5,6	1	272.8	gypsum	5370	5425
1,3	2	203.5	gypsum	5185	5304
2,4	2	203.4	gypsum	5290	5410
5,6	2	274.8	gypsum	5260	5425
1,3	5	205.5	gypsum	5176	5304
2,4	5	205.4	gypsum	5200	5410
5,6	5	276.8	gypsum	5145	5425

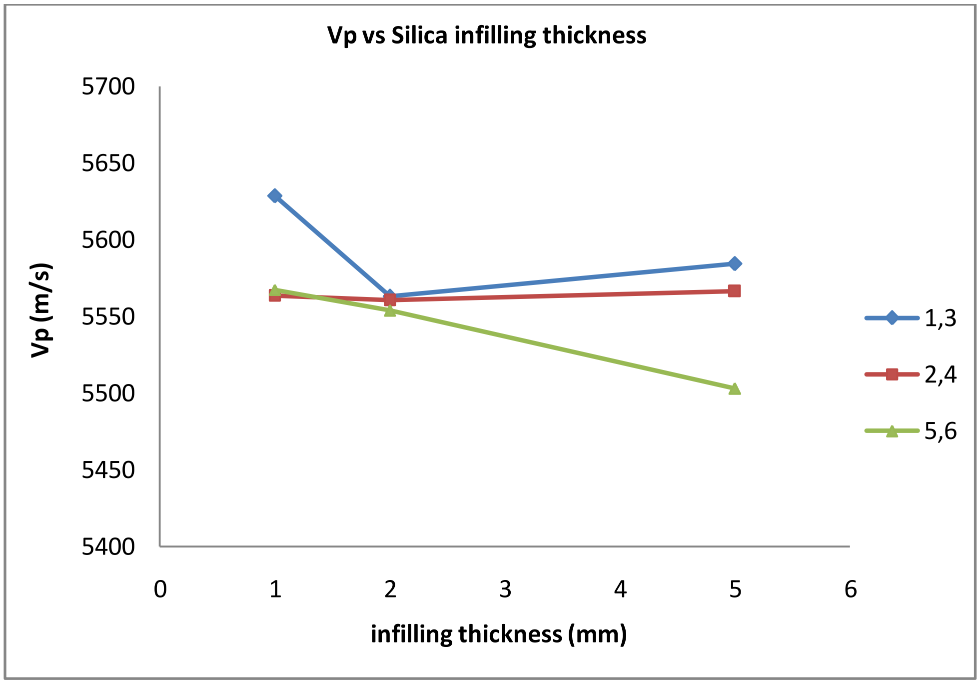

Figure 3: P-wave velocity vs. Silica infilling thickness

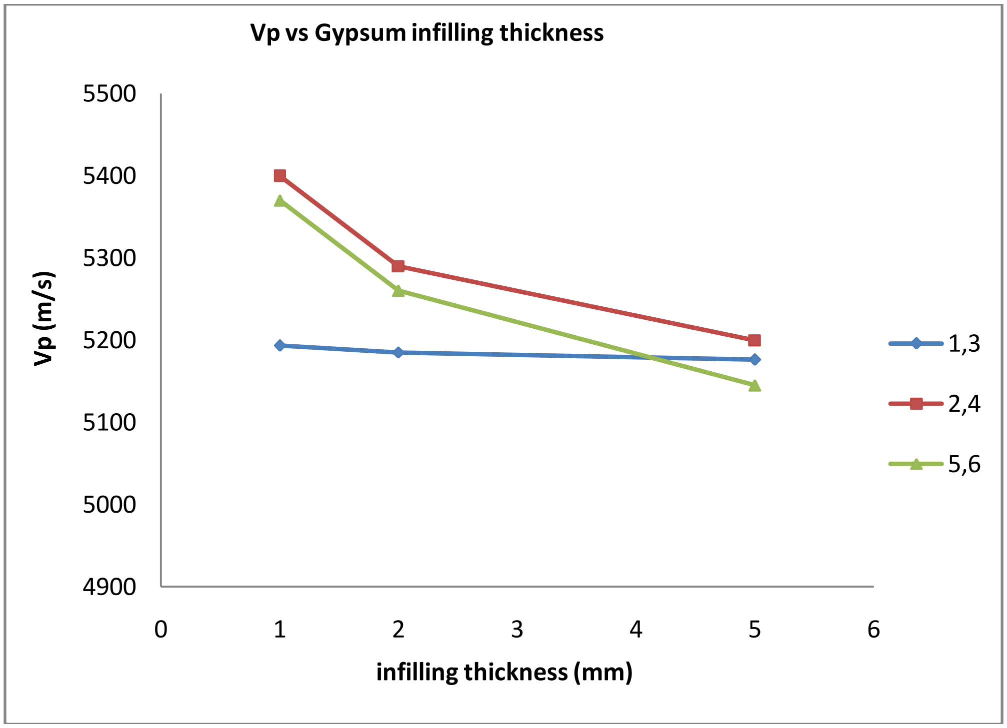

Figure 4: P-wave velocity vs. Gypsum infilling thickness

By comparison the P-wave velocity at different stage with original P-wave velocities in the samples, the velocity reduction ratio (VRR%) was defined. The results show VRR% increase with increasing of the infilling thickness in Silica & Gypsum but this rate is not much noticeable in Silica, also VRR% is positive in Gypsum and negative in Silica. (0 shows the VRR% value for samples and 0 shows the average VRR% versus infilling thicness in Silica and Gypsum).

Table 4: P-wave velocity reduction ratio (VRR%) in different infilling thickness

samples	infilling thickness (mm)	total length (mm)	Silica inf.		Gypsum inf.		without infilling
			Vp (m/s)	VRR%	Vp (m/s)	VRR%	Vp (m/s)
1,3	1	201.5	5628	-6	5193	2	5304
2,4	1	201.4	5564	-3	5399	0	5410
5,6	1	272.8	5567	-3	5370	1	5425
1,3	2	202.5	5563	-5	5185	2	5304
2,4	2	202.4	5560	-3	5290	2	5410
5,6	2	273.8	5554	-2	5260	3	5425
1,3	5	205.5	5584	-5	5176	2	5304
2,4	5	205.4	5566	-3	5200	4	5410
5,6	5	276.8	5503	-1	5145	5	5425

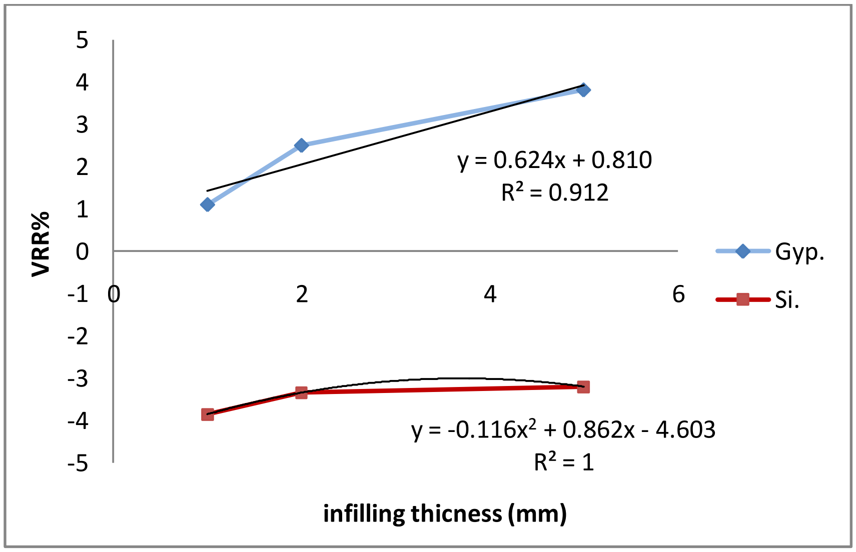

Figure 5: Average of VRR% vs. infilling thickness in different type infilling

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 attainded for each regression. The VRR% was correlated with the infilling values for samples. The plots of the infilling thickness versus VRR% values are shown in 0. Both the polynomial relationship (second degree) and linear relationship are valid for Silica and Gypsum infilling but as can be seen in figure Silica is more compatible with polynomial relationship than linear relationship.

Table 5: Regression equations and R-square coefficients

Infilling type	Regression equation	R-square (r^2)
Silica	$y = -0.1163x^2 + 0.862x - 4.6031$	$R^2 = 1$
Gypsum	$y = 0.624x + 0.8102$	$R^2 = 0.9129$

y = VRR% (velocity reduction) and x=infilling thickness (mm)

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 infilling thickness 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 joint infilling. 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. Silica and Gypsum were selected as infilling type. By measuring P-wave velocity in different joint infilling thickness (1, 2, 5 mm), and comparing the measured velocities 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 (r^2) between the VRR% and infilling thickness in Gypsum.

2- There are polynomial relationships with high R-square (r^2) between the VRR% and infilling thickness in Silica.

3- There was an increase in VRR% with increasing in the infilling thickness in Silica and Gypsum but the rate of this increasing in Gypsum is higher than Silica.

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

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