Evaluation of the Relationships Between P-Wave Velocity *(Vp)* and Joint Density (J„)

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ABSTRACT: Certain parameters such as rock type, density of joints, unit volume weight, porosity, amsotropy, weathering, temperature, water content, gram size and shape etc have direct effect on the values of seismic velocities

In this research, the trend of quantitative effect of joints on *P* waves *(Vp)* was investigated m laboratory since rock properties are greatly affected by the presence of discontinuities in the medium Therefore, prismatic rock samples of different thicknesses were prepared from a total of four different rock types, three of sedimentary and one of metamorphic origins For each rock type, set of samples with artificial joints were formed by adjoining several pre-sawn samples of different thicknesses, 1 to 6, and *Vp* values were measured The relationships between the number of joints and *P wave* velocities were statistically investigated and the results were assessed together with the results found in literature

1 INTRODUCTION

Seismic techniques are widely used in laboratory and as well as m the field in order to determine the dynamic properties of rocks In underground mining, seismic methods are often employed to predict stress re-distnbutions which induce break zones around underground openings This technique is also widely used to establish the blast-hole pattern m open pit mining and to determine fracture patterns in marble quarries to enhance block productivity

Various researchers have produced meaningful results by investigating the relationships between rock properties and seismic velocities Kahraman (2001) has carried out seismic velocity measurements on six different rock types (2 of granites, 3 of travertines, 1 of marble) containing three artificial joints and reported that *Vp* values decreased as the number of artificial joints increased, suggesting an inverse relationship between the *Vp* and the number of joints (J_N) Muftuoğlu (1990) has conducted a research to determine whether seismic velocities can be correlated with the spacing between the discontinuities in rock mass and has concluded that although the solution to this problem is difficult and complicated there is a limited solution

The evaluation of joints (frequency, trace length and orientation of joint sets) bears great importance in rock mechanics since shape of the block, their volume in the rock masses and their mechanical strength (compression and shear strength, deformation modulus, etc) are all affected by joint density in rock masses The degree of jointing is directly affected at the outcrops using scanhnes or on drill cores by means of Rock Quality Designation (RQD) (Deere, 1963), providing a direct block size measure Sjugren et al (1979) and Palmstram (1995) proposed two hyperbolic correlations linking respectively the unıdımensıonal joint frequency and the RQD to in situ longitudinal wave velocity (Vp)

2. LABORATORY STUDY

In the scope of this study, four different rock types were investigated (Table 1) Some of the physical properties of the rocks were determined m compliance with the ISRM (1981) and displayed in Table 2 A number of block samples in size of 10x10x35 cm were prepared and *P wave* velocities were measured on each block prior to sawing. Later, the samples were sawn off the blocks in thicknesses of 1,2,3,4,5,6 and 7 cm in order to form sets of test samples with consecutive artificial joints varying in number between 0 to 6 as shown in Figure 1. Contact surfaces of the sawn-off samples were polished sufficiently for smooth planes. A good coupling along the contact surfaces of joints was satisfactorily maintained even in the absence of vertical load by carefully clamping sample sets at the ends. Then, *P-wave* velocity measurements were conducted on the sample sets by Ultrasonic Testing Equipment with 54 kHz frequency. The results of the measurements depending on the number of joints were illustrated in Table 3.

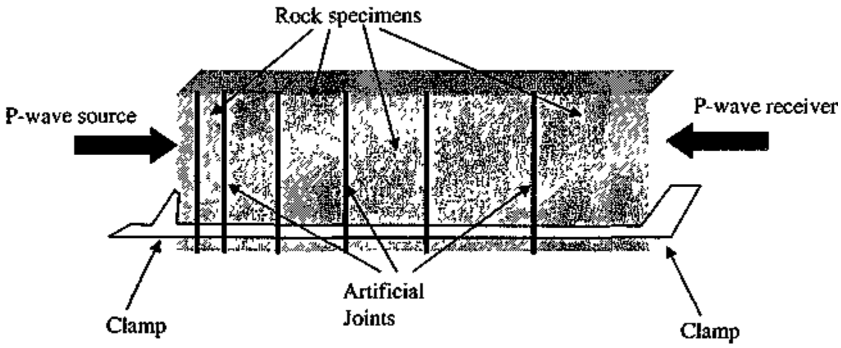


Figure 1. Schematic view of a sample set with six artificial joints

Table 1. Some characteristics of the rocks tested

Code Number	Rock Type	Rock Class	Bedding
1	Limestone	Sedimentary	Present
2	Limestone	Sedimentary	Present
3	Limestone	Sedimentary	Present
4	Marble	Metamorphic	Absent

Table 2. Physical properties of rocks

Code Number	Density (g/cm^3)	Effective Porosity (%)	Shore Hardness (SH)	Pre-sawn *VpO* (km/s)
1	2.72	9.06	41.9	5.752
2	2.69	7.37	52.8	5.334
3	2.85	0.84	46.5	5.040
4	2.66	11.74	29.1	4.963

3. STATISTICAL ANALYSIS

The sound velocity test results were analysed using the least squares technique. The equation of the best-fit line, the 95% confidence limits, and the correlation coefficient (r) were determined for each regression.

For each rock type, P-wave velocities and the number of artificial joints were correlated. The plots of the number of joints as a function of the *P*-wave velocities and the reduction rates in *Vp* with increasing number of joints (JN) are shown in Figures 2-5. It can be noted that there are inverse linear relations between the number of joints and the P-wave velocities for each rock type. The P-wave velocity decreases as the number of joints increases. The regression equations and the correlation coefficients are given in Table 4.

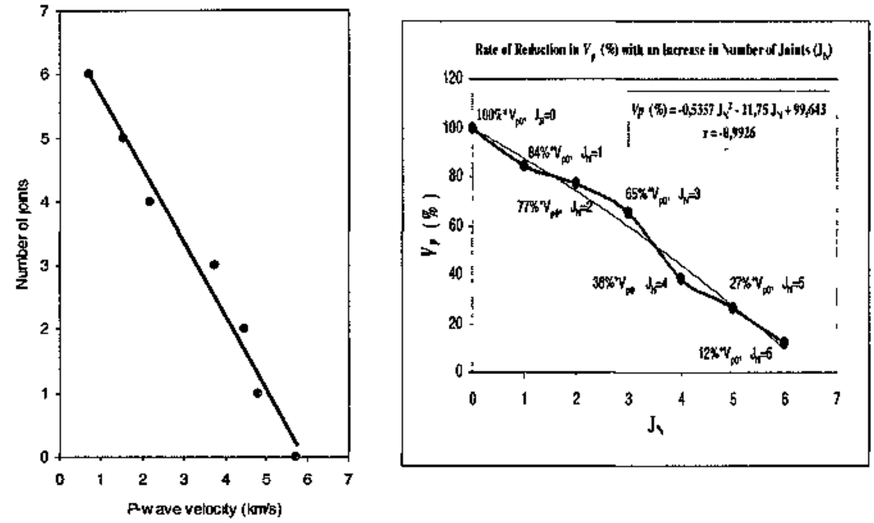
Table 3. The results of P-wave velocity measurements

Code Number	Number of Joints *(JN)*	P-wave velocity (km/s)	Rate of Reduction in Vp with an increase in *JN* **(%)**
1	0	5.752 (Vpo)	100
	1	4.803	84
	2	4.436	77
	3	3.731	65
	4	2.168	38
	5	1.514	27
	6	0.701	12
2	0	5.334 (*Vpo)*	100
	1	3.400	64
	2	2.777	52
	3	1.872	35
	4	1.661	31
	5	1.289	24
	6	1.238	23
	7	0.685	13
3	0	5.040(*Vpo)*	100
	1	3.984	79
	2	2.767	55
	3	2.666	53
	4	2.241	44
	5	1.578	31
	6	1.176	23
4	0	4.963(*Vpo)*	100
	1	4.118	83
	2	4.014	80
	3	3.932	79
	4	3.131	63
	5	1.196	24
	6	0.941	19

Table 4. Regression equation for each rock type*

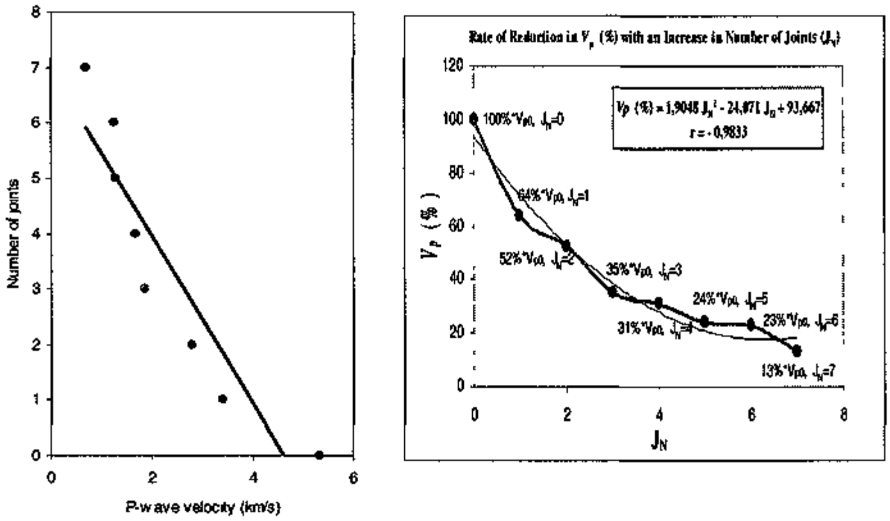
Code Number	Equation	Correlation coefficient
1	/AT=-1.1441 Vp + 6.7763	r= -0.990
2	J_N= -1.5019 Vp + 6.9271	r=-0.927
3	J_N=-1.5563 Vp + 7.3248	r=-0.970
4	J_N= -1.3168 Vp + 7.1942	r=-0.940

* J_N = Number of joints, Vp = P-wave velocity (km/s).



(a) (b)

Figure 2. (a) J_N vs. *Vp* (b) *Vp* reduction rate (%) as J_N increases for rock code 1.



(a) (b)

Figure 3. (a) J_N vs. Vp (b) *Vp* reduction rate (%) as J_N increases for rock code 2

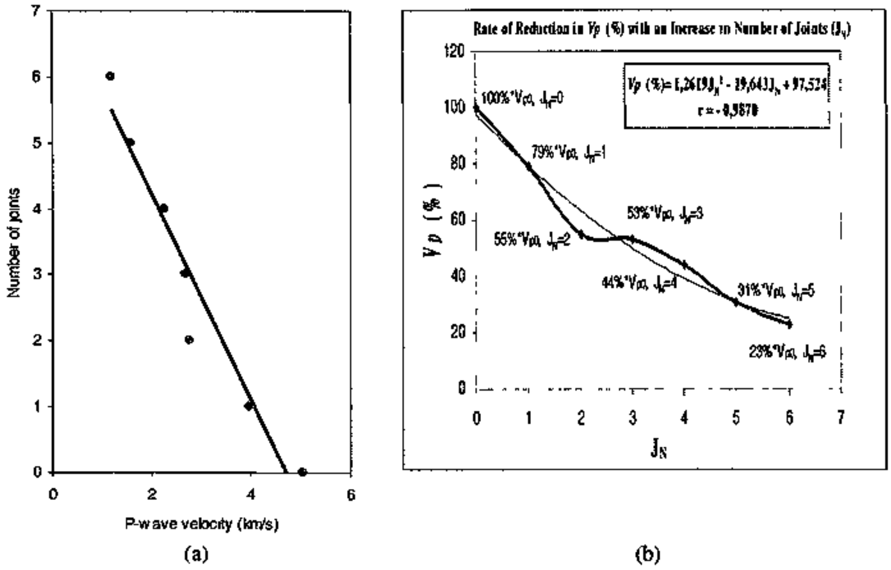


Figure 4. (a) JN VS. *Vp* (b) *Vp* reduction rate (%) as JN increases for rock code 3

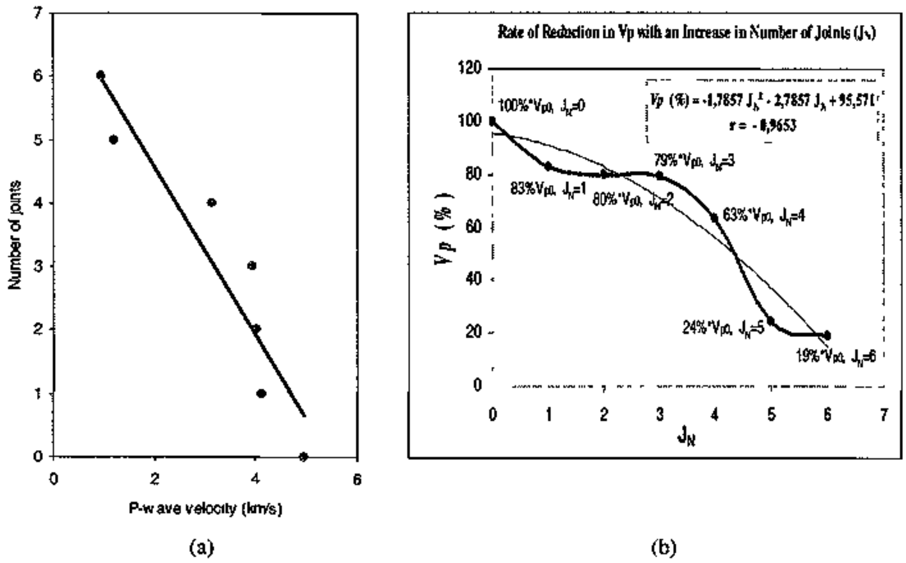


Figure 5. (a) J_N vs. *Vp* (b) *Vp* reduction rate (%) as JN increases for rock code 4

4. CONCLUSION

As well known, the degree of jointing, which is one of the most important parameters influencing seismic velocities in rock mass must be considered by researchers and engineers when designing structures m rock masses Therefore, the effect of joint density on seismic velocities were investigated on four different rock types associated with artificial joints as many as 6 The results of the experiments confirm that *P-wave* velocity decreases with an increase in the density of joints in rocks, agreeing with the results obtained by Kahraman (2001) Furthermore, there is a good polynomial correlation between the number of joints and the reduction rates in *Vp (%)* indicating that *P-* waves are attenuated rapidly as the number of joints increases

This study needs further laboratory investigation to clarify the effect of degree of jointing on seismic velocities by assessing the origins of the rocks and other significant rock physical properties

5. REFERENCES

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