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The Effect of Rock Sample Dimension on the P-Wave Velocity

M. Fener

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Abstract P-wave velocity is one of the non-destructive geophysical methods directly or indirectly used by engineering working by various filed. Thus the accuracy of the recorded P-wave velocity affects these parameters. In this survey whether the sample dimensions measured in laboratory have effect on P-wave velocity or not was investigated. Nine different rock groups were used in this study. Six different diameter core samples were prepared from each of the groups. Ultrasonic tests were carried out on the core samples having different diameter to investigate how the sound velocity varies with sample dimension. The test results were statistically analyzed using the method of least squares regression, exponential, and polynomial relationship with high correlation coefficient were found between the sample diameters and P-wave velocities. In four sample groups a decrease in ultrasonic velocity depending on an increase in diameter was observed. In five other sample groups in the samples up to 78.68 mm diameter, a decrease in P-wave velocity value was observed but a significant increase in the P-wave velocity was observed for the biggest diameter samples. This observed decrease connected with sample dimension varies dependently on physical characteristic properties of the sample.

Keywords P-wave velocity · Sample dimensions · Correlation · Physical properties

M. Fener (✉)
Geological Engineering Department, University of Nigde, Nigde, Turkey
e-mail: mfener@nigde.edu.tr

1 Introduction

One of the seismic techniques, P-wave velocity, has been used for several years in the fields of geotechnical practice. These seismic techniques are used in the field of geophysical researches and in the laboratory for the determination of the dynamic properties of rocks. Since ultrasonic techniques are non-destructive and easy to apply, both for site and laboratory conditions, they are increasingly being used in geotechnical applications. Attempts have been made to assess grouting [1, 2], rockbolt reinforcement [3], blasting efficiencies in the rock mass [4] and rock characterization [5] by seismic velocity determination. The estimation of rock mass deformation and stress [6, 7], the estimation of the extend of fracture zone developed around underground openings [8], the determination of rock weathering degree [9], detection of rock material variation [10] and fractured rock mass characterization [11–13] are some of the other application of the seismic techniques.

Most researchers [14–28] studied the relationship between rock properties and sound velocity and found they are closely correlated.

Some researchers [29–34] have investigated the effect of saturation on P-wave velocity of different rock. Almost all researchers found relationship P-wave velocity and saturation but none of them has derived an empirical equation between dry-and wet-rock P-wave velocities. At the same time, Kahraman [35] has derived equations that can be used for the prediction of wet-rock P-wave velocity from the dry-rock P-wave velocity.

There are number of factors that influence the sound velocity of rocks. Main factors influence the P-wave velocity; density, rock type, shape and grain size, porosity, anisotropy, porewater, confining pressure, temperature, rock mass properties. In addition to these factors, weathering, alteration zone, bedding planes and joint properties (filling materials, roughness, water, dip and strike, etc.) also influence the sound velocity. P-wave velocity measurements are made on samples with different core diameters or on block samples with different dimensions. The sample dimension varies depending on the frequency of the device. The aim of this research is to investigate the effect of the sample dimension on P-wave velocity in laboratory.

2 Sample Characterization

Rock textures directly affect P-wave velocity [36, 37]. Rocks with anisotropic characteristic, rocks including schistosity and foliation were not preferred. It was taken into consideration of the dispersion of the pores to be homogeneous in the rock. Three item sedimentary rocks, six item igneous rocks were used and metamorphic rocks were not preferred because of their anisotropic characteristic.

Natural stone factories, quarries and natural outcropping in Nigde, Kayseri, Konya, Aksaray, Nevşehir, Antalya regions of Turkey were visited and block samples were collected. The name, the location and the class of the collected rocks are given Table 1.

To fulfill the aim of the study, core samples were taken at six different diameters from all the rock groups. The size for smallest core is 29.68 mm diameter and the size for biggest core is 113.50 mm diameter (Fig. 1). Used core diameter values are given Table 2.

3 Experimental Procedure

P-wave velocity, physical properties (dry density, wet density, and pore) and same mechanical properties (uniaxial compressive strength, point load index, Brazilian tensile strength) of all rock groups were tested in the Geological Engineering laboratory of Nigde University.

ISRM [38] recommend the minimum lateral dimension be not less than ten times the wave length while ASTM [39] stipulates 5 times the wave length. The PUNDIT 6 Pulse Generator Unite controls made by company and two transducer (transducer's diameter is 50 mm) having a frequency of 1 MHz were used in this study. The frequency of 1 MHz corresponds to a 0.3 mm wave length. Consequently, the lateral minimum dimension of the sample should be 1.5 mm ASTM [39] or 3 mm ISRM [38]. In this study; the lateral minimum diameter of the sample is 29.68 mm and the vertical minimum sample length is 110 mm, which would be acceptable for both Standards.

Another important factor affecting the ultrasonic velocity is the grain size of the rock tested. ISRM (1981) recommends that the travel distance of the pulse though the rock will be at least 10 times the average grain size. The tuff (Kayseri, Nevsehir), ignimbrite (Nigde), basalte (Kayseri), andesite (Aksaray) used in the study are with igneous origin, for this reason the textures of these rocks are afanatic and micro minerals are dispersed in matrix material. Limestone (Antalya), dolomite (Konya) and travertine (Konya) have a small grain size. The biggest grain size of Granit (Spain) is 5 mm. The travel distance of the pulse is 100 mm, again satisfying the Standards.

The sample heights are approximately the same for each rock group in order to minimize the interaction between sample height and P-wave velocity. The end surfaces of the core samples were polished to provide a good coupling between the transducer face and the sample surface to maximize accuracy of the transit time measurement. Stiffer grease was used as a coupling agent in this study. P-wave velocity measurement may be performed in three different methods in the laboratory: direct method, semi direct method and indirect method. Direct method was used in this study (Fig. 2). Transducers were pressed to either surface of the sample and the pulse transit time measured. P-wave velocity values were calculated by dividing the length of the core and the transit pulse time. The tests were repeated at least twice for all different diameter samples and the average value was taken as P-wave velocity value.

All core samples used for P-wave velocity measurement were also used in the determination of dry density, wet den-

Table 1 The name, the location and the class of the collected rocks

Rock code number	Rock type	Rock class	Location
1	Tuff	Igneous	Kayseri
2	Limestone	Sedimentary	Antalya
3	Dolomite	Sedimentary	Konya
4	Tuff	Igneous	Nevşehir
5	Basalt	Igneous	Kayseri
6	Andesite	Igneous	Aksaray
7	Ignimbrite	Igneous	Nigde
8	Granit	Igneous	Spain
9	Travertine	Sedimentary	Konya

Fig. 1 Core samples at six different diameters

Table 2 Core diameter values

	1. Core drill	2. Core drill	3. Core drill	4. Core drill	5. Core drill	6. Core drill
Diameter(mm)	29.68	37.57	41.56	53.72	78.68	113.50

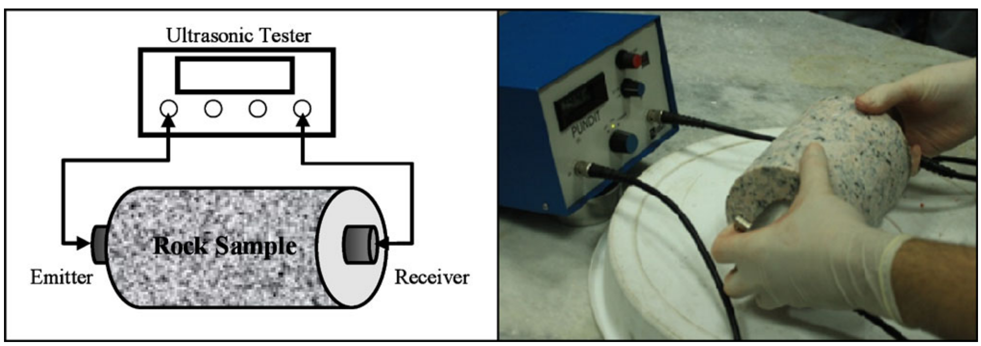

Fig. 2 Direct method

sity and porosity. The specimen volume was calculated from an average of at least two caliper readings. The density values were obtained from the ratio of the specimen mass to the specimen volume. Porosity at atmospheric pressure was determined using saturation and caliper techniques. Saturation was controlled by measurement of weight increase.

Uniaxial compression tests were applied on core samples, which had a diameter of 54 mm and a length-to-diameter ratio of 2. The stress rate was applied within the limits of 0.5–1.0 MPa/s. The diametral point load test was carried out on the cores having a diameter of 42 mm and a length-to-diameter ratio of 1.2. The results were corrected to a specimen diameter of 50 mm. Brazilian tensile strength tests were applied on core samples having a diameter of 42 mm and a height to diameter ratio of 1. The tensile load on the specimen was applied continuously at a constant stress rate such that failure will occur within 5 min of loading. All tests in line with the ISRM suggested methods, results of all physical properties and mechanical properties tests are listed Table 3.

4 Results and Discussions

In all the rock groups, the P-wave velocity values measurements of the samples having different diameters were conducted. Obtained data were analyzed using the least square regression method. The equation of the best fit line, the 95% confidence limits and the correlation coefficients (r^2) were determined for each regression.

The P-wave velocities were correlated with the sample dimension for each rock type. There is an inverse relationship between P-wave velocity and sample diameter in tuff (Kayseri), Basalt (Kayseri) and ignimbrite (Nigde) rock

Table 3 Results of all physical properties and mechanical properties tests

Rock codes	Dry density (gr/cm^3)	Wet density (gr/cm^3)	Porosity (%)	Uniaxial comp. strength (MPa)	Brazilian tensile strength (MPa)	Point load strength (MPa)
1	1.802	2.063	26.19	25.82	2.16	1.2
2	2.702	2.705	0.33	85.19	5.69	3.5
3	2.686	2.690	0.46	35.28	5.56	1.8
4	1.545	1.822	27.71	6.45	1.25	0.7
5	2.577	2.602	2.47	96.16	12.2	5.4
6	2.736	2.760	2.43	120.95	9.53	6.3
7	1.302	1.657	35.48	3.92	1.52	0.8
8	2.600	2.610	0.94	121.76	7.89	3.2
9	2.280	2.337	5.74	13.73	3.50	1.3

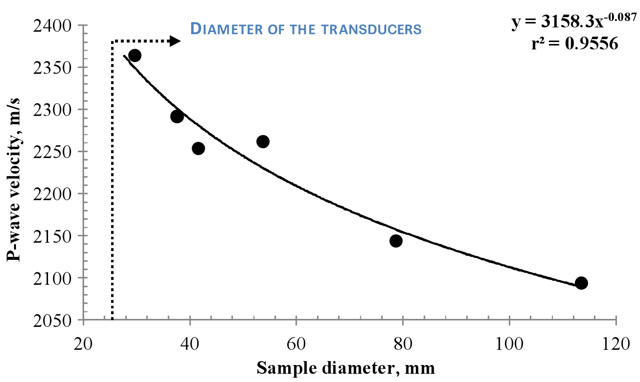

Fig. 3 P-wave velocity versus sample diameter for tuff (Kayseri)

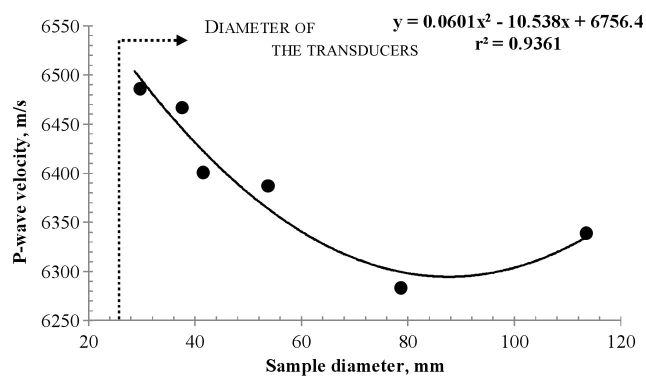

Fig. 4 P-wave velocity versus sample diameter for limestone

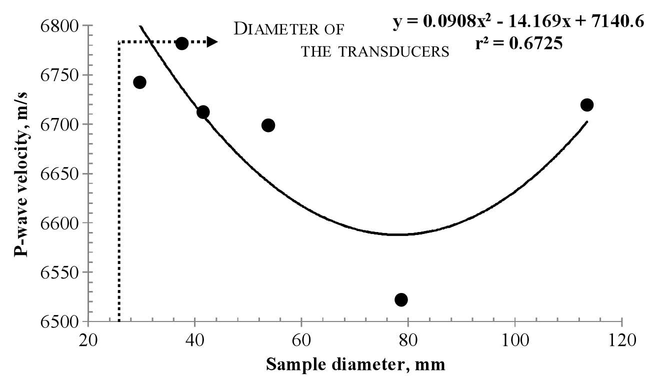

Fig. 5 P-wave velocity versus sample diameter for dolomite

groups. The P-wave velocity recorded in the smallest diameter sample (29.68) is the highest, the P-wave velocity recorded for the biggest diameter sample (113.50) is the lowest. There is a similar relationship in Andesite (Aksaray) samples, but the highest P-wave velocity value was recorded 41.56 mm diameter sample, not in the smallest diameter sample. The plots of the P-wave velocities as a function of the sample diameter values are shown in Figs. 3, 7, 8, 9. As seen from these figures, the relation between P-wave velocity and sample diameter in Tuff (Kayseri) and Basalt (Kayseri) rock group is exponential. In Andesit (Aksaray) and ignimbrite (Nigde) rock groups, this relation between P-wave velocity and sample diameter is polynomial. The correlation coefficient for this rock types are very high.

There is an inverse relationship between P-wave velocity and sample diameter in limestone (Antalya), dolomite (Konya), tuff (Nevsehir) and granite (Spain) rock groups. But the lowest P-wave velocity value was not recorded in the biggest diameter sample, it was recorded in the previous one (78.68 mm). The similar relationship exists in travertine (Konya) rock group but the lowest P-wave velocity value was recorded in 53.72 mm diameter sample, not in 78.68 mm diameter sample. The plots of the P-wave velocities as a function of the sample diameter values are shown in Fig. 4, 5, 6, 10, 11. It is seen that there is a polynomial relationship between the sample diameter and P-wave velocity. The correlation coefficient is very high for these, like in the other rock groups.

Also the highest P-wave velocity and the lowest P-wave velocity for different sample diameter, the difference value (ΔPs) was calculated for each rock group and given Table 4. The ΔPs were correlated with the porosity, dry density for

Table 4 P-wave velocity difference of all rock groups

	Rock Code 1	Rock Code 2	Rock Code 3	Rock Code 4	Rock Code 5	Rock Code 6	Rock Code 7	Rock Code 8	Rock Code 9
(ΔPs)	270	202	260	218	89	113	2127	305	891

ΔPs: The P-wave velocity value variations

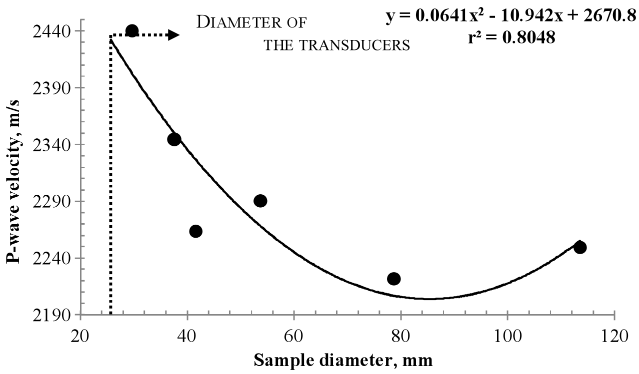

Fig. 6 P-wave velocity versus sample diameter for Tuff (Nevşehir)

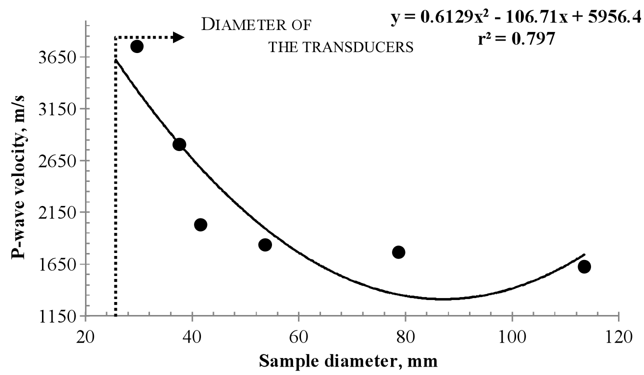

Fig. 9 P-wave velocity versus sample diameter for ignimbrite

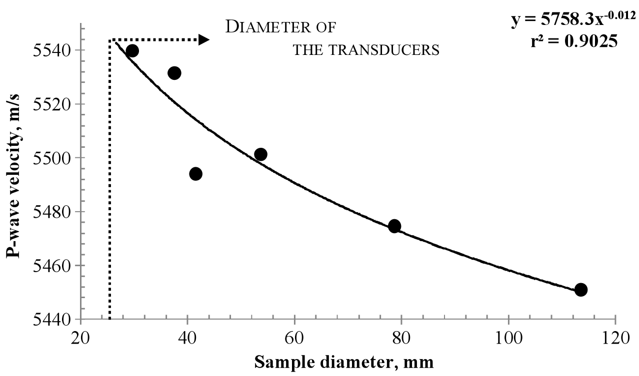

Fig. 7 P-wave velocity versus sample diameter for basalt

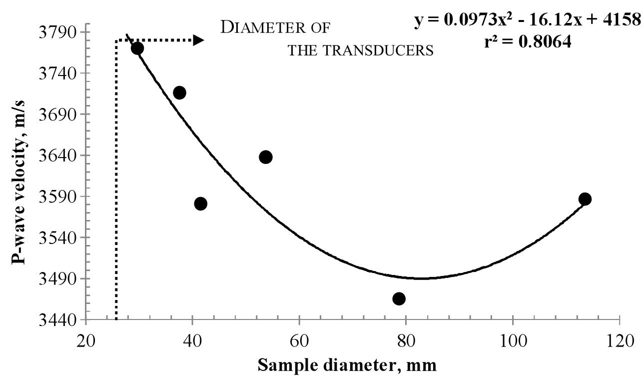

Fig. 10 P-wave velocity versus sample diameter for granite

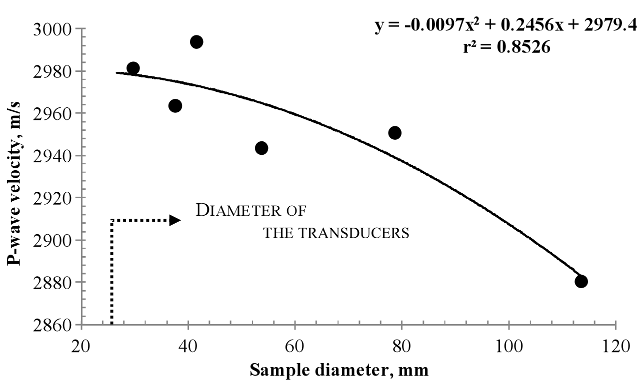

Fig. 8 P-wave velocity versus sample diameter for andesit

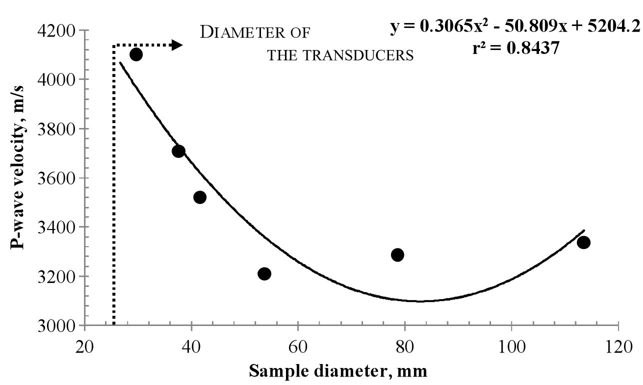

Fig. 11 P-wave velocity versus sample diameter for travertine

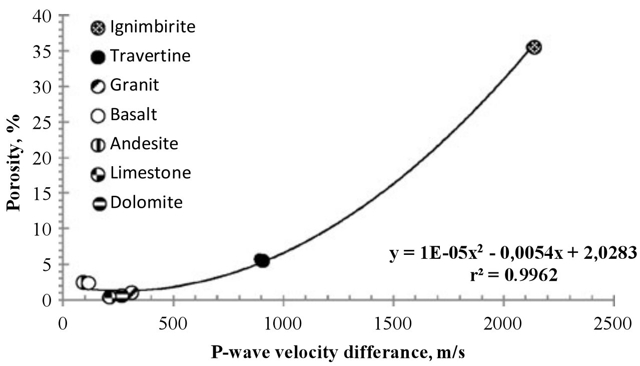

Fig. 12 A polynomial relationship between P-wave velocity difference and porosity

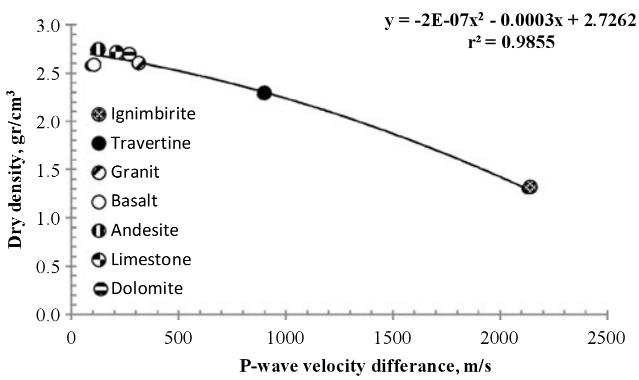

Fig. 13 A polynomial relationship between P-wave velocity different and dry density

all rock type. These two rocks in tuff group were not evaluated for their having high clay ratio. There is a polynomial relationship between P-wave velocity difference and porosity (Fig. 12). This variation is approximately 200 m/s for the rocks with porosity values less than 5% and this change is 2127 m/s for the ignimbrite whose porosity is the highest (35.48%). There is a polynomial relationship between P-wave velocity different and dry density (Fig. 13). P-wave velocity variation is around 250 m/s for the rocks with dry density value less than 2.5% and this variation is the highest for the ignimbrite with lowest density.

5 Conclusions

In this study, core samples were taken from 9 different rock groups at 6 different diameters and the effect of sample dimension on P-wave velocity was researched. Also the effect of some physical properties of the rocks on this change was researched and the results are given below.

In four sample groups a decrease in ultrasonic velocity depending on an increase in diameter was observed. In five other sample groups in the samples up to 78.68 mm diameter, a decrease in P-wave velocity value was observed but a significant increase in the P-wave velocity was observed for the biggest diameter samples. The test results were statically analyzed using the method of least squares regressions, exponential and polynomial relationship with high correlation coefficient were found between the sample dimension and P-wave velocities.

The P-wave velocity value variation (ΔPs) depending on sample dimension, the porosity of rocks and dry density values were statistically evaluated. According to these results, ΔPs is low with the rock groups having low porosity values, and ΔPs is high in rock groups having high porosity values. A polynomial relation with high correlation coefficient was observed between ΔPs and porosity values. Also there is an inverse polynomial relation with high correlation coefficient between ΔPs and dry density values. ΔPs is low for the samples with high dry density and it is high for the samples with low dry density.

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