

Correlations Between Physical and Mechanical Properties of a Syenogranite as a Function of the Degree of Alteration

Correlaciones entre las propiedades físicas y mecánicas de un sienogranito en función del grado de alteración (Correlações entre propriedades físicas e mecânicas de um sienogranito em função do grau de alteração).

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ABSTRACT: The determination of the physical and mechanical properties of rocks is of utmost importance for understanding their performance in engineering projects. Additionally, it is crucial to highlight that weathering can affect the behavior of the rock under imposed field conditions in the medium and long term. In this context, the present study aimed to evaluate the variation of compressive wave velocity (V_p) and the Schmidt hammer rebound hardness value (Q) as a function of the degree of alteration of a syenogranite, quantified by its natural apparent specific mass (ρ). For this purpose, 31 samples of a syenogranite from the Southeast region of Brazil were tested, including specimens ranging from sound to moderately altered rock. This evaluation resulted in the establishment of mathematical correlations between V_p and Q as a function of ρ , which showed coefficients of determination (R^2) higher than 0,90. Thus, these correlations contribute to the assessment of rock integrity at different degrees of alteration and provide geomechanical property data in a simpler manner, aiding in the understanding of their mechanical behavior without causing damage to the samples.

KEYWORDS: Geomechanical properties, Rock weathering, Syenogranite, Compressional waves, Schmidt Hammer rebound hardness.

1 INTRODUCTION

The main reason for most issues associated with engineering projects such as rock foundations, underground structures, infrastructure works, tunnels, dams, among others, is the inaccurate assessment of rock properties. In this context, determining the physical and mechanical properties of rocks is crucial to ensure the safety and economic viability of engineering projects.

However, direct determination of these properties is often a costly and time-consuming process. Additionally, obtaining representative samples of real field conditions for laboratory testing can pose additional challenges. Thus, non-destructive testing becomes very useful for estimating the geomechanical properties of rocks and predicting their behavior under field stress, as highlighted by Khandelwal (2013).

Among the non-destructive tests, the compressional wave propagation velocity test and the Schmidt Hammer test stand out for their simplicity and the ability to be conducted both in the field and in the laboratory. In this regard, several authors have proposed correlations between the properties determined in these non-destructive tests and the mechanical properties of rocks, such as those developed by Yasar and Erdogan (2004), Kurtulus *et al.* (2011), Sarkar, Vishal and Singh (2011), Azimian, Ajalloeian and Fatehi (2014), Jamshidi *et al.* (2016) and Kurtulus, Sertçelik and Sertçelik (2016).

Furthermore, it is essential to highlight that weathering can impair the rock's behavior under imposed field conditions in the medium and long term, as evidenced by Jaques *et al.* (2020), who studied the effect of weathering on samples of a syenogranite

collected in the same region as the material under analysis in the present study.

Considering this context, the present study aimed to evaluate the variation of compressional and shear wave velocity (V_p), and the Schmidt rebound hammer hardness (Q) properties, as a function of the weathering degree of a syenogranite, which is directly related to its natural apparent specific mass (ρ).

To achieve this objective, the Schmidt Hammer Test was performed, which has very useful in providing an estimate of the compressive strength of the material; as well as the ultrasonic wave propagation velocity test, which is of great relevance for the evaluation of the quality and strength of rocks. For this, 31 samples of a syenogranite collected in the southeast region of Brazil were tested, ranging from sound rock to moderately weathered condition.

Thus, equations were established, linking the physical and mechanical properties of the studied syenogranite. These equations contribute to the assessment of rock integrity under different weathering degrees and provide geomechanical property data in a simplified manner, aiding in the understanding of rock mechanical behavior of igneous rocks without causing damage to the samples.

2 MATERIALS AND METHODS

2.1 Syenogranite

For the development of this study, four rectangular blocks of a syenogranite from the southeast region of Brazil were collected, two of which were classified as sound rock (W1), one as slightly weathered (W2), and the other as moderately weathered (W3),

following the weathering alteration classification system proposed by the International Society of Rock Mechanics – ISRM (1981).

The collected syenogranite was an intrusive igneous rock composed predominantly of alkali feldspar, quartz, plagioclase, and accessory minerals such as biotite and sericite. In the more weathered samples, there was progressive degradation of the minerals, with feldspars being replaced by clay minerals and the presence of fissures and microfractures filled with weathering products.

Overall, regarding the textural aspects, the rock was classified as phaneritic, holocrystalline, and inequigranular. The sound rock samples (W1) exhibited a fine to medium granular texture, while the slightly (W2) and moderately weathered (W3) samples presented medium to coarse-grained phenocrysts embedded in a fine to medium-grained matrix.

2.2 Sample preparation

In total, 31 test specimens were extracted from the rock blocks, with 14 of them in the W1 condition, 5 in the W2 condition, and 12 classified as W3. These rock samples were sawn and machined and had a height-to-diameter (H/D) ratio close to 2.0, with an approximate diameter of 54 mm.

2.3 Natural apparent specific mass

The determination of the natural apparent specific mass of the samples was carried out through direct measurement of the dimensions and mass of each test specimen, aiming to quantify the effect of weathering action on the rock and correlate this effect with properties quantitatively obtained through non-destructive tests.

This test was performed for the 31 samples mentioned in item 2.2. Thus, the value of the natural apparent specific mass (ρ) of each sample was calculated using Eq. 1, where "m" represents the mass and "V" represents the volume of each test specimen.

$$\rho = \frac{m}{V} \quad (1)$$

2.4 P-wave propagation velocity test

For conducting this test, the Proceq Pundit PL-200 equipment was utilized. The determination of the compressive wave propagation velocity (V_p), also known as P-waves, was carried out using a pair of 250 kHz transducers. To ensure adherence between the sample and these transducers, as well as to optimize the quality of the recorded signal, a water-based gel was used for reading these waves. The test procedure was conducted following the recommendations of ASTM International (ASTM, 2000), using the 31 samples mentioned in item 2.2.

2.5 Schmidt Hammer test

For the Schmidt Hammer test, a SilverSchmidt type L sclerometer from Proceq was used, enabling the determination of the impact value "Q". The testing procedure followed the recommendations of ISRM (2014), using the 31 samples mentioned in item 2.2, which were free from visible defects and fissures.

2.6 Statistical treatment of data

After the laboratory tests were conducted, statistical analysis of the obtained data was performed. For each group of samples, the mean values, sample standard deviation, and coefficient of variation of each individually evaluated geomechanical property were calculated.

Furthermore, two mathematical correlations were established, one of V_p as a function of ρ and the other of Q as a function of ρ , using a mathematical data processing software.

3 RESULTS AND DISCUSSION

3.1 Natural apparent specific mass

The results of the natural apparent specific mass (ρ) obtained for the groups of samples are presented in Table 1. These results were similar to those achieved by Lamas (2023), Jaques *et al.* (2020), Heidari, Momeni and Naseri (2013) and Dagdelenler, Sezer and Gokceoglu (2011) for granitic rocks.

Table 1. Results of the natural apparent specific mass.

Natural apparent specific mass (ρ)			
Statistic	W1	W2	W3
Average value (g/cm ³)	2.65	2.66	2.48
Standard deviation (g/cm ³)	0.01	0.01	0.01
Coefficient of variation (%)	0.50	0.56	0.52

Based on these results, it is possible to observe that the values for W1 and W2 were very close to each other, while for W2, there was a more significant loss in this property compared to the sound rock. It was also observed that the average value of W2 was slightly higher than that of W1, which may have occurred due to possible mineralogical differences between the tested samples.

3.2 P-wave propagation velocity

The results of the P-wave propagation velocity (V_p) obtained for the groups of samples are presented in Table 2. These results were similar to those achieved by Lamas (2023), Jaques *et al.* (2020) and Basu, Celestino and Bortolucci (2008) for granitic rocks.

Table 2. Results of P-wave propagation velocity.

P-wave propagation velocity (V_p)			
Statistic	W1	W2	W3
Average value (m/s)	4891.38	5629.60	3268.39
Standard deviation (m/s)	201.62	90.05	154.22
Coefficient of variation (%)	4.12	1.60	4.72

From these results, an increase of approximately 15% was observed in the average value of V_p recorded in W2 compared to that of W1, which is consistent with the slightly higher value of ρ in W2 compared to the sound rock, as described earlier. Thus, this behavior can be attributed to possible mineralogical and microstructural differences between the tested samples.

Additionally, a more pronounced decrease in the value of V_p was noted for the W3 group compared to the samples of the W1 group.

3.3 Schmidt rebound hammer hardness

The results of the Schmidt rebound hammer hardness value (Q) obtained for the groups of samples are presented in Table 3. Based on these results, it is noted that the average value of Q decreased with the increase in the weathering degree of the syenogranite. This behavior has also been observed by other researchers who studied granitic rocks, such as Lamas (2023) and Jaques *et al.* (2020).

Table 3. Results of Schmidt rebound hammer hardness value.

Schmidt rebound hammer hardness value (Q)			
Statistic	W1	W2	W3
Average value	47.65	42.12	28.94
Standard deviation	1.90	0.82	2.07
Coefficient of variation (%)	3.98	1.95	7.15

3.4 Correlation between ρ and V_p

The correlation between the values of natural apparent specific mass and P-wave propagation velocity is presented in Figure 1, described by Eq. 2.

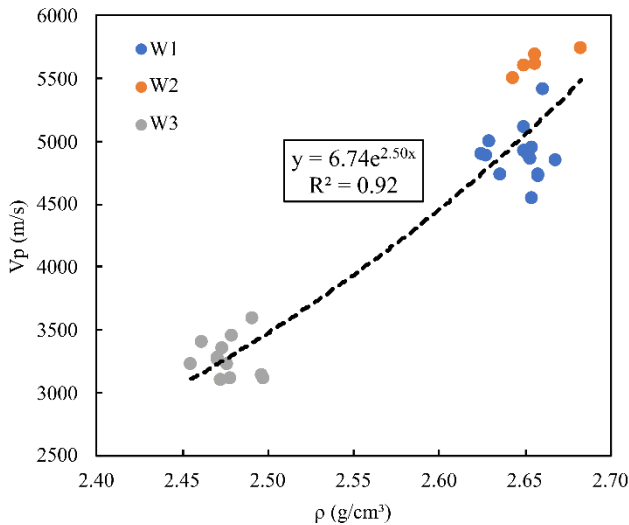


Figure 1. Correlation between ρ and V_p .

$$V_p = 6.74e^{2.50\rho} \quad (2)$$

This equation was determined from the individual results of each sample, resulting in a coefficient of determination (R^2) of 0.92, considered high. Thus, it was possible to demonstrate the directly proportional relationship between these two properties, in addition to enable the estimation of one from the other.

3.5 Correlation between ρ and Q

The correlation between the values of natural apparent specific mass and the Schmidt rebound hammer hardness value is presented in Figure 2, and described by Eq. 3.

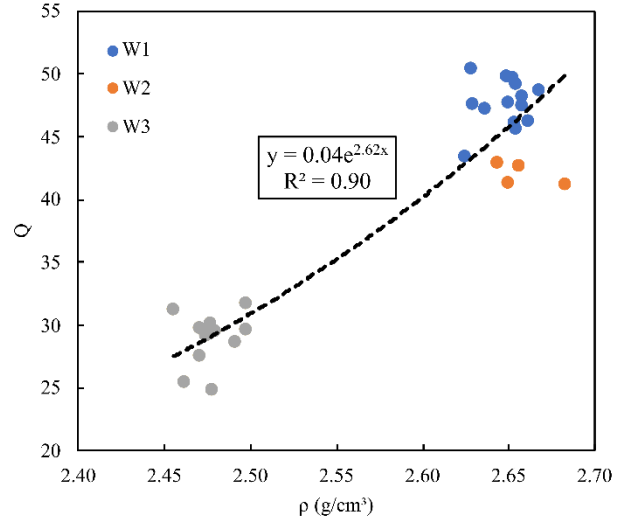


Figure 2. Correlation between ρ and Q .

$$Q = 0.04e^{2.62\rho} \quad (3)$$

The equation correlating the values of ρ and Q was determined from the individual results of each sample, resulting in a high coefficient of determination (R^2) of 0.90. Thus, it was found that there is a directly proportional relationship between these two properties, making it possible to estimate one from the other.

It is important to emphasize that, whenever possible, conducting tests to determine the physical and mechanical properties of rocks, whether in the laboratory or in situ, is recommended. However, in cases where direct measurement of these properties is not feasible, the correlations proposed in this study can be highly valuable for estimating parameters crucial in geotechnical projects, using properties that are easily determined, such as the natural apparent specific mass.

4 CONCLUSIONS

Based on the results presented in this study, it was observed a slight increase in the values of the apparent natural specific weight (ρ) and the P-wave propagation velocity (V_p) for the slightly altered rock (W2) when compared to the sound rock (W1). This behavior may be related to mineralogical and microstructural differences among the tested samples and support that the initial weathering process (from W1 to W2) do not promote significant changes in the mechanical behavior of the rocks under study. However, in the moderately weathered samples, a greater reduction in these properties was observed compared to the sound rock. Regarding the value of the Schmidt hammer rebound hardness (Q), a directly proportional decrease was observed with the increase of weathering alteration. This happens because the chemical

weathering starts to control the weathering process, replacing the more physical one occurring on its initial steps.

Additionally, two correlations were established between the properties of P-wave propagation velocity and Schmidt hammer rebound, as a function of the apparent natural specific weight of the syenogranite, both with high coefficients of determination (R^2), exceeding 0.90. Therefore, these correlations contribute to the assessment of rock integrity under different weathering degrees and provide geomechanical property data in a simplified manner, aiding in the understanding of rock mechanical behavior of igneous rocks without causing damage to the samples.

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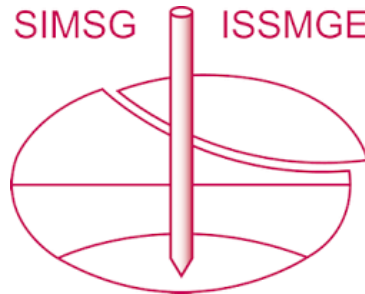
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