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Research Article

SUGGESTING CONVERSION FACTOR COEFFICIENTS FOR ESTIMATING DIFFERENT TYPES OF SCHMIDT HAMMER REBOUND HARDNESS VALUES

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Keywords
Schmidt Hammer Rebound Number,
Conversion Factor Coefficient,
Rock.

Abstract

Mechanical properties of rocks such as uniaxial compressive strength, tensile strength, shear strength are the properties that determine their behavior under load. These properties of rocks are often determined by difficult, complex, time-consuming and expensive test methods. Therefore, instead of determining these properties directly, these properties can be estimated indirectly by using relatively inexpensive, fast and easily applicable methods. The surface hardness parameter of Schmidt hammer rebound hardness is fast, inexpensive, and easy to apply to determine the hardness of rocks and concrete. It is also used to indirectly determine the mechanical properties of rocks. It is seen that two different types of hammers (N-type and L-type) with different impact energies are commonly used in the literature. In this study the correlations between the surface hardness of different rocks obtained using N-type and L-type Schmidt hammers were analyzed. For this purpose, data were compiled from studies in the literature, which included both N-type and L-type Schmidt hammer rebound hardness of different rock types, and the collected data were analyzed statistically. Coefficients have been proposed for the conversion of N-type and L-type Schmidt hammer rebound hardness to each other.

KAYALARIN FARKLI TİP SCHMİDT ÇEKİCİ GERİ TEPME SERTLİK DEĞERLERİNİN TAHMİNİ İÇİN DÖNÜŞÜM KATSAYISI ÖNERİLMESİ

Anahtar Kelimeler
Schmidt Çekici Geri Tepme Sertliği,
Dönüşüm Katsayısı,
Kaya.

Öz

Kayaların tek eksenli basınç dayanımı, çekme dayanımı, makaslama dayanımı gibi mekanik özellikleri yük altındaki davranışlarını belirleyen özellikleridir. Kayaların bu özelliklerini çoğu zaman zor, karmaşık, zaman alıcı, pahalı deney yöntemleri ile belirlenmektedir. Bu yüzden bu özellikleri doğrudan belirlemek yerine nispeten ucuz, hızlı ve kolay uygulanabilir yöntemlerle belirlenen kaya özellikleri ile bu özellikler dolaylı olarak tahmin edilebilir. Schmidt çekici geri sıçrama sertliği de kayaların ve betonun yüzey sertliğini tespit etmek için kullanılan bir yöntemdir. Schmidt çekici testi hızlı, görece ucuz ve kolay uygulanabilirdir. Aynı zamanda kayaların mekanik özelliklerinin dolaylı olarak belirlenmesinde kullanılır. Yöntemin hem arazide hem laboratuvarda uygulanabiliyor olması yöntemin diğer avantajlı yönüdür. Literatürde yaygın olarak kullanılan farklı darbe enerjilerine sahip iki farklı çekiç tipinin (N-tipi ve L-tipi) kullanıldığı görülmektedir. Bu çalışma kapsamında N-tipi ve L-tipi Schmidt çekici kullanılarak elde edilmiş sertlik değerlerinin birbiri ile arasındaki ilişkiler incelenmiştir. Bunun için literatürde farklı kaya türlerine ait hem N-tipi hem de L-tipi Schmidt çekici geri sıçrama sertliklerinin yer aldığı çalışmalardan veriler derlenmiş, derlenen veriler istatistiksel olarak incelenmiştir. N-tipi ve L-tipi Schmidt çekici geri sıçrama sertliklerinin birbirine dönüşümü için katsayılar önerilmiştir.

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SUGGESTING CONVERSION FACTOR COEFFICIENTS FOR ESTIMATING DIFFERENT TYPES OF SCHMIDT HAMMER REBOUND HARDNESS VALUES

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Highlights (At least 3 and maxium 4 sentences)

- Conversion factors were proposed to predict rock surface hardness using the Schmidt hammer.
- A total of 195 data from literature and laboratory tests were analyzed.
- High correlations and low MAPE values were obtained between the different type of Schmidt hammers.

Purpose and Scope

The aim of the research was to suggest conversion factor coefficients for estimating different types of Schmidt Hammer rebound hardness values. The importance of determining the material properties of rocks in engineering applications and the difficulties associated with traditional testing methods was discussed. It was proposed to use the Schmidt Hammer rebound hardness test as an alternative method for estimating mechanical properties of rocks. Specifically, the study analyzed the correlations between the surface hardness of different rocks obtained using N-type and L-type Schmidt hammers, and proposed conversion factor coefficients for the two types of hammers.

Design/methodology/approach

The methodology of this study is to analyze and statistically examine the relationship between the rebound hardness values obtained using N-type and L-type Schmidt hammers for different rock types. To this end, data from studies containing rebound hardness values for different rock types both in N-type and L-type Schmidt hammers have been collected and analyzed statistically. Coefficients have been suggested for the conversion between N-type and L-type Schmidt hammer rebound hardness values.

Findings

It was determined that the SH values were approximately close to each other, and the SH values for the two hammer types were relatively high in Metamorphic rocks, followed by Igneous and Sedimentary rocks, respectively. Within the scope of this study, measurements were made with N-type and L-type Schmidt hammers on rocks of igneous, metamorphic, and sedimentary origin. By examining the relationships between the measured hardness values, conversion factor coefficients that can be used to predict the surface hardness measured by using different types of Schmidt hammers are proposed.

Originality

The originality of this study is proposing conversion factor coefficients for estimating different types of Schmidt hammer rebound hardness values. The study analyzes the correlations between the surface hardness of different rocks obtained using N-type and L-type Schmidt hammers and proposes coefficients for the conversion of N-type and L-type Schmidt hammer rebound hardness to each other. This is important because different types of hammers were used in previous studies, resulting in very different empirical equations. The proposed conversion factor coefficients can be used to predict the surface hardness measured by using different types of Schmidt hammers more accurately.

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1. Introduction

Determining the material properties of the rock in engineering applications that are intertwined with the rock is very important for the feasibility and sustainability of the project. Strength values such as uniaxial compressive strength (UCS), tensile strength (TS), shear strength etc. of rocks are important design parameters taken into account by the project engineers in the construction of the structure and ensuring its stability. These values are obtained as a result of the sizing of the field samples brought to the laboratory according to the dimensions specified in the relevant test standards, and then the tests performed on these samples. These test methods can be expressed as time-consuming and costly methods, or in some cases, samples may not be prepared in the sizes recommended in the standards. For example, it is difficult to get cores or prepare test specimens of required dimensions from weak, weathered and thinly bedded rocks (Palchik, 2007; Mishra and Basu, 2013; Wang and Aladejare, 2015; Wang et al., 2016; Aladejare, 2020). In such cases, index properties of rocks can be determined with index methods that are easy to apply, give fast results, do not require sample preparation, or can be applied to small samples and by means of empirical equations, mechanical properties such as uniaxial compressive strength and tensile strength needed in the design can be estimated using index properties. In the literature, there are many empirical equations developed especially for the indirect estimation of UCS. In these studies, the relationships between UCS and index and physical properties such as point load index (PLI), Schmidt hammer rebound number (SH), porosity and density were investigated.

Among these test methods, the most preferred and most accurate methods are PLI and SH tests. The common feature of the test instruments used in the two methods, which can be applied both in the field and in the laboratory, is that they are relatively light and portable. Since the test sample standards and tests required for these instruments are practical, they are also frequently used in field studies (Mesutoğlu and Özkan, 2019). However, in a study, 154 scientific studies containing PLI data were examined in detail, and it was seen that only four of these studies included the data of PLI tests applied in the field. In other words, only 2.5% of the studies on PLI testing were conducted in the field (Akbay and Altındağ, 2020). The reason for this is thought to be due to restrictive factors such as the need for a flat place to position the PLI test instrument in the field, and the recommendation of aspect-length-thickness ratios in the test standard even when using irregular/shapeless samples. Such situations have limited the use of the PLI test in the field. On the other hand, Schmidt hammer has a design that eliminates these disadvantages. In this way, it is widely used in field applications.

In the literature, there are many empirical equations developed for the indirect estimation of UCS with SH (Yılmaz and Sendir, 2002; Buyuksagis and Goktan, 2007; Çobanoğlu and Çelik, 2008; Karaman et al., 2011; Bruno et al., 2013; Minaeian and Ahangari, 2013; Karaman et al., 2015; Tandon and Gupta, 2015; Jamshidi et al., 2016; Demirdag et al., 2018; Kong and Shang, 2018; Çelik and Çobanoğlu, 2019; Mesutoğlu and Özkan, 2019; Wang and Wan, 2019; Özkan and Kaya, 2020). However, since different types of hammers were used in these studies, very different empirical equations were derived. Within the scope of this study, measurements were made with N-type and L-type Schmidt hammers on rocks of igneous, metamorphic, and sedimentary origin. By examining the relationships between the measured hardness values, conversion factor coefficients that can be used to predict the surface hardness measured by using different types of Schmidt hammers are proposed. It is thought that it will be more accurate to evaluate the equations obtained when corrections are made with the conversion factor coefficients obtained from this study.

2. Schmidt Hammer Rebound Number

The Schmidt hammer, which is the subject of this study, is a surface hardness measuring instrument used by all disciplines dealing with rock and concrete. The Schmidt hammer was designed as an index testing device for in-situ nondestructive testing of concrete in the late 1940s (Aydın and Basu, 2005). SH has been widely used in rock mechanics applications since the early 1960s to estimate the UCS, mostly as an indicator of the surface hardness of rocks (Goktan and Ayday, 1993). pending on where the material under test is, Schmidt hammer test method can be conducted either in the field or in the lab.

The Schmidt hammer consists of a compressed spring and a piston. When the hammer is pressed against the surface of a test material, the spring is released and, together with the piston, strikes the surface of the test material. Depending on the surface hardness of the test material, the piston rebounds. The distance traveled by the piston is read from the indicator on the Schmidt hammer and is defined as the SH (Figure 1).

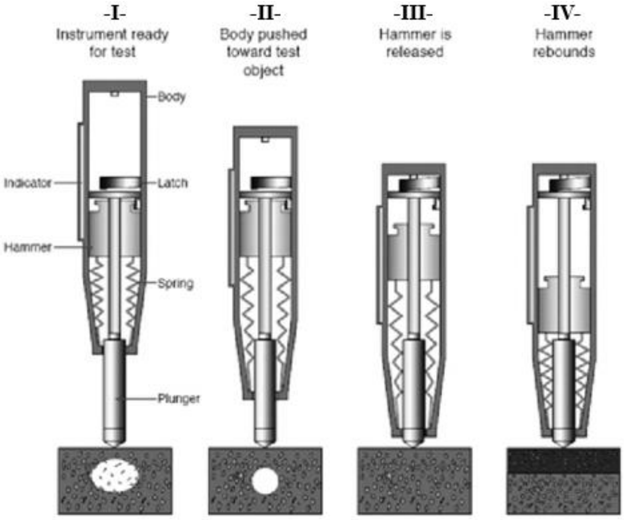

Figure 1. Working principle of a Schmidt hammer (Jedidi, 2020)

In the method proposed by ISRM (2007) for measurement, measurements are made from 20 different points with a distance of at least a piston diameter from the material to be determined, and the arithmetic average of the remaining 10 measurements is taken by discarding the lowest 10 of these 20 measurements. In the method revised by Aydin (2009), the steps suggested by ISRM (2007) are followed. At the same time, the test can be terminated when the difference between the lowest and the highest value is four (±2 SH) in any ten consecutive measurements. With the help of a chart developed by Deere and Miller (1966), the UCS of the material can be determined indirectly by using the SH and the unit weight value of the rock. (Figure 2).

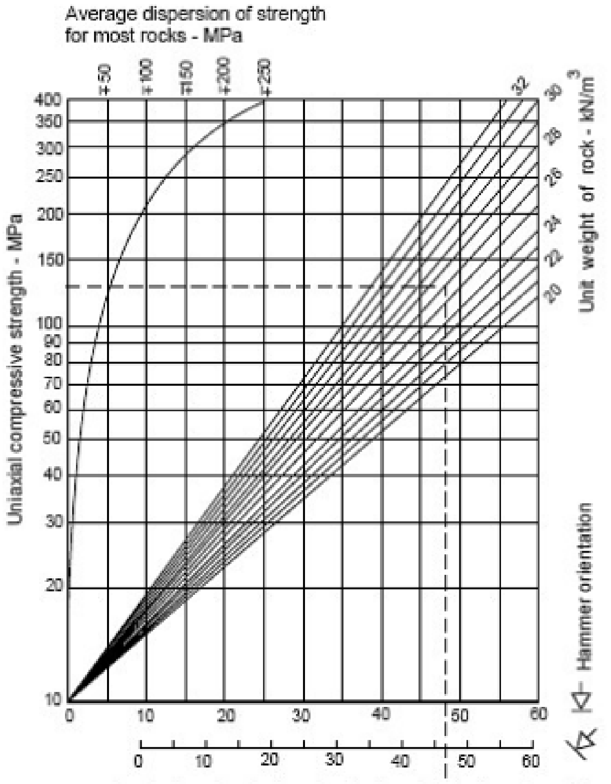

Figure 2. Conversion chart for Schmidt (L) hammer (Deere and Miller, 1966)

There are various Schmidt hammer models developed for different impact energies. Commonly used types are L and N type Schmidt hammers. The N-type Schmidt hammer has an impact energy of 0.735 Nm, and the L-type

Schmidt hammer has an impact energy of 2.207 Nm. Although the L type hammer is generally used for testing relatively soft rocks, the strength range of the rocks to be used is researched and discussed (Buyuksagis and Goktan, 2007; Aydın and Basu, 2005). The International Society for Rock Mechanics and Rock Engineering (ISRM) and the American Society for Testing and Materials (ASTM) have proposed standards for the test method and use of the test device. According to ISRM (1978), the N-type hammer should be used to characterize the hardness of rocks with UCS values between 20 and 150 MPa. The N-type hammer seems appropriate for rocks in this strength range because the L-type Schmidt hammer has not been approved by ISRM for use in rock characterization (Buyuksagis and Goktan, 2007). It was stated in the previous section that there are many studies in the literature examining the correlations between the SH determined with an N-type or L-type Schmidt hammer and UCS. However, there are few studies examining the relationships and differences between the SH determined using different types of Schmidt hammers. Ayday and Goktan (1992), Asteris et al. (2021) directly examined the relationships between N-type and L-type Schmidt hammers in their research. They found strong correlations between the SH obtained by using N-type and L-type Schmidt hammers. On the other hand, Buyuksagis and Goktan (2007) examined the effect of Schmidt hammer type on the uniaxial compressive strength estimation of rocks and determined strong relationships between both N-type and L-type Schmidt hammer and UCS. They also underlined that the correlation coefficient of the correlation between the SH obtained by using L-type Schmidt hammer and UCS is relatively higher than the correlation coefficient of the relationship between the SH obtained using the N-type Schmidt hammer and UCS.

3. Material and Method

Within the scope of this study, SH tests were applied on seven different rock types using N-type and L-type Schmidt hammers (Figure 3). SH tests of the rocks were carried out on cube samples of 70×70×70 mm in size according to ISRM (2007) and the results were presented in Table 1. Data compiled from studies in the literature that included N-type and L-type SH values and the data obtained from this study were evaluated together (Table 2).

Table 1. The SHL and SHN values of rocks

Rock Origin	Rock Type	SHL	SHN	Impact direction
Igneous	Granite	46	54	⤓
Igneous	Granite	49	54	⤓
Igneous	Granite	54	60	⤓
Metamorphic	Marble	48	55	⤓
Sedimentary	Limestone	43	45	⤓
Sedimentary	Limestone	45	52	⤓
Sedimentary	Limestone	48	52	⤓

SHL: L-type Schmidt hammer rebound number
SHN: N-type Schmidt hammer rebound number

Figure 3. N-type and L-type Schmidt hammers

Table 2. Studies in which the data used in the study were compiled

References	Rock origins	Number of data
Aydin and Basu (2005)	Igneous	40
Güney et al. (2005)	Metamorphic	1
	Sedimentary	6
Buyuksagis and Goktan (2007)	Igneous	6
	Metamorphic	8
	Sedimentary	13
Ekincioğlu (2008)	Igneous	1
	Sedimentary	6
Kayabali and Selcuk (2009)	Igneous	41
	Metamorphic	2
	Sedimentary	22
Şengün (2009)	Igneous	3
	Metamorphic	3
	Sedimentary	9
Capik and Yılmaz (2017)	Igneous	13
	Sedimentary	14
This study	Igneous	3
	Metamorphic	1
	Sedimentary	3

4. Results

Within the scope of the study, a total of 195 data were analyzed for both test methods. These data are not the raw reading values, but the arithmetic mean values in the results section of the studies. The SH values obtained as a result of the tests performed are given in Figure 4. It was determined that the SH values were approximately close to each other, and the SH values for the two hammer types were relatively high in Metamorphic rocks, followed by Igneous and Sedimentary rocks, respectively (Figure 5). Among the evaluated Igneous rocks, it is seen that the rocks with low hardness value such as tuff decrease the average surface hardness value. At the same time, such Igneous rocks caused the standard deviation value to be large. Standard deviation values were calculated as the lowest for Metamorphic rocks with a homogeneous structure and high hardness value. It is seen that SHN values are higher than SHL values. It is possible to say that the SHN values are higher due to the impact energy transmitted by the L-type Schmidt hammer, which has a higher impact energy than the N-type Schmidt hammer, to the rock surface during the measurement, increasing the distance traveled by the piston.

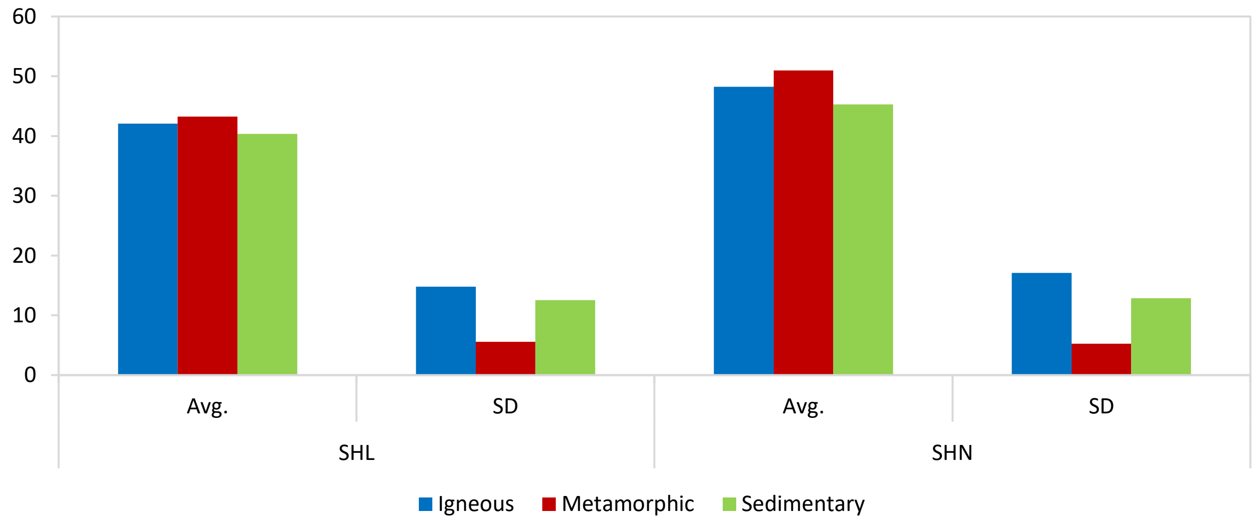

Figure 4. N-type and L-type SH of rocks

In this study, the relationships between the SH values of the rocks obtained by using different hammer types were investigated. A statistical study was carried out and estimation models were created with simple regression analysis, and the conversion factor coefficients (K) were determined by the graphical method (Figure 5). Data from

Aydin and Basu (2005), Buyuksagis and Goktan (2007), Ekincioğlu (2008), Kayabali and Selcuk (2009), Şengün (2009), Capik and Yılmaz (2017) and, this study were used for igneous rocks, data from Güney et al. (2005), Buyuksagis and Goktan (2007), Kayabali and Selcuk (2009), Şengün (2009) and, this study were for metamorphic rocks, and data from Güney et al. (2005), Buyuksagis and Goktan (2007), Ekincioğlu (2008), Kayabali and Selcuk (2009), Şengün (2009), Capik and Yılmaz (2017), and this study for sedimentary rocks. For Igneous rocks the data were used In order to make the results more meaningful and to make easy the evaluation, the rocks were analyzed by grouping them according to their geological origins. When the correlations between the SHL and SHN of the rocks are examined, it is seen that the values obtained are close to each other and vary between 0.81 and 0.96 (Figure 5). It was observed that the highest correlation was 0.96 in Igneous rocks, and the lowest correlation was 0.81 in Metamorphic rocks. It is thought that the reason for the relatively low correlation value in metamorphic rocks is due to the low number of data. The correlation coefficients of the conversion factor coefficients (*K*) calculated for each rock type were determined as 0.99 (Figure 5).

Within the scope of this study, it was determined that SHN and SHL could be used reliably to predict each other, with high correlations obtained similar to the results of Ayday and Goktan (1992)'s study.

It is clearly seen that the correlation coefficients of the determined conversion factor coefficients are higher than the correlation coefficients of the prediction models created by simple regression analysis (Figure 5). The mean absolute percentage errors (MAPE) were calculated to measure the accuracy of the estimations by the estimation models and conversion factor coefficients to convert/predict the SH of the rocks using different types of hammers (Table 3). It is seen that the MAPEs calculated for each rock type are lower for the values estimated by the conversion factor coefficients (Table 3). The conversion factor coefficients determined in the conversion of hardness values to each other provide more reliable results than the prediction models created.

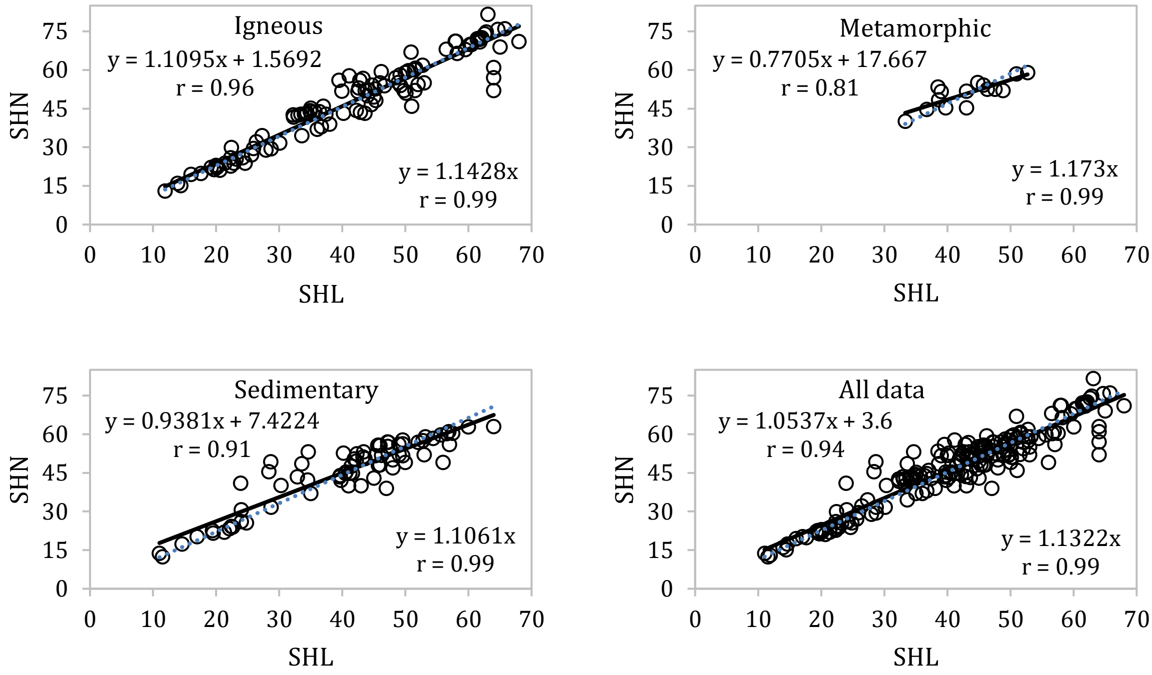

Figure 5. Relationships between SH of rocks obtained by using N-type hammer and L-type hammer

Table 3. Estimation models and conversion factor coefficients (*K*) for the SH conversion

	Estimation model	MAPE	Conversion factor coefficients (*K*)	MAPE
Igneous rocks	y = 1.1095x + 1.5692	8.55	y = 1.1428x	8.21
Metamorphic rocks	y = 0.7705x + 17.667	16.32	y = 1.173x	8.66
Sedimentary rocks	y = 0.9381x + 7.4224	10.7	y = 1.1061x	8.35
All data	y = 1.0537x + 3.6	9.24	y = 1.1322x	8.20

5. Conclusions and Discussions

SH is one of the widely used inexpensive, portable, and non-destructive hardness methods for determining the surface hardness of rocks. Although there are hammer types with different impact energies, the most common types of hammers for measuring the surface hardness of rocks are N-type and L-type Schmidt hammers. In this study, measurements were made with N-type and L-type Schmidt hammers on different rock types. At the same time, a data set was created by compiling data from studies in the literature that included SH values obtained using both hammer types, and statistical analyzes were made. In the light of the results obtained, it has been seen that both hammer types can be used to measure the surface hardness of rocks. SHN were determined higher due to the higher impact energy of the L-type Schmidt hammer than the N-type Schmidt hammer. When necessary, it is thought that the hardness values measured with different types of hammers can be converted to each other with high reliability by using the conversion factor coefficients (K) suggested in this study.

It is obvious that SH is an important rock property for determining the surface hardness of rocks and that the SH test method will continue to be used as an important index test method due to its idiosyncratic characteristics. Although data obtained from many rock types were used in this study, it is thought that the data on metamorphic rocks should be increased in order to make healthier interpretations and obtain results.

Conflict of Interest

No conflict of interest was declared by the authors.

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