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Evaluation of the Relationships between Schmidt Hardness Rebound Number and Other (Engineering) Properties of Rocks

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ABSTRACT: This study aims to investigate the relationships between the Schmidt hardness rebound number (N) and certain engineering properties of rocks by evaluating the results obtained from two different Schmidt hammers and three different test procedures.

In the scope of this research, numerous rock samples were collected from various locations in Turkey and laboratory experiments were implemented in order to determine certain mechanical and physical properties of rocks such as uniaxial compressive strength (UCS), bending strength (BS), point load strength index (Is^o;), shore hardness (SH) and P-wave velocity *(Vp)*. The models of Schmidt hammers (N-type and L-type) were employed in the experiments for the comparison of the respective results obtained by three different assessment methods. Later, the statistical correlations were established by regression analyses to evaluate the relationships between Schmidt hardness rebound numbers and other parameters such as UCS, BS, Is5o> SH and *Vp* for each rock type, yielding high correlation coefficients.

1 INTRODUCTION

Hardness is known to be one of the physical properties of materials. Various methods to determine the hardness have been proposed (Brinell, Vickers, Rockwell, Knoop, Schmidt, Shore, Mohs) depending on the properties' of the material to be tested. In this study, hardness of the rocks was determined by N-type and L-type Schmidt hammers.

The Schmidt hammer, which was orginally developed for measuring the strength of hardened concrete (Schmidt, 1951) has later been improved to predict the strength of rocks. The Schmidt hardness test is also quick, cheap and nondestructive. In rock engineering, it is widely used for its simplicity, portability and the capability of instant data production. Today, eventough variety of Schmidt hammers are available for use, the models of L-type and N-type are extensively employed.

Presently, Schmidt hammer can be used to predict the uniaxial compressive strength of rocks, the performances of tunnel boring machines (TBM), advance speed of drilling machines as well as the evaluation of discontinuities in rock formations. Krupa et al. (1993), have developed a relationship between the specific energy W (MJ/m^3) and Schmidt hammer rebound number (N), W=0.29Af + 61.3, with a correlation coefficient of r=0.45 between the specific energy measured during the operation of full face tunnel boring machine - Wirth TB 11-330 H - in andésite and the data of hardness measurements on the walls of the same tunnel by N-type Schmidt hammer.

Young and Fowell (1978) monitored the performance of Dosco MKII-A roadheader used on mudstone in the UK and they pointed out that in fractured rock formations the primary influence on the performance of the machines were rock discontinuities characteristics rather than the intact material properties and the Schmidt hammer rebound value was a good indicator of rock discontinuity. Similar results were observed by Poole and Farmer (1980).

Numerous empirical relationships between Schmidt hammer rebound number and other mechanical and physical properties of rocks have been published in literature. A list of the some relationships proposed to predict UCS of rocks is presented in Table 1.

Table 1 Some correlations between Schmidt hardness rebound number (N) and uniaxial compressive strength (UCS) in literature

Equations	Correlation Coefficient (r)	Literature
ucs = io (0 0 0 0 1 4 ^ + 3 1 6)	0 94	Deere and Miller (1966)
UCS = 6 9 n 0 ' 1 3 4 W + 3 1 6]	-	Aufmuth(1973)
UCS = 12 74 exp(0 185YA0	–	Beverly et al (1979)
UCS = 0 447 exp[0 045(/V+3 5)+ y)	—	Kıdybınskı (1980)
UCS = *2N*	0 72	Singh et al (1983)
UCS = 04AM 6	0 94	Shoeryetal (1984)
UCS = 0 *99N* 0 383	07	Haramy and DeMarco (1985)
UCS = 0 88AM 2 11	0 87	Ghose and Chakraborti (1986)
UCS = 702AM104	0 77	0'Rourke(1989)
UCS = (AM5 7244)/0 239	0 96	Sachpazis(1990)
UCS = exp(a/V+b)	0 88	Xuetal (1990)
ucs^oooi/v 320 ^	0 84	Gokçeoğlu(1996)
UCS = 4 5*10 -4 *(NY)* 2 4fi	0 93	Kahraman (1996)
UCS = exp(0 818+0 059AO	—	Katzetal (2000)
UCS = exp(0 818+0 *059N)*	0 98	Yılmaz and Sendir (2002)
UCS = 2917 2In(AO-11098	0 88	Yaşar and Erdoğan (2002)
UCS = 2 7537/V-36 826	0 97	Dmçeretal (2003)
UCS = 4 72/V°69	081	Başarır et al (2004)
UCS = 4 124AM 34 33	091	This study

N Schmidt hardness rebound number, y Density, a,b Constants,

2 LABORATORY STUDIES

Rock blocks were collected from various locations in Turkey as shown in Table 2 Seven different rock types of metamorphic and sedimentary origins were selected to conduct the Schmidt tests on cubic samples dimensioned to be 100x100x100 mm The data obtained from N-type and L-type Schmidt hammers were assessed by the methods proposed by Poole-Farmer (1980), Hucka (1965) and ISRM (1981) on these blocks All the tests were carried out with the hammer held vertically downwards and at right angles to horizontal faces of large rock blocks Therefore, a total of six different evaluation combinations were constituted for each rock type

Other rock properties studied here (compressive strength, bending strength, P-wave velocity, point load strength index and Shore hardness) were determined in compliance with the ISRM (1981), TS699 (1987) and ASTM standards as illustrated in Table 3

The tests were performed by an N type Schmidt hammer with an impact energy of 2 207 Nm, and L-type Schmidt hammer, with an impact energy of 0 735 Nm Following three of widely accepted test procedures with different Schmidt hammer rebound techniques were selected and applied on rock samples

Test Procedure 1 Poole and Farmer (1980) suggested that the peak value from at least five continuous impacts at a point should be selected

Test Procedure 2 Hucka (1965) recommended that the peak value from at least ten continuous impact at a point should be selected

Test procedure 3 ISRM (1981) suggested that twenty rebound values from single impacts separated by at least a plunger diameter should be recorded and the upper ten values averaged

Each testing method was repeated at least three times on any rock type and the average value was recorded as the rebound number The results are displayed in Table 4

Table 2 Name and location of rocks collected

Rock Code Number	Rock Type	Rock Class	Location
1	Limestone	Sedimentary	Burdur
2	Travertine	Sedimentary	Konya
3	Limestone	Sedimentary	Bilecik
4	Limestone	Sedimentary	Burdur- Karamanlı
5	Limestone	Sedimentary	Antalya-Fınıke
6	Limestone	Sedimentary	Burdur-Yeşilova
7	Marble	Metamorphic	Muğla

Table 3 Some of the mechanical properties of rocks tested

Rock Code Number	IS(50) (MPa)	UCS (MPa)	BS (MPa)	SH	*Vp* (m/s)
1	4 54	138 21	176 46	64 62	6007
2	5 2	58 81	129 28	45 62	5383
3	5 12	92 6	173 91	59 85	6124
4	6 2	110 24	173 84	62 44	6188
5	3 07	52 49	123 18	33	4636
6	4 24	13191	177 63	62 25	5979
7	4 05	48 71	124 33	42 21	5789

Table 4 Schmidt hardness test results

Rock Code Number	L-Type			N-Type		
	Test Procedure 1	Test Procedure 2	Test Procedure 3	Test Procedure 1	Test Procedure 2	Test Procedure 3
1	55	56	57 5	60	60 67	60 3
2	46 33	48 67	45 7	50	50 33	47 9
3	61	61 33	56 6	63 33	64	60 2
4	52 33	54	60	65 33	65 67	62 8
5	45	47 33	39 7	48 33	50 33	44
6	59 67	60 67	56 9	62 67	63 67	61
7	43 67	47 67	43	48	49	45 3

3 STATISTICAL ANALYSIS

In order to be able to describe the relationships between Schmidt hardness rebound number and the UCS, BS, *Vp,* (IS(50)) and SH, regression analyses were performed The equation of the best-fit line, the 95% confidence limits, and the correlation coefficient (r) were determined for each regression analysis Best fit lines for each test procedure are shown m Figures 3-8 In this work, high correlation coefficients between *N* values and other rock properties (UCS, BS, *Vp,* ($Is_{(50)}$)) and SH), as shown m Table 5, were established indicating that Schmidt hammer rebound number is strongly related with other mechanical and physical properties of rock materials

Table 5 Correlations between Schmidt hardness (N-type) rebound number (N) and other properties of rocks

Equations	Correlation coefficient (r)
Vp = 0 0541N+2 7796	0 817
IS(50) = 0 0739/V+0 604	0617
UCS = 4 124AM34 33	0 908
BS = 0 3117^-1 8812	0 989
SH = 1 4502W-26 182	0 971

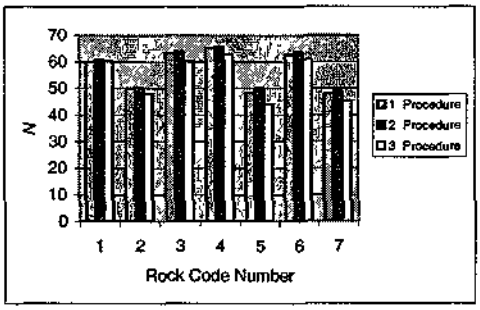

Figure I Rebound values for N-type Schmidt hammer

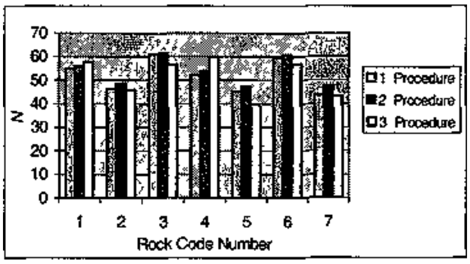

Figure 2 Rebound values for L-type Schmidt hammer

The results obtained from N-type and L-type Schmidt hammers via three different test procedures as descibed earlier were illustrated in Table 4 and then assessed in bar graphs in Figures 1 and 2, in which the hardness rebound numbers of N-type Schmidt hammer appear to be slightly higher than those of L-type Schmidt hammer. When the results of test procedures were compared, procedure 3 yielded relatively lower rebound numbers for both Schmidt hammers than that of other two test procedures, perhaps owing to differences in the application of this procedure. Thus, test procedure 3, we assume, may represent the surface hardness of rocks more reliably since measurements are conducted on at least twenty seperate points on the same sample, unlike other two procedures m which the peak value out of five or ten impacts on the same point is selected to be the Schmidt hardness of the rock tested. Besides, procedures 1 and 2 may result in higher Schmidt hardness rebound values for inelastic rocks owing to the repeated impacts on the same point, which may lead to an increase in the elasticity of the rock on the impact point and consequently induce a rmsrepresentaion on behavior of entire rock sample. Therefore, in this study, statistical analyses of the data of N-type Schmidt hammer were implemented solely by procedure 3 suggested by ISRM as depicted in Figures 4 through 8.

Relationship between Schmidt hammer rebound number and other properties of rocks resulted in reliable relationship equations with considerably high correlation coefficients as demonstrated in Table 5.

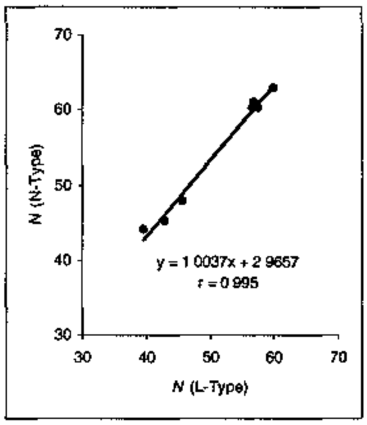

Figure 3 The relationships between Schmidt hardness rebound number *(N)* of N-type vs. L-type

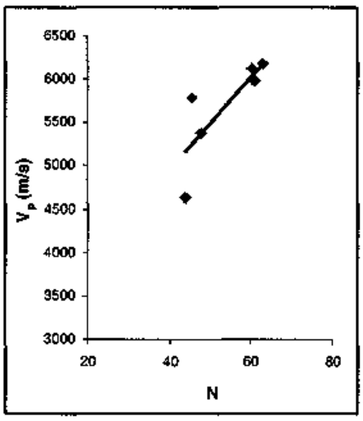

Figure 4 P-wave velocity vs Schmidt hardness rebound number (N-type)

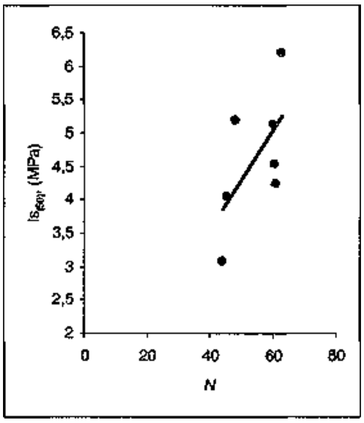

Figure 5. Point load strength index vs. Schmidt hardness rebound number (N-type).

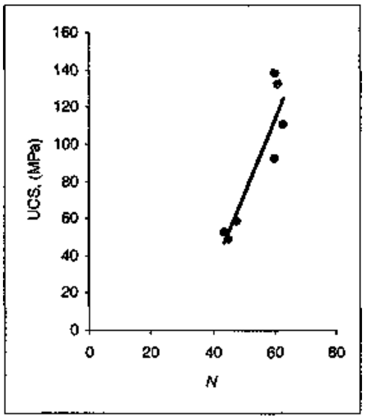

Figure 6. Corripressive strength vs. Schmidt hardness rebound number (N-type).

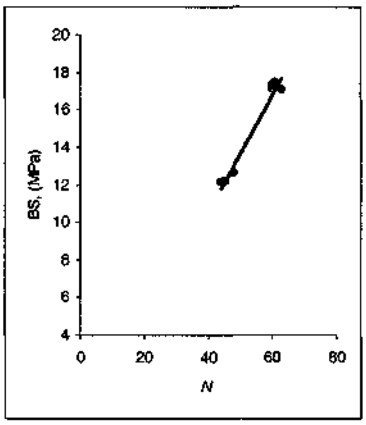

Figure 7. Bending strength vs. Schmidt hardness rebound number (N-type).

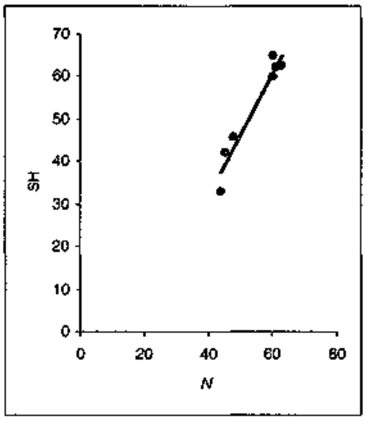

Figure 8. Shore hardness vs. Schmidt hardness rebound number (N-type).

4. RESULTS AND CONCLUSION

In this study, the data obtained by two different models of Schmidt hammers and three different test procedures were evaluated and the comparisons were made between the two models of Schmidt •hammers in addition to establishing relationships between Schmidt hammer rebound number and other mechanical and physical properties of rocks.

Experiments conducted with N-type Schmidt hammer produced slightly higher rebound numbers than those with L-type Schmidt hammer on all three test procedures However, the procedure proposed by ISRM (Test Procedure 3) yielded lower Schmidt rebound numbers than those of other two test procedures exercised m this study

Schmidt hammer, since its simplicity and capability of instant data production, has so far been a powerful tool utilized by many researchers to predict other mechanical and physical properties of rocks Although empirical relations published m literature (Table 1) do not replicate the results of the tests conducted to determine a specific rock material property Schmidt hammer rebound numbers can be correlated to other rock properties withm a reasonable error (Table 5), so that the data of Schmidt hardness tests may help designers acquire instant knowledge regarding other engineering properties of rock materials

In fact, prediction of engineering properties of rock materials e g UCS via Schmidt hardness needs to be improved to take into account more qualitative values that represent rock material better, such as the origin of the rocks, porosity, gram size and grain shape These factors affect the surface area of the interlocking bond forces at mineral gram to gram contacts In most rocks the higher the surface area of mineral gram to grain contact the harder the rock becomes The authors of this paper believe that a further study considering the factors depicted above is needed to be able to suggest more realistic empirical relations between the Schmidt hardness and other engineering properties of rocks by multi-regression analyses

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