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Application of Schmidt rebound number for estimating rock strength under specific geological conditions

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Abstract

A literature review revealed that most of the empirical equations introduced for determination of the uniaxial compressive strength (UCS) of rocks based on the Schmidt hammer rebound number (N) are not sufficiently reliable mostly due to the relatively low coefficient of correlations. This is attributed to the fact that in most cases one formula is used for all types of rocks, although the density of rocks is introduced to the formulae in some cases. On the other hand, if one specific relationship between N and UCS is introduced for one rock type, the equation will yield a much higher coefficient of correlation. During a research program supported by the Shahrood University of Technology, Iran, a third type of approach was considered. The study aimed to establish a relationship between N and UCS of a rock mass under particular geological circumstances. As an example, in this study, the immediate roof rock of coal seams in North-Eastern coal fields of Iran was selected. In order to determine the N and UCS, a significant number of samples were selected and tested, both in-situ and in the laboratory, and a new equation was established. The equation can be used to predict UCS of the roof rock in coal extracting areas in this zone by performing simple in-situ Schmidt hammer tests. It is predicted that such a procedure will be feasible for other geological conditions.

Keywords:*Coal field, Roof rock, Schmidt number, uniaxial compressive strength*.

1. Introduction

Rock mechanics engineers design structures built in rock for various purposes, and therefore need to determine the properties and behavior of the rock. The UCS of rocks is one of the important input parameters used in rock engineering projects such as design of underground spaces, rock blasting, drilling, slope stability analysis, excavations and many other civil and mining operations. Testing of this mechanical property in the laboratory is a simple procedure in theory but in practice, it is among the most expensive and time-consuming tests. This calls for transportation of the rock to the laboratory, sample preparation and testing based on the international standards. In order to carry out these standard tests, special samples, such as cylindrical core or cubical samples, need to be prepared. Preparing core samples is difficult, expensive, and time-consuming. Moreover, the preparation of regular- shaped samples from weak or fractured rock masses is also difficult. Under these circumstances, the application of other simple and low-cost methods to carry out the above tasks with acceptable reliability and accuracy will be important. Therefore, indirect tests are often used to estimate the UCS, such as Schmidt hammer, point load index and sound velocity. Indirect tests are simpler, require less preparation, and can be adapted more easily to field testing.

The Schmidt hammer rebound hardness test is a simple and non-destructive test originally developed in 1948 for a quick measurement of UCS [1], and later was extended to estimate the hardness and strength of rock [2, 3]. The mechanism of operation is simple: a hammer released by a spring, indirectly impacts against the

rock surface through a plunger and the rebound distance of the hammer is then read directly from the numerical scale or electronic display ranging from 10 to 100. In other words, the rebound distance of the hammer mass that strikes the rock through the plunger and under the force of a spring, indicates the rebound hardness. Obviously, the harder the surface, the higher the rebound distance.
This test can be used both in the laboratory and in the field. It is well known that the Schmidt hammer has been used worldwide for a quick rock strength assessment due to its portability, ease of use, rapidity, low cost and its non-destructive procedure of application.
During a study conducted at the Shahrood University of Technology (SUT), Schmidt hardness test was applied to estimate the mechanical properties of rocks, particularly the unconfined compressive strength, under specific geological circumstances. The North-Eastern coal fields of Iran were selected as the site of investigation. This paper describes the methodology and test procedures, both in the field and in the laboratory, and the analysis and interpretation of the results. In addition to the tests carried out in-situ, rock samples from the roof have been collected from various locations at North-Eastern collieries. This included samples from Panel No. 1 and Panel No. 2 at Tazareh Colliery, Takht retreating and advancing panels at Takht Colliery, East-ZemestanYort and West-ZemestanYort districts at Gheshlagh Colliery and Olang mine. The samples were transferred to the laboratory and tests were carried out for determining N and UCS. The results were correlated, regression analysis was performed to establish a relationship between N and UCS, and an acceptable coefficient of correlation was obtained. It was concluded that there is a possibility of estimating UCS of roof rock, from the N by using the introduced equation. However, the equation must be used only for the hangingwall rock of the North-Easrtern collieries of Iran for estimation of the UCS. In practice by using the N obtained from the field or laboratory, in any convenient location at these collieries, unconfined compressive strength of the roof rock in these locations can be estimated with a reasonable reliability.

2. Schmidt hammer

The Schmidt hammer has been widely used for testing the quality of concrete and rocks. It has been increasingly used worldwide because of its simplicity, rapidity, non-destructiveness and portability. The Schmidt hammer is a light hand-held device which consists of a spring-loaded mass inside a piston that is released when the hammer is pressed orthogonally onto a surface. The rebound height of the mass (R) is recorded on a linear scale and gives an indication of the strength of the material being tested. Schmidt hammer models are designed with different levels of impact energy, but the types L and N are commonly adopted for rock property determinations. The type L has an impact energy of 0.735 Nm which is only one third that of the type N [1]. The results of the tests are given as the rebound height andfor the L- and N-type Schmidt hammers respectively.
Figure. 1 shows the details of an L-type Schmidt hammer [3]. To perform a test, the device is positioned normal to the rock surface and the plunger (13) is pressed against the rock during which the reset spring (1) is pressed and the impact spring (6) is extended. At the end of the course, hammer holding lever (3) contacts the calibration screw (7) and consequently by the rotational movement of the hammer holding lever (3), the hammer is released and after sliding along the plunger neck (11) hits the impact surface of the plunger (12). Based on the hardness of the rock surface onto which the plunger is pressed, the hammer rebounds and the amount of rebound is indicated by the number indicator (10) which is now moved upwards along with the rebound movement of the hammer.
Considering its long history and widespread use, standard methods for the Schmidt hammer test have been prepared by International Society for Rock Mechanics (ISRM) [4] and ASTM [5]. Detailed test procedures for both systems, especially for their application to core and block samples, are shown in Table 1.

3. Previous studies

The Schmidt hammer has been used in rock mechanics practice since the early 1960s as an index test for a quick rock strength and deformability characterization due to its rapidity and ease of application, simplicity, portability, low cost and non-destructiveness. Most researchers in this area have proposed various empirical equations for calculating UCS from N. They have found that Schmidt hardness and the UCS are closely related. The relationships between Schmidt hardness and UCS are summarized in Table 2.

The correlations can be classified into three categories:

(a) Exponential relationships, e.g., Kidybinski (1980); Xu et al. (1990); Yılmaz et al. (2002) and Fener et al. (2005);

(b) Algebraic power relationships, e.g., Gokceolglu (1996); Kahraman (1996); Yasar et al. (2004) and Kilic et al. (2008);

(c) Linear relationships, e.g., Singh et al. (1983); Shorey et al. (1984); Haramy et al. (1985) and Sachbasis (1990).

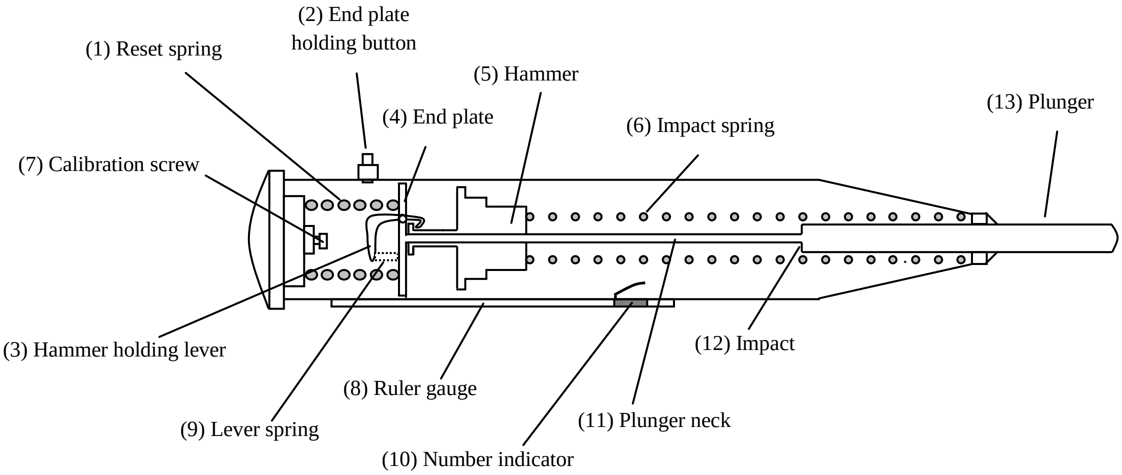

Figure1. Details of an L type Schmidt hammer

Table 1. The comparison between ISRM and ASTM recommendations

Parameter	ISRM recommendation	ASTM recommendation
Core dimension	NX or larger	NX or larger core of at least 15 cm in length
Block edge length	6 cm	15 cm
Range of applying	Not considered	UCS = 1–100 MPa, except very weak and very hard rock
Impact number	20 impact on sample, at different points	10 impact on sample, at different points
Calculation	Record 20 rebound values from single impacts separated by at least a plunger diameter, and average the upper 10 values	Record 10 rebound values from single impacts separated by at least the diameter of the piston, and discard readings differing from the average of 10 readings by more than 7 units and determine the average of the remaining readings

Miller (1965) has put forward a correlation table for N values [6]. This table generally reflects the relationship between unit weight, UCS and rebound values. Deere and Miller (1966) have proposed a correlation chart which includes rock density, Young's modulus and rebound values [7]. Aufmuth (1973) and Beverly et al. (1979), examining samples of different rocks, have established a high correlation coefficient between rock density and Young's modulus, UCS and N values [8, 9]. Kindybinski (1980) has suggested an empirical formula, making use of N values for estimating UCS [10]. Singh et al. (1983), Shorey et al. (1984) and Haramy and De Marco (1985) found a reliable correlation coefficient between N and UCS for different rock types [11, 12, 13]. Ghose and Chakrabarti (1986) have suggested an empirical relationship between Schmidt rebound values and UCS for Indian coals [14]. O'Rourke (1989) carried out similar research on sedimentary rocks and reported an empirical correlation [15]. Sachpazis (1990) has put forward formulae relating UCS and Young's modulus [16]. Xu et al. (1990) discussed the use of the Schmidt hammer for estimating the mechanical properties of weak rocks [17]. Gokceoglu (1996) proposed an empirical relationship between N values and UCS for marls [18]. Aggistalis et al. (1996) compared the point load index, N values and E of gabbros and basalts, and suggested an empirical relationship for these rocks [19]. Kahraman (1996) stated that UCS values could be established using the N [20]. Katz et al. (2000) compared the N with the UCS, E and rock density of different types of rocks [21]. Using published data on 48 different rocks, Kahraman (2001) evaluated the correlation between UCS values and the corresponding results of Schmidt hammer and concluded that the variability the test results is within acceptable limits for most engineering purposes [22]. By collecting gypsum samples from various locations in the Miocene-aged gypsum of Sivas Basin, Turkey, and testing them for determination of the relationship between the rebound number and UCS, Yilmaz and Sendir (2002) established an empirical relationship between N values and UCS [23]. They compared the results with different empirical equations proposed by different authors and suggested that it is impossible to obtain only one relation for all types of the rocks and emphasized that the equation must be used only for gypsum to get an acceptable accuracy. By collecting six different rock types including two types of limestone, two types ofmarble, sandstone and basalt and examining nine samples of each rock Yasar and Erdogan proposed an empirical equation [24].

By testing six igneous rocks, three metamorphose rocks and two sedimentary rocks, Fener et al. (2005) proposed an empirical relationship between N values and UCS for these rocks [25]. By collecting 19 different rock types and testing them, Kılıc and Teymen (2008) proposed an empirical relationship between Schmidt hardness and UCS for these rocks. Results of regression analyses showed satisfactory correlations [26].Within the framework of the present study, rock samples were taken from working coal faces and panels and also from adjacent drifts containing the roof rock of the seam all located North-East of Iran. These samples were examined in laboratory and their UCS was obtained. N values were also obtained from both the field and the laboratory tests.

Table 2.Correlation between Schmidt hammer hardness and uniaxial compressive strength (UCS)

Researcher	Equation	R	Rock type
Deere and miller (1966) [7]	$UCS = 10^{(0.00014\gamma N + 31.6)}$	0.94	Three base rock types
Aufmuth (1973) [8]	$UCS = 6.9 \times 10^{[1.348\log(\gamma N) + 1.86]}$		Three base rock types
Beverly et al. (1979) [9]	$UCS = 12.74\exp[0.0185\gamma N]$		Three base rock types
Kidybinski (1980) [10]	$UCS = 0.447\exp[0.045(N + 3.5) + \gamma]$	0.72	Rock coal
Singh et al. (1983) [11]	$UCS = 2N$	0.94	30 Sedimentary units
Shorey et al. (1984) [12]	$UCS = 0.4N - 3.6$	0.7	20 Sedimentary units
Haramy and DeMarco (1985) [13]	$UCS = 0.994N - 0.383$	0.87	10 Sedimentary units
Ghose and Chakraborti (1986) [14]	$UCS = 0.88N - 12.11$	0.77	Coal
O' Rourke (1989) [15]	$UCS = 702N - 11040\ (psi)$	0.88	Sandstone, siltstone, limestone and anhydrite
Sachpazıs (1990) [16]	$N = 0.2329UCS + 15.7244$	0.81	33 Lithological units (marble, limestone, dolomite)
Xu et al. (1990) [17]	$UCS = \exp(aN + b)$ a, b coefficient depend on rock type	0.91	Mica-schist, prasinite, serpentinite, gabbro, mudstone
Cargill and Shakoor (1990) [2]	$UCS = 4.3 \times 10^{-2}(N\gamma) + 1.2$		Sandstones
Cargill and Shakoor (1990) [2]	$UCS = 1.8 \times 10^{-2}(N\gamma) + 2.9$		Carbonates
Gokceoglu (1996) [18]	$UCS = 0.0001N^{3.2658}$	0.84	Marl
Aggıstalıs (1996) [19]	$UCS = 1.31N - 2.52$	0.55	Gabbro and basalt
Kahraman (1996) [20]	$UCS = 4.5 \times 10^{-4}(N\gamma)^{2.46}$	0.93	10 Lithological units
Katz et al. (2000) [21]	$LnUCS = 0.792 + 0.067N \pm 0.231$	0.96	7 Different rock types
Kahraman (2001) [22]	$UCS = 6.97\exp(0.014N\gamma)$		48 different rocks
Yılmaz and Sendir (2002) [23]	$UCS = \exp(0.818 + 0.059N)$	0.98	Gypsum
Yasar and Erdogan (2004) [24]	$UCS = 4 \times 10^{-6}N^{4.2917}$		Two types of limestone, two types of marble, sandstone and basalt
Fener et al. (2005) [25]	$UCS = 4.24\exp[0.059N]$		6 igneous rocks, 3 metamorphose rocks and 2 sedimentary rocks
Kılıc and Teymen (2008) [26]	$UCS = 0.0137N^{2.2721}$	0.97	19 Different rock types

R: regression coefficient, N: Schmidt values, UCS: uniaxial compressive strength (MPa), γ : density of the rock (g/cm^3)

4. Tests procedure

Field work was carried out at 7 working coal faces and panels and also in adjacent drifts containing the roof rock of the seam all located North-East of Iran, North of Shahrood city as follows: Panel no. 1 face and Panel no. 2 face in the Seam P10 at Tazareh Colliery, East-ZemestanYort Mine, West-

ZemestanYort Mine, Takht Advance Mine, Takht Retreat Mine and Olang Mine. Some details of the sampling area and mine site are shown in Table 3. The tests included the application of an L-type Schmidt hammer to assess the hardness of the hangingwall rock in as many points as practicable in the coal production areas as well as in the roadways through the above mentioned mines. At each point about 20 cm by 20 cm surface of the rock was prepared by peeling the remaining coal and cleaning the area and performing about 25 tests on each area.

Table 3. Sample definitions and their locations

Mine site	Coal seam	Rock type
Tazareh-Panel No. 1	P10	Siltstone, Sandstone, Shale
Tazareh-Panel No. 2	P10	Siltstone, Sandstone, Shale
East- ZemestanYort	K60	Fine to moderate Sandstone, Siltstone, fossiliferousShales
West-ZemestanYort	K3	Sandstone, Argillaceous sandstone
Takht Advance	K19	Fine Sandstone, Siltstone, tabular Argyle
Takht Retreat	K19	Fine Sandstone, Siltstone, tabular Argyle
Olang	-	Sandstone, Siltstone, Argyle

Among the numbers obtained, the five smaller values were discarded and the mean value of the rest was considered as the Schmidt number for that point. This procedure of performing Schmidt test was a compromise to the ISRM suggested method [27] where ten higher numbers are selected from twenty tests in the selected area. It is argued that the ISRM suggested method suffers from some shortcomings due to very selective nature of the procedure [28]. The reasoning behind this is the fact that eliminating a great number of the low numbers inevitably results in erroneous outcomes as low numbers might be the reaction of inherently weak portion of the rock and not merely the effect of test deficiencies.

To perform the laboratory tests, samples from around sixty points of the above mentioned mines roof rock were collected and moved to the laboratory. In the laboratory, near cubic-shaped samples were prepared of the side dimensions of at least 20 cm. After fixing the prepared sample on a concrete base, following the same procedure as the one used in the field, and using the same L type hammer, Schmidt tests were performed applying relevant correction factors for the apparatus direction effect.

The second phase of the laboratory work consisted of the preparation of cores of the rock samples corresponding to the Schmidt tests and conducting UCS tests using a pressure jack (1500 KN Controls) based on the ISRM standards. Three to five tests were conducted on each specimen (totaling 41 samples, Table 4). The statistical summary of the variables is given in Table 5.

5. Data analysis

Previous researches show that in performing Schmidt tests, the correlation between the field and the laboratory data is normally in an acceptable range and can be used alternatively. Consequently, the results from the laboratory were used to perform the analysis.

In order to be able to describe the relationships between N and the UCS, regression analyses were performed. The equation of the best-fit line, and the correlation coefficient were determined for each regression analysis. Best fit line is shown in Figure. 2. The best fit to the relationship is:

$$UCS = 0.0465N^2 - 0.1756N + 27.682 \quad (1)$$

where UCS is in MPa.

In this work, high correlation coefficient between N values and UCS was established indicating that N is strongly related to UCS value. The formula can be acceptable only in the preliminary stage of assessment, but for more detailed investigations additional measurements should be applied. On the other hand, high dispersion of the data for lower Schmidt numbers (below around 35) as shown in Figure 1.indicates that this method is not reliable within this range. This range corresponds to the Shale, Argile and part of Siltstone in the roof rock.

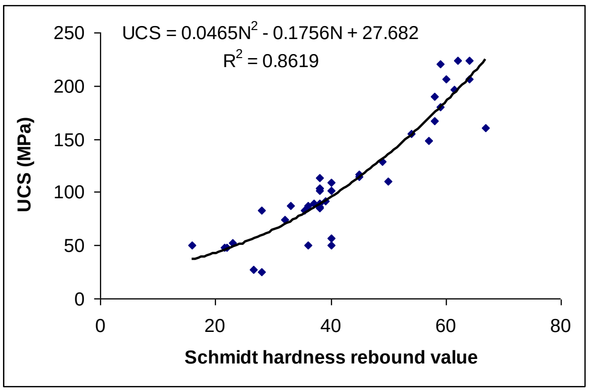

Figure2.Relationship between Schmidt number and UCS for the roof rock of North-Eastern collieries of Iran.

Attention should also be paid to the fact that firstly, this relationship is unique for this geological situation and secondly, in the case of relatively high variety of rock types in a specific geological situation, it might be more advisable to use the existing relationships, some of which are mentioned in section 3. The reason is that previous studies show that, on one extreme, one equation cannot handle all types of rock to predict the UCS based on rebound number as mentioned in the literature. On the other extreme one equation for one type of rock yields more precise results. This study aimed to find a way in between by introducing an equation for each specific geological situation. However, in the case of a geological situation where the variety of the rocks is high, the situation may near the former extreme, i.e., one equation for all types of rock.

Table 4. Test data of the samples

No.	Schmidt hardness rebound value	UCS (MPa)
1	16	50
2	28	83
3	28	25
4	33	87
5	36	50
6	36	87
7	38	102
8	38	113
9	38	104
10	38	104
11	38	85
12	38	86
13	38	90
14	39	92
15	40	57
16	40	50
17	40	109
18	49	129
19	57	148
20	58	167
21	58	190
22	59	220
23	59	180
24	62	224
25	64	206
26	67	160
27	64	224
28	60	206
29	32	74
30	21.5	48
31	35.5	83
32	26.5	27
33	45	117
34	54	155
35	22	48
36	61.5	197
37	23	52
38	37	90
39	45	115
40	50	110
41	40	102

Table 5. Statistical summary of variables

Variable	Min.	Max.	Mean	S.dev.
Schmidt hardness	16	67	42.73	13.43
UCS (MPa)	25	224	113.32	56.95

6. Conclusions

UCS of rocks plays a significant role in rock engineering projects. As a simple tool for quick UCS assessment, Schmidt hammer has been used worldwide. In order to calculate UCS, using the results of Schmidt tests; different types of formulas have been introduced.

Review of the literature showed that the early relationships, where one formula covered all types of rocks, were not reliable. The relationships in which the density of the rock was introduced yielded more acceptable results. On the other hand, the formulas which were used for a particular type of rock yielded more reliable results. In this research work, however, a new approach was considered, where a specific geological situation, in this case the hangingwall rock of the North-Eastern collieries in Iran, was selected and a relationship was developed. The resulting formula can be used to assess the UCS of the hangingwall of collieries in this region by performing simple in-situ Schmidt tests.

It is suggested that such a procedure be followed in each specific geological situation and a unique relationship between the Schmidt number and UCS be developed. The obtained relationship can be used as a quick reference to suggest a preliminary value for UCS.

In addition to the situation selected in this study, the specific geological situation can be, for example, a metamorphic zone comprising several metamorphose rocks or a magmatic zone comprising some igneous rocks. In this context, it is presumed that the geological causes acting on the formation have imposed some common characteristics on the rock types in the formation. Consequently, if the equations proposed to date are categorized in three groups of general equations for all types of rock, equations proposed for specific types of rock, and the ones proposed for specific situations, comparison of the proposed equations should be performed among the ones limited in one category.

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