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# AN EMPIRICAL APPROACH IN PREDICTION OF THE ROOF ROCK STRENGTH IN UNDERGROUND COAL MINES

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**ABSTRACT:** In study of the behaviour of roof strata in underground coal mines the strength of the roof rock, particularly, the unconfined compressive strength (UCS) plays a significant role. Application of simple tools in assessment of the rock strength has been practiced by many researchers one of which being Schmidt hammer. Due to its portability, easiness in use, rapidity, low cost and its non-destructive procedure of application, it is among the most popular tools in this respect. Application of this tool in prediction of the roof rock strength, in a new context, is the aim of this research work.

A comprehensive review of the literature revealed that most of the empirical equations introduced for determination of the unconfined compressive strength of rocks based on the Schmidt hammer rebound number (Rn) are not practically reliable enough as in most of the cases one formula is used for all types of rocks, although the density of rocks is introduced to the formulas in some of these cases. On the other hand, if one specific relationship between hammer rebound number and unconfined compressive strength is introduced for one type of rock, 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 express the relationship between Schmidt rebound number and unconfined compressive strength of rock mass under a particular geological circumstances. As an example, in this study, the situation selected was the immediate roof rock of coal seams at Tazareh Colliery, Shahrood, Iran. In order to determine the Schmidt number and the unconfined compressive strength, a significant number of samples were selected and tested both in-situ and in the laboratory and a new relationship was introduced. The equation can be used to predict UCS of the roof rock in coal extracting areas at this colliery by performing simple in-situ Schmidt hammer tests.

## INTRODUCTION

Unconfined compressive strength (UCS) of the rocks plays an important role in many underground and surface rock engineering projects. Determination of the UCS, in theory, is a simple procedure but, in practice, it is among the expensive and time consuming tests which calls for the transportation of the rock to the laboratory, sample preparation based on the existing standards and conducting the tests by using compressive hydraulic jacks.

At these circumstances the application of other simple and low cost methods to carry out the above task with acceptable reliability and accuracy will be important. Among these methods is the application of Schmidt hammer which can be used both in the laboratory and in the field.

As known, the Schmidt hammer has been used worldwide as an apparatus for a quick rock strength assessment due to its portability, easiness in use, rapidity, low cost and its non-destructive procedure of application (Isik, 2002).

During a research work conducted at The Shahrood University of Technology, application of Schmidt hardness in estimating the mechanical properties of rocks, particularly the unconfined compressive strength, under determined geological circumstances was investigated. This paper explains the methodology, test procedures both in the field and the laboratory and analysis and the interpretation of the results.

In addition to the tests carried out in-situ, immediate roof rock samples, predominantly including fine grained sandstone, siltstone and shale have been collected from various locations at Tazareh colliery and tested. The tests included the determination of Schmidt hammer rebound number (Rn) and unconfined compressive strength (UCS). Obtained data were correlated and regression equations were established between Schmidt hammer rebound hardness and unconfined compressive strength, presenting an acceptable coefficients of correlation. It was concluded that there is a possibility of estimating unconfined compressive strength of immediate roof rock, from the Schmidt hammer rebound number by using the obtained equation.

However, the equation must be used only for the hangingwall rock of the Tazareh colliery for estimation of the UCS. In practice by using the Schmidt hammer rebound number obtained from the field or laboratory, in any convenient location at Tazareh colliery, unconfined compressive strength of the roof rock in the location can be estimated with a reasonable accuracy.<sup>1</sup>

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### SCHMIDT HAMMER

The Schmidt hammer has been used for testing the quality of concretes and rocks. Schmidt hammer models are designed in 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 (Kahraman, 2001).

Figure 1 shows the details of an L type Schmidt hammer (Torabi, 2005). 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 now is moved upwards along with the rebound movement of the hammer.

### PREVIOUS WORKS

In study of the relationship between the Schmidt number and the UCS, numerous research works have been carried out by others, the notable ones include:

1. Deere and Miller in 1966 (Kahraman, 2001) tested rock cores of the diameter of 55 mm obtained from 28 regions. 48 tests were conducted on each sample. The best fit for the relationship was as follows;

$$q_u = 6.9 \times 10^{[0.16+0.0087(R_n \rho)]}$$

Where  $q_u$  is the uniaxial compressive strength in MPa,  $R_n$  is the Schmidt number and  $\rho$  is the density in g/cm<sup>3</sup>.

2. Aufmuth in 1973 (Kahraman, 2001) conducted tests on about 800 rock core samples representing 168 geological formations and 25 rock types, The following formula was introduced:

$$q_u = 6.9 \times 10^{[1.348 \log(R_n \rho) - 1.325]}$$

3. Beverly et al in 1979 (Kahraman, 2001) pursuing the Deere and Miller's attempt, collected samples from another 20 regions and by combining data, introduced the following formula:

$$q_u = 12.74 e^{[0.0185(R_n \rho)]}$$

4. Haramy and DeMarco in 1985 (Kahraman, 2001) using Schmidt tests on large sized coal blocks from 10 sites introduced the following formula:

$$q_u = 0.094 R_n - 0.383$$

5. Cargill and Shakoor in 1990 (Kahraman, 2001) conducted tests on NX sized rock cores of sandstone and carbonates produced the following equation;:

$$\ln q_u = 4.3 \times 10^{-2} (R_n \rho_d) + 1.2$$

$$\ln q_u = 1.8 \times 10^{-2} (R_n \rho_d) + 2.9$$

Where  $\rho_d$  is the dry density of the rock.

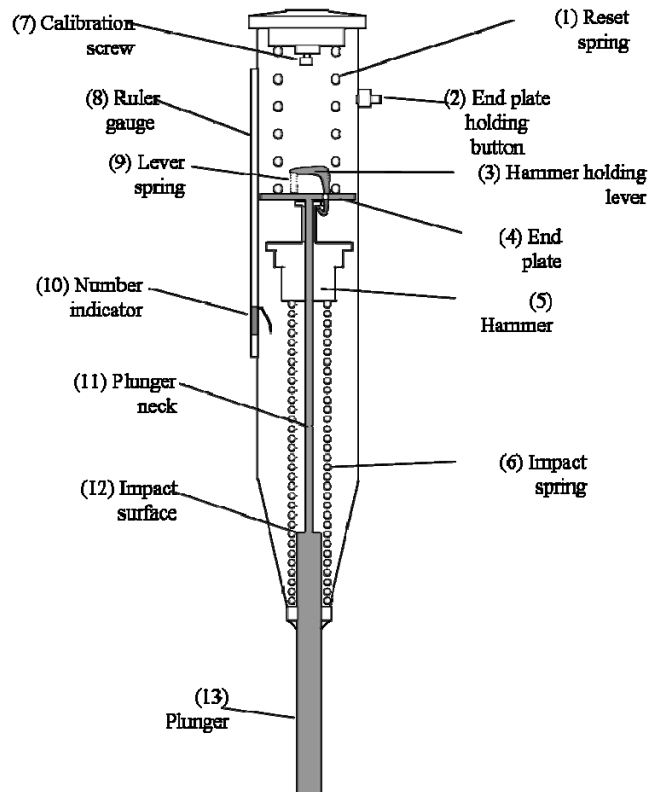


Figure 1 – Details of an L type Schmidt hammer

### TESTS PROCEDURE

Field work was carried out in the Seam P10 at Tazareh Colliery in panels no. 1 and 2 and the roadways containing the roof rock of the seam.

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 stopes as well as in the roadways. In each point an about 20cm by 20cm surface of the rock was prepared by peeling the remaining coal and cleaning the area and performing about 25 tests on each area. Among the numbers obtained, five small amounts were discarded and the mean value of the rest was considered as the Schmidt number for that point. This method of performing Schmidt test was a compromise to the ISRM suggested method (Brown, 1981) where it is argued that the method suffers from some shortcomings due to very selective nature of the procedure (Goktan, 1993). In ISRM suggested method ten higher numbers are selected from twenty tests in the selected area. The applied method in this research work was persistent.

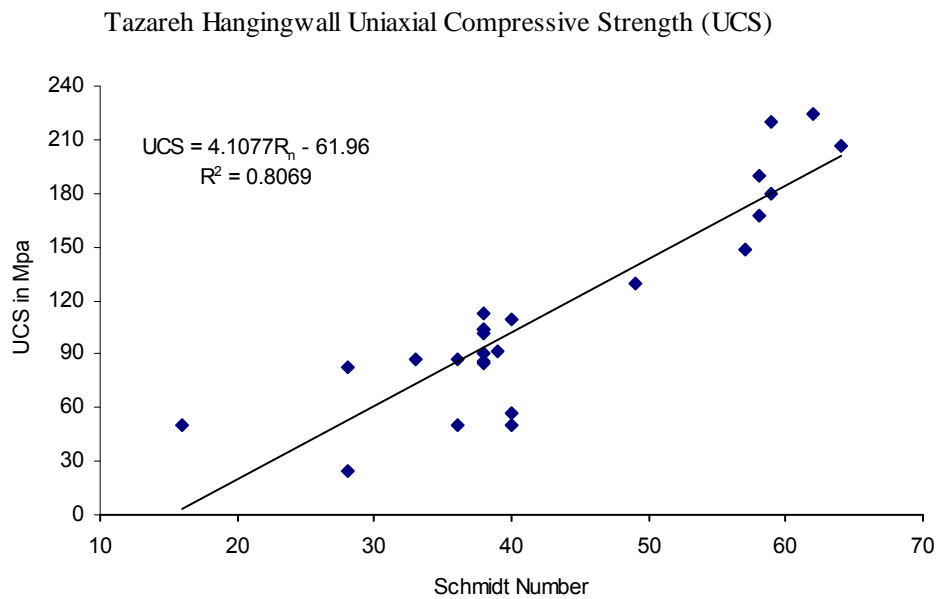
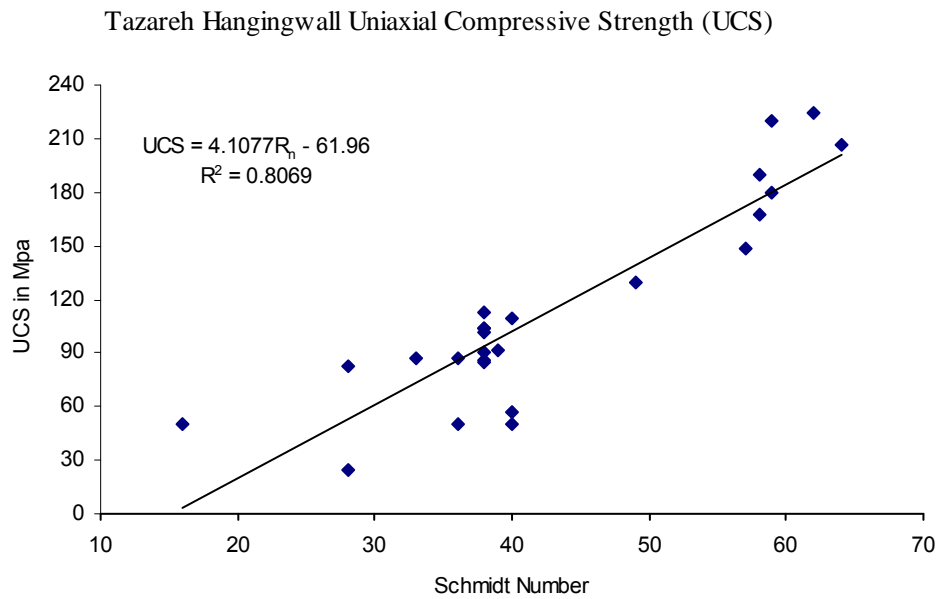
To accomplish the laboratory tests, samples from about thirty points were collected and moved to the laboratory where near cubic shaped samples were prepared of the dimensions of at least 20 cm. After stabilizing the prepared sample on a concrete basement, the same as the procedure followed during the field work and using the same L type hammer, Schmidt tests were performed. In practice, 25 separate points in the surface of the rock specimen were tested and the mean value of the 20 higher values was calculated.

The second phase of the laboratory work consisted of the preparation of the NX sized cores of the rock samples corresponding to the Schmidt tests and conducting direct uniaxial compressive strength tests using a pressure jack (1500 KN, CONTROLS) based on the ISRM standards. Three to five tests were conducted on each specimen.

### DATA ANALYSIS

Data from the field and the laboratory were close enough to be used alternatively. Consequently, the results from the laboratory were used to perform the analysis. Previous research (Kahraman, 2002) shows that the correlation between the field and the laboratory data is normally in an acceptable range particularly when the ISRM method is used to conduct the tests.

The data from Schmidt tests and corresponding direct uniaxial compressive strength tests was plotted and best fit was determined as shown in Figure 2.



**Figure 2 - Relationship between Schmidt number and UCS for the roof rock of Tazareh colliery**

The best fit to the relationship is as equation (1):

$$UCS = 4.1077R_n - 61.96 \quad (1)$$

The correlation coefficient of the relationship,  $R^2$ , being in the order of 0.8, indicates that the formula can be acceptable only in the preliminary stage of assessment and for more detailed investigations additional measures should be applied. On the other hand, high dispersion of the data in lower Schmidt numbers (below around 35) as shown in Figure 2, indicates that this method is not reliable within this range. This range corresponds to the Shale and part of Siltstone in the roof rock.

Attention should be paid to the fact that firstly this relationship is unique for this geological situation and secondly in the case of relatively high dispersion of rock types in a specific geological situation, it might be more advisable to use the existing relationships.

### CONCLUSIONS AND SUGGESTIONS

Unconfined compressive strength 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 the UCS using the results of Schmidt tests different types of formulas were introduced by researchers.

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 Tazareh colliery was selected and a relationship was developed. The resulting formula can be used to assess the UCS of the hangingwall of this colliery by performing simple in-situ Schmidt tests.

It is advisable that such a procedure be followed in considering any colliery to study 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 at any point in the colliery during the mine life. Furthermore, as another outcome of this study, in addition to the collieries' roof strata, other specific geological or geotechnical situations can be selected and tested. In this context it is presumed that the geological agents acting on the formation has imposed some common characteristics on the rock types forming the formation rendering it homogeneous in response to the hardness tests. However, this is practicable only if the dispersion of the rock types in the formation is not high causing the correlation coefficient to fall into an unacceptable range, otherwise the existing relationships introduced for different types of the rocks will be more acceptable.

### ACKNOWLEDGMENT

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