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Use of the Schmidt hammer for rock and coal testing

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1 INTRODUCTION

Several authors have reported specific applications of the Schmidt hammer for rock mass characterization, resulting in its acceptance as a convenient tool to index rock quality and to estimate engineering rock properties. The Bureau of Mines advanced the use of this instrument by testing 10 U.S. coals to determine the utility of the Schmidt hammer in designing underground coal mine pillars. Specifically, the tests investigated the correlation of hammer rebound index to uniaxial compressive strength of laboratory-prepared coal samples. Unconfined strength is of particular interest in coal mining since it is used in the majority of published equations on coal pillar design. A description of the Schmidt hammer, a summary of related research performed by several noted investigators, and results of the Bureau's investigation are presented in this paper.

2 THE SCHMIDT HAMMER

Developed in 1948 by Swiss engineer Ernest Schmidt, the Schmidt hammer is a portable, cost-effective instrument capable of estimating intact rock strength with distinct advantages over traditional laboratory testing (Schmidt, 1951). Laboratory tests are time consuming, expensive, and nearly always subject to bias due to platen effects, integrity loss during coring and preparation, and sample alteration from environmental conditions. Conversely, a large number of nondestructive Schmidt hammer tests can be performed quickly and efficiently in either the laboratory or the field. Significant ranges of scatter are typically produced when many hammer tests are performed. Statistically, this provides an excellent description of rock mass homogeneity and allows determination of realistic degrees of confidence to incorporate in design performance evaluations.

Straightforward principles apply when operating the Schmidt hammer, shown in figure 1. A constant amount of stored spring energy is imparted through a hammer mass to the plunger, causing the mass to rebound a distance proportional to the total energy absorbed by the impact surface. The rebound distance is shown by the indicator and is defined as the "rebound index." The degree of rebound varies,

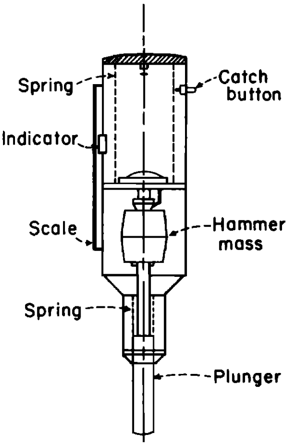

Figure 1. Schmidt hammer schematic.

depending upon the rock elastic properties. Studies also show that a variety of additional factors may affect laboratory and field-determined index values, including the following:

1. Varying degrees of surface irregularity.
2. Impact surface moisture content.
3. Inhomogeneities in the rock fabric.
4. Presence of cleavage slips, bedding planes, porous cavities, and other local anomalies.
5. Orientation and size of test surface.
6. Duration and degree of test surface weathering.
7. Rock mass confinement; in place versus unconfined laboratory setting.

After reviewing literature describing the consistency and reliability of Schmidt hammer data, Poole and Farmer (Poole, 1980) concluded that rebound values have a tendency to increase and show considerable variation during the first three to four individual impacts at a point. They added that the most consistent results are obtained by selecting the peak values from at least five discrete impacts at a point. In contrast, Kazi and Al-mansour, in an empirical study comparing the Los Angeles abrasion and Schmidt hammer tests, decided that at least 35 rebound index values should be taken at each point (Kazi, 1980). The 10 lowest values are discarded, and the average rebound index is then calculated from the remaining 25 readings. As indicated in table 1, some confusion exists concerning the appropriate use of this instrument.

AUTHOR	IMPACTS/POINT	REMARKS
Hucka, V.Z. 1965	10	Use maximum rebound value obtained from closely spaced impacts
Deere, D.U. and R.P. Miller 1966	15	Use average of the 10 highest rebound values from impacts separated by at least 25 mm
British Standards Institution "BSI" 1971	9 - 25	Use average range of multi-test standard deviations
Proceg, S.A. 1977	10	Rock mass properties derived from average of all rebound values obtained from tests over a 100 square meter area
Intn'l. Society Of Rock Mechanics 1978	20	Use upper 10 rebound values for impacts at least a plunger diameter apart
Young, R.P. and R.J. Fowell 1978	1	Divide rock mass area into grids and use average of single impacts from each grid
Poole, R.W. and I.W. Farmer 1980	Until 5 continuous readings	Use peak value from at least 5 similar rebounds
Kazi, A. and Z. Al-Mansour 1980	35	Drop the 10 lowest readings and use the average of the 25 highest rebound values

Table 1. Summary of literature describing the Schmidt hammer. (All authors referenced in text.)

3 PREVIOUS INVESTIGATIONS

Numerous empirical equations have been proposed for calculating uniaxial compressive strength (σ_a) and modulus of elasticity (E_t) of rock and coal from Schmidt hammer index values (H_s). Most researchers have used similar approaches for deriving these equations, four of which are discussed here.

3.1 Kidybinski (Kidybinski, 1980)

At the Central Mining Institute in Poland, Kidybinski evaluated the use of the Schmidt hammer by testing different rock types from Northern Silesia. He observed a correlation between rebound index and uniaxial compressive strength for rock and coal, and derived the following equation for estimating the strength of rock:

$$\sigma_a = 0.447e^{(0.045\ H_s\ +\ \gamma_a)},$$

where e = base of the natural logarithms.
σ_a = uniaxial compressive strength, MPa,
E_t = modulus of elasticity, MPa,
γ_a = rock density, gm/cm^3,
H_s = average rebound index.

Prior to this equation, Kidybinski applied corrections for the relative angles at which tests were performed. He presented these corrections in the form of a nomograph (fig. 2).

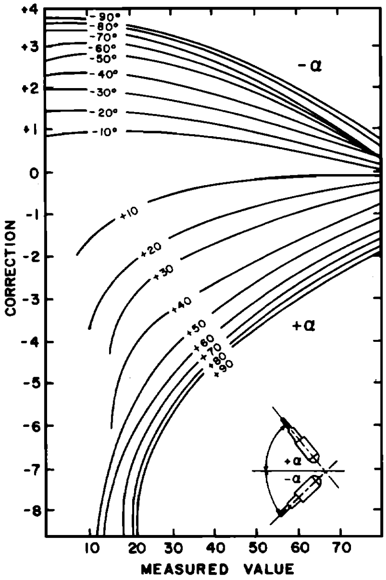

Figure 2. Schmidt rebound index correction chart. (Kidybinski, 1980).

3.2 Aufmuth (Aufmuth, 1973)

Aufmuth acquired Schmidt hammer data from approximately 800 core samples, representing 168 geologic formations and 25 lithologic types. Four rebound readings were taken at different locations along the center axis of the core. When comparing rebound values to laboratory-determined compressive strengths and elastic moduli, Aufmuth found a better correlation was obtained by multiplying the rebound index by the rock density. The following equations describe the best-fit approximations relating compressive strength and elastic modulus to the Schmidt hammer index:

$$\sigma_a = 6.9 \times 10^{[1.348 \log (H_s\gamma_a) - 1.325]}, \text{ and}$$

$$E_t = 6.9 \times 10^{[1.861 + 1.061 \log (H_s\gamma_a)]}.$$

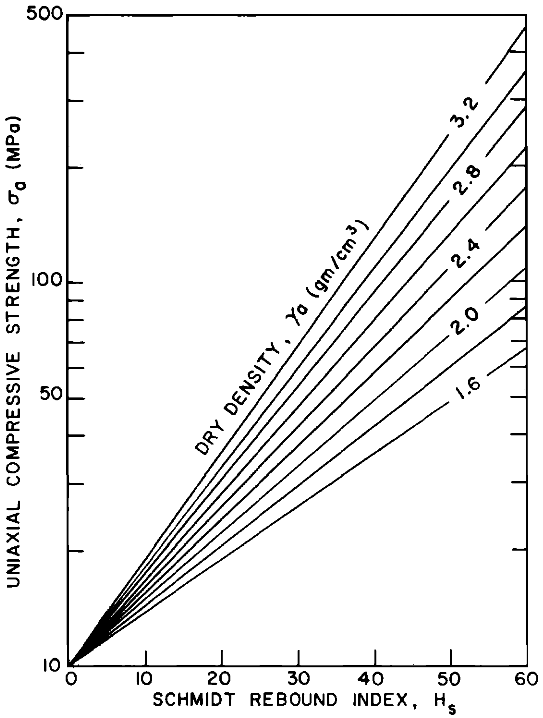

Figure 3. Relationship between uniaxial compressive strength and Schmidt rebound index (Deere, 1966).

3.3 Deere and Miller (Deere, 1966)

In 1966, Deere and Miller reported testing 55 mm (NX) diameter core from 28 different locations. A total of 257 samples were tested with length to diameter ratios of 2 to 1. Twelve readings were recorded along the length of the core for each 90° rotation. "Anomalous" values were discarded and the remaining readings averaged. Average rebound index and rock density were plotted versus compressive strength and elastic modulus, an example of which is shown in figure 3. These plots represent testing done while holding the hammer vertically downward. A correction chart for testing at various angles was also developed by Deere and Miller with significant differences from that previously presented by Kidybinski.

The best-fit approximations for compressive strength and elastic modulus are as follows:

$$\sigma_a = 6.9 \times 10^{[0.16 + 0.0087(H_s\gamma_a)]}, \text{ and}$$

$$E_t = 600.5(\gamma_a H_s) - 20{,}276.$$

3.4 Beverly, Schoenwolf and Brierley (Beverly, 1979)

These investigators used the same test procedures as Deere and Miller to obtain additional Schmidt hammer data from 20 new locations. They combined their data with that of Deere and Miller and derived the following relationships (example in figure 4):

$$\sigma_a = 12.74\ e^{[0.0185(H_s\gamma_a)]}, \text{ and}$$

$$E_t = 192(H_s\gamma_a^2) - 12{,}710.$$

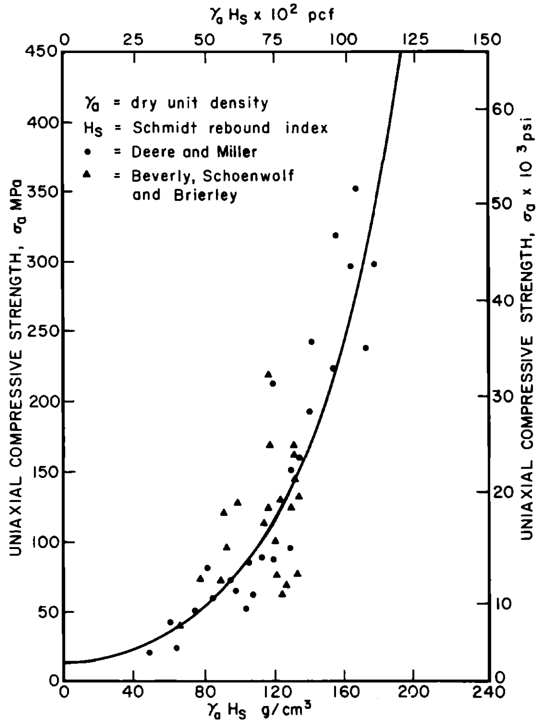

Figure 4. Relationship between uniaxial compressive strength and normalized Schmidt Hammer rebound index. (Beverly, 1979).

4 BUREAU OF MINES INVESTIGATION

To further investigate the suitability of the Schmidt hammer to characterize coal properties, the Bureau of Mines conducted tests using large coal blocks acquired from 10 different U.S. locations. The following test procedure was used:

1. All blocks were cleaned of dirt and loose coal and thoroughly inspected for excessive fracturing.
2. Each block was set squarely upon a smooth, solid concrete floor.
3. Rebound test locations on the sample were selected and prepared, if necessary, to ensure minimal influence of surface irregularities, edge effects, and nearby fractures.
4. Four rebound tests were conducted perpendicular to bedding at each test location.
5. The R-710* Schmidt hammer, recommended for soft materials, was used in a vertically downward position for each test.

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*Reference to specific equipment does not imply endorsement by the Bureau of Mines.

Table 2. Statistical summary of Bureau of Mines test data.

MINE	A	B	C	D	E	F	G	H	I	J
SCHMIDT HAMMER										
No. of Tests	296	73	210	68	144	216	68	29	215	192
Mean H_s	43.90	28.51	33.09	40.34	39.16	33.75	12.09	34.80	29.26	31.67
Standard Deviation	6.04	3.83	6.00	8.49	7.45	4.49	2.06	4.78	3.12	4.99
UNIAXIAL TESTING										
No. of Samples	20	20	10	10	21	20	15	20	20	20
Mean σ_a, MN/m^2	45.56	18.15	37.05	30.61	22.03	38.14	6.94	37.56	39.71	28.60
Standard Deviation	6.37	4.69	6.79	7.16	4.92	4.36	2.68	9.73	2.38	4.85

Statistical means and standard deviations for all rebound tests are presented in table 2. In addition, approximately 20 cubes were cut from each coal test block and conventionally tested to obtain average uniaxial compressive strengths. These values are also presented in table 2.

Correlation of rebound index to compressive strength by simple regression analysis (fig. 6) resulted in the following best-fit equation:

$$\sigma_a = 0.994H_s - 0.383.$$

This equation has a correlation coefficient of 0.840, suggesting limitations in the generic application of the Schmidt hammer to evaluate coals of similar rank. Uncertainties to be considered in this evaluation include the following:

1. Variations in the coal fabric, e.g., percent ash, sulfur, and fixed carbon, and clay or sand splits.
2. Test block size and shape.
3. Environmental alteration incurred during procurement.
4. Definition of cleats and bedding features.
5. Use of cubes taken from impacted blocks.

Although relative to all tests conducted on the blocks, the energy absorbtion characteristics of a hard versus soft test floor must also be considered. Ideally, to provide more

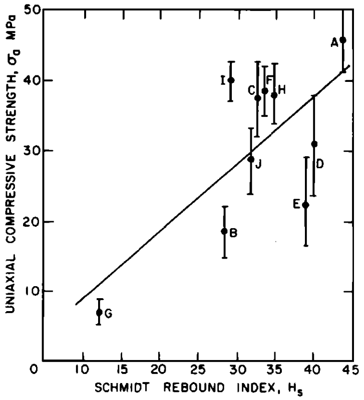

Figure 6. Relationship between uniaxial compressive strength and Schmidt rebound index for Bureau of Mines tests on coal.

concise engineering design information, all Schmidt hammer tests should be conducted in situ on recently exposed coal.

5 CONCLUSION

Using the Schmidt hammer on either in-place rock or coal, NX (55 mm) diameter core, or large block samples was found by the referenced authors to be inexpensive, fast, and reliable for providing relative rebound-hardness values and estimates of strength and elastic moduli without the sample destruction and expense of conventional testing. Their findings have been presented as derived equations relating rebound index, rock density, uniaxial compressive strength, and elastic modulus. The wide range of results obtained when evaluating these equations with similar input parameters reflects uncertainties associated with variable rock lithologies, test environments, and test methods. These uncertainties similarly influenced the Bureau of Mines investigation. Although comparing the presented equations may preclude the formulation of a single strength relationship for all rocks, the Schmidt hammer can effectively determine relative strengths and degrees of homogeneity throughout a rock mass. This is evidenced by the good data correlation each author achieved.

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