MEASURING ENGINEERING PROPERTIES OF NYC ROCKS USING A SCHMIDT REBOUND HAMMER – PRELIMINARY RESULTS

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INTRODUCTION

Attempts to correlate Schmidt rebound hammer values (H_R) with engineering geological properties of different rock types has been reported in geotechnical literature (Dinçer et al. 2004; Bilgin et al. 2002; Katz et al. 2000). These attempts have yielded correlation equations, summarized in Table 1, that have been used to determine the mechanical properties of rock specimens. Yet, few if any published studies have previously addressed the use of a rebound hammer on the predominant rock types that are characteristic of the New York City region.

Table 1. Empirical relationship between UCS and the impact generated rebound hardness number (H_R) of tested rock material, a dimensionless measure reported by others.

Source	Equation*	R	Rock Type(s)
Singh et al. (1983)	$UCS = 2 H_R$	0.72	30 Sedimentary units
Shorey et al. (1984)	$UCS = 0.4 H_R-3.6$	0.94	20 Lithological units
Haramy and DeMarco (1985)	$UCS = 0.994 H_R-0.383$	0.70	10 Lithological units
O'Rourke (1989)	$UCS = 702 H_R-11040$ (psi)	0.77	Sandstone, Siltstone, Limestone and Anhydrite
Sachpazis (1990)	$UCS = (H_R-15.7244) / 0.2329$	0.91	33 Lithological units
Aggistalis (1996)	$UCS = 1.31H_R-2.52$	0.55	Gabbro and basalt
Katz et al. (2000)	$UCS = 0.792+0.067 H_R \pm 0.231$	0.96	7 Different rock types

R regression coefficient, the notation of H_R was used in lieu of *N* to represent Schmidt values
*Equations as presented in Dinçer et al. 2004.

Widely used in geotechnical practice, the determination of basic mechanical properties of rock for a specific engineering project generally requires the preparation of several core samples and the use of expensive laboratory equipment. Several mechanical properties, including unconfined compressive strength (UCS), have become widely accepted criteria for rock design projects (Baskerville 1987). This preliminary study has been undertaken to determine if any reproducible pattern of rebound hammer values exists among the prevalent rock types of the New York City region.

As a result, this pilot Schmidt hammer study was undertaken to estimate the engineering geological properties of fifteen rock core component examples of the complex geology of the New York City region. The device has been established as a useful tool in estimating rock strength values in crystalline rocks for engineering applications. The initial results are encouraging as reported in this abstract, and support the need for further research to develop specific correlations the prevalent rock types of the New York City region.

Geology of the New York City Region

The New York City Metropolitan region is characterized by complex geology and structure as it overlies three physiographic units, namely, the New England Upland on the northwest, the Triassic Lowland on the southwest, and the Atlantic Coastal Plain to the southeast. New York City is situated at the extreme southern end of the Manhattan Prong, a northeast-trending, deeply eroded sequence of metamorphosed Proterozoic to Lower Paleozoic rocks that widen northeastward into the crystalline terrains of New England.

The Manhattan Prong is a landscape of rolling hills and valleys whose configurations are closely controlled by the structure and lithology of the underlying bedrock. The bedrock of the Manhattan Prong is composed of metamorphic rocks ranging from Proterozoic to Ordovician in age. The hilly terrains are underlain by rocks that are resistant to erosion (Fordham Gneiss, Yonkers Gneiss and by various schists and gneisses of the Manhattan, Walloomsac, and Hartland formations). Generally, the valleys are underlain by brittle faults or the Inwood Marble because of carbonate weathering susceptibility.

About 450 million years ago, during the Taconic orogeny, the rocks of the Manhattan Prong were tightly folded and metamorphosed. Consequently, complex fold and fracture patterns have resulted from many stages of polydeformation. The geologic structure of metamorphic bedrock is typically dominated by surfaces of foliation and gneissic layering formed by the preferential alignment of platy minerals within the rock.

The Schmidt Rebound Hammer

The rebound hammer consists of a spring-loaded steel piston-type hammer (Item 14 in Figure 1), which when released, strikes a metal plunger (Item 1 in Figure 1) in contact with the rock surface to be tested. The rebound test hammer used was a Type L original Schmidt Hammer (S/N 7281) calibrated on 25 August 2006. The device measured the rebound value (H_R), a dimensionless value with a specific relationship between the hardness and rock strength.

The rebound test hammer housing is held firmly by hand in a position aligned vertically downward (~90 degrees) so that the impact plunger will strike at an angle perpendicular to the test surface of the rock core specimen. With the impact plunger aligned perpendicular to the rock specimen, gradual pressure is applied to the housing, retracting the impact plunger within the housing. Once fully depressed and actuated the hammer automatically releases, yielding an impact reading (H_R) which is displayed on a graduated scale (Item 19 in Figure 1).

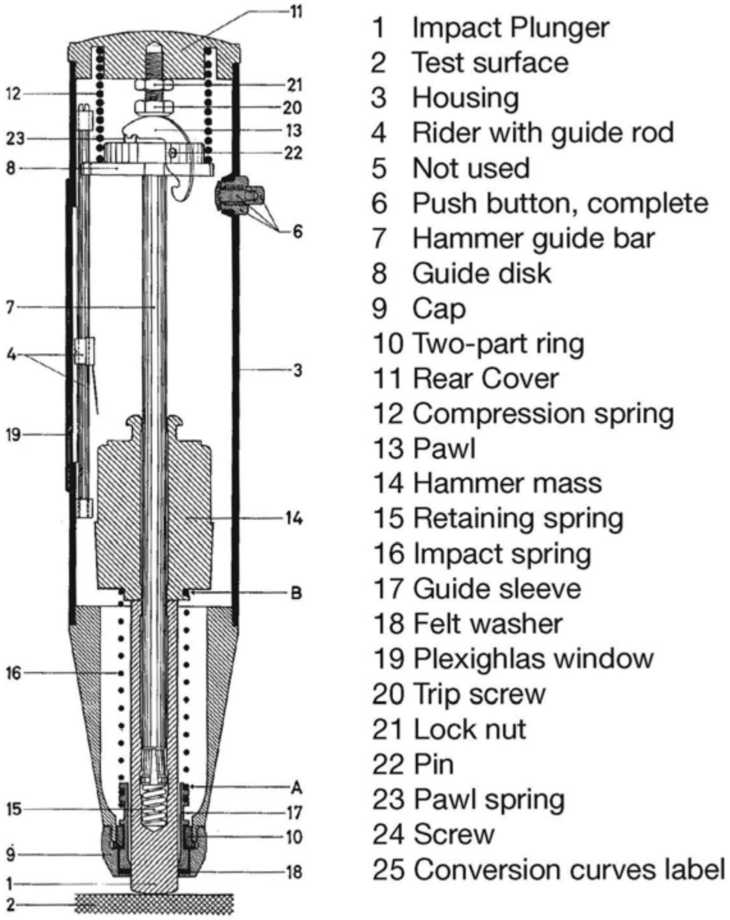

Figure 1. Longitudinal section of the Type L Schmidt hammer for field-testing of rock strength.

Materials and Methodology

Fifteen rock core specimens were selected from various units and localities in New York City for this pilot study to represent common rock types of the region. A rebound hammer was used in general accordance with ASTM D5873 to assess the relative hardness characteristics of select rock core samples. Prior to testing, each core sample was visually inspected for surface defects resulting from sampling irregularities and rock fabric/structure to avoid testing near fractures. The test surfaces of all specimens were smooth over the area as a result of coring. Samples were visually observed to be free of apparent joints, fractures, or other incipient breaks. Hammer readings were determined on rock core samples of size NX (2-1/8”) in accordance with ASTM D5873. However, Tarkoy (2002) has reported that rebound hammer (Type L) hardness tests may be performed using NQ diameter core, although it was noted that the use of NQ size specimens may yield lower readings than those determined on NX core samples.

Ten to twenty impact readings were recorded from each rock core specimen dispersed evenly around the core barrel in orthogonal orientations. The test locations along the core specimen were separated by at least the diameter of the hammer piston. After the plunger impact for each reading, the surface of the rock was examined. Readings were rejected if any individual impact test resulted in cracking or any other visible damage.

Preliminary Results

The measured rebound hammer values for our diverse group of fifteen samples display a wide range of properties (Table 2). The correlations between H_R and unconfined compressive strength were assessed statistically and compared with published strength results presented by Baskerville (1987) and unpublished UCS results from prior engineering studies by Tectonic Engineering.

Table 2. Test results by major lithologic categories for all samples as part of this study.

Rock Type	Measurement	Average Measurement	Maximum	Minimum	Standard deviation
Hartland schistose rocks	Schmidt hammer rebound values (H_R)	25.3	35.0	12.0	5.5
Hartland Amphibolites	Schmidt hammer rebound values (H_R)	30.1	39.0	23.0	3.8
Inwood Marble	Schmidt hammer rebound values (H_R)	33.3	42.0	23.0	4.5
Manhattan Schist	Schmidt hammer rebound values (H_R)	34.0	45.0	21.5	4.1
Walloomsac Interlayered schist and calc-silicate	Schmidt hammer rebound values (H_R)	43.1	54.5	29.0	4.6
Fordham Gneiss	Schmidt hammer rebound values (H_R)	44.3	56.5	28.5	3.2

The empirical relationships previously summarized in Table 1 were chosen based upon the variability of lithological units considered, since no prior research has examined the crystalline rocks of NYC. Baskerville (1987) noted that foliation planes, which can be highly variable under in-situ conditions, was measured in the field to have dip angles varying from 18 degrees to 90 degrees; therefore the UCS would be greatest in the direction normal to the foliation of the rock. Similarly, it was observed that unpublished UCS testing of core samples was largely affected by shear failures occurring along the rock fabric or bedding planes for the steeply-angled foliation of Manhattan bedrock.

In order to calculate the UCS for comparison to published data, the statistical average of Schmidt hammer test results for each rock type was used with the empirical relationships developed by others. This relationship of measured rebound numbers to calculated UCS is plotted as solid lines on Figure 2. Since this pilot study was preliminary in nature and lacked a large sample set, as well as lacking specific UCS data for the fifteen samples selected, the Baskerville (1987) data was used with the empirical relationships to calculate corresponding rebound numbers. This relationship of measured UCS data to calculated rebound numbers are plotted as circles on Figure 2.

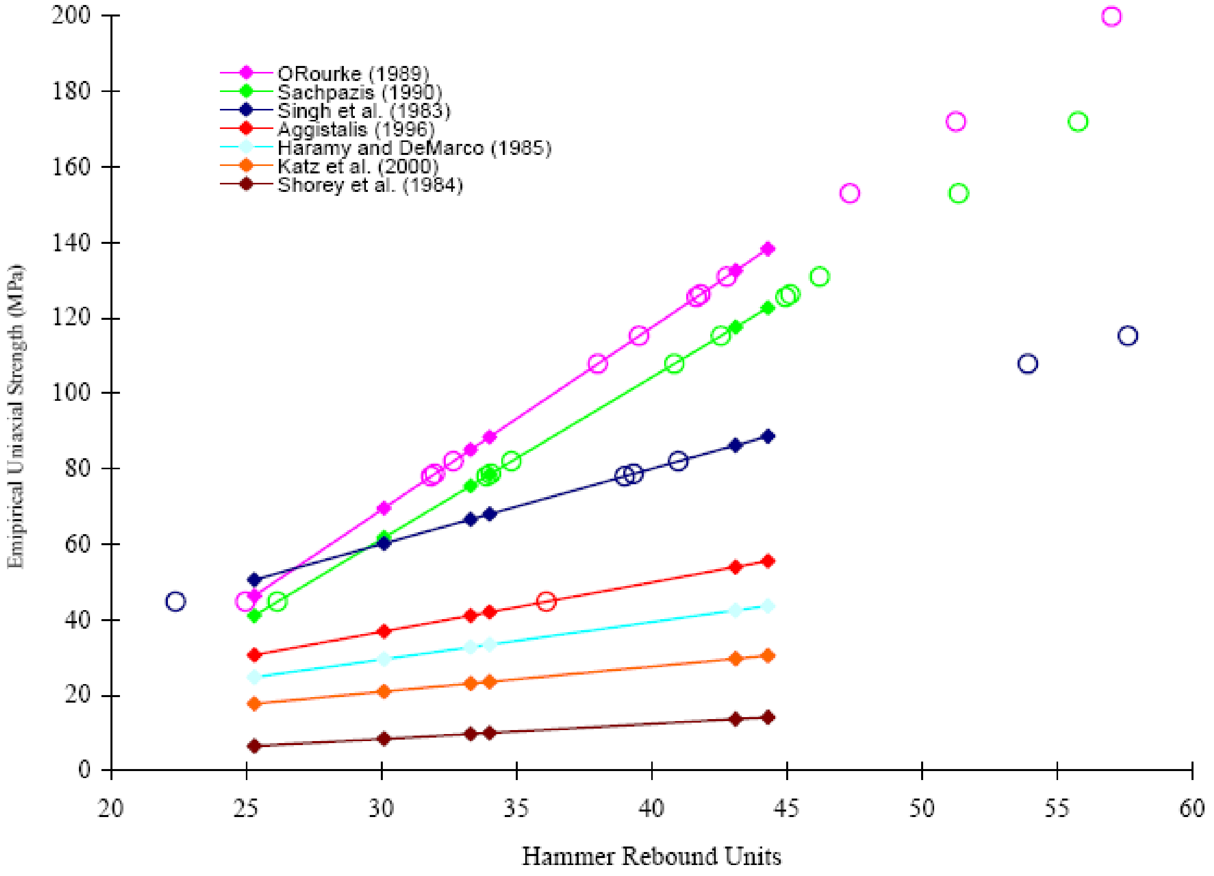

Figure 2. Relationship of empirical uniaxial unconfined compressive strength to Schmidt hammer rebound units.

As shown in Figure 2, applying the empirical relationships developed by Singh et al. (1983), O'Rourke (1989) and Sachpazis (1990) provides for reasonable correlations of UCS and rebound number for lower rock strength. However, each of the relationships developed by the other listed researchers fails to reasonably predict the full range of strength of the rocks of New York City (this study) based on UCS values presented by Baskerville (1987). The empirical relationships developed by Shorey et al. (1984), Haramy and DeMarco (1985), Aggistalis (1996), and Katz et al. (2000) significantly underestimated the UCS and thus did not provide for a reasonable comparison to published data.

CONCLUSIONS

As a result of industry-wide acceptance of rock testing to determine the mechanical properties for geological design and construction projects, the use of expensive laboratory testing and equipment is required for engineering projects. The Schmidt hammer rebound number (H_R) has been used by prior researchers (Dinçer et al. 2004; Bilgin et al. 2002; Katz et al. 2000) to measure the engineering geological properties of different types of rocks. Additionally, researchers such as Bilgin et al. (2002) have proposed the use of rebound hammers to predict the performance of underground engineered works such as tunnel drivages.

Rocks of the New York City Metropolitan region are characterized by diverse mineralogy, metamorphic grade, and exhibit complex geological structures. The structures are dominated by surfaces of foliation and gneissic layering formed by the preferential alignment of platy and linear minerals within the rock. All of the features that help break out units in the field (composition, texture, metamorphic grade, fabric orientation, and mica content) also have been observed to control penetration destiny in TBM excavations (Merguerian 2005a, b; Merguerian and Ozdemir 2003) and control means and methods in shallow construction excavations.

This pilot Schmidt hammer study was undertaken to estimate the engineering geological properties of fifteen rock core component examples of the complex geology of the New York City region. The statistical average of Schmidt hammer test results for the rock samples as part of this study were used in combination with the empirical findings put forth by previous studies for comparison to published UCS results as presented by Baskerville (1987) and unpublished UCS results from prior engineering studies by Tectonic Engineering. The preliminary results indicate that a reasonable relationship is shown between the geologic sequence of NYC rocks and the average rebound measurement. Additionally, the relationships of a few researchers provide for reasonable correlations of UCS and rebound number for lower rock strength. These initial Schmidt hammer study results are encouraging and support the need for further development of specific relationships to reasonably predict the geological engineering properties of rocks of the New York City region.

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