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Estimation of Compressive Strength of Rocks usingNon-Destructive Testing Methods

Sowmya Kochukrishnan[1[0000-0003-3197-1750]] and **Premalatha Krishnamurthy**[2[0000-0002-5893-1495]]

[1] Research Scholar, Department of Civil Engineering, College of Engineering, Guindy, Anna University, Chennai

[2] Professor, Department of Civil Engineering, College of Engineering, Guindy, Anna University, Chennai

sowmya.civil@gmail.com

Abstract

Unconfined Compressive Strength (UCS) is the most important mechanical property and its determination is indispensable for all projects involving rocks. In this paper, anattempt is made to estimate the unconfined compressive strength of rocks using non destructive test methods such as Schmidt rebound hammer and ultrasonic pulse velocity(UPV) tests. The ratios of UPV and ρ_d, UPV and RN and also RN and ρ_d defined as a function of a UCS would work as a better indicator for evaluating the mechanical prop-erties of the rocks. Rock samples were prepared as per ASTM standards and tests such as Schmidt hammer, UPV, UCS and dry density (ρ_d) were conducted on the prepared specimens. Schmidt hammer test for different positions (A scale, B scale and C scale) were conducted with precautions to arrive at the exact rebound number and thus the integrity of the samples were examined. Ultrasonic pulse velocity was measured usingProceq UPV tester as per ASTM standards. The UCS test observations made were cor-related with the ratios of UPV and ρ_d, UPV and Rebound Number (RN) on A,B,C scales, RN in A,B,C scales and ρ_d. A simple regression study showed good outcomes, with all the regression coefficients being greater than 0.80 and the highest being 0.97 for the estimation of UCS using the ratio of RN(A scale) and ρ_d. This study can be usedas a tool for the preliminary estimate of UCS.

Keywords: Rebound Number, UPV, Dry density, UCS

1 Introduction

Unconfined Compressive strength is probably the easiest ‘quality’ test to carry out and there is a large volume of published data available. The method for determining the UCS has been standardized by both International Society for Rock Mechanics (ISRM) and the American Society for Testing and Materials (ASTM). The direct measurement of the UCS is possible if suitable core samples and specimen preparation facilities are available. When at the site where rocks are available but laboratory testing cannot be carried out, a point load tester can be used to indirectly estimate the UCS. A Schmidt hammer is a very useful and portable item of testing equipment that will enable tests to be carried out very quickly on rock cores, lumps of rock, or exposed rock surfaces. When none of these approaches is applicable, the published results and the proposed empirical equations for the rock types may be useful. Studies have been performed and correlations proposed between UCS and various other properties of rocks. Among the most widely used techniques, rebound hammer and pulse velocity tests are frequently used as they are portable and less expensive.

Correlations were derived between the rebound hammer number and the UCS for different types of rocks and the results indicated that the correlation was dependent on the rock type [1]. Regression analysis showed a linear relationship between rebound number vs. UCS values for various rock types [2]. Numerical equations were suggested for estimating the mechanical properties of rock using non-destructive and indirect test methods and satisfactory correlations between UCS vs. Schmidt hardness were reported [3]. A comparison study was made between P wave velocity and Schmidt hardness in the estimation of UCS and reported that the P wave velocity is more reliable than Schmidt hardness [4]. General correlation trends were established between UCS and other indirect tests such as rebound hammer and P-wave velocity and suggested that the reliability of the equations was dependent on the rock type and the type of test in- volved [5]. Relationships were expressed between rebound number and UCS for gyp- sum rocks and recommended that these relations must be used only for gypsum, partic- ularly at the initial phase of designing a structure [6]. Empirical equations were sug- gested to estimate UCS value using rebound numbers and these formulas provided ac- curate results only when used for volcanic rocks with similar weathering and miner- alogical structures [7]. Arithmetical relationships were established amongst rebound number, UCS, ultrasonic pulse velocity and the ratio of UPV/UCS based on two ISRM suggested methods and established that strong relationships existed for all the tested rocks [8]. A comparative study in the estimation of UCS with rebound number and point load strength index was performed and predicted that the reliability in using a rebound hammer is not very high and the proposed relationships can be used to predict UCS only for limestone of Nammal Formation [9]. A high correlation was established between surface hardness and UCS of intact rocks and showed that the ratio of UCS/Hardness number increases with increasing compressive strength at an increasingrate [10].

Empirical equations were developed for the estimation of UCS and other mechanical properties from P-wave velocity [11]. Strong correlations were established between P wave velocity and the physical properties of different types of rocks [12]. A very good correlation between UCS and UPV was established for andesite rocks [13]. The statistical relationship established between UCS and P wave velocity for basalt rocks showed high values of correlation coefficient [14]. A firm correlation was established between P wave velocity and strength properties for coal and the results were confirmed using a t-test [15]. A linear relationship was obtained between UCS and P wave velocity in the range 1682 - 4657 m/s [16]. Empirical equations were proposed to estimate UCS from P wave velocity for dry schist rocks in Malaysia [17]. Linear and nonlinear empirical relationships were established using regression analysis to predict UCS using other properties for sedimentary rocks obtained at a particular depth in Germany [18]. Good correlations were developed to estimate UCS using UPV for basalt rocks. The correlations were restricted to intact rocks of basalt in the UPV range greater than or equal to

4000 m/s [19]. Rock properties, especially the UCS were predicted from P wave velocity. A very good relationship was obtained with a high correlation coefficient for different rock types [20].

Several aspects combinedly govern the strength of a rock. The empirical equations established by the previous researchers often consider a single parameter, the results of which might be misleading and are not dependable when representative results are desired. Indexes such as the rebound hardness numbers reveal the external surface of the rocks and are not sensitive to the inherent properties of the rocks. UPV test is more significant in establishing the intrinsic property as the wave's velocity and depends on the rocks' internal structure. In this study, the ratios of UPV/ρ_d, UPV/RN, and RN/ρ_d were correlated with the UCS of rocks obtained from some locations in Chennai. The obtained empirical equations will be useful in estimating the UCS value during the preliminary stage of design.

2 Sample preparation and testing

A total of ten rock blocks were sampled from different locations in Chennai and tested for this study. Large blocks, free of macroscopic defects, were collected to obtain at least three core samples from each. Rock cores of NX size (54 mm) and the length-to-diameter ratio of two were prepared in the laboratory using the tools for drilling and cutting meeting the requirements of the ASTM D 4543 – 85 [21] standards. The core specimens were oven-dried at 105^0C for 24 hrs before subjecting it to further testing. The core specimens prepared in the laboratory are shown in fig. 1.

Fig. 1. Rock core specimens

Non-destructive and Destructive tests The dry density of the oven-dried rock cores was obtained by dividing the weight by its respective volume.

The dry density of the three cores obtained from a block was averaged.

The Schmidt Rebound Hammer tests were performed on the rock cores as per ASTM D 5873 [22] standards. Rebound Number was measured on the rock cores which were securely clamped to prevent any vibration and by positioning the Proceq Rebound Hammer in three different directions (A scale – horizontal, B scale – vertically downward, C scale – vertically upward). The test was repeated three times in each direction and the mean value was recorded.

UPV tests were performed using the PUNDIT Lab ultrasonic instrument and following the ASTM D 2845 -08 standards [23]. Direct arrangement of the transducers is the most effective method among the methods available and the same was used. The surface of the rock cores was ensured to be smooth and the transducers were covered with a thin coat of electrode gel. Pulse velocity measurements were taken directly from the display unit after positioning the transducers by feeding the path length as the input. A rock core specimen subjected to UPV test in the laboratory is shown in fig. 2.

UCS test was performed on the core samples following the ASTM D 2938 – 95 standards [24]. For the test, a servo-controlled Universal Testing machine with a load cell capacity of 40 T was used. Rock specimens were axially loaded without any eccentricity and the test was repeated three times on three core specimens and the mean value was recorded as the UCS.

Fig. 2. UPV test on a core specimen

3. Results and Discussions

Various tests were performed on the rock core specimens to obtain the dry density, Rebound number in A,B and C scales, Ultra sonic pulse velocity and Unconfined compressive strength. Using these test results correlations of UCS were made with UPV/ρ_d, UPV/RN, and RN/ρ_d using regression analysis. RN was measured along A, B and C scales.

Regression analysis

The primary objective of this study is to estimate the unconfined compressive strength of the rocks for which correlations were developed using Regression analysis. Regression analyses were performed with the dependent variable UCS and the independent variables (UPV, RN, ρ_d). The relationship between the dependent and independent variables can be represented by different curves and the analysis produced R^2 (correlation coefficient), which was high when the fitting curve was linear. The empirical equations obtained are given in Table 1.

Table 1 Proposed Empirical Equations

Parameters related	Equations	R^2 after regression
UCS vs. UPV/ ρ_d	UCS = 0.1688*[UPV/ ρ_d]-298.79	0.907
UCS vs. UPV/RN (A)	UCS = -1.2302*[UPV/RN(A)] + 325.56	0.926
UCS vs. UPV/RN (B)	UCS = -1.7549*[UPV/RN(B)] + 344.02	0.964
UCS vs. UPV/RN (C)	UCS = -3.6367*[UPV/RN(C)] + 564.84	0.806
UCS vs. RN (A) / ρ_d	UCS = 14.453* [RN(A)/ρ_d] - 83.527	0.977
UCS vs. RN (B) / ρ_d	UCS = 12.243*[RN(B)/ρ_d] - 81.845	0.970
UCS vs. RN (C) / ρ_d	UCS = 14.461*[RN(C)/ρ_d] - 163.15	0.962

The relationships between the different parameters with the UCS were plotted as 3D contour plots and are represented in the figs. 3,4,5,6,7,8 and 9.

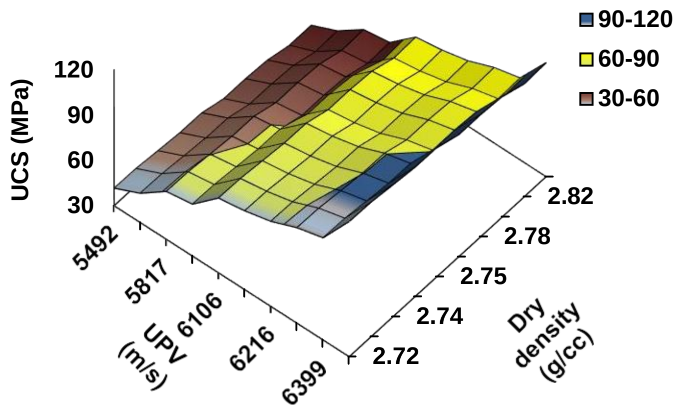

Fig. 3. General relations between UPV and dry density against UCS

The UCS, UPV and Dry density ratio of the tested rock samples were plotted and presented. It was observed that for the UPV range of 5492 to 6745 m/s UCS and ρ_d correlated well with a regression coefficient of 0.907.

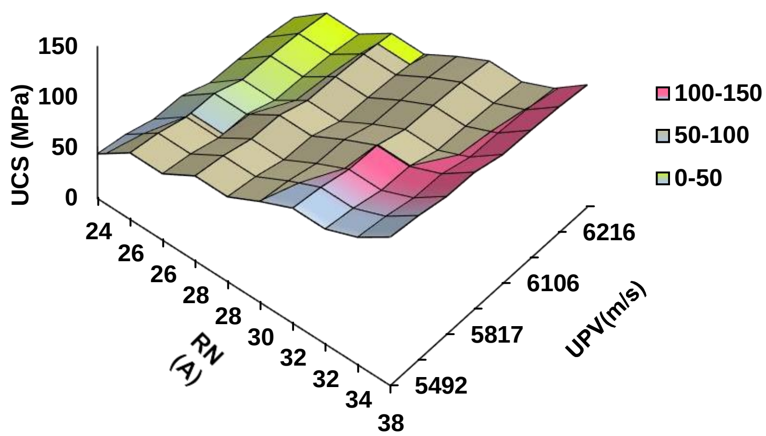

Fig. 4. General relations between UPV and RN (A) against UCS

From Figure 4, it is observed that for the UPV range of 5492 to 6745 m/s UCS and RN(A) correlated well with a regression coefficient of 0.926.

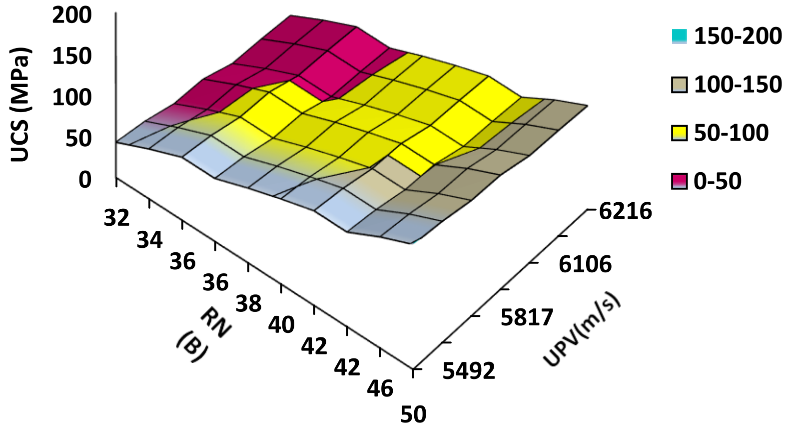

Fig. 5. General relations between UPV and RN (B) against

From Figure 5, it is observed that for the UPV range of 5492 to 6745 m/s UCS and RN(B) correlated very well with a regression coefficient of 0.964.

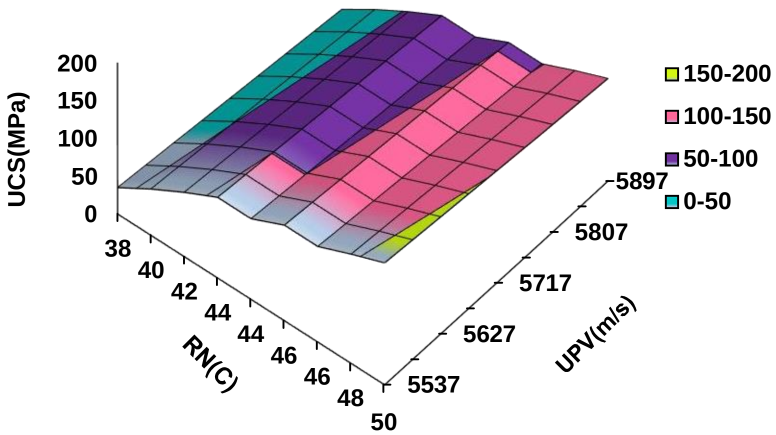

Fig. 6. General relations between UPV and RN (C) against UCS

From Figure 6, it is witnessed that for the UPV range of 5492 to 6745 m/s UCS and RN(C) correlated with a regression coefficient of 0.808.

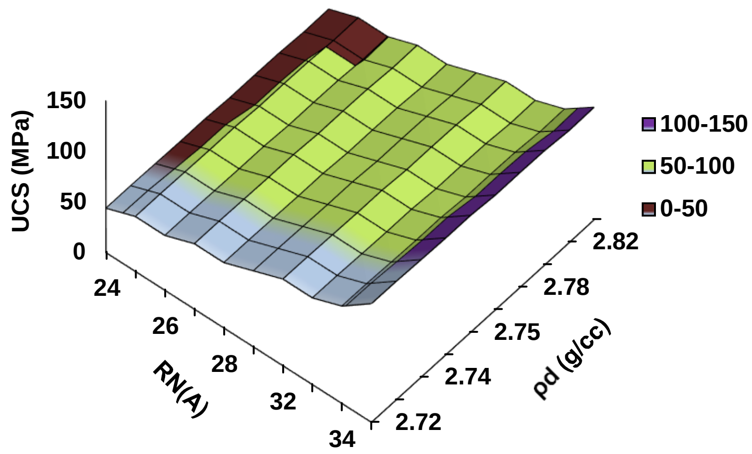

Fig. 7. General relations between RN (A) and ρ_d against UCS

From the Figure 7, it is witnessed that RN(A), UCS and ρ_d correlated very well with a regression coefficient of 0.977.

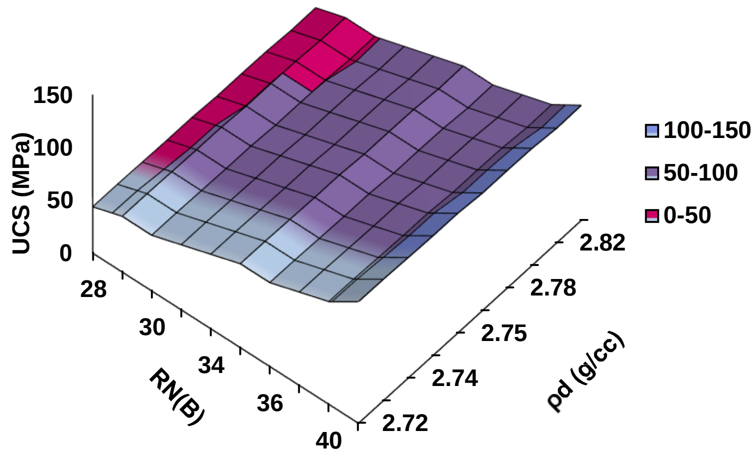

Fig. 8. General relations between RN (B) and ρ_d against UCS

From the Figure 8, it is observed that RN(B),UCS and ρ_d correlated very well with a regression coefficient of 0.977.

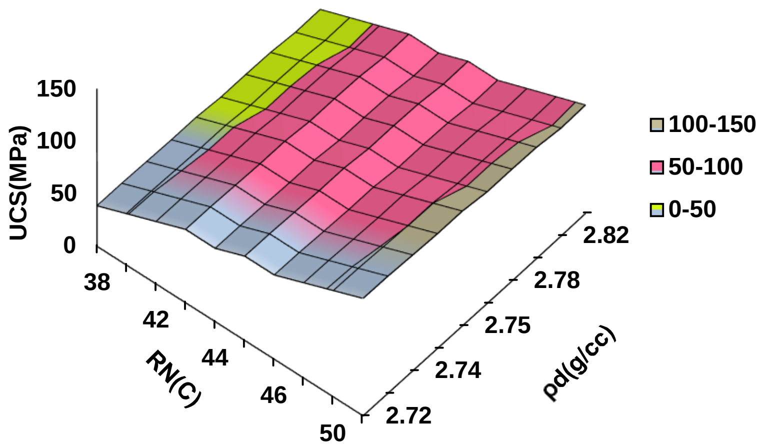

Fig. 9. General relations between RN (C) and ρ_d against UCS

From the Figure 9, it is observed that RN(C),UCS and ρ_d correlated very well with a regression coefficient of 0.962.

4. Conclusions

UPV and RN are represented as an index of rock strength for ten rock core samples collected from the Chennai region and the following conclusions are drawn.
Simple linear relationships were proposed to estimate the UCS of rocks. The ratios of UPV and ρ_d, UPV and RN and also RN and ρ_d serve as better indicators for the estimate of UCS as the parameters in the ratios are strongly affected by the UCS of the rocks.

Regression analysis for UCS with the ratio of UPV and ρ_d appears to be significant in predicting the compressive strength of rocks as the strength values predicted from the regression analysis are in very close proximity to the observed values. UPV/RN ratio provides significant correlations with UCS for the RN taken in the A and B scales. The ratio gives an satisfactory correlation along the C scale.

Regression analysis for UCS with the ratio RN and ρ_d gives very substantial correlations in all three scales of Rebound Hammer. The empirical equations proposed in this study are reliable as the ratio of two important parameters is together considered for the determination of UCS.

The proposed relationships are applicable to compute the UCS value for rocks in the UPV range of 5400 to 6800 m/s. Further research is recommended to consider the effect of all the factors such as grain size, water content, porosity, and cementing agents on the UCS of these rocks.

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