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An Experimental Approach to Develop Correlations for Determining Geo-Mechanical Properties of Sedimentary Rock

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Abstract

Rock failure is a prevalent challenge in underground construction, necessitating reliable assessments of geo-mechanical properties. This study investigates the relationship between Schmidt rebound hardness (R) and two key mechanical properties—Uniaxial Compressive Strength (UCS) and Indirect Tensile Strength (ITS)—of sedimentary rocks from the Sitakund and Kaptai geological formations in Chattogram, Bangladesh. Given the time-consuming nature and complex experimental setup of traditional UCS and ITS testing, correlating these with rebound hardness offers a more efficient method for initial design assessments. Eighteen rock samples were analyzed, with nine designated for UCS tests and nine for ITS tests, while two additional samples served to validate the developed correlations. The results indicate a maximum deviation of 17.22% from experimental values for the ITS test in Sitakund samples. The developed correlations may help engineers as a primary tool for estimating rock strengths, enhancing decision-making in the early stages of underground construction projects.

Keywords: Rock mechanics, Sandstone, UCS, ITS

1. Introduction

Sedimentary rock forms through the accumulation and consolidation of sediments, which are fragments of pre-existing rocks, organic materials, minerals, or chemical precipitates transported and deposited by geological processes [6]. The mechanical properties of sedimentary rock formations are crucial for understanding their stability and behavior under various geological and engineering scenarios. In Bangladesh, sedimentary rocks like Clay, Conglomerate, Limestone, and Sandstone are more prevalent, with sandstone being the most common [7]. Study of the mechanical properties of these rocks can enhance our understanding of the rock properties in Bangladesh.

In time of drilling or building underground tunnels ‘rock failure’ can be a common incident. To avoid these kinds of incidents rock strength must be studied to assess the stability of the underground equipment [1]. The Uniaxial Compressive Strength (UCS) test and the Indirect Tensile Strength (ITS) test are two of the fundamental tests to estimate rock quality. Rebound Number (R) testing by the Schmidt rebound hammer determines the hardness of the rock. Normally large machineries, long procedures, and experiments are required to determine the UCS and ITS where the rebound number can be determined only using a carriable rebound hammer. Sometimes it can be problematic to obtain cores of the right sizes for UCS and ITS tests. In such cases, engineers need to rely upon rebound hardness for design purposes.

Many recent studies have correlated different mechanical properties of rock from different parts of the world, such as R and UCS, R and point load index. Amjad et al. [1] established the relationship between the rebound number and both the UCS and the ITS for the northern Irani rocks testing claystone, sandstone, and limestone. A statistical analysis was performed based on the results of the tests. Farah [2] studied the UCS and other mechanical properties of aged Ocala limestone and established correlations among the studied properties. The author concluded that correlation between the UCS and the ITS was better than the correlation between the UCS and the point load index.
Saptono et al. [3] performed the UCS and the Schmidt hammer tests on sedimentary rocks from Warukin Formation at Tutupan open pit coal, South Kalimantan, Indonesia, and constructed a highly reliable empirical

equation. Nazir et al. [4] examined UCS and the Schmidt hammer hardness of Malaysian rocks and established a highly reliable empirical equation to predict UCS using Schmidt rebound hardness. Dinçer et al. [5] conducted experiments on different volcanic rocks (andesites, basalts, and tuffs) from the Bodrum Peninsula and developed a relationship among UCS, elastic Modulus (E), and rebound number (R).

So far, few studies have examined the mechanical properties of rocks from Bangladesh. The objective of this study is to develop correlations among the mechanical properties (UCS & R, ITS & R) of sedimentary rocks collected from the Sitakund and Kaptai geological formation which will enable the estimation of UCS and ITS values for rocks from the same formation more easily using the correlations instead of going through the experimental procedures and using large machinery. To the best of our knowledge, this is the first study to develop correlations for determining the geo-mechanical properties of sedimentary rocks in Bangladesh.

2. Experimental procedure

This section discusses the geographical origin of the rock samples, describes the preparation process of the samples for the experiments, specifies the quantity of samples obtained, and details the experimental procedures conducted.

Sample collection

Three rock specimens were extracted from the geological layers near the cascading waterfalls of Sitakund Eco Park in Chattogram, and three were collected from a small waterfall of Kaptai (Fig 2), and prepared for detailed experimental analysis. Figure 1 displays the locations of the extracted sample.

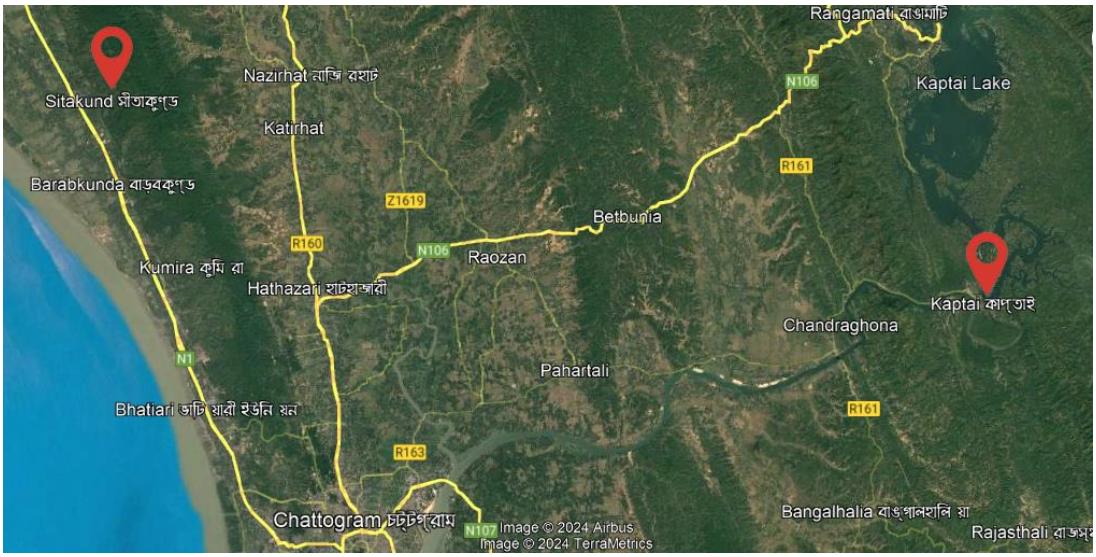


Fig. 1. Location and geological map of the study area.



Fig. 2. Sample extraction from the study area.

Core preparation

After collecting the rock specimens, core samples were prepared from three distinct specimens within the Core Analysis Laboratory of the Department of Petroleum and Mining Engineering at CUET (Chittagong University of Engineering and Technology), where the rocks underwent initial plugging followed by precision cutting to achieve the required dimensions (**Fig**. **3, 4** and **5**). The measurement of prepared core samples are presented in Table 1.



Fig. 3. Plugging



Fig. 4. Cutting



Fig. 5. Prepared Cores

Table 1. Dimensions of the prepared cores

Test Type	Average Diameter	Average Thickness
UCS	54 mm	108 mm
ITS	54 mm	27 mm

Performing the tests

After preparing, the cores were dried thoroughly. Subsequently, the rebound hammer test, UCS test, and Tensile Strength test were conducted on the cores. The Schmidt rebound hammer and automatic strength testing machine were used for carrying out these tests.



Fig. 6. Schmidt hammer test



Fig. 7. UCS test



Fig. 8. ITS test

Schmidt rebound hammer test: The Schmidt rebound hammer is a simple, carriable device that can determine the rebound hardness (R) of rock specimens. This test is a non-destructive test. So that, the same specimen used in this test can be used again for another test. To determine the rebound number the test was done on all the prepared core samples using a Schmidt rebound hammer with a strike stroke of 75 mm and impact energy of 0.735 Nm.

UCS and ITS test: Strength is one of the most crucial mechanical properties of rock which can be assessed by the UCS test and the ITS test. A large number of samples are needed for both UCS and ITS tests and done very carefully. Both of the tests are destructive tests. The test samples can't be re-used after the tests.

For this research, both the UCS and the ITS tests were done by the Automatic Strength Testing Machine on 9 core samples for each test prepared from the collected rock specimens. The machine has a maximum capacity of 4000

kN and the loading rate was 0.5 MPa/s. For UCS test all the specimens had a thickness to diameter ratio of 2 and for ITS test the ratio was 0.5.

3. Results and Discussion

The uniaxial compressive and the indirect tensile strength tests were carried out on a total of 9 core samples prepared from three different rocks. Sample 1 to 7 were prepared from the rocks collected from Sitakund region and the remaining two samples were prepared from rock of Kaptai region.

Unfortunately, three additional rocks from these regions became unusable due to internal fractures that became visible during core sample preparation. Later on, it was not possible to collect more rocks, which might have increased the accuracy of the experiment.

Table 2. UCS and Schmidt rebound hammer test

Sample no.	Rebound Number (R)	UCS (MPa)
1	35	34.2
2	42	79.3
3	19	14.9
4	36	42.5
5	15	17.24
6	18	22.42
7	32	28.34
8	22	25.5
9	18	15.8

The R values of the samples for the UCS test range from 15 to 42 (**Table 2**). Most of the UCS values from the experiment lie approximately between 15 MPa to 43 MPa except the UCS value of sample no. 2. It has a higher UCS value (79.3 MPa) that lies far above the range of the UCS of other samples. This sample may have undergone more intense diagenesis or compaction, increasing the cementation between grains, making the rock more resistant to deformation.

Table 3. ITS and Schmidt rebound hammer test

Sample no.	Rebound Number (R)	ITS (MPa)
1	48	7.86
2	45	9.56
3	22	1.46
4	21	1.96
5	42	8.69
6	31	4.5
7	30	4.88
8	32	2.99
9	20	3.45

For the samples prepared for the ITS test, the Rebound hardness number varies between 20 to 48 (**Table 3**). The ITS values are in the approximate range of 1.5 MPa to 9.5 MPa.

The UCS and the ITS values were plotted against the rebound number based on the experimental results. The plots (**Fig** 9 and **Fig** 10) display the trendlines, linear equations, and the R^2 values.

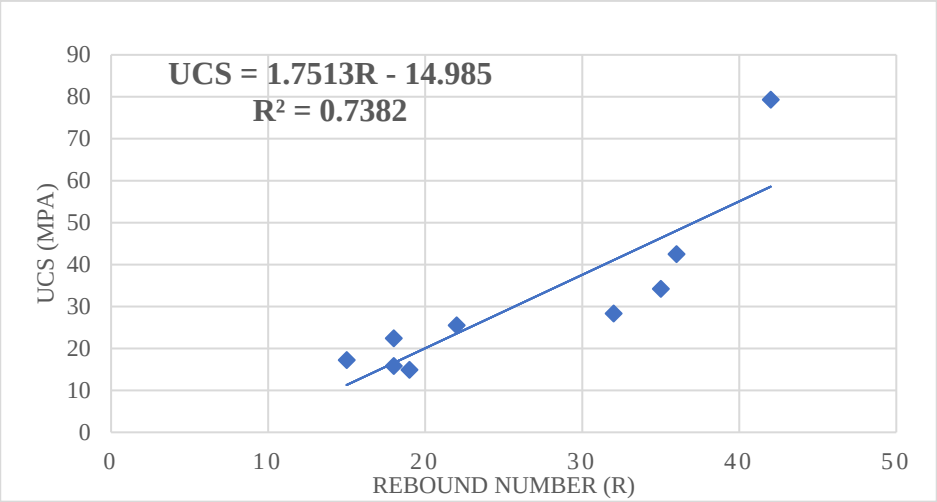


Fig 9. Relationship between the UCS and R

The graph for the relationship between the UCS and R was plotted with R values on the x-axis and the UCS values on the y-axis. The equation for this relationship is based on the trendline of the graph,

$$\text{UCS} = 1.7513\text{R} - 14.985 \quad (1)$$

The R^2 value of this graph is 0.7383. If the data from sample no. 2 had not been used, the trendline would be more accurate, and the R^2 value would be closer to 1.

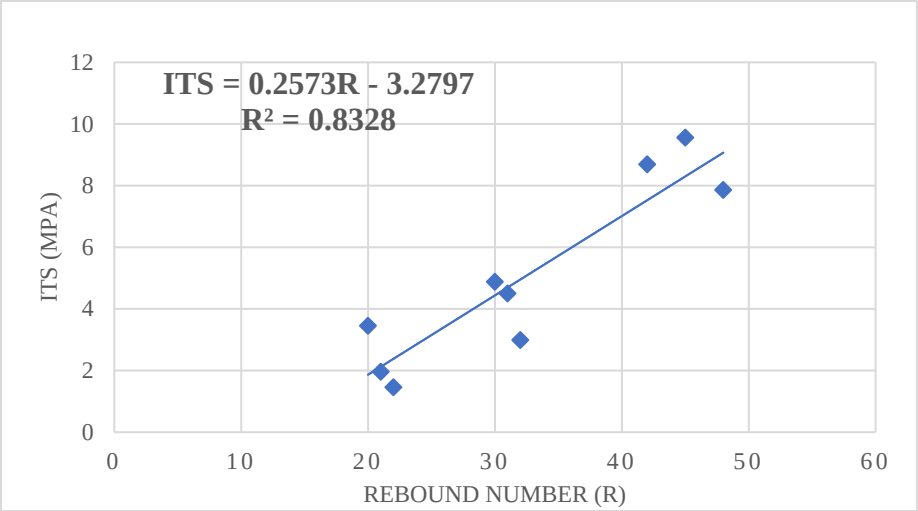


Fig 10. Relationship between the ITS and R

The graph depicting the relationship between the ITS and R was created with R values on the x-axis and ITS values on the y-axis. The equation developed from this relationship is,

$$\text{ITS} = 0.2573\text{R} - 3.2797 \quad (2)$$

The R^2 value of this graph is 0.8328, indicating higher accuracy of the equation.

Validation

Two different rocks (one from Sitakund and another one from Kaptai) were used to check the reliability of the developed equations. Core samples for both UCS and ITS tests were prepared from these rocks.

Table 4. Relative Deviation of the developed equations

Sample No.	Rebound Number	Test Type	From Equation	From Experiment	Relative Deviation
A(Sitakund)	27	UCS	32.3 MPa	28.42 MPa	12.01%
A1(Kaptai)	16	UCS	13.04 MPa	13.84 MPa	5.78%
B(Sitakund)	32	ITS	4.95 MPa	5.98 MPa	17.22%
B1(Kaptai)	30	ITS	4.44 MPa	3.91 MPa	13.55%

The relative deviation was calculated using the experimental value as the reference. The highest deviation was observed in sample B (17.22%) while the lowest deviation was in sample A1 (5.78%).

4. Conclusion

The main objective of this study was to develop correlations between R and UCS as well as R and ITS of sandstone rocks collected from the Sitakund and Kaptai geological formations in Chattogram, Bangladesh. The key findings are:

- The developed correlation for ITS showed greater R-squared value (83.28%) compared to the UCS (73.82%).
- The UCS values predicted by the developed equation deviated by 5.78% from experimental values for Kaptai region sample, with a maximum deviation of 12.01% for sample from Sitakund.
- For ITS, approximately 15% deviation was exhibited for samples from both regions.

The equations developed from this study could be useful at the early stages of design to determine rock strength and they should only be used for sandstone rock types.

5. Limitations

If it was possible to do the experiments by collecting more rock samples, the experiment would be more accurate and the equations would be more reliable. As the equations were developed by using the rock of rebound hardness ranging from 15 to 48, the equations can be useful around this range.

6. Recommendations

For further studies, using more rock samples and equipment without error might lead to better results.

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