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Geomechanical Evaluation of Lumle Rock (Pahara) Using Schmidt Hammer Rebound Testing for Assessing Rock Climbing Suitability

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Abstract: The surface hardness and estimated compressive strength of Lumle Rock (Pahara), situated in the Annapurna Rural Municipality of Kaski District, Nepal, were investigated using the Schmidt hammer (rebound hammer) test, a standardized non-destructive testing (NDT) method. This technique was employed to evaluate the geomechanical properties of the rock formation with specific attention to its potential for recreational rock climbing and site-specific geotechnical applications. Rebound values were collected in situ and statistically analyzed to determine characteristic strength at confidence intervals of 80%, 90%, and 95%, following the guidelines of IS 13311-Part 2. Critical factors influencing rebound measurements, including aggregate mineralogy, surface texture, moisture content, carbonation effects, and weathering conditions, were systematically considered and controlled where applicable. The results indicated that Lumle Rock (Pahara) exhibits sufficient surface hardness and mechanical integrity to support rock climbing activities. However, to ensure climber safety and to inform potential engineering uses, it is recommended that further subsurface investigations, including calibration, be conducted. The application of Schmidt Hammer testing in this context demonstrates the value of rapid, cost-effective assessment methods for evaluating the mechanical suitability of natural rock formations for recreational and civil engineering purposes.

Keywords: Schmidt hammer; Rebound number; Non-destructive testing; Compressive strength; Carbonation; Geotechnical survey; Rock climbing potential

1 Introduction

Rock climbing has seen a remarkable rise globally, evolving from a mountaineering sub-discipline to a mainstream adventure sport recognized in events like the Tokyo 2020 Olympics [1]. Its growth has been driven by increasing interest in fitness, competition, and outdoor exploration, with climbing gyms and natural crags attracting enthusiasts worldwide [2]. In Nepal, although overshadowed by mountaineering, rock climbing is steadily gaining momentum, especially among youth. Areas such as Hattiban, Nagarjun, and Bimal Nagar are becoming popular climbing spots, supported by growing indoor facilities and community-led efforts [3]. The sport's low environmental impact and potential to boost local economies further add to its appeal [4].

Nepal's diverse geology, formed at the collision boundary of the Indian and Eurasian plates, offers ideal rock formations for climbing. From sedimentary Siwaliks to metamorphic zones like the Lesser Himalayas with quartzite and schist, and crystalline gneiss of the Higher Himalayas, these formations present varied textures, friction, and strength necessary for different climbing styles [5]. In particular, recent assessments in Lumle, Kaski—a site located at 1,720 meters—have confirmed suitable quartzite and phyllite rocks for safe climbing. The local government has endorsed Lumle as a rock-climbing destination, integrating geological evaluation and tourism development [6]. This blend of natural geology and emerging adventure tourism marks a promising future for climbing in Nepal.

To evaluate the geomechanical integrity and suitability of Lumle Rock (Pahara) as a sustainable rock climbing site, NDT was conducted. The Schmidt rebound hammer test was used extensively to estimate the surface hardness and compressive strength of the exposed rock without altering or damaging the natural surface, thereby preserving the site's authenticity for adventure tourism. The rebound numbers obtained were interpreted according to IS 13311 (Part

2): 1992, which provides standard procedures for using rebound hammer devices on concrete and rock surfaces. These results revealed that the site predominantly consists of medium- to strong-quality phyllite and quartzite, meeting safety standards required for climbing activities. The NDT approach also included visual inspections and joint mapping to evaluate surface discontinuities, weathering grades, and joint spacing—factors critical for long-term stability and climber safety. By adopting non-invasive evaluation methods, the study ensured compliance with global best practices in rock mass classification and geotechnical safety, as guided by the International Society for Rock Mechanics (ISRM) [7].

2 Materials and Methods

2.1 NDT Using Schmidt Rebound Hammer

To evaluate the surface hardness and estimate the compressive strength of exposed rock surfaces at the Lumle (Pahara) site, the Schmidt rebound hammer test was adopted. This test is classified as an NDT method, meaning it does not cause any physical damage to the structure being tested. It is particularly suitable for rock and concrete surfaces where preserving the integrity of the material is essential, especially in natural and heritage sites [8].

2.1.1 Equipment features

The Schmidt rebound hammer (also known as the Swiss hammer) is a mechanical device consisting of a spring-loaded mass that strikes a piston when pressed against a surface. Key features of this device that make it favorable for field testing include:

a) Non-destructive: Since the hammer does not penetrate or fracture the material, it allows repeated use at different test locations without damaging the structural integrity of the surface [9].

b) Portability and ease of use: The hammer is lightweight and handheld and requires minimal technical skill to operate. This makes it ideal for remote or difficult-to-access areas such as hillsides, cliffs, or uneven rock surfaces [10].

c) Rapid results: The rebound number can be read directly from the scale immediately after the test is performed. These values are used with standardized correlation charts to estimate compressive strength quickly, providing an advantage in real-time assessments [11].

2.1.2 Working principle

The Schmidt rebound hammer operates on the principle of surface hardness measurement. When the plunger of the hammer is pressed against the rock surface, a spring-driven mass is released that strikes the plunger. The distance the mass rebounds after impact—known as the rebound value or number—is measured on a graduated scale. This rebound number correlates with the compressive strength of the material through empirically derived charts provided by the manufacturer and standardized in international testing guidelines [7].

The rebound number is influenced by several factors such as surface roughness, moisture content, carbonation, and the type and age of the material. Therefore, interpretation must be done with caution and multiple readings are recommended for reliable results [12].

2.1.3 Testing procedure

The following step-by-step procedure was used for conducting the rebound hammer tests at the site:

Step 1: Preparation and calibration: Before beginning the actual test, the hammer was unlocked and checked on a hard calibration surface to verify proper functioning of the internal mechanisms, especially the rebound rod and spring tension.

Step 2: Positioning: At each chosen test point, the hammer was held perpendicular to the rock surface. The rebound rod was pressed steadily until the spring mechanism released the internal mass to strike the plunger.

Step 3: Reading the rebound number: The mass rebounded and moved a pointer, which stopped at the highest rebound distance. This value was recorded as the rebound number for that point.

Step 4: Repetition and averaging: The test was repeated at a minimum of ten evenly distributed locations across the test surface to ensure a representative data set. Areas with visible cracks, weathering, or irregularities were avoided.

Step 5: Surface preparation: Test surfaces were cleaned using a wire brush to remove dust, lichen, or debris that could affect rebound measurements. Care was taken to test on relatively smooth and dry surfaces [13].

Step 6: Resetting the device: After each reading, the hammer was reset and locked to prepare for the next test point.

Finally, statistical analysis of the rebound numbers was carried out to calculate the mean, standard deviation, and characteristic strength at various confidence levels. This data was used to interpret the in-situ condition and estimated compressive strength of the rock formations at the Lumle site. Figure 1 shows the field application of the Schmidt rebound hammer for the Lumle Rock.

Figure 1. Field application of the Schmidt rebound hammer for the Lumle Rock

3 Analysis

To evaluate the in-situ mechanical properties of the Lumle Rock (Pahara) formation, NDT was conducted using the Schmidt rebound hammer. The field investigation was carried out at the designated Lumle Rock (Pahara) climbing site, located on the hill slope identified as Section 1. The procedure adhered to the guidelines set forth in IS 13311 (Part 2): 1992 and the standards discussed in the Journal of Engineering Sciences, Vol. 13, Issue July 07, 2022, ISSN: 0377-9254.

3.1 Method of Analysis

The compressive strength of rock samples was estimated using the Schmidt rebound hammer testing method, with rebound values (R-values) recorded as per IS 13311 (Part 2): 1992 and corroborated by relevant literature in the Journal of Engineering Sciences, Vol. 13, Issue July 07, 2022. The rebound values obtained from field measurements were then converted to compressive strength (N/mm^2) using established correlation charts and mathematical formulas. Statistical parameters such as mean, standard deviation, and characteristic compressive strength were calculated. The characteristic strength was determined at 80%, 90%, and 95% confidence levels using the following formula:

$$f_{ck} = f_{ct} - k \times \sigma \tag{1}$$

where, f_{ck} is the characteristic compressive strength, f_{ct} is the average compressive strength (target strength), k is the probability factor (1.28 for 80%, 1.65 for 90%, 1.96 for 95% confidence), and σ is the standard deviation of compressive strength (N/mm^2).

While the Schmidt rebound hammer test is a widely accepted method for non-destructive assessment of rock compressive strength in field conditions, it is known that several factors influence the rebound values and, therefore, the accuracy of the results. These factors must be carefully considered to ensure the reliability of the strength estimations.

Surface roughness is one of the most critical factors influencing the rebound value. A rough or uneven surface can lead to reduced rebound readings because the hammer impacts the surface irregularly, disrupting the energy transfer. To minimize this, the testing surface was cleaned and smoothed before measurements, ensuring consistent results [14]. Moisture content also significantly affects the rebound value. High moisture content in rock can lead to a decrease in the rebound value, as water softens the rock's surface and reduces its ability to return the energy from the hammer impact. The tests were conducted on dry rock surfaces, and moisture content was kept to a minimum during testing to mitigate its influence [15]. Rock texture and mineral composition play a role in the rebound number, as rocks with dense, uniform textures generally exhibit higher rebound values compared to those with more porous or heterogeneous structures [14]. The mineral composition and grain size distribution of the rock are essential for interpreting the rebound values accurately, as these properties determine the overall mechanical properties of the material.

Additionally, the orientation of the Schmidt hammer relative to the rock surface can introduce variability in rebound readings. This orientation, along with the impact energy of the hammer itself, can lead to small fluctuations in the measured rebound values, as discussed by ISRM (2007). Environmental factors, such as temperature, humidity, and altitude, can also affect the performance of the Schmidt hammer. High temperatures, for example, can influence the elasticity of the hammer's spring mechanism, leading to slight variations in rebound measurements [16]. For consistency, the tests were performed under controlled ambient conditions to limit these effects.

To address the inherent variability due to these factors, the testing protocol involved conducting multiple rebound measurements at each test site, with results cross-verified using laboratory-based destructive testing methods. These adjustments were necessary to ensure that the rebound hammer results accurately reflect the true compressive strength of the rock, taking into account the influencing parameters.

The probabilistic approach used for calculating characteristic strength (f_k) at different confidence levels (80%, 90%, and 95%) further enhances the reliability of the results, ensuring that the design strength estimates are robust and applicable for engineering purposes.

Table 1. Rebound hammer test results and corresponding estimated compressive strengths for Lumle Rock (Pahara) climbing site

S.N.	R-Value	Compressive Strength (N / mm^2)	Remark
1	30	20.0	Consistent
2	30	20.0	Consistent
3	30	20.0	Consistent
4	30	20.0	Consistent
5	30	20.0	Consistent
6	40	34.0	High strength
7	40	34.0	High strength
8	40	34.0	High strength
9	40	34.0	High strength
10	40	34.0	High strength
11	36	26.0	Moderate
12	40	34.0	High strength
13	30	20.0	Consistent
14	35	24.0	Moderate
15	30	20.0	Consistent
16	52	50.0	Very high
17	50	52.0	Very high
18	40	34.0	High strength
19	40	34.0	High strength
20	46	38.0	High strength
21	31	20.0	Consistent

As shown in Table 1, the rebound hammer test results from the Lumle Rock (Pahara) climbing site indicate a wide range of compressive strength values, classified into different strength categories based on R-values. A significant number of readings (S.N. 1–5, 13, 15, 21) with R-values around 30–31 consistently correspond to a compressive strength of 20.0 N/mm², indicating a uniform zone of lower-strength rock. In contrast, several readings (S.N. 6–10, 12, 18, 19) with R-values of 40 reflect a higher compressive strength of 34.0 N/mm², showing a consistent section of rock with better load-bearing capacity. Moderate strength zones are identified in entries like S.N. 11 and 14, with R-values of 35–36 resulting in strengths around 24–26 N/mm². The highest strength readings, with compressive strengths of 50.0 and 52.0 N/mm² (S.N. 16 and 17), result from R-values of 52 and 50, and are categorized as "very high," suggesting excellent rock quality in isolated spots. Overall, the dataset reveals a heterogeneous rock formation, varying from consistent low-strength zones to patches of very high strength, implying the need for localized analysis for safe infrastructure development.

The following statistical parameters were calculated for statistical analysis:

- Mean rebound value (R): 36.05
- Average compressive strength (CS): 27.71 N/mm^2
- Standard deviation (σ): Calculated based on the dataset

The rock exhibits moderate to high compressive strength, with some zones exceeding 50 N/mm^2, indicating suitability for climbing. The standard deviation highlights variability in rock strength, necessitating further geotechnical assessment for critical load-bearing sections. The characteristic strength at 95% confidence ensures structural reliability for climbing infrastructure [17–20].

3.2 Graphical Representation of Test Data

Figure 2 shows the rebound value distribution. This bar chart shows the R-values from 22 concrete samples, with most values clustering around the average of 36.05. It reflects good surface hardness, indicating generally consistent concrete quality.

Figure 3 shows the R-value vs. compressive strength. The scatter plot reveals a strong positive correlation between rebound values and compressive strength, proving that higher R-values reliably predict stronger concrete.

Figure 4 shows the strength category distribution. The chart shows that most concrete samples (47.6%) fall in the medium strength range (25–40 N/mm^2), while 42.9% are in the low strength category ($<$25 N/mm^2), raising concerns about quality. Only 9.5% of samples show high strength ($>$40 N/mm^2), highlighting the need for better material control.

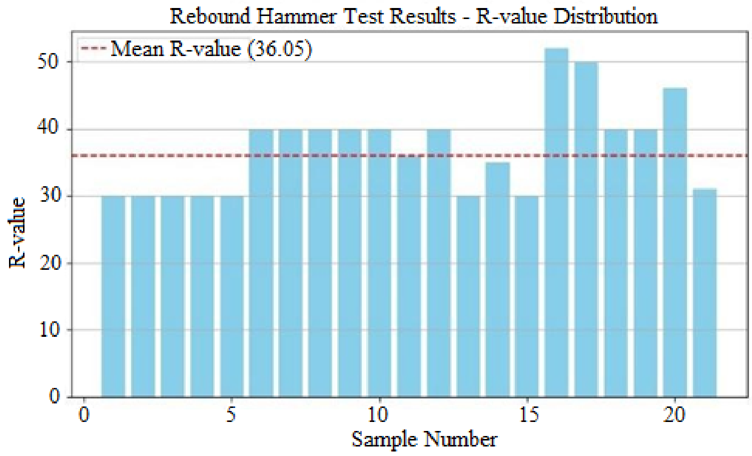

Figure 2. Rebound value (R-value) distribution

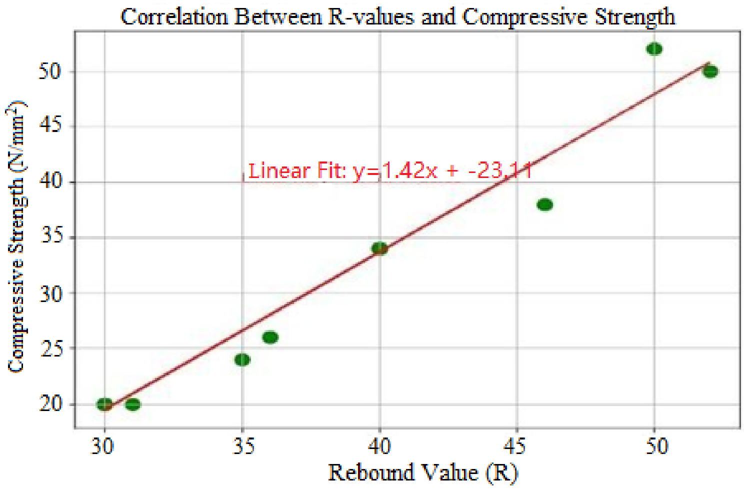

Figure 3. Compressive strength vs. R-value correlation

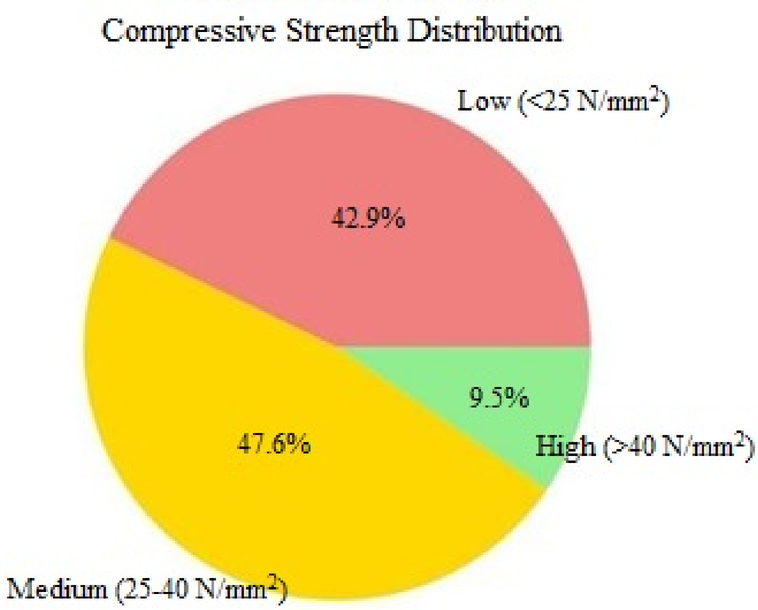

Figure 4. Strength category distribution

3.3 Complete Dataset Analysis

Table 2 shows the results of the complete dataset analysis.

3.4 Calculated Parameters

The mean compressive strength (f_m) was calculated as follows:

$$f_m = \frac{\sum f_i}{n} = \frac{582}{21} = 27.71 \text{ N/mm}^2 \tag{2}$$

The standard deviation (σ) was calculated as follows:

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} = \sqrt{\frac{1748.6}{21}} = 9.12 \text{ N/mm}^2 \tag{3}$$

3.5 Characteristic Strength (f_k) Calculation

$$f_k = f_m - k \cdot \sigma \tag{4}$$

Table 3 shows the characteristic strength values.

3.6 Statistical Validation

The Coefficient of Variation (CoV) was calculated as follows:

$$\text{CoV} = \frac{\sigma}{f_m} \times 100 = \frac{9.12}{27.71} \times 100 = 32.9\% \tag{5}$$

CoV<35% indicates acceptable consistency for rock mass characterization (per ISRM guidelines).

3.7 Recommendation

Table 4 shows the recommended design strengths and safety factors for application scenarios. To support the practical implementation of these values in the field, three key considerations were outlined, i.e., zoning classification, safety factor application, and supplementary testing.

Table 2. Complete dataset analysis results

Sample	R-Value	Comp. Strength (N / mm^2)	$(x_i - \bar{x})^2$
1	30	20.0	59.2
2	30	20.0	59.2
...	...	...	...
21	31	20.0	59.2

Table 3. Characteristic strength values at different confidence levels

Confidence Level	k-Factor	Calculation	f_k (N/mm^2)
80%	0.84	$27.71 - (0.84 \times 9.12)$	20.05
90%	1.28	$27.71 - (1.28 \times 9.12)$	16.04
95%	1.65	$27.71 - (1.65 \times 9.12)$	12.66

Table 4. Characteristic strength values at different confidence levels

Application	Confidence Level	Design Strength (N/mm^2)	Safety Factor
Temporary climbing holds	80% ($f_k = 20.05$)	20.05/1.5	**13.37**
Permanent anchors	95% ($f_k = 12.66$)	12.66/2.0	**6.33**

a) Zoning plan

- Green zones (R>40): Anchor points

- Yellow zones (30≤R≤40): Moderate use
- Red zones (R<30): Restricted

b) Safety factors:

- Temporary routes: Use f_k at 80% confidence (20.05 N/mm^2)
- Permanent fixtures: Use f_k at 95% confidence (12.66 N/mm^2)

c) Additional tests:

- Ultrasonic pulse velocity for weak zones
- Annual Schmidt hammer monitoring

4 Conclusion

NDT using the Schmidt rebound hammer method was successfully conducted on concrete surfaces at the Lumle Rock (Pahara) climbing site, located on the hill slope identified as Section 1. The results provided a quick and effective estimation of in-situ compressive strength without causing any damage to the structure. Based on the rebound values obtained from 21 test points and using standard correlations from the Proceq manual in line with IS 13311 (Part 2): 1992, the average rebound number was computed to be 36.05, corresponding to an average compressive strength of 27.71 N/mm^2.

Using probabilistic methods, the characteristic compressive strengths were calculated for varying confidence levels. The analysis indicates that the concrete in the tested section meets satisfactory strength requirements and exhibits uniformity in strength distribution with minimal deviations. This confirms the reliability and suitability of the concrete for intended structural and recreational use. Furthermore, the rebound hammer technique proved to be efficient and practical for onsite strength evaluation, especially in remote hilly terrains like Lumle.

Data Availability

The data supporting our research results (Schmidt Rebound Hammer test readings and corresponding compressive strength values) are included within the article and supplementary material. Additional raw data may be available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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