Utilization of the point load index method as an estimator of rock compressive strength in civil engineering

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Abstract. Lawa Cave is one of the geotourism sites located in Purbalingga, Central Java, specifically on the eastern slope of Mount Slamet. The large number of tourists visiting each year and the construction of several buildings inside the cave necessitate an assessment of how strong Lawa Cave is in terms of its load-bearing capacity. This study aims to analyze the compressive strength of the rock and provide recommendations on the safety level of the cave in withstanding the load from building structures and visitors. In this study, field observations and primary data collection were conducted, involving the collection of rock samples from several points within the cave. These rock samples were then analyzed at the Rock Mechanics Laboratory of the Mining Engineering Program at Institut Teknologi Nasional Yogyakarta. Rock compressive strength testing was conducted using the Point Load Index testing method. Conversion of the Point Load Index test results to rock compressive strength values was 11.21 MPa until 37.57 MPa. This value indicates that the Lawa Cave rock mass has adequate bearing capacity for structural buildings, suitable as a support layer for light to medium structures with recommended reinforcement such as rock bolts, wire mesh, and shotcrete.

1 Introduction

Geotechnical analysis and underground structural engineering depend on rock strength. Uniaxial Compressive Strength (UCS), which refers to the ability of rock to withstand axial compressive loads without lateral forces, is the most commonly used parameter [1]. UCS values are an important reference in foundation planning, slope stability, and tunnel design [2]. However, UCS testing is often time-consuming and costly because it requires perfectly cylindrical rock samples and high-pressure testing equipment in a laboratory [3]. On the other hand, the Point Load Index (PLI) method can be used to calculate rock compressive strength quickly and cost-effectively. For this test, a concentrated load is

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applied to two points on the rock surface until failure occurs. The point load index value (Is(50)) is then calculated and converted to the UCS value using an empirical correlation factor. According to the International Society for Rock Mechanics [4], the relationship between UCS and PLI can be described by the general empirical formula for UCS, which is 24 × Is(50). However, this factor may vary depending on the type of rock and its geological conditions. In sedimentary, igneous, and metamorphic rocks, the PLI method has a good correlation with UCS [5, 6].

2 Literature review

2.1 Unconfined Compressive Strength (UCS) in civil engineering

In civil engineering, unconfined compressive strength (UCS) is a key mechanical parameter that indicates the ability of rock to withstand axial compressive forces without lateral pressure [1]. The planning and design of various geotechnical structures, including slope stability, caves, tunnels, and foundations, are greatly influenced by the UCS value. According to [2], UCS testing is carried out by loading a cylindrical rock sample until it collapses. The results are classified as very low, low, medium, high, and very high [9]. However, the UCS laboratory test requires a cylindrical test specimen made of intact rock with a flat and parallel surface, 50 mm in diameter, with a height to diameter ratio of 2:1. Specifically, at the Gua Lawa research site, such test specimens cannot be obtained due to the historical value of the cave and the need to maintain its stability to prevent collapse. Therefore, in order to still be able to test the compressive strength of the rock, the Point Load Index method was chosen, where the rock samples could be irregular rocks with small fragments. The results of the Point Load Index test can be converted to UCS using an empirical factor.

2.2 Point Load Index (PLI) method

The Point Load Index (PLI) method was developed by Broch and Franklin in 1972 [5] as an alternative rapid test method for calculating rock compressive strength without the need for perfectly cylindrical specimens. The Point Load Index method is suitable for use in difficult locations such as slopes, cave walls, or tunnels. PLI testing is also very useful in the early exploration stage to quickly estimate the mechanical properties of rock in the field.

The test is carried out by applying a concentrated load at two points on the rock surface until failure occurs. The maximum load value at the time of failure is recorded as force (P), and the distance between the ends of the load points is measured as the equivalent diameter (De). The Point Load Index (Is) value is calculated using the formula :

$$I_s = \frac{P}{{D_e}^2} \qquad (1)$$

To standardize sample size conditions, the Is value was corrected to a standard diameter of 50 mm using the following correction equation :

$$I_s(50) = F \times I_s \qquad (2)$$

where F is the size correction factor [3, 4]). The Is(50) value is then converted to the UCS (Uniaxial Compressive Strength) value using the empirical relationship recommended by [4] and [1], with the general formula:

$$UCS = k \times I_s(50) \qquad (3)$$

where k is an empirical factor that varies between 20–25 depending on the rock type. In this study, a factor of k = 24 was used, which is appropriate for andesitic volcanic rock [5, 6].

2.3 Classification of rock strength based on SNI and ISRM

Several national regulations, such as SNI 13-6724-2002 [10], accept rock classification based on UCS values, which have been standardized by ISRM (2007) [4]. According to these standards, rocks with UCS between 5 and 25 MPa are considered “weak”; rocks with UCS between 25 and 50 MPa are considered ‘medium’; and rocks with UCS greater than 100 MPa are considered “very strong.” This classification is very important for determining civil structure planning methods involving rock masses.

For example, when designing highway foundations and tunnels, rock with a UCS below 30 MPa must be reinforced with additional layers or undergo geotechnical improvements such as grouting or rock bolting [8]. Table 1 presents rock classification based on UCS values according to SNI and ISRM, along with technical recommendations for their use in civil structure design.

2.4 Relevance of the PLI method in civil engineering applications

The PLI method has the main advantages of ease of implementation and cost efficiency, especially for initial geotechnical surveys or areas with limited laboratory access. Several studies have shown a strong correlation between UCS and PLI values with a coefficient of determination (R^2) between 0.70 and 0.90 in various types of rock [6]. Therefore, this method is highly relevant for quickly estimating rock strength in the field before conducting a full UCS test.

In the context of civil engineering planning in volcanic areas such as Lawa Cave, the application of the PLI method provides a rational basis for determining the suitability of rock for foundation construction, highways, and slope reinforcement structures. The use of this method is in line with the spirit of efficiency and accuracy in modern geotechnical surveys recommended by [4] and [10]. The classification of rocks based on UCS values according to [4] and [10] is shown in Table 1 below.

Table 1. Classification of rocks based on UCS values according to SNI and ISRM

Rock Class	UCS Range (MPa)	General Physical Description	Technical Recommendations	Example Rock Types
Very Weak Rock	< 5	Easily crushed by hand; can be scratched with a fingernail; highly weathered	Not recommended for direct foundations. Requires soil improvement or grouting. Not stable for steep slopes or	Hard clay, weathered claystone

			basements without significant reinforcement.	
Weak Rock	5 – 25	Easily crushed with a light hammer; somewhat compact; moderately weathered	Can be used for shallow foundations with wide load distribution slabs. Reinforcement systems such as rock bolts, wire mesh, and shotcrete are required for slopes or cave walls.	Tuff, soft sandstone, weathered limestone
Moderately Strong Rock	25 – 50	Difficult to break with a hammer; relatively hard and dense	Suitable for direct foundations of medium-sized buildings. Stable for slopes of 45–60° with little reinforcement.	Andesite, slightly weathered basalt
Strong Rock	50 – 100	Very hard; can only be broken with a heavy hammer	Suitable for direct foundations of multi-story buildings. Rock slopes are relatively stable without major reinforcement	Fresh basalt, granite, dense limestone
Very Strong Rock	100 – 250	Very dense and hard; difficult to break; cracks slightly	Excellent for bridge foundations, tall buildings, and dams. Does not require slope reinforcement except on open discontinuity planes.	Diorite, hard granite, gneiss
Extremely Strong Rock	> 250	Cannot be broken with a hammer; can only be cut with a drill	Ideal for heavy building foundations and underground structures. Excavation requires heavy mechanical equipment or controlled blasting.	Quartzite, fresh granite, crystalline basalt

3 Research methodology

3.1 Research area

This research was conducted in the Lawa Cave area, located in Siwarak Village, Karangreja District, Purbalingga Regency, Central Java Province. Geographically, this area is located at coordinates approximately 7°16' south latitude and 109°22' east longitude, with an altitude of ± 800 meters above sea level. This area is a geological tourist area dominated by andesite volcanic rocks resulting from ancient volcanic activity. Based on the Regional Geological Map of Purwokerto and Tegal [7], the rock formations around Lawa cave consist of andesite lava, volcanic breccia, and tuff that have undergone moderate to high weathering.

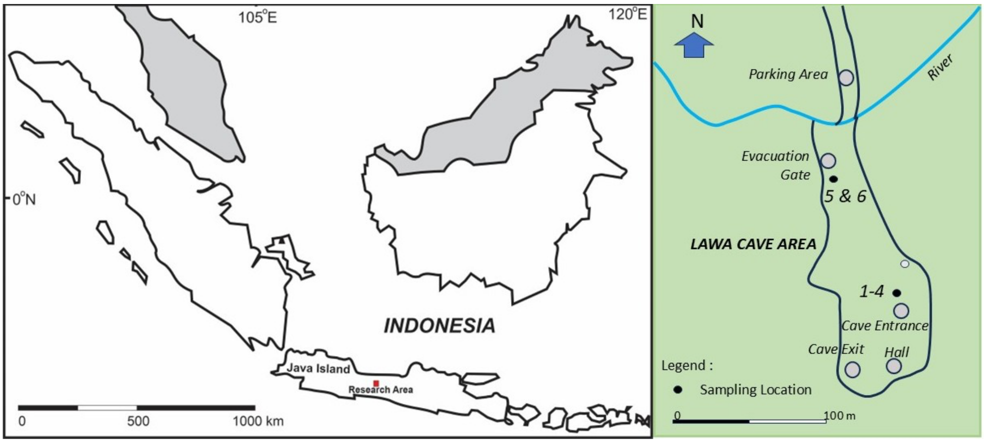

Fig 1. Map of observation locations

3.2 Rock sampling

Rock samples could only be taken from the ruins of the cave walls and cliffs around the cave, but the rock samples were representative of important parts of the tourist route available inside the cave. The selection of sampling locations took into account the compactness of the rock, the level of weathering, and lithological representativeness. Each sample was given an identification code and stored in an airtight container to avoid changes in moisture content that could affect the strength test results. A total of 6 rock samples were obtained from two main points, namely the cave entrance and nearly the evacuation gate as shown in Figure 1. The study utilized only six specimens due to strict preservation requirements at Lawa Cave, where rock extraction is limited to naturally fallen fragments to maintain its historical integrity. Such limitations are common in geotechnical investigations in protected environments, necessitating minimal destructive sampling [11]. Despite this small sample size, point load testing, as specified by the [3], can yield representative strength estimations if specimens are collected from varied locations and orientations to reflect geological variability. Opportunistic sampling of fallen blocks is also acknowledged as a valid method in heritage caves when coring isn't feasible [12], supporting the scientific justification of the sample size in this research within ethical and international guidelines.

3.3 Laboratory testing

3.3.1 Point Load Index (PLI)

The testing was conducted at the Rock Mechanics Laboratory, Institut Teknologi Nasional Yogyakarta, using a Point Load Tester in accordance with the procedures of the [4]. Each sample was tested by applying a concentrated load at two points on the surface until the rock failed. Each sample was tested three times and the results were averaged to obtain a representative Is (50) value.

3.3.2 Conversion of PLI Values to UCS

The Is(50) value was then converted to the UCS value using the empirical relationship recommended by [4] and [1]. In this study, a factor of k = 24 was used, which is appropriate for andesitic volcanic rock [5, 6].

3.3.3 Data analysis and interpretation

To determine the strength category of Lawa Cave rock, the conversion results were compared with the rock strength classification according to [10] and [4]. The UCS values of each sample were then grouped and compared with the classification limits for weak, medium, and strong rock. In addition, the analysis findings were compared with the Bina Marga Geotechnical Design Guidelines [8]. This was done to evaluate the suitability of the rock as a base material for foundations or road pavements.

4 Results and discussion

Based on the test results at the ITNY Rock Mechanics laboratory, the point load index (Is(50)) of Lawa Cave rock ranged from 0.49 MPa to 1.63 MPa. Using the empirical conversion factor UCS = 24 × Is(50) [4, 5], the rock compressive strength (UCS) values obtained ranged from 11,21 MPa to 37,57 MPa. The validation of the general conversion factor $k = 24$ for estimating UCS from PLI was examined through a simple linear regression analysis using the six rock samples collected from Lawa Cave. The regression between UCS and corrected point load strength $\left(I_s(50)\right)$ produced a strong linear correlation with a coefficient of determination $R^2 = 0.99$, indicating that more than 90% of the variability in UCS can be explained by the point load index as shown in Figure 2. The resulting regression equation UCS $= 23.05\, I_s(50)$ suggests a local conversion factor $k_{\text{lokal}} = 23.05$, which closely aligns with the widely used global value $k = 24$ recommended for volcanic and sedimentary rocks [3,5]. These results reinforce the methodological reliability of applying the standard UCS–PLI conversion in this study.
The rock classifiation values based on lab test resuts indicate that most of the rock in the Lawa Cave area falls into the low to medium strength category based on the [4] and [10] classifications, where weak rock has a UCS of 5-25 MPa and medium rock ranges from 25-50 MPa as shown in Table 2 below. The physical characteristics of Lawa Cave rock indicate that samples with higher weathering levels have lower UCS values. Rocks with higher compressive strength values originate from the interior of the cave, which is safer from weathering and moisture. The results of research by [13], which show that the degree of weathering and water content greatly affect the compressive strength of volcanic rock, are consistent with these findings.

Table 2. Rock classification based on UCS conversion using the PLI method

Sample code	LOAD (kN)	De (mm)	F	I_S PLI (MPa)	UCS (MPa)	UCS Range (MPa)	Rock Class
Sample 01	7.80	73.11	0.79	1.16	26.67	25 – 50	Moderately Strong Rock
Sample 02	10.50	82.71	1.00	1.53	35.30	25 – 50	Moderately Strong Rock

Sample 03	10.30	77.55	0.95	1.63	37.57	25 – 50	Moderately Strong Rock
Sample 04	5.30	90.08	1.00	0.65	15.02	5 – 25	Weak Rock
Sample 05	4.80	103.40	1.09	0.49	11.21	5 – 25	Weak Rock
Sample 06	13.30	96.31	1.04	1.50	34.43	25 – 50	Moderately Strong Rock

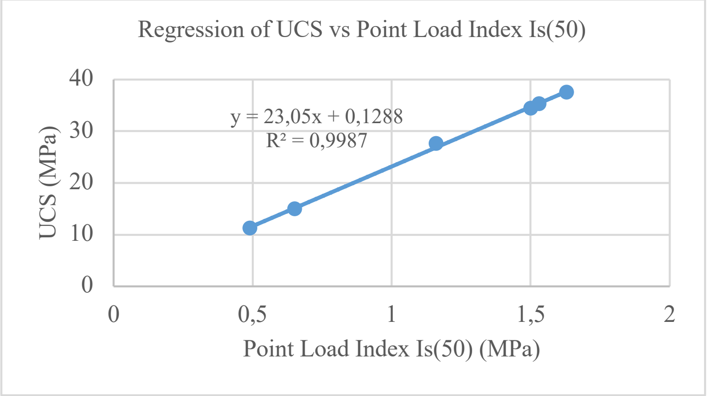

Fig 2. Linear Regression Graph of UCS vs Point Load Index Is(50)

Based on the [4] and [10] classifications, Lawa Cave rock has moderate potential to support light to medium civil structures. Rocks with an UCS greater than 20 MPa can withstand shallow foundation pressures of up to 200–300 kN/m² when used for foundations [1]. Meanwhile, low-strength rock (UCS < 25 MPa) tends to be prone to landslides and weathering when exposed to weather and rainwater if used for slope reinforcement. Therefore, additional reinforcement such as bricks, shotcrete, or retaining walls is required, combined with a surface drainage system [9]. This reinforcement is important because the characteristics of Lawa Cave volcanic rock, caused by the lava cooling process, tend to have vertical and horizontal fracture planes. If the slope is not properly reinforced, it can reduce slope stability.

Specifically [8] states that low-strength rock (UCS < 25 MPa) is not recommended for use as a main foundation layer without stabilization or additional reinforcement. However, with geotechnical treatments such as compaction, geotextile reinforcement, or graded rock coating, rocks with UCS greater than 30 MPa can still be used to improve the subgrade or subbase layer. This study is also in line with the results of [14], who stated that rocks with UCS between 15 and 30 MPa still have sufficient bearing capacity when used as light foundations with limited loads.

5 Conclusion

The UCS values converted from PLI testing on Lawa Cave rock samples ranged from 11.21 MPa to 37.57 MPa, which according to the SNI 2002 and ISRM classifications falls within the weak–moderately strong rock category. This value indicates that the rock mass in the Lawa Cave area still has sufficient bearing capacity for structural buildings in the cave location. In addition, Lawa Cave rock can be used as a support layer for light to medium structures, but additional reinforcement is needed. The recommended reinforcement includes the use of rock bolts, wire mesh, and shotcrete on the walls and ceiling of the cave.

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