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Comparative Analysis and Evaluation of the Conversion Formula for Rebound Number of Schmidt Hammer Test and Unconfined Compressive Strength Test – Case Study: Andesite Rock Slope in Graha Puspa, Lembang Fault

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Abstract

The Unconfined Compressive Strength (UCS) test is one of the most common methods for determining the rock material strength value. However, the size and complexity of the instrument do not allow UCS testing to be carried out in the field. The UCS value can be estimated in the field by converting the rebound number using the Schmidt hammer test. This research aims to carry out a comparative analysis and evaluation of the conversion formula for rock compressive strength values resulting from the Schmidt hammer test and UCS test in a case study of andesite rock slopes at Graha Puspa, Lembang Fault, Bandung, Indonesia. Rock hardness testing was carried out using the Schmidt hammer test on five segments at Graha Puspa. UCS testing was carried out using a compressive strength machine on four samples in Graha Puspa. The test results show a rebound number value ranging from 31.67 - 45, while the UCS test results show a value range of 134.96 – 171.60 MPa The results of the previously published empirical equations differed considerably from the results of the UCS tests on rock samples in the laboratory when estimating the UCS values. From this evaluation, this research proposed formulation development of andesite rock formulation in the Lembang Fault area. However, UCS testing on more samples is highly recommended in order to obtain a compressive strength conversion formula that is more suitable for the case study at this location.

Keywords:
Schmidth hammer; UCS; rock material strength; Graha Puspa

1. Introduction

Uniaxial compressive strength is a parameter that is often used to describe the mechanical properties of rocks (**Akbay and Ekincioğlu, 2023; Rai et al., 2014**). The unconfined compressive strength (UCS) test is the most accurate and widely used method for obtaining rock strength. The UCS test is carried out with the pressing of a rock sample by an instrument equipped with a device for recording the value of the applied load. The UCS test equipment is large and complicated, making it impossible to carry out UCS tests in the field. In some research areas, rock samples cannot be obtained according to the test sample standards. Destructive samples are impossible because the research area includes a cultural heritage area, a populous area, a tourist area, and private property.

The Schmidt hammer is an easy device in the field. In general, the Schmidt hammer is a device used to estimate UCS value in determining rock hardness (**Aydin and Basu, 2005; Bolla and Paronuzzi, 2021; Mohammed et al., 2020; Saptono et al., 2013; Wang et al., 2017**). In recent decades, Schmidt hammers have been used for various purposes, including determining the physical and mechanical properties of rock for evaluating the production of rock cutting machines (**Goktan and Gunes, 2005; Khoshouei et al., 2020; Mikaeil et al., 2021**), determining joint wall strength (**Bolla and Paronuzzi, 2021; Sow et al., 2016; Zadhesh and Majdi, 2022**), determining discontinuities wall strength (**Solak and Tuncay, 2023**), determining rock quality in large samples (**Briševac et al., 2023**), determining drill-

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Figure 1: Study area (from Google Maps).

ing rate and penetration (**Aslan et al., 2022; Ataei et al., 2015**), and the Schmidt hammer can even be used to determine the geological dating age of rocks (**Matthews and Winkler, 2022; Shakesby et al., 2006**). Therefore, the conversion value of the Schmidt hammer rebound number determines the characteristics of various rock materials.

The Schmidt hammer is a non-destructive rock strength test in the form of a pressing hammer and can be used directly in the field. Schmidt hammers are divided into two types, that is type L and type N. Schmidt hammer type N is widely used in field application while type L is better used in in weathering and porous rock (**Ulusay et al., 2015**). The working principle of the Schmidt hammer is to relate the rebound number value (R_N) to the rock compressive strength value. The correlation between rebound number and rock compressive strength can be converted based on empirical assessments of previous research (**Karaman and Kesimal, 2015; Kong and Shang, 2018; Moomivand, 2011; Selçuk and Yabalak, 2015; M. Wang and Wan, 2019; Yagiz, 2009**).

The Lembang Fault Area is an active fault with a sliprate between 1.95 – 3.45 mm/year and is estimated to produce an earthquake of Mw 6.5 – 7 (**Daryono et al., 2019**). The threat of earthquakes along the Lembang Fault area requires rock strength analysis to model its stability. However, sampling in the Lembang Fault area is difficult because environmental conditions do not allow it. The area around the Lembang Fault is difficult to take sample blocks, among other things, because it is protected by cultural heritage, a populous area, a tourist area, and private property. The determination of rock strength that can be carried out is a test with minimal damage.

This research aims to compare the rock strength results obtained from compression strength tests in the laboratory and Schmidt hammer tests in the Lembang Fault area, focusing on the igneous rock slope object at Graha Puspa. This research also intends to evaluate the conversion formula for the Schmidt hammer rebound number taken from five outcrop cross-sections and rock strength values from four sample blocks. The methods used in this research are literature studies, unconfined compressive strength tests in the laboratory, Schmidt hammer tests in the field, conversion of Schmidt hammer rebound number values to rock strength values, a comparative analysis of the two types of UCS values, and evaluation of the conversion formula for cases at the research area.

The igneous rock in the outcrop is andesite with the appearance of a dark gray aphanitic texture with the dominant minerals consisting of plagioclase and hornblende. The weathering degree of outcrops is fresh to slightly weathered. Weathering is shown on rock surfaces, and discontinuities locally depicted disintegrate and are filled with cohesive material.

2. Research Location

The research location was carried out at test locations, namely the Graha Puspa Site. Administratively, the Graha Puspa Site includes the Cihideung area, Parompong District as shown in **Figure 1**. This location includes West Bandung Regency, West Java Province, Indonesia.

Based on the Bandung Geological Map Sheet (**Silitonga, 1973**), regionally, the geological conditions of the study area are predominantly composed of volcanic rocks originating from young and old volcanic products

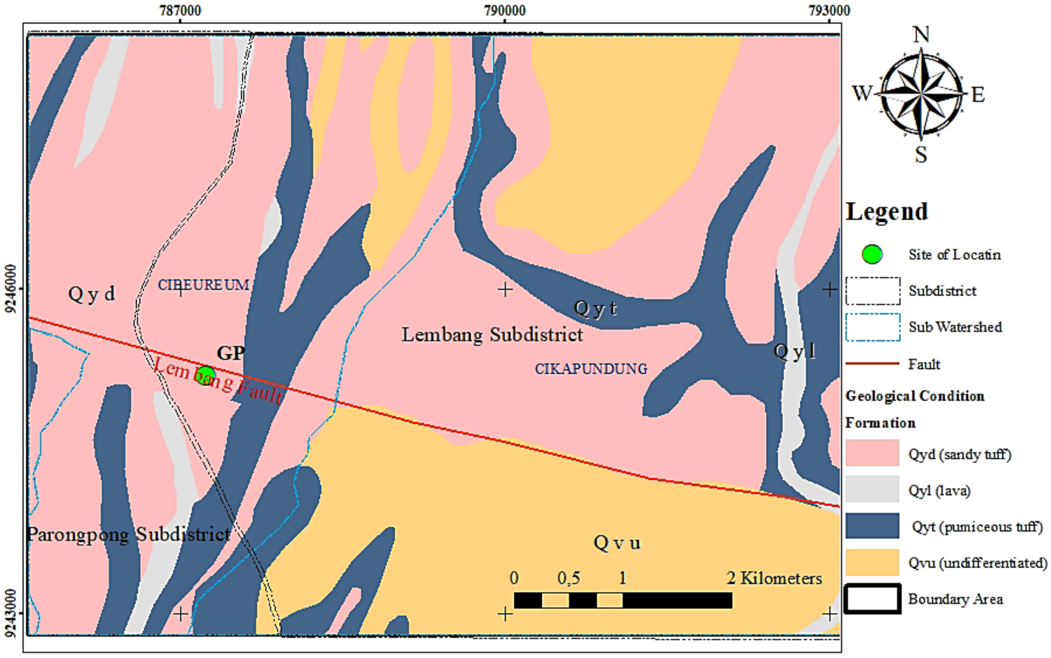

Figure 2: Geological Map (modified from **Silitonga, 1973**).

(see **Figure 2**). The following are the rock formations of the research area from old to young:

a. Qyd (sandy tuff) consists of sandy tuff from G. Tangkubanperahu, brownish sandy tuffs, very porous, containing very coarse hornblende crystals. Also red-weathered lahar, lapilli layers, and breccia.

b. Qyl (lava): consists of young lava flows, mainly from G. Tangkubanperahu. Generally of basaltic composition and scoriaceous.

c. Qyt (pumiceous tuff) consists of tuffaceous sand, lapilli bombs, scoriaceous lava, angular fragments or denseandesitic-basalt, many pumice fragments mostly from G. Tangkubanperahu.

d. Qvu (undifferentiated) is old volcanic product formation namely volcanic breccia, lahar, and lava repeatedly interlayered.

Based on the regional geological structure, the research area is in the active fault Lembang, which is located 10 km north of Bandung, as shown in **Figure 2**. The Lembang Fault is about 29 km long and trends west-east (**Daryono et al., 2019**). From east to west, the height of the fault changes from around 450 meters at Mt. Pulusari, Maribaya, to around 40 meters in Cisarua and then disappears at the Padalarang (**Brahmantyo, 2005**).

3. Methods

This research methodology uses a Schmidt hammer to obtain rock strength data in the field a scanline method to capture the discontinuity condition along the observation area. The value of Schmidt hammer rebound was then compared with the values obtained from laboratory unconfined compressive strength tests. The rebound number obtained from the Schmidt hammer test was converted using a certain formula so that the results are close to the rock strength values obtained from laboratory tests. Data was taken from andesite rocks in Graha Puspa, Lembang Fault area (see **Figure 3**). Unconfined compressive strength samples were obtained along 60 meters of scanline method in station 1 to 4.

3.1. Schmidt hammer method

The Schmidt hammer test begins with a scanline test. Scanline tests were also carried out to obtain areas of discontinuity in the field. The existence of discontinuity areas, including asperities in fresh joints, filling materials, and weathering, can affect the rebound value of the Schmidt hammer. In conditions like this, it is necessary to take a Schmidt hammer on a plate with a minimum thickness of 10 cm.

Block sampling for unconfined compressive strength tests in some areas is difficult, especially in areas protected by cultural heritage, tourist areas, and private areas. Due to equipment size constraints, Unconfined Compressive Strength testing cannot be carried out in the field. The Schmidt hammer test is often carried out to test rock strength in the field. Rock conditions in the field with many variations, especially discontinuity areas, require as much data to be collected to represent the actual conditions of the research area. The Schmidt hammer is a portable, lightweight, and non-destructive tool, making it easy to use directly in the field.

This research obtained rock strength tests on five slope segments at Graha Puspa using Schmidt hammer type N (see **Figure 4**). Type N Schmidt hammer can pro-

Figure 3: Schmidt hammer test and sampling location in the Graha Puspa area.

Figure 4: Schmidt hammer type N test.

duce a respective impact energy of 2.207 Nm and is used on rock materials with a rock strength of 20 – 150 MPa. Tests using a Schmidt hammer were carried out in the test direction perpendicular to the outcrop plane according to ISRM 2014 suggested methods (**Aydin, 2014**). The test surface of the Schmidt hammer should be smooth and free of dust. Fine sandpaper can be used to obtain a surface that meets the requirements. The surface of the test area must be dry; if this condition is not achieved, then the test results must be recorded in damp, humid, or wet conditions.

Schmidt hammer rebound number data was carried out on slopes plane at 1 m intervals in lithological domains that have the same characteristics. This test is done to obtain a test range value that represents rock strength. The Schmidt hammer test consists of a spring-loaded steel mass that impacts against the surface so that the spring touches the surface and is released onto the plunger. The results of the impacts are called the rebound number (R), which can indicate the rock strength value. The Schmidt hammer test measures the rock strength and can show relative strength when compared with laboratory test results.

3.2. Unconfined Compressive Strength test

The rock strength value is an important mechanical parameter in rock classification. The Unconfined Compression Strength test was carried out to obtain values for uniaxial compressive strength (σ_c), Young's Modulus (E), and Poisson's ratio (υ). The equipment used is the Hung Ta compressive strength machine, a computer device that shows the increase in applied load (see **Figure 5**). The displacement of the sample rock during testing was measured using three dial gauges, namely, one to read axial displacement and two to read lateral displacement. Based on ISRM 2007, the sample rock used has

Figure 5: Hungta Machine of 200 kN, ITB Geomechanics and Mining Equipment Laboratory.

Table 1: Several formulas for converting R values to UCS values.

References	Correlations	r	Validity range		
			Rock type	***UCS***	**R**
Aufmuth, 1974	$UCS = 0.33 \cdot (R_L \times \rho)^{1.35}$	0.80	25 different lithologies	12 - 362	10 -54
Aydin & Basu, 2005	$UCS = 1.45 \cdot e^{(0.07 \times R_L)}$	0.92	Granite		
Beverly et al., 1979	$UCS = 12.74 \cdot e^{(0.02 \times R_L \times \rho)}$		20 different lithologies	38 - 218	
Dearman & Irfan, 1978	$UCS = 0.00016 \cdot R_L{}^{3.47}$		Granite		
Deere & Miller, 1966	$UCS = 9.97 \cdot e^{(0.02 \times R_L \times \rho)}$	0.94	28 different lithologies	22 - 358	23 - 59
Dinçer et al., 2004	$UCS = 2.75\, R_N - 36.83$	0.95	Andesite, basalt, and tuffs		
Gupta, 2009	$UCS = 1.15 \cdot R_L - 15$		Granite		
Kahraman, 1996	$UCS = 0.00045 \cdot (R_N \times \rho)^{2.46}$	0.96	10 different lithologies		
Kahraman, 2001	$UCS = 6.97 \cdot e^{(0.014 \times R_N)}$	0.78	Dolomite, sandstone, limestone, marble, granite, diabase, serpentine, hematite		
Karaman & Kesimal, 2015	$UCS = 4.2423 \cdot R_L - 81.92$	0.84	29 different igneous rock		
Kılıç & Teymen, 2008	$UCS = 0.0137 \cdot R_N{}^{2.2721}$		Sedimentary, metamorphic and igneous		

dimensions L/D = 2 – 2.5. The sample length was between 121 mm and 123 mm and the sample diameter was 54 mm. The UCS value was obtained by laboratory tests on four rock block samples at Graha Puspa (**ISRM, 1979; Ulusay & Hudson, 2007**).

Besides the UCS value, the parameters used to convert the rebound value are physical properties, that is, density. The mineral content influences the physical properties of rocks. The rock tested is andesite igneous rock. Physical properties were obtained based on ISRM 1981 suggested methods.

3.3. Correlation factor

Correlation between the UCS value from laboratory tests and the R-value resulting from the Schmidt hammer has been carried out in many previous studies. The ISRM suggested method determined the trend for converting Schmidt hammer rebound number values with unconfined compressive strength values from various types of rock into two formula expressions (see **Equations 1** and **2**). The correlation trend between UCS, and R values is a general expression of:

$$UCS = ae^{bR} \tag{1}$$

$$UCS = aR^{b} \tag{2}$$

Where:

R – value resulting from the Schmidt hammer,

a,b – positive constants depending on the type of rock being tested.

Several formulas have been formulated by previous researchers for converting R values (both R_N from Schmidt hammer type N and R_L from Schmidt hammer type L) to UCS values. Of these several conversions, they were selected based on lithologies, igneous rock type and UCS values that were close to the rock types of samples in Graha Puspa (see **Table 1**). The formulation that used impact value R_L on the Schmidt hammer type L is converted to R_N on the Schmidt hammer type N using the ISRM 2014 suggested methods (**Aydin, 2014**) (see **Equation 3**).

$$R_N = 1.0646\, R_L + 6.3673\ (r = 0.99) \tag{3}$$

In addition, using existing formulations, regression analysis was also carried out based on existing parameters. The regression analysis used is linear (see **Equation 4**) and nonlinear regression analysis. The non-linear regressions used include logarithmic regression (see **Equation 5**), exponential regression (see **Equation 6**), and power regression (see **Equation 7**). From this formulation, a search was carried out for a conversion formulation for Schmidt hammer values and uniaxial compressive strength that was suitable for the rock mass in the Graha Puspa Lembang Fault area.

$$y = ax + b \tag{4}$$

$$y = a + ln\, x \tag{5}$$

$$y = ae^{x} \tag{6}$$

$$y = ax^{b} \tag{7}$$

4. Result and Discussion

4.1. Schmidt hammer test result

The scanline test results show that the spacing of the discontinuity is 0.26 – 0.61 m with an aperture of 0.25 – 100 mm (see **Table 2**). This condition shows that the area is an area with uniform rock conditions. The research surface roughness condition (JRC) was obtained at 10 – 15. The roughness of the test surface can affect

Table 2: Discontinuity condition in Graha Puspa

Station or Depth (m)	Type	Spacing (m)	Aperture / Width	Nature of Filling	Surface Roughness	Surface Shape	JRC	Water Flow
Station 1	Joint	0.43	0.5-10 mm	Non Cohesive	Smooth	Undulating	10	Dry
Station 2	Joint	0.45	0.25-100 mm	Non Cohesive	Rough	Undulating	10	Dry
Station 3	Joint	0.26	0.25-100 mm	Non Cohesive	Rough	Undulating	10	Dry
Station 4	Joint	0.61	0.5-100 mm	Non Cohesive	Rough	Undulating	15	Dry

Table 3: *Rebound* data.

Section	Location	Average Rebound (R_N)	Direction
1	Graha Puspa	31.67	Perpendicular to surface
2	Graha Puspa	39.75	Perpendicular to surface
3	Graha Puspa	40.00	Perpendicular to surface
4	Graha Puspa	42.25	Perpendicular to surface
5	Graha Puspa	45.00	Perpendicular to surface

Table 4: Compressive strength values for the Graha Puspa area.

No	Sample Code	Location	Lithology	*UCS* (MPa)	*density* (g/cm^3)
1	Blok01-GP	Graha Puspa	Andesite	134.96	2.60
2	Blok02-GP	Graha Puspa	Andesite	157.72	2.60
3	Blok03-GP	Graha Puspa	Andesite	158.68	2.61
4	Blok04-GP	Graha Puspa	Andesite	165.63	2.61
5	Blok05-GP	Graha Puspa	Andesite	171.60	2.60

Table 5: Comparison of UCS values using existing formulas.

Sect	Lab	Aufmuth	Aydin	Beverly	Dearman	Deere	Dinçer	Gupta	Kahraman	Kahraman	Kahraman	Kılıç
		1974	2005	1979	1978	1966	2004	2009	1996	2001	2015	2008
	UCS (MPa)											
1	134.96	86.81	7.65	44.05	9.52	34.48	50.26	12.33	23.43	10.86	18.91	35.18
2	157.72	126.19	13.02	65.47	24.91	51.23	72.48	21.06	40.97	12.16	51.11	58.96
3	158.68	127.47	13.24	66.28	25.57	51.87	73.17	21.33	41.61	12.20	52.10	59.81
4	165.63	140.69	15.65	75.10	32.94	58.77	80.18	24.09	48.44	12.65	62.26	68.82
5	171.60	153.70	18.39	84.69	41.35	66.28	86.92	26.73	55.60	13.09	72.03	78.16

Table 6: Proposed formulation between R_N, density and UCS.

No	Proposed formulation	R^2
1	$UCS = 47.799\ (R_N \cdot \rho) + 1.061$	1
2	$UCS = -321.737 + 103.467 \ln (R_N \cdot \rho)$	0.999
3	$UCS = 76.121\ e^{0.007(R_N \cdot \rho)}$	0.997
4	$UCS = 6.610\ (R_N \cdot \rho)^{0.684}$	1

the Schmidt hammer test value, so selecting an area with lower roughness and using sandpaper is necessary.

Graha Puspa area, Lembang, based on Schmidt hammer testing, shows rebound number to (R_N) ranging from 31.67 - 45 (see **Table 3**). Based on the rebound number value, it shows that the rocks in the Graha Puspa area are classified as strong to very strong rocks (**Rai et al., 2014**). Strong rock has the characteristic that it requires

Table 7: Proposed formulation results for andesite rocks in the Lembang area.

Section	R_N	*density* (g/cm^3)	UCS Laboratory (MPa)	UCS Proposed formulation (MPa)
1	31.67	2.60	134.96	135.05
2	39.75	2.60	157.72	157.76
3	40.00	2.61	158.68	158.85
4	42.25	2.61	165.63	165.71
5	45.00	2.60	171.60	171.73

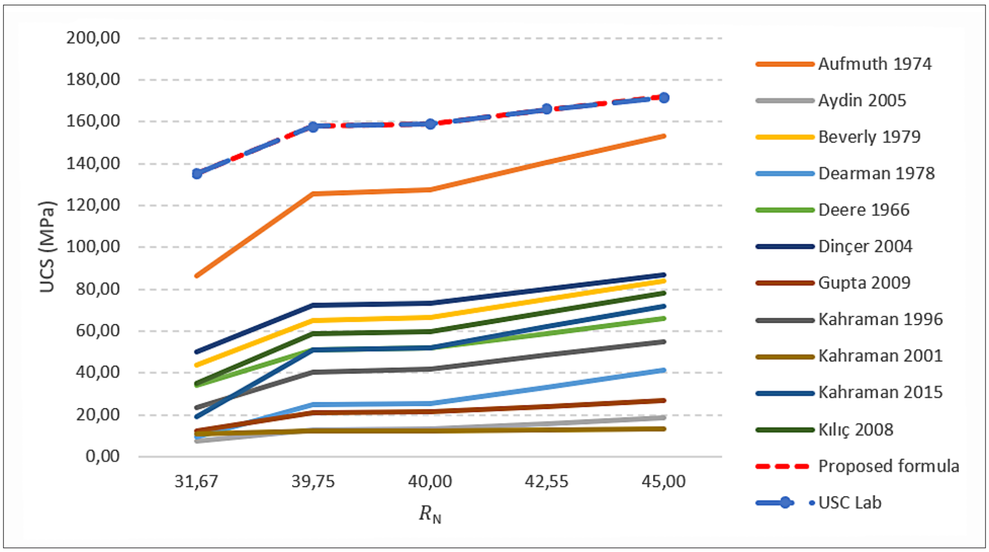

Figure 6: Comparison of correlation formulation between R_N, and UCS.

many blows from a geological hammer to break intact rock.

4.2. Unconfined Compressive Strength test result

The UCS test results show compressive strength values in the range of 134.96 – 171.60 MPa (see **Table 4**). The compressive strength value shows that the rocks in the Graha Puspa area are classified as hard rock (**Bienawski, 1976**) and classified as very strong rocks (**Brown, 1981**). The UCS value of Blok02-GP was obtained from the mean value of four sample blocks from the Graha Puspa area.

4. 3. Proposed formulation

Based on the formulation table, applied to the existing criteria in Graha Puspa (see **Table 1**). Formulated conversion formula that can be applied has similar rock types that classified as igneous rock. The converted UCS value results are then compared with the UCS values laboratory test results (see **Table 5**).

Aufmuth's (1974) conversion formula results in a UCS value that is closer to the UCS laboratory test value. However, the conversion results of **Aufmuth (1974)** are significantly different in estimating the UCS value compared to the results of rock strength tests in the laboratory.

In addition to empirical formulations, regression analysis was also carried out to obtain conversion values based on existing parameters, especially the Graha Puspa area. The results of the regression analysis were obtained as a comparison to obtain a formula that is more suitable for application to the rocks at this research location (see **Table 6**). It is expected that this conversion formula will facilitate further research discussing the strength of rocks in the Lembang Fault area as shown in **Table 7**.

Based on linear and nonlinear regression analysis, the linear and power regression analysis have R^2 equal to 1. Based on ISRM suggested method, formulates converting formulas based on exponential and power equations (see **Equations 1** and **2**). Therefore, from the results of this equation and according to ISRM suggested methods, the proposed formula conversion used for andesite rock in the Lembang area is obtained:

$$\sigma_c = 6.610(R_N \cdot \rho)^{0.684} \qquad (8)$$

The results of calculations using the formulation as shown in **Table 1** have varying results. From the empirical formulation, the closest calculation result is the Aufmuth formulation. Calculation results from other formulations have very different values due to different rock types or the combination of several different rock types. The results of this research show that the proposed conversion formulation has a conversion rebound number value that is in accordance with the laboratory test results as shown in **Figure 6**. The proposed formulation is based on one type of rock located on the Lembang Fault. The proposed formulation has R^2 equal to 1. This R^2 value proves that the Schmidt hammer rebound value has a strong influence on the UCS value. The greater the rebound number value, the greater the UCS value. This proposed formulation can be used as an initial reference for converting rebound number values into UCS values in the Lembang Fault area for andesite rock types. However, testing more rock samples is highly recommended so that correlations and formulas for converting rebound number values into more accurate UCS values can be obtained for case studies at this research location.

5. Conclusions

Based on the results of rock strength testing using a type N Schmidt hammer and testing in the perpendicular direction of the rock plane carried out at Graha Puspa, it is known that the rebound number (R) range is between 31.67 - 45 which are classified as strong to very strong rocks. Based on the results of UCS testing using the Hungta compressive strength machine and the ISRM 2007 method, it is known that the compressive strength of Graha Puspa rock samples ranges from 134.96 – 171.60 MPa which are classified as hard rock to very strong rocks. From various formulas that previous researchers have proposed, there is no match between the rebound number value and the unconfined compression strength value for andesite rocks in the Lembang Fault area. From the existing comparison formula between rebound number values and UCS values, Aufmuth’s formula shows the closest value to the UCS laboratory test. This research proposes a formulation that can be used to calculate the conversion of rebound number values to unconfined compression strength values of andesite rock in the Lembang Fault area. The conversion results of the new formulation show values that are close to laboratory compressive strength values and have R^2 equal to 1. This proposed formula can be used as an initial reference for converting rebound number values into unconfined compression strength values in the Lembang Fault area for andesite rock types. However, testing of more rock samples is highly recommended so that the correlation formula and conversion of rebound number values to UCS values are more accurate and can be obtained for case studies at this research location.

The difference between the Schmidt hammer rebound number results and the UCS laboratory test results is not an absolute value for the rock strength of the andesite rock. In fact, the UCS value is a representation of the intact rock value with fresher intact rock sample conditions so that the results will be optimistic. In contrast, in the Schmidt hammer test, by testing directly in the field will get a value according to the condition of the outcrop rock mass, which has an appropriate value according to the field conditions. Rock mass strength is well valued by in-situ test such as the Schmidt hammer test which penetrates the rock and gives the stress distribution into the rock area that can be affected by discontinuity persistence inside. Hence, the range of rebound value in outcrop testing depends on the rock mass condition and discontinuity. The value that has been converted from the Schmidt hammer to UCS can be a reference for estimating the rock strength of rocks for their engineering properties.

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SAŽETAK

Komparativna analiza i evaluacija formule za pretvorbu broja odskoka Schmidtova čekića u jednoosnu tlačnu čvrstoću – studija slučaja: Kosina andezitne stijene na lokaciji Graha Puspa, rasjed Lembang

Ispitivanje jednoosne tlačne čvrstoće (UCS) jedna je od najtočnijih metoda za određivanje čvrstoće stijenskoga materijala. Međutim, veličina i složenost instrumenta za to ispitivanje ne dopuštaju provođenje takvih testiranja na terenu. Vrijednost UCS-a može se procijeniti na temelju broja odskoka Schmidtova čekića. Cilj je ovoga istraživanja provesti komparativnu analizu i evaluaciju formule za procjenu vrijednosti jednoosne tlačne čvrstoće stijene na temelju određivanja Schmidtove tvrdoće i samoga ispitivanja UCS-a u studiji slučaja za kosine andezitnih stijena na lokaciji Graha Puspa, rasjed Lembang, u blizini grada Bandung u Indoneziji. Ispitivanje tvrdoće stijene provedeno je Schmidtovim čekićem na pet uzoraka na lokaciji Graha Puspa. Ispitivanje jednoosne tlačne čvrstoće provedeno je u laboratoriju pomoću stroja za tlačnu čvrstoću na četirima uzorcima s lokacije Graha Puspa. Rezultati ispitivanja čvrstoće stijene pokazuju vrijednost broja odskoka u rasponu od 31,67 do 45, dok rezultati ispitivanja UCS-a pokazuju raspon vrijednosti od 134,96 do 171,6 MPa. Rezultati prije objavljenih empirijskih jednadžbi znatno su odstupali u procjeni vrijednosti UCS-a u usporedbi s rezultatima ispitivanja UCS-a na uzorcima stijene u laboratoriju. Na temelju ove evaluacije predložena je formula za procjenu čvrstoće andezitne stijene u području rasjeda Lembang. Međutim, preporučuju se daljnja istraživanja koja treba usmjeriti na veći broj testiranja UCS-a kako bi se dobila relevantnija formula za procjenu u studiji slučaja na ovoj lokaciji.

Ključne riječi:
Schmidtov čekić, UCS, čvrstoća stijenskoga materijala, Graha Puspa

Authors' contribution

All the authors of this paper are major contributors with the following contributions: **Antonina Pri Martireni** (M.Eng, assistant researcher, geomechanics) initialized the idea, provided the regression analysis, presented the results, and performed the field work. **Wira Cakrabuana** (B.Eng, assistant researcher, engineering geology) provided work analysis and presented the results. **Koko Hermawan** (M.Eng, assistant researcher, rock mechanics) provided the laboratory analysis, recorded Schmidt hardness, and performed the field work. **Khori Sugianti** (M.Eng, junior researcher, engineering geology) geological map, illustrator, and helped with field work. **Arifan J. Syahbana** (Dr., senior researcher, civil engineering) provided the Schmidt hammer analysis, recorded Schmidt hardness, and performed the field work. **Sunarya Wibawa** (Dr., senior researcher, geotechnical engineering) provided the petrographic analysis, and performed the field work. **Eko Soebowo** (B.Eng, principal researcher, geotechnical engineering) provided the statistics analysis, and performed the field work. **Adrin Tohari** (Dr., principal researcher, geotechnical engineering) managed the process of research and provided the statistics analysis. **Hasan T. Atmojo** (M.Eng, lecturer, geology) provided the geological analysis, and performed the field work.