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RESEARCH ARTICLE

Influence of Weathering On The Mechanical Strength and Factor of Safety of Andesitic Rocks In the Gunung Geulis Area, Jatinangor, West Java, Indonesia

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Abstract

Weathering gradually alters the physical character and engineering performance of volcanic rocks, including andesite, which is commonly found and frequently used for construction and slope-related works within the Gunung Geulis region of Sumedang Regency, Indonesia. To examine how these changes affect mechanical behavior, this study compared the estimated uniaxial compressive strength (UCS) and the resulting factor of safety (FOS) of andesite across different weathering grades. Seventy-eight samples were collected from three geological segments, representing slightly to moderately weathered (Grade II–III) and highly weathered (Grade IV). Point Load Tests (PLT) were performed on all samples, and the resulting indices were converted to estimated UCS values using an empirical correlation. Statistical analyses, including descriptive analysis, the Mann–Whitney test, and two-factor analysis, were performed to assess strength differences between weathering grades and geological segments. These estimated UCS values were then converted into shear-strength parameters through the Generalized Hoek–Brown approach, and the corresponding cohesion and internal friction angle were obtained using RocLab 1.0 software for slope-stability modelling in Slide2. The results show a consistent and marked decline in strength as weathering progresses; overall, the estimated UCS decreases by 59.22% across all investigated segments, demonstrating that increasing weathering reduces the rock strength by more than half. This reduction in rock-mass strength is reflected in the slope-stability analyses, where slopes composed of SW–MW andesite produced FOS values ranging from 3.518 to 4.271, indicating relatively stable slope conditions, whereas HW andesite yielded lower FOS values ranging from 1.191 to 1.307, representing comparatively lower and marginally stable conditions. These findings demonstrate that progressive weathering significantly reduces the mechanical performance and slope stability of andesitic rock in the Gunung Geulis area.

Keywords: Andesitic Rock, Gunung Geulis, Weathering, Uniaxial Compressive Strength (UCS), Factor of Safety (FOS).

1. Introduction

Weathering is a natural process that alters the physical and chemical properties of rock materials through prolonged exposure to atmospheric, hydrological, and biological processes (Goel and S Mitra, 2021; Pieters and Noble, 2016; Robert et al., 2021). This process progressively reduces the strength reduction and engineering performance of rocks, particularly in near-surface environments where most civil engineering activities are conducted (Miščević and G Vlastelica, 2014). Weathering affects the mechanical properties of rock material and rock masses on the surface and at depths through physical and chemical weathering processes (Chiu and Ng, 2014). Physical and chemical weathering progressively alter a rock's fabric and mineralogy, significantly affecting the rock's strength, as most strength-related engineering properties decrease with increasing weathering (Fahimifar and Soroush, 2007; Vásárhelyi and Ván, 2006). It is crucial to describe how weathering affects the strength properties of rocks, including their transitional material, from slightly weathered to moderately weathered (SW-MW) rock to highly weathered (HW) to give valuable geotechnical information for the design of mining and civil works (Marques et al., 2020). Weathering of rock masses leads to the formation of infill material within discontinuities such as bedding planes, joints, and fractures at both macro and micro scales (Damares et al., 2024; Lan et al., 2022), reducing intact rock strength and the fragmentation of larger blocks into smaller pieces, which typically affects stability and the strength of the rocks (Hilman et al., 2026; Tating et al., 2015).

In tropical regions, such as Jatinangor, Indonesia, weathering processes are more intense due to consistently high temperatures and frequent rainfall (Marques et al., 2017; S Kusnadi, 2017). The Gunung Geulis area of Sumedang Regency, Jatinangor, consists of Tertiary sedimentary and volcanic rocks, including clay, marl, tuffaceous clay, volcanic breccia, agglomerate, conglomerate, lapilli, lava, and notably andesitic rocks, which are highly susceptible to weathering (Fig. 1) (Fadillah et al., 2024; Martireni et al., 2023; Putri et al., 2021). These rocks vary in composition and structure, resulting in differences in stress-strain relationships and deformation characteristics, which are further influenced by temperature and humidity as integral factors in the weathering process (Gökceoğlu et al., 2000). Weathering progressively modifies the physical and mechanical characteristics of the rocks, ultimately influencing slope stability and factor of safety (FOS) values.

Andesitic rocks in the Gunung Geulis area are widely utilized as construction materials for road pavements, foundations, and aggregate resources (Simatupang et al., 2024); however, these rocks exhibit varying degrees of weathering, ranging from SW–MW to HW conditions (Orhan et al., 2006; Taufiq et al., 2022). Previous studies in the Gunung Geulis and Jatinangor region have primarily focused on slope instability, discontinuity characteristics, and regional geological conditions, while limited attention has been given to the quantitative relationship between weathering grade, estimated UCS, and FOS of andesitic rocks. In particular, an integrated evaluation combining Point Load Test (PLT)-derived estimated UCS, Hoek–Brown rock mass characterization, and Slide2-based slope stability analysis has not previously been reported for the Gunung Geulis area. Therefore, this study aims to evaluate the influence of weathering on the estimated UCS and corresponding FOS of andesitic rocks across three geological segments (GG1–GG3) in the Gunung Geulis area. The findings provide site-specific geotechnical information relevant to slope hazard assessment and engineering design in tropical volcanic terrains.

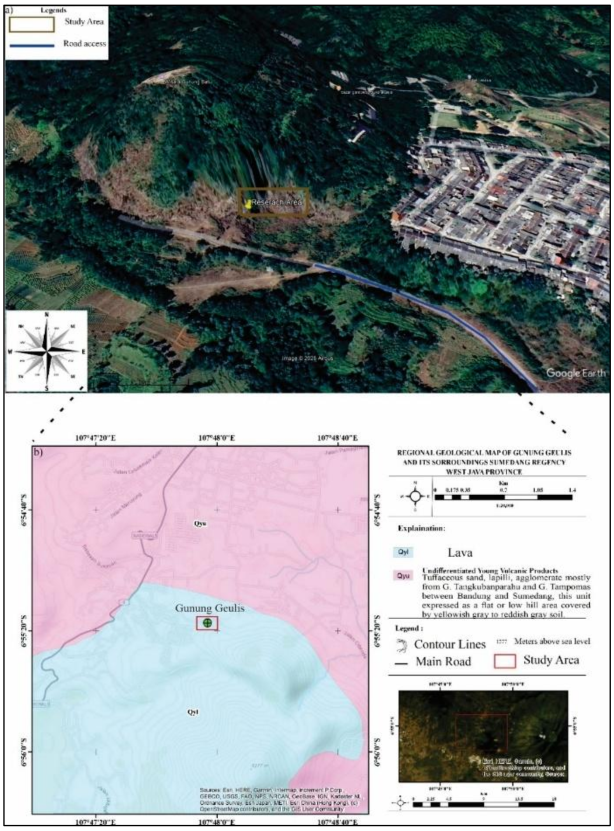

Fig. 1 Location of the research area a) Google Earth image of the Study Area b) Regional geology of the Gunung Geulis area and its surroundings, Sumedang Regency, West Java Province (Modified from Silitonga, 1973).

2. Methodology

This research was conducted in the Gunung Geulis region of Sumedang Regency, Jatinangor, West Java, Indonesia, situated at an elevation of 1,000 meters above sea level (Taufiq et al., 2021). A broad landscape view of the Gunung Geulis research site is presented in (Fig. 2a). Based on the Bandung Geological Map Sheet adopted by (P. H Silitonga, 1973), the study area is located within the Qyu geological unit, which consists of undifferentiated young volcanic products (Fig. 1). This unit is composed predominantly of tuffaceous sand, lapilli, agglomerate, and volcanic breccia derived mainly from Mount Tangkubanparahu and Mount Tampomas. According to the geological map, the Qyu unit is generally exposed as relatively young volcanic deposits with limited weathering development. The investigated outcrops within the Gunung Geulis area occur near the contact between the Qyu unit and the adjacent Qvl lava unit, forming the general topography and andesitic rock exposures where sampling was conducted. To investigate how weathering influences the estimated UCS of andesitic rocks in the Gunung Geulis area, the study area was divided into three segments, designated GG1, GG2, and GG3. The abbreviation reflects the location name, with both letters referring to Gunung Geulis. At the same time, the numbers distinguish the three mapped zones shown in (Fig. 2a). From these segments, 78 rock specimens were collected in total, 39 SW–MW and 39 HW. Each segment contributed the same number of specimens, consisting of 13 SW–MW and 13 HW specimens, as illustrated in (Fig. 2b, c). The SW–MW samples were labeled F1S1 to F13S1, F1S2 to F13S2, and F1S3 to F13S3, whereas the HW samples were labeled W1S1 to W13S1, W1S2 to W13S2, and W1S3 to W13S3. In this coding scheme, the letter represents the weathering grade, while S1–S3 indicate the geological segment of each specimen. Weathering classification was conducted based on the weathering-grade descriptions proposed by International Society for Rock Mechanics (ISRM, 1981), supported by Schmidt Hammer rebound measurements to evaluate surface hardness. SW–MW andesite was characterized by relatively fresh grey to light grey coloration, preservation of the original rock texture, and higher resistance to hammer impact, producing clearer rebound responses (Fig. 2b). In contrast, HW andesite exhibited brownish to reddish discoloration, weathered surface textures, localized disintegration, and reduced resistance to hammer impact (Fig. 2c). Schmidt Hammer rebound values (R-values) ranging from 30–50 were classified as SW–MW, whereas rebound values below 30 were classified as HW, following the approach of (Martireni et al., 2024) (Table 1). Grade II and Grade III samples were grouped into a single SW–MW category because both grades exhibited relatively similar field characteristics, overlapping Schmidt Hammer rebound responses, and comparable estimated UCS distributions during laboratory evaluation. Most specimens from both grades consistently fell within the R3 strength classification, indicating limited mechanical separation between the two weathering grades under the investigated conditions.

Table 1. Weathering classification criteria for andesitic rocks in the Gunung Geulis area.

Weathering Grade	Field Characteristics	Schmidt Hammer Response
SW–MW (Grade II–III)	Grey to light grey coloration, original texture preserved, relatively intact structure, minor weathering features	R-value = 30–50
HW (Grade IV)	Brownish to reddish discoloration, weathered surface texture, localized disintegration, weakened structure	R-value < 30

Description: SW-MW; **s**lightly to moderately **w**eathered, HW; highly **w**eathered.

The precise coordinates of each segment were noted by Global Positioning System (GPS) as 6°55'16.55"S, 107°47'57.71"E for GG1; 6°55'17.99"S, 107°47'56.81"E for GG2; and 6°55'19.00"S, 107°47'55.36"E for GG3. The mechanical behavior of the andesite specimens was analyzed in the geotechnical laboratory through the PLT, as illustrated in (Fig. 2e,f). All testing adhered to the procedures outlined by the ISRM, along with applicable American Society for Testing and Materials (ASTM) guidelines, to maintain consistency and reliability in the results (Widmann, 1996). Irregular lump specimens were tested following ISRM suggested procedures for PLT. Specimen dimensions, including width, diameter, and length, were measured prior to testing to determine the equivalent core diameter (De). Load was progressively applied until visible tensile failure occurred (Fig. 2f). The point load index (Is) was subsequently corrected to the standardized Is50, using the ISRM size-correction factor (F). The estimated UCS values were then calculated using the empirical relationship UCS = 24 × Is50. Detailed raw testing parameters, including specimen dimensions, correction factors, failure mode, Is values, Is50, and estimated UCS values for all samples, are provided in the Supplementary file. All collected specimens were considered suitable for testing, and no specimens were rejected during the laboratory analysis. For each specimen, Is50 was obtained by applying an increasing load to the sample until it failed, and this value served as the basis for estimating UCS. The obtained Is50 values were then converted into estimated UCS values using the empirical correlation UCS = 24 × Is50, as suggested by (Tsiambaos and Sabatakakis, 2004). Although empirical PLT–UCS conversion factors may vary depending on lithology, and weathering conditions, the conversion factor proposed by (Tsiambaos and Sabatakakis, 2004) was adopted because it has been widely applied for volcanic rocks with mechanical characteristics comparable to andesite. Direct UCS laboratory testing was not conducted in the present study; therefore, the estimated UCS values should be interpreted within the limitations of empirical PLT-based correlations. Nevertheless, the consistent application of the selected conversion factor across all specimens allows comparative evaluation of weathering-related strength variations among the investigated segments, while detailed PLT raw-data tables are provided in Supplementary file. Descriptive statistical analysis was carried out to determine the mean and standard deviation (SD) of estimated UCS values, as well as to assess the differences between SW-MW and HW specimens. An interval plot was plotted to display the spread and variation of estimated UCS values for both SW-MW and HW andesite groups using Minitab statistical software (Fig. 4). To quantify the influence of weathering on rock strength, the percentage reduction in estimated UCS between the SW–MW and HW samples was computed for each geological segment. The calculation compared the difference between the mean estimated UCS of the two weathering grades relative to the SW–MW value, providing a proportional measure of strength loss due to weathering. This approach allowed the reduction in estimated UCS to be expressed as a clear percentage, enabling direct comparison among the three segments

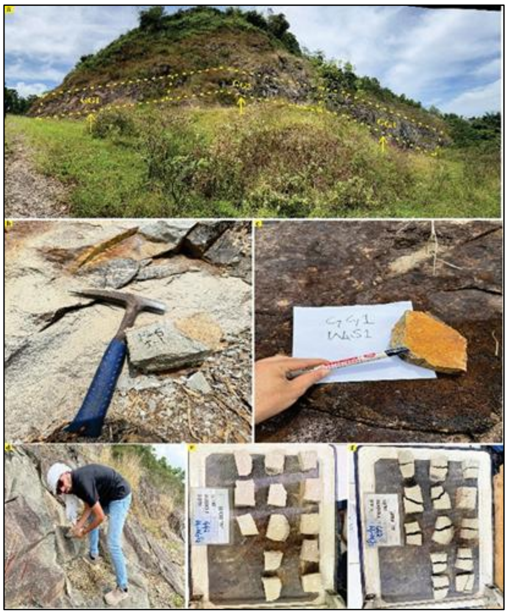

Fig. 2. a) Panoramic view of the Gunung Geulis area, along with sampling segments (GG1, GG2, and GG3). b-c) sample of SW-MW and HW from the outcrops d) Use of a Schmidt Hammer during the collection of SW-MW and HW andesite samples e-f) Andesitic rocks before and after the PLT.

To analyze slope stability, the limit equilibrium method (LEM) was applied through the Slide2 software. The Bishop Simplified method was applied assuming circular slip surfaces, whereas the Janbu Simplified and Spencer methods were applied assuming non-circular slip surfaces (Low and Tang, 1997; Spencer, 1967). The input shear strength parameters cohesion (c) and friction angle (φ) were derived from RocLab 1.0 Software for volcanic rocks (Hoek and Brown, 1997; Singh and Goel, 2012).

3. Results

3.1 Influence of weathering on UCS

The PLT was converted to estimated UCS values using the correlation UCS = 24 × Is50 (Tsiambaos and Sabatakakis, 2004). This approach allowed the comparison of strength differences between SW-MW and HW across the three segments (GG1, GG2, and GG3). The results indicate a consistent contrast in strength between the two weathering grades (Table 2).

In the GG1 segment, SW-MW andesite samples recorded a mean estimated UCS of 35.55 MPa, with a standard error (SE) of 1.51 MPa and SD of 5.43 MPa. The estimated UCS measurements varied from a minimum of 25.8 MPa to a maximum of 45.28 MPa, with Q1 at 31.83 MPa, a median of 35.9 MPa, and Q3 at 39.34 MPa. Based on these values, the SW-MW samples from GG1 fall within the R3 strength class. In contrast, the HW andesite samples in GG1 showed a lower mean UCS of 14.17 MPa, accompanied by an SE of 1.61 MPa and SD of 5.80 MPa. The estimated UCS values ranged between 5.55 MPa and 22.82 MPa, with Q1 = 8.30 MPa, a median of 14.79 MPa, and Q3 = 18.78 MPa, classifying them within the R2 strength class. The percentage reduction in estimated UCS caused by weathering in GG1 is calculated as 60.15%.

In the GG2 segment, SW-MW andesite samples recorded a mean estimated UCS of 39.19 MPa, accompanied by an SE of 2.67 MPa and an SD of 9.62 MPa. The estimated UCS values range from 25.34 MPa at the minimum to 62.70 MPa, with Q1 = 32.76 MPa, a median of 39.35 MPa, and Q3 = 43.89 MPa. These findings categorize the SW-MW samples in GG2 within the R3 strength class. In contrast, HW samples recorded a mean UCS of 18.09 MPa, with an SE of 1.35 MPa and an SD of 4.85 MPa. The estimated UCS values varied from 7.49 MPa to 24.46 MPa, with Q1 = 15.62 MPa, a median of 17.89 MPa, and Q3 = 23.06 MPa, placing them within the R2 strength class. The percentage reduction in estimated UCS caused by weathering in GG2 is calculated as 53.84%.

In the GG3 segment, the SW-MW andesite samples exhibited the highest strength, with a mean estimated UCS of 43.92 MPa, an SE of 1.12 MPa, and an SD of 4.03 MPa. The estimated UCS values ranged from 37.39 MPa to 50.98 MPa at the maximum, with Q1 = 40.82 MPa, a median of 43.68 MPa, and Q3 = 47.07 MPa. Based on the adopted strength classification, these samples remain within the R3 strength class. The HW samples experienced a notable decline in strength, showing a mean estimated UCS of 15.95 MPa, with an SE of 1.64 MPa, and SD of 5.93 MPa. The estimated UCS values varied from 6.75 MPa to 23.38 MPa, with Q1= 9.70 MPa, a median of 18.52 MPa, and Q3 = 21.20 MPa, placing them within the R2 strength class. The percentage reduction in estimated UCS caused by weathering in GG3 is calculated as 63.68%.

When all segments are considered together, SW–MW samples consistently fall within the medium-strength rock category (R3), whereas HW samples remain in the weak rock category (R2) (ISRM, 1981). The average reduction in estimated UCS across the three segments is 59.22%, showing that weathering reduces the compressive strength of the andesite by more than half throughout the study area.

Table 2. Estimated UCS results for SW–MW and HW andesitic rocks from the Gunung Geulis region.

Segment	n	Mean	SE	SD	Min	Q1	Median	Q3	Max	Strength Class	Estimated UCS reduction (%)
GG1 (SW-MW)	13	35.55	1.51	5.43	25.8	31.83	35.9	39.34	45.28	R3	60.15
GG1 (HW)	13	14.17	1.61	5.80	5.55	8.30	14.79	18.78	22.82	R2	
GG2 (SW-MW)	13	39.19	2.67	9.62	25.34	32.76	39.35	43.89	62.70	R3	53.84
GG2 (HW)	13	18.09	1.35	4.85	7.49	15.62	17.89	23.06	24.46	R2	
GG3 (SW-MW)	13	43.92	1.12	4.03	37.39	40.82	43.68	47.07	50.98	R3	63.68
GG3 (HW)	13	15.95	1.64	5.93	6.75	9.70	18.52	21.20	23.38	R2	

Description: GG; Gunung Geulis, SW-MW; slightly to moderately weathered, HW; highly weathered, n; number of specimen, UCS; uniaxial compressive strength, SD; standard deviation, Q1; first quartile, Q3; third quartile, SE; Standard Error.

Table 3. Statistical comparison of estimated UCS values between SW–MW (Grade II–III, n = 39) and HW (Grade IV, n = 39) andesitic rocks based on non-parametric and two-factor analyses.

Parameter	SW-MW (Grade II-III)	HW (Grade IV)	Statistical Summary
Mean UCS (MPa)	39.55	16.07	SW-MW exhibits significantly higher UCS compared to HW.
SD	7.47	5.64	Indicates higher variability in SW-MW compared to HW samples.
Mean Difference (MPa)	-	-	23.48 MPa (95% CI: 20.49 – 26.47 MPa)
Mann–Whitney Test	-	-	p < 0.001 (significant difference between weathering grades)
Two-Factor Analysis	-	-	Weathering grade and geological segment significantly influenced estimated UCS values (p < 0.05).

Description: SW-MW; slightly to moderately weathered, HW; highly weathered, n; number of specimens, UCS; uniaxial compressive strength, SD; Standard Deviation, CI; confidence interval.

The probability plot indicates that the estimated UCS values exhibit slight deviation from a normal distribution (Fig. 3). The Anderson–Darling statistic is 1.282 with a p-value < 0.005, suggesting that the normality assumption is not fully satisfied. Therefore, the Mann–Whitney test was applied to compare the estimated UCS distributions between SW–MW and HW samples. The results indicate a statistically significant difference between the two weathering grades ($p < 0.001$), confirming that SW–MW andesite exhibits substantially higher estimated UCS values than HW andesite (Table 3). The SW–MW group recorded a mean estimated UCS of 39.55 MPa with an SD of 7.47, whereas the HW group recorded a mean estimated UCS of 16.07 MPa with an SD of 5.64. The mean difference between the two groups was 23.48 MPa, with a 95% confidence interval (CI) ranging from 20.49 to 26.47 MPa. The two-factor analysis demonstrated that weathering grade and geological segment significantly influenced the estimated UCS values, thereby accounting for segment-based grouping effects within the dataset. The interval plot further illustrates the marked reduction in estimated UCS from Grade II–III to Grade IV andesite (Fig. 4).

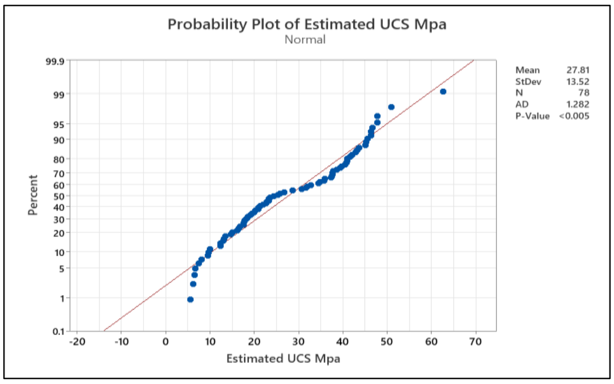

Fig. 3. Probability plot of estimated UCS values for all andesitic rock samples showing slight deviation from normality.

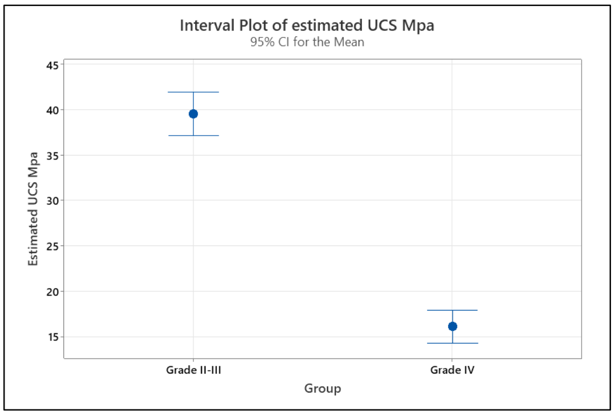

Fig. 4. Interval plot of estimated UCS for Grade II–III and Grade IV andesite.

3.2 Influence of estimated UCS on slope stability

Field observations indicated that the SW–MW andesite generally exhibited more intact and blocky rock-mass conditions, moderate discontinuity spacing, rough discontinuity surfaces, limited infill material, and lower degrees of alteration. In contrast, HW andesite showed more disturbed and fragmented rock-mass conditions characterized by closer discontinuity spacing, greater discontinuity persistence, smoother and more weathered discontinuity surfaces, localized infill material, and increased surface alteration. Based on these rock-mass and discontinuity characteristics, Geological Strength Index (GSI) values were assigned following the (Hoek and Brown, 1997) rock mass classification approach (Table 4). GSI values of 65 were assigned to SW–MW R3 rock masses, whereas HW R2 rock masses were assigned a lower GSI value of 45 due to their weaker and more altered rock-mass condition. The intact rock constant (mi) was set to 25 based on the RocLab 1.0 lithological database, in which andesite is classified as a medium-textured igneous rocks with a recommended mi value of 25 ± 5. Therefore, this value was considered appropriate for the investigated andesitic rock mass. The disturbance factor (D) was assigned as 0.7 represents moderately disturbed slope conditions associated with mechanical excavation. The resulting (c) values are expressed in kilopascals (kPa), while the (φ) is presented in degrees (°). The calculated parameters obtained from these values for each geological segment are summarized in the (Table. 5).

Table 4. Rock-mass characteristics and assigned GSI values for SW–MW and HW andesitic rocks.

Segment	Weathering Grade	Rock-Mass Characteristics	Assigned GSI
GG1	SW–MW	Blocky structure, moderate discontinuity spacing, rough surfaces, limited alteration and infill	65
GG1	HW	Disturbed structure, altered discontinuities, localized infill, weakened surfaces	45
GG2	SW–MW	Moderately intact blocky rock mass with rough discontinuity surfaces	65
GG2	HW	Fragmented rock mass with weathered discontinuity surfaces and local infill	45
GG3	SW–MW	Better-preserved blocky structure with lower alteration and rough surfaces	65
GG3	HW	Disturbed and altered rock mass with localized disintegration and infill	45

Description: GG; Gunung Geulis, SW-MW; slightly to moderately weathered, HW; highly weathered, GSI; Geological Strength Index.

Table 5. Generalized Hoek–Brown rock-mass parameters and calculated FOS using Bishop Simplified, Janbu Simplified, and Spencer methods.

Segment	Strength Class	Mean estimated UCS (MPa)	mi	D	φ (°)	c (kPa)	Unit weight, γ (kN/m³)	FOS Range
GG1 (SW-MW)	R3	35.55	25	0.7	37.17	22.90	23.028	3.518–3.790
GG1 (HW)	R2	14.17	25	0.7	27.92	6.09	22.701	1.191–1.300
GG2 (SW-MW)	R3	39.19	25	0.7	37.17	25.25	24.155	3.620–3.900
GG2 (HW)	R2	18.09	25	0.7	27.92	7.77	22.883	1.270–1.307
GG3 (SW-MW)	R3	43.92	25	0.7	39.50	31.30	23.345	3.950–4.271
GG3 (HW)	R2	15.95	25	0.7	27.92	6.85	22.804	1.208–1.250

Description: GG; Gunung Geulis, SW-MW; slightly to moderately weathered, HW; highly weathered, UCS; uniaxial compressive strength, mi; intact rock Constant, D; disturbance factor, φ; friction angle, c; cohesion, FOS; factor of safety.

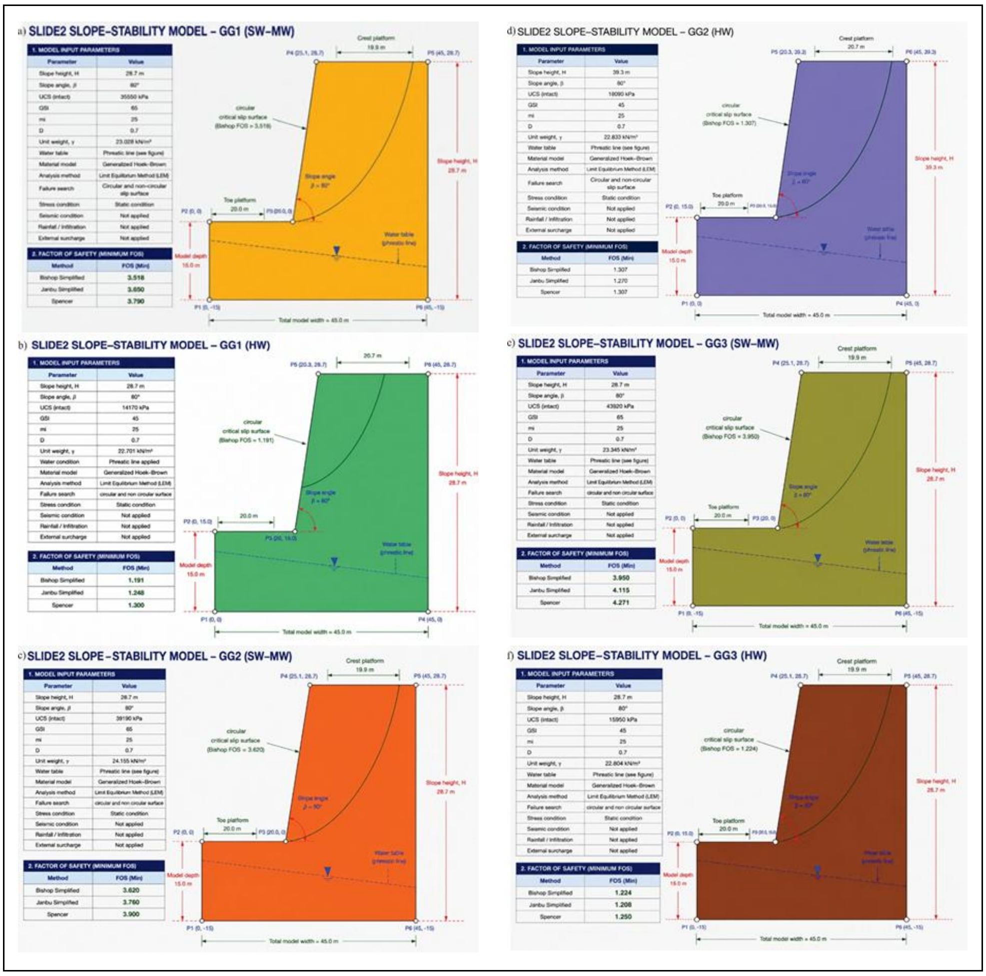

Fig.5 Slope-stability models for SW–MW and HW andesitic rock masses in geological segments GG1–GG3 using the Generalized Hoek–Brown failure criterion and LEM.

The slope-stability modelling based on the Generalized Hoek–Brown criterion demonstrated a clear reduction in slope stability with increasing weathering intensity across all geological segments (GG1–GG3) (Table 5; Fig. 5). In GG1, the SW–MW andesite exhibited a mean estimated UCS of 35.55 MPa, c of 22.90 kPa, φ of 37.17°, and γ of 23.028 kN/m³. These parameters produced FOS values ranging from 3.518 to 3.790 using the Bishop Simplified, Janbu Simplified, and Spencer methods (Fig. 5a), indicating relatively stable slope conditions under the assumed static conditions. In contrast, the HW andesite in the same segment showed substantially lower mechanical properties, with estimated UCS decreasing to 14.17 MPa, c to 6.09 kPa, and φ to 27.92°, resulting in lower FOS values ranging from 1.191 to 1.300 (Fig. 5b). The reduction in FOS reflects significant weakening associated with advanced weathering.

A similar trend was observed in GG2. The SW–MW andesite, characterized by a mean estimated UCS of 39.19 MPa, c of 25.25 kPa, φ of 37.17°, and γ of 24.155 kN/m³, yielded FOS values between 3.620 and 3.900 (Fig 5c), indicating relatively high slope stability under the modeled conditions. Conversely, the HW andesite, with reduced strength parameters including a mean estimated UCS of 18.09 MPa and c of 7.77 kPa, produced lower FOS values ranging from 1.270 to 1.307 (Fig. 5d), suggesting a comparatively less stable condition.

In GG3, the SW–MW andesite displayed the highest rock-mass strength among all segments, with a mean estimated UCS of 43.92 MPa, c of 31.30 kPa, φ of 39.50°, and γ of 23.345 kN/m³. Consequently, this segment produced the highest FOS values, ranging from 3.950 to 4.271 (Fig. 5e), representing the highest stable slope within the study area. Under HW conditions, the mean estimated UCS decreased to 15.95 MPa, and c declined to 6.85 kPa, resulting in FOS values between 1.208 and 1.250 (Fig. 5f), indicating a marked reduction in slope stability due to weathering.

The results demonstrate that consistently SW–MW andesite possesses substantially higher stability than HW andesite across all geological segments. The progressive decline in estimated UCS, c, and φ with increasing weathering grade directly reduced the calculated FOS values. These findings confirm that weathering exerts a major control on the mechanical behavior of the andesite slopes and significantly influences slope stability within the Gunung Geulis area.

4. Discussion

The findings of this study reveal that weathering strongly influences the mechanical strength and FOS of andesitic rocks in the Gunung Geulis area. The above results showed that increasing degrees of weathering in the andesitic rock are associated with a progressive reduction in estimated UCS, which in turn lowers the derived shear-strength parameters obtained through the Generalized Hoek–Brown approach (Hoek and Brown, 1997). This overall weakening results in a reduction of andesitic rock in estimated rock strength by more than half, which in turn significantly lowers the slope stability (FOS) across the studied segments.

The findings from this study indicate several factors that influence the strength of andesitic rocks in the Gunung Geulis region. Textural characteristics, the degree of weathering, and the development of void space strongly influence how the material behaves under loading (Asif et al., 2024; Idris et al., 2024; Villasenor, 2011). As weathering progresses, these features undergo notable changes, and the rocks lose much of their original integrity to resist compressive forces (Ciantia and Castellanza, 2016). This progressive deterioration is initially reflected in declining estimated UCS values and subsequently in related shear strength parameters, such as c and φ (Farazi et al., 2018; Lee et al., 2021). Similar patterns have been reported, including basalt, dacite, and tuff, where reductions in UCS are commonly accompanied by decreases in both c and φ (Villeneuve and Heap, 2021). Previous studies have suggested that weathering-related weakening in volcanic rocks may be associated with progressive deterioration of rock-mass characteristics, which can decrease rock stiffness and frictional resistance under loading conditions (Kereszturi et al., 2023; Villasenor, 2011).

When the decreasing estimated UCS values are converted into equivalent shear-strength parameters and applied in LEM analyses, the influence of weathering on slope behavior becomes apparent. The reduction in c and φ results in a corresponding decrease in FOS (Dawson et al., 1999). The comparison between SW–MW and HW andesite reinforces this connection. Higher-quality rock masses produce larger FOS values, whereas more weathered material, exhibiting lower rock-mass strength, reduces the stability margin of the slope (Hasan et al., 2024; Zhang et al., 2010; Zhang and Anthony T. C. Goh, 2012). The depth and uneven distribution of weathering may also affect the stability in the region. In areas where weathering is unevenly distributed, weaker rock masses may occur alongside relatively stronger blocks, potentially reducing local slope stability under loading conditions (Hasan et al., 2024). The results indicate that increasing degrees of weathering directly affect the mechanical strength of the andesite and, consequently, the FOS values. This progressive reduction in strength has a direct influence on slope stability and the mechanical performance of andesite across the study site. Considering these factors in engineering assessments will improve the accuracy of slope-stability evaluations in similar volcanic environments (Kanakiya, 2024).

5. Conclusion

Weathering has a significant influence on the mechanical strength and slope stability of andesitic rocks in the Gunung Geulis area. Analysis of 78 samples collected from the three investigated segments (GG1–GG3) showed a clear decrease in estimated UCS as the rock mass progressed from the SW–MW grade to the HW grade, with an overall reduction of 59.22%. This decline in estimated UCS was accompanied by reductions in c and φ, which consequently lowered the FOS values across all modeled slopes. The conversion of estimated UCS values into equivalent shear-strength parameters using the Generalized Hoek–Brown approach demonstrated a direct relationship between weathering intensity and slope performance. Slopes composed of SW–MW andesite produced higher FOS values ranging from 3.518 to 4.271, indicating relatively stable slope conditions under the modeled scenarios. In contrast, HW andesite yielded lower FOS values ranging from 1.191 to 1.307, reflecting comparatively lower and marginally stable slope conditions. These results confirm that increasing weathering progressively weakens the engineering properties of andesitic rock masses and reduces overall slope stability. The study demonstrates that weathering grade is an important parameter in geotechnical characterization and slope-stability assessment, particularly in volcanic-rock environments dominated by andesite. The application of estimated UCS-based correlations combined with the Generalized Hoek–Brown approach and LEM modelling provides a practical framework for evaluating slope performance under different weathering conditions. Understanding the influence of weathering on rock-mass behavior is therefore essential for improving slope design, hazard assessment, and long-term engineering stability in andesitic terrains.

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