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Assessing the Influence of Geomechanical Properties on the Stability of Weathered Sedimentary Rock Slope

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Abstract

Devastating incidents of rock slope failures have led to numerous fatalities, injuries, property damage, and structural failures. A detailed examination of the risks and hazards associated with rock slopes should be conducted to prevent such incidents from occurring. The purpose of this study is to evaluate the slope stability of interbedded sedimentary rock slopes for Slope Mass Rating (SMR) and Q-Slope classification using scan line surveys and photogrammetry techniques. In this work, the stability of the rock slope is classified, its kinematic properties are assessed, and a 3D model is displayed using the Slope Mass Rating (SMR) and Q-Slope methods. Furthermore, the weathering grade of sedimentary rock has been successfully correlated with its strength, stability, and durability. Weathering grade II rock was found in zones Alpha and Beta, whereas weathering grade III rock was found in zone Theta. The higher mechanical strength and weathering resistance values in zones Alpha and Beta correspond to their weathering grade. On the other hand, zone Theta's grade III sedimentary rock, which is classified as moderately weathered, exhibits the lowest strength and weathering resistance. Agisoft Metashape and Stereonet 11 are two tools that significantly enhance the accuracy and reliability of the data collected. Zone Alpha is expected to be stable, according to SMR and Q-slope data, while Zones Beta and Theta are predicted to have wedge failure and planar failure, respectively. The application of bolting, shotcrete, adequate drainage systems, and ongoing monitoring on the rock slopes, which have different grades of weathering and structural weaknesses, thus necessitates strict procedures to improve the safety and stability of the rock slope.

Keywords: Slope stability, photogrammetry, geomechanical properties, weathering grade, rock mass classification

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1. Introduction

The evaluation of slope stability is one area of geological surveying. For engineers to gather knowledge about the survey region, geological surveys are essential. The slope's features that must be used to assess the formation's stability are among the details. For the area's development, these are crucial, such as constructing buildings or highways. To avoid slope models or designs failing, geological survey data must be precise. The investigation of rock formation stability must include a geostructural survey. The geostructural survey concentrated on the rock's mechanical and physical characteristics, including faults and joints. In this investigation, sedimentary rock formation was the main emphasis. Joints found on rock faces are known as interbedded planes and fractures or discontinuities for sedimentary or interbedded formations and need to be factored into stability assessment (Pathan et al., 2023). The results of Heidarzadeh et al. (2021) support this assertion by highlighting the significance of geological and laboratory studies in describing the geomechanical characteristics of heterogeneous rock masses. Moreover, in predicting the stability of rock slopes, Qi & Tang (2018) and Kosarev et al. (2021) highlighted the role of geometrical parameters, indicating both intrinsic rock properties and external conditions, such as Young's modulus (E), Poisson's ratio (v), and others.

Slope Mass Rating (SMR) was developed by Romana (1985). This system is derived from the basic Rock Mass Rating (RMR) by Bieniawski (1973). The same purpose is served by both systems, which is to assess rock stability; however, SMR considers extra modifying elements, such as excavation factors. According to stability circumstances and expected behaviour, this rock mass classification approach has been shown to be successful in analytically classifying slopes, offering engineers a fundamental tool (Albar & Mohd-Nordin, 2022; Pastor et al., 2019). The roughness and frictional characteristics of the joint walls or filler materials, the block or particle size, and external influences and stress are the three functions that make up the Q-slope system. This system's rating guidelines can be used by others to assess a rock mass's strength (Bar and Barton, 2017). The new Q-slope classification has also improved the ability to forecast the stability of rock slopes, according to a study by Azarafza et al. (2020), which advanced stability evaluation for sedimentary rocks. The significance of comprehensive analyses that integrate theoretical models and empirical data to tackle intricate geological problems is highlighted by this integrated method.

In this study, the impact of sedimentary rocks' geomechanical characteristics on the stability of the rock mass will be evaluated. This investigation was carried out utilising both sophisticated techniques employing photogrammetry and traditional techniques using scan line survey. The discontinuity survey data sheet has been utilised to assess all the parameters required to study the stability of the rock mass in the scan line method. In photogrammetry, the use of an unmanned aerial vehicle (UAV) yields valuable first results quickly and with minimal investment. The strength and durability of a few geomechanical characteristics derived from laboratory tests on rock samples were better correlated with the stability of the slope.

2. Research Method

2.1 Research Area

This study was carried out at Bukit Chondong in Beseri, Perlis, using the scan line method, photogrammetry, and sample collection. The outcrop at this location is known as the Uppermost Kubang Pasu Formation based on the study by Hassan et al., 2013. Sandstone and mudstone, two distinct sedimentary rocks, are interbedded to form this rock slope. Figure 1 illustrates its distribution as a layer of repetition. The precise coordinates of the site study are 6°33'10.8"N and 100°14'11.3"E, with Padang Besar to the northeast, Arau to the southeast, Kuala Perlis to the southwest, and Kaki Bukit to the northwest.

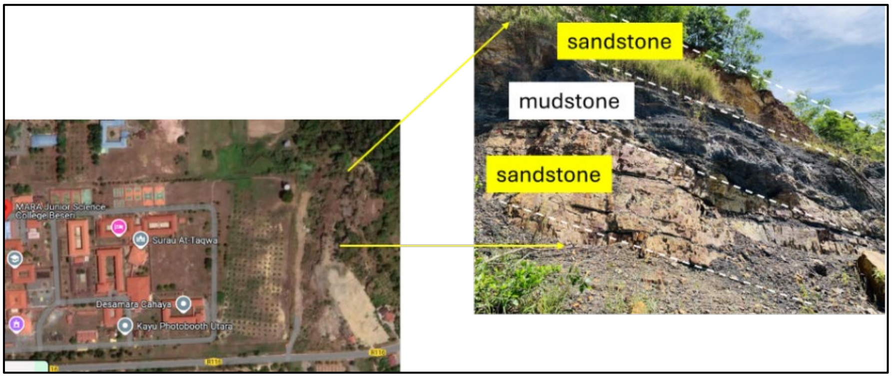

Figure 1. The interbedding of sandstone and mudstone layers on the rock slope.

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2.2 Fieldwork Data Collection

2.2.1 Photogrammetry Survey

The photogrammetry technique uses drones, specifically the DJI Spark, to take high-resolution pictures to collect precise data. The more exact the created 3D model, the better the quality of the photograph should be. Additionally, the site must have adequate space for drone operations to facilitate the process of taking surface photos of the rock slope. In addition, the rock slope surface needs to be exposed for the discontinuity to be readily seen. 943 photos in all were captured at varying flight heights between 6 and 20 meters above the ground, with a 5-meter gap between the drone and the slope's surface. Figure 2 shows the drone flight path and the three different zones for this study.

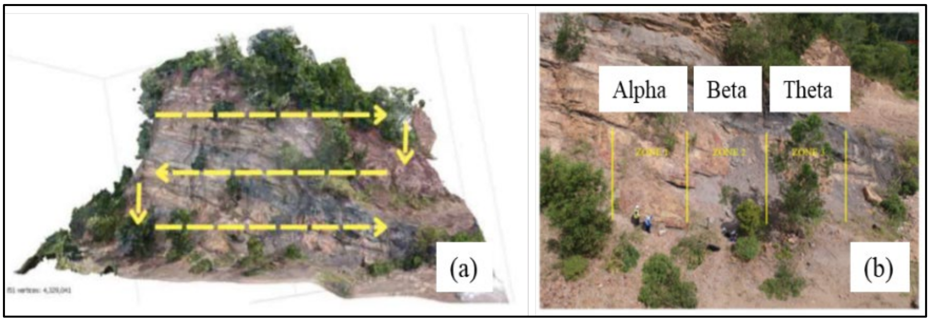

Figure 2. Photogrammetry survey: (a) Drone flight path; (b) Three zones for the study

2.2.2 Scanline Survey

Prior engineers and researchers chose to employ the traditional scan line approach for assessing the rock slope. This method was made possible by the research area's accessibility, as most of the parameters required for this survey could be gathered and measured with accuracy. The slope must be between 30 and 100 meters long to perform this survey using the ISRM (1981) method. The following tools and equipment were utilised in this survey: spray, rebound hammer, geological compass, measuring tape, and JRC comb profiler. The rock slope is measured and extended 15 meters using a measuring tape. Using a geological compass, the dip angle and dip direction were meticulously noted along the 15-meter rock slope. A rebound hammer was used to assess the rock slope's strength. On the data sheet for the discontinuity survey, each of these factors was measured and noted. A JRC comb profiler was used to measure the joints' roughness. As advised by ISRM (1981), the roughness profile can be used to calculate the JRC value. The scanline survey data measurement is shown in Figure 3.

Figure 3. Scanline survey: (a) Establishing scanline of 15 meters (b) Measuring dip angle and dip direction of the discontinuity (c) Determination of JRC using Comb Profiler

2.3 Rock Sampling and Testing

Five different types of rock boulders, including mudstone and sandstone, were gathered from the study region. After that, all the rock samples were kept in the UiTM Pulau Pinang Geology Laboratory. Machines are then used to core and trim the rock boulders that have been transported to the laboratory.

2.3.1 Weathering Grade

The Schmidt hammer is handy in the field as well as in the laboratory and is portable. As a nondestructive, reasonably priced, and portable hardness testing instrument, the Schmidt hammer is widely used to obtain an indirect measurement of Uniaxial Compressive Strength (UCS) (Wang and Wan, 2019). Rock quality and strength are now frequently assessed using the Schmidt hammer test method. For evaluating the mechanical characteristics of rock, the Schmidt hammer provides a quick and economical way to measure surface hardness. (Sharma, Khandelwal, and Singh, 2011). The weathering classification system suggested by Mohamed (2007) has been compared to the average amount of rebounds. Figure 4 shows the Schmidt hammer test conducted on site.

Figure 4. Schmidt Rebound hammer test conducted on (a) mudstone and (b) sandstone layer

2.3.2 Point Load Test

To ascertain the rock mass's compressive strength, point load tests are performed. The International Society for Rock Mechanics (ISRM 2007) provided references for the equipment and procedures utilised in this test. For this test, ten samples of irregular lumps were used. As shown in Figure 5, the rock sample is placed within the machine and then jacked until the upper and lower plates are closed to create contact at the sample's smallest dimensions. As the jacking procedure began, the rock samples were subjected to the load. The applied stress develops gradually as failure happens in 10–60 seconds. After the rock samples failed, the total load applied was recorded and tabulated. The ISRM (1985) recommended equation is used to calculate the point load strength index (I_{s50}).

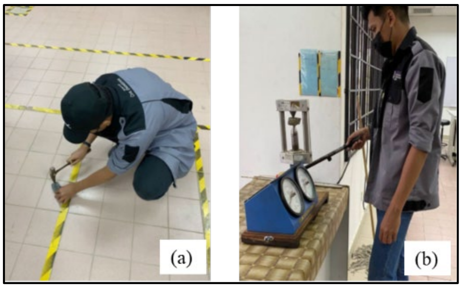

Figure 5. Point Load Test. (a) Breaking lump sample using geological hammer (b) Point load test conducted on rock lump samples

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2.3.3 Uniaxial Compression Test (UCT)

The UCT test is a commonly used laboratory test for assessing the compressive strength of intact rock. With uniaxial loading, this test is used to find the most axial compressive stress a rock specimen can sustain before failing. In accordance with ISRM (1985), the sample's form has been indirectly predicted from the value of I_{s50}, the UCS value. The cored sandstone and mudstone samples for pre- and post-testing, respectively, are shown in Figure 6.

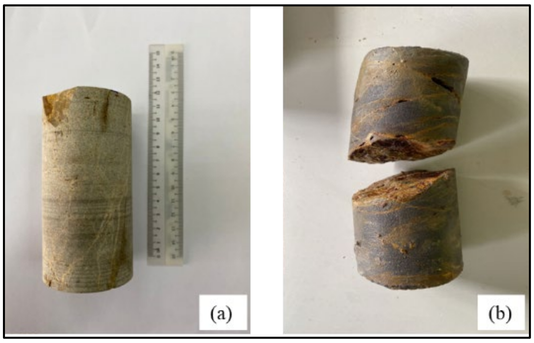

Figure 6. Uniaxial Compression Test cored sample (a) before testing—sandstone (b) after testing—mudstone

2.3.4 Slake Durability Test

Franklin and Chandra (1972) were the first to introduce the slake durability test. By measuring a rock sample's resistance to deterioration and disintegration due to drying and wetting cycles, the ISRM Commissions on Testing Methods subsequently recommended and validated this method as the standard procedure to assess the influence of alteration, which includes weathering and hydrothermal, on rocks. As shown in Figure 7, ten rock samples were used for this investigation, one for each of the mudstone and sandstone that were kept from the point load test.

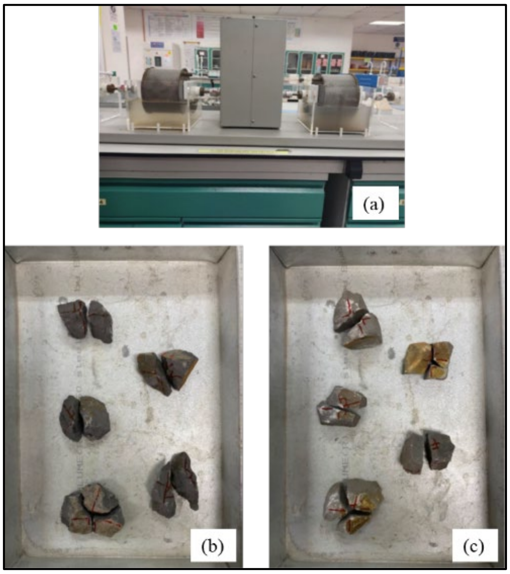

Figure 7. Slake Durability Test (a) Experimental set up (b) Mudstone sample (c) Sandstone sample

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2.4 Data Analysis

2.4.1 Photogrammetry Method

Agisoft Metashape Pro was used to analyse UAV data and produce 3D images. The software's workflow includes aligning the photos, dense cloud construction, mesh, texturing, tiled model, DEM, and orthomosaic. Figure 8 displays the 3D model created by Agisoft Metashape software beside the actual drone photo.

The discontinuities, including dip angle and dip direction, were then extracted from the acquired point cloud data using the CloudCompare software. The discontinuities that CloudCompare software extracted for Zone Alpha are displayed in Figure 9.

Finally, the discontinuity value was imported into the Stereonet program to do the kinematic analysis and identify the potential rock slope failure mode. Stereonet software features are displayed in Figure 10.

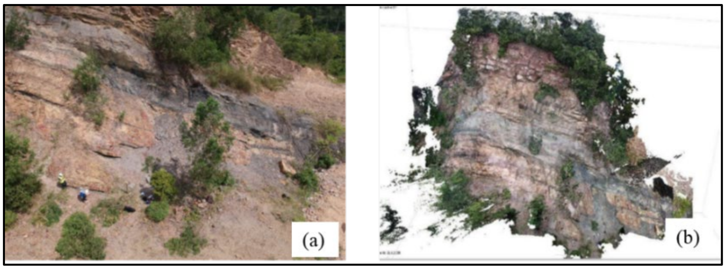

Figure 8. Photogrammetry Method (a) Images captured from UAV (b) 3D images in Agisoft Metashape software

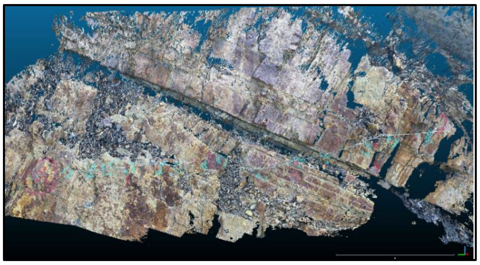

Figure 9. Dip angle and dip direction extracted from CloudCompare for Zone Alpha

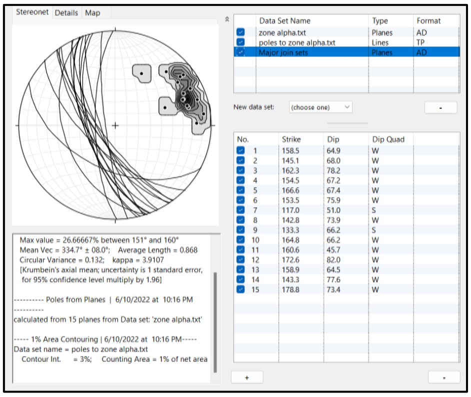

Figure 10. Plotting the Great Circle of Discontinuities in Stereonet 11

2.4.2 Rock Mass Classification System

2.4.2.1 Rock Mass Rating (RMR)

The RMR value was calculated using Bieniawski's (1989) approach, which is the total of the ratings for six parameters. The characteristics include joint condition, groundwater condition, discontinuity spacing, joint orientation, other intact rock strengths, and Rock Quality Designation (RQD). A number that reflects the properties of the rock is assigned to each of the six parameters. The sources of this data are laboratory experiments and outdoor surveys. The RMR value is a number between 0 and 100 that is obtained by adding the six parameters.

2.4.2.2 Slope Mass Rating (SMR)

For assessing the stability of rock slopes, Romana (1985) developed a classification system known as the Slope Mass Rating (SMR) approach. Correction variables from the joint-slope relationship and a factor depending on the excavation technique from Bieniawski's rock mass rating (RMR) are added to determine SMR. The adjustment factor for the excavation method, the relationship between slope and joint dips, the joint dip angle in the planar mode of failure, and the parallelism between joints and slope face strike are among the correction factors.

2.4.2.3 Q-Slope System

As per Barton (2017), the Q-slope continued to use the same parameters as the Q-system, which include the following: environmental and geological condition number (J_{wice}), stress reduction factor (SRF_{slope}), joint set number (J_n), joint roughness number for the critically orientated joint set (J_r), and joint alteration number for the critically orientated joint set (J_a).

3. Results and Discussion

3.1 Geomechanical properties of rock

3.1.1 Classification of Weathered Rock

This study used Mohamed et al. (2007) as a guide to determine the weathering grade of two bulk samples of mudstone and two bulk samples of sandstone that were collected from the study site. Table 1 shows the average value for each bulk sample based on the origin collected zone after nine sites are examined with the Schmidt Rebound Hammer. For Alpha, Beta, and Theta zones, the average Schmidt rebound values are 40, 41.7, and 30.1, respectively. Zone Alpha and Beta values fall under the grade II category, per Mohamed (2007). For zone Theta, the value falls under grade III and falls between 20 and 30 Schmidt Hammer Value (SHV). According to ISRM (1981), grade III is categorised as moderately weathered, and grade II as slightly weathered. The weathering grade of sedimentary rocks obtained from the site is aligned with the studies by Hamzah & Yusof (2022) and Mohamad et al. (2015) on tropical weathered sedimentary rocks, which ranged from grade II to IV.

Table 1. Schmidt Rebound Hammer value and weathering grade classification

Zone	Average of Rebound Hammer Value	Weathering Grade	Description
Alpha	40.0	II	Slightly weathered
Beta	41.7	II	Slightly weathered

Theta	29.1	III	Moderately weathered

3.1.2 Influence of Weathering Grade on Point Load Test, Uniaxial Compression Strength Test, and Slake Durability Index

The strength and durability indices of sandstone and mudstone samples from all zones were assessed using point load, UCS, and slake durability tests. Table 2 listed the average results for each test. The average IS50 value for each zone, as determined by the point load test, falls between 0.3 and 5.0 MPa. As per Brooch and Franklin (1972), this result suggests that sandstone and mudstone in zones Alpha and Beta are regarded as having high strength, whereas zone Beta has low strength.

The UCS value for zones Alpha and Beta, as reported in Liang et al. (2015), these samples are slightly weathered, with strength values of 84.16 MPa and 86.88 MPa, respectively, whereas zone Beta has a moderately weathered value of 15.48 MPa. This demonstrates that rock strength is affected by weathering, indicating a downward trend in strength throughout all zones. This is consistent with the findings of the study conducted by Mang and Rafek (2018), which found that rocks gradually lose their initial strength because of weathering.

In this study, the Slake Durability Test was performed on sandstone and mudstone samples in all zones over the course of seven days of wetting and drying cycles. Referring to Franklin and Chandra (1972), the durability index revealed a declining trend for both samples, with zone Alpha recording the smallest decline to 98.0% and zone Beta dropping to 98.11%, while the rocks in zone Theta reported a significant decline to 81.48%, indicating extremely high and high durability, respectively. Albar et al.'s (2022) investigation on Kuala Ketil, Kedah mudstone likewise found a declining trend. The solid part of the micromechanical interlocking grain has changed into clay minerals, and micropores have formed inside, which is related to the chemical breakdown and modification of this phenomenon. The links between mineral grains would be weakened by the presence of water, which has triggered the chemical breakdown. As a result, the weak plane will become unstable, and the pore water pressure will rise based on the findings by Liang et al. (2015). In addition, the rock becomes less continuous due to the expansion of pore structure and fissures; as a result, contact forces acting on the particle skeleton and breakability under compression rise as porosity increases.

Table 2. Summary of average index properties of each zone

Zone	Weathering Grade	Point Load 50 (MPa)	UCS (MPa)	Slake Durability Index ID7 (%)
Alpha	II	4.21	84.16	98.00 (Extremely High)
Beta	II	4.34	86.88	98.11 (Extremely High)
Theta	III	0.78	15.48	81.48 (High)

3.2 Kinematic Analysis

The geometric link between these discontinuity orientations and the slope face determines a slope's kinematic stability. According to Matheson's (1983) recommendation, a reference internal friction angle of 35° was used in this investigation. Zone-by-zone evaluation of the degree of agreement and variation between these two approaches revealed information on the tolerance and dependability of photogrammetric techniques as an additional tool in the mapping of geological structures for the evaluation of slope stability.

The kinematic analysis for each zone was shown in Table 3. Two large joint sets were found in zone Alpha, and the friction cone region encompasses all discontinuity sets. Furthermore, zone Alpha is still in a stable state because no critical crossing between J1 and J2 was found within the possible failure zone. Two significant joint sets were found in zone Beta; a crucial zone intersection between joint sets 1 and 2 suggested the possibility of wedge failure. However, kinematic analysis in zone Theta for both approaches reveals a prediction that is inconsistent. While scanline survey data suggests that the rock slope may be vulnerable to planar failure,

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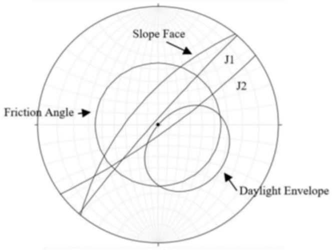
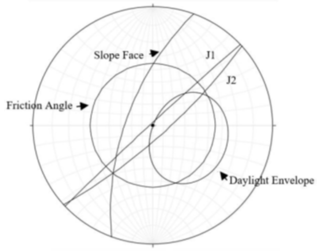
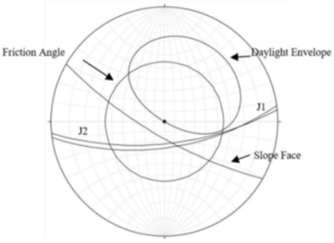
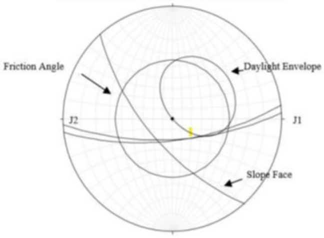
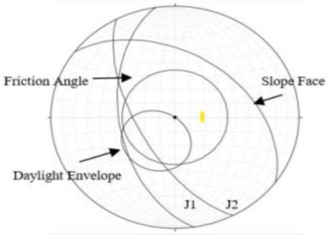
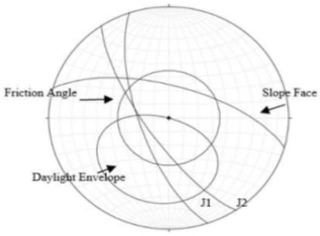
photogrammetry data currently indicates that the Theta zone is stable.

Table 3. Comparison of Major Joint Set for All Zones.

Zone	Scanline Survey	Photogrammetry
Alpha		
Beta		
Theta		

3.3 Rock Classification System

3.3.1 Rock Mass Rating (RMR), Slope Mass Rating (SMR), and Q-Slope

The rock mass in Zone Theta is categorised as fair according to Bieniaswki (1989 & 1993), whereas the RMR value for Zones Alpha and Beta is categorised as good based on the data in Table 4. SMR results indicate that the slopes in zones Alpha and Beta are constant. Zone Theta is categorised as partially stable; nevertheless, planar failure is evident. Therefore, according to Romana's (1985) rating, it is classified as class III.

The slopes in zones Alpha and Beta are classified as poor for Q-slope calculations. It is characterised as an extremely poor and quasi-stable slope for zone Theta. After being plotted using the Q-value and steepest slope angle obtained from the study by Bar and Barton (2017), the Q-slope stability chart is displayed in Figure 11. Data obtained for this study were validated with previous research. According to Ghanbari et al. (2011), a study on the Bidu Formation found the value of Q-slope varying from 0.04 to 5.012. In addition, a study on sandstones and shales of Malaysia's highway outcrops by Mohd. et al. (2021) found that the Q-slope value varies from 2.696 to 6.550. Lastly, the Q-slope value obtained for this study varies from 0.41 to 3.38, which is in line with other previous studies.

Table 4. Summary results for RMR, SMR, and Q-Slope

Relevant Parameters	Zone Alpha		Zone Beta		Zone Theta	
	Description	**Rating**	**Description**	**Rating**	**Description**	**Rating**
Point Load Index (MPa)	4.21	7	4.34	7	0.78	2
RQD (%)	71.4	13	75.2	17	55	13
Average spacing of discontinuities	0.2-0.66	10	0.2-0.66	10	0.06-0.2	8
Condition of discontinuities	Rough and slightly weathered	25	Rough and slightly weathered	25	Slightly rough	20
Groundwater condition	Completely dry	15	Completely dry	15	Completely dry	15
Total RMR Value, RMB_b	**Good**	**70**	**Good**	**74**	**Fair**	**58**
Parallelism between discontinuities, F1	Very unfavorable	1.0	Very unfavorable	1.0	Very unfavorable	1.0
Joint dip angle, F2	Very favorable	1.0	Very favorable	1.0	Very favorable	1.0
Relationship between slope and joint and dip, F3	Very favorable	0	Very favorable	0	Very favorable	0
Excavation, F4	No excavation	0	No excavation	0	No excavation	0
SMR Value	**Stable**	**72**	**Stable**	**76**	**Partially Stable**	**60**
Joint set number, J_n	Two joint sets	4	Two joint sets	4	Two joint sets	4
Joint roughness, J_r	Slickenside, undulating	1.5	Rough or irregular, planar	1.5	Smooth, planar	1
Joint alteration, J_a	Slightly altered joint walls. Non-softening mineral coatings	2	Unaltered joint walls, surface staining only	1	Softening or low-friction clay mineral coatings	4
Environmental and geological number, J_{wice}	Stable structure; incompetent rock	0.3	Stable structure; incompetent rock	0.3	Stable structure; incompetent rock	0.3
Stress Reduction Factor (physical condition), SRF_a	Slightly loosening due to surface location	2.5	Slightly loosening due to surface location	2.5	Slightly loosening due to surface location	2.5
Stress Reduction Factor (stress and strength), SRF_b	Moderate stress-strength	1.0	Moderate stress-strength	1.0	Moderate stress-strength	1.0

	range		range		range	
Q-Slope Rating	**Poor**	**1.61**	**Poor**	**3.38**	**Very poor**	**0.41**

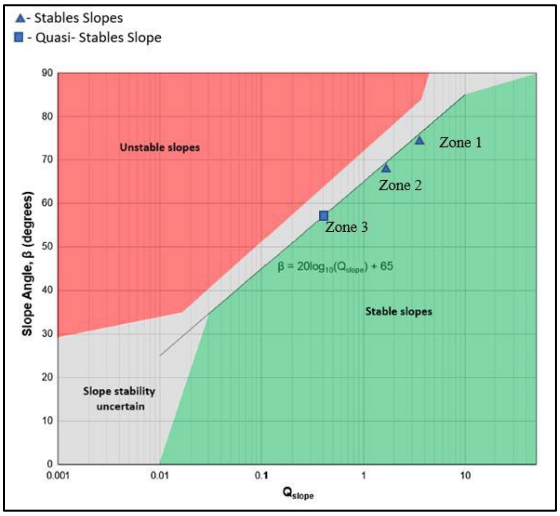


Figure 11. Q-Slope stability chart for all zone

3.4 Influence of Geomechanical Properties on Stability of Rock Slope

The stability of rock slopes is greatly impacted by a number of geomechanical factors, including the geological, mechanical, and physical attributes of the rock masses. Numerous studies highlight the importance of characteristics like strength and discontinuities in influencing slope stability. In their explanation of the multidisciplinary character of slope stability analysis, Sanjeewa et al. stress the significance of combining understandings from rock mechanics, soil mechanics, and engineering geology (Sanjeewa et al., 2024). The outcomes of this investigation, which used an integrated strategy, are shown in Table 5.

Theta was classified as moderately weathered (Grade III), whereas Alpha and Beta were classified as slightly weathered (Grade II). The rock's mechanical and physical characteristics within designated zones demonstrate that it is significantly impacted by the rising weathering grade. Rock samples from grades II to III showed declining strength values from the point load and uniaxial compression strength tests. Several case studies have used weathering indices to analyse the engineering qualities of rocks, such as those on schist (Geçkin et al., 2021) and dacites (Arıkan & Aydın, 2012), supporting the idea that rock weathering is a crucial factor in slope stability evaluations. All three zones show a similar pattern in weathering resistance, with grade III rock having the lowest durability index. According to the study by Martino & Mazzanti (2014), the outcome is consistent with the significance of water-induced weathering, which can accelerate the deterioration of rock joints and ultimately lower the shear strength of rock masses.

A rock slope's stability decreases as the characteristics of the rock materials deteriorate. The lowest rock property and rating values from zone Theta are consistently observed. The rock surface of zone Beta may experience wedge failure, whereas zone Alpha is anticipated to remain stable. This conclusion is consistent with research by Abdellah et al. (2020), which shows that faults and joint sets, among other geological structures, significantly influence failure mechanisms in slopes, thereby impacting stability.

In areas identified as vulnerable, particularly zone Theta, a systematic anchorage that involves bolting and shotcrete is required to enhance stability by counteracting shear forces acting on the slope (Huber, 2020). The installation of drainage systems can reduce water accumulation and associated pressure on potential failure planes, different rock types, and complex failure mechanisms (Zhong et al., 2011; Osika et al., 2018). In addition, Nagendran et al. (2019) suggested that continuous supervision of rock slope characteristics is dynamic for evaluating rock slopes and can inform appropriate interventions.

Table 5. Summary results of geomechanical properties and stability analysis.

Zone	Weathering Grade	Point Load Index, Is50 (MPa)	Uniaxial Compression Strength (MPa)	Slake Durability Index (ID (%)	Stereographic projection	Slope Mass Rating (SMR)	Q-Slope
Alpha	II	4.21	84.16	98.00	Stable	72	1.61
Beta	II	4.34	86.88	98.11	Wedge failure	76	3.38
Theta	III	0.78	15.48	81.47	Planar failure	60	0.41

4. Conclusion

To improve rock slope assessment data and outcomes, both traditional and advanced techniques are used to examine slope stability. In Agisoft Metashape software, the 3-dimensional modelling of rock slopes from Unmanned Aerial Vehicles (UAVs) has been successfully produced, and it is helping CloudCompare software extract discontinuities. Stereographic projection was used to predict the mode of failure of the rock slope based on the values of the dip angle and dip direction of the discontinuities from the photogrammetry survey and scanline. Zone Alpha is likely to remain stable, but zones Beta and Theta are expected to undergo planar failure and wedge failure, respectively.

The laboratory successfully examined the rocks' geomechanical properties to see how they impacted the stability of the rock slope. Zones Alpha and Beta yielded weathering grade II rock, but zone Theta contains weathering grade III rock. The weathering grade of zones Alpha and Beta is reflected in the mechanical strength test and weathering resistance values, which range from 4.2 to 4.4 MPa, 84 to 87 MPa, and 98% to 99% for the Point Load Index, Uniaxial Compression Strength (UCS), and Slake Durability Index, respectively. In contrast, zone Theta's sedimentary rock of grade III (moderately weathered) has the lowest strength and weathering resistance results, measuring 0.78 MPa, 15.48 MPa, and 81.47% for the Point Load Index, UCS, and Slake Durability Index, respectively. According to the study's geomechanical characteristics, the rock's deteriorating strength and durability have been influenced by its increasing weathering grade.

To determine the stability of the rock slope, kinematic analysis, Slope Mass Rating (SMR), and Q-Slope are employed. The SMR and Q-slope values in zone Theta were consistently lower than those in the other zones, at 60 and 0.41, respectively. The SMR number indicates that the zone is partially stable; however, the Q-slope value indicates that the rock is in poor condition. Therefore, shotcrete, bolting, proper drainage management, and ongoing monitoring are integrated strategies for stabilising the zone that can be used to ensure the stabilisation of rock slopes with different grades of weathering and structural problems.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

Author Contribution

Conceptualization, Aniza, Mohd Mustaqim; Methodology, Muhammad Irfan, Aniza; Validation, Aniza, Mohd Mustaqim; Formal Analysis, Muhammad Irfan; Investigation, Muhammad Irfan, Aniza, Mohd Mustaqim; Resources, Mohd Mustaqim; Data Curation, Muhammad Irfan; Writing – Draft Preparation, Muhammad Irfan; Writing – Review & Editing, Aniza, Mohd Mustaqim; Visualization, Aniza, Mohd Mustaqim; Supervision, Aniza, Mohd Mustaqim; Project Administration, Muhammad Irfan; Funding Acquisition, Aniza.

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