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COMPARATIVE ASSESSMENT OF ROCK SLOPE STABILITY ANALYSIS USING GENERALIZED ANISOTROPIC AND JOINT NETWORK

PENILAIAN PERBANDINGAN KESTABILAN LERENG BATUAN MENGGUNAKAN GENERALIZED ANISOTROPIC *DAN* JOINT NETWORK

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ABSTRACT

Rock slope stability analysis in a geotechnical study is an important issue in mining engineering. Kinematic analysis is a well-known method to determine potential failures of the rock slope based on structural orientations, but it sometimes disregards the structural properties information. Structural properties are often known as the highly interpreted domains in rock slope engineering; thus, simplification was made for the analysis. Simplification may lead to vague conditions of analysis and reduce its accuracy. Therefore, the aims of this research is to assess the effect of rock structure properties such as heterogeneity, discontinuity, and anisotropic properties of the rock mass. The assessment conducted using the limit-equilibrium method employed the Generalized Anisotropic (GA) material model were compared with finite element method (FEM) using the shear strength reduction (SSR) method employing the joint network rock mass model. The analysis results show that an actual rock slope with a generalized anisotropic material model in the LEM analysis and joint network material model in the FEM analysis is stable with Safety Factor > 1, and the maximum strain model is less than the minimum strain threshold (maximum strain < 0.1). Combining rock slope stability analysis methods aims to produce accurate and representative results regarding the rock mass' condition. This research improves the interpretation of rock slope stability analyses, resulting in a more accurate estimation of the factor of safety (FOS).

Keywords: slope stability, limit equilibrium method, finite element method, anisotropy, jointed rock masses.

ABSTRAK

Analisis kestabilan lereng batuan dalam kajian geoteknik merupakan permasalahan penting dalam bidang teknik pertambangan. Analisis kinematika adalah metode yang pada umumnya digunakan untuk menentukan potensi keruntuhan lereng batuan berdasarkan orientasi struktur dan terkadang mengabaikan informasi sifat struktur. Karakteristik struktur sering dikenal sebagai domain yang diinterpretasikan dalam rekayasa lereng batuan sehingga dilakukan penyederhanaan untuk analisisnya. Penyederhanaan dapat menyebabkan analisis menjadi samar dan mengurangi tingkat keakuratannya. Oleh karena itu, penelitian ini bertujuan untuk menganalisis pengaruh dari karakteristik struktur batuan yaitu heterogenitas, diskontinuitas, dan anisotropi terhadap massa batuan. Analisis kestabilan dilakukan dengan menggunakan metode kesetimbangan batas dengan material model generalized

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anisotropic *(GA) dan dibandingkan dengan metode elemen hingga (FEM) dengan metode reduksi kekuatan geser (SSR) dengan menggunakan model massa batuan* joint network*. Hasil analisis menunjukkan bahwa lereng batuan aktual dengan material model* generalized anisotropic *pada analisis LEM dan material model* joint netwok *pada analisis FEM diketahui dalam keadaan stabil dengan nilai faktor keamanan > 1, dan regangan maksimum model lebih kecil dari ambang batas regangan minimum (regangan maksimum < 0,1). Kombinasi metode analisis kestabilan lereng batuan bertujuan untuk menghasilkan hasil yang akurat dan representatif mengenai karakteristik massa batuan. Penelitian ini meningkatkan interpretasi analisis kestabilan lereng batuan sehingga menghasilkan nilai faktor keamanan yang lebih akurat.*

Kata kunci: kestabilan lereng, kesetimbangan batas, elemen hingga, anisotropi, massa batuan.

INTRODUCTION

Rock-mass excavation is a common practice in mining and civil engineering to create earth structures. All of these activities require interaction with the rock mass, which originally involved geotechnical characteristics such as geological structures or discontinuities that are defined through geological processes, and which can be disturbed since the construction. Rock engineering characteristics deal with rock mechanics and structural geology, making the geotechnical analysis of rock slopes both as an art and a science (Kliche, 2018). Rock slope stability analysis is routinely performed in many engineering studies and is an important issue in both civil and mining engineering (Wyllie, 2018). These rock masses fail due to the failure that is defined by intersecting counts of discontinuities and the geotechnical properties collectively (Hoek, 2023), which the potential of the rock blocks can be estimated through the stereographic projection and kinematic analysis.

Today, various methods such as kinematics analysis, simple limit equilibrium and numerical methods are established to assess the safety factor of the rock's slope stability. In the 1990s, most of the rock slope stability analyses were analysed using stereographic projections and kinematic analysis to identify the potential of rock block failure (Mebrahtu *et al.*, 2022). In the 2000s, stability modelling of slope analysis approaches developed, and a more sophisticated 2D limit equilibrium method was expanded in conjunction with the numerical method for isotropic strength analysis (Bar, Yacoub and McQuillan, 2019). As a result of geological processes, rock mass is generally intersected by different lithologies and complex structures. According to extensive research into rock mechanics and behaviour, most of the rock materials are anisotropic (Nagendran and Ismail, 2021). The rock sample in the same formation can have different properties because of the anisotropic characteristic and infilling material can reduce the mechanical strength of the rock mass (Saptono, Wiyono and Dewi, 2014). The anisotropy rock mass is frequently discounted in geotechnical design due to the simplification of isotropic modelling principles instead of anisotropic. However, the principal concern lies in the accuracy of the model. The accuracy could improve when rock behaviour is studied and its strength model is described as an anisotropic material in nature (Ambrose, 2014).

The required parameters for geotechnical slope analysis are slope geometry, situation map and geological model (Ayob *et al.*, 2019). The rock slope stability analysis using LEM has become a more common method in geotechnical practice, mainly due to its simplicity of use. The limit equilibrium method determines the critical failure surface by minimizing the safety factor, which is calculated from the ratio of driving force to resisting force (Wyllie, 2018). The finite element method's (FEM) way of representing sophisticated boundary and interface conditions has resulted in it being a popular tool for assessing the stability of the rock slope in recent years. There are several techniques of slope stability analysis using the numerical method (FEM) and one of those is shear strength reduction (SSR) (Griffiths and Lane, 2001). Joints can be incorporated into the FEM by using designated fracture elements that take into account spacing, aperture, infilling, and continuity (Jing and Hudson, 2002). Sari (2019) stated that comparing the results of different methods for stability conditions of rock slopes is necessary because a single solution could result in an inadequate interpretation.

To improve the understanding of the stability analysis of actual slope, slope stability with generalized anisotropic by LEM and a jointed rock by FEM using the SSR technique were used in the geotechnical models of rock slope analysis. This research was carried out to define the concept of rock strength anisotropy material and joint network material model, which were modelled in the Rocscience™ Slide2 and Rocscience™ RS2 programs. The stereographic projection and kinematic analysis of discontinuities in 2D slope assessment were conducted by the previous studies (Akbar and Wiyono, 2023). In this study, SSR technique was used to calculate a shear strength reduction (SRF) or factor of safety (FOS) associated with a slope on the rock mass characteristic. The safety factor is a useful index for estimating the degree of safety or the distance between a slope and a failure.

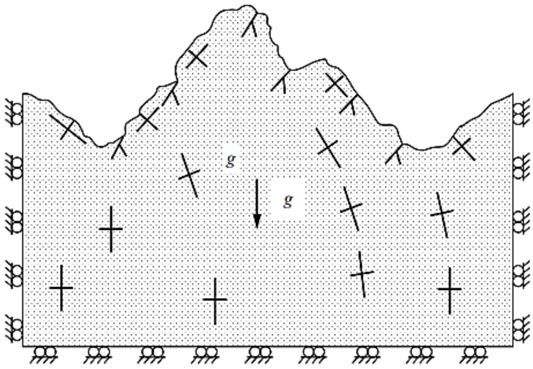
METHODOLOGY

Anisotropy

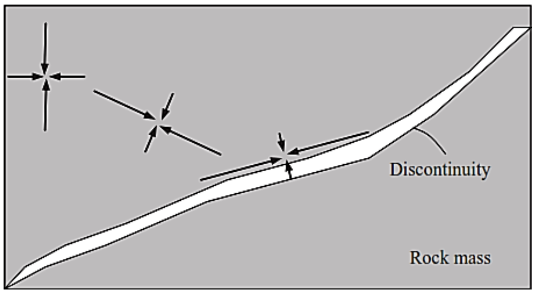
The rock mechanics principles used to analyse slope stability are heterogeneous and usually anisotropic. However, rock material exhibits several physical anomalies that must be addressed to obtain a representative solution to overcome rock mechanics issues. Anisotropy strength is generally defined as changes in properties (physical, mechanical, hydraulic, etc.) that indicate the directional features of rocks (Hoek, 2023). Anisotropic rock has properties that differ in different directions. Strength anisotropy is also observed in rock masses with discontinuities (Zhang, 2016). The previous study often assumed that the principal stress of the rock mass is usually isotropic, but extensive research has revealed that most rock materials are anisotropic. An illustration of the anisotropic condition of homogeneous rock that has discontinuities and principal stress direction is shown in Figure 1.

Generalized Anisotropic Material Model

In geotechnical engineering, anisotropy refers to a rock whose mechanical properties vary with direction as a result of the rock's geological history, and varying properties of different layers and/or preferred orientation of mineral grains (Bar and McQuillan, 2018). The definition of rock mass is the same with fractured or jointed rock, and it will be populated within the ranges specified in the generalized anisotropic (GA) model definition to create a composite strength model, in which any strength model can be assigned to any range of slice base orientations (Snowden, 2007).



(a)



(b)

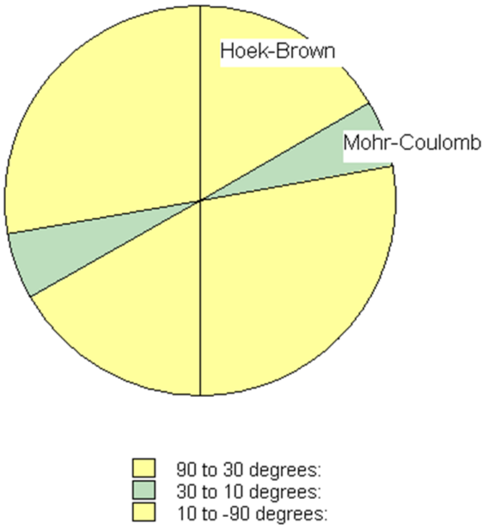
Source: (a) Amadei and Stephansson (1997);
(b) Hudson, Cornet and Christiansson (2003)

Figure 1. Anisotropy of rock mass: (a) Principal stress direction in a rock mass; and (b) An open discontinuity change in the stress direction

The GA material model option allows the analysis to assign any combination of strength models to any range of orientations; for example, as shown in Figure 2, the model could generate a material with Hoek-Brown in some orientations and Mohr-Coulomb in others. The first angular range is always -90° to +90°. The function updates to show the GA material model as data is entered. Any material can be assigned to specific ranges; since the formation is based on the jointed rock, it is required to distinguish the rock mass and joints distributed within defined limits.

Rock slope stability analysis requires failure criteria, which the well-known criteria for jointed rock can be applied Generalized Hoek-Brown was introduced by Hoek, Carter and

Diederichs (2013) and the bedding/weak joint can be defined using the Mohr-Coulomb criteria, which are still the most widely used in geotechnical practice (Nagendran and Ismail, 2021).



Source: Snowden (2007)

Figure 2. Interpretation of generalized anisotropic model by one joint set

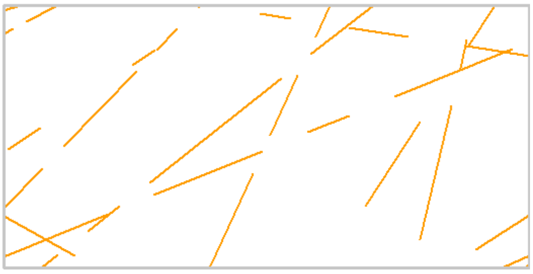
Jointed Rock Model

The joint network model enables the rock slope stability analysis to generate the slope geometry of a jointed rock mass to simulate patterns of induced jointing in rock masses. The role of secondary structures, such as joints, in controlling the behaviour of the rock mass is more of a problem in the practical engineering of rock slope stability (Hoek, 2023).

The jointed model as shown in Figure 3 can be defined using the Mohr-Coulomb failure criteria when weak plane orientation is present. The joint network model is implemented as follows:

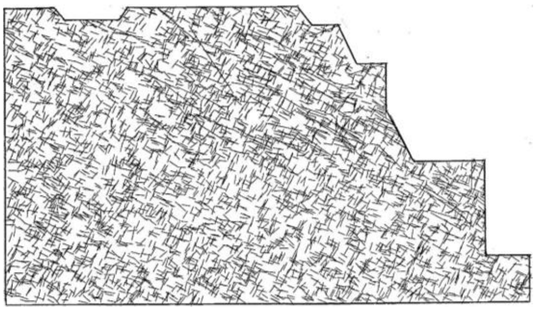
- Creating an infinite number of joint lines, each of which passes through a point determined by a point process (points distributed in the trace plane). Line orientations can be constant or vary depending on the orientation of a joint;
- Dividing each joint line on the model into random length segments defined by the joint length and length of persistence to a specified joint characteristic.

As mentioned in Hoek (2023), Figure 4 illustrates a jointed model of the Three Gorges Dam, by the previous study of Wang and Jia (1998) and (Deji, 1999). This map was created using Monte Carlo analysis to simulate the joint characteristics such as dip, strike, spacing, and trace length (Hoek, 2023). The map was therefore used for a high slope stability analysis to find joint and rock bridge combinations with the lowest shear strength along potential failure surfaces.



Source: Rocscience (2023)

Figure 3. Joint network model with random joint length, orientation, and persistence



Source: Hoek (2023)

Figure 4. Joint network for the high rock slope

When the slope reaches a critical state, the SSR principle is calculated as the division between the actual shear strength and the reduction shear strength within the fault, joints, and intact rock (Lu *et al.*, 2020). Simulations are run to perform slope stability analysis using the SSR technique, and the factor of safety is calculated as the ratio of the actual strength to the calculated reduced shear strength at failure. Kliche (2018) mentions that shear strength reduced by a factor of safety can be calculated using by using the equation:

$$c_r = \frac{c}{SRF} \quad (1)$$

$$\varphi_r = \tan^{-1}\left(\frac{\tan\varphi}{SRF}\right) \quad (2)$$

Where, SRF = strength reduction factor, c_r = reduced cohesion (kN/m^2), φ_r = reduced friction angle (°) and c = actual cohesion (kN/m^2), φ = actual friction angle (°).

RESULTS AND DISCUSSION

Studies Area and Geotechnical Characteristic

The study area is located in Sidomulyo Village, Kulon Progo Regency. The geological settings of the study area are the Oligo-Miocene volcanic rocks and the Old Andesite Formations (Van Bemmelen, 1949). The actual rock slope has discontinuities with the orientation of dip/dip direction measured along a reference line within a 15m line each single slope about 1.50m above ground level, which could be reached by an average-height human. The rock slope's dip/dip direction was measured along four lines at each single slope with different elevations. The orientation of the discontinuity obtained from the rock slope were imported into the Rocscience™ Dips Version 7.0 program, which was used to analyse and interpret the discontinuity mapping data, for graphical and statistical orientation data analysis, as shown in Figure 5. As shown in Figure 5, the final slope was composed of four single slopes with an overall slope height of 65m and a slope angle of 62°. In this study, the geotechnical characteristics were conducted by the previous study such as geological descriptions, discontinuity mapping, and kinematical analyses (Akbar and Wiyono, 2023). The geological description of the study area is listed in Table 1.

The orientation of dip/dip direction for the overall slope discontinuity can be determined from the composite of all discontinuities of every single slope, with a total discontinuity mapping count of 445 entries. Figure 6 depicts the stereographic projection of the discontinuity orientations measured of the overall slope in pole vector

Table 1. Geological description of the study area (Akbar and Wiyono, 2023)

No	Characteristic	Description
1	Main lithology	andesite
2	Slope condition	dry and excavated
3	Slope height	15m to 20m
4	Slope angle	66° to 75°
5	Joint orientation	unfavourable
6	Joint number	2 to 3
7	Joint spacing	0.21m to 0.25m
8	Joint roughness	rough & undulating
9	Joint alteration	unaltered
10	Joint aperture	closed-filled discontinues
11	Infilling	mostly clay
12	Seepage	mostly dry

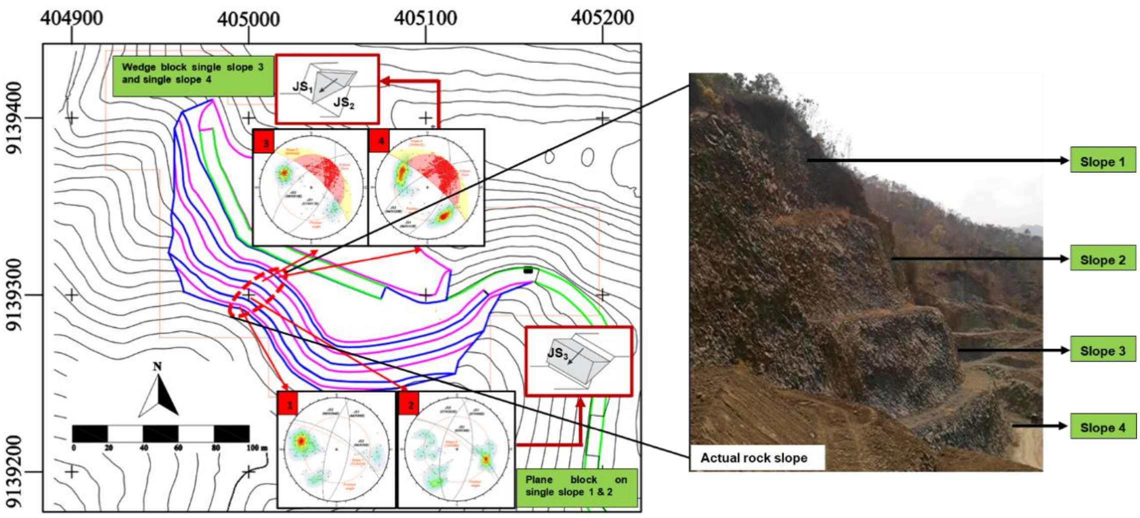


Figure 5. The projection of kinematical analysis and research location

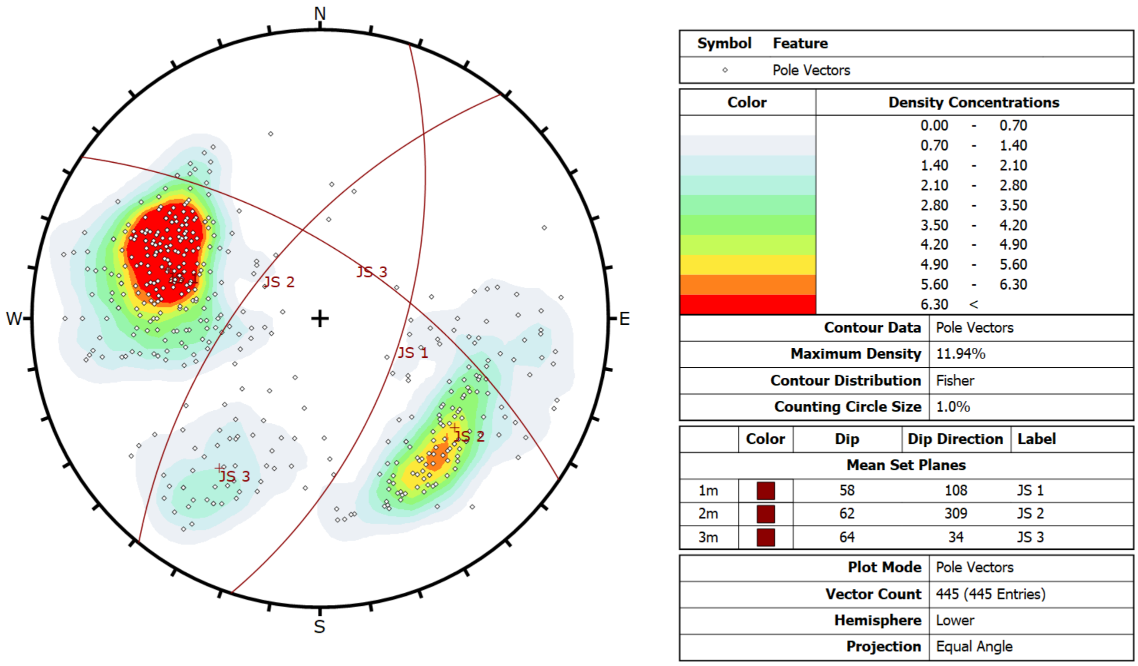


Figure 6. Stereographic projection of overall slope

mode using the Rocscience™ Dips Version 7.0 program, where there are three (3) major set planes or joint sets. The results of joint sets in dip/dip directions are summarized in Table 2. The mean dip measured for each single slope by manual measurement is 65.67°, 59.00°, 57.50°, and 59.00°, and the overall slope is 61.33°. To represent the structure condition in the rock slope, the mean dip orientation was used as the dipping of the structure plane for generalized anisotropic projection analysis.

Geotechnical Rock Input Parameter

The geotechnical input parameter was determined through site investigation, physical properties test and uniaxial compressive (UCS) test, which represents the strength of the rock. As mentioned by Dwinagara *et al.* (2021), one of the most important variables of geotechnical engineering in terms of efficiency is material properties. Samples of the UCS test were prepared with a ratio of sample geometry is 2 to 2.5, as recommended by the International Society for Rock Mechanics. Young's modulus and Poisson's ratio of rock were examined by Griffiths and Lane (2001) who recommend the value of E = 10^5 kPa, and ν = 0.3, If more precise values are not available, the results should be reasonable (Duncan, Wright and Brandon, 2014).

The Generalized Hoek-Brown failure criterion was used to express rock mass strength. The uniaxial compressive strength of intact rock (σ_{ci}) is determined from laboratory tests. The material constant m_i value is determined from the andesite lithology of the study area, and disturbance factor (D) uses 0.7 because rock excavation of the study area uses mechanical excavation. The GSI was calculated using the

Table 2. Result of discontinuity orientation at research locations (Akbar and Wiyono, 2023)

Location	Joint orientation				Slope Orientation
	J1	J2	J3	Mean Dip	
Slope 1	64°/N099°E	69°/N284°E	64°/N035°E	65.67	71°/N031°E
Slope 2	57°/N095°E	57°/N283°E	63°/N036°E	59.00	73°/N039°E
Slope 3	57°/N117°E	58°/N319°E	-	57.50	66°/N044°E
Slope 4	54°/N113°E	64°/N329°E	-	59.00	75°/N041°E
Overall Slope	58°/N108°E	62°/N309°E	64°/N034°E	61.33	62°/N039°E

relationship between the Q-slope value (Bar and Barton, 2017) and the GSI value for igneous rock based on Narimani *et al.* (2023), which was then incorporated into Equation 3.

$$GSI = 6.23\ln(\text{Q-slope}) + 44.94 \quad (3)$$

The Q-slope values were conducted by the previous studies by (Akbar and Wiyono, 2023) and the GSI estimation for classification of discontinuity condition is listed in Table 3. The Mohr-Coulomb failure criterion has been used to define the joint properties, and the strength properties were obtained from the literature by Hoek (2023), taking into account that the joint's filling material is mostly clay. The parameters of material properties for the rock slope stability analysis are shown in Table 4. The rock slope geometry known from the actual slope was then exported into the Rocscience™ Slide2 and Rocscience™ RS2 programs, as shown in Figure 7.

Table 3. GSI estimation based on Q-slope

Parameter	Slope 1	Slope 2	Slope 3	Slope 4	Mean
Q-slope	2.291	2.341	2.099	2.094	2.206
GSI	50.10	50.24	49.56	49.54	49.87

Table 4. Material properties of rock material

Material	Parameter			Remarks
Rock mass	Unit weight	23.88	kN/m^3	From previous studies
	Uniaxial Compressive Strength (σ_{ci})	85.04	MPa	(Akbar and Wiyono, 2023)
	Geological Strength Index (GSI)	49.87	-	Calculated based on (Narimani et al., 2023) Equation 3
	mi value	25	-	Andesite rock
	Disturbance factor (D)	0.7	-	Mechanical excavation
	Young modulus (E)	105	kPa	Griffiths and Lane (2001)
	Poisson ratio (ν)	0.3	-	
Joint	Peak cohesion (c)	50	kN/m^2	
	Peak friction angle (ɸ)	34.5	°	Shear strength of clay infilling material (Hoek, 2023)
	Residual cohesion (c)	25	kN/m^2	
	Residual friction angle (ɸ)	17.25	°	

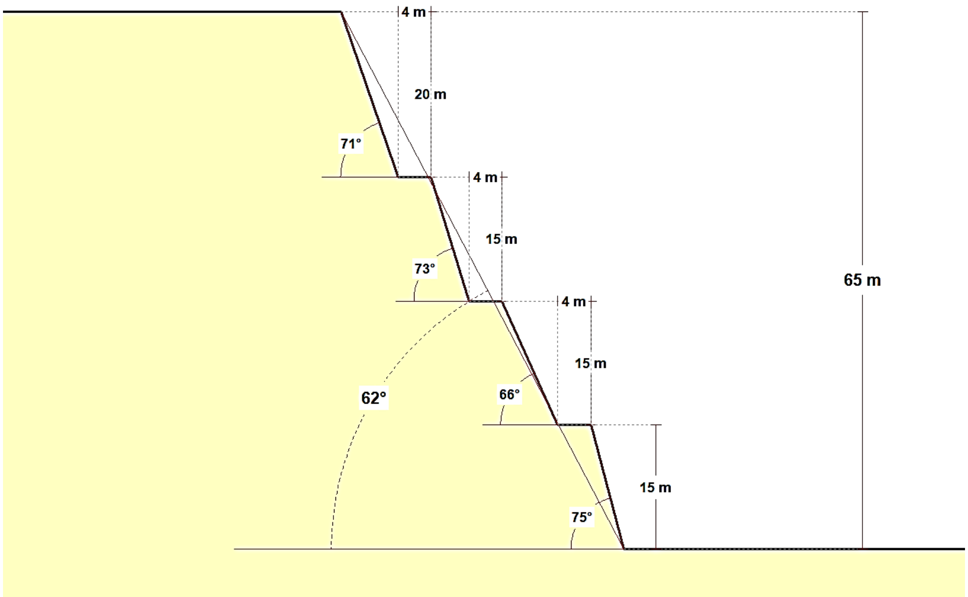


Figure 7. Actual slope geometry

Rock Slope Stability Analysis

The anisotropic model was used in this study by considering the rock mass properties, the joint properties, and the discontinuity characteristic. Because of the anisotropic plane (discontinuity), the non-circular mode are used for the slip surface, and most slope analyses will require a non-circular surface, especially for models with weak layers, anisotropic models, or even other complex models (Rocscience, 2016). In this study, the critical slip surface by LEM was carried out using the Cuckoo Search method (CS) with the local search method using Surface-Altering Optimization (SAO) because it is the primary search method that is suited for a slope model with non-circular failure mode, and it often finds a slip surface with a lower safety factor. The CS method with SAO is a stochastic method that works well on rock slopes with stochastic anisotropic planes, and also on models with non-circular slip surfaces (Nagendran and Ismail, 2021). The GLE/Morgenstern-Price criterion was used to evaluate the rock slope stability analysis using the limit equilibrium method, which includes force and moment equilibrium (Duncan, Wright and Brandon, 2014). The generalized anisotropic strength model allows the anisotropic characteristics of a material to be applied to any combination of strength types across multiple orientations of the anisotropic plane in the rock slope, resulting in a composite material. The incremental zones of the dip anisotropy are typically modelled as 5° –10° from the mean dip of a joint set or discontinuity orientation (Bar and McQuillan, 2018). The generalized anisotropic by LEM is modelled by the mean dip of discontinuity orientation, as shown in Table 2, with incremental zones of 10°, and the composite materials of the rock slope, as shown in Table 4. The Rocscience^{TM} Slide2 performed the slope stability analysis using the limit equilibrium approach, and Figures 8–11 show the generalized anisotropic material model of each slope.

The finite element method through the SSR approach way to represent complex models and interface conditions has made it a popular tool for assessing rock slope stability in recent years. The implementation of the designated jointed rock mass that takes into account orientation, spacing, continuity, and persistence of discontinuity can be incorporated into the FEM. The slope analysis method was conducted by the Rocscience^{TM} RS2 program to accommodate the discontinuity of rock through a joint network using the SSR technique. The joint network model in rock slope stability analysis of a single slope is based on geological description data in Table 1 and discontinuity orientation data in Table 2. The interpretation result of slope stability analysis can be seen in Figures 12 to Figure 19 and the recapitulation results are tabulated in Table 5.

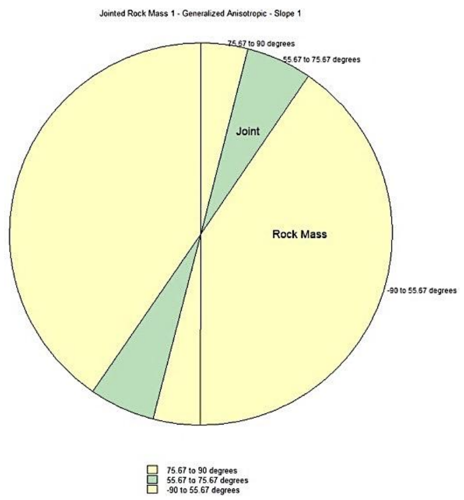


Figure 8. Generalized anisotropic model single slope 1

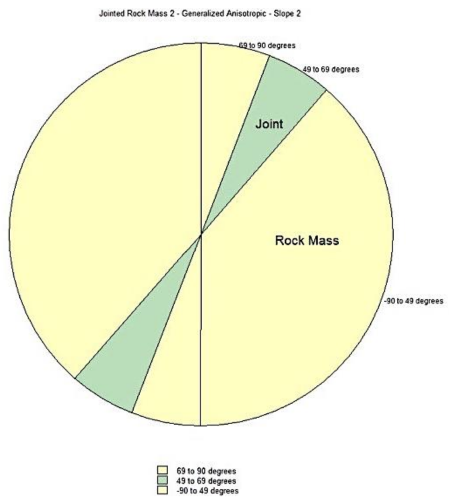


Figure 9. Generalized anisotropic model single slope 2

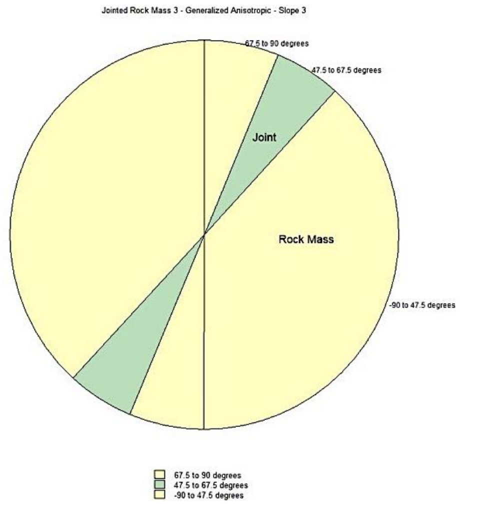


Figure 10. Generalized anisotropic model single slope 3

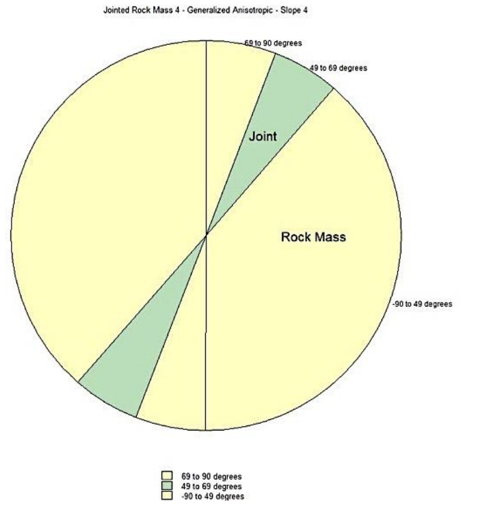


Figure 11. Generalized anisotropic model single slope 4

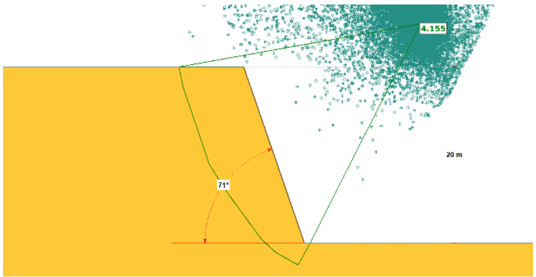


Figure 12. Single slope 1 – GA by LEM

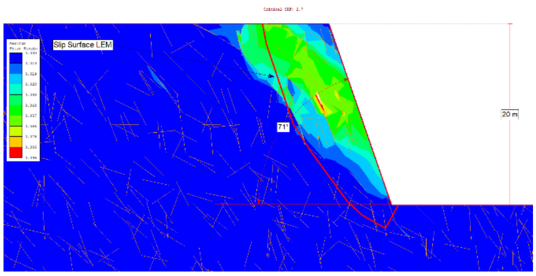


Figure 13. Single slope 1 – Joint network by FEM

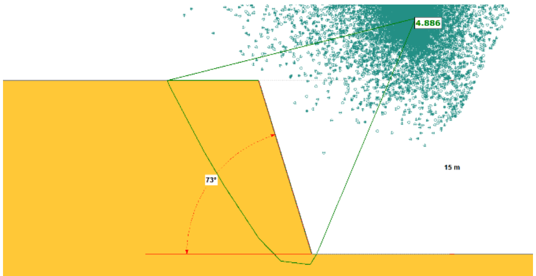


Figure 14. Single slope 2 – GA by LEM

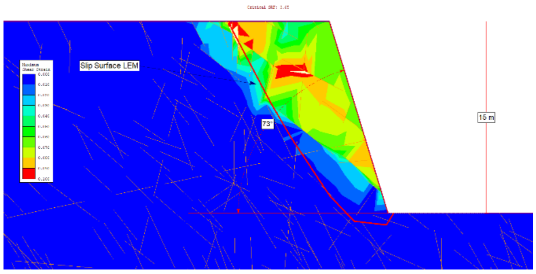


Figure 15. Single slope 2 – Joint network by FEM

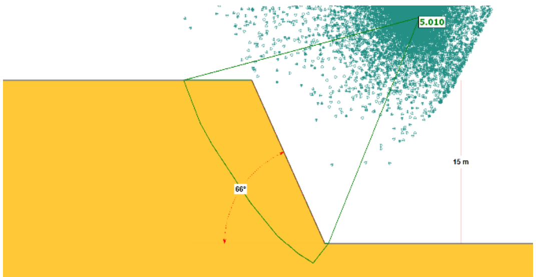


Figure 16. Single slope 3 – GA by LEM

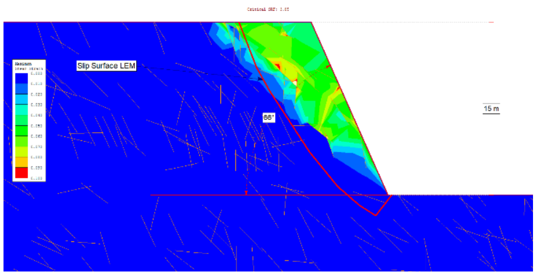


Figure 17. Single slope 3 – Joint network by FEM

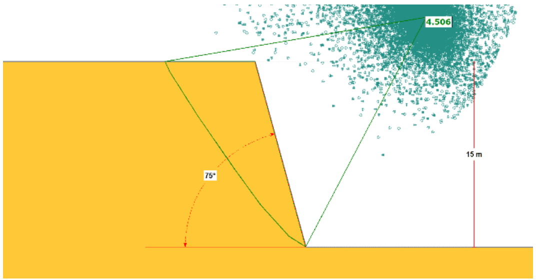


Figure 18. Single slope 4 – GA by LEM

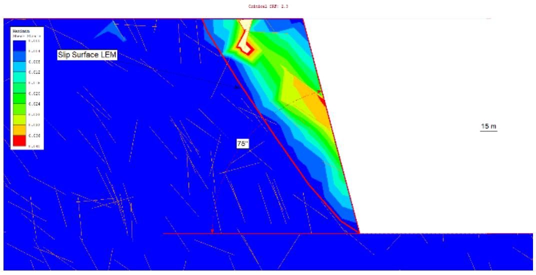


Figure 19. Single slope 4 – Joint network by FEM

Table 5. Recapitulation result of single slope analysis

Method	Slope 1	Slope 2	Slope 3	Slope 4	Mean	Remarks
Generalized anisotropic by LEM	4.155	4.886	5.010	4.506	4.309	Factor of safety (FOS)
Joint network by FEM	2.700	3.650	3.850	2.800	3.090	Strength reduction factor (SRF)

Overall Rock Slope Stability Analysis

As a result of the rock slope stability analysis shown in Table 5, the actual single slope geometry can be considered stable because the FOS or SRF is greater than 1.0. Overall rock slope stability analysis was identified to know the safety factor of the actual slope geometry of the study area. The mean dip of discontinuity orientation, as shown in Table 2, is used to model the generalized anisotropic by LEM with incremental zones of 10°. The joint network model was constructed using the dip/dip directions of discontinuity orientation data shown in Table 2, and it was then used in overall actual slope geometry by FEM using the SSR technique. The interpretation result of generalized anisotropic by LEM and jointed rock by FEM can be seen in Figure 20 and Figure 21, respectively, and the recapitulation results are listed in Table 6.

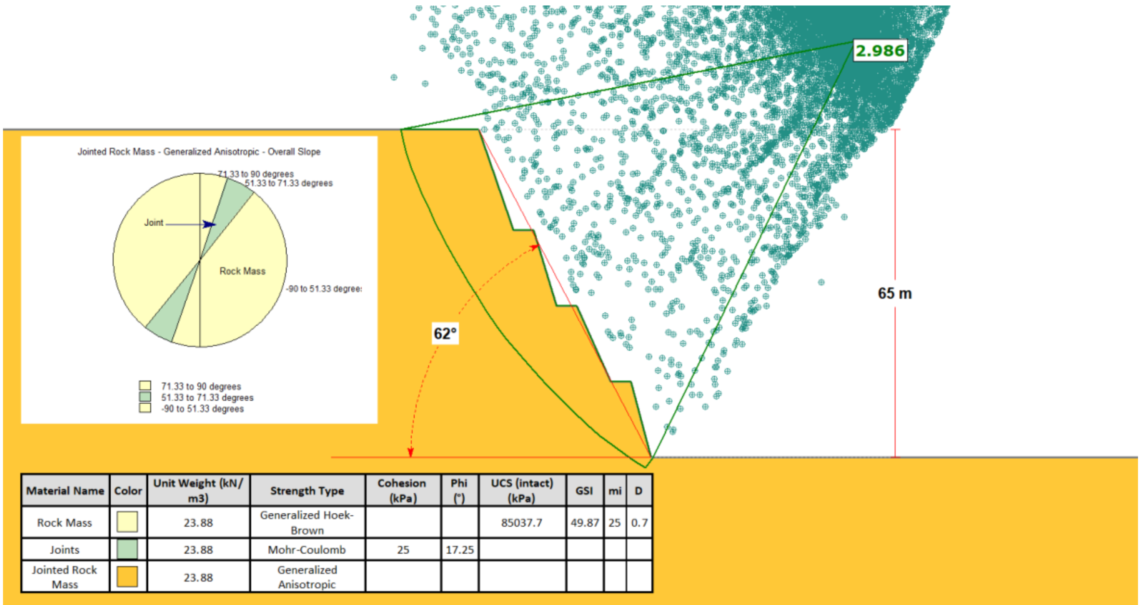


Figure 20. Slope stability analysis of overall slope - generalized anisotropic by LEM

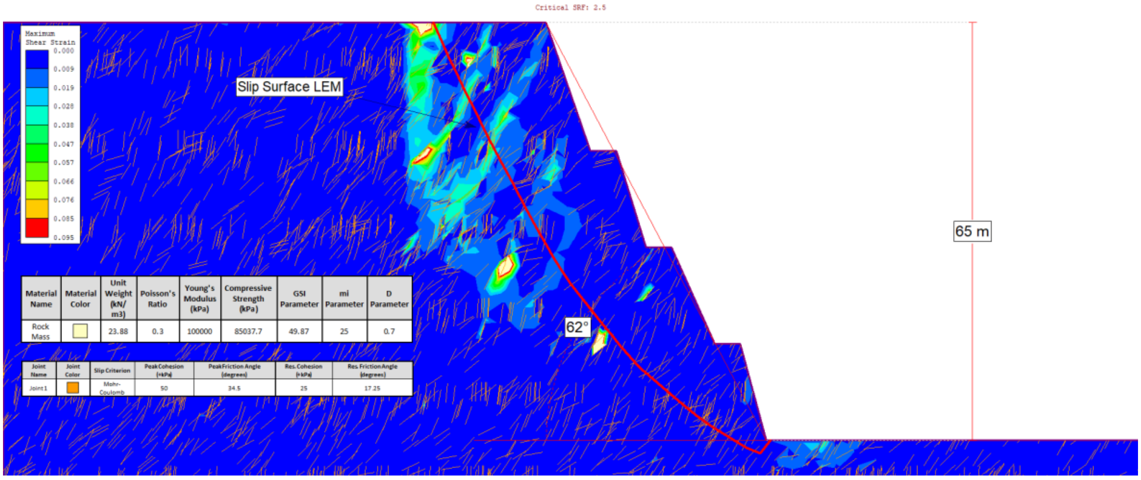


Figure 21. Slope stability analysis of overall slope – joint network by FEM

Table 6. Recapitulation result of overall slope analysis

Method	Overall slope	Remarks
Generalized anisotropic by LEM	2.986	Factor of safety (FOS)
Joint network by FEM	2.500	Strength reduction factor (SRF)

Comparative Result of Rock Slope Stability Analysis

Two case studies of rock slope stability analysis were performed, one using a generalized anisotropic method developed by LEM and the other using a joint network method developed by FEM. For both cases, the rock slope stability analysis of two different methods was obtained to assess slope stability's best result and more representative of the stability conditions of rock slopes by the actual geometry in each single slope and overall slope. Anisotropic material became an important rule for rock slope stability analysis after it was discovered that most rock materials are anisotropic due to the influence of discontinuity characteristics. The generalized anisotropic strength feature enables the slope analysis to generate a composite properties material model whereby any strength model can be assigned across any range of slice base orientations. Furthermore, the joint network by FEM produced more representative results for the actual rock mass regarding the discontinuity characteristic.

Comparing the results of generalized anisotropic by LEM and joint network by FEM shows that the FOS or SRF have a similar result with the Safety Factor > 1 that can be known in stable condition as shown in Figure 22, indicating that slope stability analysis methods aim to produce an accurate and complete representation of rock slope stability conditions. The interpreted result of the maximum shear strain of FEM occurring at the overlaid slip surface by LEM, where maximum shear strain gives a good indication of the slip surface occurring. Even more, the lower safety factor of the jointed rock slope indicates that the orientation of discontinuity can be proven to be very reliable using FEM by the SSR technique, but the analysis requires more time for the computation result. In addition, the strain-based approach can be used as an indicating value for slope stability threshold (Dwinagara *et al.*, 2024), and the suggested threshold strain level for rock mass is a strain at the lower bound value of 0.1% with an upper bound value of 3.0% (Newcomen and Dick, 2016; Coetsee, Armstrong and Terbrugge, 2020). As a result, as shown in Figure 23, the rock stability analysis using a joint network by FEM shows stable conditions with the maximum strain in the model below the minimum strain threshold (maximum strain model < 0.1). Besides that, two case studies of rock slope stability analysis show consistent results with previous studies by Akbar and Wiyono (2023), which conclude that the actual slope geometry using the empirical method Q-slope is stable.

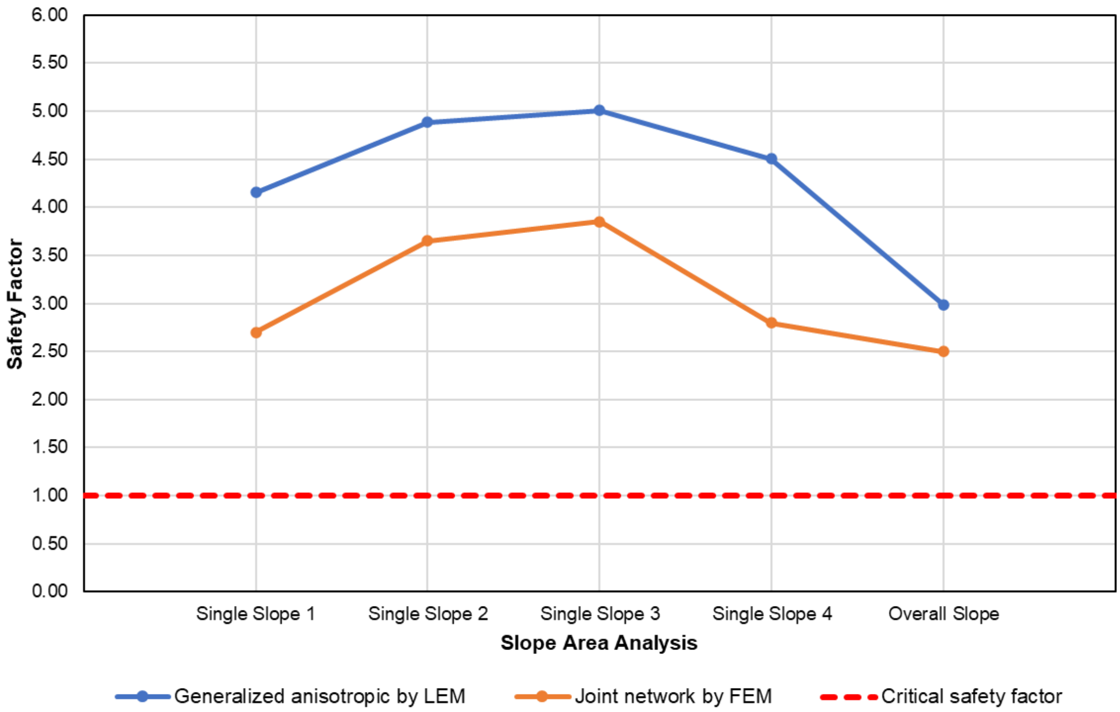


Figure 22. Comparative result of safety factor by two case studies of rock slope analysis

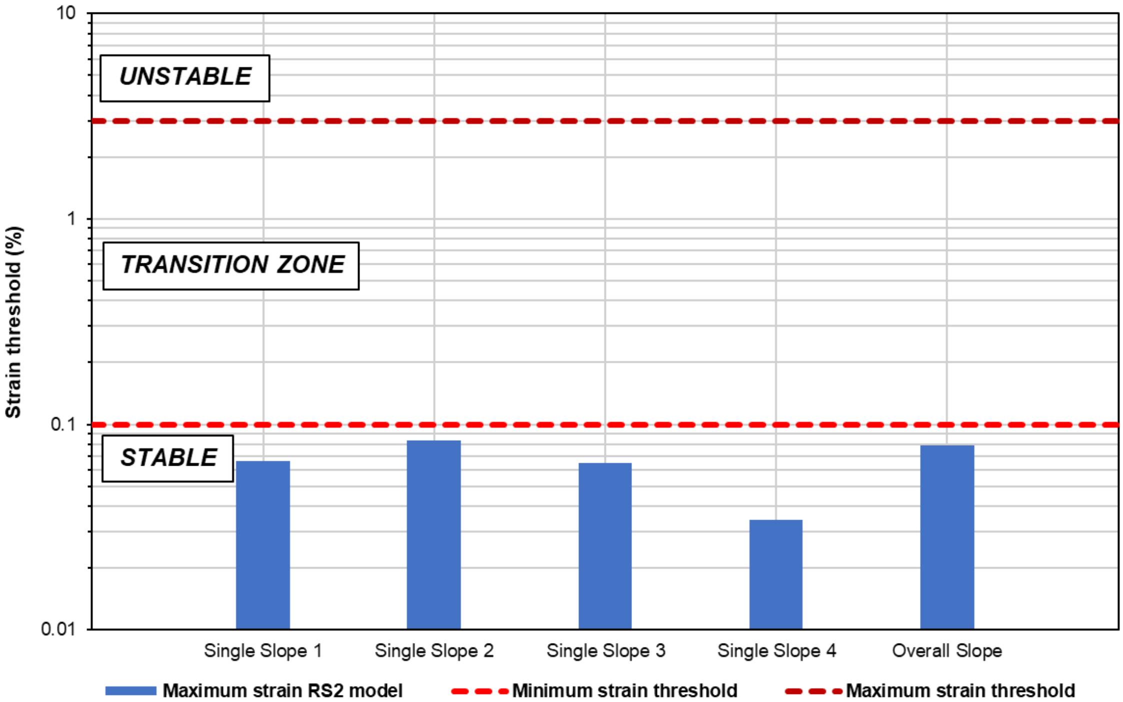


Figure 23. Maximum strain of joint network by FEM in the RS2 model

CONCLUSION AND SUGGESTION

In this paper, the actual geometry in each single slope and overall slope is used to explore two different methods of rock slope stability analysis using generalized anisotropic by LEM and joint network by FEM. When the results are compared, the

FOS and the SRF produce similar results and can be known in a stable condition with the safety factor > 1. Furthermore, the rock slope stability analysis performed with a joint network by FEM reveals stable conditions with the maximum strain result below the minimum strain threshold (maximum strain model < 0.1). Through the various method analyses of rock slope, geotechnical input parameters and discontinuity characteristics can be concluded as the influencing factors in rock slope stability.

The discrepancy in these parameters, as well as the complexity in choosing suitable quantitative data are critical in rock slope stability analysis. The study emphasizes the importance of meticulous analysis and knowledge of the geotechnical characteristics to effectively present rock slopes condition. The anisotropic condition and joint network should be taken into account in the rock slope stability study to depict the influence of discontinuities in the rock slope.

Through the application of various methods, the aspects investigated in this study provide a more theoretical and practical approach to understanding rock slope stability analysis and the approach of discontinuity characteristics to the safety factor value. A single method may produce an inadequate depiction of rock mass. It is necessary to use various methods to evaluate rock slope stability.

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