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Hoek & Brown Collapse Criteria Method on The Road Section of Lende Tovea Village, Sirenja District, Donggala Regency

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Abstract: Avalanches on public infrastructure such as highways occur unpredictable due to unstable slopes due to degraded rock material. Avalanches can potentially cause and material losses. The research was conducted to classify the rock mass with the Geological Strength Index (GSI) method as a parameter for determining the slope safety factor on the road section of Lende Tovea Village, Sirenja District, Donggala Regency, Central Sulawesi Province. To obtain the value of cohesion and angle of friction in the approach used Hoek & Brown collapse criteria. Determination of safety factor value using Spencer type method, using GeoStudio 2018 R2 software application. The slope on the road section of the research area is composed of igneous lithology in the form of rhyolite and diorite. Geological structures in the form of fracture and faults. The results showed that the slope of the road section in the northern part of Lende Tovea Village based on the Geological Strength Index (GSI) value in the range of 25-33 with the condition of the rock mass is in the category of very blockly, disturbed & poor and slicken with wedge avalanche type at observation stations 1-5. The results of the safety factors value at stations 1, 2, 4, and 5 are in a condition prone to landslides with values of 1.514; 1.482; 1.595; 1.408 respectively while at station 3 in a condition where landslides rarely occur with a value of 1.921.

Keywords: Factor of safety; Failure criterion; Geological Strength Index (GSI); Geostudio

Introduction

A slope is a sloping surface of land or rock that forms a certain angle to a horizontal plane and is unprotected (Torri, 2023). A slope will experience collapse, technically said to have lost its stability. Before experiencing collapse , the slope can be certain to have a low safety value. Meanwhile, a slope in a stable condition is considered not to experience material movement downwards or to a lower place than its original position (Botjing et al., 2020). However, a safe slope can change to unsafe at some point and can experience collapse which generally occurs due to geological processes in the form of weathering resulting from the deformation process in the rock mass that makes up the slope (Abramson et al., 2001).

Donggala Regency is one of the regencies with a high level of danger for landslides with a score of 24.00, this is based on the 2021 Indonesian Disaster Risk Index (BNPB, 2021). The road section of Lende Tovea Village, Sirenja District, Donggala Regency has the potential to experience rock slides, this can endanger road users. Based on this, the road section needs to be handled in the form of a slope stability analysis to determine the value of the slope safety factor. To ensure the stability of the rock slope, an evaluation is needed to determine the strength of the rock mass using the *Geological classification. Strength Index* (GSI) is used to obtain the cohesion value and internal friction angle based on the recommendations of the (Hoek et al., 2002) failure criteria method.

This study aims to determine the quality of rock mass on slopes based on the (Hoek et al., 2002) collapse criteria method to obtain the value of the slope stability safety factor based on *the Limit Equilibrium slope stability analysis method with the Spencer method type. In the study,* kinematic analysis was also carried out to determine the type of landslide that has the potential to occur on the slopes of the road sections of the research area based on the Classification of the main types of slope failures, and

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structural geological conditions that cause collapse (Hoek & Bray, 1981).

The research area is included in the regional geological map of the Palu Sheet compiled published by the Center for Geological Research and Development . The geomorphology of the research area is in a low hilly area with a height difference of 50-200 meters above sea level with steep - very steep slope angles with a percentage of 21% - 140% and, valley shapes in the form of the letters "V" and "U". The regional stratigraphy of the research area is in the form of rhyolite and diorite lithology (Katili, 1978).

Based on previous researchers Hennig et al. (2016), the age of this unit is included in the Granite and Granodiorite (gr) formation as explained in this formation consisting of several lithologies in the form of rhyolite and diorite which are also found in rhyolite and diorite lithologies at the research location. Both lithologies are Late Oligocene - Late Miocene . The Geological Structure consists of fault and joint structures. The fault structure is a normal fault, while the fracture structure is genetically classified as a shear fracture in the study area.

Method

Administratively, the research area is located on the northern road section of Lende Tovea Village , Sirenja District , Donggala Regency, Central Sulawesi Province or along the Tambu-Tompe road section. km 6 – km 8. Geographically, the research area is at coordinates 119° 49' 10" East Longitude – 119° 49' 50" East Longitude and 0° 8' 50" South Latitude – 0° 9' 30" South Latitude.

Figure 1. Location of the research area in Lende Tovea village, Sirenja sub-district

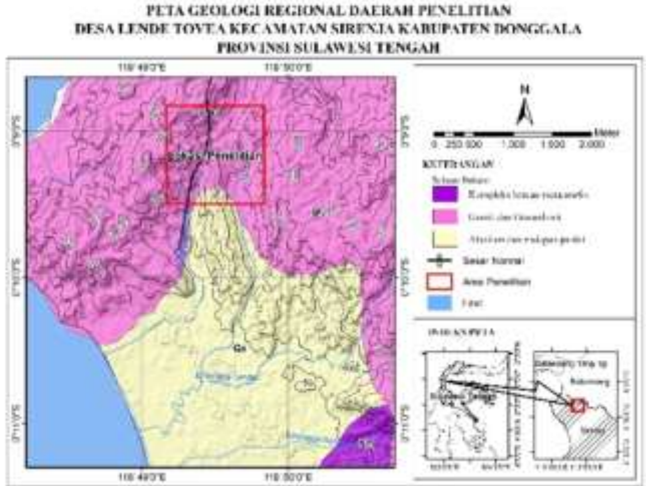

Figure 2. Regional geological map of the research area

The methods used in this study were both qualitative and quantitative. The research process was carried out using each method. Secondary and primary data collection was carried out using Geological and Engineering Geological methods, both qualitatively and quantitatively. The landslide type analysis process used a stereographic method to analyze the kinematic results . The rock mass quality analysis process used *Geological classification. The Strength Index is carried out based on the* Hoek & Brown (2002) collapse criteria method which will be used to determine the safety factor value using the Spencer analysis method.

Results and Discussion

The research area is located on an undulating hilly terrain with steep to very steep slopes. The slopes of observation stations 1 and 2 are composed of rhyolite rock material. Meanwhile, stations 3, 4, and 5 are characterized by diorite lithology. The fault and joint geological structures contribute to the weathering process and the occurrence of collapses or landslides on the slopes. Therefore, the slopes on this road section are categorized as slopes with the potential for landslides.

Geological The Strength Index is used to determine the rock mass (Narimani et al., 2023, 2024; J. Singh et al., 2023; Yang et al., 2024) and then analyzed using the Hoek & Brown failure criteria method which will be used to obtain the cohesion value and internal friction angle as parameters for calculating the slope safety factor value. Strength Index is divided based on 2 parameters, namely structure rating (SR) and surface condition rating (SCR). At observation stations 1,2,3,4,5 (numbers); distance between discontinuities (letter “a”); Soft material filling the discontinuities in the form of clay material (letter “b”).

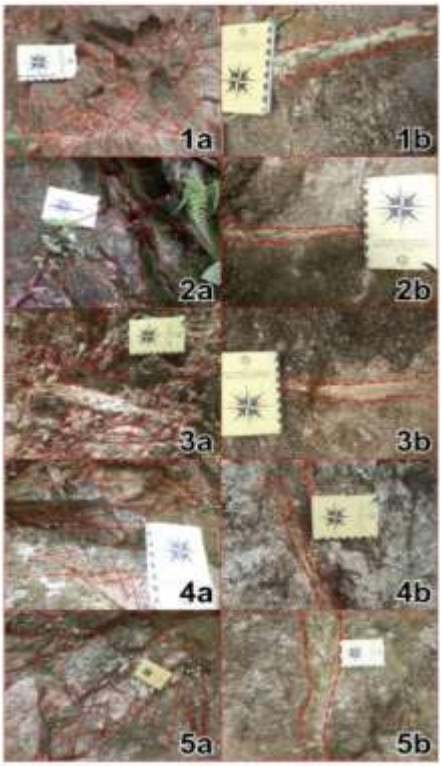

Figure 3. Rock mass conditions based on GSI.

Based on the rock mass conditions in the form of structural rating (SR) and surface condition rating (SCR), the ratings can be correlated with the GSI diagram in Table 1 and Figure 4.

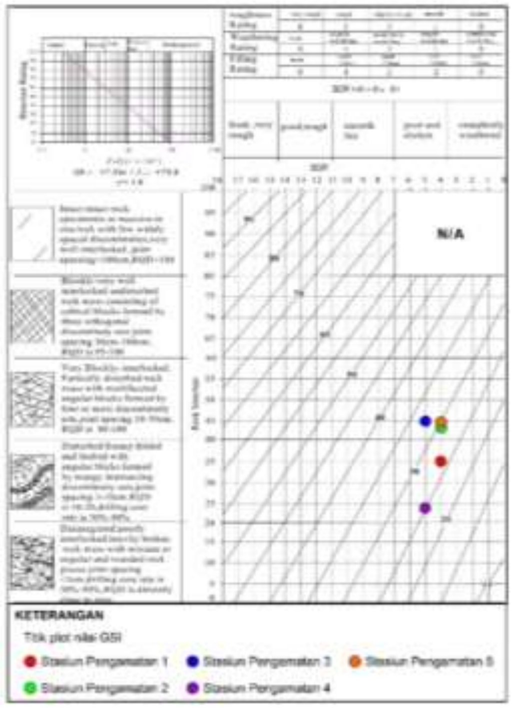

Figure 4. GSI values based on rock mass observations at stations 1, 2, 3, 4 and 5

Table 1. GSI results based on SR and SCR ranking values and conditions

STA	SR Rank		SCR Rating		GSI Value
	Mark	Condition	Mark	Condition	
1	35.40	Disturbed	4	Poor and slicken	26
2	44.44	Very Blockly	4	Poor and slicken	29
3	45.14	Very Blockly	5	Poor and slicken	33
4	24.45	Disturbed	5	Poor and slicken	25
5	45.32	Very Blockly	4	Poor and slicken	30

At stations 1 and 4, the rock mass conditions, in addition to experiencing deformation due to tectonic processes, also experienced a process of degradation resulting from water due to high rainfall intensity in mountainous areas. At stations 2, 3, and 5, the rock mass conditions on the slopes that experienced rock deformation processes resulted in slope outcrops in the lithology being fractured and faulted and experiencing weathering so that the rock mass encountered was in poor condition and disturbed (Kudapa et al., 2023; Silwal et al., 2024; D. Singh et al., 2022).

To analyze the slope stability at the research location based on the *Hoek & Brown failure criteria* . To obtain the safety factor value, the maximum stress value on the slip surface ($\sigma'_{3\,max}$) is used which will be entered into the *Hoek & Brown rock material properties* using the Geostudio Application (Slope / W). Parameters required are the rock compressive strength value, *Geological Strength Index* (GSI), rock mass material constant value (*mi*), and rock compressive strength value, and *D value* (*Disturbance*).

The above parameters are used to obtain *material property values* using equations in the form of reducing rock material constants, rock mass interlocking strength, rock mass linearity parameters related to rock mass competence, rock mass strength values (σ' cm), *in situ* stress (σ_0), maximum stress level of the slip surface ($\sigma'_{3\,max}$), normal stress, internal friction angle (ϕ') and cohesive strength (c') of (Hoek et al., 2002). All the parameter values of the equation above are used to analyze slope stability expressed by the safety factor value. The results of the collapse criteria analysis are as follows (Table 2).

Table 2. Calculation results of the Hoek & Brown failure criteria in determining the value of $\sigma'_{3\,max}$, friction angle (ϕ ') and cohesive strength (c')

STA No.	Volumetric Weight (γr) MN/m3	H m	noodles	GSI	D	σ'ci MPa	Mb	S		σ'cm MPa	σ0 MPa	σ'3max MPa	σ'3n	ϕ '	c' MPa
1	0.0202	11	20	26	0.7	18	0.34	0.00002	0.53	0.47	0.22	0.171	0.01	42	0.048
2	0.0222	13	20	29	0.7	19	0.40	0.00003	0.52	0.35	0.29	0.212	0.01	43	0.062
3	0.0209	10	20	33	0.7	17	0.50	0.00006	0.52	0.04	0.21	0.131	0.01	48	0.049
4	0.0216	8	20	25	0.7	16.1	0.32	0.00002	0.53	0.45	0.17	0.136	0.01	43	0.038
5	0.0202	15	20	30	0.7	16.2	0.43	0.00004	0.52	0.25	0.30	0.215	0.01	42	0.061

Kinematic analysis was conducted using the stereographic method to determine the potential landslide types on the slopes at each observation station. The following are the results of the kinematic analysis using the stereographic method for each station in Table 3 and Figure 5.

Table 3. Results of stereographic analysis for determining landslide type

STA	Slope	Discontinuity		Landslide Direction	ϕ '
		Set 1	Set 2		
1	70°/N 150° E	72°/ N 188° E	66°/ N 177° E	N 140° E/ 64°	42°
2	72°/N 160° E	67°/ N 192° E	79°/ N 108° E	N 172° E/ 66°	43°
3	75°/N 23° E	69°/ N 58° E	65°/ N 358° E	N 18° E/ 64°	48°
4	68°/N 265° E	71°/ N 214° E	67°/ N 289° E	N 259° E/ 64°	43°
5	70°/N 150° E	69°/ N 328° E	76°/ N 221° E	N 283° E/ 62°	42°

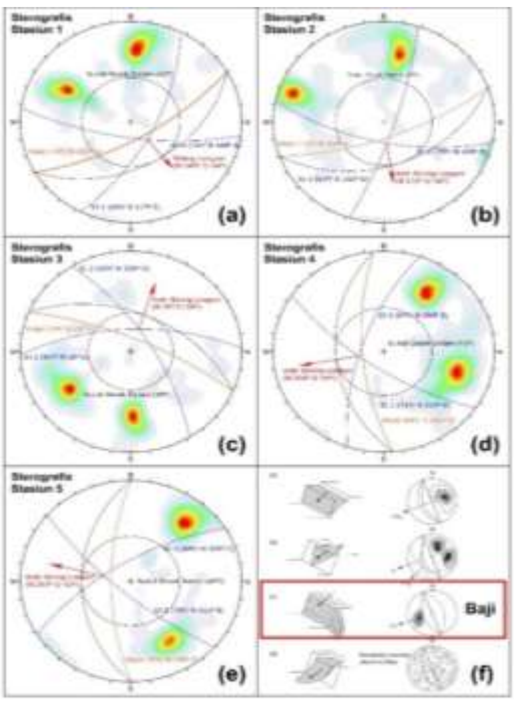

Figure 5. Results of stereographic projection of joints, slope , friction angle at stations 1, 2, 3, 4 and 5 (a, b, c, d, e); conditions for potential wedge landslides based on the classification of landslide types from stereographic results (f) (Hoek & Bray, 1981)

Stereographic analysis, wedge landslides are potential landslides at 5 observation stations. This is because the slope of the intersection *plane* of 2 sets of discontinuities is smaller than the slope slope (tren/plunge) and tilts towards the face of the slope and, the internal friction angle is smaller than the intersection *plane* of 2 sets of discontinuities (Ab Aziza et al., 2026; Liu et al., 2024; Yuan et al., 2026). Based on the slope conditions at each station, rock mass conditions were found with many paired shear joints that have the direction of the slope of the joint plane in the same direction as the slope slope, this is one of the conditions for a slope to have the potential to experience wedge landslides.

GeoStudio 2018 R2 software which will produce a safety factor (FK) value for each slope at the observation station. The slope safety factor value at each station is based on the slope geometry and material properties that have been calculated based on the Hoek & Brown failure criteria (Hu et al., 2023; Melentijević et al., 2024). The parameter values can be seen in Table 5. In this study, the safety factor value uses a value determination based on the landslide hazard classification system according to Kim & Yoon (2023) with a high to very low level of landslide vulnerability in Table 4.

Table 4. Landslide hazard classification system

FK Value	Landslide Vulnerability Level
FK ≤ 1.2	Height: Landslides Occur Frequently
FK 1.2 – 1.7	Medium: Landslides May Occur
FK 1.7 – 2.0	Low: Landslides are rare
FK > 2.0	Very Low: Landslides are very rare

Table 5. Slope safety factor values based on slope geometry and *material properties (Hoek & Brown* failure criteria) at 5 observation stations

STA	Slope Height (m)	Slope (°)	Road Width (m)	Hoek & Brown		FK Value
				GSI	$\sigma'3max$ (MPa)	
1	11	70	8	26	0.171	1,514
2	13	72	8	29	0.212	1,482
3	10	65	8	33	0.131	1,921
4	8	68	8	25	0.136	1,595
5	15	70	8	30	0.215	1,408

Hoek & Brown collapse criteria analysis which is entered into the FK processing software, namely GEOSTUDIO 2018 R2. The data is processed using the *Spencer method* which will produce a safety factor value. The value of the slope safety factor at observation station 1 is 1.514 (Landslides can occur). The value of the slope safety factor at observation station 2 is 1.482 (Landslides can occur). The value of the slope safety factor at observation station 3 is 1.921 (Landslides rarely occur). The value of the slope safety factor at observation station 4 is 1.595 (Landslides can occur). The value of the slope safety factor at observation station 5 is 1.408 (Landslides can occur).

Based on data processing in the SLOPE/W analysis product application by entering slope geometry data in the form of slope height, road width and slope gradient, as well as *material property values* in the form of mb , s, a, mi, GSI, rock compressive strength and unit weight. The results of the slope stability analysis can be seen in Figure 6.

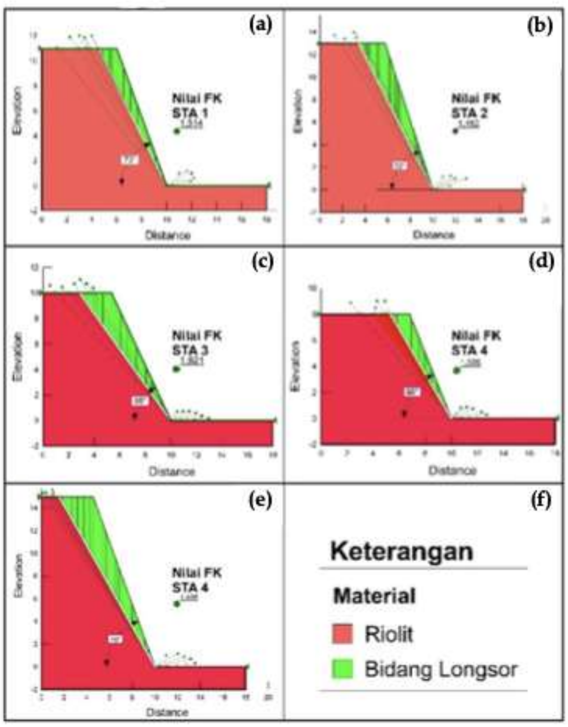

Figure 6. Results of slope safety factor values at stations 1, 2, 3, 4 and 5 (a, b, c, d, e); description in figure a - d (f).

Figure 7. Appearance of slope conditions and landslide potential at stations 1, 2, 3, 4 and 5 (in order from top)

A slope is a sloping surface of land or rock that forms a certain angle to a horizontal plane and is unprotected (Amalina & Jananto, 2026; Menon & Kolathayar, 2025). A slope will experience collapse, technically said to have lost its stability. Before experiencing collapse , the slope can be certain to have a low safety value. Meanwhile, a slope in a stable condition is considered not to experience material movement downwards or to a lower place than its original position. However, a safe slope can change to unsafe at some point and can experience collapse which generally occurs due to geological processes in the form of weathering resulting from the deformation process in the rock mass that makes up the slope (Abramson et al., 2001).

On the slopes of observation stations 1, 2, 4 and 5, there is a potential for landslides to occur which are classified as medium category or the slopes are in an unsafe condition due to weathering resulting from the geological structure deformation process which is characterized by the presence of fractures in the rock mass that makes up the slope and the influence of rainfall at this station significantly affects it, characterized by the condition of the weathered rock mass causing the rock mass to experience disintegration so that the rock mass that makes up the slope has the potential to collapse or landslide (Li et al., 2024; Nian et al., 2024). The condition of the slope at station 3 experiences weathering due to the deformation process, characterized by the presence of fractures in the rock mass and, the slope at this station is classified as low below 10 meters so that the material load at the top of the slope does not significantly affect the stability of the slope which results in the slope safety factor value at station 3 being at a low vulnerability level or landslides rarely occur (Figure 7).

Conclusion

The rock mass at stations 1 and 4 is in a *disturbed / seamy* & *poor condition. and slicken* Meanwhile , at stations 2, 3 and 5 the rock mass is in *very good condition. blockly* & *poor and slicken*. The type of landslide that has the potential to occur in the research area is a wedge landslide at stations 1, 2, 3, 4 and 5. The slope safety factor values at observation stations 1, 2, 3, 4, and 5 are 1.514; 1.482; 1.921; 1.595; 1.408 respectively with a medium vulnerability level (landslides can occur) at stations 1, 2, 4 and 5, while at station 3 it is at a low vulnerability level (landslides rarely occur).

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No conflict interest.

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