STABILITY ANALYSIS OF CUT SLOPE USING RMR AND SMR

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ABSTRACT

The Planjan - Tepus road is built on a slightly steep karst morphology, necessitating slope excavation works. Slope stability is one of the elements to consider, particularly in slope excavation work. The excavation depth of the slopes sampled in this research is up to 48 meters. It is critical to undertake slope stability analysis quickly, precisely, and safely. For rapidly examining slopes, empirical approaches such as Rock Mass Rating (RMR) and Slope Mass Rating (SMR) can be utilized. An examination of the limit equilibrium method was performed using Rocscience Slide v.6.0 software to assure the slope stability level further. The limit equilibrium method used is Morgenstern-Price and Spencer. The value of slope stability analysis using the RMR method is 41-53, and the rock mass quality is categorized as class III (fair). The value of slope stability analysis using the SMR method 41-53, the rock mass quality is categorized as class III (normal), with slope stability in partially stable conditions. Slope stability using the limit equilibrium method produces a safety factor value of 1.670 - 1.680 for conditions without seismic loads and 1.137 - 1.154 for conditions with seismic loads. According to the findings of this analysis, the slope is in stable (safe) conditions.

Keywords: *Limit equilibrium; RMR; Slope stability; SMR*

INTRODUCTION

The South - South Cross Road Java is one of the Ministry of Public Works and Housing's programs that aims to encourage the development of local economic potential and bridge the gap between northern Java and southern Java. One of the section road is on the Planjan - Tepus route in Gunungkidul Regency, Special Region of Yogyakarta. Slope excavation is taking place as part of the development of the Planjan-Tepus road section, and the stability of the slope is one of the aspects that need special attention. Disruptions to slope stability can jeopardize safety, harm the environment, and dissolution road connectivity.

Slope stability analysis can be performed using a variety of methodologies, including empirical and limit equilibrium methods (Karaman et al., 2013). Empirical approaches such as Rock Mass Rating (RMR) and Slope Mass Rating (SMR) can be utilized to measure slope stability quickly. However, to assure that the slope is stable (safe), slope stability utilizing the limit equilibrium approach must be performed. This research aims to determine slope stability using the empirical approach and the limit equilibrium method. The slopes sampled in this research are between STA 8+400 and STA 8+500.

Rock Mass Rating (RMR) is an efficient approach for determining rock stability (Ismail et al., 2022; Kundu et al., 2020). The use of rock mass quality classification with the RMR approach is undeniable, and it is widely utilized in planning and design (Kumar & Pandey, 2021). The assessment in the RMR classification must be divided into regions that have the same character,

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particularly in terms of structural parameters, both quality and quantity. As shown in Table 1, five parameters in assessing rock mass classification using the RMR method: rock compressive strength, rock quality designation (RQD), spacing of discontinuities, conditions of discontinuities, and groundwater conditions. Based on the outcomes of each assessment, the rock mass quality is classified into five classes for each characteristic, as indicated in Table 2. The RMR value is associated with the stability of the rock mass (Pantaweesak et al., 2019). From the RMR assessment, an estimate of the safe slope cut angle is obtained (Waltham, 2003).

Slope Mass Rating (SMR) is one of the rock mass classification methods that can be applied to analyze slope stability (Azarafza et al., 2017, 2020) quickly (S. Kamutchat, 2007). SMR classification is obtained from the RMR classification (RMR_{basic}) with four adjustment factors (Pastor et al., 2019), such as the relationship factor of the strike and dip of the slope and the discontinuities, the topology of the slope, and the excavation method.

SMR is formulated by Romana et al. (2003) in Goel & Singh (2011) through the following equation:

$$SMR = RMR_{basic} + (F_1.F_2.F_3) + F_4$$

Where RMR_{basic} is the RMR value for the Bieniawski classification (1989); F_1, F_2, and F_3 are the correction factors for the relationship between strike direction and dip of slopes and discontinuities (Table 3); and F_4 is the correction factor for the excavation method (Table 4).

Slope Stability based on the Limit Equilibrium Method

The limit equilibrium method is the most commonly used method for assessing slope stability (Azmoon et al., 2021; Qi et al., 2021; Stianson et al., 2015; X. Liu, 2019). This method is straightforward, can evaluate the stability of numerous input parameters, is specific to implementation in various computer languages, and is easily understood by practitioners (Zheng et al., 2020). Different methods in the limit equilibrium method are based on various assumptions, such as the normal force between the slices, the shear force between the slices, the form of the slip plane, and the equilibrium conditions. The Morgenstern-Price and Spencer methods will be used to analyze slope stability models.

The limit equilibrium method evaluates the driving forces to move the rock mass as well as the resisting forces, and the ratio of resisting forces to driving forces is defined as the factor of safety (Bishop, 1955; Bushira, et al., 2018; Raghuvanshi, 2019; Renani & Martin, 2020). The slopes are declared stable (safe) for rock slopes and fulfill the authorized standards following SNI 8460:2017, which are more significant than 1.5 for conditions without seismic loads and greater than 1.1 for conditions with seismic loads.

METHODS

The research method carry out by determining the research location, identifying the problems, literature review, collecting datas, and analysis the data. The data used came from observations in the field as well as laboratory test results.

The field observations include observing the litology, the slope, the strike's direction, the dip's angle, and the joint. Discontinuity conditions such as joint distance, RQD, discontinuity length, discontinuity aperture, roughness level, discontinuity filling, weathering rate, and groundwater conditions were

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assessed using joint observations. The rock mass quality was weighted based on the RMR and SMR observations.

Laboratory test were performed on rock samples. Laboratory testing determines the rock's compressive strength, index and mechanical properties, friction angle, and cohesion value. Secondary data that used in this research are core drill report, seismic data, and slope geometry design. Furthermore, slope safety factor analysis with limit equilibrium modeling using the Rocscience Slide v.6.0 software facilitates a more accurate slope stability analysis. The flowchart for this research method as shown in Figure 1.

RESULTS AND DISCUSSION

Geological Conditions

Figure 2 shows that observations are conducted every 25 meters along the slopes between STA 8+400 and STA 8+500. Based on the Geological Map of Surakarta-Giritonto by Surono et al., (1992) and direct megascopic observations at the research site, the lithology composed of the research site is limestone. The slope at the research site was classified as slightly steep based on observations and slope categorization by Husein & Srijono (2007) and Zuidam (1985). The research slope was moderately weathered (III) to highly weathered (IV). The color of limestone changes practically occurs across the entire slope surface, with the fresh color of the rock being white and the weathered color being brownish white. On moderately weathered limestone slope (III) was characterized by color changes, and less than half of the rock material was dissolved into the soil, whereas limestone with a highly weathered (IV) had more than half of the rock material degraded and disintegrated into the soil.

Slope stability analysis based on RMR

Table 7 shows the results of RMR parameter measurements and observations. Based on field observations, the research slope is classified as a weak rock (R2) with an estimated compressive strength of 5 - 25 MPa. The ISRM 1978 approach indicated rock strength estimates where specimens were difficult to peel off with a knife, but geological hammer blows could create small indentations. According to Table 7, the slopes at STA 8+400, 8+425, and 8+475 have an RQD value of 50 - 75% and a discontinuity distance of 200 - 600 mm. The discontinuity area along the research slope has an aperture more than 5 mm, the roughness level is very coarse, and the weathering level is moderate. The slopes at STA 8+450 and 8+500 exhibit RQD values ranging from 25 to 50% and a discontinuity plane distance of 60 to 200 mm. The condition of the discontinuity along the research slope has an aperture more than 5 mm, a high level of roughness, and a high degree of weathering. Groundwater observations suggest that the slopes' surface is dry; hence the parameter value for groundwater is 15. RMR values of the research slope range from 41 and 53. According to Bieniawsky (1989), the slope with RMR value 41 - 53 is included in the fair rock mass quality. The safe slope cut angle for RMR class III with fair rock mass quality is 55^{o}, according to Waltham (2003).

Slope stability analysis based on SMR

Plotting on the rose diagram was done based on the findings of the joint orientation measurements in the field, as shown in Table 8. The rock mass quality value was calculated using the SMR method by processing the rose diagram and the previous RMR value. The weight of the SMR value is determined after

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many changes are made to the RMR value, namely:

1. The first adjustment (F_1) was made to the strike direction slope and joint correlation. Based on Table 3, Table 8, and Figure 3, it is known that the correlation of the strike direction of the slope is N225^{o}E and the joint is N235^{o}E, so the rating for the F_1 parameter is 0.7.
2. The joint dip angle and the correlation between the joint dip and the slope angle were adjusted in the second (F_2) and third (F_3) steps. According to Tables 3 and 8, the rating of the F_2 parameter is 1, and the rating of the F_3 parameter is 0.
3. The fourth adjustment (F_4) was made to the slope excavation method, where mechanical excavation was performed at the research site. According to Table 4, the rating for parameter F_4 is 0.

The research slope has an SMR value range of 41 - 53 when applying the SMR equation developed by Romana et al. (2003). As presented in Table 5, the research slope is classified as class III with normal rock mass quality. According to Romana et al. (2003) the level of slope stability with an SMR value of class III is partially stable, with a failure chance of 0.40. A low possibility of collapse is due to the trim level of alignment, which is 10^o in the F_1 adjustment factor, and the difference between slope angle and the discontinuities, which is 12 in the F_3 adjustment factor.

Slope stability analysis based on the Limit Equilibrium Method

Slope stability analysis utilizing the limit equilibrium approach necessitates a slope design model, index and rock mechanics property parameters, and loading parameters. The model analysis uses the design slope from Special Region of Yogyakarta National Road Planning and Supervision Working Unit (2020), the depth of the excavation slope is up to 48 meters, the height is 8 meters for each bench, and a slope ratio of 63^o for each bench. Laboratory testing results were used to determine index parameters and rock mechanical properties (Table 6). The specific gravity of moderately weathered limestone (III) is 2.19 gr/cm^3, the compressive strength is 22.92 MPa, the Poisson's ratio is 0.18, and the cohesion value is 8.19 kg/cm^2, and the friction angle is 61.71^o. The specific gravity of highly weathered limestone (IV) is 1.89 gr/cm^3, the compressive strength is 8.91 MPa, the Poisson's ratio is 0.17, the cohesion value is 10.31 kg/cm^2, and the friction angle is 63.30^o.

The following loading parameters are utilized as input data in slope stability:

1. Dead loads (due to slope mass).
2. The surcharge loads expected to apply on the slope's top surface is 10 kPa.
3. The live loads assumed to work as a traffic loads on the road surface is 15 kPa.
4. Seismic loads are calculated based on the bedrock peak acceleration map, site class categorization based on core drill NSPT value, amplification factor for Peak Ground Acceleration, and a period of 0.2 seconds. According to National Earthquake Study Center (2017), the bedrock peak acceleration zone at the study site is 0.3g - 0.4g for a likelihood of exceeding 10% within 50 years. The PGA value used is 0.4g. Based on the NSPT core drill value (Table 10) and SNI 8460:2017, the research location is in the SC site class (soft rock). A PGA value of 0.4g has an amplification factor of 1.0. Thus, from the data processing results presented in Table 11, the following value of the seismic loads

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for slope stability analysis is obtained:

$$kh = 0{,}5 \times PGA \times F_{PGA}$$
$$kh = 0{,}5 \times 0{,}40 \times 1{,}00 = 0{,}20$$

The slope with the most profound excavation depth and the lowest compressive strength value is represented in the slope stability analysis modeling. The limit equilibrium method was employed to assess slope stability using Morgenstern Price and Spencer. The value of the safety factor without seismic loads and the value of the safety factor with seismic loads are determined from the slope stability analysis using the limit equilibrium method. The findings of the slope stability study using the Morgenstern Price method (Figure 4) reveal that the slope safety factor is 1.670 in conditions without seismic loads and 1.137 when seismic loads are included. The Spencer slope stability analysis method yields a safety factor value that is not significantly different from the Morgenstern Price method. The factor of safety for the Spencer approach (Figure 5) is 1.680 in settings without seismic loads and 1.154 in conditions with seismic loads. Table 12 shows the value of the safety factor derived by the Morgenstern Price and Spencer technique and the requirements for the safety factor permit limit. The results of the analyses using both methodologies suggest that the slope is stable (safe). The addition of seismic loads reduces the value of the safety factor by 31% - 32%. It shows that the influence of seismic loads is quite significant on slope stability.

CONCLUSION

The slope stability analysis results utilizing the RMR and SMR methods reveal that the slopes are relatively stable. The safety factor determined using the limit equilibrium method is more than the required permit limit in conditions without and with seismic loads, implying that the slopes are in a safe (stable) condition. The RMR and SMR methods may swiftly examine slope stability, and the results are comparable to those obtained using the limit equilibrium method.

Even if the slope is in a stable (safe) condition, slope instability is likely. It is due to the likelihood of instability using the SMR method of 0.40. Further research on the addition of slope reinforcement to reduce the risk of slope instability is expected in the future.

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Appendix

Table 1. The Rock Mass Rating (RMR) System. (Bieniawski, 1989)

Classification Parameters and Their Ratings									
	Parameter		**Ranges of values**						
1	Strength of intact rock material	Point load strength index (MPa)	>10	4-10	2-4	1-2	for this low range, *uniaxial compressive test is preferred*		
		UCS (MPa)	>250	100-250	50-100	25-50	5-25	1-5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality (RQD)		90-100%	75-90%	50-75%	25-50%	<25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6-2 m	200-600 mm	60-200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces, not continuous, no separation, unweathered wall rock	Slightly rough surface, separation < 1 mm, slightly weathered walls	Slightly rough surface, separation < 1 mm, highly weathered walls	Slickensided surfaces or gouge < 5 mm thick or separation 1-5 mm, continous	Soft gouge >5 mm thick or separation >5 mm, continous		
	Rating		30	25	20	10	0		
5	Groundwater		Dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

Table 2. Rock Mass Classes as per RMR Values. (Bieniawski, 1989)

RMR Value	**81 - 100**	**61 - 80**	**41 - 60**	**21 - 40**	**≤20**
Rock Mass Description	*Very good*	*Good*	*Fair*	*Poor*	*Very poor*
Slope cut angle (º)	>70	65	55	45	<40

Table 3. Values of Adjustment Factors for Different Joint Orientations (F_1, F_2, F_3). (Romana, 1985 in Singh and Goel, 2011)

Case of Slope Failure		**Very favorable**	**Favorable**	**Fair**	**Unfavorable**	**Very Unfavorable**
Planar ***Toppling*** ***Wedges***	$\lvert\alpha_j - \alpha_s\rvert$ $\lvert\alpha_j - \alpha_s - 180\rvert$ $\lvert\alpha_i - \alpha_s\rvert$	>30º	20º - 30º	10º - 20º	5º - 10º	<5º
P/W/T	F_1	0,15	0,40	0,70	0,85	1,00
Planar ***Wedges***	$\lvert\beta_j\rvert$ $\lvert\beta_i\rvert$	<20º	20º - 30º	30º - 35º	35º - 45º	>45º
P/W	F_2	0,15	0,40	0,70	0,85	1,00
T	F_2			1,0		
Planar ***Wedges***	$\lvert\beta_j - \beta_s\rvert$ $\lvert\beta_i - \beta_s\rvert$	>10º	0º - 10º	0º	0 º - (-10º)	<-10º
Toppling	$\lvert\beta_j + \beta_s\rvert$	<110º	110º - 120º	>120º	-	-
P/W/T	F_3	0	-6	-25	-50	-60

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Table 4. Values of Adjustment Factors for Method of Excavation (F_4).
(Romana, 1985 in Singh and Goel, 2011)

Method of Excavation	**Natural slope**	**Presplitting**	**Smooth blasting**	**Normal blasting or mechanical excavation**	**Poor blasting**
F_4	15	10	8	0	-8

Table 5. Various Stability Classes as per SMR Values.
(Romana, 1985 in Singh and Goel, 2011)

Class No	**I**	**II**	**III**	**IV**	**V**
SMR Value	81-100	61-80	41-60	21-40	0-20
Rock Mass Description	Very good	Good	Normal	Bad	Very bad
Stability	Completely stable	Stable	Partially stable	Unstable	Completely unstable
Failures	No failure	Some block failure	Planar along some joints and many wedges	Planar or big wedge	Bidang, Busur
Probability of Failure	0	0,2	0,4	0,6	0,9
Suggested Support	None	Support at several points (spot or systematic bolting)	Rock bolts and rock anchors	Re-calculation related to material index properties	Re-excavation

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Table 6. The results of laboratory test of index properties and rock mechanics

Lithology and Weathering Rate	Natural density (gr/cm^3)	Natural density (kN/m^3)	UCS (MPa)	Modulus Young (MPa)	*Poisson's Ratio*	Cohesion (c) (kg/cm^2)	Friction angle (º)
Limestone (III)	2,19	21,48	22,92	7.453,99	0,18	8,19	61,71
Limestone (IV)	1,89	18,53	8,91	8.060,50	0,17	10,31	63,30

Table 7. Rock mass description of slope outcrop STA 8+400 to STA 8+500 using RMR method

STA	COORDINATE		RMR Parameter											
	X	Y	UCS	RQD	Spacing of discontinuities	Condition of discontinuities					Ground -water	RMR Value	Rock Mass Description
						Length	Aparture	Roughness	Infilling	Weathering			
8+400	457420	9100347	2	13	10	4	0	4	2	3	15	53	Fair
8+425	457437	9100331	2	13	10	4	0	4	2	3	15	53	Fair
8+450	457456	9100306	2	8	8	1	0	4	2	1	15	41	Fair
8+475	457469	9100284	2	13	10	4	0	4	2	3	15	53	Fair
8+500	457479	9100273	2	8	8	1	0	4	2	1	15	41	Fair

Table 8. The results of the measurement of the strike and dip joint

Strike (N …ºE)	225	55	60	55	250	224	11	260
Dip (º)	48	75	84	80	83	70	81	76

Table 9. Rock mass description of slope outcrop STA 8+400 to STA 8+500 using SMR method

STA	SLOPE		JOINT		RMR	F_1		F_2		F_3		F_4		SMR Value	Rock Mass Description
	Strike	*Dip*	*Strike*	*Dip*		Value	Rating	Value	Rating	Value	Rating	Value	Rating		
8+400	225	63	235	75	53	10	0,7	75	1	12	0	Mechanic	0	53	Normal
8+425	225	63	235	75	53	10	0,7	75	1	12	0	Mechanic	0	53	Normal
8+450	225	63	235	75	41	10	0,7	75	1	12	0	Mechanic	0	41	Normal
8+475	225	63	235	75	53	10	0,7	75	1	12	0	Mechanic	0	53	Normal
8+500	225	63	235	75	41	10	0,7	75	1	12	0	Mechanic	0	41	Normal

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Table 10. Site class classification based on the average value of N_{SPT}

Depth (y-i) (m)	Depth interval (di) (m)	N-SPT at y-i	di/Ni	Average Value of N-SPT	Site class
BH-05A (STA 8+425)					
2	2	>60		>60	Soft rocks (SC)
4	2	>60			
6	2	>60			
8	2	>60			
10	2	>60			
12	2	>60			
14	2	>60			
16	2	>60			
18	2	>60			
20	2	>60			
22	2	>60			
24	2	>60			
26	2	>60			
28	2	>60			
30	2	>60			
32	2	>60			
34	2	>60			
36	2	>60			
BH-05B (STA 8+425)					
2	2	16	0,12500	51	Soft rocks (SC)
4	2	60	0,03333		
6	2	60	0,03333		
8	2	60	0,03333		
10	2	49	0,04082		
12	2	60	0,03333		
14	2	60	0,03333		
16	2	60	0,03333		
18	2	60	0,03333		
20	2	60	0,03333		
22	2	60	0,03333		
24	2	60	0,03333		
26	2	51	0,03922		
28	2	58	0,03448		
30	2	60	0,03333		
32	2	60	0,03333		
34	2	60	0,03333		
36	2	60	0,03333		

Table 11. Horizontal seismic coefficient value (kh)

ID	Depth	N_{SPT}	Site class	PGA	F_{PGA}	Seismic Coefficient (a)	Horizontal Seismic Coefficient (kh)
BH-05A	0 - 36	>60	SC	0,40	1,00	0,40	0,20
BH-05B	0 - 36	51	SC	0,40	1,00	0,40	0,20

Table 12. Slope stability safety factor value

Condition	Requirement	Morgenstern Price	Spencer
without seismic loads	1,50	1,679	1,680
with seismic loads	1,10	1,137	1,154

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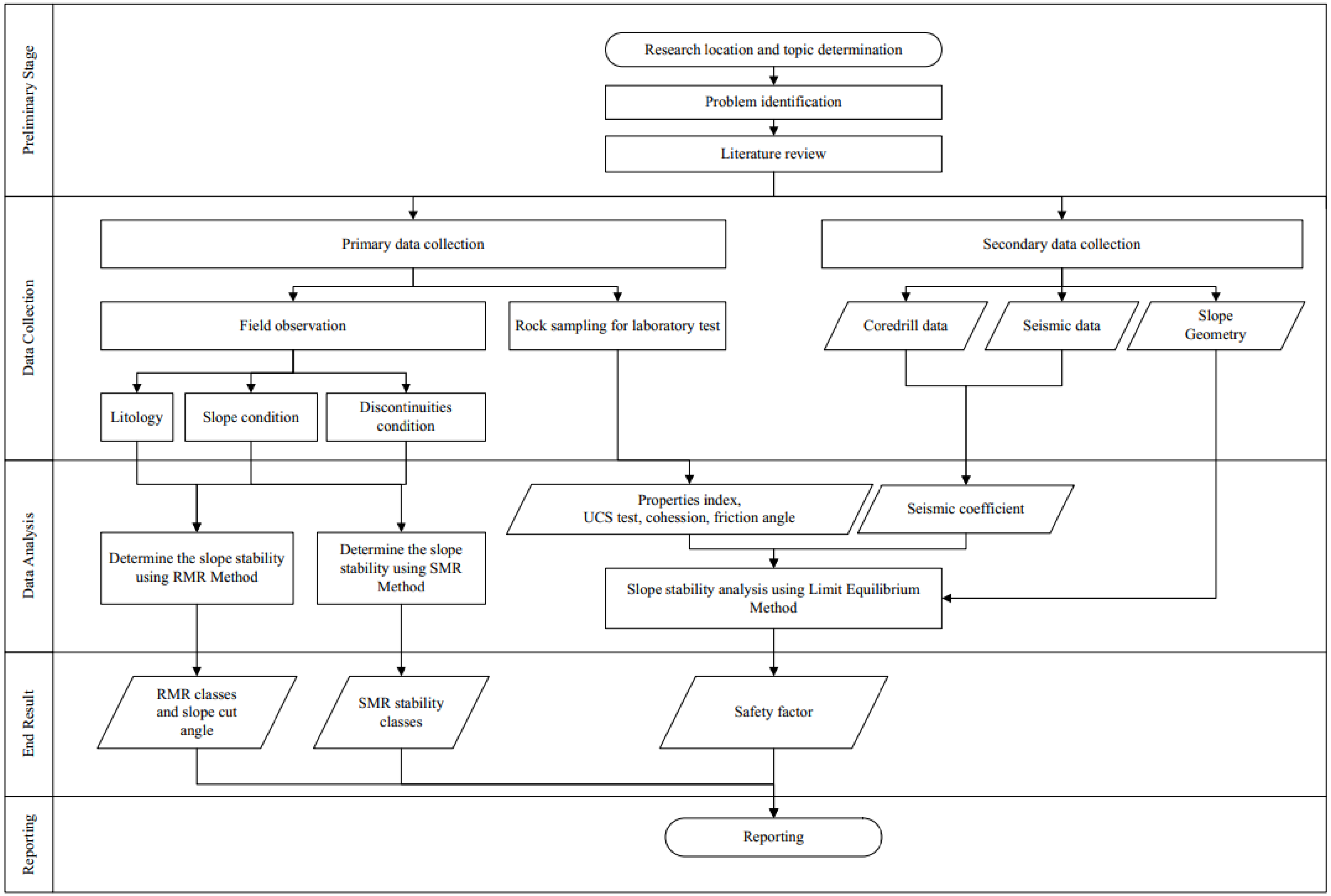

Figure 1. Flowchart of research

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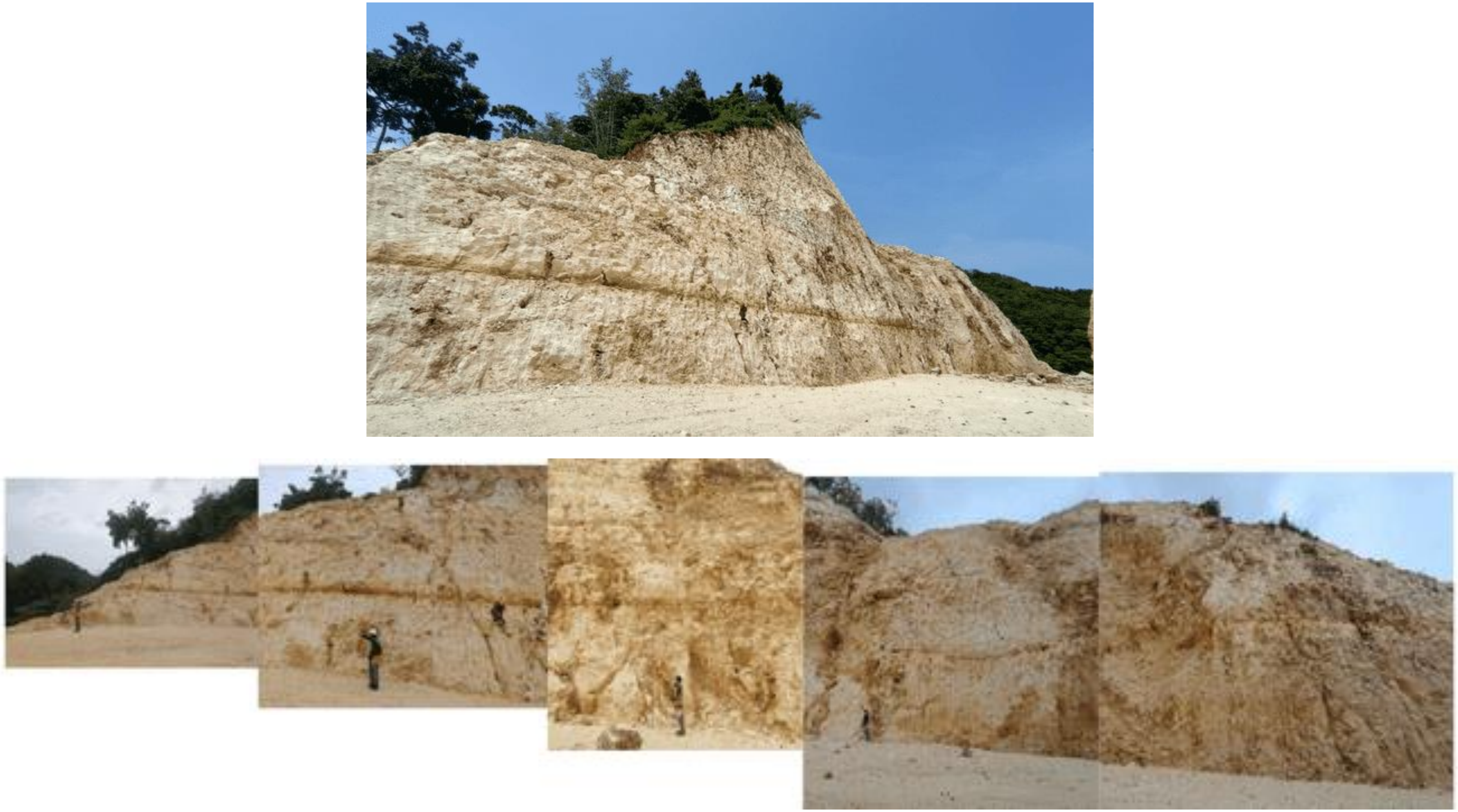

Figure 2. Slope outcorp STA 8+400 to STA 8+500

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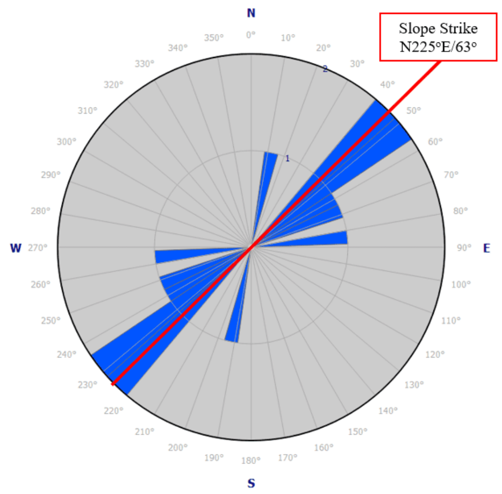
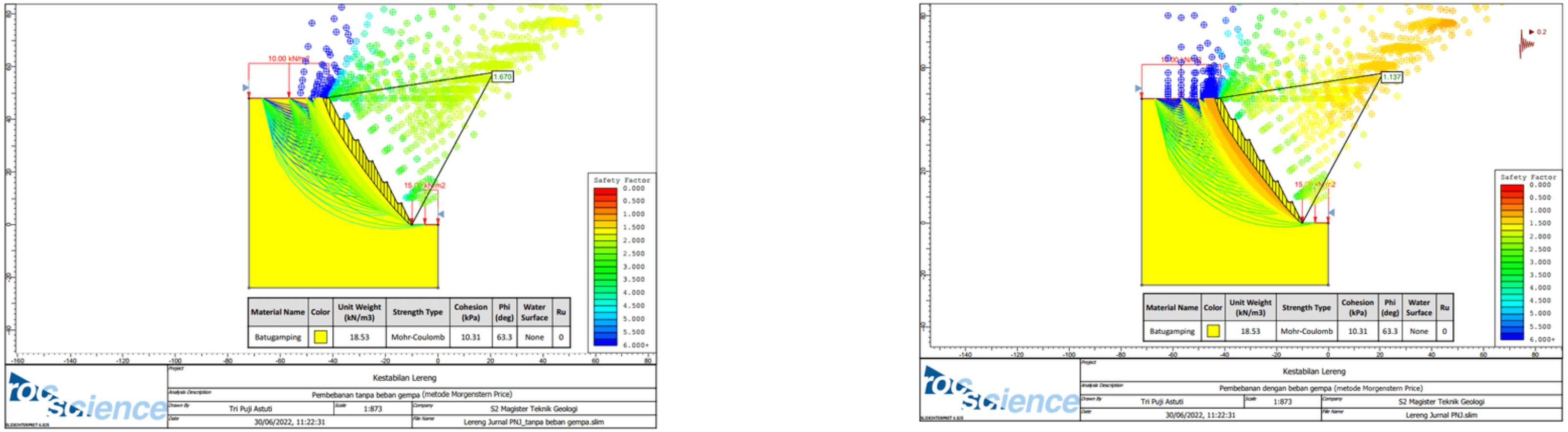


Figure 3. Rose diagram for joint and slope



(a) (b)

Figure 4. The results of analysis of slope stability with Morgenstern-Price's; in conditions (a) without seismic loads; (b) with seismic loads

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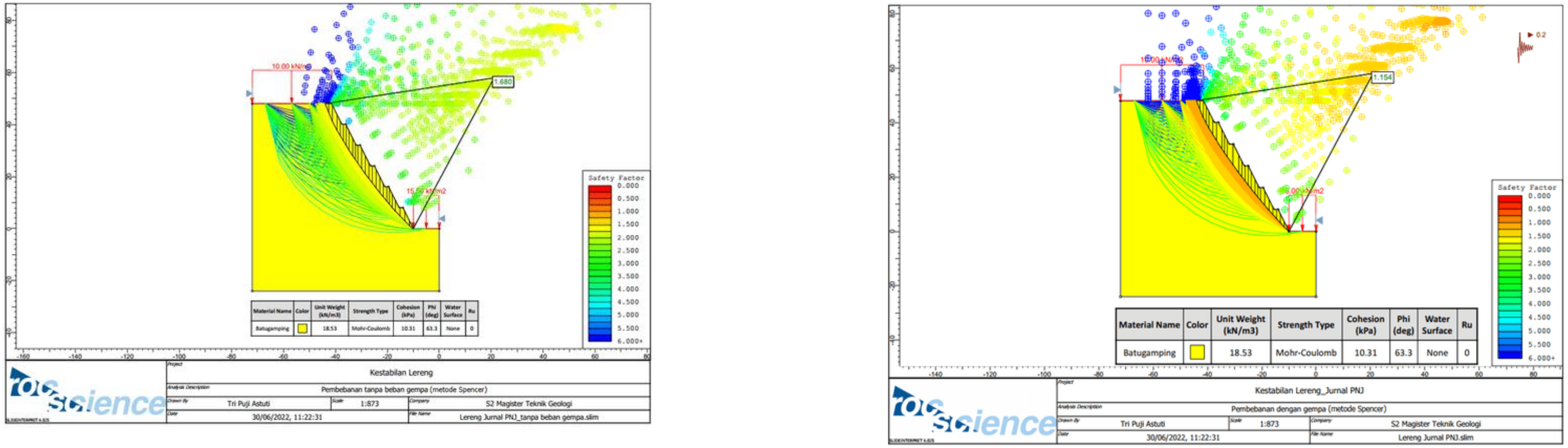

(a) (b)

Figure 5. The results of analysis of slope stability with Spencer’s; in conditions (a) without seismic loads; (b) with seismic loads

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