

Assessment of Slope Stability and Reinforcement for the Trans Liang Melas Datas Road Using HYRCAN

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Abstract: The Trans Liang Melas Datas Road in Karo Regency serves as a strategic route connecting six villages and three hamlets; however, unstable geological conditions pose significant landslide hazards that disrupt accessibility and socio-economic activities. This study aims to analyze slope stability and evaluate the effectiveness of reinforcement methods suitable for site-specific geometry and geological conditions. Soil parameters were obtained through laboratory testing of six landslide samples, while geometric data were collected using topographic surveys with a hypsometer. Slope stability was analyzed using analytical approaches with Bishop, Janbu, Spencer, and GLE/Morgenstern-Price methods, as well as a numerical approach based on the finite element method utilizing HYRCAN 2.0.19 software. The results indicate that all slope locations are unstable with safety factor (SF) values below 1.8, with the lowest SF recorded at 0.250 in Location 1. Comparisons between analytical and numerical approaches revealed average differences of 9 to 10% across all methods, yet consistently indicated slope vulnerability. Reinforcement simulations using terracing and shotcrete successfully improved SF values beyond the safe threshold ($SF > 1.8$). Terracing proved more effective in reducing slope gradient and enhancing overall stability, while shotcrete is recommended for areas with limited space or where surface protection against erosion and weathering is required.

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INTRODUCTION

Natural ground surfaces are not always perfectly planar but often exhibit elevation differences that result in slopes. Slopes are common topographic elements, particularly in hilly and mountainous regions, and play a critical role in civil engineering works such as road, bridge, dam, and other infrastructure construction (Naryanto et al., 2019). Slopes may form naturally through geological processes such as weathering and erosion or artificially as a result of excavation for infrastructure development (Rumbyarso & Pribadi, 2023).

Slope stability analysis is a fundamental aspect of planning and executing civil engineering projects to prevent slope failures that could lead to material losses and casualties. Slope stability is influenced by multiple factors, including slope geometry and the physical and mechanical properties of the soil (Qarinur, 2015). To evaluate slope stability, a variety of analytical and numerical methods have been developed. Analytical limit equilibrium methods, such as those proposed by Bishop and Janbu, have been widely applied due to their ability to evaluate the balance between resisting and driving forces (Hardiyatmo, 2003). Meanwhile, software tools based on the Limit Equilibrium Method (LEM), such as GeoSlope and Slide, have become the preferred choice for numerical analyses as they have undergone extensive updates and validation. Additionally, the HYRCAN program an open-source LEM-based software developed by Roozbeh Geraili Mikola and published as a preprint in 2023 offers a simple framework designed for projects with limited geotechnical data, enabling users to review,

modify, and verify its computational code. However, HYRCAN remains relatively new and has not yet been widely adopted in scientific research in Indonesia.

Karo Regency, located in North Sumatra Province, is among the regions with high susceptibility to landslides (Kurniawan, 2008). This vulnerability results from a combination of steep topography, high rainfall, and easily erodible volcanic deposits (Qarinur et al., 2024). Qarinur et al. (2024) reported that slopes in Karo Regency are predominantly composed of poorly graded sand with low cohesion and variable internal friction angles, resulting in generally low slope stability. These findings provide a crucial basis for conducting slope stability analysis in the region, given the weak and landslide-prone soil conditions, and underscore the need for comprehensive studies, including the design of appropriate slope reinforcement strategies tailored to the local geotechnical conditions.

The Trans Liang Melas Datas Road serves as the primary transportation route for farmers to deliver their harvests. The road connects six villages and three hamlets in the Liang Melas Datas area and is situated along the slopes of the Bukit Barisan mountain range (Balai Besar Pelaksanaan Jalan Nasional Sumatera Utara, 2024). On April 11, 2022, this road was completely blocked at four locations due to landslides, leaving residents isolated (Meliala, 2022). Subsequent landslides again disrupted access on November 28, 2024 (Kembaren, 2024), and further landslides occurred on December 21 and 23, 2024, following continuous heavy rainfall (Ginting, 2024).

Beyond stability analysis, landslide mitigation efforts through slope reinforcement systems represent an important aspect of geotechnical engineering practice. Slope reinforcement aims to improve the shear strength of soil masses by increasing cohesion (c) and the internal friction angle (ϕ) (Nurrohim, 2023), as well as to reduce slope deformation by restraining soil movement. Common reinforcement techniques include retaining walls, soil nailing, geosynthetics (geotextiles, geogrids), and drainage improvements to control pore water pressure (Unaizahroya & A'yuni, 2022). The selection of appropriate reinforcement methods should be based on local geotechnical conditions, slope geometry, and the risk level associated with the protected infrastructure, ensuring both an increase in the factor of safety and the long-term functionality of the roadway.

This study aims to analyze the stability of slopes along the Trans Liang Melas Datas Road in Karo Regency using both analytical and numerical approaches based on the limit equilibrium method (LEM), with numerical modeling performed using the HYRCAN software. The results of this analysis will serve as the basis for formulating alternative slope reinforcement strategies to minimize landslide risk and ensure the sustainability of the road infrastructure.

The contribution of this study lies in the site-specific assessment of six landslide-prone slope locations along the Trans Liang Melas Datas Road in Karo Regency. The study compares manually calculated factors of safety with results obtained using several limit equilibrium formulations implemented in HYRCAN and evaluates terracing and shotcrete as alternative reinforcement configurations. By considering variations in slope geometry and geotechnical parameters across the investigated locations, the study provides a comparative basis for identifying reinforcement alternatives that require further design verification. The applicability of these findings depends on the reliability of the input parameters and the representation of each reinforcement system in the stability model.

In general, the research workflow includes the collection of geotechnical and topographic data, determination of soil parameters from laboratory testing, slope stability analysis using analytical methods (Bishop, Janbu, Spencer, and GLE/Morgenstern-Price), and numerical modeling using

HYRCAN, followed by simulation of various slope reinforcement measures. The results of this study are expected to provide valuable input for landslide disaster mitigation efforts and for the planning of more sustainable infrastructure development in mountainous regions.

RESEARCH METHOD

This study was conducted at several landslide points along the Trans Liang Melas Datas Road in Karo Regency, as shown in Figure 1. Slope geometry was obtained through direct field measurements using a hypsometer. The physical and mechanical properties of the soil were determined through a series of laboratory tests.

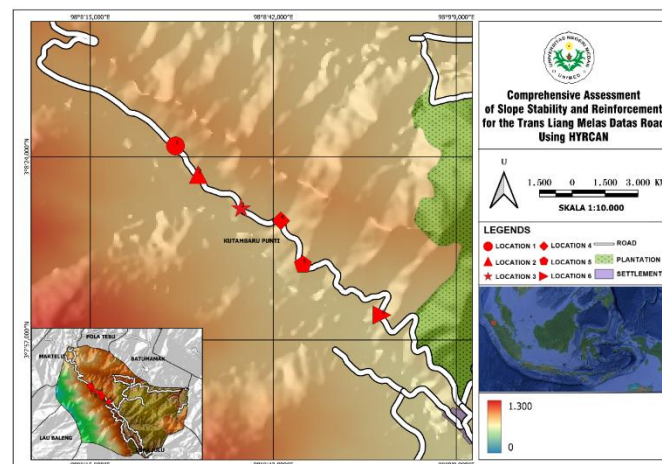


Figure 1. Spatial Distribution of Landslide Points in the Study Area

The geological conditions at the study site were identified based on the geological map published by the Kementerian Energi dan Sumber Daya Mineral (ESDM), as illustrated in Figure 2. After characterizing the geological setting, the physical and mechanical parameters of the rock mass were assumed with reference to the study by Look, 2007.

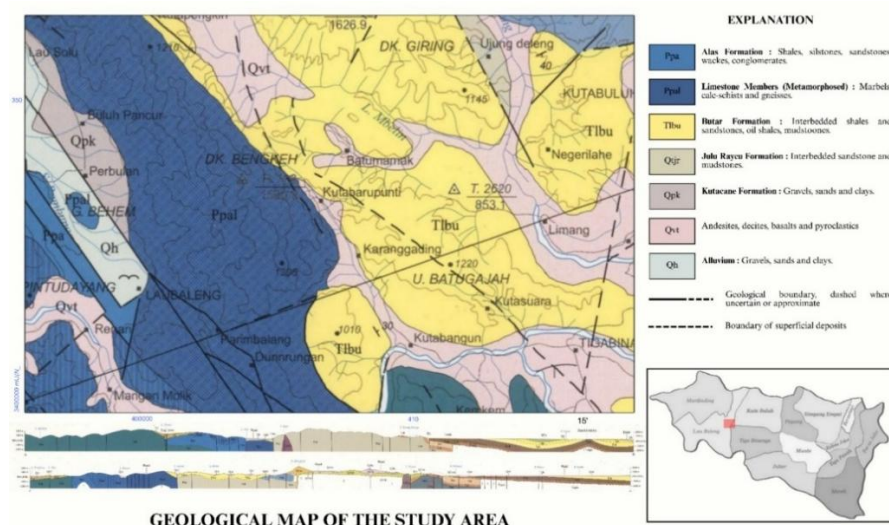


Figure 2. Geological setting of the study area

The slope stability analysis in this study was carried out using the HYRCAN software, and the results were compared with four analytical limit equilibrium methods, namely Bishop, Janbu, Spencer, and GLE/Morgenstern-Price. The determination of the slope safety factor (SF) for each method was based on the following mathematical formulations:

Bishop Method

$$SF = \frac{\sum_{i=1}^{i-n} [c.b + (W - ub) \tan \varphi] \frac{1}{\cos \alpha (1 + \tan \theta \tan \varphi / F)}}{\sum_{i=1}^{i-n} W_i \sin \alpha} \quad (1)$$

where SF is the factor of safety, c is the soil cohesion [kPa], b is the slice width [m], W is the weight of the slice [kN], u is the pore water pressure [kPa], α is the slope inclination [°], φ is the internal friction angle of the soil [°], and F is the assumed trial factor of safety.

Janbu Method

$$SF = \frac{\sum_{i=1}^{i-n} (c.b + (W - ub) \tan \varphi) \frac{\sec \alpha^2}{1 + \tan \alpha \cdot \tan \varphi}}{\sum_{i=1}^{i-n} W \tan \alpha} \quad (2)$$

Spencer and GLE/Morgenstern-Price Method

Both methods take into account the factor of safety in terms of both force equilibrium and moment equilibrium, as well as the effect of interslice shear forces, which can be mathematically expressed as:

$$\frac{X}{E} = f(x) \cdot \lambda \quad (3)$$

where X is the vertical force acting on the slice [kN], E is the horizontal force acting on the slice [kN], $f(x)$ is the assumed interslice force function, and λ is the scaling factor.

The difference lies in the assumption of $f(x)$: in the Spencer method, the function is assumed to be constant ($f(x) = 1$), where as in the GLE/Morgenstern-Price method, $f(x)$ is generally assumed to follow a half-sine function.

The factor of safety based on moment equilibrium (F_m) is calculated using the following equation:

$$F_m = \frac{\sum (c'l + (P - ul) \tan \phi')}{\sum W \sin \alpha} \quad (4)$$

where P is the normal force acting on the slice [kN].

The factor of safety based on force equilibrium (F_f) is computed using the following equation:

$$F_f = \frac{\sum (c' + l + (P - ul) \tan \phi') \sec \alpha}{\sum (W - X_R - X_L) \tan \alpha} \quad (5)$$

RESULTS AND DISCUSSION

Slope geomtery

The geometric profile of each slope was analyzed based on direct field measurements and is technically visualized in Figure 3.

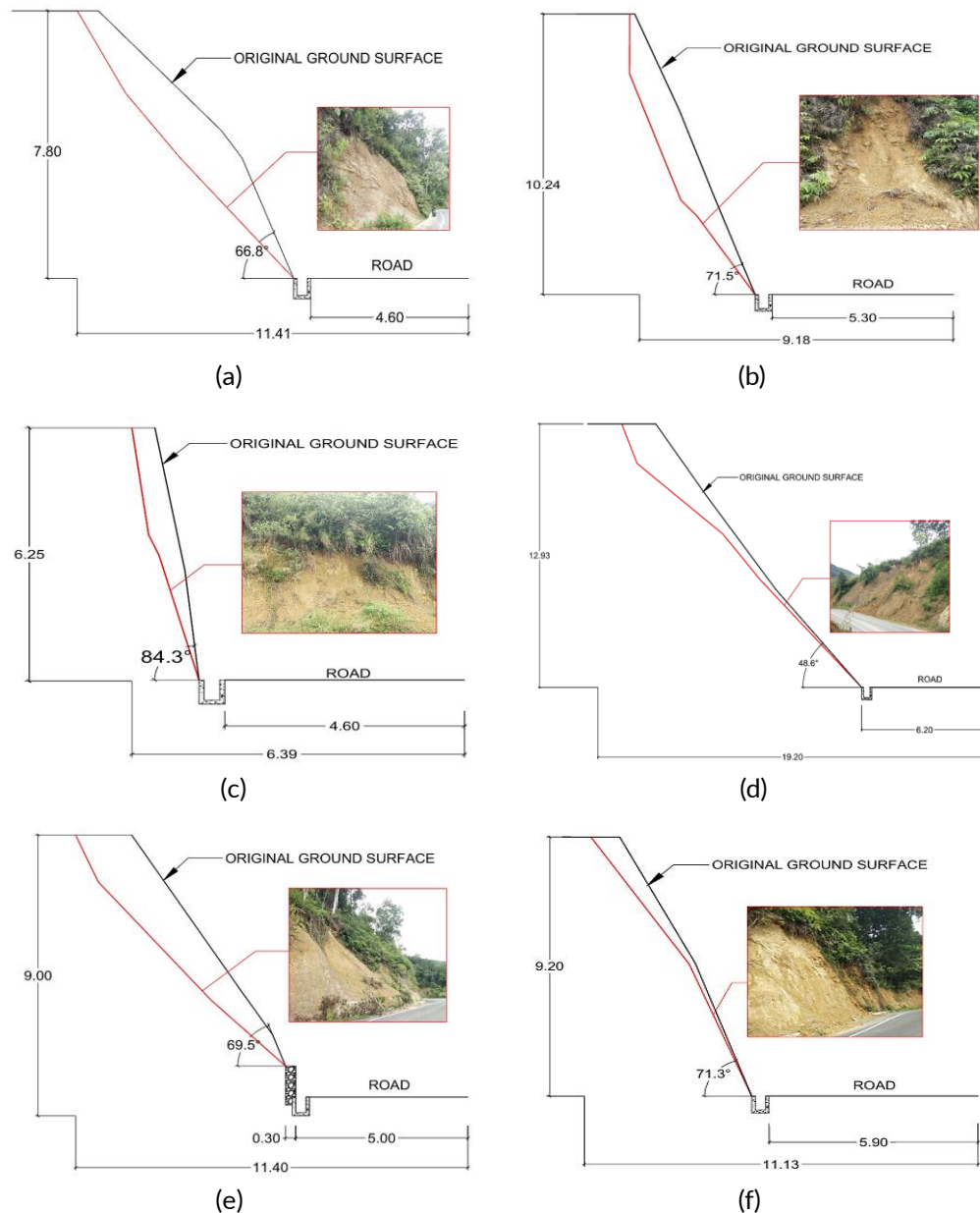


Figure 3. Slope geomtery: (a) Location 1, (b) Location 2, (c) Location 3, (d) Location 4, (e) Location 5, (f) Location 6

Based on the field measurements, the slope geometry at the study site exhibits considerable variation, with a general tendency toward relatively steep inclinations. The highest slope was recorded at Location 4 with a height of 12.93 meters, while the steepest inclination was observed at Location 3, reaching 84.3°. Such high inclination values indicate that the slope is able to maintain stability even at

extreme angles, suggesting that the soil composing the slope possesses cohesive properties. This finding is consistent with the general characteristics of cohesive soils, which are capable of sustaining steep slopes due to the strong interparticle bonding.

Soil Physical Properties

The physical properties of the soil were obtained from laboratory testing. Sampling for the determination of natural unit weight was performed using undisturbed samples, whereas disturbed samples were used for other laboratory tests. The results of the soil physical property tests are presented in Table 1.

Table 1. Soil physical properties test results

Physical Property	Unit	Loc. 1	Loc. 2	Loc. 3	Loc. 4	Loc. 5	Loc. 6
Moisture Content (w)	%	11,02	12,72	14,10	15,53	14,67	14,62
Wet Unit Weight (γ)	gr/cm ³	1,960	1,830	1,810	1,820	1,810	1,850
Dry Unit Weight (γ_d)	gr/cm ³	1,762	1,624	1,587	1,574	1,578	1,616
Specific Gravity (G_s)		2,640	2,626	2,606	2,583	2,642	2,638
Liquid Limit (LL)	%	33,77	32,80	42,16	41,37	35,24	30,54
Plastic Limit (PL)	%	22,12	21,58	23,33	25,39	20,83	24,15
Plasticity Index (IP)	%	12,645	11,22	18,83	15,98	14,40	6,39

The results of physical property testing at the six locations indicate variations influenced by local topography and material characteristics. The moisture content (w) ranges from 11.02% to 15.53%, with a tendency to be higher at locations with lower elevation or poorer drainage conditions. The wet unit weight (γ) varies between 1.810 g/cm³ and 1.960 g/cm³, while the dry unit weight (γ_d) ranges from 1.574 g/cm³ to 1.762 g/cm³, indicating a relatively good degree of compaction across all sites. The specific gravity (G_s) ranges from 2.583 to 2.642, suggesting that the soil is classified as clayey material dominated by silicate minerals.

From the Atterberg limit tests, the liquid limit (LL) ranges from 30.54% to 42.16%, and the plastic limit (PL) ranges from 20.83% to 25.39%, resulting in a plasticity index (PI) of 6.39% to 18.83%. Higher PI values, such as those observed at Locations 3 and 4, indicate a higher clay fraction content, implying more cohesive behavior and a greater potential for volumetric changes due to fluctuations in moisture content. These variations influence the shear strength parameters of the soil, particularly under saturated conditions or during weathering.

Soil Mechanical Properties

The mechanical properties of the soil were determined through laboratory testing using the triaxial apparatus with the Unconsolidated Undrained (UU) method on remolded samples. The results are presented in Table 2.

Table 2. Soil mechanics properties test results

Location	Cohesion (c)	Internal Friction
	kPa	Angel (φ)°
Location 1	1,349	5,216
Location 2	7,676	0,479
Location 3	1,909	1,310
Location 4	2,885	1,584
Location 5	4,818	0,459
Location 6	4,188	0,699

Cohesion (c) values across the study area range from 1.349 kPa to 7.676 kPa, while the internal friction angle (φ) remains relatively low, between 0.459° and 5.216°. The highest cohesion value is observed at Location 2, whereas the highest internal friction angle is recorded at Location 1. The generally low φ values indicate that shear strength is primarily governed by cohesion rather than interparticle friction.

This condition correlates with the physical characteristics of the soil, where variations in moisture content and plasticity index (PI) significantly affect the resulting cohesion values. Locations with higher PI values tend to exhibit higher cohesion, reflecting the dominance of clay fractions that enhance cohesive behavior. Conversely, locations with lower PI values typically have lower cohesion, indicating a limited contribution of internal friction to shear strength.

From a geotechnical perspective, this relationship implies a significant potential reduction in shear strength under saturated conditions, particularly in areas dominated by cohesive soils. This must be carefully considered in slope stability analyses, as increased pore water pressure during heavy rainfall events can substantially reduce cohesion, resulting in a lower factor of safety for the slope. These findings provide critical input parameters for geotechnical modeling and for designing appropriate slope reinforcement strategies based on site-specific conditions.

Analytical slope stability analysis

The slope stability analysis was conducted analytically by applying four widely recognized methods: Bishop, Janbu, Spencer, and GLE/Morgenstern-Price. The factor of safety (SF) for each location was computed based on parameters derived from laboratory test results. The calculated SF values for each method are summarized in Table 3.

Table 3. Results of analytical slope stability analysis

Location	Method			
	Bishop	Janbu	Sepncer	GLE/M-P
Location 1	0,299	0,299	0,250	0,250
Location 2	1,431	1,476	0,942	0,940
Location 3	0,365	0,394	0,344	0,344
Location 4	0,287	0,308	0,269	0,269
Location 5	0,447	0,670	0,360	0,368
Location 6	0,995	1,044	0,734	0,733

The results of the analytical slope stability analysis using the Bishop, Janbu, Spencer, and GLE/Morgenstern-Price methods indicate that the SF at all locations generally falls below the

recommended threshold for stable conditions ($SF > 1.8$). Safety Factor Threshold and SNI 8460:2017 Compliance: The minimum allowable Factor of Safety (SF) threshold of > 1.8 adopted in this study refers to the design requirements for permanent road slopes and critical transportation infrastructure with high public safety risks, as stipulated in SNI 8460:2017. According to SNI 8460:2017 guidelines, slopes protecting vital public economic arteries such as the Trans Liang Melas Datas Road connecting multiple villages under adverse weather and high seismic/rainfall vulnerability index categories must adhere to conservative safety margins to prevent catastrophic disruptions. The lowest SF was observed at Location 4, ranging from 0.269 to 0.308. The variation in SF values among methods reflects the sensitivity of the results to the equilibrium assumptions adopted by each method, where Janbu's method tends to yield slightly higher values than Bishop's, while Spencer and GLE produce nearly identical results as both consider force and moment equilibrium simultaneously.

Locations with steeper slopes and greater slope heights, such as Locations 3 and 4, consistently exhibit low SF across all analytical methods. This finding suggests that slope geometry is a major contributing factor to instability. Furthermore, the physical properties of the soil significantly influence the results. Locations with higher moisture content and larger plasticity index (PI), such as Locations 3 and 4, exhibit cohesive materials that are sensitive to moisture variations, leading to substantial reductions in shear strength under saturated conditions.

The mechanical properties of the soil, particularly low cohesion (c) and internal friction angle (ϕ), directly contribute to the low SF values. For example, Location 4 exhibits a cohesion of only 2.885 kPa and an internal friction angle of 1.584° , which limits the soil's ability to resist shear forces. In contrast, Location 2, with the highest cohesion (7.676 kPa) despite having a very small friction angle (0.479°), is still able to yield a higher SF due to the significant contribution of cohesion to the overall shear strength. These findings demonstrate that slope stability in the study area is governed by the interaction of slope geometry, soil physical properties affecting mechanical behavior, and shear strength parameters derived from laboratory testing.

Numerical analysis of slope stability analysis

Numerical slope stability analysis at six landslide-prone locations along the Trans Liang Melas Datas Road was performed using HYRCAN software version 2.0.19, employing the Bishop, Janbu, Spencer, and GLE/Morgenstern-Price methods. The HYRCAN simulation results for Location 1 are presented in Figure 4, while the results for all locations are summarized in Table 4.

The analysis results indicate that all investigated locations exhibit factors of safety below the acceptable stability criterion ($SF > 1.8$) for all methods applied, suggesting that the slopes are generally unstable and potentially susceptible to failure. Locations 1, 3, and 4 even show extremely low factors of safety ($SF < 0.4$) across all methods, indicating a critical level of vulnerability to slope failure.

Comparison among the different methods reveals relatively minor discrepancies for most locations, except for Locations 2 and 5, which display more pronounced deviations. The absence of a factor of safety value from the Janbu method at certain locations is likely due to non-convergence of the iterative calculation under highly critical slope conditions, resulting in no valid solution being obtained. Overall, the simulation results clearly demonstrate that the slopes are in an unstable condition ($SF < 1.8$).

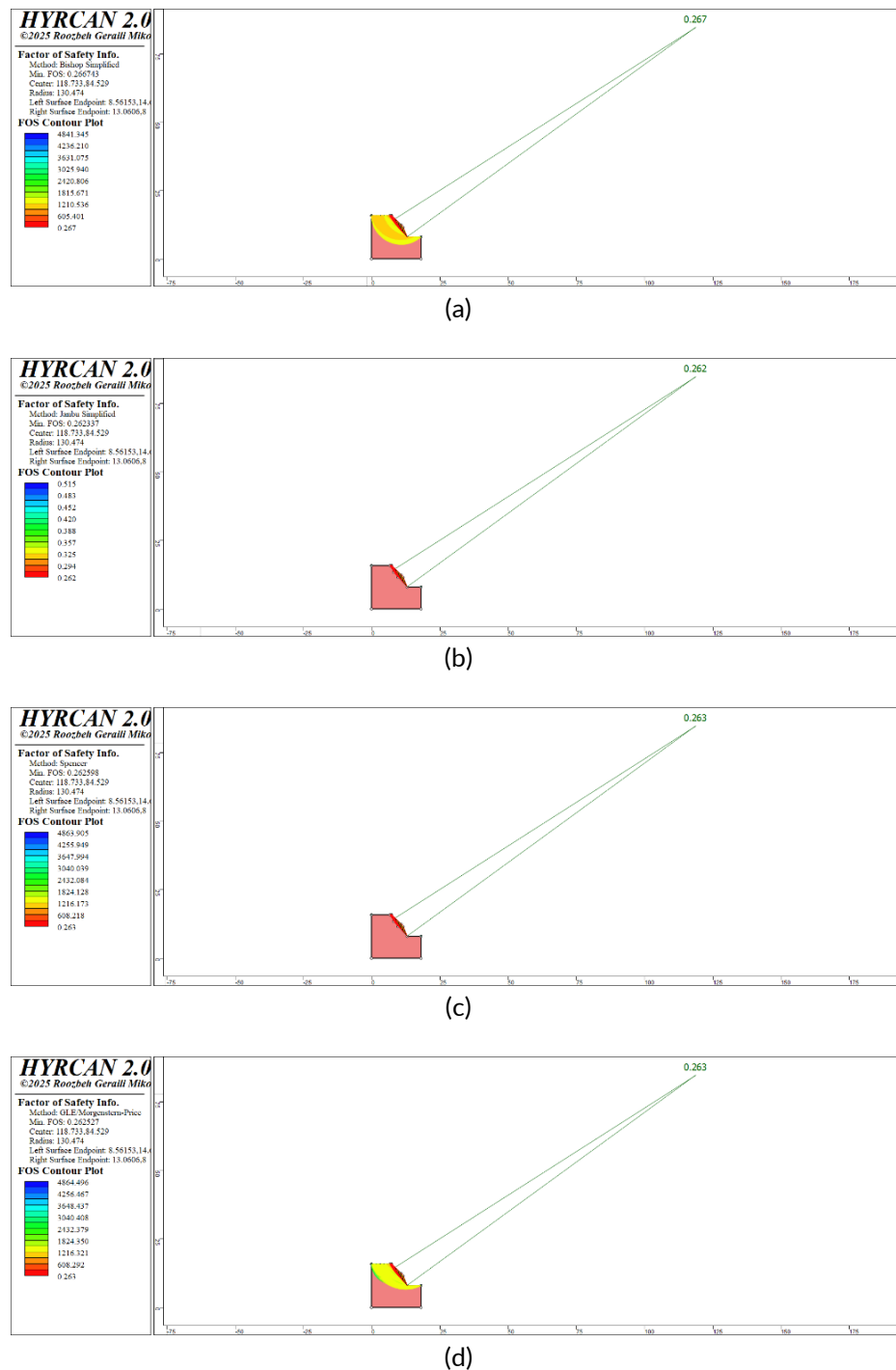


Figure 4. Factor of Safety Values at Location 1 Obtained from Numerical Analysis Using the HYRCAN, Program: (a) Bishop Method; (b) Janbu Method; (c) Spencer Method; (d) GLE/Morgenstern-Price Method

Table 4. Results of numerical slope stability analysis

Location	Metode			
	Bishop	Janbu	Sepncer	GLE/M-P
Location 1	0,267	0,262	0,263	0,263
Location 2	1,601	-	0,874	0,875
Location 3	0,372	-	0,323	0,299
Location 4	0,296	0,296	0,301	0,298
Location 5	0,422	0,589	0,441	0,425
Location 6	0,768	-	0,725	0,767

Comparison of Analytical and Numerical Slope Stability Analysis

Slope stability was assessed using both an analytical approach, based on manual calculations, and a numerical approach employing HYRCAN software version 2.0.19. Table 5 presents a comparison of the SF values obtained from the two approaches for each location, aiming to evaluate the consistency of the results and identify any differences arising from the use of different analysis methods.

Table 5. Comparison of Analytical and Numerical Slope Stability Analyses

Location	Bishop (%)	Janbu (%)	Spencer (%)	GLE/M-P (%)
Location 1	10,7	12,38	5,20	5,20
Location 2	11,88	-	7,22	6,92
Location 3	1,92	-	6,11	13,08
Location 4	3,14	3,90	11,9	10,78
Location 5	5,59	12,09	22,5	15,49
Location 6	22,81	-	1,23	4,64
Average	9,34	9,45	9,02	9,35

The average difference in SF values across all methods ranges from 9% to 10%. This discrepancy can generally be considered acceptable, given that both approaches although based on the same limit equilibrium principles differ fundamentally in terms of geometric simplification, soil parameter representation, and assumptions regarding force distribution. In the analytical method, slope geometry is typically modeled in an idealized form with manually defined slip surfaces, whereas in the numerical approach using HYRCAN, the geometry is modeled in greater detail according to field data. This difference in representation can significantly affect the final results.

The largest deviations were observed at Location 6 for the Bishop method (22.81%) and at Location 5 for the Spencer method (22.5%). These substantial differences are likely attributed to the complexity of the slope geometry, such as irregular inclinations, lateral variation of soil materials, or heterogeneous groundwater conditions. In such cases, the simplified assumptions of the analytical method may not fully capture field conditions, whereas the more detailed numerical modeling is able to account for these variations, resulting in significant differences in the outcomes.

Moreover, differences in iteration procedures and convergence criteria in the numerical approach also influence the results, particularly for slopes under very critical conditions. For example, the absence of results for certain locations when using the Janbu method may be due to the failure of the iteration process to reach convergence, triggered by input parameters and slope conditions that indicate instability at the start of the computation. This issue does not occur in the analytical approach,

as the calculations are performed directly (direct calculation) without requiring strict numerical iterations. However, analytical methods may still have limitations in representing complex soil behaviors and heterogeneous conditions.

Slope Reinforcement Analysis Using Terracing Method

Slope reinforcement was carried out using the terracing method, which involves constructing stepped benches to reduce the overall slope angle. This method was chosen because it effectively decreases shear forces and can be implemented without the need for specialized heavy equipment. The terracing geometry for the six locations was designed using CAD software, defining the height and width of each bench, as illustrated in Figure 5, and subsequently used as input for numerical modeling in the HYRCAN program.

Based on the designed terracing geometry, slope models were developed in HYRCAN by incorporating geometric data and material properties. Simulations were then conducted to obtain the post-reinforcement factor of safety, with the results for Location 1 shown in Figure 6. The SF values for all locations after reinforcement are presented in Table 6.

Table 6. Factor of Safety after Slope Reinforcement Using Terracing

Location	Method			
	Bishop	Janbu	Spencer	GLE/M-P
Location 1	17,275	-	17,357	17,357
Location 2	12,948	-	12,944	12,95
Location 3	19,101	-	19,104	19,099
Location 4	10,633	-	10,628	10,634
Location 5	14,974	-	14,97	14,975
Location 6	13,782	-	13,777	13,783

The safety factor (SF) for the six locations after reinforcement with the terracing method was evaluated through simulations conducted in HYRCAN. The analysis employed the Bishop, Spencer, and GLE/Morgenstern-Price methods, while the Janbu method did not yield results because the modeled slope parameters and conditions did not meet the method's assumptions, which are generally applicable to simple, nearly non-circular slip surfaces. The simulation results indicate variations in SF values across locations and methods, with the highest SF observed at Location 3 for all methods and the lowest at Location 4. Overall, the terracing method was demonstrated to be effective in improving slope stability, although variations were observed among locations and analysis methods.

The significant increase in SF values across most locations indicates that terracing successfully reduced the driving forces acting on the slopes. The benching geometry redistributed the soil mass, thereby lowering the overall slope inclination and increasing the resisting moments. This improvement is particularly evident at Location 4, which initially exhibited the lowest stability prior to reinforcement. Although the SF value at this location remains the lowest among all sites after reinforcement, it still shows a considerable improvement compared with the pre-reinforcement condition, thereby satisfying the minimum safety requirements for road embankment stability as recommended by national standards.

Furthermore, the results highlight the importance of a site-specific approach to terracing design, as differences in soil shear strength, slope geometry, and groundwater conditions significantly

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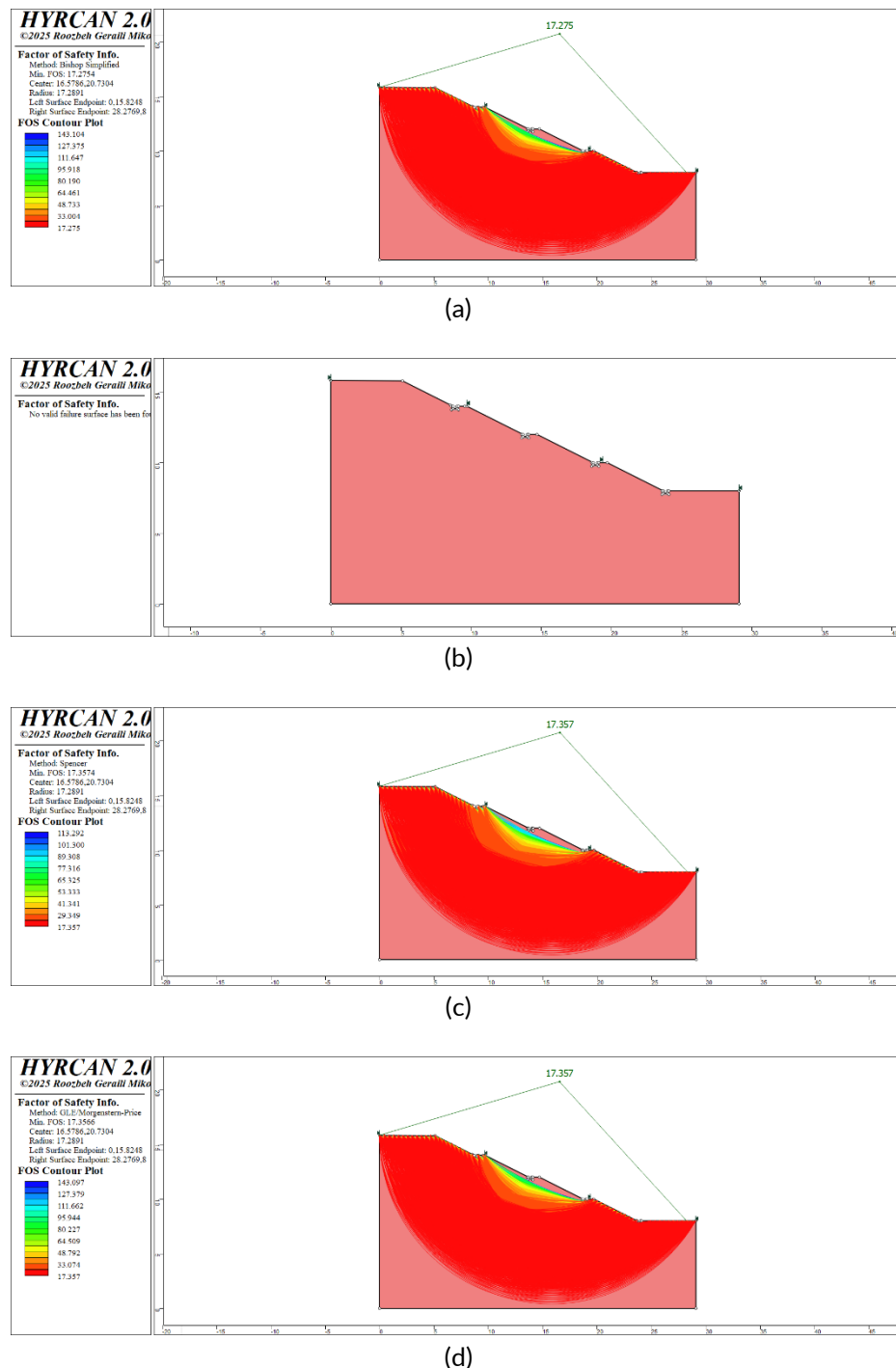


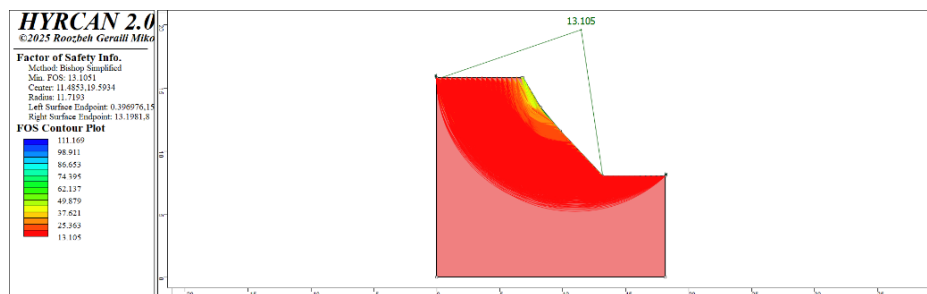
Figure 6. Results of Slope Reinforcement Simulation Using HYRCAN after Terracing at Location 1: (a) Bishop Method, (b) Janbu Method, (c) Spencer Method, (d) GLE/Morgenstern-Price Method

Slope Reinforcement Analysis Using the Shotcrete Method

As an alternative to the space limitations associated with the terracing method, slope reinforcement was implemented using shotcrete. Numerical simulation results obtained from HYRCAN are presented in Figure 7, and the SF values are summarized in Table 7. The application of shotcrete significantly improved the SF, with all locations achieving $SF > 1.8$.

Table 7. Factor of Safety after Slope Reinforcement with Shotcrete

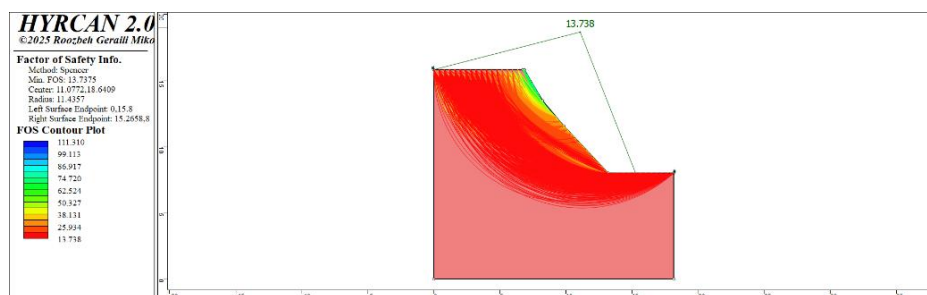
Location	Method			
	Bishop	Janbu	Sepnecer	GLE/M-P
Location 1	13,105	-	12,738	13,354
Location 2	8,669	-	10,160	10,109
Location 3	12,147	-	12,219	12,216
Location 4	8,591	-	9,141	8,946
Location 5	11,791	-	12,824	12,350
Location 6	9,485	-	9,745	9,884



(a)



(b)



(c)

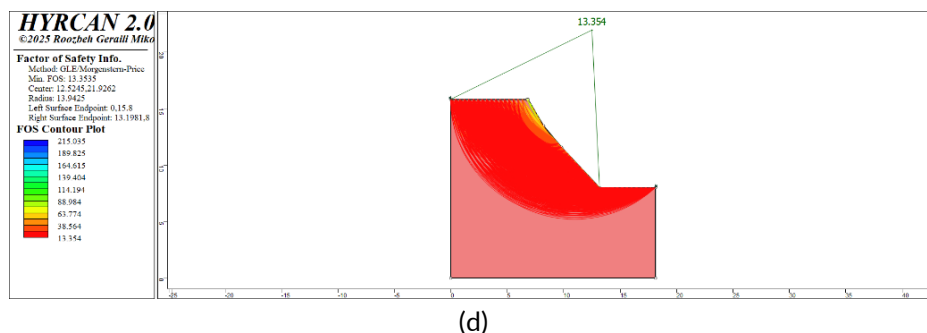


Figure 7. Results of Slope Reinforcement Simulation Using HYRCAN after Shotcrete at Location 1: (a) Bishop Method, (b) Janbu Method, (c) Spencer Method, (d) GLE/Morgenstern-Price Method

The safety factor (SF) of the six locations after reinforcement with the shotcrete method was evaluated through simulations using HYRCAN. The analysis was performed using the Bishop, Spencer, and GLE/Morgenstern-Price methods, while the Janbu method did not produce results because the dominant slip surfaces were rotational and circular, making them incompatible with Janbu's assumptions, which are more suitable for translational or non-circular slip surfaces.

The SF values varied across locations, ranging from 8.591 to 13.105 for Bishop, 9.141 to 12.824 for Spencer, and 8.946 to 13.354 for GLE/M-P. In general, the highest values were recorded at Location 1 and the lowest at Location 4 in nearly all methods. These results indicate that the shotcrete method, as simulated using HYRCAN, effectively improves slope stability, although its effectiveness is influenced by the geometry and characteristics of the slip surface at each location.

Limitations

This study has several limitations that should be considered when interpreting its results. First, the field study was geographically limited to specific landslide-prone locations along the Trans Liang Melas Datas Road in Tiga Binanga Subdistrict, Karo Regency, North Sumatra. Second, slope stability evaluations and failure surface modeling were conducted by assuming a two-dimensional (2D) plane strain problem, which does not account for complex three-dimensional topographic features or spatial variations along the slope. Finally, due to site limitations, laboratory soil and rock mechanics testing was not performed on the rock failure surface, necessitating engineering assumptions regarding the properties of specific rock masses based on secondary literature.

CONCLUSION

The safety factor (SF) along the Trans Liang Melas Datas Road section varies across locations and analysis methods, with numerical approaches generally producing higher SF values than analytical methods. The highest SF was recorded at Location 2 (SF = 1.601, Bishop numerical) and the lowest at Location 1 (SF = 0.250, Spencer and GLE/Morgenstern-Price analytical), with an average difference between analytical and numerical results of approximately 9 to 10%. Spencer and Morgenstern-Price methods proved to be the most consistent across both approaches. Slope reinforcement analysis confirmed that terracing effectively reduced slope inclination and improved stability, while shotcrete was more suitable for space-limited conditions. Future studies should focus on laboratory testing of rock slip surface materials, evaluating stabilization methods tailored to site-specific conditions, and

applying three-dimensional modeling for more representative analysis of slopes with complex morphologies.

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REFERENCES

- Amri, N., Dharmawansyah, D., Raya Olat Maras, J., Alang-Moyo Hulu, B., & Sumbawa Nusa Tenggara Barat, K. (2021). Perbandingan Metode Bishop dan Janbu dalam Analisis Stabilitas Lereng pada Oprit Jembatan Labu Sumbawa. *Journal of Civil Engineering and Planning*, 2(1), 20-33. <https://journal.uib.ac.id/index.php/jce/article/view/4393>
- Badan Standardisasi Nasional. (1994). *SNI 03-3637-1994: Metode pengujian berat isi tanah berbutir halus dengan cetakan benda uji*. BSN.
- Badan Standardisasi Nasional. (2008). *SNI 1964:2008: Cara uji berat jenis tanah*. BSN.
- Badan Standardisasi Nasional. (2008). *SNI 1966:2008: Cara uji penentuan batas plastis dan indeks plastisitas tanah*. BSN.
- Badan Standardisasi Nasional. (2008). *SNI 1967:2008: Cara uji penentuan batas cair tanah*. BSN.
- Badan Standardisasi Nasional. (2008). *SNI 3422:2008: Cara uji penentuan batas susut*. BSN.
- Badan Standardisasi Nasional. (2011). *SNI 1971:2011: Cara uji kadar air total agregat dengan pengeringan*. BSN.
- Badan Standardisasi Nasional. (2015). *SNI 4813:2015: Cara uji triaksial untuk tanah kohesif dalam keadaan tidak terkonsolidasi dan tidak terdrainase (UU)*. BSN.
- Badan Standardisasi Nasional. (2017). *SNI 8460:2017: Persyaratan perancangan geoteknik*. BSN.
- Balai Besar Pelaksanaan Jalan Nasional Sumatera Utara. (2024, May 29). *Akses panen jeruk Liang Melas Datas semakin lancar* [Photograph]. Instagram. https://www.instagram.com/p/C7iuix_ug_l/
- Bowles, J. E. (2022). *Sifat-sifat fisis dan geoteknis tanah (mekanika tanah)* (J. K. Hainim & Y. Sianipar, Eds.; 2nd ed.). Penerbit Erlangga.
- Das, B. M. (1995). *Mekanika tanah (prinsip-prinsip rekayasa geoteknis)* (N. Endah & I. B. Mochtar, Eds.; Jilid 1). Penerbit Erlangga.
- Djunaedi, R. R. (2020). Perencanaan dinding penahan tanah tipe gravitasi (studi kasus SDN Lio, Kecamatan Cireunghas). *Jurnal Student Teknik Sipil*, 2(1), 55-64. <https://doi.org/10.37150/jsts.v2i1.668>
- Hardiyatmo, H. C. (2003). *Mekanika tanah II* (3rd ed.). Gadjah Mada University Press.
- Hanifa, H., & Suwardi. (2023). Identifikasi Tingkat Kerawanan Tanah Longsor di Ajibarang Menggunakan Metode Skroing. *Jurnal Tanah dan Sumberdaya Lahan*, 10(1), 7-103. <https://doi.org/10.21776/ub.jtsl.2023.010.1.10>
- Kurniawan, L. (2008). Kajian penilaian bahaya tanah longsor Provinsi Sumatera Utara. *Jurnal Sains dan Teknologi Indonesia*, 10(2), 90-98. <https://doi.org/10.29122/jsti.v10i2.799>

- Kurniawan, I., & Endayanti, M. (2022). Analisa Perkuatan Dinding Penahan Tanah (Studi Kasus : Area Bendungan Wampu Kecamatan Kuta Buluh Kabupaten Karo. *Jurnal Ilmiah Teknik Sipil*, 11(1), 108. <https://doi.org/10.46930/tekniksipil.v11i1.1718>
- Look, B. G. (2007). *Handbook of geotechnical investigation and design tables* (1st ed.). Taylor & Francis. <https://istasazeh-co.com/wp-content/uploads/2022/06/Handbook-of-geotechnical-investigation-and-design-tables-by-Burt.pdf>
- Mikola, R. G. (2023). *HYRCAN: A comprehensive limit equilibrium software package for 2D slope stability analysis*. <https://doi.org/10.22541/au.167533016.65709246/v1>
- Naryanto, H. S., Soewandita, H., Ganesha, D., Prawiradisastra, F., & Kristijono, A. (2019). Analisis penyebab kejadian dan evaluasi bencana tanah longsor di Desa Banaran, Kecamatan Pulung, Kabupaten Ponorogo, Provinsi Jawa Timur tanggal 1 April 2017. *Jurnal Ilmu Lingkungan*, 17(2), 272–282. <https://doi.org/10.14710/jil.17.2.272-282>
- Nurrohim, F. (2023). *Analisis stabilitas lereng dengan metode perkuatan geotextile menggunakan pemodelan Plaxis 2D* [Undergraduate thesis, Universitas Sangga Buana TPKP].
- Qarinur, M. (2015). Landslide runout distance prediction based on mechanism and cause of soil or rock mass movement. *Journal of the Civil Engineering Forum*, 1(1), 29–35. <https://pdfs.semanticscholar.org/4dca/38e620f3feb32f45983b1be0d59687f79054.pdf>
- Qarinur, M., Silitonga, E., & Sibuea, D. (2024). Assessing Soil Engineering Properties for Landslide Susceptibility in Karo Regency, Indonesia. In *Proceedings of the 5 th International Conference on Innovation in Education, Science, and Culture, ICIESC*.
- Rumbyarso, T. P. A., & Pribadi, G. (2023). Penggunaan program Plaxis dalam studi penelitian perkuatan geotextile pada kestabilan lereng buatan. *Jurnal Sipil Krisna*, 9(1), 22–26. <https://doi.org/10.61488/sipilkrisna.v9i1.248>
- Setiawan, L. C., Sentosa, G. S., & Iskandar, A. (2018). Analisis Stabilitas Lereng Batuan dengan Metode Ground Anchor & Soil Nailing di Labuan Bajo, NTT. *JMTS: Jurnal Mitra Teknik Sipil*, 1(1), 102–110. <https://doi.org/10.24912/jmts.v1i1.2247>
- Silitonga, E. M. R., & Qarinur, M. (2023). Modul Praktikum Mekanika Tanah. Universitas Negeri Medan
- Takwin, G. A., E. T. A., & Rondonuwu, S. G. (2014). Analisis Kestabilan Lereng Dengan Metode Bishop (Studi Kasus: Kawasan Citraland sta.1000m). *Jurnal Sipil Statik*, 2(3), 139–147
- Takwin, G. A., E. T. A., & Rondonuwu, S. G. (2017). Analisis Kestabilan Lereng Metode Morgenstren-Price (Studi Kasus : Diamond Hill Citraland). *Jurnal Tekno*, 15(67), 66–76
- Unaizahroya, I. M., & A'yuni, I. N. Q. (2022). *Beberapa metode perkuatan yang umum diterapkan meliputi dinding penahan tanah (retaining wall), soil nailing, penggunaan geosintetik (geotekstil, geogrid), serta perbaikan kondisi drainase untuk mengontrol tekanan air pori*. Universitas Islam Sultan Agung.
- Waruwu, R. R., Telaumbanua, A. A., & Endayanti, M. (2022). Analisis Stabilitas Lereng Di Desa Padang Mas Kecamatan Kabanjahe Kabupaten Karo Menggunakan Metode Fellenius. *Jurnal Ilmiah Teknik Sipil*, 11(2), 286–298. <https://doi.org/10.46930/tekniksipil.v11i2.2758>