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Reinforcement of Piles in Landslides at KM. 619+900

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Abstract

Landslides are events that can cause both moral and non-moral losses, one of which is the damage to the Subulussalam–Lipat Kajang Road section at KM. 619+900, resulting in restricted movement and disrupted activities of the local community. This could be due to factors such as rainfall or groundwater levels. Therefore, this research was conducted with the aim of addressing the existing problems by providing appropriate and effective solutions to the landslides caused. This research uses secondary data and primary data in analyzing slope stability. The initial conditions and the slope conditions following sheet pile reinforcement are used this analysis. An application called Plaxis is required in order to examine the slope stability. This study produced a safety factor value of 1.104 under existing conditions, and after being reinforced with sheet piles, the safety factor value increased to 1.502. However, if the slope in the existing condition is subjected to an earthquake load, it will obtain a very low safety factor value of 1.044, and this requires strengthening with sheet piles and anchors to increase the safety factor value, ensuring that the slope is in a stable condition. This research provides one of the much-needed alternatives in addressing landslide issues, especially in the fields of construction and geotechnical engineering. The findings of this research can serve as a reference or guideline in the civil engineering planning process, particularly in the use of reinforcement systems such as sheet piles (retaining walls) and anchors as effective solutions.

Keywords: Sheet Pile Reinforcement, Slope Stability, Safety Factor.

1. Introduction

A slope is a surface of land that is inclined at a certain angle to the horizontal plane and is unprotected. The unevenness of the land causes gravitational forces to push the soil downward, making the risk of landslides difficult to avoid. Landslides are a geological disaster or a serious event that can cause losses, deaths, injuries, environmental damage, and infrastructure damage, especially in areas with vulnerable geographical conditions [1]–[3]. In the subject of geotechnical engineering, landslide problems are frequently encountered [4], [5]. Landslides, also known as mass movement of soil, rock, or a combination of both, often occur on natural or artificial slopes [6]–[8]. The primary cause of landslides on slopes is typically a reduction in the soil's shear strength, which renders it unable of supporting the weight placed upon it [9]. Rainfall, groundwater levels, and variations in geological activity, such as faults and cracks, can all cause instability. Similarly, natural slopes that have been stable for years can suddenly collapse due to changes in geometry, external forces, and loss of shear strength [6], [10]–[12]. In addition, long-term stability is also related to weathering and chemical effects that can reduce shear strength and cause tensile shear cracks. The main causes of landslides are human activities

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such as slope excavation, deforestation for construction, and infrastructure development in unstable mountainous areas caused by migration and population growth.

Natural slopes can collapse suddenly or become unstable due to several factors, including rough terrain, hydrological conditions, high relief, and rock characteristics. These conditions cause Indonesia to be prone to landslides [13]. Indonesia is susceptible to both natural and man made-made disasters due to is geographic and demographic circumstances [14]. One of them is in the Aceh region, specifically on the Subulussalam-Lipat Kajang Road, which is a national road connecting the city of Subulussalam in the Aceh Singkil Regency, Aceh Province, with North Sumatra Province. This section of the road has slopes with a rotational landslide type that frequently experiences landslides [15], and based on the geological conditions of the soil in the area, it consists of water-saturated sand layers [16]. The movement of landslides in this area is caused by factors such as slope inclination, geological conditions, and prolonged rainfall, which leads to an increase in groundwater levels and causes soil displacement [8], [17]–[19].

As preventive measures, several attempts have been made to lessen the impact of landslides in such circumstances. These include installing early warning systems and evacuating landslide victims. Trought infrastructure development or education to increase knowledge and preparedness for disasters, disaster mitigation is a set of actions intended to reduce the risk of catastrophes by boosting capacity and decreasing threats and vulnerabilities. It is possible to mitigate landslides using both structural and non-structural methods. It is possible to mitigate landslides using both structural and non-structural methods. Building physical infrastructure, such as retaining walls or embankments in regions with sleep slopes, is part of the structural approach. In contrast, the non-structural approach emphasizes education and training to improve community knowledge and readiness as well as the use of technology to forecast and anticipate disaster risks. In addition to social, economic, and environmental considerations, an area's physical susceptibility affects the likelihood of landslide disasters. Disaster mitigation must therefore take into account the current degree of risk and incorporate both non-physical and physical measures. Preventive measures, disaster management during the crisis, and post-disaster recovery operations are also essential components of mitigation efforts [20], [21].

In this study, one alternative has been implemented to address landslides at KM. 619+900. Subulussalam - Lipat Kajang [22] states that landslide prevention for all types of soil can be done in several ways, including: reducing the active load on the slope, increasing slope reinforcement, and avoiding or reducing sliding planes on the slope. Therefore, in this study, to address landslides, sheet pile reinforcement is used as an alternative solution. Sheet pile is a relatively long and thin vertical wall, usually made of wood, steel, or concrete [23]. The function of sheet pile reinforcement is to hold back soil and water that enter the excavation hole. Sheet piles are designed to withstand lateral (horizontal) earth pressure when there is a change in soil elevation that exceeds the angle of internal friction in the soil. The angle of the internal friction (φ) and cohesion (c) determine the lateral earth pressure behind the retaining wall, which rises from the top to the bottom of the wall. If improperly planned, soil pressure will push against the retaining wall, leading to landslides and contruction failure [24]. This study used slope analysis to reduce the likelihood of landslides at susceptible locations, where they could traffic flow and interfare with local residents' daily activities, as seen in Figure 1.

Figure 1. Landslide Location on Subulussalam-Lipat Kajang Road

Regarding the sheet pile reinforcement, an initial study has been conducted on slope stability using the bishop method [25], as well as slope stability with sheet pile reinforcement using Plaxis

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Software with varying placements and heights of the sheet pile [26]. Additionally, there is slope stability with geogrid and sheet pile on the Kikim Besar road (KM. 256) in Lahat city [27]. Most of these studies related to soil retaining wall reinforcement are concentrated in the regions of Banda Aceh, Aceh Besar, and Lintas Timur. Whereas for the Southern route, it is still inadequate, even though the Southern route area often experiences landslides. One of the studies conducted in the Southern cross region is the Analysis of road subsidence at KM. 605+400 of the Subulussalam–Lipat Kajang road section reinforced with modified chicken-foot foundation [28].

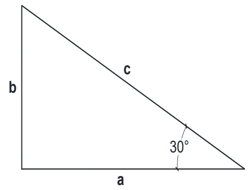
2. Methodology

In this study, the secondary data required for slope stability analysis includes SPT, cohesion (c), permeability coefficient (k), friction angle (ϕ), and unit weight (γ). The main sources of information are the slope geometry, the study location's coordinates, and the map of the area [5]. For the slope geometric data, please refer to Table 1 below. Both the beginning conditions and slope conditions following sheet pile reinforcement are used in this research. To analyze slope stability, an application called Plaxis is needed. Plaxis is a program, specifically a finite element software, used to model changes and stabilization of soil in the field of geotechnics for civil engineering construction planning [29].

Table 1. Geometry of the Slope Review Point at KM. 619+900

Location	Coordinate		α (°)	c (m)	b (m)	a (m)
KM. 619+900	098° 02' 19,73" E	02° 30' 14,02" N	30.00	7.00	3.50	6.06

Cliff description:



As for the location used in the study, it is on the Subulussalam–Lipat Kajang Road Segment KM. 619+900 in Aceh Singkil Regency, Aceh Province. The final result obtained in this study is the factor of safety value, which must meet the expected conditions as recommended in Table 2 below. To achieve the desired results, the addition of anchors, placement, and changes in the height of the sheet pile significantly affect the value of the safety factor [19].

Table 2. Safety Factor Values for the Design

No.	Safety Factor	Description
1	FK < 1,07	Collapse can happen
2	1,07 < FK < 1,25	Collapse has happened
3	FK > 1,25	Collapse is rare

Source: [15], [29]

3. Result and Discussion

The data from the soil parameter tests, slope geometry, and the placement of the sheet pile position are shown in Table 3 and Figure 2 below.

Table 3. Soil Parameter Table in Plaxis

Description	Unit	KM. 619+900		
		Top Layer	Middle Layer	Base Layer
Material model	-	MC	MC	MC
Type of behaviour	-	Undrained	Undrained	Undrained

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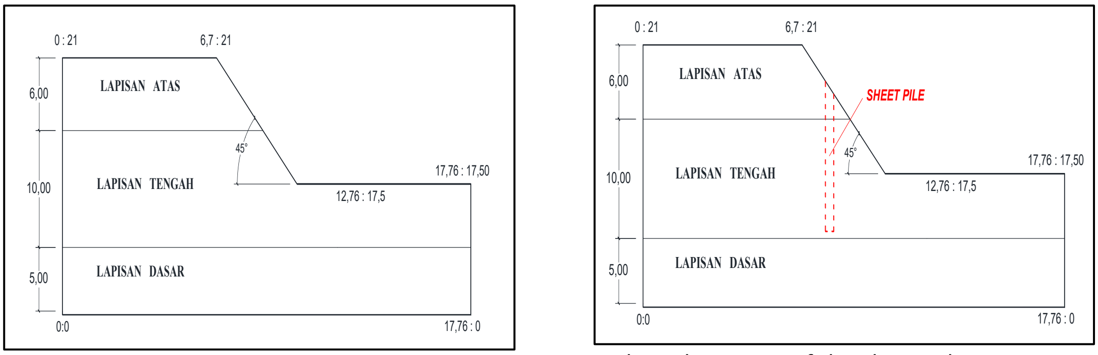
Dry soil weight (γ_{dry})	kN/m^3	12.498	12.763	14.126
Wet soil weight (γ_{wet})	kN/m^3	17.558	17.706	18.568
Horizontal permeability (k_x)	m/day	8.640	8.640	8.640
Vertical permeability (k_y)	m/day	8.640	8.640	8.640
Young's modulus (E_{ref})	kN/m^2	31,381.280	34,323.275	29,910.280
Poisson's ratio (v)	-	0.300	0.300	0.300
Cohession (c)	kN/m^2	2.461	2.511	5.639
Friction angle (ϕ)	°	28.630	29.54	32.990
Dilatacy angle (Ψ)	°	0	0	0



a. Modeling the geometric shape of the slope
b. Placement of the sheet pile position

Figure 2. Modeling the Geometry of the Slope and the Placement of the Sheet Pile

After data input using the Plaxis software, the slope stability analysis results were obtained by reviewing 3 (four) slope conditions, namely the existing condition, the existing condition with earthquake load, and the existing condition with earthquake load reinforced using sheet piles, resulting in a safety factor value that meets the safety requirement of FK ≥ 1.5. The results of the slope stability analysis also display images of the critical and safest slip surfaces along with the safety factor calculations. Based on the slope stability results obtained from the Plaxis software with slope and height measurements according to field measurements, varying safety factor values were obtained. The factor of safety values obtained after conducting the slope stability analysis are shown in Table 4 and Figure 3

Table 4. Results of the Security Factor Analysis

No.	Location	Safety Factor			
		Existing Condition	Existing Condition + Earthquake Load	Existing Condition + sheet pile	Existing Condition + Earthquake Load + Sheet Pile + Anchor
				Sheet Pile = 8 m	Sheet Pile = 10 m Anchor = 5 m
1	Km. 619+900	1.168	1.027	1.503	1.865

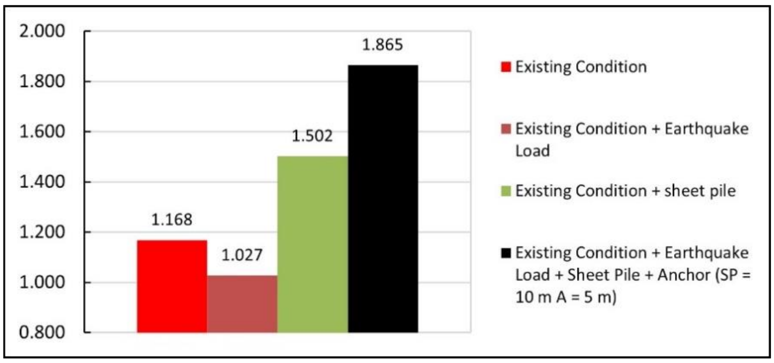


Figure 3. Slope Safety Factor Value Graph Km. 619+900

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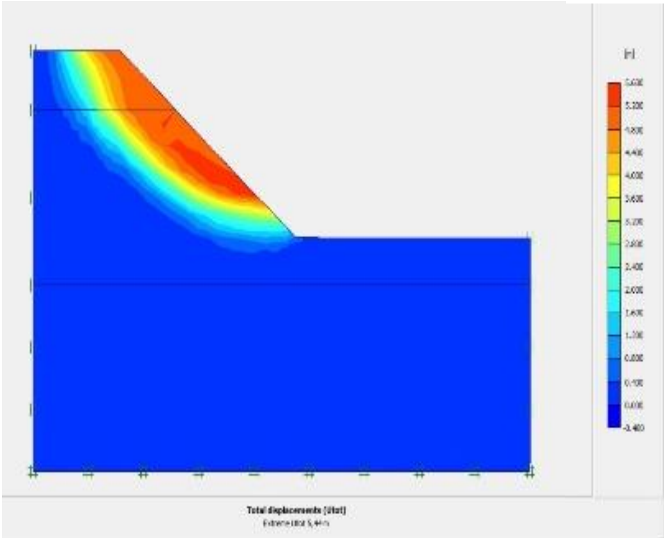
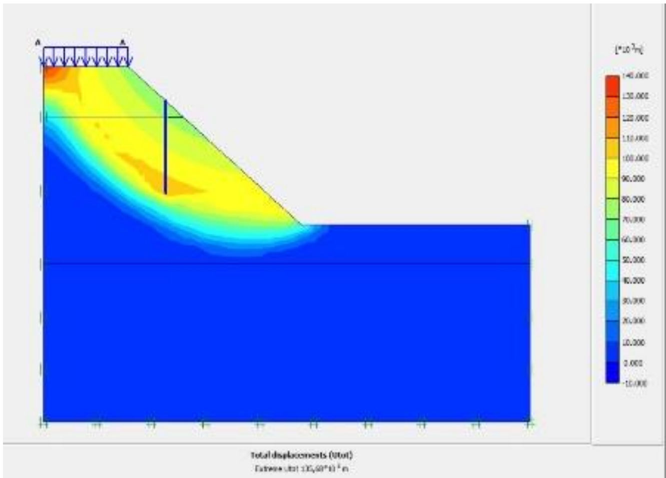
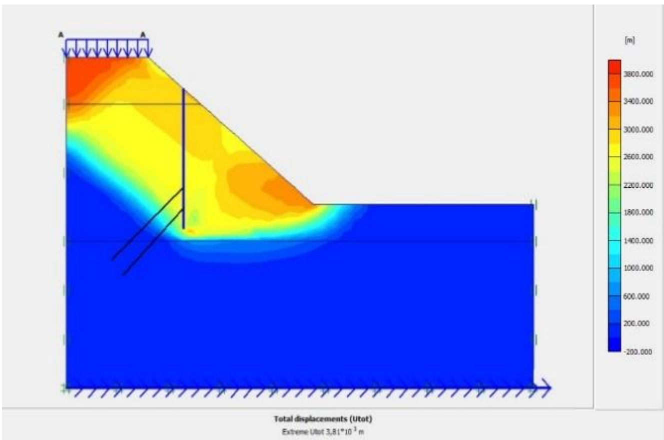
The results of the slope failure analysis under 3 conditions, namely the existing condition, the existing condition reinforced with sheet piles, and the existing condition reinforced with sheet piles and anchors, are shown in the Figure 4 below.



a. Existing condition



b. Existing condition reinforced with sheet piles



c. Existing condition reinforced with sheet piles and anchors

Figure 4. Results of the Slope Failure Analysis under 3 Conditions

The results of the safety factor analysis using the finite element method for the 3 slope conditions as shown in the image above can be seen in Table 5 below.

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Table 5. Results of Security Factor Analysis

No.	Location	Safety factor of existing conditions	Description	Safety factor after reinforcement	Description
1	KM 619+900	1.168	Unsafe	1.502	safe

Based on the description above, it shows that the slope stability calculation results at Km. 619+900 indicate that the safety factor value under existing conditions does not meet the safe permit requirements [15], [23]. Meanwhile, after the installation of reinforcement using sheet piles, the safety factor value increased significantly to 1.502, indicating that the slope is in a safe condition. However, if the slope is subjected to seismic loads, it will result in a low safety factor value, thus requiring an alternative to sheet pile reinforcement. Here, the researcher attempts to use anchors as an additional alternative. so that after strengthening the sheet pile with the addition of anchors, a safety factor value of 1.865 was obtained, which meets the required value of FS ≥ 1.5 [15], [27].

4. Conclusion

Based on the results of the slope stability analysis at the landslide location on the Subulussalam–Lipat Kajang Road in Aceh Singkil Regency, Aceh Province at KM. 619+900, it was found that the slope safety factor in the existing condition is 1.168, indicating that the slope is in an unsafe condition. With the unsafe condition of the slope, an alternative to address the issue is needed, namely reinforcement using sheet piles. The installation of an 8-meter sheet pile results in a safety factor of 1.502, and the slope is in a safe condition. However, if the slope is subjected to an earthquake load, the safety factor decreases and does not meet the allowable condition of FS<1.5, thus requiring anchors as an additional alternative. After the addition of anchors, a significant safety factor value of 1.940 was obtained with a sheet pile length of 10 m and an anchor length of 5 m. From this result, the safe permit requirement has been met, which is an FS value > 1.5. In general, it can be concluded that the longer the sheet pile and anchor installed, the higher the safety factor will be. However, if you want better results, the placement of the sheet pile should be considered, specifically below the slope failure plane or in the middle of the slope.

References

[1] F. Guzzetti, A. Carrara, M. Cardinali, and P. Reichenbach, “Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy,” *Geomorphology*, vol. 31, no. 1, pp. 181–216, 1999, doi: https://doi.org/10.1016/S0169-555X(99)00078-1.

[2] I. P. Hastuty and A. B. Sihite, “The decline of soil due to the pile of highway project Medan-Kualanamu (STA 35+ 901) with the finite element method,” in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 308, no. 1, p. 12008. doi: 10.1088/1757-899X/308/1/012008.

[3] S. Bachri *et al.*, “Landslide risk analysis in Kelud Volcano, East Java, Indonesia,” *Indones. J. Geogr.*, vol. 53, no. 3, pp. 400–407, 2021, doi: https://doi.org/10.22146/ijg.40909.

[4] P. S. Wulandari and D. Tjandra, “Analysis of Geotextile Reinforced Road Embankment Using PLAXIS 2D,” *Procedia Eng.*, vol. 125, pp. 358–362, 2015, doi: https://doi.org/10.1016/j.proeng.2015.11.075.

[5] I. P. Hastuty and A. M. Suwandi, “Slope stability analysis using sheet pile reinforcement with the Bishop method,” in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 851, no. 1, p. 12022. doi: 10.1088/1757-899X/851/1/012022.

[6] L. M. Highland and P. Bobrowsky, *The landslide handbook-A guide to understanding landslides*, no. 1325. US Geological Survey, 2008.

[7] F. Nadim, O. Kjekstad, P. Peduzzi, C. Herold, and C. Jaedicke, “Global landslide and avalanche hotspots,” *Landslides*, vol. 3, no. 2, pp. 159–173, 2006, doi: 10.1007/s10346-006-0036-1.

[8] L. M. Jaelani, R. Fahlefi, M. Khoiri, and J. P. G. Nur Rochman, “The Rainfall Effect Analysis of Landslide Occurrence on Mount Slopes of Wilis,” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 10, no.

P-ISSN: 1411-3414
E-ISSN: 2549-9815

1 SE-Articles, pp. 298–303, Feb. 2020, doi: 10.18517/ijaseit.10.1.6876.

[9] H. Hardiyatmo, *Penanganan tanah longsor dan erosi*. Yogyakarta: Gadjah Mada University Press, 2006.

[10] L. Ermini, F. Catani, and N. Casagli, "Artificial Neural Networks applied to landslide susceptibility assessment," *Geomorphology*, vol. 66, no. 1, pp. 327–343, 2005, doi: https://doi.org/10.1016/j.geomorph.2004.09.025.

[11] M. Ercanoglu and C. Gokceoglu, "Assessment of landslide susceptibility for a landslide-prone area (north of Yenice, NW Turkey) by fuzzy approach," *Environ. Geol.*, vol. 41, no. 6, pp. 720–730, 2002, doi: 10.1007/s00254-001-0454-2.

[12] F. Catani, N. Casagli, L. Ermini, G. Righini, and G. Menduni, "Landslide hazard and risk mapping at catchment scale in the Arno River basin," *Landslides*, vol. 2, no. 4, pp. 329–342, 2005, doi: 10.1007/s10346-005-0021-0.

[13] S. N. H. Sholikah, S. K. N. Prambudi, M. Y. Effendi, L. Safira, N. Alwinda, and R. Setiaji, "Analisis kesiapsiagaan dan mitigasi bencana tanah longsor di Kabupaten Ponorogo," *JPIG (Jurnal Pendidik. Dan Ilmu Geogr.*, vol. 6, no. 1, pp. 81–90, 2021, doi: https://doi.org/10.21067/jpig.v6i1.5278.

[14] S. Yulianto, R. K. Apriyadi, A. Aprilyanto, T. Winugroho, I. S. Ponangsera, and W. Wilopo, "Histori bencana dan penanggulangannya di indonesia ditinjau dari perspektif keamanan nasional," *PENDIPA J. Sci. Educ.*, vol. 5, no. 2, pp. 180–187, 2021, doi: 10.33369/pendipa.5.2.180-187.

[15] J. Ardika, H. Yunita, M. Sungkar, and A. K. Akmal, "Analysis of Slope Stability on Subulussalam-Lipat Kajang Road," *Aceh Int. J. Sci. Technol.*, vol. 12, no. 1, pp. 96–103, 2023, doi: https://doi.org/10.13170/aijst.12.1.24867.

[16] Munirwansyah, Munirwan, R. Pahlevi, and H. Yunita, "Geotechnical Engineering Aspect Related to Pidie Jaya–Aceh Earthquake Disaster and Mitigation," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 8, no. 3 SE-Articles, pp. 870–875, Jun. 2018, doi: 10.18517/ijaseit.8.3.4189.

[17] D. Muriyatmoko and S. M. Phuspa, "Analysis of rainy days and rainfall to landslide occurrence using logistic regression in Ponorogo East Java," *Geosfera Indones.*, vol. 3, no. 2, pp. 79–89, 2018, doi: https://doi.org/10.19184/geosi.v3i2.8230.

[18] K. Zhang, S. Wang, H. Bao, and X. Zhao, "Characteristics and influencing factors of rainfall-induced landslide and debris flow hazards in Shaanxi Province, China," *Nat. hazards earth Syst. Sci.*, vol. 19, no. 1, pp. 93–105, 2019, doi: https://doi.org/10.5194/nhess-19-93-2019.

[19] A. Tohari, "Study of rainfall-induced landslide: a review," in *IOP Conference Series: Earth and Environmental Science*, 2018, vol. 118, p. 12036. doi: 10.1088/1755-1315/118/1/012036.

[20] V. A. Zulfa, H. Widyasamratri, and J. Kautsary, "Mitigasi Bencana Berdasarkan Tingkat Risiko Bencana Tanah Longsor (Studi Kasus : Lereng Gunung Wilis Kabupaten Nganjuk, Desa Sendangrejo Kecamatan Sambeng Kabupaten Lamongan dan Desa Sriharjo Kecamatan Imogiri Kabupaten Bantul)," *J. Kaji. Ruang*, vol. 2, no. 2, pp. 154–169, 2022.

[21] S. Hadi, A. Hargono, and H. Saputra, "LANDSLIDE DISASTER MITIGATION BASED ON DISASTER RISK LEVEL IN GRESIK, EAST JAVA," 2024, doi: https://doi.org/10.20473/adj.v8i2.64820.

[22] Y. Syahwaner, M. Yusa, and S. Satibi, "Analisis Stabilitas Lereng Dengan Perkuatan Tiang Menggunakan Metode Elemen Hingga (Studi Kasus Jalan Diponegoro Km. 2 Pasir Pengaraian)," *Aptek*, pp. 48–59, 2019, doi: https://doi.org/10.30606/APTK.V11I1.1691.

[23] J. E. Bowles, "Sifat-Sifat Fisis dan Geoteknis Tanah: Mekanika Tanah (Edisi 2)," *Jakarta: Erlangga*, 1984.

[24] R. Iskandar and S. A. Silalahi, "Soil settlement analysis in soft soil by using preloading system

P-ISSN: 1411-3414
E-ISSN: 2549-9815

and prefabricated vertical draining runway of Kualanamu Airport," in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 309, no. 1, p. 12024. doi: 10.1088/1757-899X/309/1/012024.

[25] M. Sungkar and R. P. Munirwan, "Analisis Stabilitas Lereng dengan Metode Bishop dan Perkuatan Sheet Pile," *J. Civ. Eng. Student*, vol. 2, no. 3, pp. 309–315, 2020.

[26] M. Sungkar, M. Munirwansyah, R. P. Munirwan, and D. Safrina, "Slope stability analysis using Bishop and finite element methods," in *IOP conference series: materials science and engineering*, 2020, vol. 933, no. 1, p. 12035. doi: 10.1088/1757-899X/933/1/012035.

[27] Y. Hastuti, R. A. M. Wahyuni, and R. Dewi, "Perkuatan Lereng Dengan Geogrid Dan Sheet Pile Pada Jalan Kikim Besar (Km. 256) Kota Lahat," *Cantilever*, vol. 5, no. 1, pp. 1–6, 2016, doi: 10.35139/cantilever.v5i1.35.

[28] A. Munir, "ANALISIS PENURUNAN BADAN JALAN KM 605+ 400 RUAS JALAN SUBULUSSALAM–LIPAT KAJANG DIPERKUAT PONDASI CAKAR AYAM MODIFIKASI," *Teras J. J. Tek. Sipil*, vol. 10, no. 2, pp. 203–212, 2020, doi: https://doi.org/10.29103/tj.v10i2.317.

[29] Plaxis, *Tutorial Manual*. Rotterdam: A.A. Balkema, 2012.