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RESEARCH ARTICLE

Water and Reinforced Effects on Slope: Case Study on District Koto Panjang, Riau, Indonesia

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Abstract

This paper discussed a study case related to slope stability and its analysis. The observation and also research object was a hill side on border area between West Sumatera-Riau, Indonesia. This border area consists of numerous slopes with heterogeneous soil characteristics. This location is also susceptible for having landslides, especially on rainy season. The schemes of this research consisted of collecting samples, laboratory tests, finite element method analysis, and slope`s reinforcement planning with anchors or geosynthetic plates. The soil samples were tested on their actual condition and liquid limit condition. This purposed to predict the failures on slope. Afterwards, some reinforcement plannings need to be done. The results of this researach have shown that on existing condition, the safety factor was 1.262. If the soil reach its liquid limit, the safety factor decreased to 0.568. After the reinforcement planning was done, the safety factor went up to 1.120 and the slope stability could be maintained.

Keywords: failure, finite elemen method, reinforced, slope stability, water

1. Introduction

Indonesia is a country located in equator line with high risks of being damaged by natural hazards e.q earthquake, flood, and abration (Amran *et al.*, 2021), (Hidayat, Syah and Erianjoni, 2021), (Wulandari, Khoirunisa and Soeharta, 2020). One of the natural hazards that occasionally occurred in Indonesia, especially on hill side and its surroundings is landslide. According to Minmahddun (Minmahddun, Fathani and Faris, 2019), Several locations in Indonesia are facing these natural hazards frequently. One of the locations is the border area between West Sumatera and Riau .Both of them are located on Sumatera Island .

West Sumatera and Riau have suffered amount of disadvantage in last ten years due to these disasters, including material lost, human victims, and infrastructure damages. On the case of border area between West Sumatera and Riau, this disaster has broken the transportation line between two provinces and disabled all economy and trading sectors.

According to Hapsari (Hapsari *et al.*, 2021), (Kundu, Sarkar and Singh, 2017), (Amini, Sarfaraz and Esmaeili, 2018), Landslide is a phenomenon where a mass of rock or soil moves along the slope line and it is also under the influence of gravity power. Single landslide could brought major destruction, especially when the landslide occurred near to civilian places (T Anh Bui, Fathani and Wilopo, 2019), (Park *et al.*, 2016), (Kristyanto, 2020), (Wilopo *et al.*, 2019). An example of landslide is displayed on Figure 1.

This movement happens due to the stability between shear strength and shear stress is disturbed by outside force. Or according to Chang (Chang, Vanapalli and Li, 2016), (Das, 2014; Y. M. Cheng and C. K. Lau, 2014), (Apriani, Mustofa and Hidayat, 2020), the stability could be explained in form of safety factor parameter, as it is written below:

$$SF = \frac{M_R}{M_D} = \frac{F_R}{F_D} \quad (1)$$

Where:
M_r = Resisting Moment
M_d = Driving Moment
F_r = Resisting Force
F_d = Driving Force

Fig 1. Landslide near the civilians place Source: google Earth/Maps (2019)

2. Theoretical Basics

According to (Iqbal, Mulyono and Syahbana, 2017; Samodra and Permanadewi, 2018; Hardiyatmo, 2019), there are several factors which triggered some failures on slope, i.e. overload slope (including infrastruture`s weight on slope), long duration of rainfall, human activity (such as deforestation, etc.), rapid draw down, and other natural hazards (for example: an earthquake which leads to creation of cracks and lateral forces by water).

Overall, landslides have same pattern when it occurred. It was all started by heavy precipitation (long duration of rainfall). Huge mass of water will be absorbed by soil. Yet, it moves down along the gravitation. Whenever the water reaches the deepest part of slope or impermeable layer (usually bed rock), water`s movement changes from vertically to horizontally and creates landslide planes. The combination of soil and water weight, also with the low shear strength of slope, could make this disaster becomes inevitable.

With lots of landslide cases, it becomes a reference and basic knowledge for scientists and engineers to discover a way to predict the safety factor of slopes. This leads to slope reinforcement plannings later. One of the ways which could be utilized to analyze this case is by using finite element method. This method has been used to overcome the complicated case of slopes.

Neves (A. P. M. Neves, 2016) have used this method to solve the case of residual soil slope. According to Berisavljević (Z. Berisavljević, D. Berisavljević, V. Čebašek, 2016)have used this method to analyze the slope side of Beli Potok tunnel on the Belgrade bypass. Both of them have shown that finite element method is a very helpful, adequate and recommended in conducting some complex geometry cases computation.

Barkanov (E. Barkanov, 2001) and Ongko (Ongko, Nugroho and Yusa, 2018), finite element method is a method which is suitable for computation of beams, plates, shells, etc. Through this method, a construction is presented in a view of element assembly. It is assumed that they are connected in a finite number of nodal points. Then it is considered that the nodal displacements determine the field of displacements of each finite element. An illustration of finite element method was presented on Figure 2.

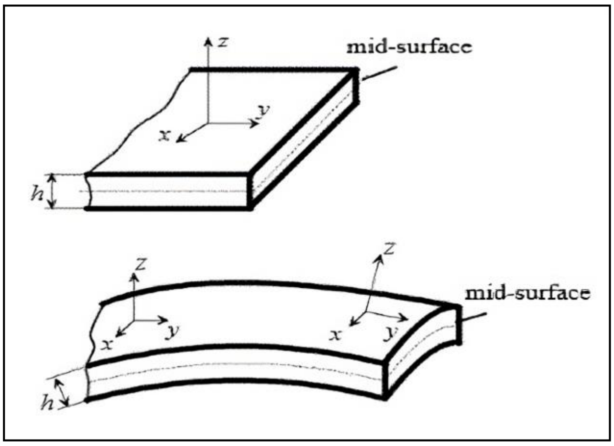


Fig 2. Shell and Plate Model by Finite Element Method (Desai, 2011)

The outcome of analysis is safety factor. This outcome could be used as a reference in designing reinforcement for slopes. Onur (Onur *et al.*, 2016), has stated that slope reinforcement could be done through geometry method (slope cutting), hydrology method (through water pore pumping), and mechanic method (through pile installation, reinforcement wall or anchors).

Ongko et al. and Park et al. (Park *et al.*, 2016; Ongko, Nugroho and Yusa, 2018) have stated that anchors installation could be done on the hill side and it significantly increased the shear strength of slopes (Farazi, Mia and Mahmud, 2018; Arman, Ganefri and Syah, 2021; Pamungkas *et al.*, 2022). Kristyanto (2021) has also utilized anchors model as an applicative solution to deal with landslide Indonesia in Tomohon, Indonesia. These prior researches have indicated that reinforcement designs are really needed to strengthen the slopes which were assumed as vulnerable to landslides.

2. Research Methodology

At the beginning of research, the field needs to be observed. This observation was necessary in order to collect soil samples and portrayed slope`s geometry. The result of field mapping could be observed on Figure 3.

Fig 3. Geometry Map of Border Area on West Sumatera-Riau (Source: google Earth/maps (2019))

Mapping result was made as basic model in modeling the slope by using finite element method. The ilustration of slope modeling was displayed on Figure 4.

According to the field observation results, the slope was consisted of three different layers of soils. Each of those layers has different characteristic. Therefore, the soil samples were collected from each layer.. When the slope was classified as vulnerable to landslides and proven with low safety factor, then some slope reinforcements need to be modeled to elevate the performance of slope.

The purpose of samples collecting was to conduct some laboratory tests. Furthermore, each samples were tested on their existing condition and liquid limit condition

3. Result and Discussions

3.1 Laboratory test Results

Results of laboratory tests were displayed on Table 1. For further explanation, c is the cohesion from slope`s existing condition. Whereas c` is the cohesion from liquid limit condition of slope. In order

to obtain the c', the soils is tested until it reached its liquid limit. Then, based on the water content, the soils is tested with cohession test. (Kusnadi, 2017).

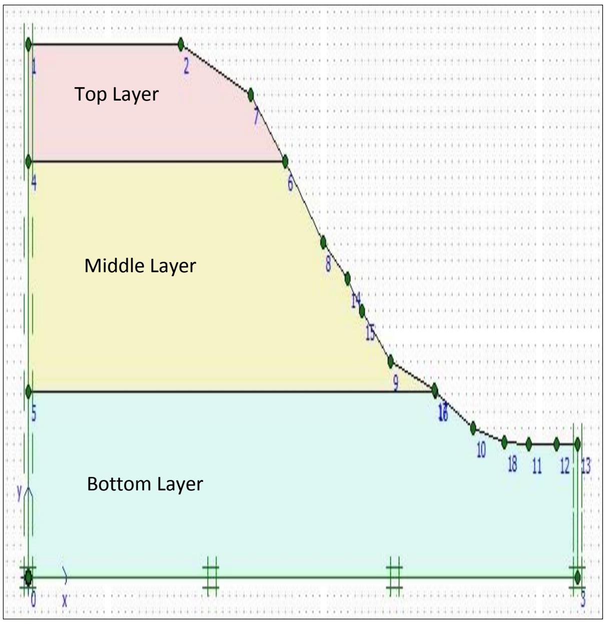


Fig 4. Slope Modeling (Source: Plaxis 2D ver 8.1x Licensed)

Table 1. Properties of soils on each layer

No.	Physical and Mechanic Properties	unit	Layer Top	Layer Middle	Layer Bottom
1.	Liquid Limit	%		34.200	39.100
2.	Unit weight (g)	kN/m^3	11.663	10.531	10.424
3.	Saturated Unit weight (□sat)	kN/m^3	15.508	16.636	16.433
4.	Modulus Elasticities (E)	kN/m^2	9810	4905	5000
5.	Hydraulic conductivity	m/day	0.070	0.060	0.042
6.	Poisson ratio, (v)	-	0.300	0.300	0.300
7.	Cohesion (c)	kN/m^2		35.200	32.500
8.	Effective Cohesion (c')	kN/m^2	0.098	4.520	3.500
9.	Friction angle (f')	degree	38.970	12.130	8.470

Source: Soil and Rock Mechanics Laboratory, Civil Engineering Department Universitas Riau

3.2 Unreinforced Slope (Actual Condition)

The analysis result which was provided by finite element method was safety factor. In first analysis, the computation was focus on the existing condition. This condition could be mentioned as real field condition. The slope was filled with ground water and the ground water table reached the height of about 2 m. In finite element method, the model was made as a representation from the real condition (Devy and Hutahayan, 2021). The outcome of model could be observed on Figure 5 as follows.

According to Figure 5, it could be seen that the safety factor of existing condition was 1.262. This value is still could be categorized as safe (Cheng & Lau 2014), (Das 2018), (Guyer 2018), (Duncan & Wright 2014). The safety factor was still up to 1.00, which means the driving force was still bearable and well-handled by the shear strength of slope.

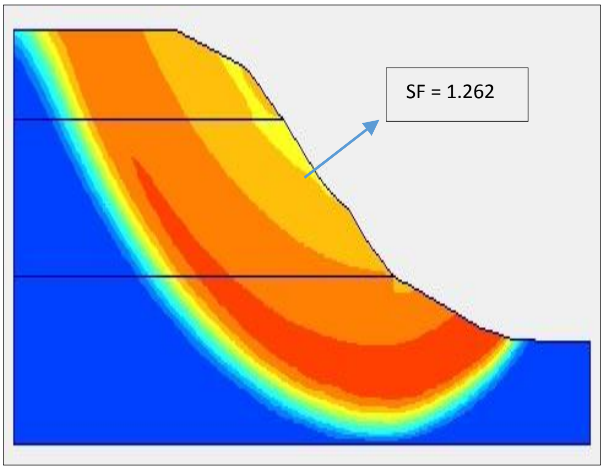


Fig 5. Existing Condition of Slope Source: Plaxis 2D ver 8.1x Licensed

3.3 Unreinforced Slope (LL Condition)

Liquid limit is a condition where a mass or soil`s body filled with water at specific water content and changes soil`s behavior and resembles it into liquid stage according to Guyer (Guyer 2018). This was also explained by Das (2018) and Duncan & Wright (2014) through Atterberg Limit on Figure 6. with:

SL : shrinkage limit
PL : Plastic limit
LL : Liquid limit

soil in field, usually contain water (natural moisture content), in range at value of water content between PL and LL

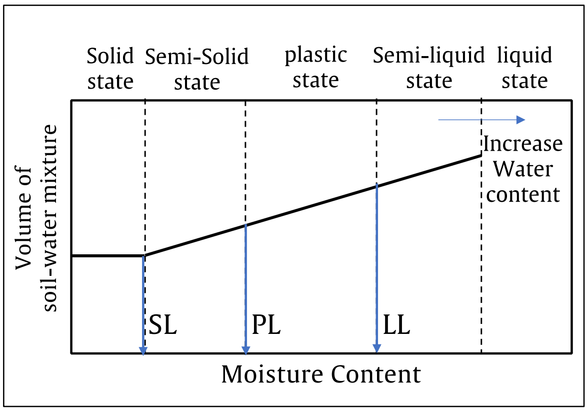


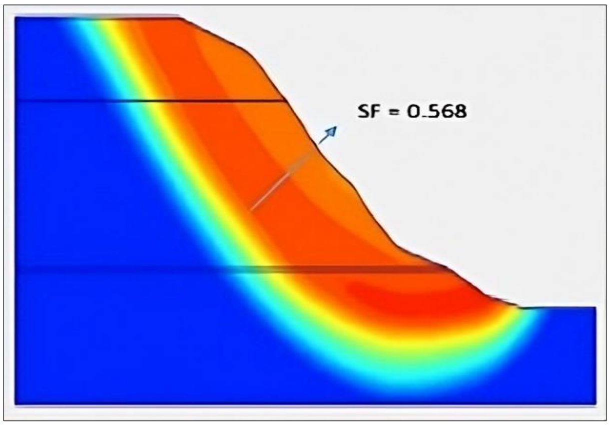
Fig 6. Atterberg Limit

In advanced study cases on slope, this condition needs to be reviewed and paid attention in order to anticipate some serious cases related to heavy rainfall and leads the water content inside of soil was over-escalated. The result of analysis could be observed on Figure 7 as follows.

Based on finite element method modeling result, it was obtained that safety factor was decreased from 1.262 to 0.568. The increment of water content inside of soil voids have caused the cohesion between each particle got weaken. This process has also made the physical bond between soil particles decreased and creates a potency of failures on slope. At this point, in order to anticipate landslide, it is necessary to conduct or embed some reinforcements. The reinforcements could be modeled by using landfill or slope stabilization reinforcement model.

Fig 7. Slope Model With Liquid Limit Condition (Source: Plaxis 2D ver 8.1x Licensed)

3.4 Reinforced Slope (LL Condition)



With the assumption of having failures due to the liquid limit condition, some reinforcements are necessary modeled. This was purposed to re-enhanced the prior low safety factor. In this case study, addition model was consisted of landfill materials and plates at the hill side to reduce the high risks of being devastated by landslide. The properties of landslide materials and plates could be observed on Table 2 and Table 3 on below:

Tabel 2. Properties of Landfill

Properties	Landfill
γ unsat (kN/m^3)	14.00
γ sat (kN/m^3)	18.50
k (m/day)	0.040
E (kN/m^2)	9810
υ	0.350
C (kN/m^2)	20.00
ϕ (°)	20.00

Source: Soil and Rock Mechanics Laboratory, Civil Engineering Department Universitas Riau

Tabel 3. Properties of Plates

Properties	Plate
EA (kN/m)	7.5×10^7
EI (kNm^2/m)	2.0×10^6
W (kN/m/m)	5.00
υ	0.100

Source: Soil and Rock Mechanics Laboratory, Civil Engineering Department Universitas Riau

Analysis result by using earthfill materials and plates was displayed on Figure 8 as follows:

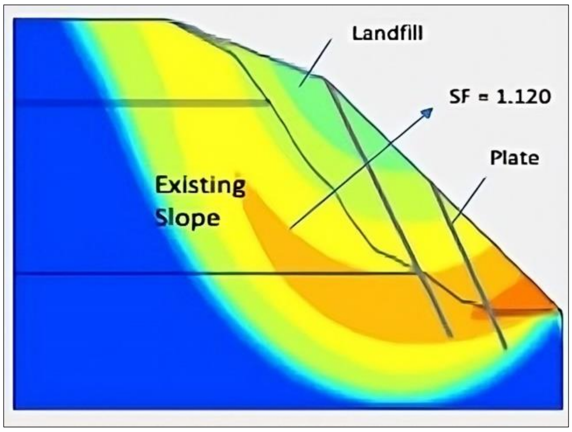


Fig 8. Slope Stability Analysis with Landfill Materials and Plates (Source: Plaxis 2D ver 8.1x Licensed)

The result has shown that safety factor by using landfill materials and addition plates at this critical point was back to up than 1.00. This reinforcements were placed on the hill side point in proper steepness. The purpose of reinforcements was to prevent some over movements of soil mass. From this analysis, the safety factor was increased from 0.568 to 1.120 even at the limit liquid condition. This should have satisfied the standard of safe slopes, and could be made as a reference for further advanced stabilization.

5. Conclusions

By gathering all results in this paper, it could be concluded that:

1. At existing condition, the slope could be stated as safe, with safety factor of 1.262.
2. At limit liquid condition, the safety factor was decreased to 0.568 which caused the slope`s condition became unstable. This condition has high possibility to happen, especially during the rainy season with high rate of precipitation.
3. In order to overcome the low safety factor situation, the slope could be stabilized by using addition materials, which were landfill materials and plates as reinforcements. In this case study, both of them were capabled to enhance safety factor back to 1.120.
4. Although the safety factor was pretty high, some other safety parameters need to be checked. Such as: displacements, material`s performance.

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References

A. P. M. Neves, V. C. (2016) ‘Slope Stability Assessment and Evaluation of Remedial Measures Using Limit Equilibrium and Finite Element Approaches’, in Procedia Engineering: 3rd International Conference on Transportation Geotechnics vol. 143, pp. 717–725.

Amini, M., Sarfaraz, H. and Esmaeili, K. (2018) ‘Stability analysis of slopes with a potential of slide-head-toppling failure’, International Journal of Rock Mechanics and Mining Sciences, 112, pp. 108–121. doi: 10.1016/j.ijrmms.2018.09.008.

Amran, M. et al. (2021) ‘Fiber-reinforced alkali-activated concrete: A review’, Journal of Building Engineering, 45(October), pp. 103–108. doi: 10.1016/j.jobe.2021.103638.

Apriani, D. W., Mustofa, U. and Hidayat, R. (2020) ‘SOIL SHEAR STRENGTH PARAMETER ANALYSIS BASED ON BEHAVIOR ANALYSIS OF LANDSLIDE CASE’, UKaRsT, 4(2), p. 163. doi: 10.30737/ukarst.v4i2.1046.

Arman, A., Ganefri and Syah, N. (2021) ‘Preparedness of Earthquake Disaster fot Communities Koto Tangan Sub-District Padang City (Case Study of Elementary School 31 Pasir Kandang)’, Sumatera Journal of Disaster, Geography and Geography Education, 5(1), pp. 24–29.

Chang, P. L., Vanapalli, S. and Li, T. (2016) ‘Review of collapse triggering mechanism of collapsible soils due to wetting’, Journal of Rock Mechanics and Geotechnical Engineering, (JANUARY). doi: 10.1016/j.jrmge.2015.12.002.

Das, B. M. (2014) Advanced Soil Mechanics 4th edition, CRC press, Taylor & Francis Group. doi: 10.1029/EO066i042p00714-02.

Desai, Y. M. (2011) Finite element method with applications in engineering. Pearson Education India.

Devy, S. D. and Hutahayan, P. P. (2021) ‘Groundwater Effect on Slope Stability in Open Pit Mining: a Case of West

Kutai Regency, East Kalimantan, Indonesia', Journal of Geoscience, Engineering, Environment, and Technology, 6(4), pp. 192–205. doi: 10.25299/jgeet.2021.6.4.6226.
E. Barkanov (2001) Introduction to the Finite Element Method, Institute of Materials and Structures Faculty of Civil Engineering Riga Technical University. Riga.
Farazi, A. H., Mia, A. J. and Mahmud, M. I. (2018) 'A Case Study Based Slope Stability Analysis at Chittagong City, Bangladesh', Journal of Geoscience, Engineering, Environment, and Technology, 3(3), p. 164. doi: 10.24273/jgeet.2018.3.3.1690.
Hapsari, A. M. et al. (2021) 'Identification of Physical and Mineralogical Properties of Riverbank Material at Sand Mining Landslide Sites of Kali Putih River, Blitar', UKaRsT, 5(1), p. 33. doi: 10.30737/ukarst.v5i1.1093.
Hardiyatmo, H. C. (2019) Mekanika Tanah Jilid 2. 2nd edn. Yogyakarta: Gadjah Mada University Press.
Hidayat, M., Syah, N. and Erianjoni (2021) 'Analysis of Flood Disaster Mitigation in West Sumatera', Sumatera Journal of Disaster, Geography and Geography Education, 5(1), pp. 35–40.
Iqbal, P., Mulyono, A. and Syahbana, A. J. (2017) 'Slope Stability Evaluation of Vulcanic Soil at Liwa-Bukit Kemuning West Traffic Road, West Lampung', Jurnal Lingkungan dan Bencana Geologi, 8(2). doi: 10.34126/jlbg.v8i2.116.
Kristyanto, T. H. W. (2020) 'Groundwater Fluctuation Simulation in Pagelaran Landslide, Cianjur, Indonesia', Jurnal Lingkungan dan Bencana Geologi, 11(1), p. 41. doi: 10.34126/jlbg.v11i1.218.
Kundu, J., Sarkar, K. and Singh, T. N. (2017) 'Static and Dynamic Analysis of Rock Slope – A Case Study', Procedia Engineering, 191, pp. 744–749. doi: 10.1016/j.proeng.2017.05.240.
Kusnadi, S. (2017) 'Slope Stability Analysis Based on Type, Physical And Mechanical Properties Rock in Teluk Pandan District, East Kutai Regency, East Kalimantan', Journal of Geoscience, Engineering, Environment, and Technology, 2(4), p. 272. doi: 10.24273/jgeet.2017.2.4.879.
Minmahddun, A., Fathani, T. F. and Faris, F. (2019) 'Determination of Stability During First Impounding in Jatigede Earth Dam', Journal of Applied Geology, 3(2), p. 1. doi: 10.22146/jag.48592.
Ongko, A., Nugroho, S. A. and Yusa, M. (2018) 'Slope Stability Analysis By Using Finite Element Method : A Case Study on Border Area of West Sumatera Riau , Indonesia', (2), pp. 25–29.
Onur, M. I. et al. (2016) 'Behavior of Soil Reinforcements in Slopes', in Procedia Engineering, pp. 483–489.
Pamungkas, G. et al. (2022) 'Residual Strength Parameter Method for Slope stability on a Toll Road with Expansive Clay', Journal of Geoscience, Engineering, Environment, and Technology, 7(2), pp. 49–58. doi: 10.25299/jgeet.2022.7.2.9251.
Park, H.-J. et al. (2016) 'Assessment of rock slope stability using GIS-based probabilistic kinematic analysis', Engineering Geology, 203, pp. 56–69. doi: 10.1016/j.enggeo.2015.08.021.
Samodra, H. and Permanadewi, S. (2018) 'Analisis Struktur Geologi Penyebab Runtuhnya Masa atuan di Pantai Sadranan, Kabupaten Gunung Kidul, DIY', Jurnal Lingkungan dan Bencana Geologi, 9(3), p. 119. doi: 10.34126/jlbg.v9i3.209.
T Anh Bui, Fathani, T. F. and Wilopo, W. (2019) 'Landslide Risk Assessment for Designing Monitoring and EarlyWarning System', Journal Application Geology, 4(1). doi: 10.22146/jag.48735.
Wilopo, W. et al. (2019) 'The 22 February 2018 landslide mechanism in Pasir Panjang Village, Brebes Regency, Central Java, Indonesia', Journal of Applied Geology, 4(2), p. 92. doi: 10.22146/jag.53255.
Wulandari, F., Khoirunisa, N. and Soeharta (2020) 'Mitigation of The Impact of Abration', Sumatera Journal of Disaster, Geography and Geography Education, 4(1), pp. 59–62.
Y. M. Cheng and C. K. Lau (2014) Slope Stability Analysis and Stabilization: New Methods and Insight. 2nd edn. New York: CRC Press.
Z. Berisavljević, D. Berisavljević, V. Čebašek, D. R. (2016) 'Slope Stability Analyses Using Limit Equilibrium and Strength Reduction Methods', GRADEVINAR, 67, pp. 975–985.