Civil and Environmental Science Journal
Vol. 05, No. 02, pp. 194-201, 2022

Landslide threat analysis and slope reinforcement method with sheet pile on Singaraja City Boundary Road – Mengwitani Km 37+900 right

I Made Adi Wirasana [1], I Nengah Sinarta [2], Ni Komang Armaeni [3]

[1] Student of Civil Engineering, Faculty of Engineering and Building Planning, Warmadewa University, Denpasar, Bali, Indonesia.
[2] Lecturer of Civil Engineering, Faculty of Engineering and Building Planning, Warmadewa University, Denpasar, Bali, Indonesia

Email: inengahsinartaftpsipil@gmail.com

Received: 28-07-2022; accepted 15-08-2022

Abstracts. Factors triggering landslides due to high rainfall intensity and long duration cause the soil to become saturated. Every rainy season, the Singaraja-Mengwitani City road section always landslides due to the geometry of the road adjacent to the slope because it is in a hilly area. The study was carried out through field investigations with two drill points 30m deep, and slope stability analysis with Geoslope software obtained the value of the existing slope safety factor of 0.939, while at the time of moderate rain for 6 hours at 0.236 based on saturated soil parameters, so it is necessary to strengthen. Strengthening is carried out with an embedded long steel sheet pile 7.15m deep, with the total length of the sheet pile used being 9.15m, based on the results of the analysis after strengthening the steel sheet pile in the safety factor value of 1.674, while at the time of moderate rain for 6 hours at 1.131 then the slope is declared stable due to SF>1.0.

Keywords: slope stability, safety factor, geostudio, steel sheet pile.

1. Introduction

The intensity of rain is high with a long rain duration so that water infiltration is increasingly entering the slopes to increase the saturation rate and pore water pressure, the pore water pressure, which is initially negative value will increase to zero value and then rise so that the positive value of this change occurs quickly, especially in loamy silt soils [1]. The ancient mountains around the walls of the southern Batur caldera, with constituent rocks sourced from the buyan – Bratan and Batur volcanic rocks, are composed of rock sand to loose and porous silt sand. These conditions tend to be easily released, so moderate rain intensity with a long frequency will cause soil movement in the form of flash floods [2]. Rainfall that falls on a slope will partially infiltrate and then saturate the soil. The condition of the physical properties of the earth, marbles, and soil layers that vary between water escape and impermeability and the amount of water that inflates will affect the occurrence of landslides [3].

The mountainous area of Bali-Tengah, especially the ancient mountains of Buyan- Beratan, is an area that is prone to landslides, especially during the rainy season because the area is a rain catchment area, the threat of landslides that often occur is landslides with mud and sandy rocks when the rain intensity reaches 87,32-92,27 mm / day [4]. The Singaraja – Mengwitani City Limits road section is a Region III National Road of Bali Province which has a length of 60,430 kilometers, the Singaraja – Mengwitani City Boundary road section starts from Simpang 4 Mengwitani at Km 13 + 950 to the Singaraja City Limit at Km 74 + 380. On the Singaraja City Limits - Starting road section precisely at Km 37 + 900 Right, there is a high and steep slope on which one day there can be a landslide. Before a landslide occurs due to high rainfall intensity, it is necessary to study or analyze the safe numbers of existing conditions and conditions after strengthening. Several studies have been conducted, particularly in analyzing slope stability on slopes that fail due to high rain intensity. Slope stability analysis requires an understanding of rain intensity and soil behavior in Partially saturated conditions [5]. The result of the infiltration of saturated soils Partly causes a change in the degree of soil saturation; an increase in the degree of saturation in a certain period will lead to landslides. This condition requires an understanding of the technical properties of partially saturated soils through an empirical approach based on rain characteristics so that it is known that changes in the degree of soil saturation to the parameters of soil shear strength (φo) and pore water stress (u). [6]

In this study, a study and analysis of slope stability due to changes in soil saturation due to rainwater infiltration was carried out with the help of Geoslope software. Geostudio is a geotechnical software developed from Canada. In this study, this program was used to analyze slope stability. Analyzing the slope stability in this program we use Slope / W, while the method used in this program is the Plastic Equilibrium Limit Method. In Slope /W there are several boundary balance methods, including those used in this study are the Bishop, Ordinary, Janbu and Morgenstern-Price Methods [7] [8]. The stability of the slopes can be improved in various ways. One of them is to increase the retaining force through the existence of an earthen retaining structure by using walls or poles. In Indonesia, several soil retaining constructions can be used as a countermeasure against cladding, one of which is to use a pile or sheet pile [9]. [10] The study began with hydrological analysis and the safe numbers of the existing slopes and then the analysis of the safe numbers after being given sheet pile reinforcement, this type of strengthening was carried out because the land on the existing slopes was limited.

2. Materials and Methods

In this study, the interpretation of rock outcrops and analysis of geomorphological conditions is an explanation of the appearance of the situation and actual morphological needs in the research area, which refers to the result of the process. - geological processes that have occurred in the past and present. Slope stability analysis using the Limit Equilibrium Method with the help of the Slope/W and Seep/W programs in Geostudio 2012, based on field data and compared with conditions in the field where a slope collapses, namely the safety factor value is less than 1. value of safety factor, as a result of rainwater infiltration.

2.1. Research sites

Locations with the potential for landslides are on the Singaraja - Mengwitani City Boundary road, precisely at Km 37+900 to the right of Figure 1a. The research location based on google earth and topography is shown in Figures 1b&1c. The figure shows that the existing land area is relatively steep with variations in land elevation of more than 10.0 m and is located in a complex of roads.

(a) (b) (c)

Figure 1. Research Location (a) Top view (b) Side view from the road (c) Side view from the bottom of the slope

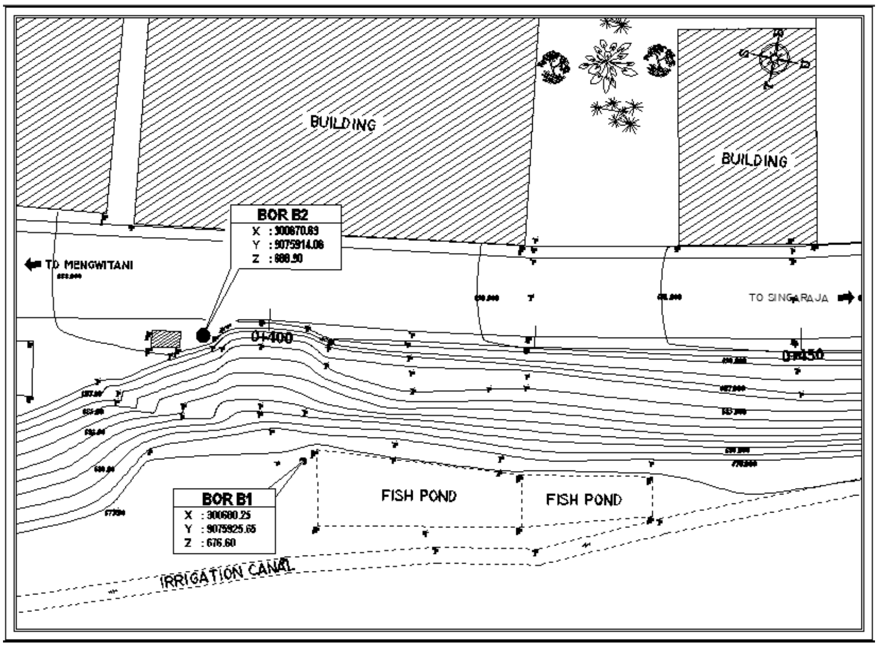

Figure 2. Existing topography

2.2. Analysis Method

Rainfall data based on high rainfall analysis is based on design rainfall data in the Pancasari village area, Gitgit sub-district. Furthermore, infiltration analysis can model seepage into the soil due to the influence of rain using a numerical method, the SEEP/W program from Geostudio. The data analysis is shown in the table below. The results of collecting journal documents obtained are as follows:

In Table 1. The number representing heavy rainfall with a 2-year return period in Sukasada (Gitgit) District is 87.33 mm/day, respectively

Table 1. Hyetograph of rain depth 87,325 mm/day

Td		It	ItTd	Δp	pt	Hytograph	
(Hours)	(Hours)	(Hours)	(Hours)	(Hours)	(%)	(%)	(mm)
1	0-1	30.27	30.27	30.27	55.03	6.75	5.89
2	1-2	19.07	38.14	7.87	14.30	10.03	8.76
3	2-3	14.55	43.66	5.52	10.03	55.03	48.06
4	3-4	12.01	48.06	4.39	7.99	14.30	12.49
5	4-5	10.35	51.77	3.71	6.75	7.99	6.98
6	5-6	9.17	55.01	3.24	5.90	5.90	5.15
Amount				55.01	100	100	87.33

Table 2. Changes in the value of the soil shear strength parameter based on the suction value

Research sites	Sr	Suction	Pers. Ho and Freudlund	
	(%)	(kPa)	c(kPa)	φ^b(°)
Pancasari Village district. Gitgit	70	100	48,120	23,668
	80	80	45,909	27,485
	90	50	34,354	31,303
	93	40	23,354	32.448
	96	30	10,932	33,593
	98	5	7,707	34,357

In Table 2. Changes in pore water pressure result in changes to the parameters of the shear strength of the soil, namely the cohesion value and the angle of internal friction of the soil. Ho and Fredlund equations are used to predict the soil shear strength parameter value based on the suction value.

The data was obtained from the Standard Penetration Test (SPT) from the Bali Province P2JN Core team. The topography of the existing land area was relatively precipitous, with variations in soil elevation of more than 10.0 m, and located in a complex road segment. Nevertheless, the results of soil investigations carried out from 2 drill points as deep as 30 meters show a fairly similar soil stratification; the topsoil layer is dominated by clay soil, followed by a silty-sand layer, and then overwhelmed by silt-clay soil. Overall, the soil stratification at the project site can be simplified.

The results of field and laboratory soil tests are shown in the table, which shows soil parameters such as cohesion (C), soil volume weight (γ), saturated or dry, and soil shear angle (φ). Soil parameter data by correlating the value of N-SPT [8] with the correlation table JE Bowles, 1984 using Linear Interpolation.

Table 3. Correlation Results of N-SPT Value Against the value of soil volume weight (γ)

Depth	Soil Classification	N-SPT Average	Y1	Y2	X1	X2	U.Weight Kn/m3	U.Weight Kn/cm3
0 m - 1 m	Blackish silty sand mixed with gravel	2.00	0	4	14	18	16.00	0.00001600
1 m - 8 m	Yellowish brown loamy silt mixed with loose sand and gravel	2.00	0	4	14	18	16.00	0.00001600
8 m - 10 m	Dark brown silty sand	21.00	11	30	14	18	16.11	0.00001611
10 m - 24 m	Brownish silty sand	21.00	11	30	14	18	16.11	0.00001611
24m -30m	Fine to medium brown sandy loam	31.00	31	50	16	20	16.00	0.00001600

Table 4. Correlation Results of N-SPT Value Against Cohesion Value (C)

Depth	Soil Classification	N-SPT Average	Y1	Y2	X1	X2	Cu Tons/m2	C' Tons/m2	C' Kn/cm2
0 m - 1 m	Blackish silty sand mixed with gravel	2.00	0	2.5	0	1.25	1.00	0.67	0.000654
1 m - 8 m	Yellowish brown loamy silt mixed with loose sand and gravel	2.00	0	2.5	0	1.25	1.00	0.67	0.000654
8 m - 10 m	Dark brown silty sand	21.00	20	40	10	20	10.50	7.00	0.006865
10 m - 24 m	Brownish silty sand	21.00	20	40	10	20	10.50	7.00	0.006865
24m -30m	Fine to medium brown sandy loam	31.00	20	40	10	20	15.50	10.33	0.010134

Slope stability analysis in this study used the Slope/W program with the Limit Plastic Equilibrium Method. In the Slope/W program there are several boundary balancing methods, one of which is used in this study is the Bishop, Ordinary, Janbu and Morgenstern-Price methods. [5] .

Table 5. Correlation Results of N-SPT Value Against Soil Shear Angle Value (φ)

Depth	Soil Classification	C' Kn/m2	Y1	Y2	X1	X2	Sliding Angle Ø
0 m - 1 m	Blackish silty sand mixed with gravel	6.54	5	10	10	20	13.08
1 m - 8 m	Yellowish brown loamy silt mixed with loose sand and gravel	6.54	5	10	10	20	13.08
8 m - 10 m	Dark brown silty sand	68.65	50	100	25	30	26.86
10 m - 24 m	Brownish silty sand	68.65	50	100	25	30	26.86
24m -30m	Fine to medium brown sandy loam	101.34	50	100	25	30	30.13

The equations for in-ground water flow used in the SEEP/W software for the complete analysis of two-dimensional transients and seepage are:

$$m_w{}^2 \gamma_w \frac{\partial h_w}{\partial t} = \frac{\partial}{\partial_x}\left(-k_{wx}\frac{\partial h_w}{\partial x}\right) + \frac{\partial}{\partial_y}\left(-k_{wy}\frac{\partial h_w}{\partial y}\right) + q \quad (1)$$

where mw2 = slope soil-water relationship characteristic curves; w = unit weight of water; hw = total head; kwx = soil permeability coefficient of water in the x-direction; kwy = soil permeability coefficient of water in the y-direction; q = flux boundary; t = time.

The SEEP/W analysis uses two important soil parameters: the soil permeability coefficient function and the Soil Water Characteristic Curve (SWCC). The shear strength equation for unsaturated soils required for slope stability analysis, SLOPE/W, can be designated as equation 2. This equation is a composite of the shear strength of the soil as a result of negative pore water pressure and unsaturated soil suction. The Morgenstern-Price method was used to obtain the factor of safety (SF) in the SLOPE/W analysis.

$$\tau = c' + (\sigma_n - u_w)\tan\phi' + (u_a - u_w)\tan\phi^b \quad (2)$$

where = unsaturated soil shear strength; c' = cohesion; n = total normal stress; ua = pore air pressure; = internal friction angle; uw = pore-water pressure; (ua – uw) = matrix suction.

Soil physical parameters were adjusted to the data from geometric measurements in the Terunyan Village area using numerical analysis.

Rock lithology analysis was carried out based on interpreting the slope outcrops around the study area. Slope stability analysis using Morgenstern-Price with pore-water pressure conditions obtained from SEEP/W analysis. Furthermore, the safety factor analysis uses SLOPE/W to get the value of the safety factor. Three execution programs SLOPE/W, namely: Define to define the slope model, Solve to analyze the calculation, and Contour to display the results. This result is expected to solve the problem - geotechnical problems related to soil or slope stability

3. Results and Discussion

A slope is said to be stable if the slope does not experience movement and does not have the potential to experience movement, that is, if the magnitude of the component of the resisting force on the slope is greater than the component of the driving force of the slope with the condition that SF> 1.0 then the slope is said to be stable.

3.1. Existing Slope Stability Analysis

The analysis of the existing slope stability, in this case, was carried out under two different conditions when the slope conditions were normal and when the conditions were moderate rain in the area, the analysis in this case was carried out using the slope/w and seep/w program with the bishop method, the load on the slope It is assumed that with a pavement load of 22 kN/m2, the design rainfall data in the Pancasari village area, Gitgit Hyetograph sub-district, *rain* depth is 87,325 mm/day.

In Figure 3. After analyzing the existing slope with the *slope/w* and *seep/w program* with the *Bishop method,* when normal conditions are obtained, *the safety factor* is 0,939 with a landslide volume of 27.962 m3, while in Figure 4. Shows the analysis results on the existing slope when the rainy conditions are getting a *safety factor* of 0,236 with a landslide volume of 30.928 m3.

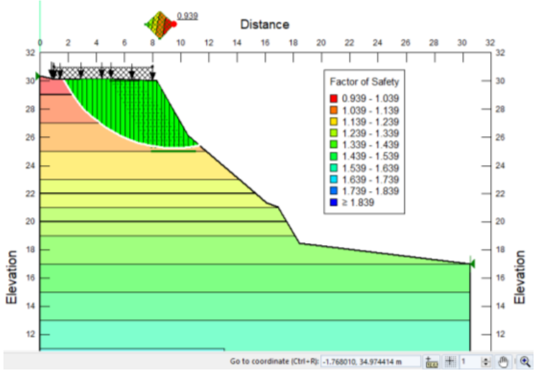

Figure 3. Results of Existing Slope Analysis in Normal Conditions

3.2. Slope Stability Analysis After Steel Pile Sheet Reinforcement

Slope stability analysis after reinforcement of steel *sheet piles* in this case was carried out under two different conditions when the slope conditions were normal and during conditions of moderate rain in the area, the analysis, in this case, was carried out using the *slope/w* and *seep/w program* with the *Bishop method.* It is because the load on the slopes is assumed to be a pavement load of 22 kN/m2. Design rainfall data in the Pancasari village area, Sukasada Hyetograph sub-district*,* rain depth is 87,325 mm/day. With planned slope reinforcement using sheet pile type PU 6 size 600 x 226 x 7.5 mm with BJ.33 quality, the shear bearing capacity of steel sheet pile material is obtained from Vn = 11,64 kN, with a sheet pile shear reduction factor of 1,5 obtained from SNI 8460:2017 Geotechnical Planning Requirements, page 179 of 303.

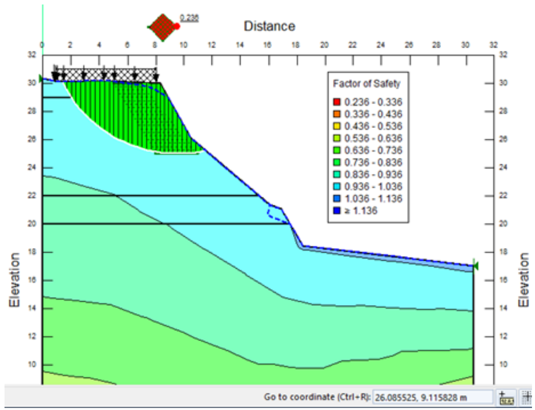

Figure 4. Results of Existing Slope Analysis in Moderate Rain Conditions

Figure 5 shows after analyzing the existing slope with steel *sheet pile reinforcement using the slope/w* and *seep/w program* with the *bishop method,* when normal conditions are obtained, the *safety factor* is 1,674 with a landslide volume of 10.874 m3, while in Figure 6. Shows the results analysis on existing slopes with steel *sheet pile reinforcement* during moderate rain conditions obtained a *safety factor* of 1,131 with avalanche volume of 10,874 m3.

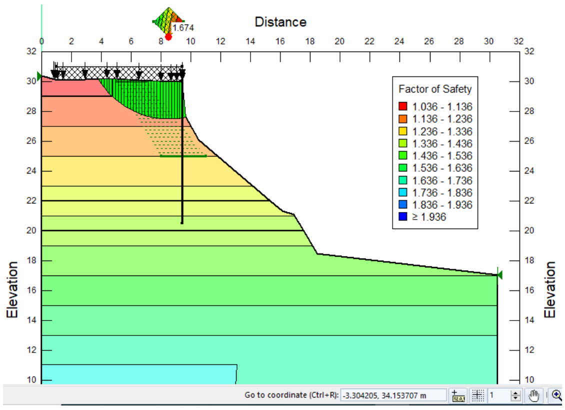

Figure 5. Results of Existing Slope Analysis Under Normal Conditions With Steel *Pile Sheet Reinforcement*

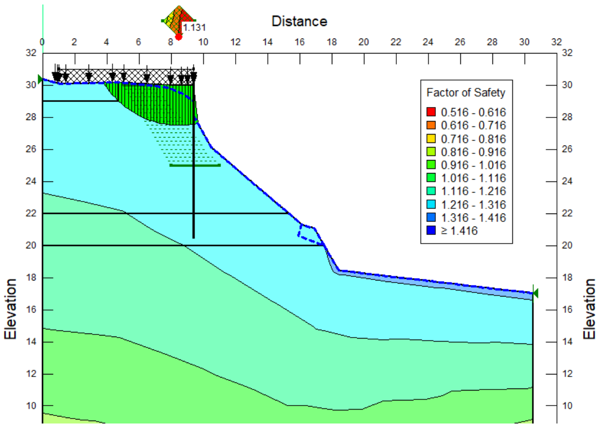

Figure 6. Existing Slope Analysis Results In Moderate Rain Conditions With Steel *Pile Sheet Reinforcement*

4. Conclusion

Based on the planning of retaining walls on slopes that have the potential for landslides on the Singaraja City Boundary, Mengwitani Km 37+900 Right, as described above, it can be concluded as follows: The results of the analysis of the stability of the existing slope using the Geostudio program with the Slope/W and Seep/W analysis system using the Bishop method , the value of the safety factor of the existing slope when there is no rain is 0,939, while the value of the safety factor of the existing slope at the time of moderate rain is for 6 hours that is equal to 0,236. Existing slopes that have a safety factor value of less than 1 are declared unsafe/unstable, so it is necessary to repair or strengthen the slopes. The value of the safety factor after strengthening the steel *sheet pile* under normal conditions is 1,674, while the value of the safety factor after strengthening the steel *sheet pile* during 6 hours of moderate rain is 1,131. So it can be concluded that steel *sheet pile reinforcement* is effective for slope reinforcement at the research site because *the safety factor* increases and is greater than 1, the slope is categorized as safe/stable.

References

[1] I. N. Sinarta and I. W. Ariyana Basoka, "Safety factor analysis of landslides hazard as a result of rain condition infiltration on Buyan-Beratan Ancient Mountain Safety factor analysis of landslides hazard as a result of rain condition infiltration on Buyan-Beratan Ancient Mountain," *J. Phys. Conf. Ser.*, vol. 1402, no. 2, 2019, doi: 10.1088/1742-6596/1402/2/022002.

[2] I. N. Sinarta, "The Threat Level of Soil Movement in Volcanic Rocks in Bali Based on a Comprehensive Geotechnical Approach," Gadjah Mada University Yogyakarta, 2018.

[3] I. G. Tejakusuma, P. Teknologi, S. Lahan, W. Dan, and M. Bencana, "Soil Water Content As Landslide Trigger At Girimekar Village Bandung West Java Province Landwater Content Triggers Landslide Girimekar Village Bandung Regency, West Java Province," *J. Science and Technology. Indones.*, vol. 15, no. 1, pp. 34–41, 2013.

[4] I. N. Sinarta, A. Rifa'i, T. F. Fathani, and W. Wilopo, "Spatial analysis of safety factors due to rain infiltration in the buyan-beratan ancient mountains," *Int. Rev. Civ. Eng.*, vol. 11, no. 2, pp. 90–97, Mar. 2020, doi: 10.15866/IRECE. V11I2.17668.

[5] I. N. Sinarta, "Negative Pore Stress as a Parameter of Soil Mechanics on Unsaturated Soil Slope stability," *Paduraksa*, vol. 5, pp. 31–42, 2016.

[6] D. Safrina, M. Sungkar, and R. P. Munirwan, "Slope Stability Analysis With Bishop Method and Sheet Pile Reinforcement," *J. Civ. Eng. Student*, vol. 2, no. 3, pp. 309–315, 2020.

[7] GEO-SLOPE International, "Seepage Modeling with SEEP/W 2007," *Geostudio Help.*, no. February, p. 307, 2010.

[8] K. P. Acharya, N. P. Bhandary, R. K. Dahal, and R. Yatabe, "Seepage and slope stability modelling of rainfall-induced slope failures in topographic hollows," *Geomatics, Nat. Hazards Risk*, vol. 7, no. 2, pp. 721–746, 2016, doi: 10.1080/19475705.2014.954150.

[9] H. Darjanto, H. Farichah, and R. Lumintang, "Slope Stability Analysis and Alternatives to Handling Cladding Case Study of Ir. H. Nursyirwan Ismail Road Section, Samarinda City," *J. Apl. Tech. Civil*, vol. 19, no. 3, p. 215, 2021, doi: 10.12962/j2579-891x.v19i3.8495.

[10] E. B. P. Hendra Sugih Arjaya and M. I. Ir Siti Hardiyati SP1.MT, Ir Indrastono DA, "Strengthening The Slopes At The Sutt Sta 19 +255 Toll Road Semarang – Solo Section Tinalun – Lemah Ireng," pp. 1–13.

[11] J. Bowles, *Physical and Geotechnical Properties Of Soil*, 2nd ed. Chicago: McGraw-Hill Company, 1984.