Geotechnical analysis of potential landslides on slopes in the Rimbo Panjang area of Padang City and mitigation

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Abstract. The Lambung Bukik area of Padang City is a relocation area for the flash flood disaster in Batu Busuk Padang on 24 July 2012. This research analyzes the potential for slope failure in the Rimbo Panjang area, where many residents' houses are built on steep slopes. Geotechnical analysis was carried out to determine the soil characteristics in the Rimbo Panjang area, which was taken at four locations. The results of the classification show that the soil in the Rimbo Panjang area is inorganic silt - high plasticity (MH). The plasticity index value is 2.5 – 10.4%, indicating that the soil has low swelling potential. The activity value in inorganic silt soil is meager, namely in the range of 0.1 – 0.99, which is the mineral kaolinite and illite activity value. The activity values agree with the XRD test results, where the soil contains kaolinite and illite minerals with low swelling properties. The low swelling characteristic causes the slopes to have a low landslide potential. The safety factor value of the slopes is in the range of 1.79 – 2.71 > 1.5, so the slope can be said to be stable.

1 Introduction

Landslides are geological hazards usually associated with extreme events such as heavy rain [1]. Landslides are also influenced by the angle of the slope, where the steeper the slope, the greater the possibility of a landslide occurring [2]. Landslides can potentially damage the environment around the slopes [3-5]. Factors that cause natural slope instability include (1) changes in the slope profile due to additional loads or reduced strength; (2) an increase in pore water pressure, which causes swelling in cohesive soil; (3) a decrease in soil shear strength due to weathering, leaching, mineralogy changes, and cracks; vibrations caused by earthquakes, blasting or pile driving [6].

The Fukuoka-ken Seiho-oki earthquake that occurred in 2005 caused severe damage to residential areas on Genkai-jima Island. Most residential houses were built on excavation and embankment slopes that experienced landslide due to the earthquakes [7]. Apart from earthquakes, landslides caused by rainfall have caused deaths, destroyed infrastructure, and hampered economic development in many countries worldwide. Shallow landslides caused by rainfall are characterized by the movement of shallow soil layer materials along the slope. This movement can have a significant impact (depending on the potential energy), which can cause severe damage to both the built and natural environments [8-10].

High and prolonged rainfall around March 2021 caused landslides in front of the Science Techno Park building (SPT) Universitas Andalas. Landslides failed in the soil retaining wall structure, which was close to the slope where the landslide occurred. Figure 1 shows that the failure of the existing retaining wall is not caused by the dimensions of the retaining wall being unsafe against overturning, shearing, and bearing capacity but rather due to the occurrence of landslides on steep slopes that have not been provided with a retaining wall and are close to the existing retaining wall [11].

Fig. 1. Damage to gravity walls

Figure 2 shows the failure of gravity walls in student dormitories due to high rainfall.

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Fig. 2. Damage to gravity walls in student dormitories

The flash flood on 24 July 2012 resulted in several houses on the banks of the Batu Busuk River being damaged and uninhabitable. Due to the high risk of a flood disaster that might happen again, the Padang City government relocated the affected residents to the Rimbo Panjang area, which is close to the location of the flash flood disaster. The Rimbo Panjang area is in a location that is safe from flooding. Until 2023, the quality of infrastructure in the Rimbo Panjang relocation area has yet to improve significantly [12]. Based on this, it is necessary to conduct a geotechnical analysis to determine the potential for landslides on slopes in the Rimbo Panjang area as a relocation area.

From the results of field visits to the Rimbo Panjang relocation area, it was found that many residents' houses were located on steep natural slopes with slopes greater than 45°, as shown in Fig. 3. These natural slopes are not equipped with soil-retaining structures, which is dangerous for houses built on these slopes. Steep slopes and high and prolonged rainfall are factors that cause landslides. Based on this, a problem-solving approach needs to be carried out using geotechnical analysis of potential slope failures in the Rimbo Panjang area and handling landslides.

Fig. 3. Residential conditions in Rimbo Panjang

2 Research methods

2.1 Study area

The Rimbo Panjang area is located in Lambung Bukit, Padang City, directly bordering Solok Regency. This area is dominated by protected forest areas and community forests, covering almost 82% of the total area, the rest of which are rice fields, gardens, and fields. In general, Rimbo Panjang has a wet tropical climate, is strongly influenced by the west wind, and has a very short dry month with an average rainfall of 347.5 mm/month. Rimbo Panjang is located in Pauh District at 10 m - 1600m above sea level. Most of the topography of this area has an average land slope of 40% (steep to very steep) [13].

2.2 Data sources

This research uses data field investigations and data from previous service reports.

2.3 Soil sampling

In this research, a location survey was carried out to describe the sampling area. Soil sampling was carried out at four locations in the Rimbo Panjang area (Figure 4) using a hoe for disturbed soil and a sampling tube for undisturbed soil. Soil sampling was carried out for four days. The coordinates of points 1, 2, 3, and 4 on the map, respectively, are -0.910068, 100.450842; -0.910476, 100.450720; -0.910379, 100.448805; and -0.910038, 100.450124 as shown in Fig. 4.

Fig. 4. Soil sampling area in Rimbo Panjang

2.4 Laboratory testing

Laboratory tests were carried out to describe the soil material at the research location. The following tests are carried out: (1) test the soil index properties or soil classification; (2) test mechanical properties; (3) SEM and XRD.

2.5 Slope stability analysis

In this research, stability analysis was carried out on natural slopes in the Rimbo Panjang area. Natural slopes are formed due to natural activities such as erosion, tectonic movements, and so on. The material that forms the slope tends to slip due to its own weight and external forces resisted by the shear strength of the soil of the material. Disturbances to stability occur when the shear resistance of the soil cannot compensate for the forces that cause sliding on the landslide surface. Natural slopes that have been stable for years can experience landslides. For slope stability analysis, the safety factors required by SNI 8460:2017 consider the costs and consequences of slope failure and the level of uncertainty in the analysis conditions.

3 Results and discussion

3.1 Geotechnical analysis

Figure 5 shows the particle size distribution curve of soil samples taken at Rimbo Panjang research areas. The sieve analysis results show that the slope material in the Rimbo Panjang area consists of 60% - 67% silt, 22% - 24% clay, 9% - 15% sand, and 0 - 2% gravel. This value shows that the silt soil type dominates the slope material.

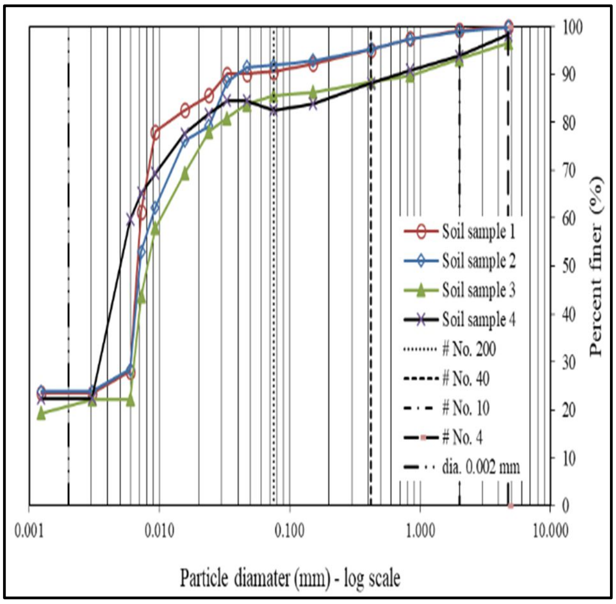

Fig. 5. Particle-size distribution for soil samples

The results of tests on soil index properties and soil classification at four locations in the Rimbo Panjang area can be seen in Table 1. From Table 1, it can be seen that the water content value of the original soil is in the range of 35.6% - 58.5%, the volume weight is in the range of 1.4 - 1.6 gr/cm3, and the average specific gravity is 2.6. The plasticity index (PI) value of the soil in the research area is meager, namely in the range of 2.5 – 10.4%, where, according to Chen (1988), soil with a PI < 12% has a low degree of swelling and according to Snethen et al. (1977) if PI < 25% has a low swelling potential classification as well. Based on the USCS, the soil in the Rimbo Panjang area can be classified as high plasticity inorganic silt soil with the group symbol MH. The activity value in inorganic silt soil is meager, namely in the range of 0.1 – 0.5, where, according to Skempton (1953), soil that has an activity value between 0.33 – 0.46 usually contains the mineral kaolinite and soil that has an activity value of 0.99 contains the mineral illite. From the XRD test results, the soil in the Rimbo Panjang area also contains the minerals kaolinite and illite.

Table 1. Index properties and classification of soils

Description	Soil Sample			
	1	2	3	4
Moisture content, w (%)	58.5	53.2	56.4	35.6
Unit weight, g (gr/cm^3)	1.6	1.5	1.5	1.4
Specific gravity	2.6	2.6	2.6	2.6
Mechanical analysis of soil:				
% passing sieve No. 200	90.6	91.9	85.6	82.5
Gravel (%)	0.0	0.1	3,37	1.8
Sand (%)	9.4	8.0	11.0	15.7
Silt (%)	67.1	68.0	63.4	60.0
Clay (%)	23.4	23.8	22.2	22.4
Atterberg Limits:				
Liquid Limit, LL (%)	55.6	54.0	51.7	55.7
Plastic Limit, PL (%)	45.5	44.2	49.2	45.4
Plasticity Index, PI (%)	10.1	9.8	2.5	10.4
Classification of soil (USCS)	Inorganic silt high plasticity (MH)			
Activity (A)	0.43	0.41	0.11	0.46

Figure 6 shows the relationship between normal and shear stress from soil samples taken at four locations in the research area.

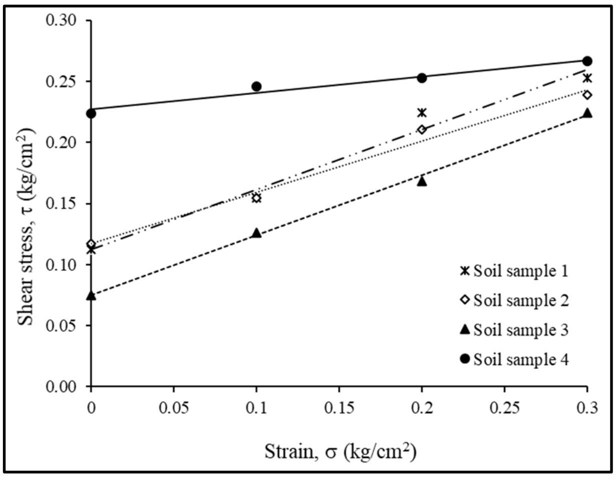

Fig. 6. Direct shear plot of soil samples

The results of shear strength tests at four locations showed internal friction angle values in the range of 6.01°-26.16° and cohesion values in the range of 0.08-0.23 kg/cm^2 (Table 2). The shear strength of soils is the most critical aspect of geotechnical engineering.

Table 2. Shear strength parameters

Parameters	Soil sample			
	1	2	3	4
Cohesion, c (kg/cm^2)	0.11	0.12	0.08	0.23
Angle of friction, ϕ (°)	26.11	22.84	26.16	6.01

Figure 7 shows the results of the Scanning Electron Microscope (SEM) test, where you can see the arrangement of groups of colloid-sized particles with variations in grain size with grain diameters smaller than 0.002 mm (2 μm) and grain variations greater than 0.002 mm.

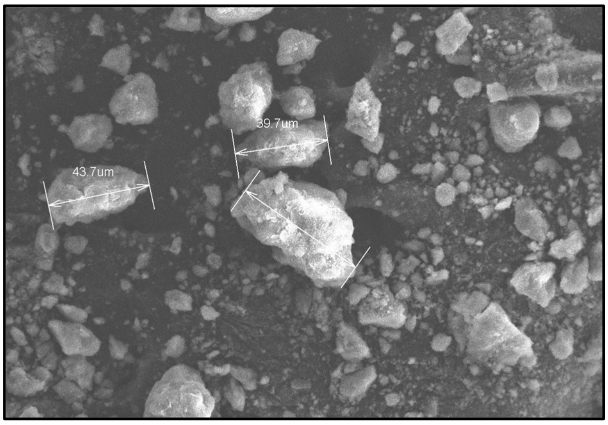

Fig. 7. Scanning electron micrograph of a specimen

Figure 8 shows the results of the XRD test on soil in the Rimbo Panjang area of Padang city. The graph shows that the soil in the Rimbo Panjang area quantitatively contains the minerals gibbsite, kaolinite, illite, cristobalite, and quartz.

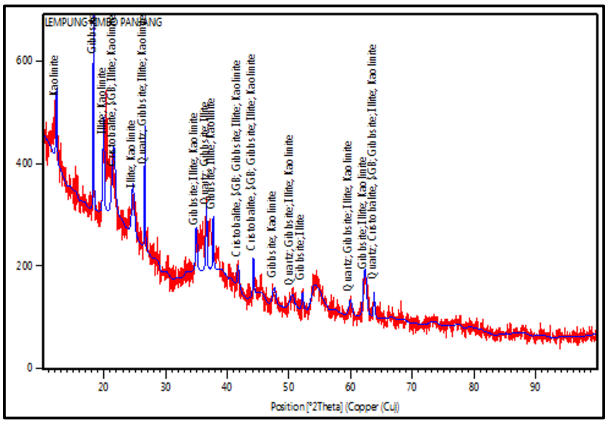

Fig. 8. X-ray diffraction of a specimen

Table 3 shows the minerals that dominate quantitatively in the soil in the Rimbo Panjang area.

Table 3. Rimbo Panjang x-ray diffraction (XRD) test results

Mineral name	Compound name	Chemical formula
Gibbsite	Aluminum Hydroxide	$Al(OH)_3$
Kaolinite	Aluminum Silicate Hydroxide	$Al_2(Si_2O_5)\ (OH)_4$
Illite	Potassium Aluminum Silicate Hydroxide	$K(Al_4Si_2O_9\ (OH)_3)$
Cristobalite	Silicon Oxide	SiO_2
Quartz	Silicon Oxide	SiO_2

The XRD test results show that the minerals found in the soil in the Rimbo Panjang area, such as illite and kaolinite, are minerals whose ability to absorb water is small, so their swelling properties are also small. When these minerals absorb water, the soil volume will increase by less. Because little water is absorbed, changes in soil volume are also small. Small volume changes do not affect the stability of the slope and do not damage the strength of the building structure that occupies the soil.

3.2 Slope stability analysis

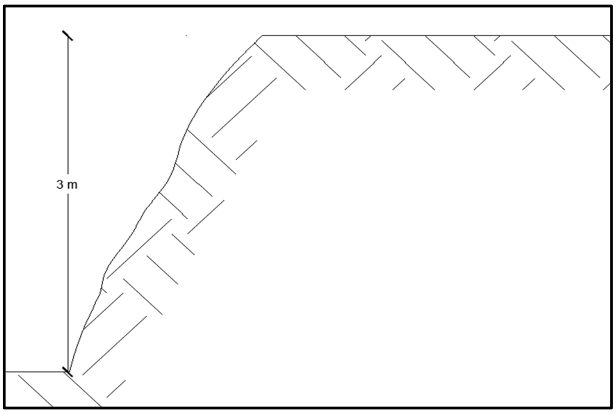

Fig. 9. Existing slope conditions

Soil slope stability analysis is generally based on the limit equilibrium approach, plastic limit theory, and numerical methods such as the finite element method. This research uses a limit-balance approach. Figure 9 shows the condition of the existing slope.

Figure 10 shows a circular landslide surface with the soil mass above divided into several vertical slices. By using the bishop method, slope stability analysis can be calculated.

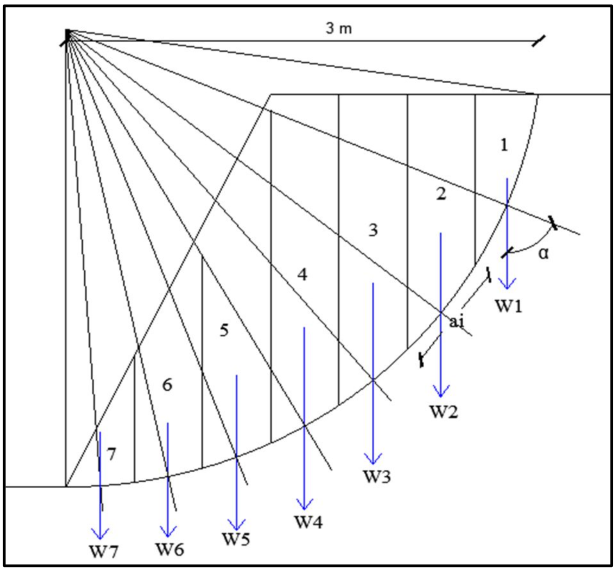

Fig. 10. Circular slip surface with vertical slices.

Based on the calculation results for the three failure areas that were tried, the minimum safety factor values were obtained as in Table 4. From Table 4, it can be seen that the minimum safety factor values at the 4 locations are in the range of 1.59 – 2.71; this shows that the slope is stable where FS > 1.5

Table 4. Safety factors of the slopes in the Rimbo Panjang area.

Location	Factors of Safety
1	2.56
2	2.32
3	1.59
4	2.71

3.3 Landslide mitigation

Forms of management and control to mitigate landslide disasters include identifying the causes of landslides and determining the level of landslide vulnerability or susceptibility of an area, which are assessed based on significant factors. The causes and characteristics of slope failure must be understood first before initiating landslide mitigation measures. Many methods have been used to stabilize slopes. Factors that need to be considered in slope stabilization [13]: (1) What is the purpose of stabilizing the slope (2) How much time is available (3) How accessible is the site, and what type of construction equipment can be mobilized there? Access considerations may limit the stabilization methods that can be used; and (4) How much will the repair cost? It makes no sense to stabilize a slope when the costs exceed the benefits. Several methods commonly used for slope stabilization are (1) Drainage; (2) Excavations and buttress fill; (3) Retaining structures (prestressed anchors and anchored, gravity walls, MSE walls, and soil nailed walls, gabions); (4) Reinforcing piles and drilled shafts; (5) Injection methods; (6) Vegetation; (7) Thermal treatment; (8) Bridging; and (9) Removal and replacement of the sliding mass. For slopes in the Rimbo Panjang area, it is recommended that Gabions as landslide protection.

4 Conclusion

The results of geotechnical analysis in the Rimbo Panjang area show that the soil in the area is classified as high plasticity inorganic silt soil with the symbol MH group. Soil types are dominated by silt soil in the range of 60% – 67% and clay soil in the range of 22.2% – 23.8%. The soil has a low swelling based on the plasticity index (PI) value, which is 2.5 – 10.4%. The activity value in inorganic silt soil is meager, namely in the range 0.1 – 0.5, which is the activity value for the mineral kaolinite, and the activity value is 0.99 for soil containing the mineral illite. This activity value is in close agreement with the XRD test results, where the soil in the Rimbo Panjang area contains kaolinite and illite minerals, which have a low level of expansion. The low level of development affects the instability of natural slopes, so the slopes in the Rimbo Panjang area have a low potential for landslides. The stability analysis results show that the safety factor value is 1.59 – 2.71 > 1.5, so the slopes in the Rimbo Panjang area are stable. Landslide mitigation must be carried out considering the many factors that cause landslides, such as those caused by excessive infiltration of rainwater into the subsurface layer of the soil, thereby increasing pore water pressure and causing a reduction in the effective shear strength of the soil. Even though the slopes are stable and do not have the potential for landslides, landslide mitigation in the Panjang forest area must be carried out using retaining walls.

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