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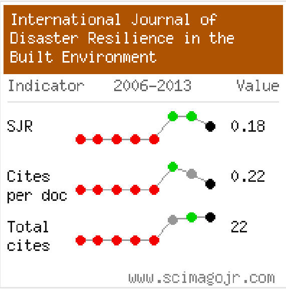

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Manuscripts with Decisions

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IJDRBE-04-2014-0027.R2	Landslide Hazard of Maninjau Area [View Submission]	12-Nov-2015	13-Jan-2016	GE: Not Assigned EIC: Haigh, Richard • Accept (13-Jan-2016) • Accepted view decision letter	Forms Completion submitted (15-Jan-2016) - view
IJDRBE-04-2014-0027.R1	Landslide Hazard of Maninjau Area [View Submission]	27-Feb-2015	03-Nov-2015	GE: Not Assigned EIC: Haigh, Richard • Minor Revision (03-Nov-2015) • a revision has been submitted view decision letter	a revision has been submitted (IJDRBE-04-2014-0027.R2)

IJDRBE-04-2014-0027	Landslide Hazard of Maninjau Area [View Submission]	09-Apr-2014	09-Feb-2015	GE: Not Assigned EIC: Haigh, Richard • Major Revision (09-Feb-2015) • a revision has been submitted view decision letter	a revision has been submitted (IJDRBE-04-2014-0027.R1)

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Landslide Hazard of Maninjau Area

Structured Abstract:

***Purpose* –** The purpose of this paper is to determine the potential landslide of Maninjau area.

***Design/methodology/approach* –** A literature review and field investigation were undertaken to determine the potential landslide of Maninjau area. The field study includes the physical and mechanical properties of the soil in Maninjau area.

***Findings* –** The Maninjau Lake area is very prone to landslides. Landslides in Maninjau may happen especially for slopes more than 40%. The action plan must be done as well as the installation of the early warning equipment in the landslide-prone areas and re-plantation on critical ground.

Originality/value– The paper is very specific as it attempts to discover how prone Maninjau area is to landslides.

Keywords: landslide, slope stability analysis, mitigation, disaster, Maninjau Lake, Indonesia

Article Classification: Research paper

1. Introduction

Maninjau Lake area in West Sumatra (Figure 1) is inhabited by 32,879 people. This area has experienced many landslides for many years, and between 2008 and 2013 there have been 12 landslides. Through these natural phenomena, named ‘galodo’ in the local language, has lead to disaster for its people. The Maninjau community has taken lessons on everything they have done in the past that may cause disaster. Then they take the responsibility against the past mistake that should not happen again in the future. However, a better understanding of potential disaster must be recognized to reduce the suffering Maninjau people.

Figure 1. Location of Maninjau lake

A geology map of Maninjau Lake is shown in Figure 2. Maninjau Lake was likely made through a series of big eruptions from an ancient Maninjau volcano in the past. The big eruptions has moved hundred cubic kilometers of andesite soil mass until a few kilometers surrounding area. This natural eruption then made Maninjau Lake with the present topography consisting of sediment material on top. The sediment soil that exists now has instability that may result in landslides from any disturbance.

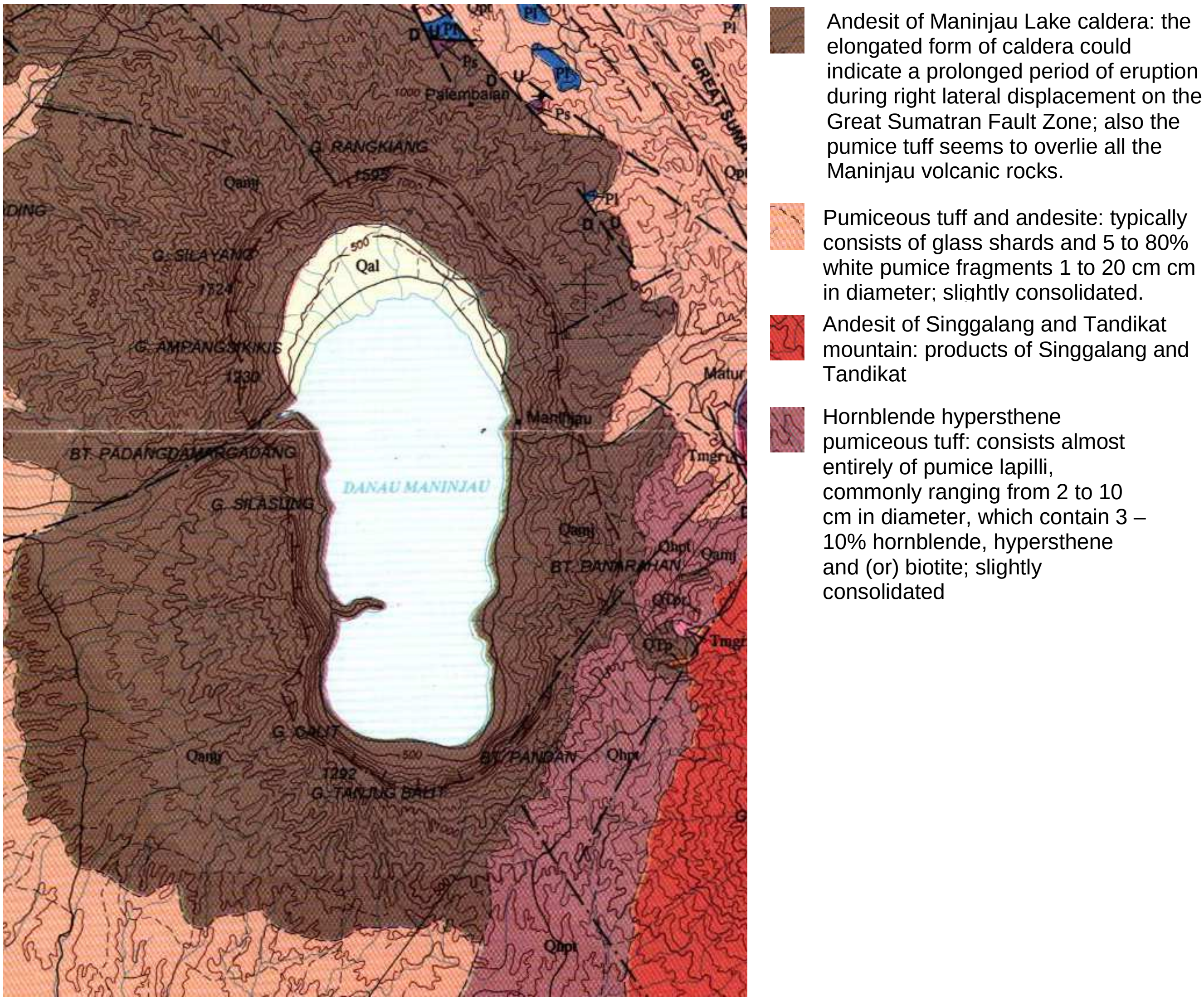

Figure 2. Maninjau Geology Map[4]

Maninjau Lake area has been recognized as a landslide-prone area. The recent landslides in Maninjau occurred in 2009 that were triggered by Padang earthquake on 30 September 2009. These landslides are located in many locations in this area in Maninjau, especially on the cliff of the hills. The most recent landslide in Maninjau took place on 26 January 2013 in a new spot that had no previous landslide activity. This disaster resulted in 22 fatalities.

This study conductes the assessment of the landslide potential in area surrounding Maninjau Lake. Landslide potential is calculated based on the soil parameters of Maninjau. The slope of the the locations are taken from the topography map. Location of potential landslides were plotted on maps with three categories: high-, medium- and low- potential. The results of this study will be very useful to use as a reference for land use in Maninjau. The results can be used for landslide mitigation in Maninjau so that the people live in safer locations in the future.

2. Field Investigation

Landslide studies have been summarized in several references, for example Huang (1983). Landslide can be categorized based on the movement of soil mass, landslides failure surface and the duration of the movement. In general, soil mass moves on failure surface from the original area to the lower depositional area (Figure 3). The soil properties and the geometry of the slope are the basic data that should be collected to investigate the behavior of landslides.

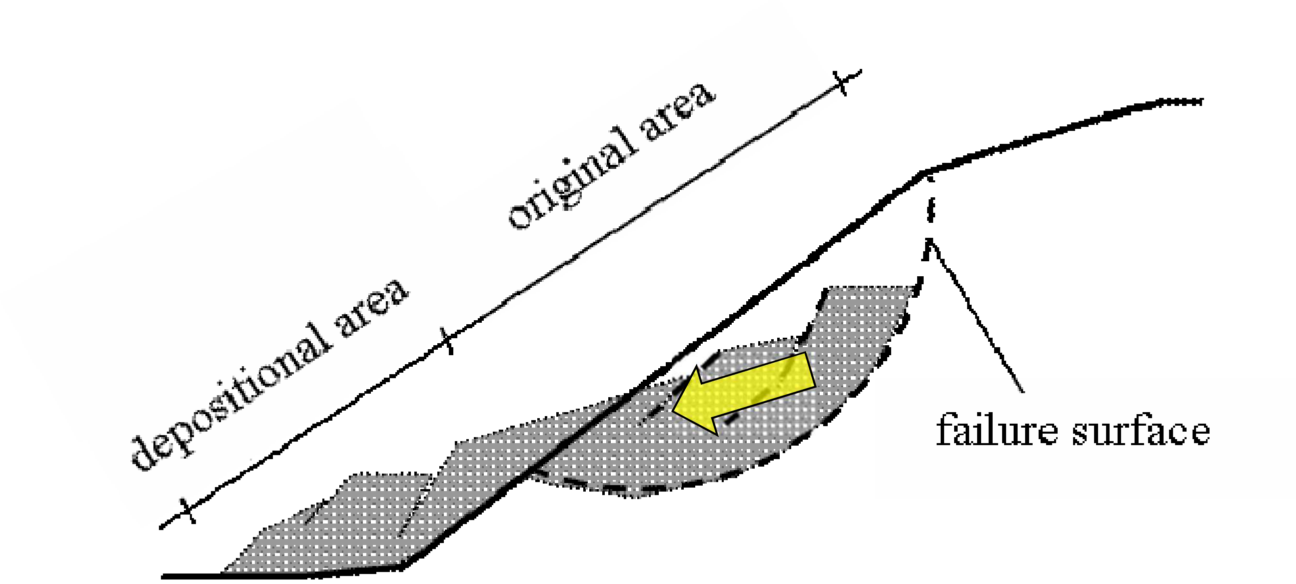

Figure 3. Typical landslide mechanism

In order to understand the behaviour of landslides in Maninjau, a field survey was conducted (Figure 4). The soil samples were also taken from the field to find out the technical properties of the soil for landslide analysis (Hakam et al., 2013). This survey aims to obtain the geometry of the landslide area. The geometry data was needed for verification data of the landslide that had happened before. Based on the field survey, it is also found that the Maninjau landslide has a linear type of failure surface. The slope stability analyses was done by assuming that the linear failure surface in the slope has the same direction with the surface slope (Figure 5).

Figure 4. Field survey on landslide location in 2013

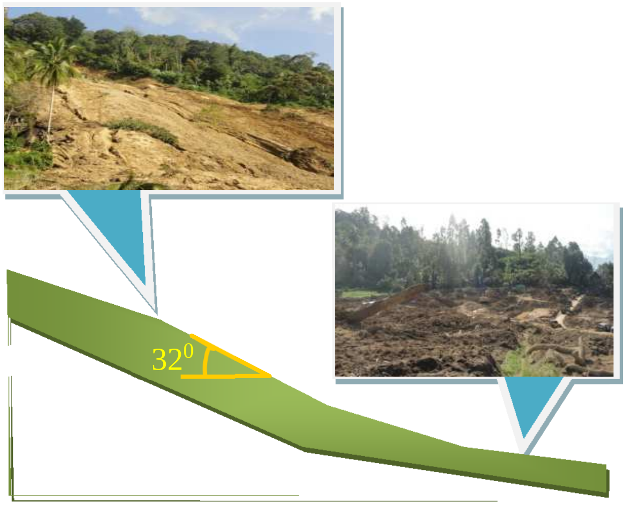

Figure 5. Soil profile at past landslide location

In many case, it is recognized that there was rain in the surrounding area of Maninjau Lake prior to the landslide. It was presumed that the landslide of slopes in Maninjau is mainly triggered by the presence of intrusive water into the soil mass. Then, the tests of the soil samples were carried out also in associated with soil behavior related to its interaction with water. The slope stability analyses then can be performed using the results of the soil parameters tests as the input data. The slope stability analyses are conducted with the variations of moisture conditions, using data from natural soil samples and soaked samples.

The Maninjau soil samples from the field were sent to the laboratory for physical and mechanical parameters tests. The testing that was conducted on soil samples were as follows:

a. Soil grain size distribution test: This test was aimed to classify the soil into main groups, either fine-grained soil or coarse-grained soil. This sieve test is also to determine the distribution of the soil grain size that dominates in the soil structure of Maninjau area. This test was performed using a series of sieves to separate the grains of the soil in certain sizes. The percentage of certain grain size of soil that passes through the sieves was plotted in a graph to determine the soil particle distribution. Based on this graph, the soil then can be classified as either fine- or coarse-grained soils.
b. The Atterberg limits tests: These tests are conducted to obtain data of the water content in the soil that can change the consistency of the soil in the terms of plastic limit and liquid limit. In fact that if a soil has a moisture content that exceeds its liquid limit, then the soil mass can easily transforms from a solid form to a liquid form. The soil mass that has excessive water content in it can flow as the behavior of liquids. In nature, this flowing soil mass usually moves together with the other objects and is known as mud flow or debris flow.
c. Shear strength testing: This test is performed in order to find out the technical values of the soil in terms of shear strength parameters. Basically the shear strength of soil is contributed by their adhesive (cohesion) and internal shear resistance (friction). The cohesion is generated by the chemical behavior of the soil minerals and the internal shear friction is influenced mainly by the shape and the size of soil particles. For the coarse-grained soils that have very little adhesion between the grains, the shear strength of these soils are determined by the inter-particle friction resistance. The measurement of soil internal shear parameter values can be done by direct shear tests in laboratory. Meanwhile for the fine-grained soils, the shear strength is contributed mainly by cohesion between soil particles. The value of the cohesion parameter of this type of soils can be easily done by an unconfined compression shear test (UCST).
d. The physical parameters tests: These tests are performed to obtain the values of the natural water content, the specific gravity and the unit weight of the soil. These parameters are required to identify soil type and also needed as the input data for the slope stability analyses.

The laboratory test of the soil samples gave the results in terms of the physical and mechanical parameters as shown in Table 1. Based on the soil sample test, it is found that the behavior of the cohesive soil dominates in Maninjau. It can be predicted that in case of landslide the soil mass will be moving together in terms of mud flow.

Table 1. Soil parameter of Maninjau (Hakam et al, 2013)

Test name	Parameter	Sample		Unit
		S1	S2	
Water content	w	28.11	36.77	%
Unit weight	γ	1.79	1.85	t/m^3
Spesific Gravity	Gs	2.65	2.65	
Sieve analysis	Gravel	4.03	3.17	%
	Sand	14.57	39.87	%
Atterberg's Limit	LL	44.90	60.24	%
	PL	34.14	31.27	%
	PI	10.76	28.97	%
Direct Shear (soaked)	c	0.94	1.50	t/m^2
	ϕ	32.28	24.85	o
Direct Shear (wet)	c	1.05	2.06	t/m^2
	ϕ	27.32	31.11	o

The soil of the hill of Maninjau is made of fine grain soil since it has approximately more than 50% of fine content. Generally soil deposit has fine soil particle content of 30% and over, the mechanical behavior will be dominated by the fine-grained soil contains. This indicates that the behavior of the slopes is dominated by the behavior of fine-grained soil.

3. Analysis and discussion

Based on the test result, in terms of the water content at plastic limit and liquid limit, the fine grain soil can be classified as inactive silt soil (Skempton (1984) in Murthy (2008)). The internal friction angle is about 30 degrees. This value indicates that if the soil loses its cohesion, the slope will remain stable if the angle of the slope is 30 degree or less. In the past landslide location, the angle of the slope is about 32 degrees (Figure 6). It confirms that the slope became unstable and moved down after it lost the cohesion due to the rain.

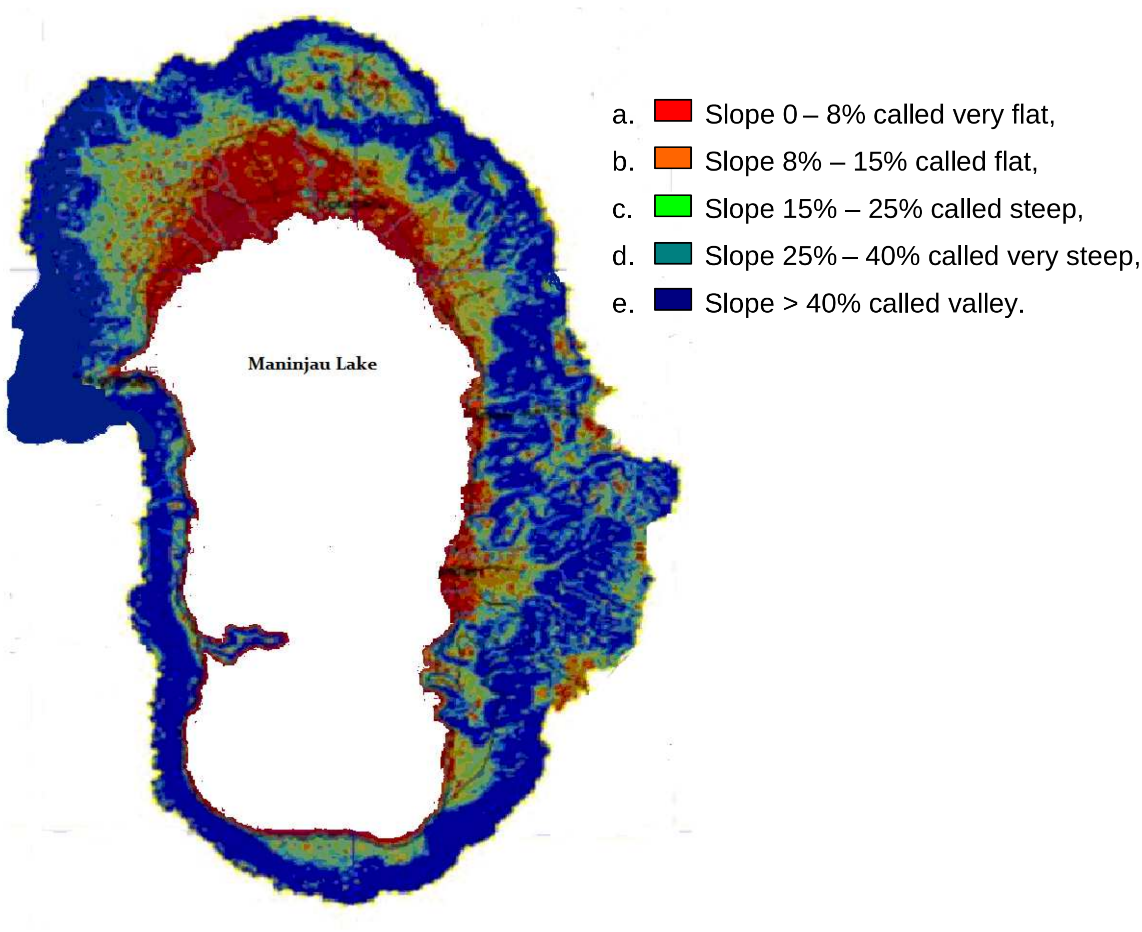

Figure 6. Slope of Maninjau region

The Department of Public Work of Indonesia has divided Maninjau region into several categories based on the existing slope as shown in Figure 6 (PU, 2013). To determine the stability of each category of the slope, the slope stability analysis for every slope was conducted.

The slope geometrics and the average soil parameters obtained from tests are used to simulate the flat failure surface in slope stability analyses. The results of the analyses are plotted in Figure 7 and 8. The results show that the slopes have the lowest safety factor less than 1.0 for gradient 100% (Figure 7). While for the slopes without cohesion the safety factors are less than the slopes with cohesion. It means that the slopes without cohesion are more unstable (Figure 8).

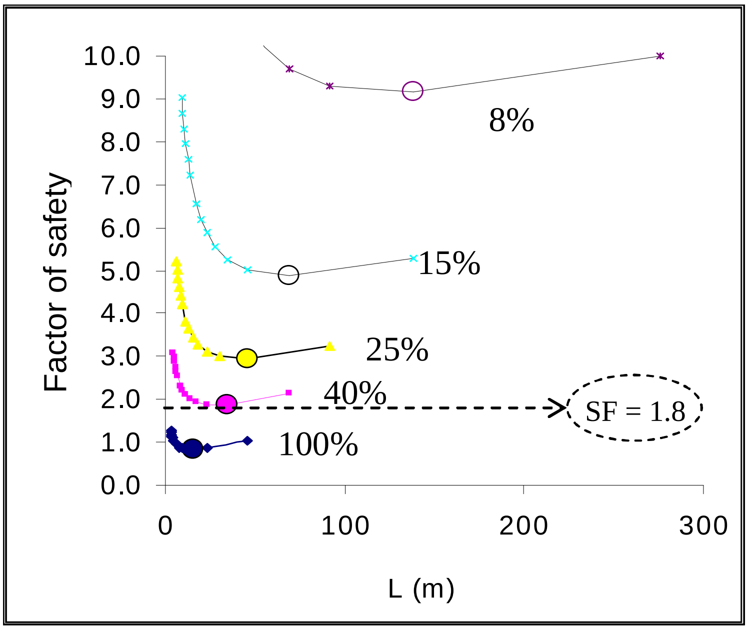

Figure 7. Factor of safety of Maninjau slope

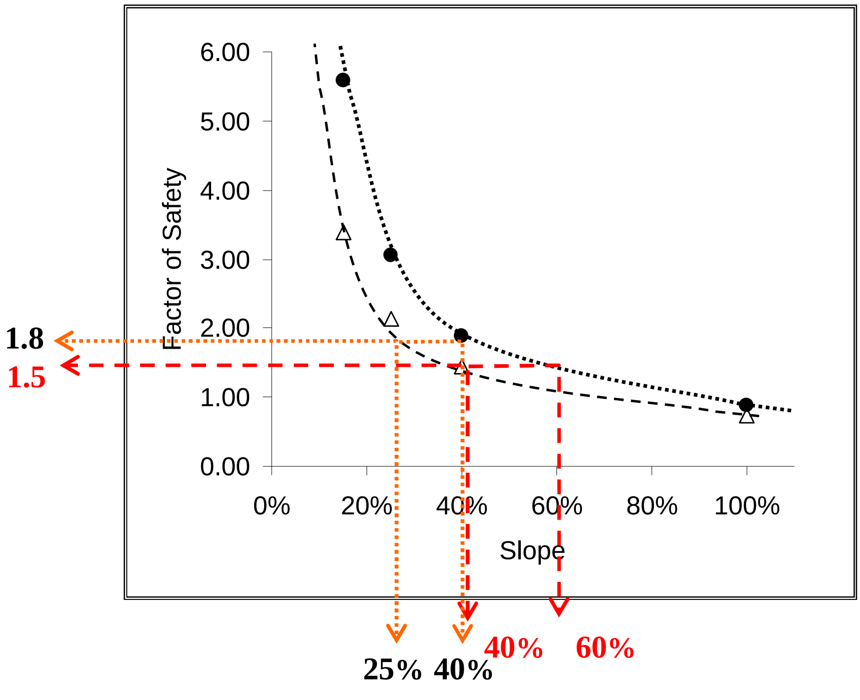

Figure 8. Factor of safety of Maninjau slope
(with c, without c)

Slopes are usually made of highly diverse materials and many uncertainty factors. Slope analysis for practical purposes must take any assumptions and safety factors into account. Then there are many varieties to adopt appropriate safety factor to categories the stability of slopes. In order to consider the safety of slope stability, Department Public Work of Indonesia has the criteria to be considered as shown in Table 2 (PU, 1987)

Table 2 Safety Factor Criteria for Slope Stability Analyses

Risk	Loading condition	Shear strength of soil			
		ultimate		residual	
		good	fair	good	fair
high	earthquake	1.50	1.75	1.35	1.50
	static	**1.80**	2.00	1.60	1.80
moderate	earthquake	1.30	1.60	1.20	1.40
	static	**1.50**	1.80	1.35	1.50
low	earthquake	1.10	1.25	1.00	1.10
	static	1.25	1.40	1.10	1.20

Maninjau is known as a famous tourism destination. Since it so popular then the high-risk criteria were taken as the determining factor of safety in case of landslide. Using the predefined criteria, it can be considered that the ground with a slope of more than 40% is an unsafe area (Figure 7). However, if it is taken intermediate risk, then slopes less than 60% had insufficient stability (Figure 8).

When the effect of water on the stability of the slope is considered, then the ground with a slope of about 25% can be categorized as critical slope. The reason is that the cohesion of the soil strength will be lost due to saturation. This condition is taken into consideration that the slope of 25% to 40% leads to moderate slope criteria. Furthermore, slope more than 40% is categorized as highland slide prone areas (red), whereas the slopes with a slope of less than 25% categorized as practically safe area (green) so the rest areas as moderate (yellow). Those criteria of hazards can be seen in Figure 9.

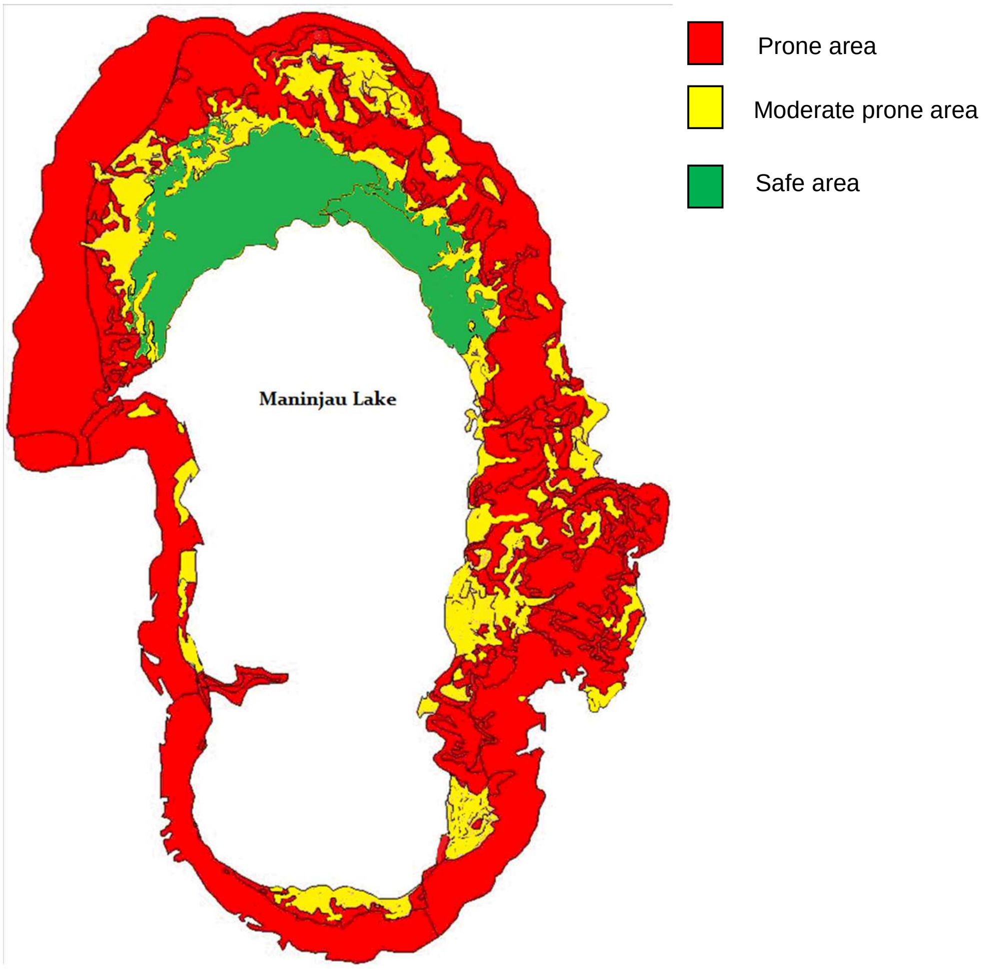

Figure 9. Landslide potential of Maninjau

This result is useful for mitigation action for people living in Maninjau. Action to mitigate the hazards can be taken by improving the land use planning in Maninjau based on the landslide potential. In order to create the land use planning, Holcombe (2010) recommends that realistic policies and its management, both at government and community levels, have to be considered. Residential locations in Maninjau must be plotted on the low landslide potential area or at least moderate one. The annual crop plants and paddy fields where the people spend a lot of time also must be plotted on the safe locations that are low potential and medium at least. In order to reduce the landslide hazard, the areas with high landslide potential must be planted with long life trees which also perform reforestation action. This land use planning should be taught and explained to the people to be implemented in Maninjau. This action will generate a safer community in Maninjau in the future.

In order to suggest the mitigation action of the slope, the critical depth of failure surface on the slopes must be determined. The critical depth is the depth of potential failure in slope that significantly affected by changes of the water content. Meanwhile the changes of water content for the uncovered slopes are strongly affected by the weather (rain and drought seasons). For the area that has the cover of the slope has been opened by human or nature, the best remedial method is the reforestation. The specific plants must be planted on the slopes. The plants' roots must increase the stability of slopes even for the weakest soil shearing resistance. The roots of selected plants should be able to reach the base area of failure line under the surface of the slope that determined as the critical depth.

Furthermore, to determine the critical depth of the slope failure surface by assuming to be parallel to the surface, the critical depth of failure is calculated as follows (Hakam et al, 2013):

$$D_{cr} = \frac{c}{\gamma} \quad \frac{H^2 + L^2}{HL} \qquad (1)$$

The average critical depth that is calculated for moderate slope area that behaves completely dominated by the soil cohesion is 1.22m. In order to prevent the landslides on the hillsides of Maninjau, the action of re-planting or reforestation is suggested. As suggested by Marden (2012), reforestation can reduce shallow landslide within 8 to 10 years after planting. In addition, replanting a slope serves to create a beautiful landscape also to reduce the influence of weather on physical and mechanical parameters of the soil. Types of trees suitable to be planted are those that have root to reach the depth exceeding 1.22 m. Technically, in order to maintain safety in heavy rain conditions that can lead to a reduction in soil strength, the recommended tree roots is one and a half times that of the critical depth that about 1.8 m from the ground surface.

In addition, it is suggested that the people together with the local government to be aware of landslide. Beside the re-plantation action on critical ground, the mitigation action plan such as the installation of the early warning equipment in the landslide prone areas must be done as well. This particular method has achieved much attention in recent years (Lacasse and Nadim, 2009). The implementation of new and advanced technologies has also been suggested, such as the installation of GPS for landslide monitoring (Anbalagan and Parida, 2013) and sophisticated spatial-temporal probabilistic landslide modelling (Van Westen et al., 2006).

4. Conclusions

The results of the landslide hazard study conducted showed that generally Maninjau area is prone to landslide. The soil of Maninjau is dominated by fine-grained soil that has the shear resistance that can decrease as the water content increases. In normal condition, it can be concluded that the slope less than 40% is on stable condition. However, saturation condition due to rain, slopes more than 25% may become unstable and lead to landslides.

Maninjau area has relatively the same geotechnical soil parameters associated with landslides. However, the differences in topography provide advantages in terms of land use. Based on the results of this study, the land use planning of Maninjau should be adjusted according to its landslide risk level. For areas with high landslide potential, the land can be planted with long life trees which also perform reforestation action. The landslide potential areas in moderate and low level, are used for annual crop plants and paddy fields where also good for safer residential locations. This land use planning should be socialized to the Maninjau community so that the next generation there will be safe from disasters.

The mitigation action to prevent the disaster due to landslide must be considered in Maninjau. The re-plantation plan may be a good idea to maintain the stability of slopes during the rainy season. The planted trees should have roots that can penetrate the soil to a depth of more than 1.8 meters from the ground surface.

5. Acknowledgement

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