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Development of Stability Criteria for Risk Reduction in the Sianok Canyon in Bukittinggi Indonesia

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Abstract: The development of Sianok Canyon area as a tourist destination in Bukittinggi - Indonesia also needs a disaster risk reduction to be included in. The city already has land use plan that restricts the development around the upper part of the Canyon. This restriction is not equally effective because it has no consideration based on the actual thinking. The study that provides a scientific consideration is needed since the city has limited land. Then, the geological study and geotechnical investigation was done to obtain required data. It is followed by the potential landslide analyses of the Canyon area. Furthermore, based on the results of the analyses the safety factor and safe distance criteria are proposed for consideration in the development plan of the city as well as to reduce the disaster risk.

Keywords: *landslide, land use, risk reduction*

1. Introduction

Sianok canyon is one of the most popular tourism destinations in Indonesia. There are two well-known theories adopted 'why this canyon is exist'. First believe that this canyon is made by erosion of water flow along the river and second one say it is made by Sumatran fault. Both need advanced investigation to prove the theories. Whatever the nature made it, the Sianok Canyon can stand up to 90^o which become a dramatically seen that attractive for tourists (Figure 1). The Canyon with length of 15 kilometer passes through Bukittinggi city which has more than 3,300 population per square kilometer.

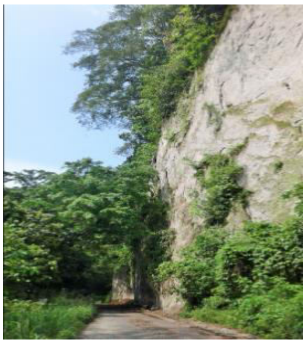

Figure 1 *Sianok Canyon wall can stand up to 90^o*

In the past the Sianok Canyon area of plantations and rice fields. Since it has beautiful scenery, then it became very popular for tourist visits. The development of the Sianok Canyon then becomes quite rapid. However, with limited land this area is also developed to build tourism support facilities like culinary shop and stay houses. Later the residential houses also exist at both under and on the top of the Canyon wall (Figure 2 and 3). The development of the township above the Sianok Canyon is now in a very dangerous situation where the distance between the building with the edge of top side of the Canyon wall just in a matter of less than 5 meters. The investigation on this area is needed to reduce the disaster risk as it has happen in the other place (Hakam et al, 2013).

It is very concern that this development does not consider the danger in behind the Canyon wall. In fact, from the experience the earthquake in 2007, the Canyon walls suffered from landslide. This concerns about the danger seems has been defeated by the needs of everyday life. Then the people in the Sianok Canyon live in a very high risk especially due to landslide.

Even worse is the regional land use plan of Sianok Canyon cannot be complied with. In the land used declares the area with a distance of 100m from the end of the Canyon must be free of construction development. This restriction is certainly a thing to devastate natural resources because it is not based on scientific judgment. The regulations to control the land use development also has not already exist (BAPPEDA, 2007). Then it should be a scientific consideration for safe development based on the knowledge as described in this paper.

In order to protect people and environment in industrial field it has been introduced a Safety Integrity Level (SIL) to include risk reduction action to a tolerable level. The SIL is proposed to help companies to specify both the risk assessment and the measures to be taken in the design of safety for emergency shutdown in hazardous conditions (Gathur, 2013). In this paper the landslide safety criteria are developed for risk assessment based on the hight and the distance from the canyon edge.

The geotechnical behavior of the Sianok Canyon initially must be explored from the field. A laboratory test series were included to have specific data that needed for slope stability analysis. The numerical simulations then were conducted to develope risk disaster criteria based on the hight and the distance.

***Figure 2** Township on the edge of the canyon*

***Figure 3** Houses and business building development under the canyon*

2. Geological and Geotechnical Overview

The Sianok Canyon is located in Bukittinggi - West Sumatra Province, Indonesia. This area is geographically located in the west-central side of the Sumatra Island (Figure 4). The Sianok Canyon is in the middle of hill area that lay from the north to the south as part of the Bukit Barisan hill. The Canyon may be geologically formed due to the existence of the Semangko fault which divides the Sumatra Island into two parts, east and west. Along the Semangko fault there are some active and non-active volcanoes which create soil deposit in surrounding areas.

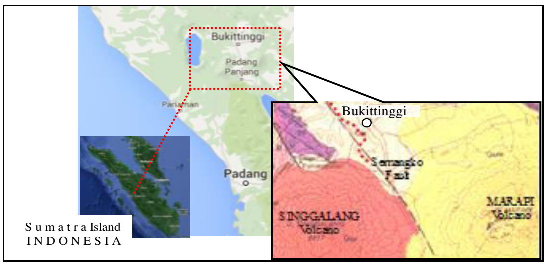

***Figure 4** Geography and geology map of Sianok Canyon*

Soil deposit that make up the Sianok Canyon is derived from ancient volcanic eruption in past. This deposit type is a Pumiceous Tuff with color of pinkish grey to slightly brown (Kastowo et al, 1996). The soil deposit then is compacted naturally that makes a layer of soil provides cohesion like effect.

In order to investigate the geotechnical behavior of the Sianok Canyon walls then the soil sample is collected from the field. Soil samples were then tested in the laboratory to obtain physical and technical parameters. The laboratory experiment performed include grain gradation, unit weight, soil consistency, unconfined compression and direct shear tests.

The soil deposit is made of non-plastic particles with liquid limit water content of 27% and plastic-index of only 1.4%. The soil contents 50% of sand and the rest is the silt particle. Based on those data the soil then can be categorized into inorganic silty-sand (ASTM, 1985). The soil mechanical data from the laboratory tests are the unit weight of 16.7 kN/m^3, the unconfined compression strength of 150 kN/m^2 with sensitivity of 18 (Figure 5) and the internal friction angle of 33^o (Figure 6).

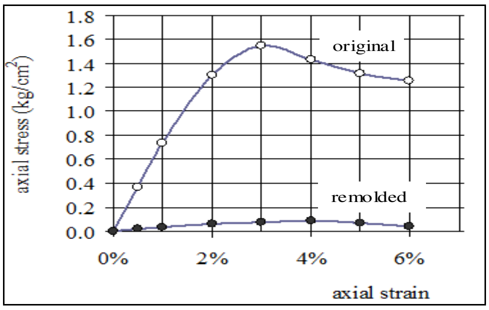

***Figure 5** Unconfined compression test results*

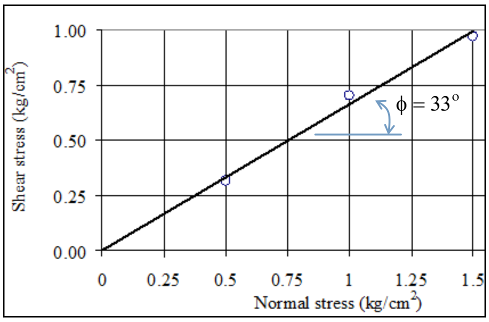

***Figure 6** Direct shear test results*

3. Landslide Hazard Simulation

Based on geotechnical data from the soil sample test results, then the landslide analyses of the Sianok Canyon were conducted. This landslide analyses were performed by numerical simulations with variations in height of the Canyon wall. The simulation results are in terms of the safety factor against sliding along the failure plane and the safe distance on the top of the Canyon as defined in Figure 7.

The landslide simulation is conducted in the Canyon height variations. The results in the term of safety factors show that the Canyon wall can stand safely up to a height of 150m. The wall with 200m of vertical height is in a very critical condition with the safety factor equal to one.

Based on the safety factor criteria for slope stability analyses (PU, 1987) as shown in Table 1, the safety factor of the Canyon wall around residential areas in case of an earthquake is at least 1.8. The height of the Canyon Wall to meet that criterion is about 90m. The height of the Canyon Wall to meet the criterion of moderate risk level is about 120m that is for access road use. In addition the area around the Canyon with the height of 150m is safe enough for farm field (Figure 8).

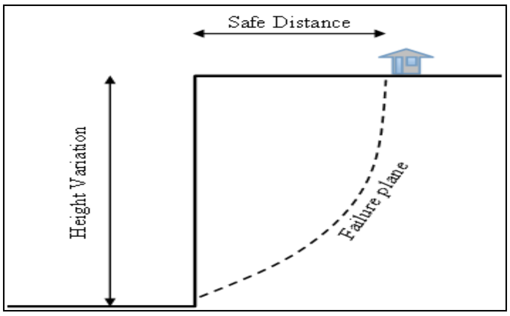

Figure 7 *Definition of term in simulations*

Table 1 *Safety Factor Criteria for Slope Stability for various risk level*

Risk level	Analysis Type	Ultimate Shear strength of soil
High (residential)	earthquake	1.50
	static	1.80
Moderate (Access road)	earthquake	1.30
	static	1.50
Low (Farm)	earthquake	1.10
	static	1.25

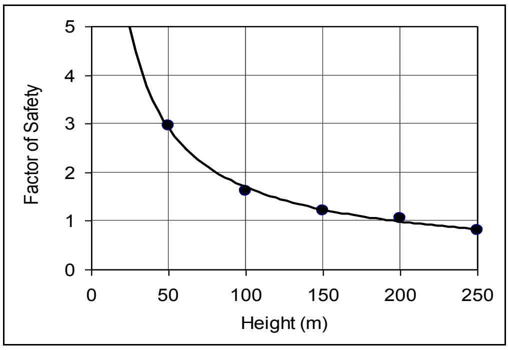

Figure 8 *Simulation results in term of factor of safety*

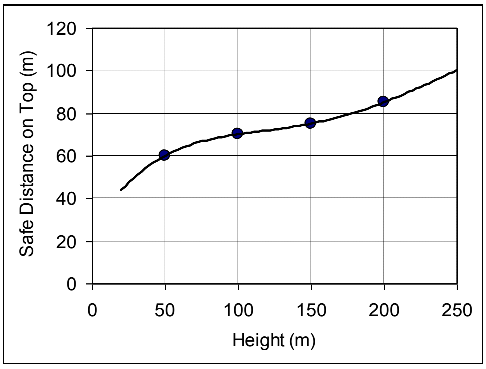

Figure 9 *Simulation results in term of safe distance on top*

The area on the top of the Sianok Canyon that can be developed must also meet the safe distance from the edge as shown in Figure 9. The Canyon height of 90m or less seem to be safe to be developed for residential area, however the safe distance must also be met such as at least 70m for the edge of the Canyon wall. Then the existing residential areas that do not meet the criteria of safe height and distance are in very high risk condition.

4. Conclusions

The Sianok Canyon and surrounding area have beautiful scenery and also hide a very high risk against landslide. The factor of safety of the Canyon is varying according to the height of its canyon. The safety factor values from analysis results start from less than 1 for height of more than 200m to more than 3 for the height less than 50m. The Canyon area with a height of 150m to 200m which is categorized as critical level still can be used for agriculture development. While height of less than 120m still to be developed safely for access roads. The area that safe for residence is the canyon with the height of less than 90m and it is at least 70m from the edge of the canyon. Based on the development and designation of the Sianok Canyon area in the land use plan, it is recommended to socialize the risk reduction in development. The easiest way of that action is by providing warning signs in associate with the height of the Canyon wall. The residential houses on the dangerous area that do not meet safe criteria are suggested to be relocated slowly. The public roads that are under the Canyon wall of 125m or more also should be relocated to avoid casualties in future earthquake.

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