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EVALUATION OF ROCKFALL OCCURRENCE IN PADANG–BUKITTINGGI ROAD,WEST SUMATRA, INDONESIA

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Abstract

A big earthquake occurred on September 20, 2009 in Padang, West Sumatra, Indonesia. This earthquake caused damage and loss of both property and lives. The earthquake also triggered the emergence of rock falls in several areas in Padang, especially in the road of Padang to Bukitinggi. After the earthquake in September, several big rockfalls occurred more than three times that cost lives. Based on field investigations, the incidence of rock falls was caused by field conditions which was prone to rockfall, such as steep slope and exposure of rocks to intensive structures that then triggered by earthquake and rainfall. Therefore, fast action is needed to be taken in order to minimize the impact of the rockfall disaster.

Keywords: *Rockfall, slope, rock structure, earthquake, rainfall*

1 Introduction

Rockfalls are major hazards in rock cuts for highways and railways in mountainous terrains such as in Indonesia. While rockfalls do not pose the same level of economic risk as large scale failures which can close major transportation routes for days at a time, the number of people killed by rockfalls tends to be of the same order as people killed by all other forms of rock slope instability. The hazard of rockfalls is higher in areas with intense seismic activity where earthquakes are the principal triggering factor (Marinos and Tsiambaos, 2002). On September 20, 2009, a big earthquake occurred in Padang, West Sumatera, Indonesia. This earthquake caused some building damages and also triggered the landslide and rockfall in many places. A big rockfalls have occurred in the road from Padang to Bukittinggi especially around Anai Waterfall, situated at the foot of a 280 m high andesite rock cliff (Figure 1). This road is the main route to Bukittinggi from Padang. Three people already died because of this disaster after the September 20, 2009 earthquake. Therefore, actions are urgently required in order to minimize the effect of rockfall disaster.

2 Engineering geological conditions

The geological formations encountered in the area consist of pumice tuff (Katowo, et al., 1996). The rock slope overhanging the road from Padang to Bukitinggi consists of andesite. A section of this road cuts the great Sumateran fault, therefore this area is very complex in term of geological structures. Two major fault zones with NE-SW and NW-SE strike intersect the formation, forming the valley as shown in Figure 1. The pumice tuff and andesite rock mass is strongly fractured and weathered, intersected by numerous major vertical and horizontal fractures which have a parallel strike to the fault structures that forms the rock face (Figures 2a and 2b). The spacing of the discontinuities is relatively small (less than 1 m); however, there

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are also big boulders in the top of slope. In places, mainly due to stress relief, the rockmass is very blocky and the size of the rock blocks is smaller especially on the upper part and the crest of the slope where the wall of road is situated.

3 Rockfall analysis

The stability conditions of the rock slope are mainly controlled by the following factors: a) due to spacing, large blocks are prone to fall, b) lack of persistency of the discontinuity planes, which results in instabilities only in specific parts of the slope, c) lack of weak zones, which would result in large shear failures, d) the rock face is in a state of relaxation due to the high inclination of the slope (Marinose, et al, 2009). The rock slope stability analyses were based on the prevailing mode of instability of each potential rock failure. The principal failure type is rockfall due to a sort of toppling and bouncing (Figure 3). The rock blocks were delineated and their geometry and mass was determined. Due to the inaccessible nature of the slope, the assessment of the above characteristics was based on the topographic map of the rock cliff. These characteristics were grouped and specific sections (A to G) were formed for separate analysis (Figure 4). The surveying and mapping of the high rock cliff were based on a new geodetic methodology and using the topographical map from secondary data. The height of the source of fallen-potential blocks is at the minimum of 70 meters above the road, while in some places it reaches 280 meters. The size of the unstable materials which are more probable to fall is only between 0.5 m^3 to about 5 m^3 (Fig. 4a), except in the area between Sections C - D (Figure 4a) where the size can go up to 20 m^3. In the area shown in Figure 4, the potentially unstable blocks have very large dimensions.

The necessary support measures can be divided into two categories: a) those which offer protection once the rockfall will occur, mainly rock fall barriers and, b). those which apply an external force on the rock face e.g. tensioned rock anchors or patterned rock bolts. Other support, such as grouting of rock joints with associated drainage, construction of buttresses in overhanging areas and removal of unstable boulders are necessary, however can be inapplicable or very difficult to construct in high rock cliffs. The installation of a steel protection net or sprayed concrete is not acceptable due to the wide area. As discussed earlier, the scale of some potential failures is such that no stabilization measures can minimize or withdraw the risk of a potential rockfall after their application. Even high-energy rock fall barriers would prove insufficient in the case that the rock blocks shown in Figure 3 are detached from the cliff. A possible support solution, in this case, would be to install tensioned wire-rope cables around the rock boulders to resist their movement and to grout any open discontinuities with appropriate drainage holes.

4 Rockfall risk assessment

In order to assess rockfall risk, a number of rating systems have been developed. Pritchard et al. (2005) developed a rating methodology, which is applied to predict rockfall risk along railways. A similar system is the Rockfall Hazard Rating System (RHRS) (Pierson et al., 1990), which is most widely accepted. These systems give a reasonable assessment of the relative hazards due to rockfalls from cut slopes adjacent to highways and railways. In the present study, a rockfall risk rating system for natural rock slopes is proposed according to Marinos et al. (2009). It defines 19 rating parameters, grouped in 3 major categories on hazard and consequences, which have a different weight factor in the assessment of the total risk. The parameters are presented in Table 1.

The rating system was applied at selected locations along the rock cliff (Figure 4) since the parameter rating differs for each slope segment. The parameters that vary from one location to another were: a) the size and number of rock blocks, b) the spacing and persistence of discontinuities, c) the seeder height, d) the width of the available catchments zone and e) the existence of structures or human activity at the underlying area. The slope height and angle of the road slopes vary significantly. The result of the

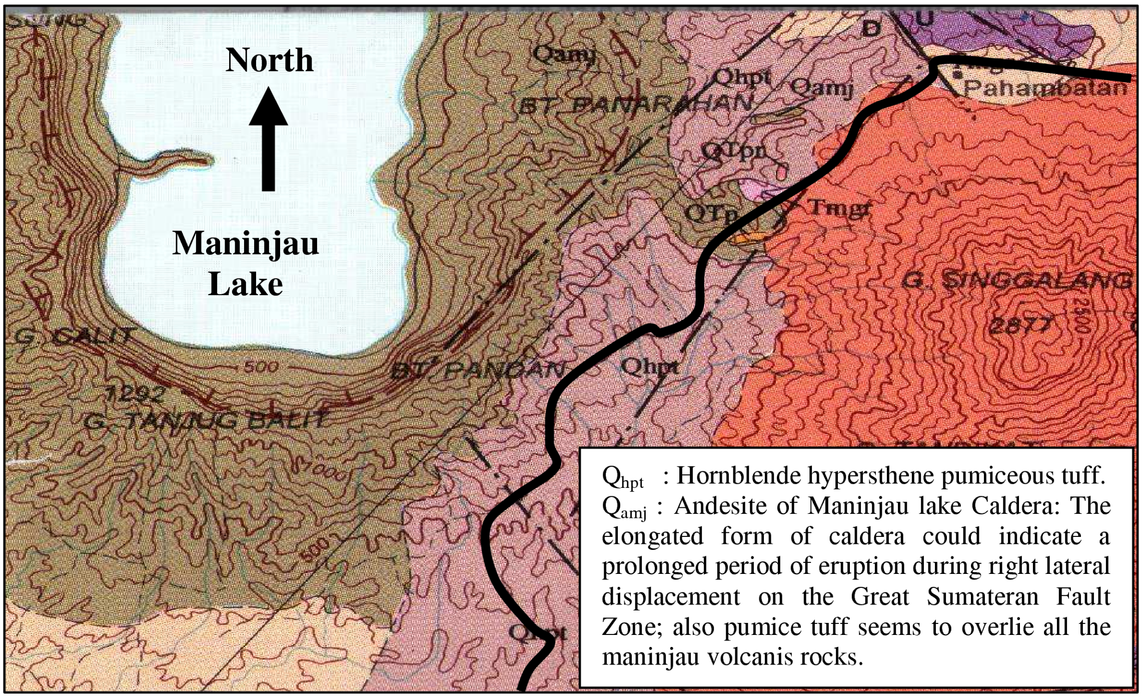

Figure 1: Geological map of the research area (Katowo, et al., 1996)

Figure 2: (a) Slope of weathered pumice tuff; (b) Fractured andesite in Anai Waterfall

Figure 3: (a) Andesitic materials that are still hanging in the top of slope; (b). A big andesite boulder from the rockfall

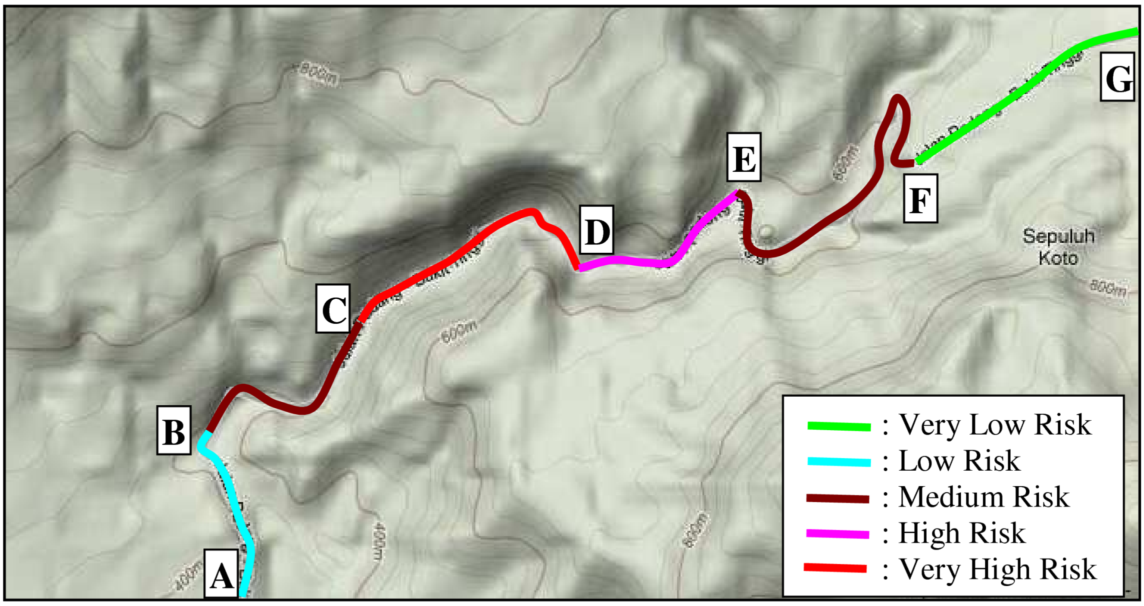

Figure 4: Risk zonation of rock slope based on rockfall rating system

Table 1: Parameters of rockfall rating system for natural rock slopes to define risk (Marinos et al, 2009)

Category	Parameters of component of risk	Relevance	Weight (%)
1	Slope angle, weathering, discontinuity condition, rock block size, permeability of rock mass and condition of drainage	Hazard	55
2	Number of potential blocks, number of pas rockfall, rainfall, seismic activity	Additional to hazard	15
3	Slope height, seeder height, availability and geometry of catchments zone at foot slope, slope accessibility, potential result of impact and value of structures, pathways.	Consequences and impact of hazard	30

application is a risk zonation of the cliff against rockfall occurrence, presented on the risk map shown in Fig.4. The map depicts the areas of having a high and very high risk due to either increased number of existing unstable boulders or restricted area for their catchments or combination of both and the high of cliff. The risk categories are presented in Table 2. The slope foot area between sections C to D presents very high risk due to the numerous unstable boulders on the high cliff with the size more than 5 m^3, therefore the installation of barriers is not possible. The area between sections D to E has high risk, due to lower cliff than C- D, which offers possible conditions for installation of barriers. The area between sections B to C and E-F does not have many boulders and stills many vegetation with medium slope and low cliff.

5 Conclusions

The rock slope stability of the high cliff overhanging the road from Padang to Bukittinggi was studied, based on field investigation of unstable boulders and prediction of their rockfall trajectories. The main triggering factor of rockfall in this road is rainfall, therefore it is necessary to close the road when rainfall occurs to minimize the negative impact. The application of active and passive support is very difficult to apply in the field due to high slope and the size of boulder. It is evident that in the case of boulders having weights higher than 10 tonnes, even the installation of high capacity rockfall barriers cannot remove the hazard due to impact of falling rocks on structures, either because the impact energy is extremely high or the catchments zone is not sufficient for optimized protection.

References

Katowo, Gerhard W. Leo, S. Gafoer and T.C. Amin (1996) Geological Map of The Padang Quadrangle, Sumatera,Geological Research and Development Centre, Republic of Indonesia.

Marinos P, Tsiambaos G (2002) Earthquake triggering rockfalls affecting historic monuments and a traditional settlement in Skyros Island, Greece. Proc. of the International Symposium: Landslide risk mitigation and protection of cultural and natural heritage, Kyoto, Japan, pp. 343-346.

Marinos P., Tsiambaos, G., Saroglou, H., Marinos V. (2009 Rockfall hazard and risk for a high promontory: Monemvasia historical site, Greece, Landslide Disaster Risk Reduction, Ed. K. Sassa et al., Springer, 2009, pp. 206 – 209.

Pierson L A, Davis S A, and Van Vickle R (1990) Rockfall Hazard Rating System Implementation Manual. Federal Highway Administration Report FHWA-OR—EG-90-01. FHWA, U.S. Department of Transportation.

Pritchard M, Porter M, Savigny W, Bruce I, Oboni F, Keegan T, Abbott B (2005) Rockfall hazard risk management system: Experience, enhancements, and future direction. Landslide Risk Management: Proc. of the Int. Conference on Landslide Risk Management, Vancouver. Balkema.

Table 2: Rockfall risk of natural rock sloped based on the Marinos, et al. (2009)

Category	Rating	Risk	Protection Measures	Section
I	< 20	Very low	Not necessary	F – G
II	20 – 40	Low	Occasionally necessary	A – B
III	40 – 60	Medium	In limited extend	B – C; E – F
IV	60 – 80	High	Combination of active and passive measures is necessary	D – E
V	80 – 100	Very high	Critical state of stability, combination of active and passive measures is absolutely necessary	C - D