

An assessment of Cikangkareng rockfall due to the Tasikmalaya earthquake on September 2, 2009

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Abstract. The earthquake that shook Tasikmalaya - West Java on Wednesday, September 2, 2009, amounting to 7.3 on the Richter scale at 02.55 pm was one of the geological natural disasters that affected Cikangkareng village - Cibinong District, Cianjur, West Java - Indonesia. According to the Bureau of Meteorology and Geophysics (BMG), Among 30 districts in Cianjur, 15 districts have great potential for land movement. The topographic condition is a fairly steep slope of hills with an almost upright angle $\pm 80 - 90^\circ$. In addition, a residential area was located at the foot of the hill. Thus, the geological conditions are fragile. Based on the map of land movement vulnerability (DVMBG, 2004), the Cianjur area is categorized as a zone of high movement potential of soil which means that movement of soil is easily triggered by rainfall and earthquakes. The Tasikmalaya earthquake event triggered a landslide on a large scale and caused rockfall. The material of the site collapse consists mainly of sedimentary rocks, sandstone rocks, sandstone, breccias, sandy tuffs, and yellow spots. The mineral testing results revealed that the existing minerals are Feldspar and Cristobalite. From the result of the slake-durability, the material has medium durability. The main cause is not only the acceleration in the horizontal or vertical direction of the rocks but also the seismic force can cause an increase in the water pressure in the pores and the rock fracture can give a change of pressure in the contact field of rock joint. As a result of this, the earthquake event triggered an avalanche on a large scale and caused rockfall. Due to the contact stress decreasing drastically, practically, the friction resistance of the joint plane could be significantly reduced.

1 Introduction

According to Hunt [1], landslides involve very complex phenomena and mechanisms. They could be small to very large scale, such as those burying cities or villages. Several earthquake-induced instances of landslide or rockfall have been reported worldwide. For example, the Tsao-Ling landslide [2,3], the Chiufengershan landslide [4], and the Las Colinas landslide during the 2001 El Salvador Earthquake [5].

Rockfall was triggered by the earthquake that shook Tasikmalaya - West Java on Wednesday, 2 September 2009, reaching 7.3 on the Richter scale at 14.55 [8]. Due to this earthquake event, the rockfall phenomena caused damage and fatalities in Cikangkareng village - Cibinong District - Cianjur city, West Java. Based on information from the National Bureau for Disaster Prevention (BNPB), until 13 September 2009, the casualties reached 81 people and 45 people were missing [9]. It is most likely that the missing people were buried by rockfall materials. The rockfall estimated has a volume of about 1,500,000 m³, as shown in Fig. 2. This picture illustrates the Cikangkareng rockfall which consisted of many large rocks.

Fig. 2 shows the location of the Cikangkareng rockfall. As seen in the figure, Cianjur shows a vulnerability to land movement. According to the Bureau

of Meteorology and Geophysics (BMG), out of 30 districts in Cianjur Regency, 15 have a great potential for land movement. The conditions of the topographic area are as follows: (1). The slopes are very steep, as their inclination is around $80^\circ-90^\circ$, (2). The geological conditions are very fragile where a landslide or rockfall could easily be triggered by earthquakes or heavy rainfall events.

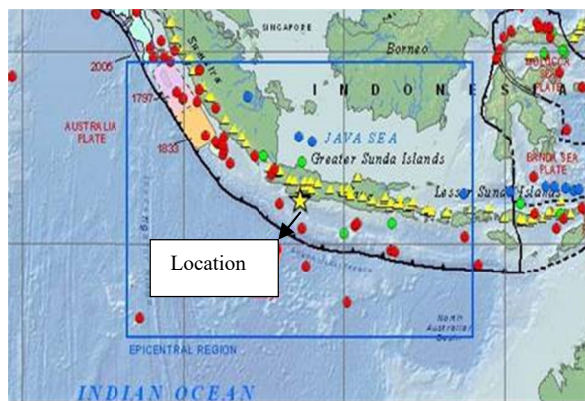


Fig. 1. Debris materials consisting of large rocks (private document)

A previous land movement disaster was also recorded in 1980 at Cikangkareng, Cibeber, and Sukanegara, where the landslides were triggered by heavy rainfall. The landslide affected ± 200 m in the

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longitudinal direction and ± 150 m in the transversal direction. The population should not live in the valley is very dangerous but the population do not want to be moved



BMG :
 event 14.55 WIB, magnitude 7.3 SR, epicenter at sea 8.24 LS and 107.32 BT, 142 km south west of Tasikmalaya – depth 30 km below the seabed

USGS :
 epicenter at 7.80 LS and 107.259 BT, South Indian sea, depth 46.2 km below the seabed

Fig. 2. Map of location earthquake and location Cikangkareng – Cianjur

2 Tectonic formation

Some factors were suspected to have caused natural disasters due to the movement of tectonic plates. The movement of those plates is relatively slow but they move continuously and could cause a disaster. Indonesia is located between three tectonic plates, namely the Indo-Australian plate, the Eurasian plate, and the Pacific plate, as shown in Fig. 3. The Australian plate continues to move as much as 6-7 cm each year, toward the north-side and collates with the Eurasian plate, causing the subduction downward

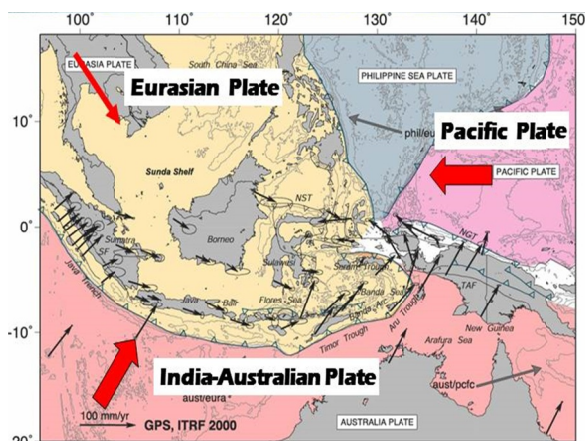


Fig. 3. Map of tectonic Indonesia plate

3 Formation of geology

Geological conditions are very important because the earthquake vibration is propagated through the sub-soil until it reaches the ground surface during the earthquake and this vibration could induce landslides or rockfall. Thus, it is very important to investigate geological conditions in order to evaluate the risk of landslides.

Based on the geological map of West Java, as shown in Fig. 4, the southern part of West Java is dominated by Holocene volcano rock (Qv). This rock is formed from an active volcanic sediment consisting of lava, breccias, tuff, loose lava sediment which generally takes the form of andesite and basalt. The sources of Qv are Galunggung mountain and Talagabodas mountain.

As shown in Fig. 5, the disaster area is composed of Koloberes (Tmk) rock formation, which is composed of sedimentary rocks with sand, crystal tuff, breccias with a parallel coating and is less massive. The rocks have been clogged with the weathering soil, such as silt and clay, and the color is brownish or reddish-brown. In addition, due to the long drought, the crack is also observed on the ground.

Based on the Cianjur Area Vulnerability Zone Map [7], the disaster area is located in a high potential ground movement zone. This means that the land movement is easily triggered by high rainfall or earthquake. With the earthquake magnitude of 7.3 SR, the sedimentary rocks clogged with the weathering collapsed and the material slid into the residential area.

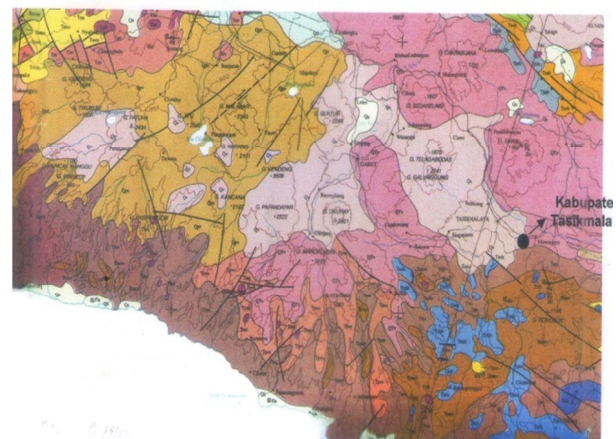


Fig. 4. Geology of West Java



Fig. 5. Regional geology of rockfall area [6]

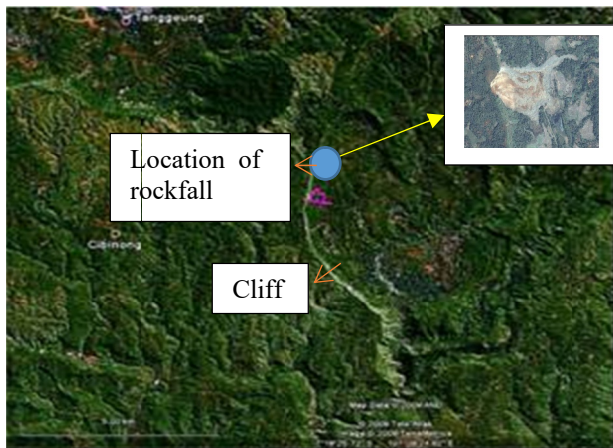


Fig. 6. Satellite image of rockfall area (Google Earth)

The large areas under the crown of old rockfall and the landslide were triggered by heavy rainfall.



Fig. 7. The rockfall at Cikangkareng



Fig. 8. Evacuation after rockfall without heavy equipment (Kompas, Sept 4th, 2009)

The topography at the disaster site has a slope with an inclination of almost 80° -90°. Below the cliff, there is Babakan Caringin village whose ground inclination is around 5°-15°. (Figs. 6 and 7). Land movement disasters at Cikangkareng are categorized as rockfall. Some debris material has also been found in this event (Fig. 8). A large earthquake force in the horizontal and vertical direction causes an increase of porewater pressure and inside the fractured rock. As a consequence, the friction resistance in the joint plane is significantly reduced. It should be noted that the stability of rock slopes is influenced by several factors such as joint orientation, joint roughness, width and spacing of joint, fill material in the joints, and the existence of water.

4 Specification of debris material

Types of debris material consist of sedimentary rocks, such as Silty/sandy rocks, clay rocks (very fragile), breccia tuffs with sandy rocks (yellow spots and very fragile), sandstone breccia mixed with clay, and clay rocks with brownish parallel layers.

Based on the field observation, the debris material was dominated by rocks mixed with soil. The type of rock is grey colored sandstone (Fig. 9) and many fracture joint (Fig.10).



Fig. 9. Soft grey sandstone



Fig. 10. Fracture joint

5 Type of Cikangkareng rocks

The size of debris was like very large weathered rockfall. Fig. 11 shows the size of rockfall debris compared to the size of the village house and Fig. 12 shows the variable size of the rocks. Fig. 13 shows the type of jointed and fracture rock at the crown of the rockfall.



Fig. 11. The size of rockfall debris



Fig. 12. Rockfall debris (Rahardjo 6 Sept 09)



Fig. 13 Jointed rock and fractured rock exposed at the crown of rockfall

6 Type of test material

Various tests were performed on the debris material at Cikangkareng. They are summarized as follows:

6.1 Mineral test

Feldspar minerals and Cristobalite minerals were predominant in the debris material. Feldspar is a kind of mineral that consists of Aluminum (Al) and Silica (Si). Feldspar is chemically divided into four groups of minerals, namely potassium feldspar ($KAlSi_3O_8$), sodium feldspar ($NaAlSi_3O_8$), calcium feldspar ($CaAl_2Si_2O_8$) and barium feldspar ($BaAl_2Si_2O_8$). Feldspar could degrade into clay due to the chemical weathering processes. These minerals are formed by varying different heat environments, during the crystallization of magma-volcanoes in the earth and the process of sedimentation. The feldspar mineral could be used for ceramic or ceramic materials. It is an easy material to melt at low temperatures.

Cristobalite is the mineral that belongs to the group of Quartz with the chemical formula SiO_2 with a density of 2,32 and the hardness is about 6.5. The color of this mineral is white in the form of spots or lines. Similar to Feldspar, this mineral comes from the volcano. These minerals formed under high heat temperature that could reach 1470° Celcius during the crystallization of magma-volcanoes in the earth and the process of sedimentation.

However, Cristobalite crystal does not change due to weather or climate changes.

6.2 Chemical test

The debris rockfall due to the chemical weathering process (Figs. 14 and 15). The chemical test shows that the composition of the chemical is SiO_2 ($\pm 59\%$), and Al_2O_3 ($\pm 14\%$) Fe_2O_3 (6 -8%), CaO ($\pm 4\%$), LOI ($\pm 6\%$).



Fig. 14. Many colors of Cikangkareng Debris



Fig. 15. Wood fossil (sedimentary rock)

6.3 Slaking test

The slaking test is a rock resistance test. This test is conducted with the rotation of a cylinder which contains some pieces of rock samples in a water medium. In addition, this test is repeated in two cycles. After each cycle, the weight and dimension of rock samples are measured. In this test, three rock samples are randomly chosen as the representative sample. From the test results, it was found that the type of rock has "medium durability". This means that, in the first cycle, the remaining rock in the cylinder amounted to 85 to 95 % of the initial weight. Furthermore, in the second cycle, after the oven process, the percentage of remaining rock in the cylinder was about 60 - 85% of the initial weight.

6.4 Point load test

The result of the point load test is summarized in Table 1

Table 1. Summary of point load test

Direction	I_s	σ_c (MPa)
Axial	0.74-1.13	17.75- 27.15
Longitudinal	0.74 - 1.85	17.75- 44.38

6.5 Piezocone test (CPTU)

The Piezocone test was conducted at the toe of the debris to investigate the soil condition and debris thickness. But due to the limitation of penetration, it was only carried out at one point. The Piezocone test consists of a biconus, a pore stone, water seals, sounding rods and reading tools. The purpose of the Piezocone (CPTU) test is to identify soil stratification and in-situ pore water pressure. The location CPTU-01 is at Cikangkareng. According to CPTU-01 the test results in Fig.16, a fine-grained was found sensitive soil of about 3.2 m in thickness. It indicates that this layer is landslide material. The clay layer with medium to stiff consistency was found at GL -3.2 m up to the end of testing (GL -13.0 m).

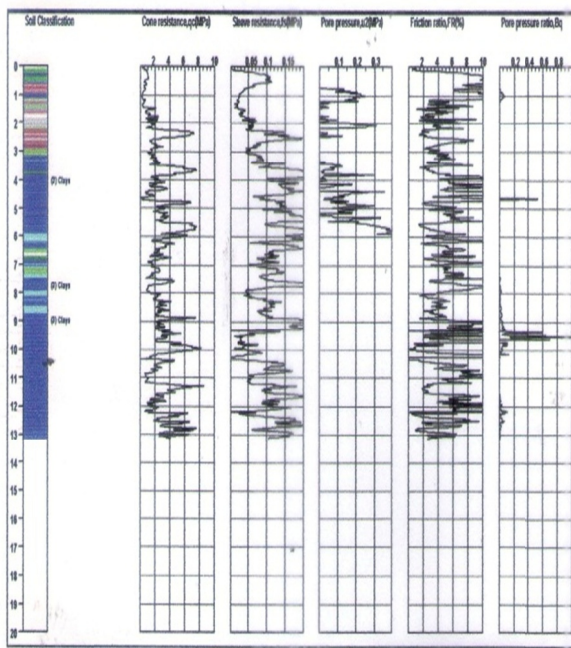


Fig. 16. Piezocone result test

7 The volume of material debris

If the average thickness of the landslide was 10 m, then it could be estimated that the volume of debris was about 1 million m^3 . From Figs. 17 - 19, it was observed that the volume of debris material at Cikangkareng rockfall was close to the other events.

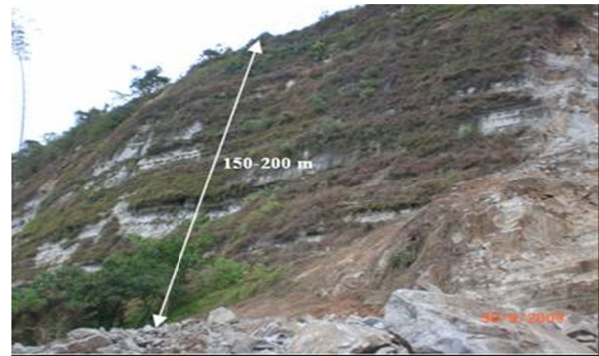


Fig. 17. Measurement of the height of cliff using GPS and rockfall distance of approximately 1.7 km

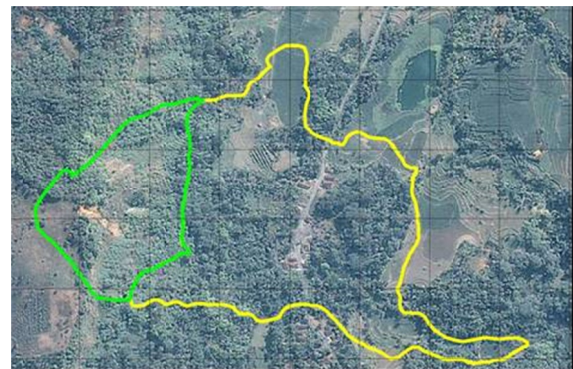


Fig. 18. Satellite image before the earthquake

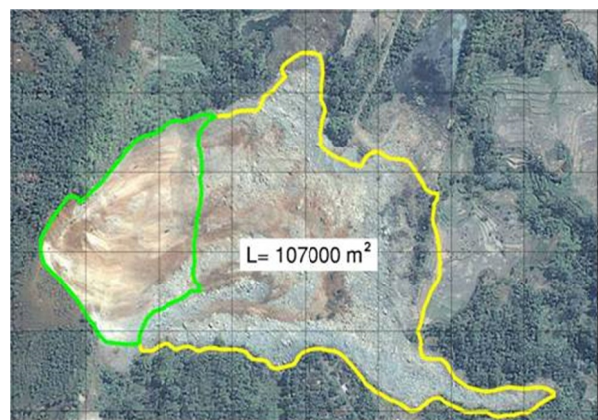


Fig. 19. Satellite image after the earthquake

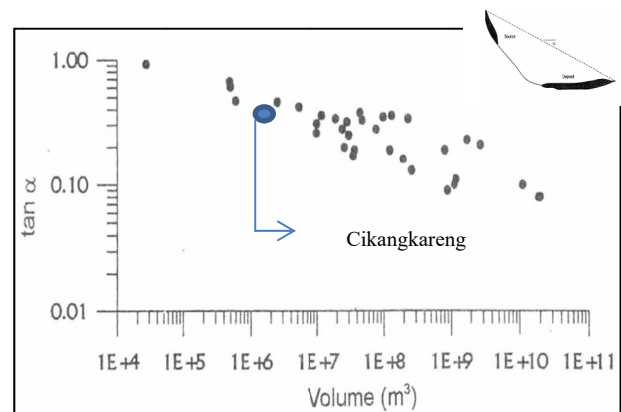


Fig. 20. The relationship between Volume debris and alpha (1)

The motion of sliding block with constant friction resistance from one end of the profile to the other was analyzed, the frictional coefficient would theoretically equal $\tan \alpha$, where α is the slope of the line connecting the crest of the source area with the toe of deposits measured on a straightened profile of the path [10].

The volume of debris rockfall at Cikangkareng and the alpha is close to the graph which correlated the alpha and debris volume (see. Figs. 20 and 21)

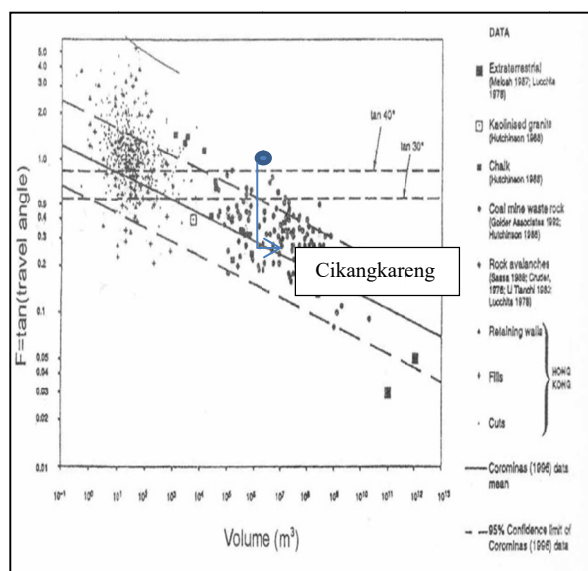


Fig. 21. Relation volume debris and alpha (2)

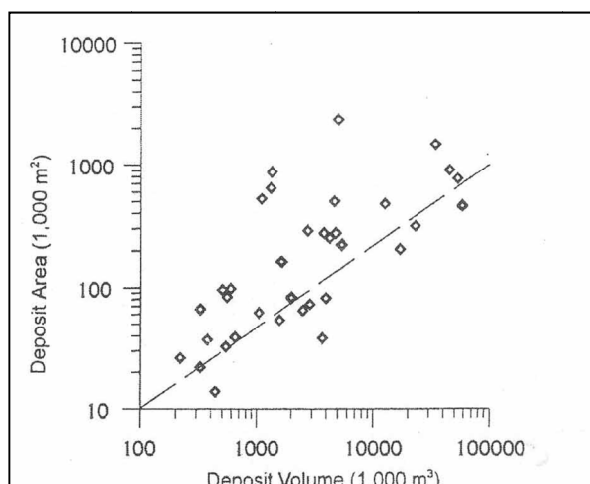


Fig. 22. Landslides & Other Mass Movement

Fig. 22. shows that the volume of debris rockfall at Cikangkareng was included on a plot of the deposit area against volume for 35 rock avalanches from North America and Europe. The dashed line has a slope of 2/3. [12]

8 Conclusion

- The Cikangkareng areas are susceptible to rock landslide. An earthquake with a magnitude of 7.3 SR

on Sept 2, 2009, triggered a natural geological disaster that caused considerable damage.

- The Rock condition at the site is fractured, jointed and soft, there is an indication of old rockslides in a wider area. Moreover, there is the possibility of fault reactivation due to the earthquake.
- Types of debris material consist of sedimentary rocks, such as silty sand rocks, clay rocks (easily fragile), Breccia tuffs sandy rocks (yellow spots and easily fragile), sandstone breccia mixed with clay, and Clay rocks with brownish parallel layers.
- The debris minerals of the Cikangkareng rockfall consist of Feldspar and Cristobalite and the chemical compositions are SiO_2 ($\pm 59\%$), Al_2O_3 ($\pm 14\%$), Fe_2O_3 (6 -8%), CaO ($\pm 4\%$), LOI ($\pm 6\%$).
- According to the slaking test, the debris material of the Cikangkareng rockfall is of medium durability. The point load index and uniaxial compressive strength in the axial and longitudinal directions are 0.74 to 1.13, 17.75 to 27.15 MPa; 0.74-1.85, 17.74-44.38 MPa, respectively.
- According to CPTu-01, a mixed sand and fine-grained soil were found consisting to approximately with 3.2 m in thickness. This indicates that this layer is a landslide material. A clay layer with medium to stiff consistency was found at GL -3.2 m to the end of testing (GL -13.0 m).
- The volume of debris rockfall at Cikangkareng and the value of alpha are closely related to the graph which correlated the alpha and debris volume from other events.
- The volume of debris rockfall at Cikangkareng was included on a plot of the deposit area against the volume for 35 rock avalanches from North America and Europe. The dashed line has a slope of 2/3.
- It is recommended that all areas under the crown of old rockfall and should be sterilized from human settlement, the risk is still high.

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