The Effect of Earthquake to Stability and Run Out Distance of Landslide During Rainfall: a case study of landslide prone area in West Java, Indonesia

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Abstract. The effect of earthquake to landslide stability and run out distance on landslide zones in West Java-Indonesia during rainfall was investigated considering different slope angle. An earthquake peak ground acceleration 0.3 gal for 20 s is applied on landslide zones under a rainfall intensity of 10mm/h for 4 hour. In this study, the slope angles of 26°, 33°, 45°, 56° and 68° are considered. We found that the safety factor decreases as the slope angle increases. With the introduction of rainfall and earthquake, the safety factor of the slope drops below 1.0 at slope angle higher than 33°. The calculations of run out distance during rainfall and earthquake shows the landslide masses generated from the slope 45° will travel more than slope 68° for the same soil characteristic. This is due to the landslide masses from the slope 45° is smaller than that from in the slope of 68°. We found that combination rainfall and earthquake makes the stability of the slope smaller than due to rainfall alone. However, the run-out distance of landslide masses due to the combination of rainfall and earthquake has no significant different when compared with due to rainfall alone.

1. Introduction
Indonesia lies within a convergent zone between three plates, the Pacific plate, the Eurasian plate, and the Australian Indian plate. The three plates move between the plates one and the other. The Pacific Plate moves westward at a rate of 7-13 cm in year, the relatively silent Eurasian plate in the northern part, while the Australian Indian plate moves northward at 6 to 10 cm in year from south-east by Hamilton [1]. The logical consequence of the condition resulted in Indonesia being a potential area of earthquake disaster.

Earthquakes are natural disasters characterized by vibrating earth's surface. One of the secondary effects of an earthquake is the occurrence of landslides. Landslide (ground movement) is a product of the process of disturbance of the slope balance which causes the movement of the soil and rock mass to a lower place. The force that holds the soil mass along the slope is affected by the physical properties of the soil and the angle in the soil shear resistance acting along the slope. The possibility of earthquake induced landslides must also be linked to several factors including topography, geological structure, other landslide causing factors and land use.

Firmansyah [2] analyze safety factor, run out distance, and velocity based on friction model simple coloumb. Khoiriyah [3] also analyze safety factor, run out distance and velocity landslide due to
rainfall. In this paper we investigate the effect earthquake after rain on safety factor, run out distance and velocity in different slope with the same soil characteristics

2. Materials and Methods

The location of this research is in Cihanjuang Rahayu-Parongpong area, West Bandung Regency, West Java Province at coordinate point -6.824264° LS, 107.573893° BT (see Figure 1) with elevation 1215 mdpl and a rather steep slope of 68°. The geological characteristics of Cihanjuang Rahayu-Parongpong are alluvial plains and volcanoes (volcanic). Cihanjuang Rahayu-Parongpong is located in West Bandung area where the area is filled by alluvial deposits and young volcanic (quarter) but in some places is a mixture of tertiary and quarter deposits by Bemmelen [4].

![Figure 1. Vulnerability map land movement. Red, yellow, green, blue in order indicates the vulnerability of ground movement zone of high, medium, low and very low.](image)

This research from research location in the form of characterization of soil engineering test in laboratory. The information is used as the material properties of the avalanche material and the slip fields of the slope model. To determine the prediction of run-out and landslide speed, use numerical simulation of rainfall intensity using Geo-Seep/W, Earthquake Acceleration using Quake/W, and slope stability can be analyzed using Geo-Slope/W. The research flow is shown in Figure 2.

![Figure 2. Research flow diagram.](image)
The effect of rainfall intensity on the security factor is done using Geo-Seep/W Software and Geo-Slope/W Software. As for the effect of earthquakes on the security factor is done using Quake/W Software and Geo-Slope/W Software and Geo-Seep/W Software as parent analysis. Geo-Seep/W software is a software related to groundwater, Quake/W Software is software related to earthquake force while Geo-Slope/W Software is software related to slope stability in the form of security factor. In this work, soil characteristic are determined using standard test measurement as shown in Table 1.

Table 1. Standard test measurement used in this work.

| Standard test Parameter measurement |
|------------------------------------|
| ASTM D 2216 Moisture content       |
| ASTM D 7263 Porosity, weight density, saturation degree |
| ASTM D 5084 hydraulic conductivity |
| ASTM D 422 grain size analysis     |
| ASTM D 854 Specific Gravity        |
| ASTM D-3080-04 Direct Shear        |
| ASTM D4318-84 Atterberg boundary, platis and liquid limit |

Morgenstern and Price [5] proposed a method to determine slope stability called Morgenstern-Price Method (MPM). The expression of safety factor (SF) in terms of force (F_f) and moment equilibrium (F_m) are given as follows:

\[
F_f = \sum \left[ \left( c' l + (N - u l) \tan \phi \right) \sec \alpha \right] \sum \left[ W - (T_z - T_i) \right] \tan \alpha + \sum \left( E_2 - E_1 \right)
\]

(1)

\[
F_m = \frac{\sum \left( c' l + (N - u l) \tan \phi \right) \sum W \sin \alpha}{\sum \left( c' l + (N - u l) \tan \phi \right)}
\]

(2)

Where \( c', \phi, \alpha, l \) is cohesion, friction angle, inclination of slip surface, and slice base length respectively in effective stress terms of each slice base.

We use Geo-Slope/W to model the slope stability and safety factor using these following parameters: unit weight, cohesion and friction angle. We use Geo-See/W to model soil water storage using these following parameter: porosity, liquid limit, hydraulic conductivity, diameter of grain size. The boundary conditions on Geo-See/W model are the pressure head is zero, the unit flux is specify conditionaly and total flux is made zero. Landslide movement can be determined using a simple geometric rule known as energy budget calculation from starting point based on a simple Coulomb frictional model. The velocity can be measured geometrically by only considering the center of landslide mass. Further detail of the method is explained by Jaboyedoff et al., [6] and recently implemented in the previous research by Firmansyah [2]. Parameters used for dynamic analysis, the parameter used is horizontal earthquake data recording with peak ground acceleration 0.3 gal with 20s quake duration. Output is the image of pore seepage.
3. Results and Discussion
Landslide material and slip surface soil properties were obtained from samples taken at the study area. The characteristic of the samples for both location are shown in is given in Table 2.

| Soil quantities                  | Landslide material | Slip surface soil |
|----------------------------------|--------------------|-------------------|
| Unit weight (kN/m$^3$)           | 8.89               | 14.73             |
| Porosity                         | 0.77               | 0.62              |
| Liquid limit (°)                 | 76.75              | 77.71             |
| Hydraulic conductivity (m/s)     | 4.76 $10^{-6}$     | 1.11 $10^{-6}$    |
| Cohesion (kPa)                   | 1.176              | 4.71              |
| Friction angle (°)               | 47.20              | 58.51             |
| Diameter 10% grain size (mm)     | 0.0013             | 0.0013            |
| Diameter 60% grain size (mm)     | 0.0200             | 0.0120            |
| Slope                            | 68°                | 68°               |

During rainfall with intensity of 10mm / h, water will enter the ground and seep down. The soil will slowly absorb water, where the negative pore pressure changes into positive pore water. The difference in the slope angle will affect the infiltrated water into the soil and the pore water pressure formed. The larger the angle of the slope, the volume of landslide soil mass will be smaller because the zone of water saturation zone formed smaller. Positive pore pressure will provide stability slope value of SF < 1 which means the stability of the slope is disturbed and negative pore pressure will give stability slope value SF > 1 which means the slope is stable.

After rain, the soil that was originally pressurized negative pore water, will turn into positive water pressure because it has become water saturated. The addition of dynamic load will affect the angle of the slope. When soils with water-saturated conditions are given additional dynamic loads, the pore water pressure will increase. Tables below show that the smaller the slope angle, the unstable soil mass volume will be smaller and the saturated zone will become narrower, the safety factor will increase.

| Angle slope | SF-1 | SF-2 | SF-3 |
|-------------|------|------|------|
| 68°         | 1.110| 0.847| 0.806|
| 56°         | 1.256| 0.855| 0.827|
| 45°         | 1.550| 0.979| 0.960|
| 33°         | 2.158| 1.287| 1.257|
| 26°         | 4.409| 2.962| 2.900|

Description: SF-1 is a slope safety factor value for slope conditions prior to rainfall, SF-2 is a slope safety factor value for slope conditions after rainfall, and SF-3 slope safety factor values for slope conditions after earthquake occurrence shortly after rain.
The value of the safety factor can be seen in Table 3 for slope after rain for angle 45°, 56°, 68° is 0.979, 0.855, 0.847 and for slopes with slope conditions after the occurrence of earthquake shortly after rain is 0.960, 0.827, 0.806. The value indicates that slope conditions 45°, 56°, 68° are unstable in case of rain and earthquake shortly after rain. The safety factor values for slope angle of 26° and 33° are 2.962 and 1.287 for slope conditions after rain, and 2.900 and 1,257 for slope conditions after earthquake shortly after rain. This value indicates that slope conditions 26° and 33° slope remain stable despite rain and earthquake shortly after the rain.

![safety Factor towards the Angle of Slope](image)

**Figure 3.** safety factor toward slope with three different condition.

The safety factor will decrease with the increasing slope angle as shown in Figure 3. It shows that under the same soil parameters conditions, the larger the slope angle, the slope conditions will be more unstable.

### Table 4. Slope Angle (φ) to run-out (L) and velocity (v)

| φ (°) | SF    | H (m) | M   | L (m) | x (m) | h (x), m | v (m/s) |
|------|-------|-------|-----|-------|-------|----------|---------|
|      | SF-2  |       |     |       |       |          |         |
| 68   | 0.847 | 4.752 | 2.475 | 1.92  | 0.096 | 0.7      | 8.732   |
| 56   | 0.855 | 4.991 | 1.482 | 3.367 | 0.316 | 0.570    | 8.890   |
| 45   | 0.979 | 4.958 | 1    | 4.958 | 0.387 | 0.537    | 8.981   |
|      | SF-3  |       |     |       |       |          |         |
| 68   | 0.806 | 4.752 | 2.475 | 1.92  | 0.202 | 0.7      | 8.429   |
| 56   | 0.827 | 4.939 | 1.482 | 3.333 | 0.316 | 0.623    | 8.771   |
| 45   | 0.96  | 5.011 | 1    | 5.011 | 0.335 | 0.537    | 9.097   |

Description: SF-2 is a slope safety factor value for slope conditions after rainfall, and SF-3 is a slope safety factor values for slope conditions after the occurrence of earthquake shortly after rain.

The predicted run-out and landslide speed will be known through the modeling geometry. The effects of rainfall and earthquake intensity on run-out and landslide speed are shown in the Table 4. The research area is a potential landslide area where the slope is in critical condition. Critical slope conditions when subjected to rains and earthquakes will result in different run-out and speed values. The safety factor of the intensity of rainfall and earthquake will affect the height of the center of mass. The high value of the center of mass is directly proportional to the value of the security factor. The greater the value of the security factor the greater the value of the center of mass.
The intensity of rainfall and earthquake affects the slope stability condition because it becomes the driving force of landslide with the formation of positive pore water pressure zone. The angle of the slope slope also affects the slope stability. The larger the angle of the slope the greater the thrust caused by the increase in the shear strength of the soil. This is the effect on the run-out, the greater the angle of the slope the lower run-out landslides.

The maximum landslide run-out at the time of the rain is 4,958 m and the minimum landslide run-out is 1,920 m as shown in Figure 4. While the maximum avalanche run-out after the occurrence of an earthquake shortly after the rain is 511 m and the minimum landslide run-out is 1.920 m. The difference of landslide run-out value is caused by the difference in slope, positive water-pore pressure zone and slope shear angle. The higher the slope the smaller the unstable mass.

The intensity of rainfall and earthquake also affect the landslide speed. The angle of the slope also influences the landslide speed. The larger the angle of the slope the greater the thrust caused by the increase in the shear strength of the soil. The larger the angle of the slope the lower the landslide speed.

The maximum avalanche velocity during rainfall is 8,981 m/s and the minimum landslide speed is 8,732 m/s as shown in Figure 5. While the maximum avalanche velocity after the occurrence of earthquake shortly after the rain that is 9,097 m and the minimum run-out landscape is 8,429 m.
4. Conclusion
The intensity of rainfall and earthquake can decrease the value of safety factor. In this study, the value of the Security Factor will decrease along with the enlargement of the slope angle. The larger the angle of the slope, the slope will be more unstable. The intensity of rainfall and the earthquake affect run-out and landslide speed. In this study, the larger the angle of the slope, the lower the run-out. The maximum landslide run-out is 4,958 m and the minimum landslide run-out is 1,920 m at the time of the rain, while the maximum avalanche run-out after the earthquake shortly after the rain is 511 m and the minimum landslide run-out is 1,920 m. Likewise with the speed of landslides the greater the angle of the slope, the lower the speed. The maximum avalanche velocity during rainfall is 8,981 m/s and the minimum landslide speed is 8,732 m/s.

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