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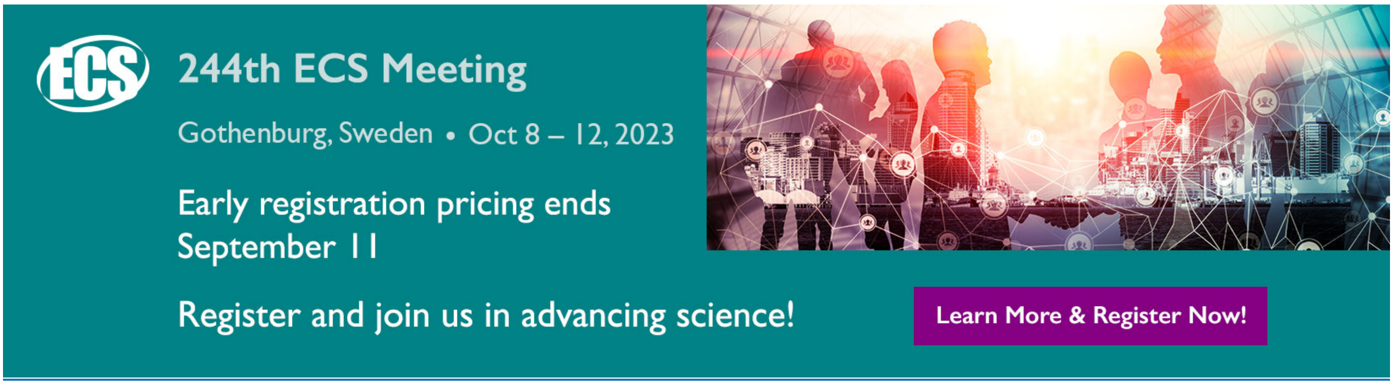

Buffer Zone Prediction for Simulated Earthquake-Induced Slope Failures in Mesilou, Kundasang, Sabah, Malaysia

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Abstract. The research area is located at Mesilou, Kundasang, Sabah at 1400 meters to 2000 meters from the sea level. It focuses on slopes of Pinousuk Gravel Unit, tilloid deposits from the glaciation of Mount Kinabalu during Late Pleistocene age. Four slopes were chosen for the estimation of 'buffer zone' of earthquake-induced slope failures. The simulation of the earthquake is conducted by using shaking table method and the earthquake event occurred in the research area on year 2018. The analysis shows the location of the buffer zones are within 1.5 meters to 13.5 meters from the toe of the slope, where the run-out distance is farther with the increment of shaking's duration and slope height. Simulation analysis shows that all slopes have detrimental impact of the settlement area of Kg. Mesilou, Kundasang but only 60% to 87% of respondents are still staying in the area. However, 74% to 84% of respondents are willingly to relocate if given new disaster-free settlements.

Keywords: Buffer zone, earthquake-induced landslide, Pinousuk Gravel, slope failure

1. Introduction

The tremor caused by an earthquake is seen as among of the causes to slope instability which may trigger the landslide occurrences. This led to increase the risk to the safety of life, infrastructures and socio-economy of population on the affected area [1,2]. Slope failure that occurs during earthquake is due to the reduction of the shear strength of the soil to withstand the tremor force produced by the earthquake. It is influences by the local materials of the slope which the stability is reduced due to the seismic activity [3]. It produces sets of fractures along the slope and enhances the potential of slope instability by reducing the soil strength. This showed that the pressure from earthquake can affect the formation of failure surface on slope thus decrease its factor of safety [4,5].

Topographic plays an important role in increasing the slope instability during earthquake. The terrain of the highland area is more tends to increase the ground movement which resulted from the shaking [6]. This increases the risk potential in the highland areas compared to the lowland areas. The increment of magnitude along with the slope height and angle do affect to the slope instability where slope with more than 25° is prone to basement failure and vulnerable to slope failure occurrences [7].

Buffer zone is defined as a neutral area to separate from the potential hazard zone. The seismic activity in areas with steep slopes have tendency to fail and put risk to lives and properties of the residents. Buffer zone acts as safe area to estimate safer distance from the slope for building constructions to ensure safety from the failure potential. It is based on the run-out distance of slope materials which collapse during the earthquake [8]. Run-out distance can be estimated through simulation of the earthquake tremor using shaking table method. The shaking table or earthquake simulator system is an instrument used for seismic event simulation. It is used widely to determine and measure dynamic characteristics and mechanism of slope failure during earthquake in laboratory [9-10]. This can use to estimate the location for buffer zone to decrease the risk of the affected area during earthquake actual event.

1.1. Research Area Background

The research area is located at Mesilou, Kundasang, Sabah which comprises of Trusmadi Formation of Paleocene to Middle Eocene age, Crocker Formation (Late Eocene to Early Miocene), Pinousuk Gravel (Pleistocene) and Quaternary alluvium deposits (Figure 1).

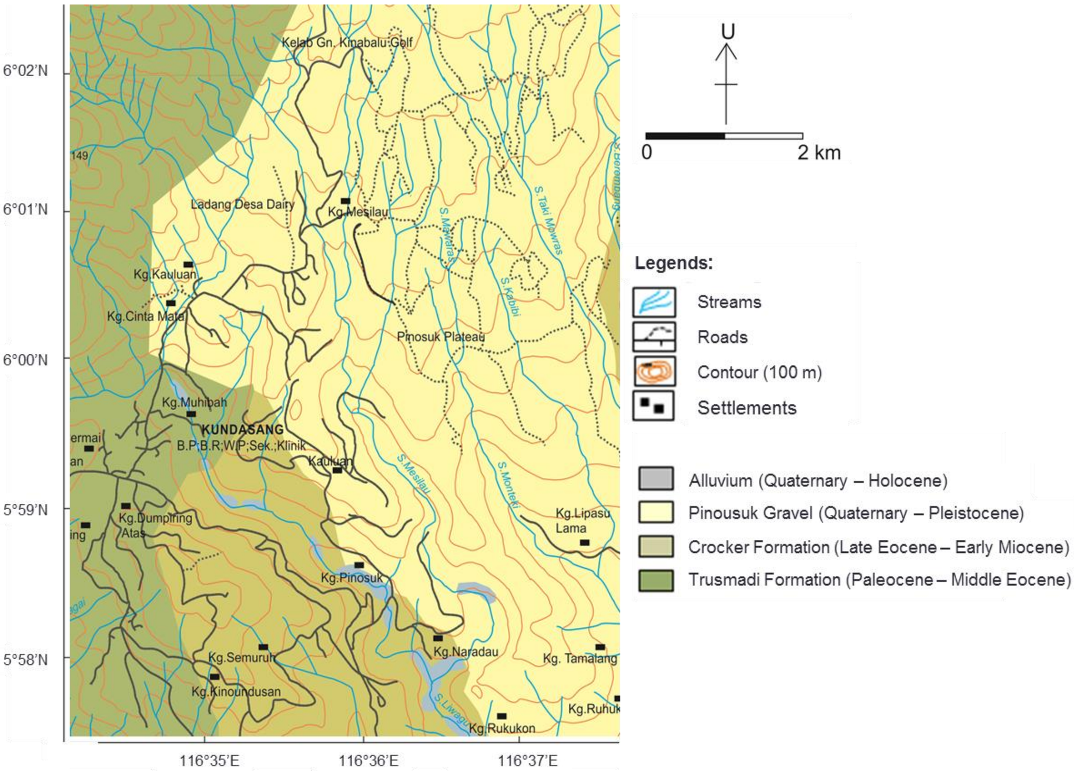

Figure 1. Geological map of the research area

Trusmadi Formation is divided into two parts namely Slate Formation and Phyllite Trusmadi Formation [11] which consist of turbidite deposition and argillaceous rocks which metamorphosed to green schist facies with quartz veins from tectonic processes [12-13]. Crocker Formation is deep water deposition comprises of sandstones, shale and interbedded of sandstone and shale units with particle size ranges from fine to coarse grains. Pinousuk Gravel is also known as tilloid deposits which formed from the glaciation of Mount Kinabalu and ancient mud flow during Late Pleistocene around 34000 to 40000 years ago [14-15]. It is formed with two episodes of deposition namely Lower Unit which consists of angular sandstones and ultrabasic rocks and Upper Unit which characterized by boulder sized granodiorite [14].

The research area focuses on Pinousuk Plateau in Mesilou which comprises of Pinousuk Gravel Unit. It is considered as risky area due to the location is within active fault zone; the intersection between Lobou-Lobou Fault and Mensaban Fault [16]. The research area is located on high topography of 1400 meter to 2000 meter, along with the lithology of unconsolidated Pinousuk Gravel, resulted to high potential of slope failure and landslide occurrences especially when been triggered with vibration of earthquake tremor. Therefore, the objective of this research is to determine the distance of slope materials of simulation earthquake-induced slope failure to estimate the buffer zone for risk prevention.

2. Materials and Methodology

Early study involves of map preparation and literature studies have been conducted to understand the research area before field works began. The field works focused on the selection of potential slope by observing their location, history of instability and slope geometry. Four slopes from Pinousuk Gravel Unit (namely S1 to S4) were chosen based on their different lithology and the domination of clasts or matrixes (soil) as main slope materials based on the percentage of fine particles [17] (Figure 2). Slope S1 is matrix dominated of ultramafic soils with various types of 1 meter diameter rocks; S2 is domination of ultramafic rocks clasts up to 1 meter size; while S3 is dominated by smaller fragments of ultramafic rocks and exhibits active fault lines; and S4 comprises of soil domination from granodiorite with up to 2 meters size blocks. All slopes were selected due to their location which is situated along the main road or nearby to buildings within the research area. The location of these slopes put the residents and their infrastuctures in risk potential, in addition the research area has directly experienced the earthquake in year 2015, which caused them landslides and debris flow.

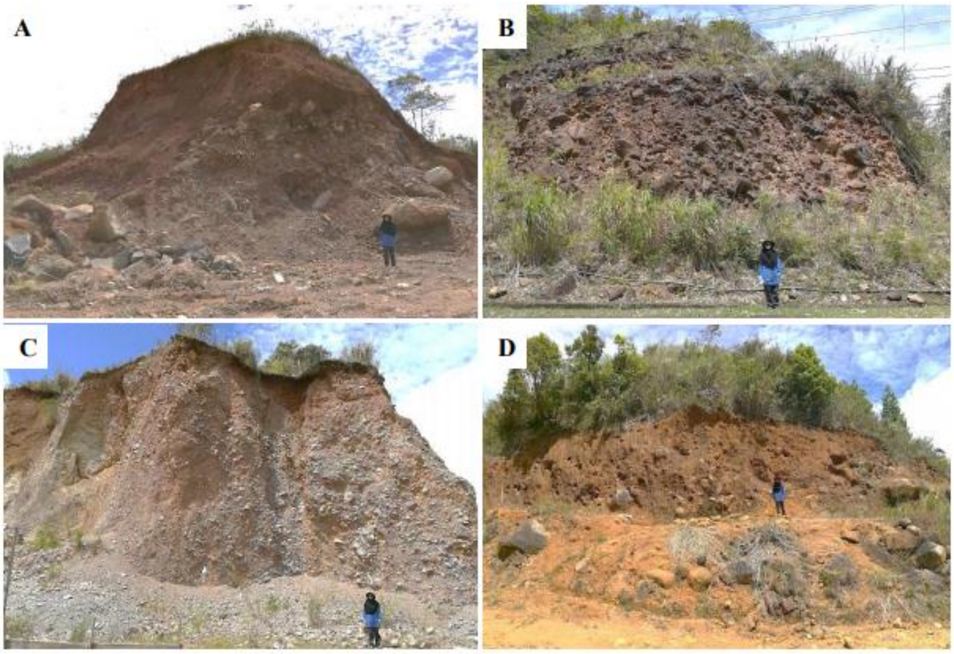

Figure 2. Research slopes labelled as (A) S1; (B) S2; (C) S3; and (D) S4

Shaking table method is used for this research to measure the ground movement when simulation tremor is acted on the slope model. It comprises of rectangular platform to move in one axis direction when been subjected to simulated vibration (Figure 3A). This method is widely used in seismic study to simulate the ground movement especially slope failure and landslide during actual earthquake event. This test was conducted in National Centre for Research on Earthquake Engineering, Taiwan. To simulate the earthquake vibration, time series of earthquake event in the research area occurred on

7 March 2018 with 5.2 Richter Scale has been selected and retrieved from USGS Earthquake Catalogue. The time series is later to be calculated to obtain value of velocity, acceleration and displacement over time to produce simulated waveform (Figure 3B).

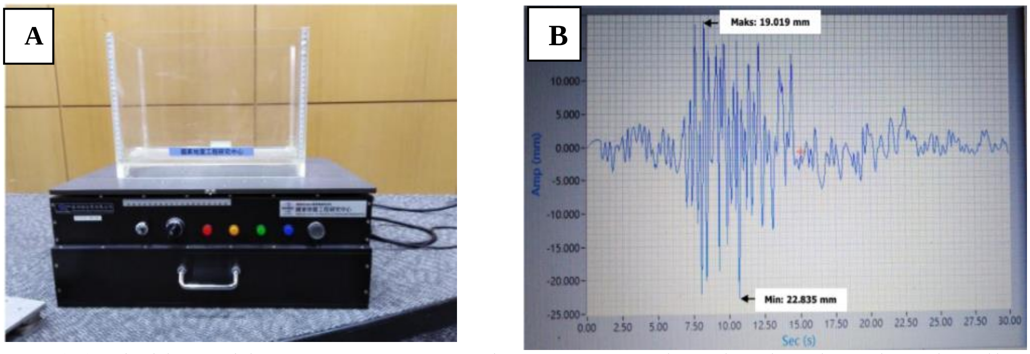

Figure 3. (A) Shaking table to measure ground movement using simulated earthquake vibration; (B) The production of waveform generated from time series of earthquake event in 2018

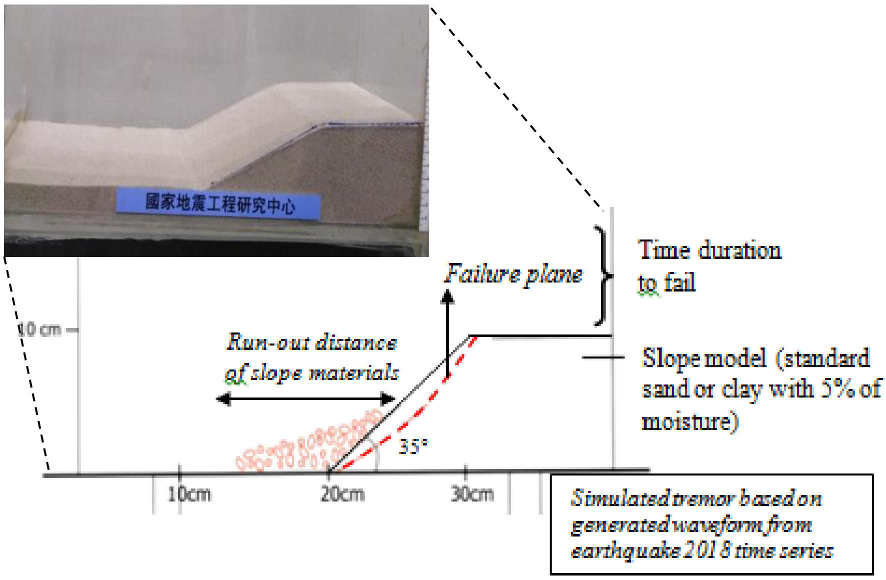

Figure 4. Slope model design and failure estimation (Small box: slope model using standard sand)

The waveform is entered using Rmax Simulator software to produce vibration for the shaking table to act on the slope model. The slope model is designed with 10 cm height and 20 cm width using materials from uniform sand and clay and compacted into the test box with angle of 35°. The angle used as an optimum angle for sand in repose state. 5% or moisture is added to the soil to bond the cohesion between grains. The ration of the slope model and the research slopes are using scale factor of similitude law [18]. The vibration lasted for 15 seconds to 30 seconds to record the failure pattern of the slope model by estimating the run-out distance of the slope materials when the slope fails. This can used to predict the potential disaster zone and estimate the buffer zone from the toe of the slope to prevent more destruction during earthquake (Figure 4).

3. Results and Discussions

The limitation for this research is using standard material as control instead actual slope material in the research area. Slope model for this research purpose is using standard sample of clean sand and clay. It will provide basic results which later is recalculated using actual percentage of sand and clay in research slopes. The percentage is obtained using particle size distribution analysis based on Unified Soil Classification System. Several 'boulders' were moulded in various sizes to imply the unconsolidated material of Pinousuk Gravel slopes.

Similitude law is used to correlate the simulation of run-out of slope model with the actual research slopes. Scale factor λ is applied for height ratio between actual slope and the slope model (Table 1). Table 1 showed the distance of slope material when been subjected to continuous vibration where it started with 5 cm from the slope before exceeds to 18 cm away from the toe of the slope model. The increment of slope height may deepen the falling displacement due to the gravity which increases the run-out distance [19]. Based on the result, it has linear correlation between the height of slope and the run-out distance during landslide, particularly for rotational slides. The distance of run-out will be farther and the volume of materials fail will be greater due to earthquake events compared to rainfall-induces landslide.

Table 1. Calculation of estimated run-out distance based on movement of slope model

	S1	**S2**	**S3**	**S4**
Slope Height (m)	7.11	6.32	11.80	3.95
Factor Scale	71.1	63.2	118.0	39.5
Run-out During First Vibration – Slope Model (m)	0.05	0.05	0.05	0.05
Run-out During First Vibration – Actual Slope (m)	3.6	3.2	5.9	2.0
Final Run-out After Second Vibration – Slope Model (m)	0.18	0.18	0.18	0.18
Final Run-out After Second Vibration – Actual Slope (m)	12.8	11.7	21.2	7.1

Table 2. Run-out distance recalculation of research slopes when fail due to continuous vibration

	S1	**S2**	**S3**	**S4**
% Sand	28.91	60.34	34.39	48.56
% Clay	26.10	31.83	29.16	30.35
(Total %)	*55.01*	*92.17*	*63.55*	*78.91*
Run-out during First Vibration (m)	2.0	2.9	3.7	1.5
Final Run-out After Second Vibration (m)	7.0	10.5	13.5	5.6

Early vibration of first 15 seconds produced fractures and reduced the slope stability shown by materials sliding down the slope. The fracture on the top of the slope is quite unnoticeable but has indicated distinct and shallow curve plane as its failure surface. It got worsened with longer duration of vibration which accelerates the failure plane for landslide to occur where the debris is accumulated along the movement path of the run-out. The movement of material due to earthquake will slide down in short distance before continues to flow and deposited in farther distance when received continuous and stronger vibration [20, 21]. This can be seen with deeper circular plane when the slope model experienced longer vibration. More 'boulders' falling and accumulated at the toe of the slope before the run-out distance is getting farther approximately 18 cm from the slope (Figure 5). Slope angle greater than 37° have potential to experience failure for exceeds the angle of repose and friction angle between particles. Continuous vibrations increase the amplification factor particularly on the top of slope which accelerates the slide of unconsolidated materials downslope in a shorter time.

Therefore, based on Table 2, the buffer zone of each research slope can be determined when the estimation of run-out distance during earthquake-induced slope failure is obtained (Table 3). It can be deduced that the distance is based on the slope height where much greater in height, the potential for hazardous zone is twice of the slope height [22]. In addition with energy and duration of time received for vibrations, the end deposits and accumulation of slope materials is getting farther and bigger in volume when the vibration is longer.

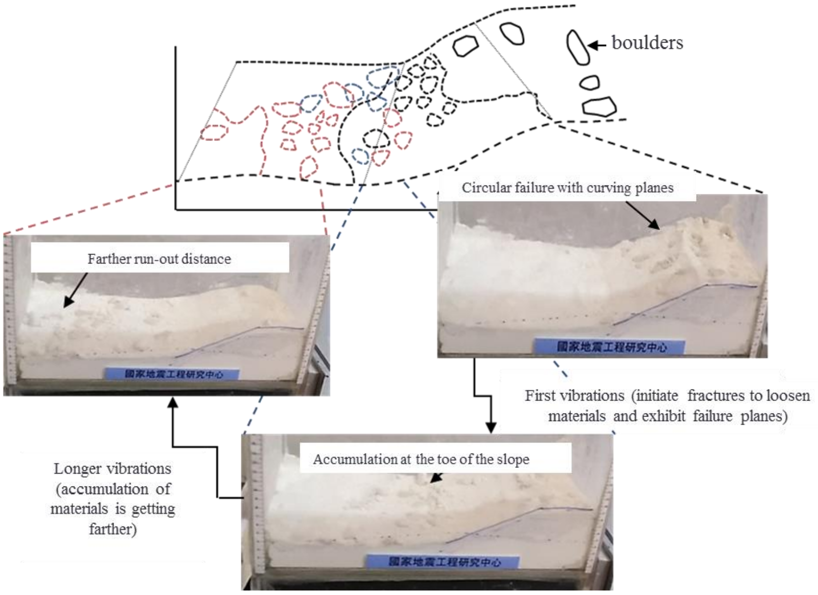

Figure 5. Descriptive sketches of run-out distance of slope material when continuous shaking received

Table 3. Estimated buffer zone for research slopes in the research area

	Buffer Zone Estimation (m)
S1	2.0 – 7.0
S2	2.9 – 7.5
S3	3.7 – 13.5
S4	1.5 – 5.6

From Table 3 above, slope S3 showed the biggest radius of buffer zone up to 13.5 meters due to the highest slope in this research, in comparison with C4 which is only 3.95 meters in height. The lithology of S3 is also playing a role where the slope comprises of smaller fragments with low cohesion and friction angle due to less percentage of sand (34.39%). The gradient of C3 (82°) reduced the slope stability with low cohesion and high plasticity, thus decrease the stability of the slope [23, 24]. These factors may result to weaker materials thus are very vulnerable and prone for failure especially if subjected with strong and long vibrations.

Figure 6 below shows estimated buffer zone for all research slopes where all selected slopes have risk potential to damage buildings or main road which located very near to the slope. Most settlements in the research area were built in high topography with steep slopes in most places. Based on this research, community in the research area (Kg. Mesilou) has been informed about the slope failure risk and the damage it can caused due to its farther run-out distance especially when earthquake occurs. Kg. Mesilou is specifically chosen for this research to raise the awareness since they have experienced the impact of earthquake on year 2015 and are exposed to the potential risk of future disasters.

Based on the questionnaire feedback, 87% of respondents are still staying in Kg. Mesilou where 60% of them refused to move to other places (Figure 7A). Although have been well informed about the potential of slope failure or landslide in the area, most of the respondents are still staying nearby to the slope due to their long period of residence in the village (more than 15 years). However, 74% to 84% of respondents are willing to relocate from their current houses if given new disaster-free settlements (Figure 7B). This is due to their understanding that Kg. Mesilou is vulnerable to disasters such as earthquake or landslide for its location and the lithology, yet there are no other places for them to relocate although they always prepared to evacuate the area upon warning from the authorities.

Figure 6. (Above) Sketch of buffer zone estimation based on run-out distance, (Below) Buffer zone estimation for research slopes in the research area

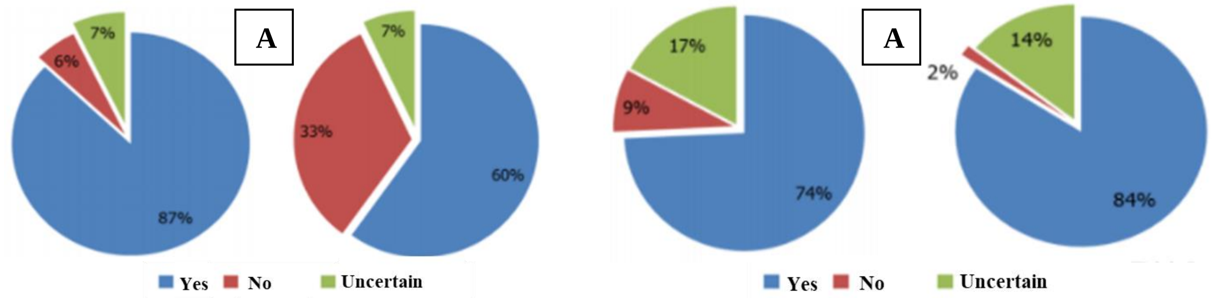

Figure 7. (A) Percentage of respondents who are willing to stay in Kg. Mesilou (left), and percentage of respondents who still stay nearby to steep slopes (right); (B) Percentage of respondents who willing to relocate from earthquake zone (left) and landslide zone (right) if given new disaster-free settlements

4. Conclusions

The research is focused on Pinousuk Gravel slopes to estimate the buffer zone by run-out distance of earthquake-induced slope failure. The simulation of earthquake shaking is using shaking table instrument based on time series of year 2018 in the research area. Results showed the buffer zones are range within 1.5 meters to 13.5 meters from the toe of the slope, where the run-out distance is getting farther with the increase of slope height and the duration of shaking received. All research slopes have risk potential to the community of Kg. Mesilou but only 74% to 84% of them are willing to relocate due to duration of residency of more than 15 years.

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