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Landslide Runout Distance Prediction of Pinousuk Gravel Slope in Mesilou Kundasang, Sabah Using Slope Characterization

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Abstract. The study area is located at Mesilou, Kundasang, which focuses on slopes of the Late Pleistocene Pinousuk Gravel unit. This study aims to determine the landslide runout distance (L) against the slope height (H), slope angle (θ), percentage of sand and clay of slope materials. Data were obtained from a shaking table instrument used to simulate earthquake tremors that resulted in landslides. The results show that the higher the slope it is, the farther the runout will occur with correlation, R = 0.87. Based on the slope failure model, the increase of slope angle will add to 60% of the runout distance with R = 0.81, while the longer time of the tremor received increases more than 120% of the distance from the previous point. Results also show insignificant correlation between clay percentage with runout distance (R = 0.23) while higher percentage of sand shows a greater distance from the slope. The greater distance of movement was due to its incohesive and unconsolidated characteristics with correlation, R = 0.64. All the findings show that slope characteristics, such as slope geometry and slope soil properties, influence the distance of landslide runout.

Keywords: Landslide, runout prediction, shaking table, Pinousuk Gravel

1. Introduction

Landslide, a natural hazard, commonly occurred either is triggered by seismic activity or high rainfall reception. The impact of landslide can be observed through the destruction of properties and fatalities. Thus, the understanding of landslide's behaviour is vital for hazard mitigation and risk assessment mainly to the vulnerable locations. The prediction for landslide runout distance is essential as a safety measure for buffer zone construction to curb the impact of landslide. Several methods were introduced to predict the runout distance including using center of mass (COM) approach, 3D models and statistical analysis [1, 2, 3]. It also can be estimate that the runout distance is influenced with the characteristics of the slope and its materials. Therefore, the aim of this paper is to predict the runout distance of landslide which triggered by seismic simulation by taking consideration of slope geometry and properties of slope materials.

The study area is located at highland of Mesilou, Kundasang, Sabah which has experienced numerous impacts from Ranau Earthquake 2015 such as landslides and debris flows. The area consists

of several rock units but focuses on Pinousuk Plateau which comprises of Pinousuk Gravel Unit (Figure 1). Pinousuk Gravel is a tilloid deposits from the glaciation of Mount Kinabalu during Late Pleistocene around 40000 years ago [4]. It is formed by two depositional phases and is characterized with unconsolidated, weak materials. The location is within Lobou-Lobou Fault and Mensaban Fault, makes the area prone for any landslide occurrences [5].

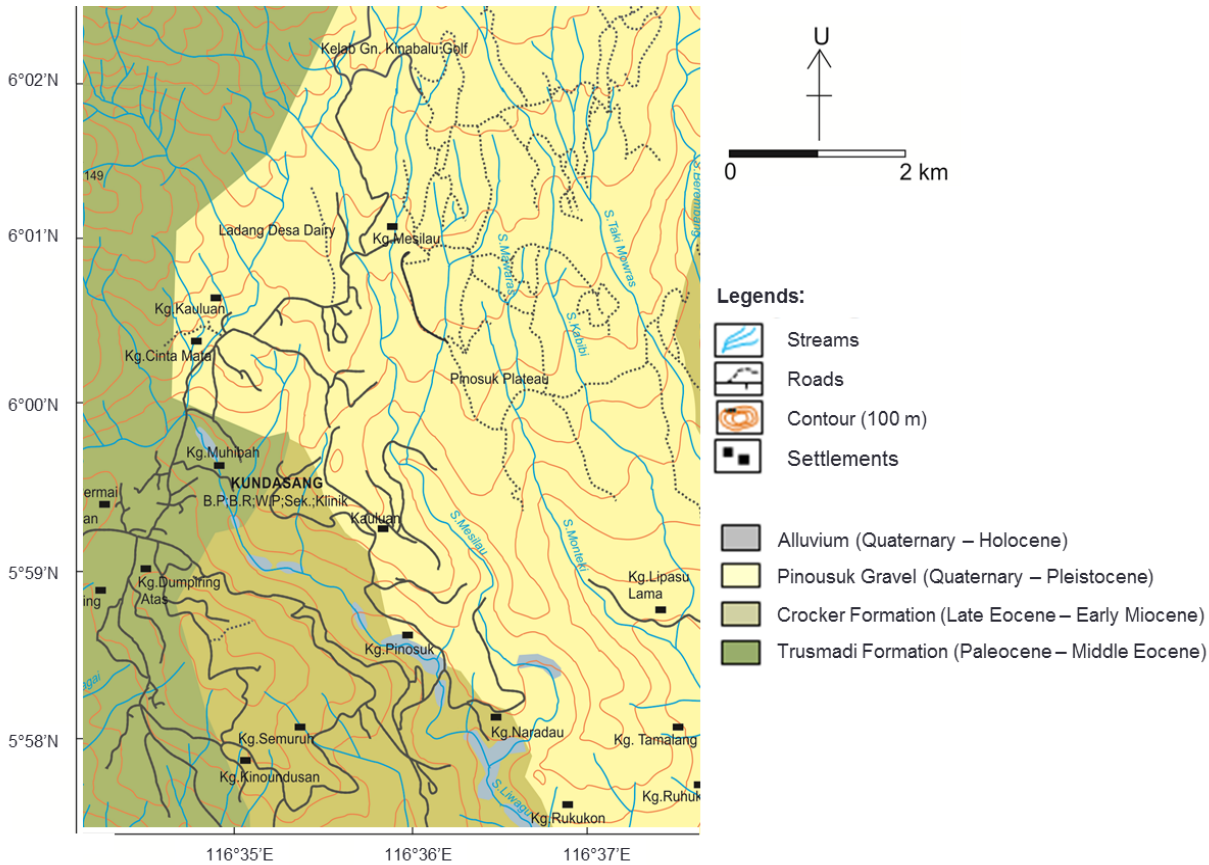

Figure 1. Geological map of the study area

2. Methodology

For this study, shaking table method is used where simulation of seismic tremor is formed to be applied on the slope model. Shaking table method has widely conducted to study the failure design of slope when experienced earthquake [6, 7, 8]. Time series of earthquake event on 7 March 2018 with 5.2 Richter scale in Ranau is selected to generate simulated waveform (Figure 2). It is later applied on the slope model which is designed in test box of 10 cm x 20 cm in height and length, respectively, using uniform sand and clay with 35° angle. The slope model is subjected to 15 seconds to 30 seconds vibration to observe the failure design and the runout distance (Figure 3). Similitude law is used to correlate the result of simulation runout with the actual slopes [9] using scale factor λ which is the height ratio between actual slope and the slope model. The runout distance is later recalculated again using actual percentage of sand and clay of research slopes to estimate the in-situ runout distance of the study area.

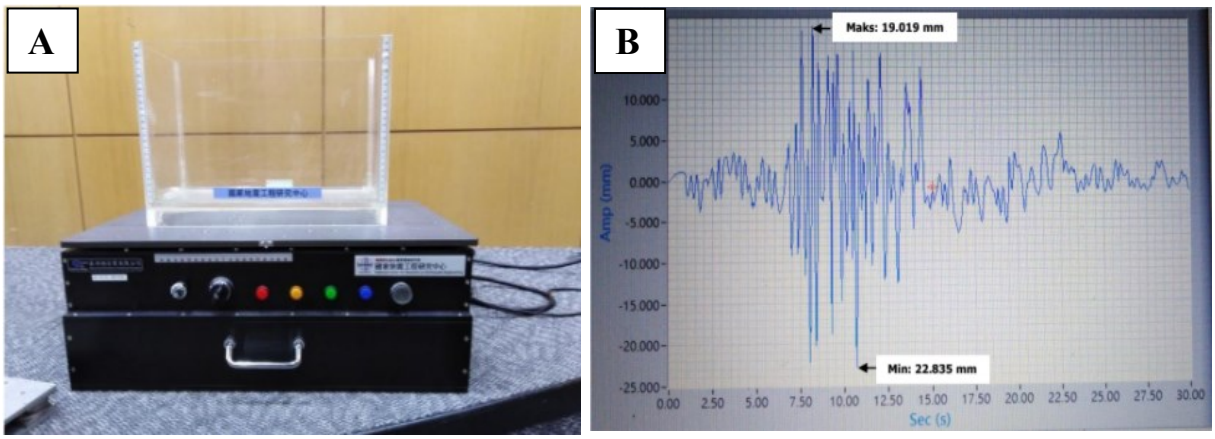

Figure 2. (A) Shaking table; (B) Simulated waveform from earthquake event in Ranau on 2018

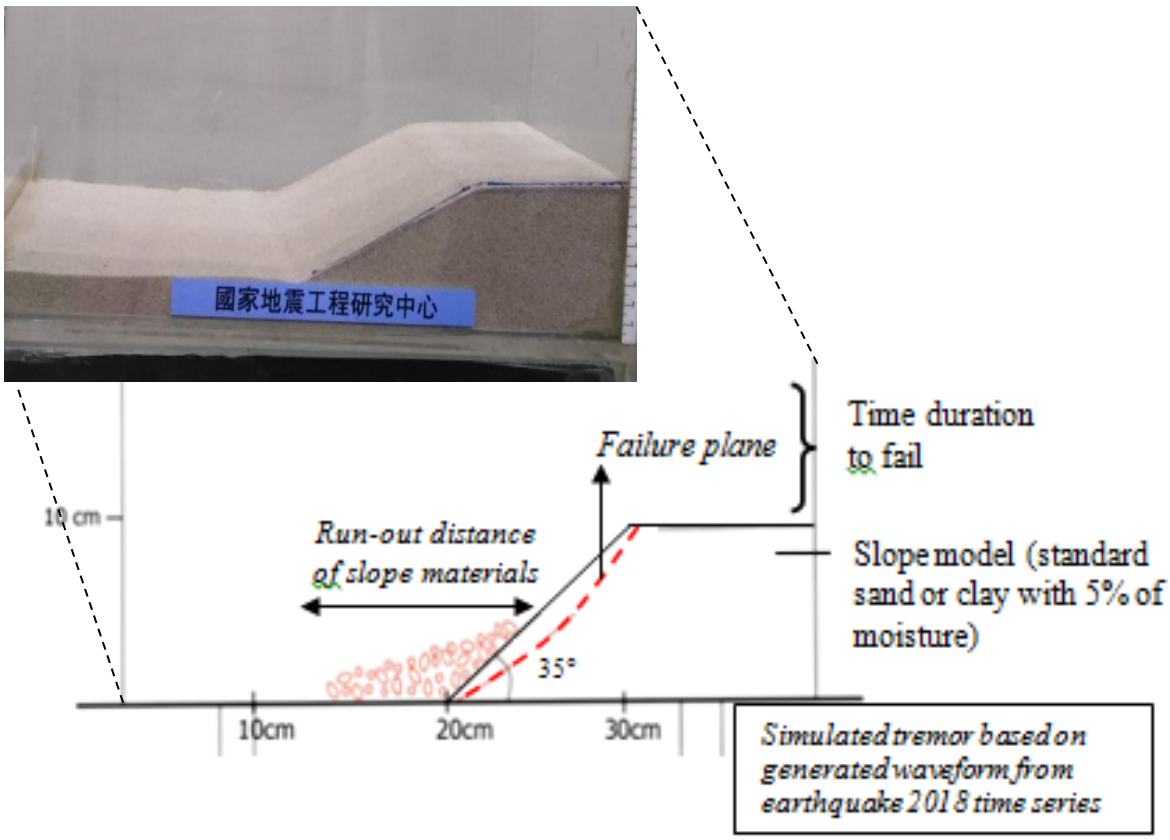

Figure 3. Slope model design and failure estimation (Small box: slope model before tested)

Four slopes from Pinousuk Gravel unit (labelled as S1 to S4) (Figure 4) were chosen with different lithology and locations. S1 is matrix dominated of ultramafic soils, S2 is dominated with ultramafic rocks clasts, S3 consists of smaller fragments of ultramafic rocks and active fault lines and S4 is dominated with granodiorite soil and boulders. All slopes are located nearby to the buildings and main road causing high risk if landslide occurs.

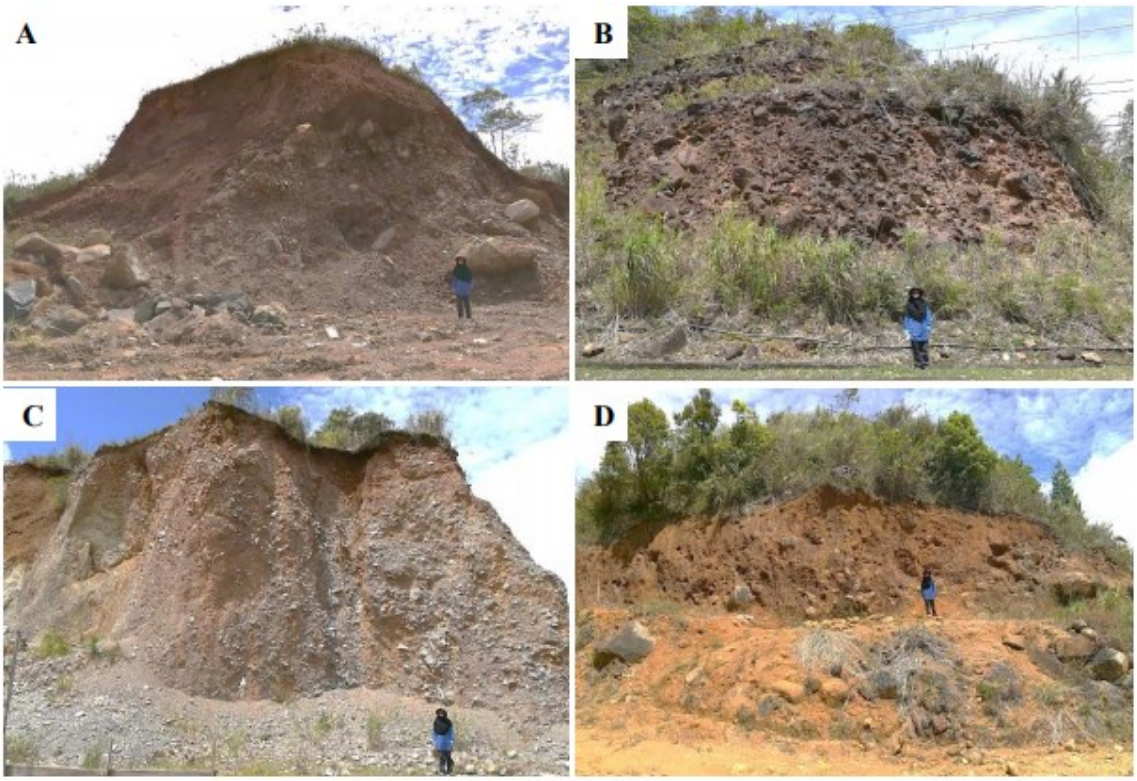

Figure 4. Research slopes in the study area from Pinousuk Gravel Unit of unconsolidated materials

3. Results and Discussion

Table 1 below shows the data for slope geometry and soil properties. These parameters are later used for interpreting the possible runout distance in the study area from simulation data which obtained from the shaking table method.

Table 1. Data for slope geometry and soil properties of research slopes

	S1	S2	S3	S4
Slope Height	7.11 m	6.32 m	11.80 m	3.95 m
Slope Angle	55°	70°	82°	71°
Moisture Content	61.74%	42.93%	53.49%	43.51%
Plasticity	30.48%	25.22%	16.19%	13.31%
Sand	28.91%	60.34%	34.39%	48.56%
Clay	26.10%	31.83%	29.16%	30.35%

Based on Erfen [10], the safety factors of research slopes range from 1.15 to 2.63 which indicate as stable slopes. However, the cohesion for soil slopes which acted as the binding material for the clasts are low (1.6 kN to 2.8 kN) [10]. It exhibits varies of moisture value and texture which reduce the ability to hold and facilitate for loose material to slide.

3.1 Runout Distance Prediction

From shaking table method, the slope model showed runout distance of 5 cm from the slope toe when experienced first tremor. It later getting 18 cm farther when subjected to continuous tremor which is twice or more than 120% than the first runout distance (Figure 5 and Figure 6). This is consistent with landslides from Wenchuan Earthquake in China where the movement of the material travel for short

distance but continue to move away when receive stronger or continuous tremors [11]. It is also supported by Havenith and Bourdeau [12] that slope materials can move further on longer tremors. This can be seen from recalculation using percentage of sand and clay of actual slopes, the runout distances range from 2.5 meters to 6.0 meters during first vibration, before moving farther from 5.6 meters to 13.5 meters after second vibration (Table 2).

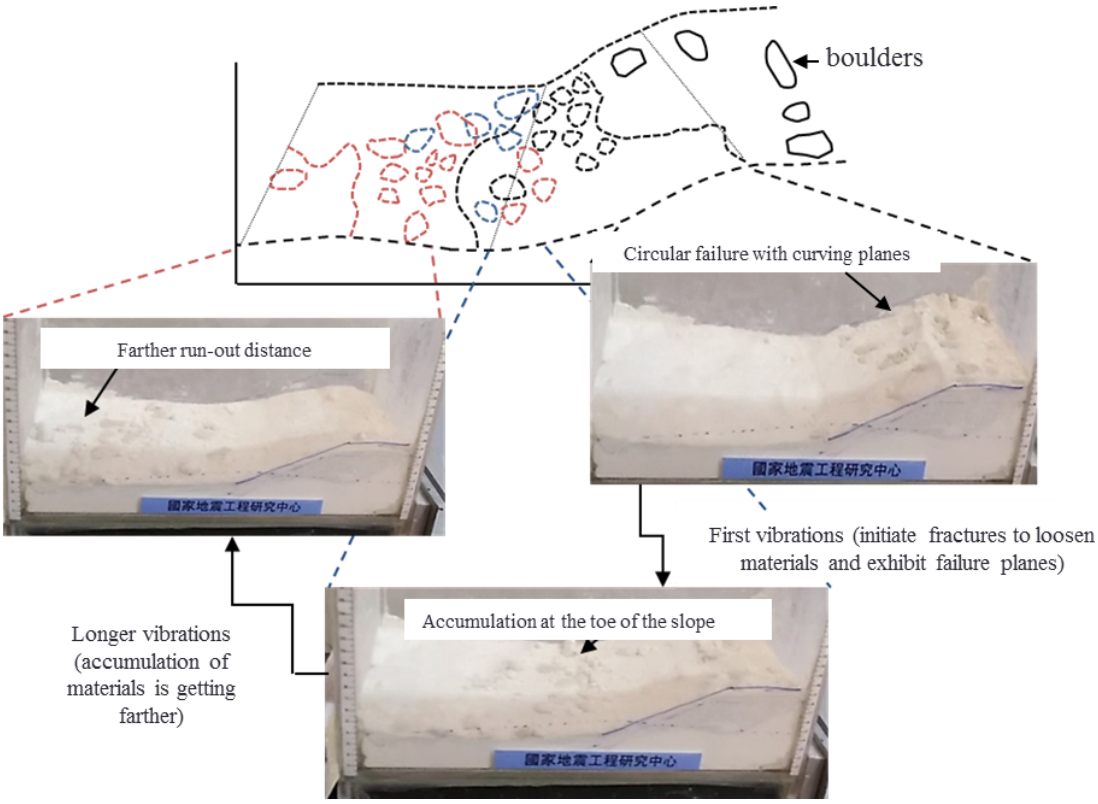

Figure 5. Descriptive sketches of run-out distance of slope material during first shaking (15 seconds) and continuous shaking received.

Table 2. Runout distance prediction using simulation failure from slope model

	S1	S2	S3	S4
Slope Model				
Runout During First Vibration (m)	0.05	0.05	0.05	0.05
Final Runout After Second Vibration (m)	0.18	0.18	0.18	0.18
Actual Slope (Recalculation)				
Slope Height (m)	7.11	6.32	11.80	3.95
% 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*
Runout during First Vibration (m)	3.1	4.7	6.0	2.5
Final Runout After Second Vibration (m)	7.0	10.5	13.5	5.6

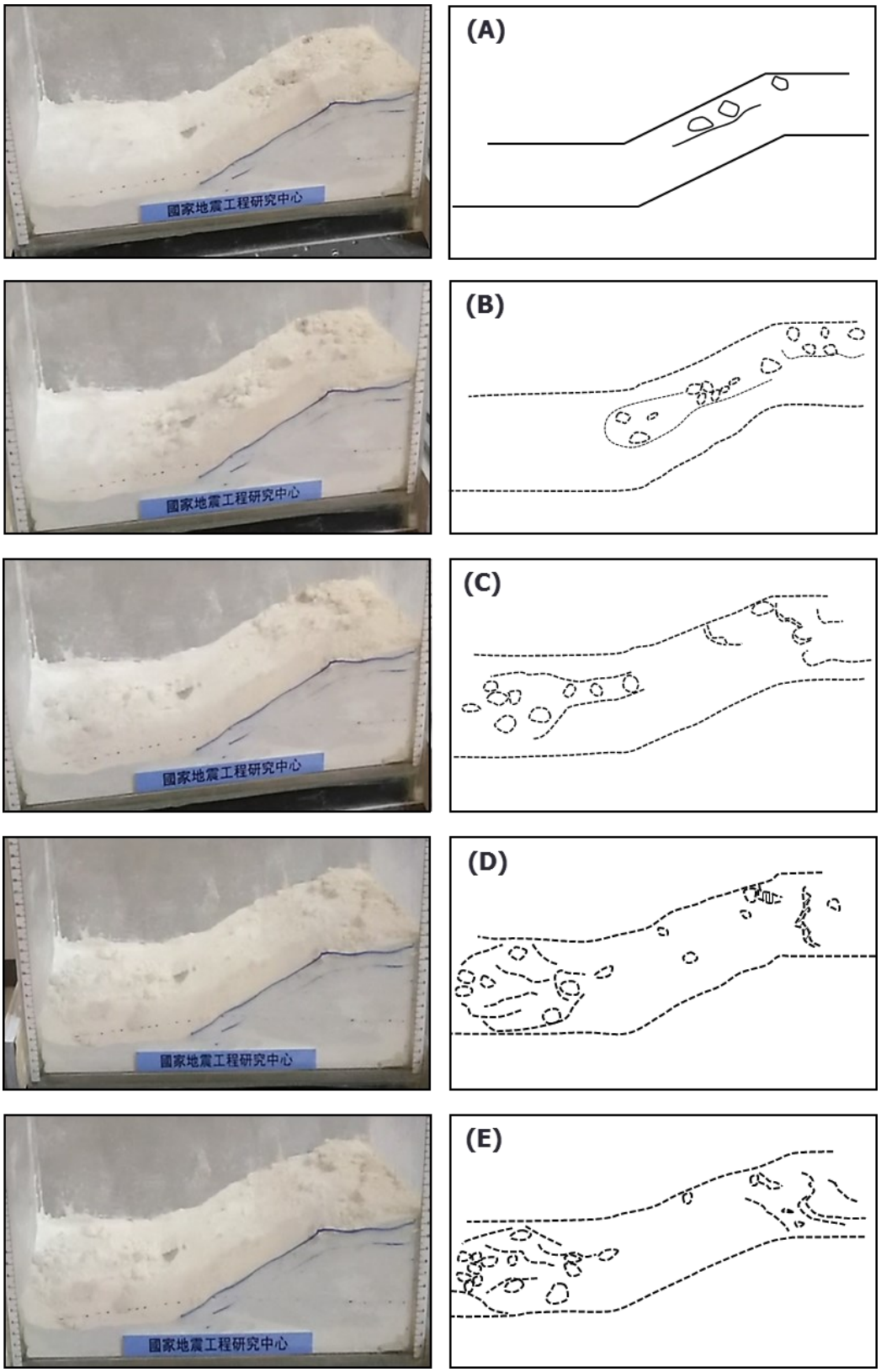

Figure 6. Diagram (A) to (C) showed the failure and movement of materials after first vibrations of 15 seconds, followed by (D) and (E) to exhibit farther run-out distance of debris accumulation of 18 cm from the toe of the slope model when received continuous vibration

3.2 Correlation with Slope Characterization and Soil Properties

The slope height also plays an important role in estimating the runout distance. The increase in slope height will influence the slope material to move further. Figure 7 show slope geometry of height and angle of slope which linearly correlated, with value of R is 0.87 and 0.81, respectively (Table 3). R value more than 0.8 show strongly correlated between two variables which indicate farther runout distance with the increase of slope height and angle.

Table 3. Correlation between slope geometry and soil properties with runout distance

	L
Runout distance, L	1
Slope height, H	0.870
Slope angle, tan (θ)	0.808
Moisture content	-0.561
Plasticity	-0.132
% Sand	0.643
% Clay	0.229

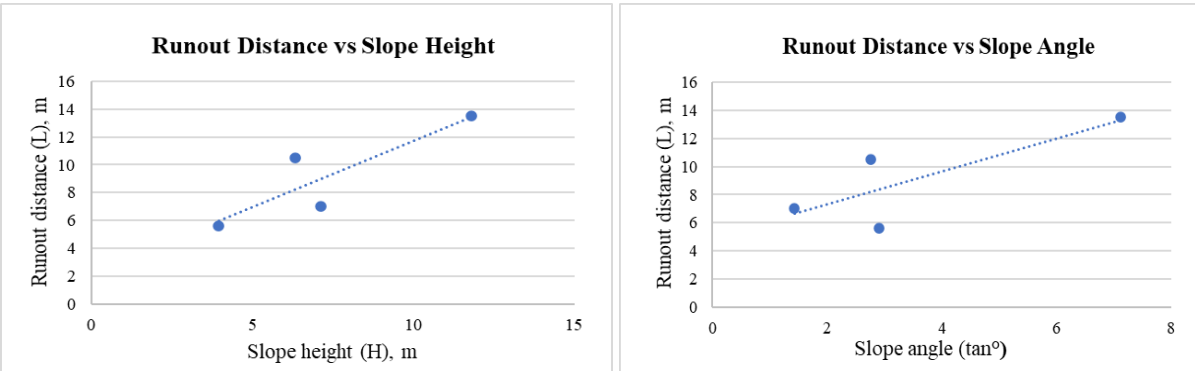

Figure 7. Strongly correlated between runout distance with the slope height and angle

Slope with higher sand percentage leads to larger runout distance. This is due to cohesionless materials with less moisture accelerates the materials to travel faster and farther [1,13]. The correlation between sand percentage and runout distance for slopes in the study area show moderate correlation with R = 0.64. However, clay percentage in the study area show small and negligible correlation to influence the runout distance (R = 0.23). High percentage of clay with high fraction of moisture may initially enhances the runout [14] but reduce it when too much clay forming viscous flow [13]. Figure 8 below shows the correlation between percentage of sand and clay with the runout distance. It exhibits moderate to insignificant correlation, relatively, which depending on other factors such as moisture content that might affects the distance of runout prediction.

Based on Pinousuk Gravel slopes in the study area, slope S1, S2 and S3 which consist of ultramafic materials have larger runout distance between 7 meters to 13.5 meters, than slope S4 which has granodiorite materials with only 5.6 meters runout. This shows that each parameter of slope geometry and soil texture must be considered together to predict better runout distance for any landslide occurrence in the future.

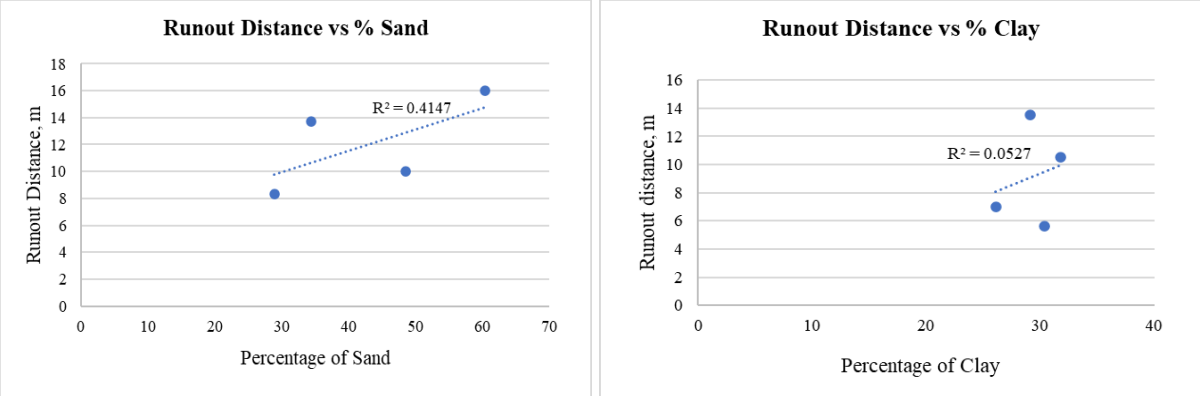

Figure 8. Moderately correlated between runout distance with percentage of sand (left); negligible correlation between runout distance with percentage of clay (right)

4. Conclusions

The research is focused on Pinousuk Gravel slopes to predict the runout distance using computational method from a simulation of earthquake-induced landslide model. Results showed that slope geometry (height and angle of slope) are strongly correlated with the runout distance with $R < 0.80$. The percentage of sand and clay also influenced the runout distance depending on the moisture content, plasticity and cohesion of the slope material with moderate and negligible correlation, respectively.

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