

Dynamic slope stability analysis for Sabah earthquake

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Abstract: An earthquake commonly triggers widespread and destructive damages, which these can include building collapse, tsunami, liquefaction, and landslide. The earthquake that struck the western region of Sabah on June 5th, 2015, with a local magnitude of 5.9, induced severe and extensive land instabilities in areas such as Ranau, Tambunan, Tuaran, Kota Kinabalu, and Kota Belud. Unfortunately, there is only a very limited literature on earthquake induced landslides in Malaysia. Therefore, the aim of this study is to understand the mechanism of earthquake induced landslide at Sekolah Menengah Kebangsaan (SMK) Ranau using 2D finite element method in RS². The displacement measured from the slope at SMK Ranau is used to verify the model and the effect of the seismic load has been monitored. A good agreement was found between the numerical model and actual site condition. In depth understanding of earthquake triggered slope failure was successfully studied using the RS² software.

Keywords: Dynamic slope stability analysis, Sabah earthquake, finite element modelling, RS²

INTRODUCTION

Sabah is located in the east of Malaysia, which is classified as moderately active in seismicity. This area experiences earthquakes of local origins (Tjia, 2007) and also originating from the nearby area located over the southern Philippines, the Straits of Macassar, the Sulu Sea, and the Celebes Sea. Sabah suffers more earthquake activities than other states in Malaysia (Abas, 2001). The 2015 Sabah quake happened at around 07:15 local time on the 5th of June with a magnitude of 5.9. The quake's epicentre was located 12 km WNW of Ranau, at a depth of 10 km. Roads and buildings, including schools and a hospital on Sabah's west coast, were also damaged (USGS, 2015). Based on the earthquake history of Sabah, this was the most powerful earthquake in Sabah for 39 years, since 1976 (Bernama, 2015).

Earthquake induced landslides are among the most deadly disasters occurring to humans, and have caused thousands of deaths as well as great economic losses (Keefer, 1984). Earthquake motion generates a movement of natural or engineered slopes or earth structures; landslides will occur when the slope fails to sustain the force of gravity. The most dangerous impact is when the slope fails suddenly without warning and the speed of the soil materials can travel down the slope to damage people or property nearby. The slope materials can travel varying

distances, from a few centimeters to many kilometers, depending on the gradient of the slope and the volume of the materials.

This paper deals with the slope instability analysis using the finite element method (FEM) at SMK Ranau. The slope condition was assessed during the field visit to Ranau on the 10th June 2015 (Figure 1). The maximum settlement was found under the building with approximately 1.0 m and 0.6 m in vertical and horizontal directions respectively. Tension cracks were also observed that reflect slope movements due to the earthquake event.



Figure 1: On site slope condition, red circle mark as Point A.

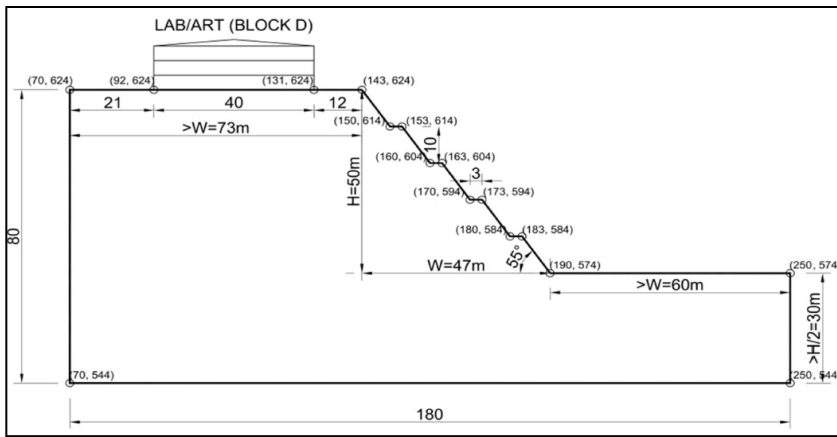


Figure 2: Slope geometry of SMK Ranau.

METHOD OF ANALYSIS

Model generation

The RS² software, a 2D FEM program was utilized in constructing the slope at SMK Ranau (Rocscience, 2015). The models were divided into two cases; 1) Case 1 is the initial state in a static condition before the earthquake and 2) Case 2 is the slope model with dynamic load, so as to simulate the earthquake event at SMK Ranau. The slope geometry is displayed in Figure 2, showing a building block located 12 m away from the slope crest. The slope consists of six benches with a slope angle of 55° and 50 m in height. The soil properties are tabulated in Table 1 (Kumpulan IKRAM (Sabah) Sdn. Bhd., 2002).

Uniform mesh with six (6) node triangles and employing 1500 elements was used in the modelling. The hydraulic condition was determined, and in using this model, the groundwater condition was assumed to be in a steady state. The boundary conditions of the slope model for the initial and dynamic analyses are as shown in Figure 3. The boundary at the base of the static model was fixed for both the *x* and *y*-directions, while the vertical side boundaries were fixed for the *x*-direction. For the dynamic model boundary conditions, a damping condition was assigned to the bottom boundary that would enable absorption of the incoming shear and pressure waves travelling through the soil. A transmit boundary condition was applied to the *x*-direction restraint segments to allow the input

wave motion to enter the soil system while absorbing the shear and pressure waves that would be leaving the soil domain.

Initial condition and dynamic loading

The initial loading condition in this study was the field stress and body force. Gravity stress was assigned as the field stress in the model, and the horizontal and vertical stresses were assumed to be equal. A uniform loading of 40 kN/m² was applied in the model to take account of the 3-storey building on the site (British Standard, 1996).

In RS², the dynamic analysis option can be used to examine earthquake, blast, and machine loading scenarios. Dynamic boundary conditions will allow the model to absorb incoming pressure and shear waves, transmit motion into the model, and insert user-defined dashpot dampers and nodal masses. In this study, earthquake records were input along the base of the model in terms of an acceleration time history. As such, the maximum

Table 1: Summary of soil properties.

Engineering Properties	Clayey Sandy Silt	Sandy Silt	Silt with Sandstone
Unit Weight (kN/m ³)	20	22	22
Young Modulus (MPa)	30	30	50
Poisson Ratio	0.3	0.3	0.25
Friction Angle (°)	32	40	50
Cohesion (kPa)	50	22	30

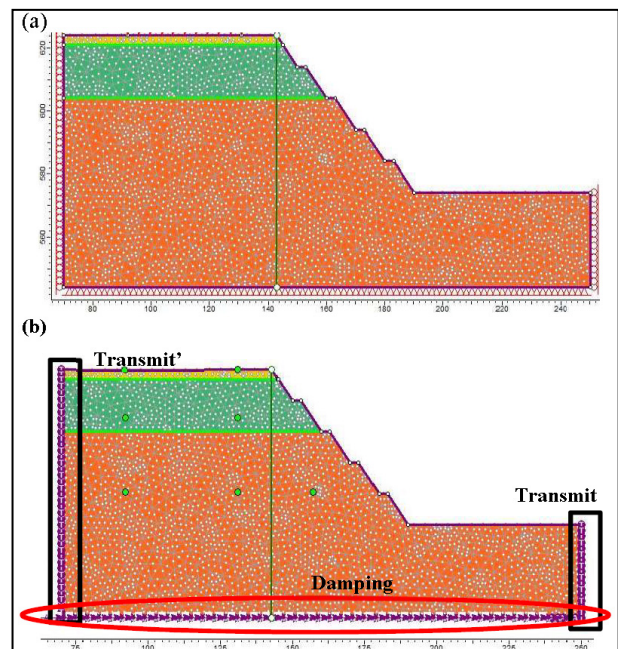


Figure 3: Boundary condition for (a) Case 1 and (b) Case 2.

displacement occurring between each stages of the dynamic analysis can be observed. With the time query capability, the maximum displacement, velocity and acceleration observed during the simulation at all nodes were recorded, however, the Shear Strength Reduction Factor (SSRF) cannot be determined due to the software limitation.

An additional loading of the earthquake was incorporated in the Case 2 model using a dynamic condition; the dynamic loading was compiled from the Malaysian Metrological Department (Malaysian Metrological Department, 2015). The data shown in Figure 4 was recorded by a seismograph located at the Kota Kinabalu station. Even though the data was collected at 67 km away from Ranau, the acceleration time history is adaptable since the pattern of the wave is the primary consideration. One of the most important factor affecting the displacement is the pattern of the seismic wave. Then, the data of the acceleration in meters per square second and time history were used to actuate a dynamic vibration in the RS² software. Drift correction was assigned in the acceleration analysis to obtain a normalised displacement, so that the nodes will start and end at zero.

RESULTS AND DISCUSSIONS

In this study, the SSRF for the initial condition (Case 1) was determined to validate the model. The critical strength reduction factor is equivalent to the “safety factor” of the slope. It was found that the SSRF of the slope before the earthquake struck was 1.33, while the safety factor of a cut and fill unreinforced slope should be at least 1.30 (Public Work Department, 2010). Therefore, the slope at SMK Ranau is categorised as being in a stable condition.

Once the dynamic load was applied to the model in Case 2, the slope was monitored for displacements at Point A. The location of Point A reflected the edge of the building, where the maximum settlement was observed during the field work. Figure 5 shows the displacement vector of the slope when the earthquake occurred. It was found that the biggest movement took place under the building, with a downward movement. The model also showed a typical circular failure plane of the soil slope, but with a larger radius, which again cover the area of the building. This is due to the earthquake vibrations, additional loading from the building had promoted the settlement with the re-arrangement of the soil mass thus causing the downward movement and producing a huge settlement under the building area. This condition has generated formation of a tension crack at Point A (Figure 6).

Meanwhile, Figure 7 shows the vertical and horizontal displacements at Point A respectively; from the surface to 70 m below the ground. As expected, the highest vertical and horizontal displacements of 1.60 m and 0.6 m were found at the surface and decreases with increasing depth. From the model, there is no settlement as the depth

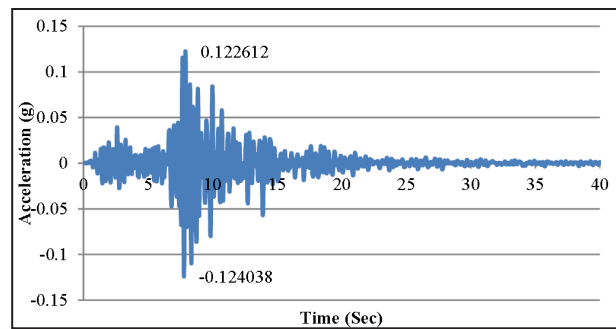


Figure 4: Earthquake acceleration time history obtained from seismograph (Malaysian Meteorological Department, 2015).

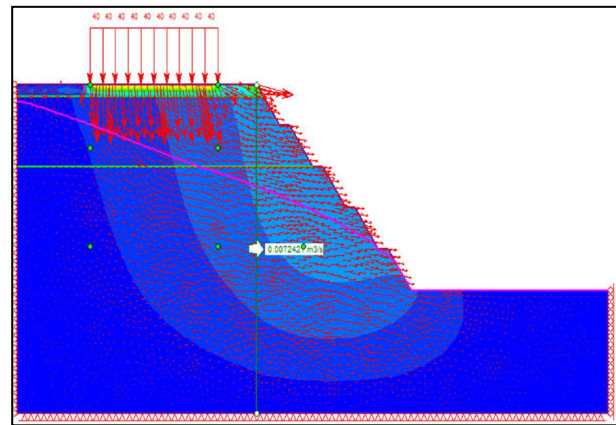


Figure 5: Displacement vector for Case 2.

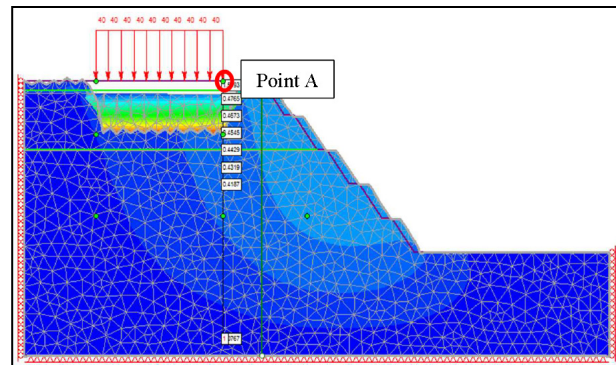


Figure 6: Slope deformation for Case 2.

approaches 70 m. This is because as depth deepens, the confining pressure will increase, and this diminishes the vibration of the soil and thus eliminates the movement. Table 2 compares the results obtained from the numerical model of Case 2 (with dynamic load) and the actual site condition observed after the earthquake at Point A, in terms of displacement. A good agreement was found between the two conditions with a percent difference of only 1.6% for horizontal displacement values.

CONCLUSIONS

The slope stability analysis of the SMK Ranau was successfully simulated using the finite element method using RS² software. The slope before the earthquake event was

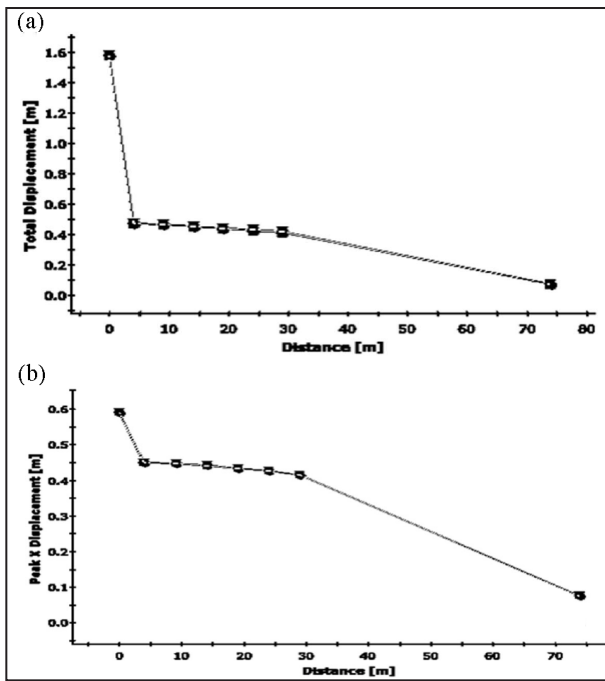


Figure 7: Displacement along the Point A at (a) vertical and (b) horizontal directions.

considered as stable, with a SSRF of 1.33. The dynamic performance of the slope subjected to an earthquake has been investigated in this study. The failure mechanism was computed, and it was found that the effect of the earthquake has triggered the slope movement. The earthquake vibrations had affected the slope stability and produced the tension cracks at the slope near the building after the earthquake. The results of the numerical analysis and the real site conditions show a good agreement, with the difference of only 1.6%.

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Table 2: Comparison of displacement values between numerical model and site condition at Point A.

	Numerical model	Site condition
Vertical displacement (m)	1.6	1.0
Horizontal displacement (m)	0.6	0.6

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