EARTHQUAKE-INDUCED LANDSLIDE ANALYSIS FOR BATU FERINGGHI, PENANG

Mastura AZMI[1], Junji KIYONO[2] and Aiko FURUKAWA[3]

[1] Doctorate Candidate, Department of Urban Management, Kyoto University,
Kyoto 615-8530, Japan, masturaazmi@gmail.com
[2] Professor, Department of Urban Management, Kyoto University,
Kyoto 615-8530, Japan, kiyono@quake.kuciv.kyoto-u.ac.jp
3 Associate Professor, Department of Urban Management, Kyoto University,
Kyoto 615-8530, Japan, furukawa.aiko.3w@kyoto-u.ac.jp

This paper discuss on the assessment of earthquake-induced landslide for Batu Feringghi, Penang, Malaysia. Although the island is far from the earthquake source but some record shows that tremors were felt on the island. Location of interest were selected based on a residential project done by local developer and was analyzed using Ordinary Slice Method and Newmark Method. The results show that with increase of maximum Peak Ground Acceleration, lower value of Factor of Safety can be found. Different types of soil also give impact to the changes of factor of safety in the slope.

***Key words**: Slope Stability Analysis, Earthquake-induced landslide*

1. INTRODUCTION

Landslide is a part of a geomorphologic movement of earth that changes the landscape of earth surface. It occurs in many ways such as mudflow, slope failure and rock/soil movement. It may affect directly or indirectly to human and their activities depending on its size and location. The massive and uncontrollable land-use has increase the susceptibility of landslide. Of course this cannot be denied when it comes to urbanization especially in city area.

Most of the locations where landslides occur are in developing countries where regulations are insufficient and management is hard to sustain. All landslides have few things in common that is they are the result of soil/rock movement controlled by gravity and this can occurs due to several factors such as earthquakes, volcanic eruptions, soils saturated by heavy rain or groundwater rise, and river undercutting. Earthquake shaking of saturated soils creates particularly dangerous conditions. Although landslides are highly localized, they can be particularly hazardous due to their frequency of occurrence.

In hazard risk assessment and management, landslide hazard prediction and warning normally includes spatial prediction and time warning[1)]. But it will be different for each country depending on its needs and control measures. For example, developed countries like USA and Japan provided a real-time warning system which is public-oriented based. The accuracy is very high due to the availability of accurate data and precise calculation on probability. The system comprises of accurate rainfall data, advance remote controlling and detail investigation of hazard zonation work.

2. MALAYSIA LANDSLIDE HISTORY

The first recorded national landslide in Malaysia was in 1961[2)]. Although it was not the first one officially recorded, but it was the official first after the Malaysia independence in 1957. The tragedy occurred at Ringlet, Pahang and claimed 16 deaths.

After that event, increasing number of deaths due to landslide tragedy had occurred. From 1973 to 2000, about 440 landslides have been recorded with almost 600 lives had been claimed due to landslide catastrophes[2)]. This is shown in Figure 1. It can be seen that more number of fatalities occurred after 1990s. This was the time when development of hilly terrain and slope was significant due to urbanization.

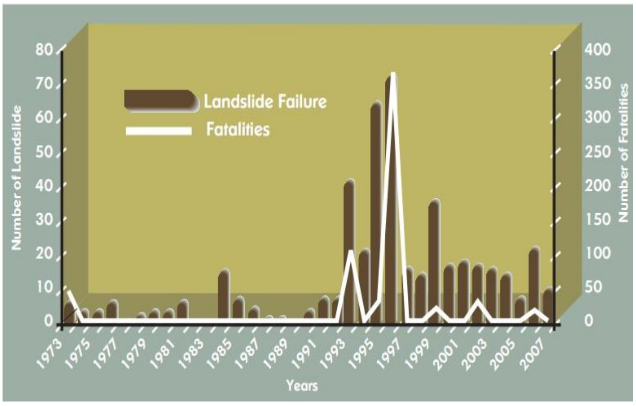

Figure 1 - Reported landslides and fatalities 1973-2007[2)]

It was due to the Highland Towers Tragedy on 11 December 1993 that claimed 48 lives that the government decided to set up several related agency to form the special force to help mitigate the nation when disaster occurs[2)]. This was the time when not only the government but also public started to notice the importance of landslide catastrophe. Another record of the highest fatality for a single landslide event occurred on 26 December 1996 when debris flow caused by Tropical Storm Gregg wiped out a few villages in Keningau, Sabah and claimed 302 lives.

Landslides do not only affected human lives but also the nation economy. This can be seen through the losses of public infrastructure such as road network and indirect losses such as business trips and interrupted schedule. Therefore, a landslide early warning system together with probability assessment of future landslides is important not only to predict landslide but also to plan future land-use.

3. MALAYSIA EARTHQUAKE HISTORY

The Malaysia Peninsular is located far from seismic source zone of Sumatra which is approximately 400km from the peninsular[3)]. But it is close enough to seismically active plate boundaries (the Indo-Australia and Eurasian plates). Major earthquakes from the plate boundaries are felt in Malaysia[4)].

Malaysia Peninsular is located at a low-seismicity region and almost will not experience any earthquake damage until 2nd November 2002 which caused tremors at several cities including Penang Island[3)]. The 2004 Indian Ocean earthquake also has affected few cities in Malaysia.

Table 1 shows previous earthquakes shocks felt in Malaysia from year 1909 to 2005. According to Malaysian Meteorological Agencies (MMA), most earthquakes felt in Malaysia are between magnitude 4 to 6 based on Modified Mercalli Scale.

It can be seen that the highest number of shocks felt were in Selangor/Kuala Lumpur followed by Penang Island.

Table 1 – Earthquakes shock felt in Malaysia

State	Frequencies	Maximum Intensity Observed (Modified Mercalli Scale)
Peninsular Malaysia (1909-2005)		
Perlis	2	IV
Kedah	9	V
Penang	31	VI
Perak	18	VI
Selangor/ Kuala Lumpur	37	VI
Negeri Sembilan	4	V
Melaka	9	V
Johor	21	VI
Pahang	4	III
Terengganu	1	IV
Kelantan	3	IV
Sabah & Sarawak (1923-2005)		
Sabah	24	VII
Sarawak	5	V

4. CURRENT MALAYSIA APPROACH

In Malaysia, government is the center of all decision that is being made related to either in mitigating or controlling any hazard. It is undeniably true that the government need to control all regulations related to development of hill slope. However, it is time to educated public and private sectors that everybody is important in order to reduce the risk by increasing risk mitigation rather than spending more money on restoration.

Developed countries has shown that the success of reducing landslide responsibilities relies not only on the government side but also the state and local authorities, private sectors, researches and non-profit community organizations.

In disaster and restoration management cycle, the approach illustrated in Figure 2 is well known worldwide and summarizes the main actions to be carried out in relation to a disaster[5)]. Four sectors in the cycle are used to differentiate what to be done before and after disaster. “Risk Control” is expected before any disaster occurs with certain preparedness and mitigation where else “Crisis Mitigation” is measures to be taken after the event with stressing on response and repair-restoration phase.

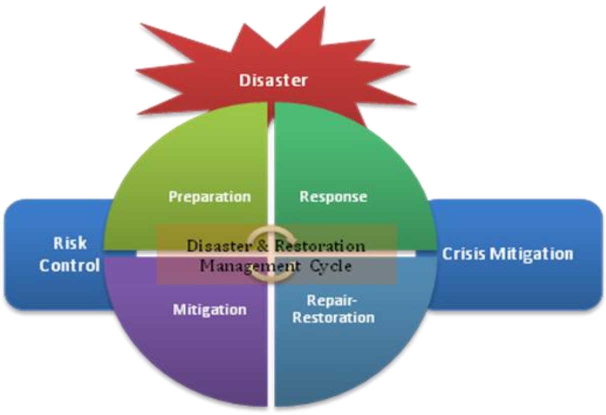

Figure 2 – Disaster and Restoration Management Cycle

Currently, there are very limited institutions that are looking into method to reduce risk, monitoring potential risk and to educate public knowledge on landslide hazard awareness. Therefore, the government needs to play important role to reduce considerably economic damage and loss of human lives resulting from the occurrence of disastrous natural events.

5. LOCATION OF INTEREST

There are several locations in Malaysia which can be classified as highly risk landslide area (Figure 3)[2]. One of it is Penang Island.

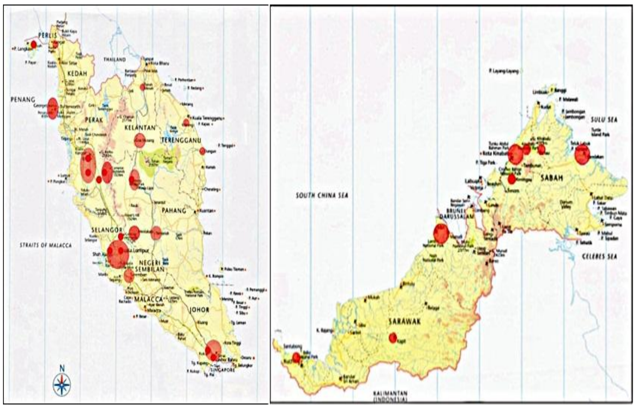

Figure 3 – Location of high cases of landslides in Malaysia

Penang Island is one of the highly populated areas in Malaysia with a population of 1.5 million people. It is highly dense area, located at the northwest of Peninsular Malaysia[9] and fast in development. Penang Island is consisted of 2 areas – an Island ($293km^2$) and a portion of mainland ($738km^2$).
It is the third largely populated state in Malaysia but most of the population stays on the island area where it is hilly. Malaysian government also stated that Penang Island (Figure 4) is one of the highly risk landslide area.

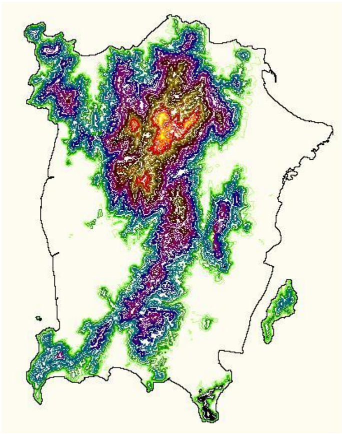

Figure 4 – Penang Island

In this paper, the location of interest was specified to Batu Feringghi. This is one of the highest locations on Penang Island and a lot of residential was built here. This place is known for its beautiful beaches and is favourite among tourists and locals.

6. METHODOLOGY

This paper selects two slopes to be checked with the possibility of landsliding due to earthquake. These two slopes were taken based on a housing project done by local developer in Penang Island. Houses were built on these slopes as well as some public utilities such as roadwork as well as drainage system.
Although these slopes does not replicate the entire Batu Feringghi site, but it will be a good start to enable further investigation on the whole Penang Island. Table 2 below shows the summary of soil properties of the two slopes selected as a case study for this paper. The soil properties were taken based on several tests done during the site investigation phase. The soil was bored through Standard Penetration Test as well as standard soil tests such as Triaxial test and Liquid Limit and Plastic Limit test.

Table 2 – Soil Characteristics for Batu Feringghi, Penang

Slope 1-1			
Soil Type	Unit weight (kN/m^3)	Cohesion	Friction angle
Sandy Clay	18.5	2.0	30
Silty Clay	18.5	2.5	36
Weathered Granite	19.5	15.0	37
Fresh Granite	26.5	25.0	40
Slope 2-2			
Sandy Clay	18.75	6.0	36
Weathered Granite	19.5	15.0	37
Fresh Granite	26.5	25.0	40

Calculation on the static force factor of safety was based on the slice method. A program was done to calculate based on the following Ordinary Method of Slice equation:

$$F = \frac{\sum (W\cos\alpha - ul)\tan\phi + \sum cl}{\sum W \sin\alpha} \qquad (1)$$

With F = factor of safety, c=cohesion, ϕ=friction angle, W = slice weight, α = inclination of base of slice, u = pore pressure on based on slice and l=length of base of slice.

For analysis of slope stability due to earthquake, Newmark method was used. This method considers that if the inertial forces acting on a potential failure mass become large enough that the total (static plus dynamic) driving forces exceed the available resisting forces, the factor of safety will drop below 1.0[10)].

This method considers yield acceleration in the calculation of factor of safety.

$$a_y = k_y g \qquad (2)$$

with a = acceleration, k_y = yield coefficient and g = gravitational force. The yield acceleration is the minimum pseudostatic acceleration required to produce instability of the block.

7. ANALYSIS AND DISCUSSION

Figure 5 and 6 shows the elevation of slope 1-1 and slope 2-2 accordingly. The details were then calculated based on the equation 1 to predict the factor of safety for the slope due to earthquake.

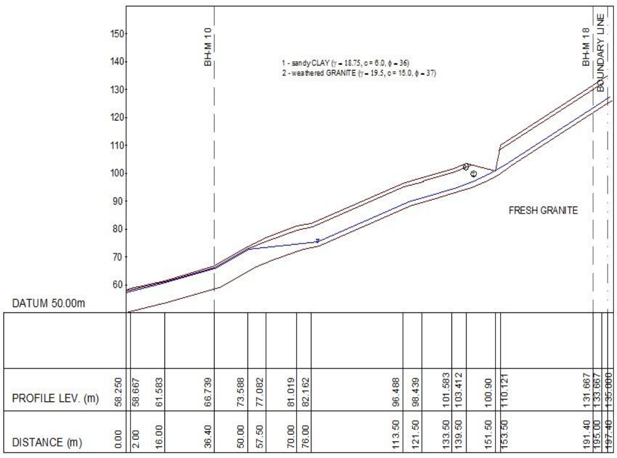

Figure 5 – Slope 1-1

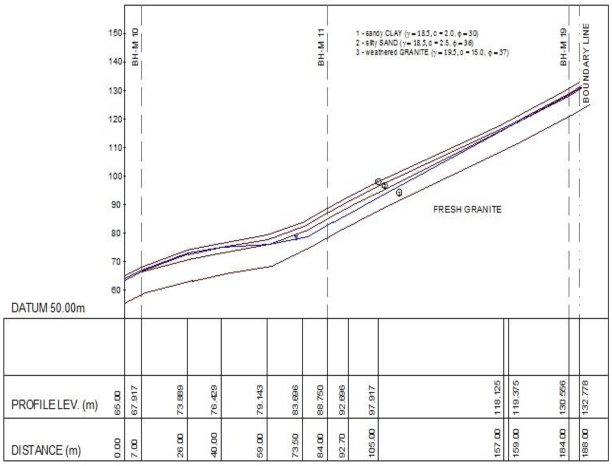

Figure 6 – Slope 2-2

Both slopes were analyzed based on the initial elevation prior to construction. Further investigation on the differences before and after construction can be done in the future for better understanding.

Based on Adnan et al[11)], the maximum value of peak ground acceleration (PGA) for west Malaysia is between 0.02g to 0.05g. It can be seen from Table 3, for slope 1-1, the minimum factor of safety for slope decreases from 1.72 to 1.45 when the peak ground acceleration increase. This is true since with the increase of PGA will reduce the shear strength of the soil thus reduce the resistant force.

Table 3 Calculated factor of safety due to earthquake for Slope 1-1

Slope 1-1				
Maximum Peak Ground Acceleration for West Malaysia[11)] (g)	0.02	0.03	0.04	0.05
Minimum Factor of Safety	1.72	1.62	1.53	1.45
Radius of circle	30			
X-coordinate of circle origin	93.0			
Y-coordinate of circle origin	117.69			

For Slope 1-1, it can be seen that the different value of PGA does not affect the location of critical slip surface.

In Table 4, the calculated factor of safety for slope 2-2 is shown. It can also be seen that the factor of safety for the slope is reduced when the PGA increases. But, for slope 2-2, the location for critical slip surface is different for each of the calculated PGA. This might happen due to the different layer of soil and the depth of the loose soil.

Table 4 Calculated factor of safety due to earthquake for Slope 2-2

Slope 2-2				
Maximum Peak Ground Acceleration for West Malaysia[11] (g)	0.02	0.03	0.04	0.05
Minimum Factor of Safety	1.31	1.24	1.17	1.11
Radius of circle	36	31.5	31.5	31.5
X-coordinate of circle origin	69.0	75.0	75.0	75.0
Y-coordinate of circle origin	118.46	116.15	116.15	116.15

From Table 3 and Table 4, it is interesting to see that not only the difference peak ground acceleration gives different value of factor of safety but also different location of critical slip surface. Therefore, this will be an interesting case to investigate further to get better idea of earthquake-induced landslide in Malaysia particularly in Penang Island.

With more inputs on the different soil characteristics including different soil type as well as different soil strength value, more understanding on the subject can be done. Further investigation on this subject shall also include the effect of rainfall to landslide.

8.0 CONCLUSION

This study shows that the effect of earthquake should not be neglected in slope stability analysis. Interestingly, the calculation were merely done based on maximum peak ground acceleration without taking into account the effect of rainfall which is the most significant attributes for Malaysian Landslides. Therefore, further investigation should be done to investigate both impacts of earthquake as well as rainfall intensities on Malaysian slope. This will help to give better understanding on slope design and analysis in Malaysia.

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