Risk Assessment of Slope in Urban Environment

Harahap, I.S.H.
Civil Engineering Department
UniversitiTeknologi PETRONAS
Perak, Malaysia

Faraheen Hazirah
Civil Engineering Department
UniversitiTeknologi PETRONAS
Perak, Malaysia

***Abstract*-- Geotechnical Hazards, especially for hillside development is known to be able to cause huge losses if occurred. Though there are many mitigation techniques have been developed, it is more practical if the risks are managed from its root for better control of the hazards and more cost-effective solution. However, it is not possible to provide equal treatment to each risk as the resources are very limited. Because of that, it is important to manage the hazards efficiently in order to optimize resources such as capital and work force besides preventing losses especially in terms of lives and monetary. The outcome of the project isaimed atprofessional geotechnical/civil engineers although it will also be useful to the general public.This paper describes the effective method in Geotechnical Hazards Management for Hillside Development.**

I. INTRODUCTION

In Malaysia, there are 2 types of Slope Assessment System practiced which are Large Scale Assessment and Small Scale Assessment. The authority that is responsible for Large Scale Slope Assessment is the Public Works Department and the work involves prioritizing slope along roads and highways (Jabatan Kerja Raya, 2006). Meanwhile, the parties that are responsible for the Small Scale Slope Assessment are the Department of Mineral and Geosciences Malaysia (DMG) and Malaysia Center for Remote Sensing (MACRES) but their work is only limited to controlling development in hilly areas (Suhaimi Jamaludin & A. Nadzri Hussein, 2006).

There is no specific slope prioritization system for other areas i.e. residential areas like the one PWD is having for slopes along federal road (Jabatan Kerja Raya Slope, 2010).

It is proven from statistics (Farisham Abu Samah, n.d.) that landslides occurring in areas other than highway/road areas especially residential urban areas are prone to more fatalities. It is because: (i) there are more population in the area, (ii) hazards occurring more often due to more variety of usage and (iii) people in the area are mostly static, compared to people in road/highway area; they are mostly dynamic and on-the-go. In this paper, attempt has been made to apply Australia's System for Landslide Risk Management which uses Semi-Quantitative type Risk Based Inspection (Patel, 2005) to some slopes in Malaysia regardless of the area. The system is to be tested on 4 slopes which are:

i. Slope at Taman Bukit Mewah, Bukit Antarabangsa, assuming the tragedy have not occurred yet. (Mariappan et al., 2010)

TABLE 1
STATISTIC OF LANDSLIDECASES FROM 1993-2007 ACCORDING TOTHE CATEGORIESOF THE AREA. (Source: Abdullah et al., 2008)

Date of Occurrence	Landslide Location (Name)	Category	Fatality (Nos)	Disruption to Transportation Network
11 Dec. 1993	Highland Tower	Residential	48	No
20 Nov. 2002	Taman Hillview	Residential	8	No
26 Oct 2003	Bukit Lanjan	Highway	-	Yes
12 Oct 2004	GuaTempurung	Highway	1	Yes
23 Mar. 2007	Putrajaya	Public Amenities	-	No
13 Nov. 2007	Pulau Banding	Public Amenities	-	No

ii. Slope at New Klang Valley Expressway near Bukit Lanjan Interchange, assuming the tragedy have not occurred yet (Sapari et al., 2011)

iii. Slope at Cameron Highlands, Khamarrul Azahari Razak et al., 2011 and Ibrahim Komoo et al., n.d.) and;

iv. Slope at UniversitiTeknologi PETRONAS, Tronoh

II. FRAMEWORK FOR RISK ASSESSMENT

The way the system is conducted is first, to use the data collected from the 4 slopes in order to calculate the value of Probability of Occurrences (P), Elements at Risk (E) and Vulnerability (V) according to Australia's Landslide Risk Management method of calculation.

Then, using only the value of P and E, the slope is assessed whether it is in the category of Tolerable, Not Tolerable, or as Low as Reasonably Practicable (ALARP) by plotting the value in the Graph of Societal Risk Criteria. For the slopes that are in Not Tolerable category, meaning the slope is quite dangerous, they are to be prioritized using their risk value which shows the higher the value is, the more risk it carries.

The risk value is calculated using the formula (Lee & Jones, 2004):

$$\sum(E \times R_S) = (E \times P \times V) \qquad (1)$$

The ranking will indicate which slope needs the quickest mitigation and which goes next. The detailed process is shown in the subtopics that follow.

Figure 1 below shows the flowchart of Australia's System for Landslide Risk Management:

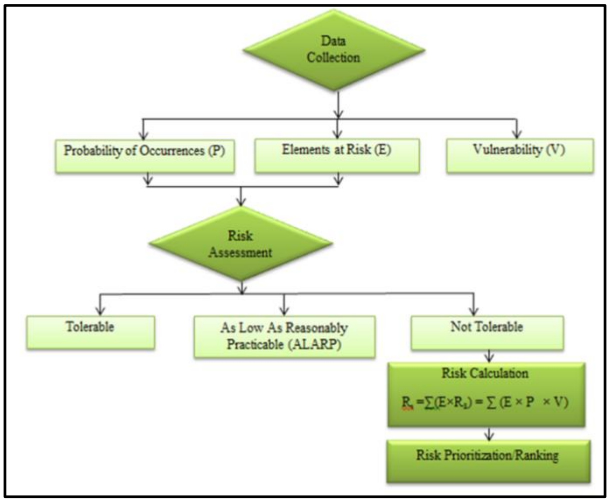

Fig.1. Flowchart of project work

A. Assessment of Probability of Occurrences

According to Australia's Landslide Risk Management Concepts and Guidelines 2000, the frequency of land sliding can be expressed by these methods:

i. Observation and experience
ii. Inventories
iii. Triggering
iv. Cause and effect
v. Deterministic/Probabilistic

In this paper, the method that is going to be used is Triggering Method where the triggering event of land sliding is identified and the probability of that event is equated to the probability of landslide. The triggering event in this paper is heavy rainfall events since it is the main triggering cause for almost all landslide cases in the country.

Rainfall data of the locations is obtained from the Department of Irrigation and Drainage Malaysia. The data was taken from the rainfall station closesttothe location studiedwhich are ParitRainfall Station for UTP slope, Brinchang Rainfall Station for Cameron Highlands slope, Bukit Antarabangsa Rainfall Station for Bukit Antarabangsa slope and also Ladang Edinburgh Rainfall Station for Bukit Lanjan slope. The approximate annual probability of the recurrence of land sliding, P_a is calculated using the formula (Chit et al., 2004):

$$P_a = N/T_H \qquad (2)$$

where N = the number of critical rainfall triggering events over the historical recorded time period T_H.

The recorded time period is the number of days in a year which is 365, and the number of critical rainfall is the number of days of heavy rainfall occurring. Heavy rainfall is considered by meteorologists around the world as average daily rainfall that is more than 0.30 inches (7.5 mm) of rain per hour.

B. Assessment of Elements at Risk

Elements at Riskis defined as the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides (Australian Geomechanics Society Sub-Committee on Landslide Risk Management, 2007).

The elements at risk will include:

i. Property, which may be subdivided into portions relative to the hazard being considered.
ii. People, who either live, work, or may spend some time in the area affected by landsliding.
iii. Services, such as water supply or drainage or electricity supply.
iv. Roads and communication facilities.
v. Vehicles on roads, subdivided into categories (cars, trucks, buses).

The table below shows the group no. with the example of facilities and expected number of fatality. The type of facilities affected is to be determined because it directly distresses the spatial and temporal distribution of population. The type of facilities is also related to the societal requirements for its use, particularly during or following extreme events.

C. Assessment of Vulnerability

Vulnerability refers to the degree of damage (or damage value in absolute or relative terms) which is judged to be likely if the landslide does occur (Australian Geomechanics Society Sub-Committee on Landslide Risk Management, 2007). It is expressed on a scale of 0 - no loss to 1 - total loss (AGS, 2007).

According to risk management guidelines by Australian Geomechanics Society in 2007, Vulnerability is measured by its impact on person and property, however Indetermining the weightage for the damage to properties, the rate of movement of slides is less important for structures compared to lives (Walker, n.d.).

According to Finlay et al. (1999), a person's vulnerability lies in the case where a building collapses or burial by debris. If a person is buried, the cause of death is more likely to happen because of asphyxiation rather than crushing impact. When a person suffers from crushing impact, injuries are more likely to occur compared to death.

These factors affected vulnerability values for person: (i) volume of slide, (ii) typeofslide, mechanism of slide initiation and velocity of sliding, (iii) depth of slide, (iv) whether the landslide debris buries the person(s), (v) whether the person(s) are in the open or enclosed in a vehicle or building, (vi) whether the vehicle or building collapses when impacted by debris, (vii) the type of collapse if the vehicle or building collapses.

TABLE 2

GROUPING OF FACILITIES AND EXPECTED NUMBER OF FATALITIES(Source: Wong, H.N., Ho, K.K.S. & Chan, Y.C., 1997)

Group no.		Facilities	Expected no. of Fatality
1	a)	Buildings with a high density of occupation or heavily used - Residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/clinic, welfare centre.	3
	b)	Others - Bus shelter, railway platform and other sheltered public waiting area - Cottage, licensed and squatter area - Dangerous goods storage site (e.g. petrol station) - Road with very heavy vehicular or pedestrian traffic density	3
2	a)	Building with a low density of occupation or lightly used - Built up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)	2
	b)	Others - Road with heavy vehicular or pedestrian traffic density - Major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir) - Construction sites	1
3		Roads and Open Space - Densely-used open space and public waiting area (e.g. densely-used playground, open car park, densely-used sitting out area, horticulture garden) - Quarry - Road with moderate vehicular or pedestrian traffic density	0.25
4		Roads and Open Space - Lightly-used open aired recreation area (e.g. district open space, lightly-used playground, cemetery, columbarium) - Non-dangerous goods storage site - Roads with low vehicular or pedestrian traffic density	0.03
5		Roads and Open Space - Remote area (e.g. country park, undeveloped green belt, abandoned quarry) - Road with very low vehicular or pedestrian traffic density	0.001

Notes:

(1) To account for the different types of building structure with different detailing of window and other perforations etc, a multiple factor ranging from 1 to 5 is considered appropriate for Group No. 1(a) facilities to account for the possibility that some incidents may result in a disproportionately larger number of fatalities than that envisaged. For global QRA, an average value of 3 is taken for the multiple fatality factor.

(2) For incidents that involve the collapse of a building, it is assumed that the expected number of fatalities is 100.

An estimate is indicative cost of damage, which may include the 'real cost' of the damaged property to the owner itself (Walker, n.d.).In determining the weightage for the damage to properties, the rate of movement of slides is less important for structures compared to lives. Slides which move slowly tend to cause less damage than rapid moving slides. This means properties affected by a slower moving slide are expected to have a lower vulnerability than those on a rapid moving slide.

The factors which most affect vulnerability of property are the volume of the slide in relation to the element at risk, the position of the element at risk relative to the sliding mass i.e. sited in the sliding mass or down slopefrom the sliding mass, the magnitude of displacement (for element down slope from the sliding mass) and relative displacement (for element sited in the sliding mass) and lastly the rate of slide movement(Australian Geomechanics Society Landslide Taskforce, 2007).

Vulnerability assessment involves the understanding of each affected elements if landslides are about to occur. Vulnerability, v, are considered as follows, Fell (1994):

$$v = v_s \times v_t \times v_l \qquad (3)$$

Where:

v_s= Probability of spatial impact of a landslide on an element

v_t = Probability of temporal impact (e.g. that the element is occupied during impact)

v_l= Probability of loss of life or proportion of the value of the element

The details for each type of vulnerabilities are described below:

i) Probability of spatial impact of a landslide on an element

This vulnerability value indicates the probability of the impact partially caused from the spatial character of the area itself. The value is measured based on the impacts on three elements; people, buildings and roads.

Table 3 below shows the Example of Vulnerability Values for Destruction of People, Buildings and Roads. The areas of the land slide were classified into 3 Geomorphic Units which are Hill Slopes, Proximal Debris Fan and Distal Debris Fan.

TABLE 3
EXAMPLE OF VULNERABILITY VALUES FOR DESTRUCTION OF PEOPLE, BUILDINGSAND ROADS. (Source: Australian Geomechanics Society Landslide Taskforce, 2007)

Geomorphic Unit	Vulnerability Values		
	People	Building	Road
Hill Slopes	0.05	0.25	0.3
Proximal Debris Fan	0.5	1.0	1.0
Distal Debris Fan	0.05	0.1	0.3

ii) Probability of temporal impact (e.g. that the element is occupied during impact)

Table 4 shows the cases that might occur in case of a landslide and recommended vulnerability value for each of the cases. The value varies for each case as each one of them carries different impact whether to person or properties.

TABLE 4.
VULNERABILITY RANGES FOR PERSONS AND RECOMMENDED VALUES FOR LOSS OF LIFE FOR LANDSLIDING IN SIMILAR SITUATIONS (Source: Dai et al. 2002)

Case	**Range in Data**	**Recommended Value**	**Comments**
Person in Open Space			
If struck by rockfall	0.1-0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8-1.0	1.0	Death by asphyxia almost certain
If not buried	0.1-0.5	0.1	High chance of survival
Person in a Vehicle			
If the vehicle is buried/crushed	0.9-1.0	1.0	Death is almost certain
If the vehicle is damaged only	0-0.3	0.3	High chance of survival
Person in a building			
If the building collapses	0.9-1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	0.8-1.0	1.0	Death is very likely
If the debris strikes the building only	0-0.1	0.05	Very high chance of survival

Since Vulnerability is judged by the degree of damage the landslide causes, death is undeniably the worst damage it could cause. Thus any case that leads to death has the value of 1.0 which is the highest. Other cases that do not lead to death are given reasonable vulnerability value.

iii) Probability of loss of life or proportion of the value of the element

The table below shows the likely probability of loss of life for slopes according to their slope angle. The angle, ranging from 30° until 60° and above possesses different vulnerability values as shown.

TABLE 5
PROBABILITYOF LOSSOF LIFEFOR DIFFERENT RANGESOF SLOPE ANGLE. (Source: Wong et al. 1997)

Likely Probability of Death for Different Ranges of Shadow Angle of Affected Person with Respect to Slope Crest								Freq. of landslides
>60°	55°-60°	50°-55°	45°-50°	40°-45°	35°-40°	30°-35°	25°-30°	
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)	5% of cases
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)		60% of cases
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.60 (0.95)	0.20 (0.60)	0.05 (0.20)			35% of cases
0.95 (0.95)	0.95 (0.95)	0.95 (0.95)	0.83 (0.95)	0.48 (0.83)	0.17 (0.48)	0.04 (0.15)	0.0025 (0.01)	Vuln. value calculated
Legend: 0.2 - Likely probability of death for a person in a building given the impact of the landslide, at a given range of α and β. (0.6) – Likely probability of death for a person on a road given the impact of the landslide, at a given range of α and β.								

III. RESULTS

A. Probability of Occurrences

In calculating P, the daily rainfall data in a year is obtained from the Department of Irrigation and Drainage Malaysia, the hyetograph reading as shown in Figure 2 to Figure 5 in the following according to the respective location.

The data is collected at the rainfall station closest to the location studied which are Parit Rainfall Station for UTP slope, Brinchang Rainfall Station for Cameron Highlands slope, Bukit Antarabangsa Rainfall Station for Bukit Antarabangsa slope and also Ladang Edinburgh Rainfall Station for Bukit Lanjan slope.

From the calculations that have been made from the daily rainfall data which is derived from the hyetograph reading, using equation at (2), it is obtained that the annual probability of occurrences, P_a for every location studied are:

i. UTP, Tronoh – 0.035
ii. Cameron Highlands – 0.052
iii. Bukit Antarabangsa – 0.09
iv. NKVE near Bukit Lanjan Interchange – 0.071

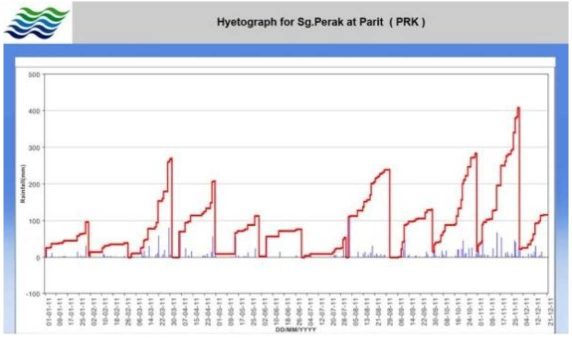

Fig. 2. Hyetograph reading for Sg. Perak Rainfall Station

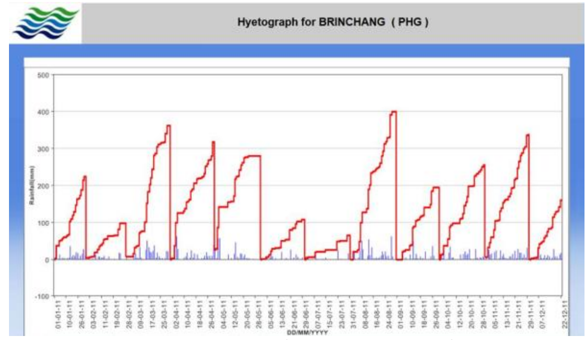

Fig. 3. Hyetograph reading for Brinchang Rainfall Station

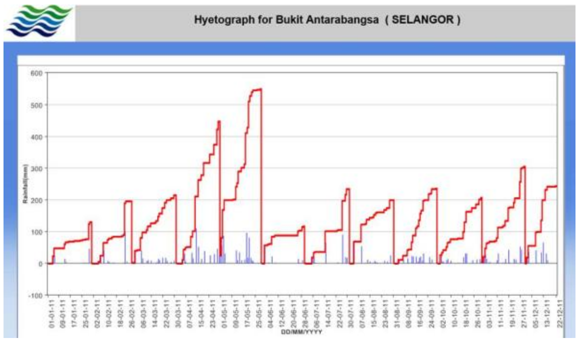

Fig. 4. Hyetograph reading for Bukit Antarabangsa Rainfall Station

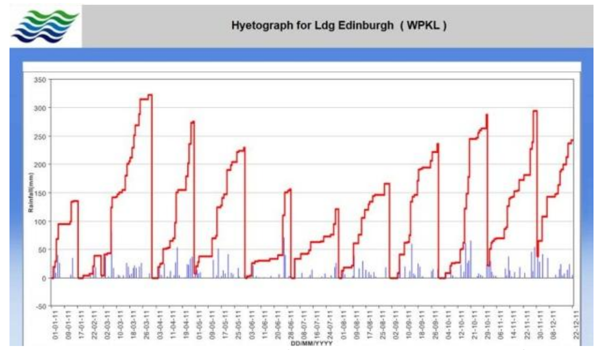

Fig. 5. Hyetograph reading for Ladang Edinburgh Rainfall Station

The result simply shows that by using Triggering Method, there is a 3.5% possibility of landslide occurring in the slope at UTP in a year, 5.2% of possibility at Cameron Highlands, 9.0% at Taman Bukit Mewah, Bukit Antarabangsa and 7.1% for slope at NKVE near Bukit Lanjan Interchange.

The possibility is quite high for all four locations as Malaysia is a country which receives rain almost every day in a year although there is a quite distinct different amount of rainfall if compared between the rainy season in November and dry season which is in July.

B. Elements at Risk

Based on Table 2 which is Grouping of Facilities and Expected Number of Fatalities (Wong et al., 1997), the four slope locations are classified into the facilities they serve, and the facilities show the number of expected fatalities.

i. UniversitiTeknologi PETRONAS , Tronoh
Group 5 (Roads and Open Space)
Description: Remote area (e.g. country park, undeveloped green belt, abandoned quarry) with very low vehicular or pedestrian traffic density
Expected Fatalities: 0.001

ii. Cameron Highlands
Group 3 (Roads and Open Space)
Description:Road with moderate vehicular or pedestrian traffic density.
Expected Fatalities: 0.25

iii. Taman Bukit Mewah, Bukit Antarabangsa
Group 1(a)
Description:Buildings with a high density of occupation or heavily used residential building
Expected Fatalities: 3

iv. NKVE near Bukit Lanjan Interchange
Group 2(b)
Description: Roads with heavy vehicular or pedestrian traffic density
Expected Fatalities: 1

C. Vulnerability

TABLE6
CALCULATED VULNERABILITY FOR VARIOUS LOCATIONS

No.	Location	v_s	v_t	v_l	v
1.	UniversitiTeknologi PETRONAS, Tronoh	0.05	0.2	0.01	0.0001
2.	Cameron Highlands	0.35	1.00	0.83	0.29
3.	Taman Bukit Mewah, Bukit Antarabangsa	0.6	1.0	0.95	0.48
4.	NKVE near Bukit Lanjan Interchange	0.35	0.75	0.95	0.25

IV. SLOPE PRIORITIZATION

The risk is assessed using the Graph of Societal Risk Criteria where the Probability of Occurrences (*P*) and Elements at Risk (*E*) are taken into consideration. Interpolation of the graph has been made for each slope and shown in Figure 6 to Figure 9 as the values mostly fall outside the range provided by the graph. The subsequent process is shown in the following table.

TABLE7

CALCULATED RISK AT VARIOUS LOCATIONS

No.	Location	*P*	*E*	*V*	Risk
1.	Univ. Teknologi PETRONAS, Tronoh	0.035	0.001	0.0001	The risk category of the slope in Univ. Teknologi PETRONAS, Tronoh is Tolerable; therefore risk value calculation is not needed.
2.	Cameron Highlands	0.052	0.25	0.29	0.00037
3.	Taman Bukit Mewah, Bukit Antarabangsa	0.09	3	0.48	0.13
4.	NKVE near Bukit Lanjan Interchange	0.071	1	0.25	0.018

V. FINDINGS

From the interpolation of the Graphs of Societal Risk Criteria for 4 of the slopes, it is found that the only slopes that fall in the Not Tolerable category are the slopes at Bukit Antarabangsa, NKVE near Bukit Lanjan Interchange, and Cameron Highlands. The slope at UniversitiTeknologi PETRONAS, Tronoh falls into the Tolerable category therefore Risk Value calculation does not take place for the slope and it will not be ranked as well.Ranking the slopes in Not Tolerable category according to their risk values from the highest to the lowest, the result is shown in the table below:

TABLE8

RANKING OF SLOPES IN NOT TOLERABLE CATEGORY

Slope	Risk Value	Rank
Taman Bukit Mewah, Bukit Antara Bangsa	0.13	1
NKVE near Bukit Lanjan Interchange	0.018	2
Cameron Highlands	0.00037	3

From Table 7, it can be seen that the slope in Taman Bukit Mewah, Bukit Antarabangsa owns the highest priority for slope mitigation/countermeasure, followed by slope at NKVE near Bukit Lanjan Interchange and then the slope at Cameron Highlands is the lowest in priority.

If say, all of the slopes are to be mitigated; the slope in Taman Bukit Mewah, Bukit Antarabangsa deserves to be mitigated the earliest, followed by the slope in NKVE near Bukit Lanjan Interchange, then only the slope at Cameron Highlands.

VI. CONCLUSION

The result has shown that by using Australia's Landslide Risk Management Guidelines, the most dangerous slope out of the four slopes is the slope at Bukit Mewah, Bukit Antarabangsa, followed by the slope at Bukit Lanjan Interchange.

Although the assumption was made that the landslide tragedy never occurred yet, it makes sense that the slope in Bukit Mewah is more dangerous than Bukit Lanjan as the tragedy sacrificed 4 lives while Bukit Lanjan tragedy sacrificed none (Mariappan et al., 2010).

The result also shows that the risk for slope in UTP is tolerable, which also makes sense. Though the slope at Cameron Highland falls in the Not Tolerable category, it is less dangerous than the slope at Bukit Antarabangsa and Bukit Lanjan, which is also proven as there is still no tragedy had occurred at the location.

The conclusion is, Australia's Landslide Risk Management is proven suitable to be applied to manage the maintenance of Malaysia's slopes.

After being assessed by this system, the slopes in the Tolerable and ALARP category are further managed by periodical/routine maintenance. Routine Maintenance Inspections (RMI) should be carried out a minimum of twice a year for slopes with negligible or low risk-to-life (Gue, S.S. &Wong, S.Y., n.d.). It will be beneficial to allow detection if there is any irregularities on the slope that might change its risk category. Meanwhile, as for the slopes in the Not Tolerable category, they should be quickly mitigated in order of their rank of priority. This system does not only allow more effective slope countermeasure, but also optimizing time and budget.

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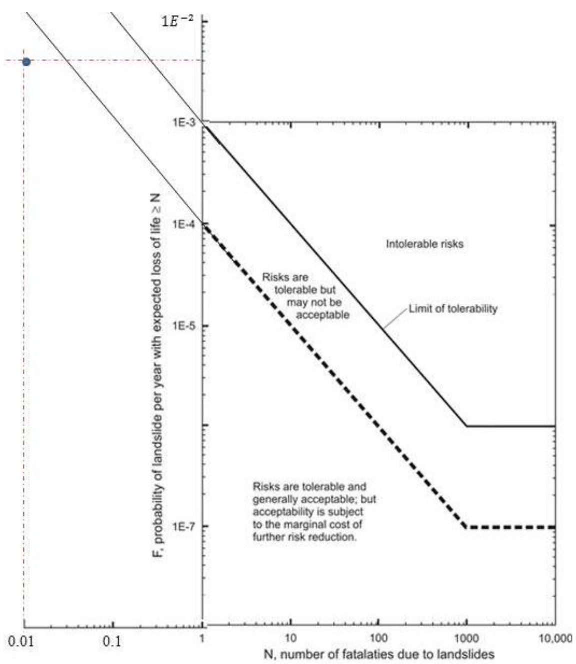

Fig. 6. Interpolation of P and E for determination of Risk Category at UTP slope

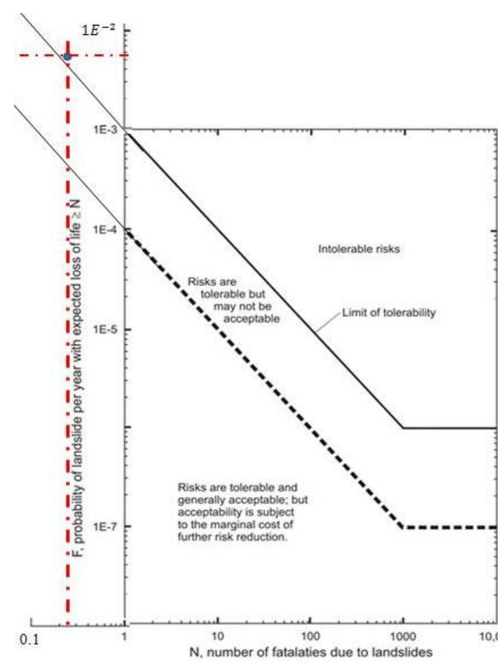

Fig. 7. Interpolation of P and E for determinationof Risk Category at Cameron Highlands slope

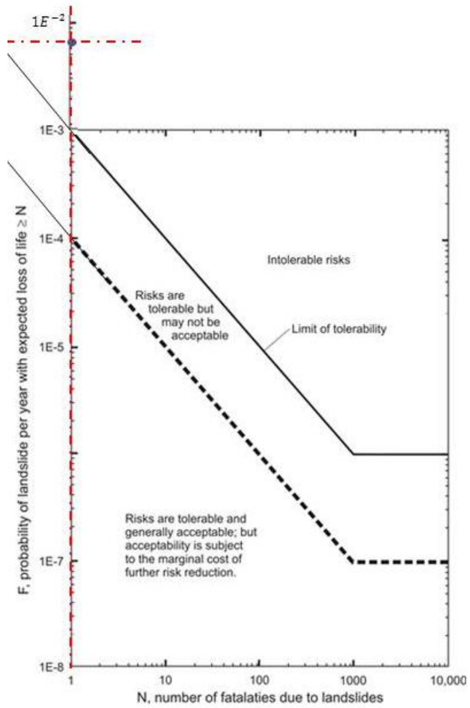

Fig. 8. Interpolation of P and E for determinationof Risk Category at Bukit Antarabangsa slope

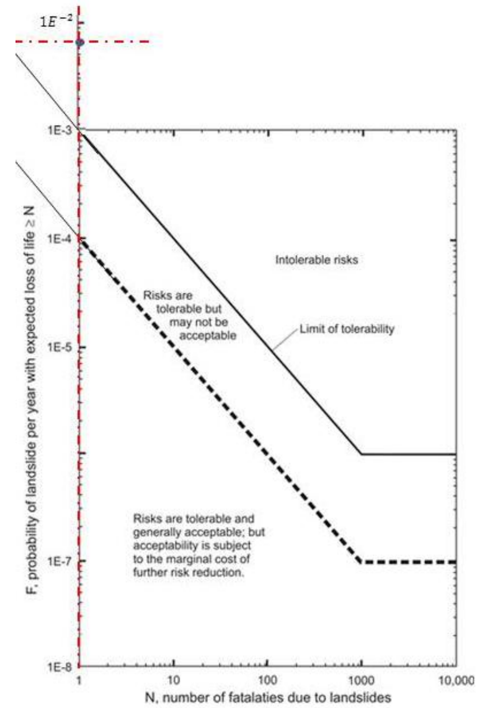

Fig. 9. Interpolation of P and E for determination of Risk Category at Bukit Lanjan slope