An Overview of Slope Failures during Monsoon Seasons in Malaysia

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ABSTRACT: Landslide constitutes one of the major geohazards in Malaysia. The frequent landslide occurrences are mainly attributed to rainfall (extrinsic factor) and tropical residual soil (intrinsic factor). This paper provides insights into the mechanisms of rainfall-induced landslides in the country and reviews efforts that have been taken to mitigate the hazard. Despite of the fact that local authorities, government agencies and practitioners have played their enormous roles in producing a better hillside development planning and control in the country, there are still areas for future improvement. The basic understanding of the unsaturated soil mechanics among practitioners and the laboratory facilities to support the theories still need to be enhanced. Besides that, the country can move towards a better landslide risk control and management by advancing the studies in run-out behaviours of landslide, establishing database for soil profiles particularly in landslide prone areas, and switching to risk-informed approach of slope stability assessment.

KEYWORDS: Landslide, Residual soil, Rainfall, Hazard mitigation, Unsaturated soil

1. INTRODUCTION

Malaysia is "free" from major natural disasters thanks to its strategic geographical location. The country is located just outside of the "Pacific Ring of Fire" and the "Tropical Cyclone Basins", and hence the direct risks of earthquakes, volcanoes, and typhoons are minimal. Neighbouring countries have also shielded large parts of the coastal areas from tsunami attacks.

Landslide constitutes one of the major geohazards in Malaysia. In general, landslides can be triggered by numerous factors which may vary from one region of the world to another. For instances, studies of landslide problems in the central region of China Mainland focus mainly on geological evolution and engineering geology (Huang et al., 2011). Geological joints, earthquakes and mining activities induced landsides are common in the country. In Switzerland, numerous slopes are affected by small movements related to ancient landslide mechanisms of post-glacial age (Lateltin et al., 2005), while rainfall-induced debris flows are the major threats in Japan (Osanai et al., 2010). It is widely recognised that landslide is a regional / localised problem. As such, findings from other parts of the world may not be applicable to the landslide problems in Malaysia.

Like many tropical countries in the South East Asia Region such as Thailand (Jotisankasa and Mairaing, 2010), Indonesia (Rahardjo, 2002), and Singapore (Rahardjo, 2010), massive landslides in Malaysia are mainly attributed to rainfall (extrinsic factor) and tropical residual soil (intrinsic factor). According to the statistical data published by the Public Work Department (2009), 61% of the landslides in Malaysia are triggered by rainfall. The landslide problem is further complicated by the unsaturated state of tropical residual soil which is known to be highly heterogeneous due to varying weathering effects.

This paper aims to provide overviews of rainfall-induced landslide problems in Malaysia. Firstly, historical landslide events, rainfall characteristics and tropical residual soil properties in Malaysia are presented, followed by revisit of fundamental theories of soil mechanics which are related to slope stability analysis. Some previous studies pertaining to landslide preventive measures are also reviewed. Lastly, future directions for a better landslide control in Malaysia are discussed.

2. MAJOR LANDSLIDE EVENTS IN MALAYSIA

Landslide problems in Malaysia started to gain public awareness since December 1993, when a block of residential apartment known as Highland Towers collapsed causing a tragedy involving 48 deaths (Figure 1) (Gue and Cheah, 2008). Over the following two decades, a series of catastrophic landslides have been reported.

Numerous efforts have been taken to mitigate the landslide problems in the country. A slope engineering branch was established in 2004 under the Public Work Department (PWD) Malaysia. The Slope Engineering Branch published the National Slope Master Plan (NSMP) in 2009 to oversee the slope stability problems in the country from ten aspects, i.e. policy and institutional framework, hazard mapping and assessments, early warning system and real time monitoring, loss assessment, information collection, public awareness and education, loss reduction measures, training, emergency preparedness and responses, and research and development (Hassandi, 2014). The PWD has identified 21,000 landslide-prone areas in Malaysia, of which 76% are located in more developed lands of Peninsular Malaysia, while the remaining 24% are shared between Sabah and Sarawak. It should be noted that the total land area of the two latter states combined is 1.5 times larger than the entire Peninsular Malaysia. This implies that urbanization process is another important contributing factor to the landslide occurrences in the country.

Table 1 tabulates selected major landslide events in Malaysia between 1993 and 2015. The Keningau, Sabah 1996 landslide recorded the high fatality (302 deaths) for a single landslide event in Malaysia where a debris flow was triggered by the Tropical Storm Gregg that wiped out the villages. Another major rainfall-induced landslide (44 deaths) struck an aborigine village in Kampar, Perak sweeping dozens of houses into a river near the downslope. In Kuala Lumpur, several landslides occurred in well-developed residential areas in Hulu Kelang. Most of the landslides were triggered by prolonged Monsoon rainfalls. Figure 2 shows a satellite image of the Bukit Antarabangsa Landslide, 2008 that claimed 5 lives.

Figure 1 Highland Towers landslide 1993 (Photo courtesy of The Star, Malaysia)

Table 1 Major landslide events in Malaysia between 1993 and 2015

Date	Location	Casualties
11.12.1993	Highland Towers, Kuala Lumpur	48 deaths
30.6.1995	Genting Highlands, Pahang	21 deaths
29.8.1996	Kampar, Perak	44 deaths
26.12.1996	Keningau, Sabah	302 deaths
25.12.1997	Ampang, Kuala Lumpur	3 deaths
7.2.1999	Sandakan, Sabah	17 deaths
15.5.1999	Bukit Antarabangsa, Kuala Lumpur	-
20.11.2002	Taman Hillview, Kuala Lumpur	8 deaths
12.2003	Bukit Lanjan, Selangor	-
31.5.2006	Kampung Pasir, Selangor	4 deaths
26.12.2007	Kapit, Sarawak	2 deaths
6.12.2008	Bukit Antarabangsa, Kuala Lumpur	5 deaths
21.5.2011	Hulu Langat, Selangor	16 deaths
29.12.2012	Setiawangsa, Kuala Lumpur	-
30.12.2014	Cameron Highlands, Pahang	2 deaths
11.11.2015	Bentong, Pahang	-

Figure 2 Bukit Antarabangsa landslide 2008 (Coordinates: 3°11'12.4"N, 101°46'12.5"E; Photo courtesy of http://www.crisp.nus.edu.sg)

3. RAINFALL CHARACTERISTICS

Malaysia experiences tropical rainfalls which are typically characterized by short and intense throughout a year. In addition, two Monsoon seasons, namely the Southwest Monsoon from late May to September and the Northeast Monsoon from November to March bring intense and prolonged rainfalls to the country. Nonetheless, the highest rainfall normally occurs during the transition period between the Monsoon seasons, or known as inter-Monsoon season. Department of Irrigation and Drainage (Department of Drainage and Irrigation, 2000) reported that April and May normally receive the highest rainfall amount, and followed by October and November. From a study reported by Lee et al. (2014), over 60% of the landslides in Hulu Kelang area occurred during these wet periods. The findings implied that rainfall is an important triggering factor to the frequent landslides.

The annual rainfalls in the country range from 2000 to 4000 mm depending on their geographical locations (Figure 3). The average mean monthly rainfall distributions in Peninsular Malaysia are presented in Figure 4. The eastern coast of Peninsular Malaysia normally experiences higher rainfall amounts than the western coast because of the wetter Northeast Monsoon that predominantly affect the eastern coast of Peninsular Malaysia.

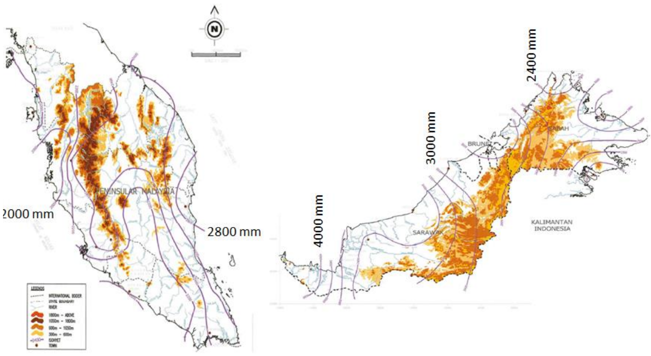


Figure 3 Rainfall distributions in Malaysia (Coordinates: 1°12'29.1"N - 6°43'31.3"N, 99°42'42.5"E - 119°17'56.0"E; NAHRIM, 2008)

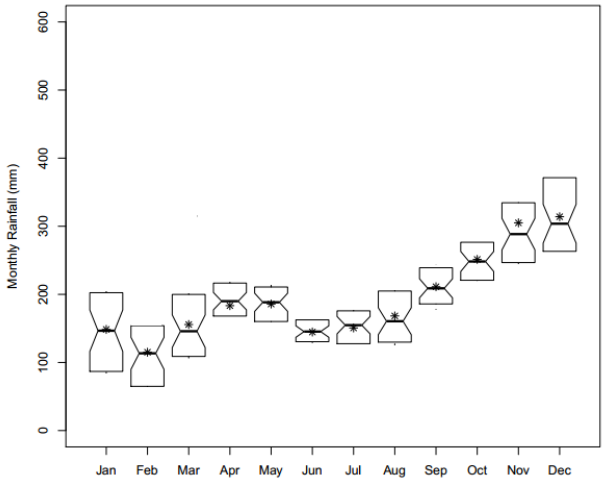


Figure 4 Average mean monthly rainfall (1971-2006) in Peninsular Malaysia. The asterisk denotes the mean value, the solid line represents the median, the height of box is the difference between the maximum and minimum (Wong et al., 2009)

4. TROPICAL RESIDUAL SOIL

Residual soils cover more than 75% of the total land area of Peninsular Malaysia (Taha et al., 2000). The high temperature and intense rainfall of tropical climates result in a massive physical weathering of the parent rock. As the result, thick formations of residual soil deposits (often > 30m, and varies from place to place) are commonly found in Malaysia (Tan, 2004). The major compositions of residual soil in Malaysia consist of sand and silt. These compositions are mixed in varying proportions depending on their geological settings.

The properties of tropical residual soils are known to be highly heterogeneous and anisotropic subjected to the weathering profile (Figure 5). The inconsistent physical properties of the residual soils have complicated the study of rainfall-induced landslide in Malaysia. From previous literatures, short and intense rainfalls are critical to granular soil slopes, while prolonged rainfalls are responsible for triggering failures of fine-grained soil slopes. For the tropical residual soils, their hydraulic properties lie between the granular and fine-grained materials depending on their degree of weathering. For the reason, it is difficult to identify a specific threshold rainfall for the landslides in Malaysia.

The tropical residual soil typically has a deep groundwater table with a thick unsaturated soil. Therefore, the fundamentals of unsaturated soil mechanics are essential for explaining the mechanism of rainfall-induced landslides in the tropical regions. Despite of the fact that the unsaturated soil mechanics have been well accepted worldwide, the practical applications of the theories among practising engineers in Malaysia is still very limited at present.

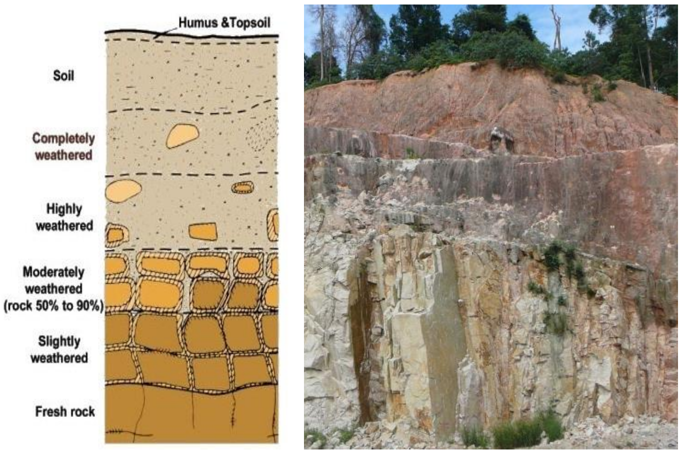


Figure 5 Typical weathering profile of tropical residual soil (Fredlund and Rahardjo, 1993)

5. MECHANISM OF RAINFALL-INDUCED LANDSLIDE

Figure 6 explains the mechanisms of rainfall-induced landslides in tropical residual soil slopes. The shear strength of soil can be reduced by a build-up of perched water table, a loss of matric suction, or a rise of water table under rainfall infiltration. Owing to the deep groundwater table and significant thickness of unsaturated zone in the tropical residual soil, it is common that the shear strength reductions are initiated by the loss of matric suction in the unsaturated zone. The shear strength reduction causes a decrease in factor of safety of the slope and subsequently triggers landslides (Fredlund and Rahardjo, 1993; Lu and Godt, 2008; Travis et al., 2010).

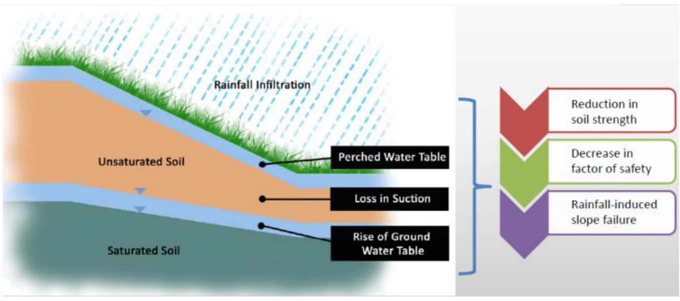


Figure 6 Mechanisms of rainfall-induced landslides

In the unsaturated zone, the upper layer (1 to 3 m from ground surface) is known as the *seasonal unsteady zone* because the matric suction in this zone is very sensitive to the surface boundary conditions. The hydraulic properties of soil in the *seasonal unsteady zone* play an important role in determining the hydraulic responses of soil to the rainfall infiltration. The hydraulic properties of soil are mainly governed by the hydraulic conductivity function and soil water characteristic curve (SWCC). The former determine the seepage velocity, while the latter determine the water holding or retention ability of the unsaturated soil. Figure 7 shows typical examples of SWCC and hydraulic conductivity functions of residual soils obtained in Malaysia.

Shear strength is an important parameter for any slope stability analysis. The factor of safety of a slope is defined by the ratio of the resistance force (quantified by the shear strength of the soil) to the mobilized force. The shear strength computed from the conventional Mohr-Coulomb failure criterion and effective stress concept (Terzaghi, 1936) is expressed as:

$$\tau_f = c' + \sigma' \tan\phi' \quad \text{(Eq. 1)}$$

Where, τ_f = shear stress at failure
c' = effective cohesion
σ' = effective normal stress
ϕ' = effective friction angle

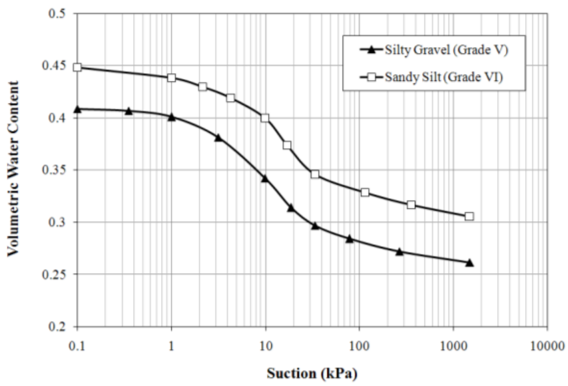
For unsaturated soil, the water phase occupies only partial of the pore volume, while the remainder is filled by air (Cai and Ugai, 2004). Therefore, the main difference between the shear strength of saturated and unsaturated soils is the functional relation between matric suction and effective stress in unsaturated soil. Fredlund *et al.* (1978) developed a widely accepted equation that included a parameter known as the angle of frictional resistance due to contribution of matric suction or angle by which cohesion intercept increases with increasing suction (ϕ^b):

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)\tan\phi^b \quad \text{(Eq. 2)}$$

Where $(\sigma_n - u_a)$ and $(u_a - u_w)$ are the net normal stress and the matric suction, respectively. The ϕ^b angle can be obtained by performing a series of triaxial compression tests with varying matric suctions.

The applications of unsaturated soil mechanics in slope engineering have been well accepted worldwide. The shear strength of unsaturated soil is fundamentally related to the matric suction $(u_a - u_w)$, which in turn is governed by the rainfall infiltration. These relationships reveal the importance of investigating the correlation between rainfall infiltration and initiation of landslide.

(a)



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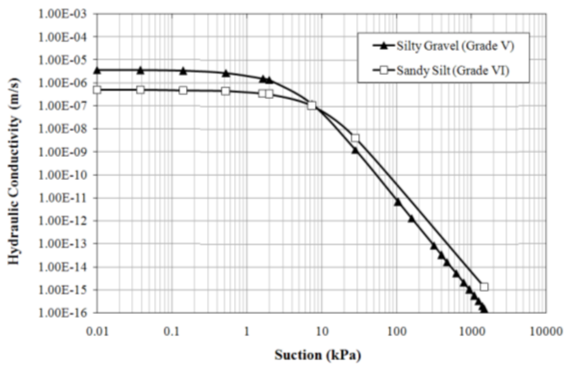


Figure 7 Typical examples of (a) SWCC and (b) hydraulic conductivity functions of tropical residual soils in Malaysia

6. ANALYSIS OF LOCALISED LANDSLIDE PROBLEMS

Landslides are widely regarded as a localized problem as the stability of a slope is often governed by the soil properties, geometry and responses of the soil slope concerned to rainfall. As such, it is important to review the available techniques to assess the rainfall-induced landslide problems from the perspective of localised scale.

6.1 NUMERICAL ANALYSIS OF RAINFALL_INDUCED LANDSLIDES

With the advancement in computing power, the use of computing tools such as finite element and limit equilibrium software to simulate the transient rainfall infiltration process and landslide initiation is increasingly popular through numerous reported case studies (Lee et al., 2014; Ibrahim et al., 2013; Low et al., 2012; Huat et al., 2006). These analyses are useful to explain the causative factors of a landslide event. However, engineers should possess adequate fundamentals of unsaturated soil mechanics and modelling techniques in order to perform a simulation which is accurately replicating the actual landslide event.

When performing seepage analysis, it is important to define the unsaturated properties of soil such as SWCC, unsaturated hydraulic conductivity function, and angle indicating the increase in shear strength due to the increase in matric suction (ϕ^b). Laboratory testing for obtaining these parameters, however, are still not popular in Malaysia. It is thus important to develop good laboratory facilities for the unsaturated soil testing.

Special cares should also be taken when modelling the initial conditions, boundary conditions and finite element meshes of a finite element model (Figure 8). Modelling an initial condition reflecting the field initial suction conditions is a particularly challenging task. Several attempts by trial and error are required before a representative initial condition can be achieved prior to an actual analysis. Appropriate boundary conditions are equally important to avoid unrealistic build-up of pore-water pressure during an analysis. Common modeling practices adopt no flow boundary (Q =0) for the side boundary above water table while those below water table are assigned with head boundary equal to the elevation of the water table. These boundary conditions should give reasonable simulation of the seepage flow in soil if the downslope side boundary is modeled sufficiently far away from the toe of the studied slope. The finite element meshes should also be carefully modelled to avoid unnecessary convergence problems.

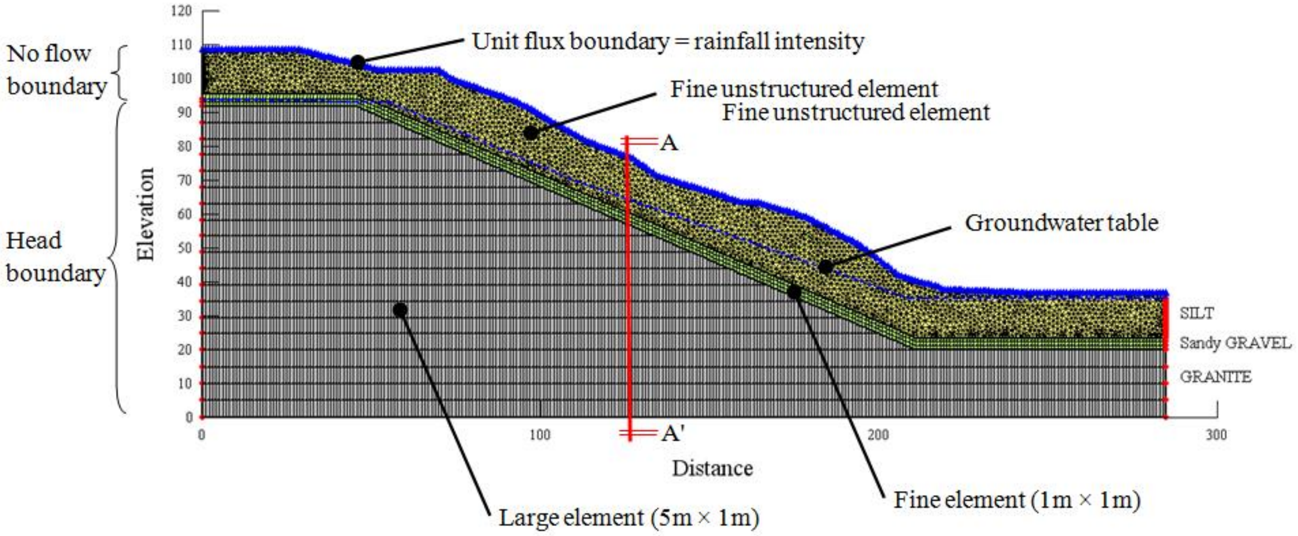


Figure 8 An example of seepage analysis using finite element model

6.2 FIELD MONITORING AND EARLY WARNING SYSTEM

Field monitoring and early warning system have been attempted on several pilot plots in Malaysia. Figure 9 shows a study plot of instrumented soil slope carried out in Johor, Malaysia (Kassim et al., 2012). Din et al. (2013) developed an early warning system for landslides at a remote site in Kelantan to ensure the stability of a transmission tower. They reported that reliability of the monitoring sensors and integrity of the captured data from the remote site are the main challenges of the project. Ali and Tew (2006) developed a near real time early warning system for erosion at a pilot plot in Cameron Highlands. The system utilized satellite imagery database to track land use changes in the study area. Lateh et al. (2010) also performed a field monitoring work in Cameron highlands to investigate the slope movement at a study site.

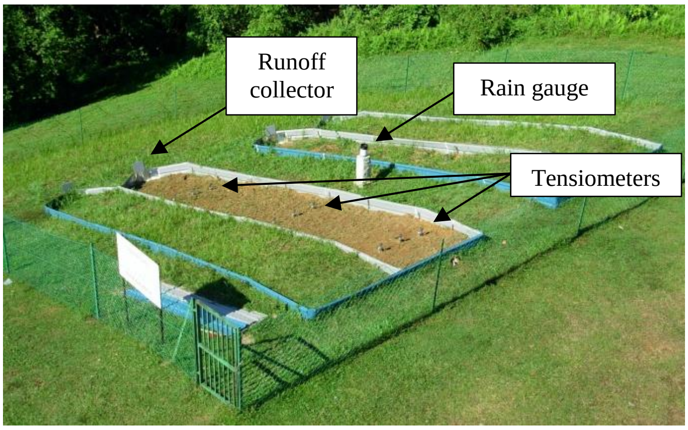


Figure 9 Field instrumentation on a study plot for landslide

Field instrumentations are commonly used to monitor soil movement, water table and matric suction in soil. Even though the instrumentations are costly, these direct measurement data can be extremely useful for predicting any slope failure provided the mechanism of the slope failure is well-understood in the first place. This is because different types of landslides may require different instrumentations. For instances, inclinometer (Figure 10a) which is used to monitor soil movement may not be effective for providing early warning for a debris flow because the failure normally occurs instantly without any indication of pre-movement. For such cases, monitoring of the hydro-geological behaviours of the soil slope such as by tensiometer (Figure 10b), piezometer (Figure 10c), rain gauge (Figure 10d) etc. are recommended. An early warning alarm can be triggered when a build-up of pore-water pressure or a significant loss of matric suction is detected in the soil slope. Table 2 summarizes the recommended instrumentations for different types of landslides.

(a)

(b)

(c)

(d)

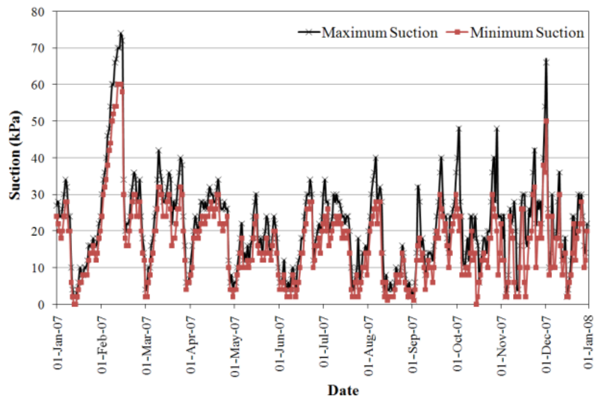
Figure 10 (a) Inclinometer for detecting soil lateral movement, (b) tensiometer for monitoring matric suction, (c) standpipe piezometer for detecting water table, (d) tipping bucket rain gauge for measuring rainfall intensity

Table 2 Recommended instrumentations for different types of landslides

Type of landslide	Characteristics of movement	Monitoring Instrumentation	
		Deformation	**Water**
Deep seated failure	Slow	Extensometer Inclinometer	Rain gauge Piezometer
Debris flow / shallow slide	Sudden	-	Rain gauge Piezometer Pore-water pressure gauge Tensiometer
Rock failure	Rapid	Extensometer Inclinometer Crack deformation sensor	Rain gauge

Figures 11a and 11b show typical suction variations monitored at a sandy silt slope and a silty gravel slope in Malaysia. Apparently, the sandy silt (fine-grained soil) exhibited a wider range of suction variations (0-74 kPa) than the silty gravel (coarse-grained soil) (0-26 kPa only). Based on these suction values, the factor of safety of a slope can be assessed by performing a slope stability analysis with the inputs of unsaturated soil parameters as described earlier. Figure 12 shows the changes in factor of safety as the result of rainfall infiltration obtained from a back analysis on a case study in Malaysia.

(a)



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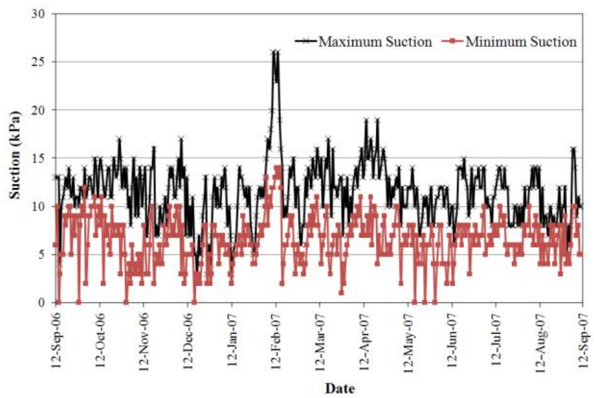

Figure 11 Typical suction variations in a (a) sandy silt slope, (b) silty gravel slope

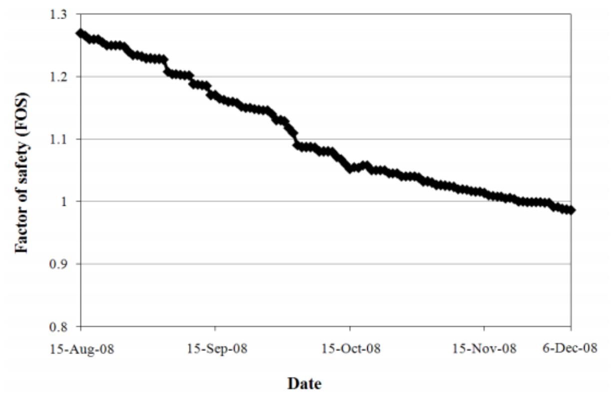

Figure 12 An example of changes in factor of stability of slope over time as the result of rainfall infiltration (Lee et al., 2014)

6.3 RUN-OUT SIMULATION OF LANDSLIDE

Run-out simulation is used to predict run-out behaviours, i.e. travel distance, movement time, and volume of sliding mass etc. if a landslide occurs. Discrete element modelling (DEM) is a common method used to perform the simulation (Figure 13). The analysis is useful for evaluating the hazard of a potential landslide site and assessing the consequences or damaging area caused by the landslide.

There are several drawbacks associated with the DEM analysis. In the DEM analysis, the soil mass is modelled as individual particles. This assumption may be appropriate for granular materials, but not for tropical residual soils that contain high amounts of cohesive materials. In addition, the analysis requires careful calibration of the input parameters such as damping ratio, residual shear strength etc. which are normally obtained from back-analysis after a landslide has actually occurred. Recent development trend has seen wide applications of coupled finite and discrete element analysis to overcome the shortcomings of the DEM.

In Malaysia, studies and applications of the run-out simulation of landslides are still very limited. This could be attributed to complicated modelling techniques and uncertainty associated with the input parameters of the analysis, particularly when dealing with the tropical residual soils. This is an area worth more research efforts to promote a better quantitative assessment of landslide risks.

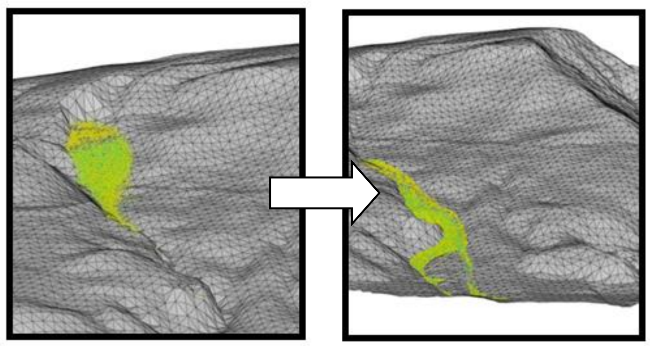

Figure 13 An example of three-dimensional run-out simulation using PFC3D

7. ANALYSIS OF REGIONAL LANDSLIDE PROBLEMS

The use of geographical information system (GIS) and remote sensing technology for landslide susceptibility mapping have been reported by numerous researchers in Malaysia. The landslide susceptibility maps are useful for regional planning of hillside development. The mapping can be performed by various methods including bivariate, multivariate, inventory, logistics regression, analytical hierarchy process (AHP), probability-frequency ratio (FR), statistical index, and weighting factor etc. (Saadatkhah et al., 2015; Pradhan and Lee, 2010; Mukhlisin et al., 2010) Recent development has seen an incorporation of the deterministic approach into the landslide susceptibility mapping. The probability of a landslide occurrence can be computed by analytical methods using unsaturated soil parameters. By doing so, it enables the computation of transient landslide susceptibility quantitatively based on real-time rainfall conditions (Figure 14).

Saadatkhah et al. (2016) studied the effect of plant cover on the regional stability of slopes in Hulu Kelang area, Malaysia. They found that the regional slope stability assessments are more realistic with the inclusion of plant cover effect as the tendency of giving false alarm to landslide occurrence prediction could be significantly reduced. Plant cover improves the stability of slope by mechanical and hydrological means. The hydrological effect is temporal and subject to the climatic conditions while the mechanical effect is essentially permanent. Deforestation is reported as an important factor that causes the alterations in the plant cover, and hence the slope instability.

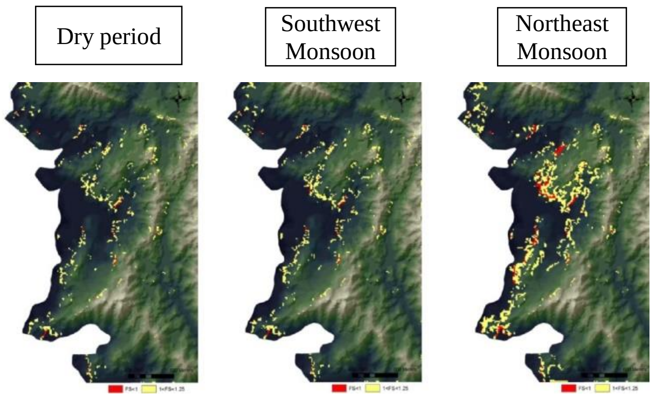

Figure 14 Transient landslide susceptibility based on real-time rainfall conditions (Coordinates: 3°09'28.5"N - 3°14'47.1"N, 101°43'30.1"E - 101°54'15.7"E; Saadatkhah et al., 2016)

Acquisition of quality input data remains one of the main challenges of GIS-based landslide susceptibility mapping. In Malaysia, rainfall, lithology and topography data are readily retrievable from the respective local authorities / government departments. However, lacking of a comprehensive database for the regional soil profiles and their engineering properties often deters the reliability of a map produced. There is a pressing need to develop a database or 3-dimensional modelling of soil profiles based on available soil investigation data in Malaysia

8. MOVING TOWARDS RISK-INFORMED APPROACH

Under the current practice, the technically-based approach is adopted for a slope stability assessment in Malaysia, where the factor of safety (FoS) of a slope against failure is analyzed by considering established rules as to the design events, loading conditions and soil properties. The FoS obtained shall comply with the minimum FoS requirement as stipulated in the established guidelines. Slopes satisfying the stability requirements are assumed to be completely "safe".

Recently, international geotechnical community has shifted the focus of slope stability assessment from the conventional "technically-based safety justification" to "risk-informed justification". The Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD), Hong Kong is among the pioneers in practicing the risk-informed approach in slope stability assessment. The overall landslide risk associated to the man-made slopes in Hong Kong was successfully reduced by 75% since implementing the approach (Wong and Ho, 2006). In the risk-informed approach, the landslide risk of a slope is analyzed quantitatively, in which the probability of the slope failure occurrence is computed, and the consequences or damages caused by the potential failure are assessed. The need for such a significant change in the assessment approach is supported by the fact that the long-term stability of slopes that are technically categorized as "safe" (FoS > minimum requirements) can no longer be guaranteed due to numerous inherent uncertainties, such as increased regional precipitation caused by climatic change, intense urbanization process in landslide-prone areas, and continued deforestation, etc.

Landslide risk assessment involves estimation of risk level, deciding whether the risk is acceptable, and exercising appropriate control measures to reduce the risk level if it is unacceptable. The key issue pertaining to the approach is "What is the risk level that can be considered as acceptable?" From the definitions by the International Union of Geological Sciences (IUGS), "acceptable risk" is defined as a risk, which for the purposes of life or work, everyone who might be impacted is prepared to accept assuming no changes in risk control mechanisms. There is another risk level lies above the "acceptable risk", which is known as "tolerable risk". The "tolerable risk" is a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to keep under review and reduce it as low as reasonably practicable (ALARP). ALARP evaluation normally involves estimation of cost effectiveness or cost per statistical life saved (CSLS) of the proposed risk control measure. Implementation of the measure is not mandatory, but will only be employed if it is deemed as cost effective.

"Acceptable" and "tolerable" risk criteria vary from country to country, and even from region to region within a country. It depends considerably on the societies' perceptions and their historic exposure to landslide hazard. The societal risk can be evaluated by plotting cumulative frequency (F) versus number of deaths (N) in a log-log scale, known as F-N curve. The "acceptable" and "tolerable" risk criteria are normally defined in the F-N curve. The approach has been implemented in Hong Kong, Australia, UK, and Canada. An example of the "acceptable" and "tolerable" risk criteria adopted by Hong Kong is shown in Figure 15. Generally, most of the developed countries impose stringent "acceptable" risk criteria against loss of life, i.e. $1{:}10^4 – 1{:}10^6$ risk of loss of life per annum.

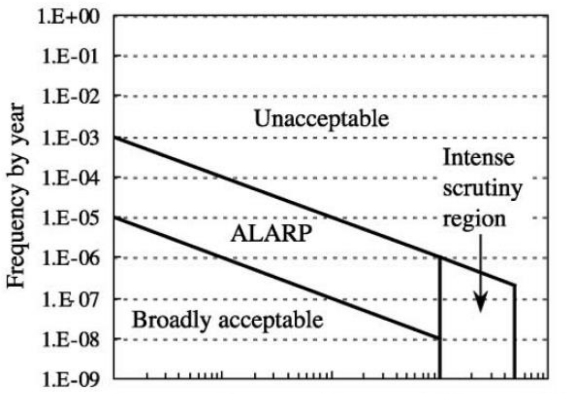

Figure 15 "Acceptable" and "tolerable" landslide risk criteria in Hong Kong (Dai et al., 2002)

Successful development of the F-N curves with well-defined "acceptable" and "tolerable" risk criteria could be a stride towards a more established landslide risk assessment and management practice in Malaysia. It can be used as a guideline to assess a design, to consent a proposed development, and to prioritize treatment and monitoring efforts for an existing development that is susceptible to landslide. For a newly proposed development, the probability of landslide occurrences can be assessed by performing slope stability analysis with the considerations of uncertainties associated with intrinsic properties (e.g. soil properties) and extrinsic factors (i.e. rainfall) of the slope. The consequences of the potential landslide can be evaluated by performing a run-out simulation using DEM. Plotting the corresponding F-N curve could give useful guides for the authorities to approve or reject the proposed development. Besides, the F-N curve can also be used to give information about the risk level of a region. This is important to create the public awareness about the landslide risk level at their living areas.

9. CONCLUSION

This paper provides overviews of rainfall-induced landslide problems in Malaysia. Over the past 20 years, local authorities, government agencies and practitioners have played their enormous roles in producing a better hillside development planning and control in the country. Stringent regulations have been imposed on proposed developments in landslide-prone areas. However, there are still areas that need further improvement as summarized in the following point forms:

i. **Promote unsaturated soil mechanics and improve laboratory testing facilities.** It is impossible to ignore unsaturated soil mechanics from the study of rainfall-induced landslides. This is because most of the slip planes of landslide occurrences in Malaysia are located in the unsaturated soil because of the deep groundwater table in the tropical residual soil. There is still a lack of established laboratory facilities in Malaysia for supporting the unsaturated soil testing.
ii. **Explore studies in run-out behaviours of landslides**. Understanding the run-out behaviours of a potential landslide is useful for assessing the hazards associated to a hillside development. Despite of the fact that such analysis has been widely practiced in other parts of the world since 1970s, there are still very limited studies can be traced in Malaysia.
iii. **Establish systematic management of landslide inventory and soil profile data**. Developing a comprehensive database of soil profiles and their engineering properties particularly in landslide-prone areas could be useful for a better regional planning of hillside development.
iv. **Moving towards the risk-informed approach**. Slope stability is no longer about "factor of safety". The inherent risk of a landslide hazard should be assessed and the public should be well-informed about the risk level associated to a slope. This will certainly leads to a more mature landslide risk management in the country.

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