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# LANDSLIDE RISK IN HONG KONG UNDER EXTREME STORMS

T. Abimbola Owolabi[1], Limin Zhang[2] and Suzanne Lacasse[3]

*[1,2]Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong.*
*[1]E-mail: taowolabi@connect.ust.hk*
*[2]E-mail: cezhangl@ust.hk*
*[3]Norwegian Geotechnical Institute, Oslo, Norway*
*[3]E-mail: suzanne.lacasse@ngi.no*

Landslides are a major hazard in Hong Kong which can lead to loss of life, injury to people, or economic losses. This paper assesses the landslide risk in western part of Hong Kong Island under extreme rainstorms of 29%, 44%, 65% and 85% of the 24-h Probable Maximum Precipitation. The number of buildings affected and the total population inside the buildings have been identified. The vulnerability factor was evaluated as a function of travel angle and time of landslide occurrence. It was observed that the vulnerability factor increases as the travel angle increases for all the PMP levels. At 85% and 65% PMP, the occurrence of landslides and the risk they pose on buildings are much higher than those at 44% and 29% PMP. The lowest potential loss of life is observed in schools, hospitals, community centres and government buildings. The findings from this work suggest that the time of occurrence of landslides can significantly affect the distribution of potential loss of life in each building.

***Keywords:*** Landslide, risk assessment, vulnerability, element at risk.

## 1 *Introduction*

Landslides are a major natural hazard in Hong Kong that poses risk to live, valuable properties, and natural environment. As climate change is expected to alter the frequency, magnitude, and other characteristics of extreme rainstorms, the impact of rain-induced landslides is expected to increase (Nadim, 2016). Landslides include a wide range of ground movements, such as rock falls, deep-seated failure of slopes and shallow debris flows. A "mammoth" rainfall in 72 hours caused disasters on June 18, 1972 in which a luxury block in Mid-Levels toppled down, claiming 67 lives, and a squatter village in Sau Mau Ping was buried earlier in the day, killing 71 people. The debris demolished a 13-storey building (Ho and Ko, 2007). The landslide was one of many that plagued Hong Kong in 1972. A total of 148 people were killed in the major landslides that year and many apartment complexes and houses were wiped out in the Kotewall road landslide. Many landslides can be triggered simultaneously by one rainstorm event and a specific element at risk may be exposed to multiple landslide hazards (Zhang et al. 2014). The socio-economic impact of landslides is sometimes underestimated because landslides are usually not separated from other natural hazard triggers, such as extreme rainfall, earthquakes or floods (Lacasse and Nadim, 2009). Common methods for geological hazard identification are based on Satellite images, aerial-photo interpretation, field surveys and collection of local data (Zhang et al., 2012). In this paper, the intensity and magnitudes of extreme storms are characterized by the Probable Maximum Precipitation (PMP). The Probable Maximum Precipitation (PMP) is defined by the World Meteorological Organisation (WMO, 1986) as the greatest depth of precipitation for a given duration meteorologically possible for a given size of storm area at a particular geographical location at a particular time of year. The future critical rainstorm scenarios under the changing climate, particularly extreme rainstorms with intensities of 29, 44, 65 and 85% of the 24-h PMP, have been identified by Zhang et al. (2017). In previous research, the risk of landslides under extreme storms of 29, 44, 65 and 85% of the 24-h probable maximum precipitation has not been assessed in a physical manner, especially the vulnerability, which could be due to limited information.

The objective of this paper is to assess the risk of landslides in western part of Hong Kong Island under extreme storm of 29, 44, 65 and 85% of the 24-h probable maximum precipitation. This assessment will serve as a decision tool that gives significant information for risk mitigation.

## 2 *The study area*

In Hong Kong, the natural terrain is hilly with 75% of the land steeper than 15° and 30% steeper than 30°. The natural terrain is susceptible to shallow, small to medium scale landslides (Ho, 2013). Hong Kong is dominated by Mesozoic volcanic and granite rocks (Sewell et al., 2000). The steep terrain and high frequency of tropical rainstorms make landslides occur on natural terrain, which is a common phenomenon in Hong Kong (Fuchu and Chack, 2002).

## 3 *Landslide risk assessment*

Landslide risk may be quantified in terms of potential loss of life or economic loss due to a destructive landslide event within a period. Thus, landslide risk can be expressed as the product of landslide hazard, vulnerability and elements at risk (e.g., Pathak, 2016). The elements at risk can be people in buildings, infrastructures, road and properties. The vulnerability of a given facility is related to the scale of slope failure and mobility (Wong et al., 1997). Vulnerability indicators are regarded as variables that can be considered as operational illustrations of the characteristics or the quality of a system, providing information regarding the components of its vulnerability (Kappes et al., 2012). Vulnerability also involves analysing the interaction between a given landslide intensity and corresponding affected elements (Li et al., 2010). It is essential to assess slope failures quantitatively at a regional scale under extreme storm conditions before forming any landslide hazard mitigation policy (Zhang et al., 2017). Quantitative risk is the probability of an adverse event times the consequences if the event occurs; the consequences are obtained from the elements at risk and their vulnerability (Lacasse et al, 2008). Quantitative risk assessment for regional rainfall-induced landslides can be conducted for both loss of lives and loss of properties (Chen et al., 2016).

## 4 *Methodology*

The landslide risk under extreme storms in western part of Hong Kong Island has been assessed quantitatively. The risk has been evaluated in terms of potential loss of life. Landslide data record in Zhang et al. (2017) was used in the risk assessment. The risk to people inside the buildings was considered as the element at risk. The buildings involved in the study area are residential buildings, schools, hospitals, commercial centres, temples, factories, community centres, government and church buildings. The number of buildings affected by the landslides were identified by combining the landslide map and the building map in a GIS environment. The area of each affected building was recorded from the building information map and multiplied by the number of persons in a square meter of a building in Hong Kong to get the total population in each of the affected buildings.

### 4.1 *Vulnerability factor*

The vulnerability has been analysed as a function of the travel angle of the landslide and the likely time spent by people in a building per day. The travel angle was determined from each cell of the landslide affecting each building. The percentage of cases of travel angle that fall within each range was determined and the likely probability of death of a person in a building was assigned to each range based on the probability values adopted by Wong et al. (1997). The combination of the outcome was multiplied by the probable time spent by people in the building:

$$V_f = P_D \text{ x \% cases of travel angle x } V_{time} \quad (1)$$

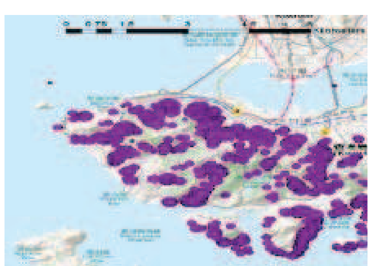
where $V_f$ is the vulnerability factor; $P_D$ is the probability of death of a person in a building; $V_{time}$ is the probable time spent by people in a building per day during the landslide incidence. The expected number of people inside the building was multiplied by the vulnerability factor to give the risk in terms of potential loss of life.

## 5 *Results and discussions*

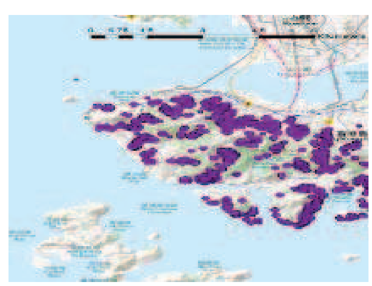
### 5.1 *Landslide map*

Figure 1 shows the spatial distributions of landslides under extreme storms of 29% PMP, 44% PMP, 65% PMP and 85% PMP. At 85% and 65% PMP, the occurrence of landslides and the risk they pose on buildings are much higher than those under 44% and 29% PMP. Also, the level of coverage spot of the landslides is widespread, together with a high level of convergence of several landslides at a point.

a)



b)



d)

c)

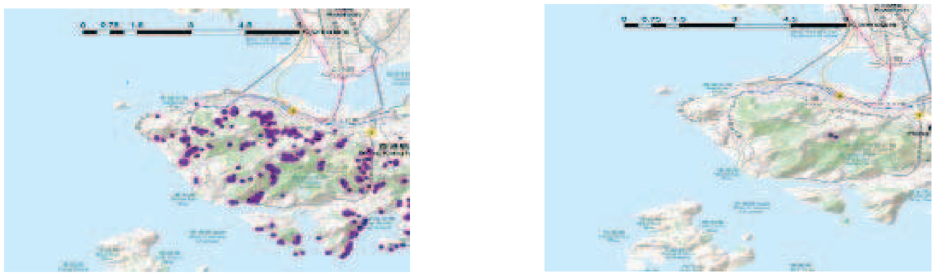


Figure 1. Landslide maps under storms of (a) 85% PMP; (b) 65% PMP; (c) 44% PMP; (d) 29% PMP.

### 5.2 *Total population and buildings affected*

The total population and number of buildings affected are shown in Figure 2. In all the PMP's considered, it was discovered that residential buildings have the highest number of occupants. The total population of affected buildings increases with increasing PMP. The total affected population by the 85% PMP is approximately 65% higher than the population affected by the 44% PMP. As shown in the figure, more buildings were affected by the 85% PMP storm than the 65% and 44% PMP storms. This is due to the increase in the rainfall intensity. Also, it was discovered that the lowest percentage of population may stay in the church buildings at 85% and 65% PMPs while at 44%PMP, the hospital buildings have the lowest population.

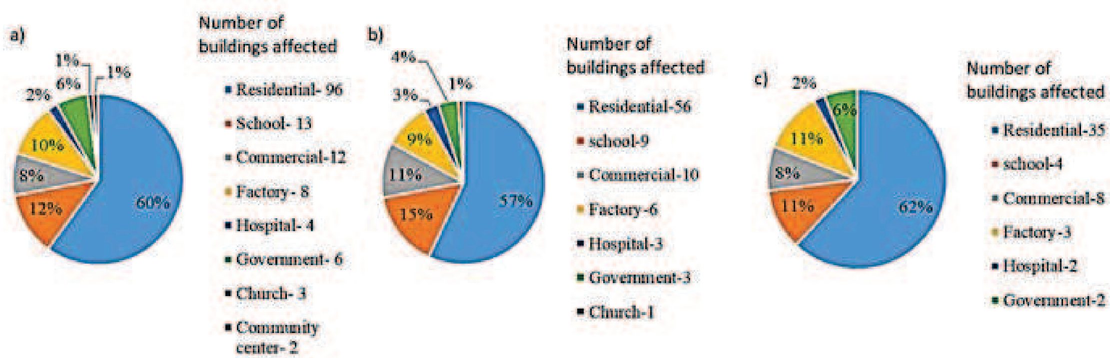



Figure 2. Total population in affected buildings: (a) 85% PMP; (b) 65% PMP; (c) 44% PMP.

### 5.3 *Vulnerability*

The vulnerability of persons in the affected building is shown in Figure 3 for all PMP's. The vulnerability factors increase as the travel angle increases for 85, 65 and 44 %PMP. Only the 85% PMP case has vulnerability factors that fall within the range of 50-60° travel angle. No vulnerability factor is defined for the 29% PMP case since no building was affected.

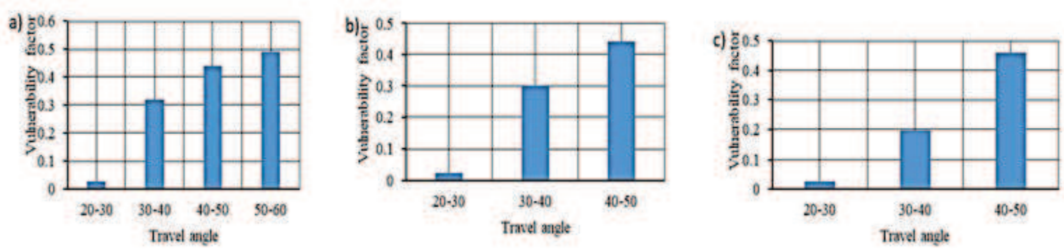



Figure 3. The vulnerability of persons in building to landslide at (a) 85%P MP, (b) 65% PMP (c) 44% PMP.

## 5.4 *Potential loss of life*

Figure 4 presents the potential loss of life inside the affected buildings. As reported earlier that the residential building has the highest number of occupants. Hence the potential loss of life is higher in the residential buildings compared with all other buildings. For the 85%, 65% and 44% PMPs, their potential loss of life (PLL) values are calculated based on the number of buildings affected by each PMP. The percentages of the PLL in residential buildings are 64%, 64% and 79% for the 85%, 65% and 44% PMPs, respectively. The lowest potential loss of life may be recorded in hospitals, community centres and government buildings for all the PMPs.

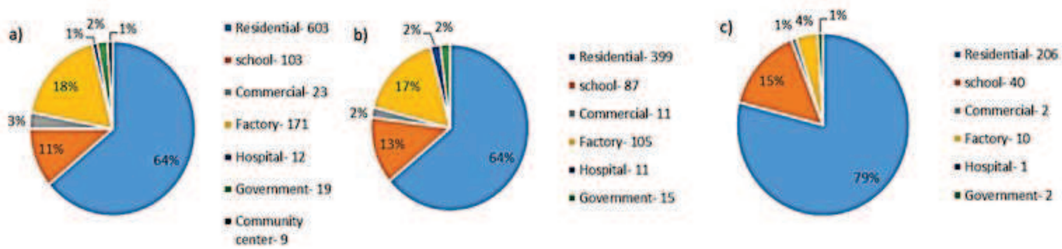



Figure 4. Percentages of potential loss of life in buildings: (a) 85% PMP; (b) 65% PMP; (c) 44% PMP.

Figure 5 shows the spatial distributions of the potential loss of life in the western part of Hong Kong Island under the 29, 44, 65 and 85% PMP storms. The 65 and 85% PMP cases give similar results that higher than those at 44% PMP. Meanwhile the 29% PMP strum does not lead to loss of life since no building was affected in the study area under 29% PMP.

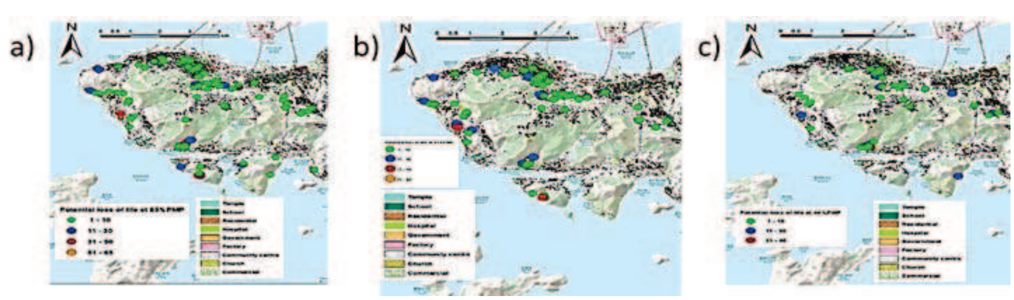


Figure 5. Distribution of potential loss of life map under storms of (a) 85% PMP; (b) 65% PMP; (c) 44% PMP.

## 6 *Conclusions*

This study assesses the risk of landslides in western part of Hong Kong Island under extreme storms of 29, 44, 65 and 85% of the 24-h probable maximum precipitation. A quantitative assessment method has been used in the analysis and the vulnerability factor has been determined as a function of travel angle and time of landslide occurrence. The number of buildings affected, size of buildings and population at risk were recorded and combined with vulnerability factors to give the potential loss of life. In general, the majority of the population are found in the residential buildings. The affected population in residential buildings is the highest in the 85% PMP case. As a result, the 85% PMP storm may lead to the highest potential loss of life because of the high rainfall intensity. The findings from this work suggest that the time of occurrence of landslides can significantly affect the distribution of potential loss of life in each building. Due to the time of occurrence of the landslides, the lowest potential loss of life may be observed in schools, hospitals, community centres and government buildings.

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