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Qualitative Assessment of the Sham Tseng San Tsuen Landslide in Hong Kong

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Abstract— Landslide risk assessment methods in Hong Kong have been well documented. The choice of the method of investigation into reported slope failures depend on the slope aspect to be emphasised. Insights have been gained into the role of geomorphology as an important factor in performing a qualitative risk assessment review of the Sham Tseng San Tsuen Landslide event. The geology, hydrogeology and geotechnical aspects of the slope materials have been presented. The implications of the hazards and associated risks as well as the risk management aspects of the landslide event have also been presented. Some suggestions with respect to improving slope management in Hong Kong are made.

Index Terms— Hong Kong, hazard, geomorphology, landslide, qualitative, risk

1 Introduction

Broadly, the methods of landslide risk assessment may either be qualitative or quantitative. The detailed classification of assessment methodologies depend on the choice of the aspect(s) to be emphasised. Generally, geotechnical engineers evaluate the stability of natural slopes in which the slope reliability is estimated by calculating a factor of safety commonly using the conventional deterministic methods. Quantitative landslide risk assessment has been developed for and is widely used in Hong Kong. Qualitative landslide risk assessments are generally considered simplistic and technically less reliable methods. This paper presents a review of the qualitative method of the cause, and the associated risk of the slope instability for the Sham Tseng San Tsuen Landslide in Hong Kong. The method has been carried out by evaluating its geomorphological aspects and presenting the hazard and the consequence of the landslide.

2 Hong Kong Slope Safety System

Hong Kong has a history of frequent landslides activity. More than 470 fatalities were recorded since 1947. The steep terrains which characterised the geomorphology of Hong Kong landscape are prone to slope instabilities. The increasing rate of fatalities and infrastructural damages in landslides prone areas increases with settlement and construction activity. There was a steady rise in population from 1.8 million to 4.6 million between 1948 and 1977. The Hong Kong's Geotechnical Engineering Office (GEO) since then started to reduce landslide risk through a comprehensive programme of slope safety.
The landslip preventive measures (LPM) programme was adopted to exercise geotechnical control of new man-made slopes and remediation of exercising substandard slopes. The overall objective is to effectively reduce by the end of 2010 the landslide risk to less than 25% of the 1977 level. Longer term hazard mitigation measures were introduced for landslip prevention from natural slopes. The GEO launched in 2010, the Landslip Prevention and Mitigation Programme (LPmitP) to succeed the LPM programme. Since the focus of the LPM has been on high risk man-made slope remediation, the LPmitP is set to complete upgrade of the remaining moderate risks from man-made slopes. The LPmitP would upgrade 15,000 man-made slopes and some 2,700 natural hillsides with known hazards [3].

3 COMMON SLOPE STABILITY ANALYSIS METHODS

Generally, the stability of slopes can be expressed using Factor of Safety (FS); where the stability is quantified by the limiting equilibrium of the slope which is stable if FS > 1. Stability is also expressed as strain; where failure is defined by onset of strains great enough to prevent safe operations of the slope. Stability is often expressed as probability of failure; where stability is quantified by probability distribution of difference between resisting forces and displacing forces which are expressed as probability distributions.
Load and Resistance Factor Design expresses stability by comparing the factored resistance being greater than or equal to the sum of the factored loads [9].

4 COMMON LANDSLIDE RISK ASSESSMENT METHODS

The entire risk assessment chain for landslides comprises three parts; risk analysis, risk evaluation and risk management. Risk analysis can be done either in a qualitative or quantitative manner. Semi quantitative risk assessment involves the combination of qualitative and quantitative measures of probability and consequence [2].

The need for either qualitative or quantitative risk assessment methods for landslides depends on the aims of the hazard assessment. In any case, a clear understanding of the geology, hydrogeology, geomorphology, historical seismicity from available maps, reports and field surveys, geotechnical investigations as well as slope failure mechanisms are critical. Aleotti & Chowdhury (1999) have presented a broad qualitative and quantitative classification of

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landslide hazard assessment methods (Fig 1).

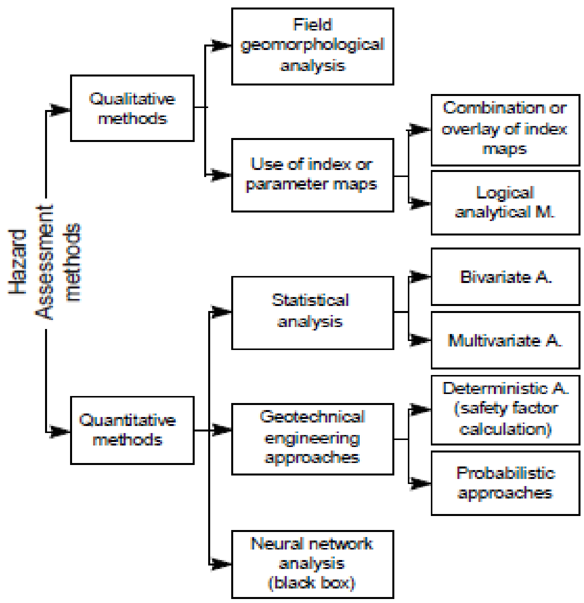

Fig 1. Landslide hazard assessment methods (Aleotti & Chowdhury, 1999)

In landslide risk analysis, qualitative assessment is almost entirely subjective, based on expert judgement and depending on the person(s) carrying out the hazard assessment. In qualitative risk assessment, the components of risk which are basically; hazard, the elements at risk and vulnerability are expressed verbally and the final result is in terms of ranked or verbal risk levels [2]. Qualitative risk could also be presented as a matrix with qualitative hazard in first dimension and qualitative consequence in the second dimension. (Table1). In qualitative geomorphological assessment, the input data are usually derived from assessment during field visits possibly supported by aerial photo interpretation. These methodologies can be divided into two types; field geomorphological analysis and the combination or overlaying of index maps [1].

Table 1: Qualitative Risk Matrix (Modified from Glade, 2002).

(Hazard)	**(Consequence)**			
	Low	**Moderate**	**High**	**Very High**
	(Risk Level)			
Low	Low	Low	Low	Low
Moderate	Moderate	Moderate	High	High
High	Moderate	High	Very High	Very High

5 SHAM TSENG SAN TSUEN LANDSLIDE CASE STUDY

5.1 ENGINEERING GEOLOGY AND GEOMORPHOLOGY

The debris flows occurred at the natural hillside 22°22'16"N – 114°03'37"E above Sham Tseng San Tsuen Village in Hong Kong southern China. The slopes were moderately steep with an average hillslope angle recorded at 24°. The topography of the area is very rugged with several steep slopes (Fig 2). Geomorphological assessment of the area shows fluvial processes are dominant due to high slope inclination which drives weathered materials downslope. The slopes were observed to consist predominantly of convex slope breaks. (Fig 3). The Sham Tseng San Tsuen landslide area is part of the Lantau Granite outcrops in Hong Kong. Stratigraphically, it is within the Lamma Suite Jurassic intrusive rocks with ages approximately 161.5 ± 0.2 million years (Davis *et al.*, 1997).

The lithology of the rock in the area consisted of predominantly medium grained megacrystic granite. At the northern end of the main scarp of the primary source of the landslide, the granite is in contact with a finer grained granitic rock. The rock varies from highly to moderately weathered outcrop near the northern end of the scarp. Colluvium deposits are present on both sides of the main scarp. The thickness of the colluvium is 1.2m. Three joints are present with persistence up to 5m. Geotechnical properties of the colluvium layer and the completely decomposed granite (CDG) were assessed by consolidated undrained triaxial compression test using samples recovered from the main landslide site. The angle of shearing resistance of the surface colluviums and the completely decomposed granite are 37° and 38° respectively with zero cohesion [7].

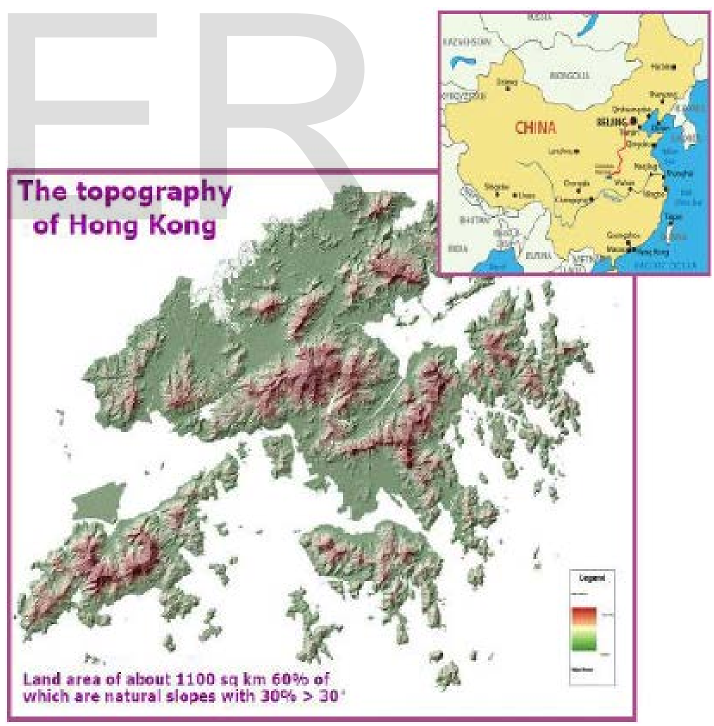

Fig. 2. The topography of Hong Kong

5.2 LANDSLIDE EVENT AND MECHANISM

Four landslides labelled (A-D) occurred on 23rd August 1999 on the natural hillside of the Sham Tseng San Tsuen village (Fig. 4). The landslides gave rise to a channelized debris flow pattern downstream. Average width of the channel is 1.5m. A house was demol-

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ished and several others were damaged. One fatality and thirteen injuries were recorded. The landslides A-D were triggered by a severe rainstorm. The rainstorm had an estimated return period of about 49 years based on rainfall data. The rainfall data were obtained from an automatic rain gauge situated approximately 300m to the south of the landslides area. The debris flow path within the rugged topography has a length of 210m.

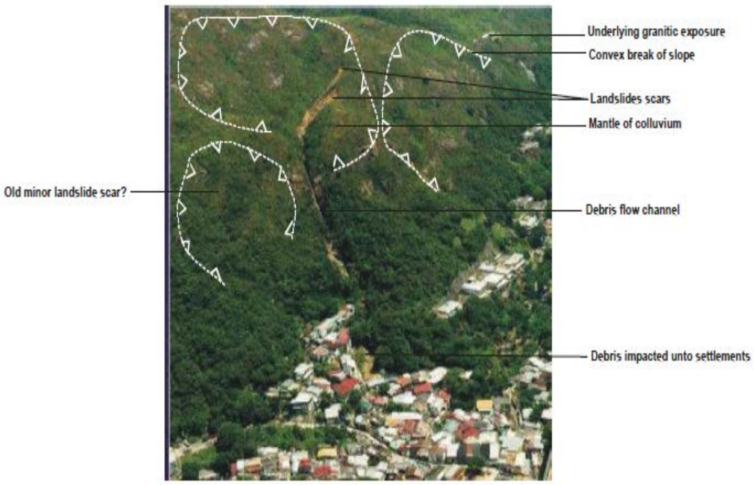

Fig. 3. Geomorphological setting of the of the Sham Tseng San Tsuen Landslide section

The difference in elevation from the scarp down to the debris deposit area within the squatter settlements is 90m. Landslide A with an estimate of 600m³ of debris material and a maximum depth of 3.8 m was the primary source of the debris flow. Slope gradient at landslide A varies from 32˚ to 37˚, while landslides B-D ranges from 40˚ - 45˚. Total volume of material involved in landslides B-D is 20m³. Failure mechanism was triggered from a thin mantle of bouldery colluvium overlying relatively less permeable weathered granite at the hillside. Perched water tables and elevated water pressures during the heavy rain storm were generated within the colluvium deposits. Presence of relic failures within the rock mass would probably have caused weakening and instability.

These adversely influenced the local groundwater regime by promoting direct infiltration of rainwater into the joint systems. These joints are likely to influence the hydrogeological regime by getting infilled with water during rainfall.

This could increase the pore water pressure within the rock and develop into the rock slope instability. Historical hill fires about 4-5 years before the failure had also removed much of the vegetation cover which could reduced the rate of direct erosion of loose slope materials. The landslide debris stopped after impacting on the squatter buildings through a nullah (a native term for a concrete lined channel designed to prevent flooding) [7].

5.3 HAZARDS AND RISKS

Identified elements at risks include the people and buildings at the downslopes of the Sham Tseng San Tsuen squatter settlement (Fig 3). Sham Hong minor road and the Tuen Mun major road were also identified. Hazards identified prior to the landslide event include the 24hr and 12hr rainfalls before the event, 479 mm and 341 mm depths respectively. Estimated probability of occurrence of the heavy rainfall capable of triggering a landslide was 49 years. Progressive deterioration of the hillside with opening discontinuities in the colluvium layer was observed. During the heavy rainstorm, water flow down slope was triggered then later followed by the debris flow. Post event hazard assessment indicated the four landslides A-D totalling 620m³ volume of debris material impacted onto the squatter settlements. Risk assessment classification under the landslip mitigation measures (LDM) by the GEO indicated that the slope was not processed to the required geotechnical standard [4]. Risk assessed during the landslide event is the short travel time debris flow through the 210m path down 90m elevation height.

Fig. 4.Close view of the Sham Tseng San Tsuen Landslides A-D scarps

5.4 SLOPE RISK MANAGEMENT

In 1995, the Hong Kong Geotechnical Engineering Office (GEO) engaged the University of Hong Kong to conduct a detailed study of the seismic hazard in Hong Kong [5]. The results of the study indicated there was no record of landslides due to earthquakes. The return period for a major earthquake of Intensity VII to occur in Hong Kong is estimated to be 350 to 400 years, and Intensity VIII could be once in 2,500 years. The GEO also carried out a study to compare the risk of failure of man-made slopes induced by earthquakes to those induced by rainfall show that slopes failure risks due to earthquake is much smaller than those due to heavy rainfall [8]. A check dam was constructed within the squatter settlements downslope as a measure of mitigating potential landslides or heavy runoff. Pre-landslide event risk management aspects also included a comprehensive slope safety system operated by the GEO. This incorporated the application of geotechnical control to slopes in order to combat landslide hazards. The goals were to reduce landslide risks and address public attitudes towards slopes managements.

The Hong Kong slope system aimed at reducing risks through implementation of four principal duties; Policing new slopes and recommending safety clearance to vulnerable squatters threatened by hill slopes, works project for substandard government man made slopes and natural terrain mitigation, researching and setting standards, education and information for slope maintenance campaigns and risk awareness and landslip warning emergency services [6]. The post landslide event management techniques include: Latest developments of systematic landslide investigation and slope engineering, use of quantitative risk assessment (QRA) techniques, mitigation of natural terrain landslide hazard, application of digital and remote sensing technologies (e.g. digital photogrammetry, airborne LiDAR). Current strategy is the 'react to known hazard' principle. Common remediation techniques include soil nailing, check dam (rigid barrier) and flexible barriers.

5.5 RISK ASSESSMENT

Qualitative risk assessment carried out is based on the hazard and consequence factors identified to be associated with the Sham Tseng San Tsuen natural and physical setting. Table 2 presents the hazards identified at the Sham Tseng San Tsuen Landslide setting and their corresponding qualitative hazard ratings. Table 3 presents the consequent factors and their corresponding qualitative consequence ratings. The consequence identification is carried out based on the elements at risk and probability of spatial impact and vulnerability within the site's environment. Thus the total risk computed as a product of the overall hazard and consequence rating for the Sham Tseng San Tsuen physical hillside setting was high to very high.

Table 2. Hazard Classification

Hazard Factor	Qualitative Hazard Rating
Topography	High
Debris flow	High
Overlying colluvium	High
Joints	High
Rainstorm return period	Low
Rock fall	Moderate

Table 3. Consequence Classification

Consequence Factor	Qualitative Consequence
Squatter settlers	High
Weak squatter buildings	High
Major and minor road beside settlements	Moderate

6 DISCUSSIONS AND CONCLUSIONS

Based on the natural hilly topography of Hong Kong, geomorphological processes could easily be influenced by severe rainstorms. The engineering properties of the sparsely vegetated colluvium deposits overlying the weathered granite in the area were also favourable to potential slope instability. The colluvium layer was more likely to rupture than at its interface with the underlying weathered granite. Significant water pressure was created within joints present in the colluvium and triggered the disturbance of the slope. The 24˚ average hillslope angle at the hillside was adequate to facilitate debris flows downslope. Although only one fatality was reported in the Sham Tseng San Tsuen Landslide event, the geomorphological setting clearly indicated that potential hazard posed by the ground conditions at the hillside was high and capable of exposing the squatter settlement downslope to direct risks of potential landslides. An overall qualitative landslide risk assessment for the Sham Tseng San Tsuen is high to very high based on the geomorphological setting and the associated risks present at the site prior to the landslide activity. Adequate field geomorphology in combination with aerial maps study would have revealed the hazards present at the site and the consequences of the risks exposed would've been noted.

It is recommended here that slopes close to squatter settlements undergo comprehensive engineered slope safety maintenances. If qualitative risks and vulnerability of elements at risks were proven to be high based on geomorphological assessments, squatters' evacuation and relocation would be quickly necessary. Mitigation measures such as rigid/flexible barriers could be installed at the downslope spanning across the entire potential landslide catchment will also be required. Intensive cooperation with the weather observatory department in the wake of recent climatic change forecasts is important. This would predict rainstorms and a Landslip Warning can then be issued by the GEO.

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