DEVELOPMENT OF A RISK ASSESSMENT METHODOLOGY FOR LANDSLIDES IN SRI LANKA

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1. Introduction

Landslide risk management, like many other forms of risk management of natural and/or civil engineering hazards, is a relatively new discipline with evolving analysis techniques. In Sri Lanka, very little has been done towards introducing scientific practices of landslide risk assessment delineating the degrees of hazard, identifying elements at risk, risk assessment and risk treatment. This study describes framework for site-specific landslide risk assessment and can be use at any site of the landslide-prone hilly areas of Sri Lanka.

2. Risk Assessment on Landslides

The overall framework for quantitative risk assessment of slopes and landslides is general and multidisciplinary, consisting of the following activities; (a) hazard identification and probability of occurrence, (b) identification of the elements at risk, (c) estimation of vulnerability of the elements at risk, and (d) calculation of total risk. The definition of total risk (R_t) is expected from the number of lives lost, persons injured, damage to property and disruption of economic activity. It is product of specific risk (R_s) and element at risk (E) over all landslides and potential landslides in the study area, given as follows:

$$R_t = \sum R_s \times E \quad \ldots\ldots (1)$$

Specific risk (R_s) is product of the annual probability of occurrence (P_a) and the vulnerability (V) for a specific element at risk, given as:

$$R_s = P_a \times V \quad \ldots\ldots (2)$$

Combining Eqs. (1) and (2) yields the following equation;

$$R_t = \sum P_a \times V \times E \quad \ldots\ldots (3)$$

From the morphological characteristics, landslide can be divided into four major areas. There are head region, main body, foot and toe. Total risk is sum of the risk on each areas of the landslide and given as equation (4);

$$R_t = R_{t\text{-}Head} + R_{t\text{-}Body} + R_{t\text{-}Foot} + R_{t\text{-}Toe} \quad \ldots\ldots (4)$$

From equation (3) and (4), following equation is obtained as:

$$R_t = \{ (\sum P_a \times V_{Head} \times E_{Head}) + (\sum P_a \times V_{Body} \times E_{Body}) + (\sum P_a \times V_{Foot} \times E_{Foot}) + (\sum P_a \times V_{Toe} \times E_{Toe}) \} \quad \ldots\ldots (5)$$

The elements at risk (E) can be divided to two major group; property and person. Also the element at risk (E) can be quantified by placing a Sri Lankan rupee value or some other form of value (U.S. Dollar or Japanese Yen) on them. Then risk (R) becomes a risk cost (R_c) and total risk (R_t) become a total risk cost ($R_{t\text{-}c}$). In here $R_{t\text{-}c}$ is the annual total risk cost, or annualized total risk cost, of the expected losses from the landslide hazard and equation (5) can also be written as:

$$\begin{aligned} R_{t-c} = \{ & (\sum P_a \times V_{Head(property)} \times E_{Head(property)} + \sum P_a \times V_{Head(person)} \times E_{Head(person)}) \\ & + (\sum P_a \times V_{Body(property)} \times E_{Body(property)} + \sum P_a \times V_{Body(person)} \times E_{Body(person)}) \\ & + (\sum P_a \times V_{Foot(property)} \times E_{Foot(property)} + \sum P_a \times V_{Foot(person)} \times E_{Foot(person)}) \\ & + (\sum P_a \times V_{Toe(property)} \times E_{Toe(property)} + \sum P_a \times V_{Toe(person)} \times E_{Toe(person)}) \} \end{aligned}$$

For the demonstration of proposed simplified method we make a case study in Yatiyantota probable landslide area in the central hills.

2.1 Hazard Identification and Probability of Occurrence

The currently available landslide hazard zonation maps being on the scale of 1:10,000 not sufficiently detailed for utilization in assessing hazard or risks in location specific situations in hilly areas of Sri Lanka. Therefore in this study following field score evaluation method (Table 1) was introduced.

Table 1 Field score evaluation on landslide hazard

G1 Bed rock geology and Structure (20)	Lithology (8)	0 1 3 5 8	Marble Weathered rock Granite, Gt.bt.gn, all others Charnockite, Granulite, NBE Quartzite
	Amount and direction of Dip (4)	0 1 2 3 4	Dip and scarp 70-90 Dip and scarp 55-70 Dip 10-30, scarp 45-55, inter. Dip 0-10, scarp 30-45 Dip 30-55, scarp 0-30
	Deviation Angle (6)	0 2 4 6	25-120 10-25 or 120-155 155-180 0-10
	Discontinuities (2)	0 2	Absent Present
G2 Overburden deposits (10)	Soil Thickness (10)	0 2 8 9 10	Bed rock Coll < 1, overburden < 2 Coll 1-3, overburden 2-8 Coll 3-8, overburden >8 Coll > 8, overburden >8
G3 Slope angle (25)	Slope Angle (25)	5 15 25 20 10	>40° 31°- 40° 17°-31° 11°-17° 0-11°
G4 Hydrology (20)	Piezometer level (ground water table) (20)	3 7 10 15 20	Below slip plane Above slip plane Between ground level & slip plane At ground surface Artesian or above ground level
G5 Landform and landuse (25)	Landform (15)	3 8 10 12 15	*Simple slope (no previous slides)* Simple slope with surface cracks Old slip but modified by erosion New slip now stable no erosion Recent slip, erosion at toe
	Landuse (10)	1 2 3 5 7 8 10	Natural woods (undisturbed) Cleared and cultivated well Cleared for pasture land Disturbed by cattle Controlled construction Disturbed by construction but precautions taken Heavy construction
100	Total score	77%	

The study area of the unstable slope on which houses are located was divided into 3 geomorphologic sections according to the slope angle and direction. By summing up the scores, landslide hazard (H) can be quantitatively evaluated. The evaluation pointed out the Section (I), Section (II) and Section (III) have a hazard (H) is 77, 61 and 62 respectively. The relationship between hazard and qualitative term use in hazard evaluation is shown in Table 2.

Table 2 Relationship between hazard and probability

Hazard Range	Qualitative Term Hazard Zonation	Probabilistic Criterion Grade	Indicative Annual Probability
H<40	*Safe Areas*	*Very Unlikely <5%*	10^{-5}
41<H<55	Moderate Hazard	Unlikely 5-20%	10^{-4}
56<H<70	Hazard	Likely 20-80%	10^{-3}
71<H<100	Most Hazard	Very Likely >95%	10^{-2}

According to Table 2 Section (I) was identified most hazardous area and Section (II) & (III) were on hazardous area. Also the result of preliminary field investigation, Part (A) area of the Section (I) indicate the most vulnerable to future disaster due to landslide hazard (Fig.1). This area was selected for further studies and assessment of risk.

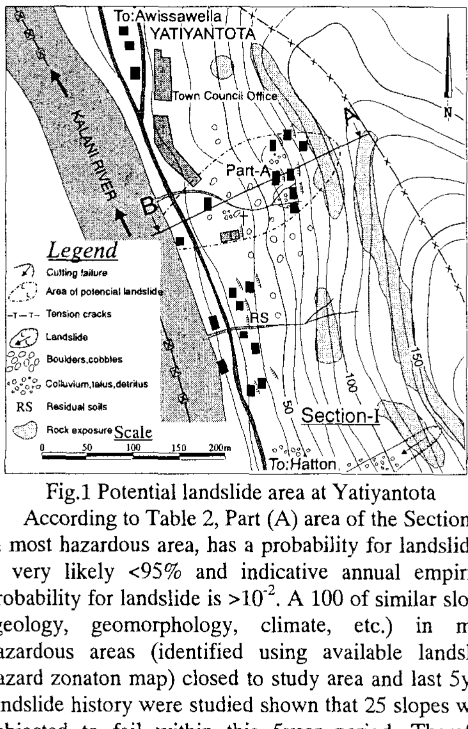

Fig.1 Potential landslide area at Yatiyantota

According to Table 2, Part (A) area of the Section (I) in most hazardous area, has a probability for landsliding is very likely <95% and indicative annual empirical probability for landslide is $>10^{-2}$. A 100 of similar slopes (geology, geomorphology, climate, etc.) in most hazardous areas (identified using available landslide hazard zonaton map) closed to study area and last 5year landslide history were studied shown that 25 slopes were subjected to fail within this 5year period. Therefore statistically, Part (A) area in the most hazardous area with probability of landsliding as very likely, has annual probability of failure of $0.5x10^{-2}$ may be applied.

2.2 Elements at Risk

In the overview paper of the IUGS working group on landslides (1997), the definition of elements at risk is meaning the population, buildings and engineering works, economic activities, public services utilities and infrastructure in the area potentially affected by landslides. When the probable landslide boundary is superimposed with the human settlements and infrastructure of the area, it was observed that following humans and properties are vulnerable to future landslide events (Fig. 1 and Table 3).

Table 3 Elements at risk in study area

Area of the landslide	Element at risk	Property value[1] (Rs.)	Person Value[2] (Rs.)
Head region	2 houses/ 7 person	1000000	7 x 150000
Main body	5 houses/ 20 person 50m footpath	5000000 100000	20 x 150000
Foot	1 house/ 5 person 20m foot path 2 shops/ 20 person 1 church/ 50 person Telephone Exchanger	700000 50000 3000000 2000000 1000000	5 x 150000 20 x 150000 50 x 150000
Toe	1 house/ 3 person 125m highway	700000 1250000	3 x 150000 2 x 150000

2.3 Estimation of Vulnerability

Vulnerability (V) is the degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed as a scale of 0 (no loss) to 1 (total loss). Vulnerabilities of property and persons in the study area were estimated based on my field experience (about 10 years) in the past landslide disaster history of similar slopes in Sri Lanka. The assumed values are given in Table 4.

Table 4 Estimation of landslide vulnerability

Area	Factors	$V_{Property}$	$V_{Persons}$
Head region	High velocity, medium depth, little warning, short escape distance	0.7	0.3
Body	High velocity, high to medium depth, little warning, long escape distance	1.0	0.5
Foot	Medium velocity, debris accumulation, some warning, short escape distance	0.4	0.01
Toe	Low velocity, more warning, short escape distance, debris flow< mud flow	0.1	0.001

2.4 Calculation of Total Risk Cost

$R_{t\text{-}c}$ is the annual total risk cost, or annualized total risk cost, of the expected losses from the landslide hazard and could be calculated from the equation (6);

$$R_{t-c} = \begin{Bmatrix} [(0.05 \times 0.7 \times 1000000) + \{(0.05 \times 0.3 \times 150000)7\}] \\ + [\{0.05 \times 1.0(5000000 + 100000)\} + \{(0.05 \times 0.5 \times 150000)20\}] \\ + \begin{bmatrix} \{0.05 \times 0.4(700000 + 50000 + 3000000 + 2000000 + 1000000)\} \\ + \{(0.05 \times 0.01 \times 150000)75\} \end{bmatrix} \\ + [\{0.05 \times 0.1(700000 + 1250000)\} + \{(0.05 \times 0.001 \times 150000)5\}] \end{Bmatrix}$$

$$R_{t-c} = 0.5311625\, Rs\, Million$$

Therefore annual total risk cost, or annualized total risk cost, in the potential landslide area or Part (A) of Section (I) is 0.5312 Million Rupees.

3. Concluding Remarks

The proposed methodology for risk assessment given in this paper will facilitate determination of risk through scientific analysis of landslide hazards. The expected annual total risk cost due to landslide disaster at specific site and/ or risk cost on specific element at risk (property and/ or person) due to landslide disaster could be calculated through the given methodology. It may assist in the designing of cost effective solutions and mitigation actions for the area. It is also expected to help non-technical decision-makers to assess the situation before taking appropriate futuristic measure.