HUMAN ERROR RELATED RISKS OF MALAYSIAN LANDSLIDES

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ABSTRACT

This paper discusses landslide risks. Rainfall is not always the major contributing factor at every landslide. Most of the times the actual root causes are engineering (e.g. flaws in slope design, errors during construction etc.) or non engineering activities (e.g. deforestation, poor vegetation cover, poor maintenance etc.). In both cases contributions of humans error to failure exists. In this paper landslide failure probabilities due to human errors have been estimated using fault tree analysis (FTA). Human errors are classified on the basis of design, construction and maintenance errors. Consequences of failure are the second basic parameter used to evaluate risks but in this study on the basis of probability of failure level of risk has been estimated. Level of risk is dependent upon the intensity of human errors involved in subtask items of design construction and maintenance. As conclusions the study furnishes probability of failure of those subtasks which are highly under the influence of human errors.

Keywords: Human errors, Fault Tree Analysis (FTA), Probability of failure, Uncertainties

INTRODUCTION

Landslide is defined as rock or debris movement or slope earth down (Cruden 2003). Problems of landslides often occur, due to instability of slopes, distressed slopes, cut slopes. (Cheung and Tang 2005) pinpointed that on an average hundreds of landslides are reported every year in Hong Kong due to old slope failures. Cut slopes are usually 40 to 70 degrees and fill carries 30 to 35 degrees. These are manmade (cut and fill) slopes formed at the time, when no geotechnical control exists. It means in any case slope engineering design and construction practices has to be revised or reviewed as it helps in reducing the risks of land sliding. Quick variations in ground water table along the slope, easily triggers the landslides. It is recognized by (Varnes 1978) that it's the chain of events from "cause to effect" occupied in slope movements. Effective remedies for controlling slope movements/failures can only be worked, if proper distinction between landslides triggering and causal factors is there (Popescu 2002).

The objective of this study is to focus landslide risks in connection with human errors. As risks occurs due to uncertainties. Uncertainties are generated through various means, for example spatial variation in soil properties, testing methods, inaccurate measurements (Nadim 2007) but one aspect on which until now construction industry is not moving is risks related to human uncertainties. (Morgenstern 1995) pointed out the catastrophic failure of Kwun Lung Lau landslide in Hong Kong. It is the input of human uncertainty. It is also reported by (Ellingwood 1987) that mostly accidents or structural failures are not due to variation in the loads or resistances but in actual it's the outcome of the human errors.

OVERVIEW OF LANDSLIDES IN MALAYSIA

The first reported landslide of Malaysia is in December 1919 which claimed 12 lives. Another tragedy took place in 1961 (Jaapar 2006). However this study only discusses those major landslides which occur after 1990. Total 49 cases of large landslides are reported since last 6 years out of which 88% are attributed to manmade slopes. Large landslides are those which cover more than 5,000 cubic metres.

National slope master plan 2009-2023 reflects the cases of massive landslides. Case of Highland Tower Condominium, Hulu Klang Selangor is also reported. This incident has been occurred on 11 December 1993. The highest number of deaths recorded by a single landslide event took place in Sabah on 26 December 1996. It claimed 302 lives as few villages were totally destroyed due to debris flow. Its not only the fatalities recorded but sometimes blockage of roads and hindrances in the communication system disturb the whole planning and schedule of that particular period.

TRIGGERING AND CAUSAL FACTORS

Causal factors are most often contributed in cluster to make the slope vulnerable. It may be geological, morphological or human (Table 1.). In comparison with causal factors, triggering factors has to work solely in initiating landslides or sometimes no evident of triggering factor is noted. Triggering factors include intense rainfall, snow melt, and variations in water level, volcanic eruption, earthquake tremors and slope geometry change.

Triggering factor is mainly rainfall as Malaysia is facing two monsoon seasons every year. Its average rainfall is 2550mm per year which is exceeding the worldwide average. With reference to landslide cases of Malaysian region, the causal factors are abuse of prescriptive method, deficiency in design, improper knowledge of past failures, inaccurate geotechnical data, inadequate drainage facility, unconfirmed ground water table, poor or non maintenance and flaws in construction.

Table 1: Explanation of Causes of Landslides (Popescu 2002)

Geological Causes	Morphological Causes	Human Causes
Poor/Susceptible materials	Weathering effects, Freeze/thaw, shrink/swell	Digging of slope
Splitting, Jointing, Shearing in materials	Techtronic/Volcanic pressure	Pumping out, Leakages/ Irrigation Mining
Negatively acquainted (Faults/Bedding etc)	Accumulation loading slope/crest	Cutting of forests
Contrast to permeability, Material stiffness	Piping/Erosion Removal of vegetation cover	Encroachments on slopes

COMMON MITIGATING MEASURES

Soil nailing is one of the prevalent techniques used to stabilize distressed slopes and also fit for very steep cut slopes. Soil nail slopes of more than 25m high are frequently used in Malaysia. Its main purpose is to give strength to the existing ground by inserting steel nails (closely spaced) as construction goes on from top –down. This mitigation strategy will only work if soil nails of adequate length are inserted.

(Chen 2004) discussed the case of failed soil nail slope. Failure of the slope takes place after few days of heavy rains. Investigations shows that slip surfaces are not in contact with steel bars. Reinforced soil wall is used for slope reinstatement work at the toe of the slope. Another case is also reported by (Chen 2004) that at the backyard of two bungalows, slope fails after heavy rain falls. Investigating authorities after detailed survey prepared a report of sub soil parameters and slip surfaces locations. On the basis of collected information remedial actions has been chosen. Due to site limitations, geometrical method is avoided, and possible option of retaining walls comes into use. Reinforced soil wall is also selected sometimes as among other retaining structures it is less expensive. During the construction process of reinforced soil wall, temporary retaining structure of sheet piles is also erected to stop any of the soil movements. After the completion of reinforced soil wall, surface drains along with berm drains and cascaded drains are installed to reduce infiltration. Another incident of collapse of segmental retaining wall, (proposed to stabilize cut slope) having a height of 8m to 9m, and a sloping surface of 6m. It felled down when it's almost completed. This is basically the case of internal instability. As constraints of space and running reservoir at the top makes the excavation (into the toe of slope) limited. The limited anchorage length for segmental retaining wall fails to provide adequate resistance. In this complex situation, contiguous bored piles are the only option used to work as a retaining structure. Cost effectiveness is not the only selection criteria but site constraints and causes of failures have to be considered in taking up the remedial works.

RISK ASSESSMENT OF LANDSLIDES

Risk is basically a product of severity of event (C) and the probability of that event (P). In mathematical expression it is

$$R = F(C, P) \tag{1}$$

Risk of landslides can be quantified through likelihood of slope failures and the losses occurred. When slope stability problems are measured, the prime factor is to conclude the safety level of that particular slope. An accurate determination of safety level should appropriately deal three geotechnical basics that work with slope stability, geometry, pore pressure and strengths (Silva, Lambe et al. 2008).

As development on hilly areas is growing fast in Malaysia a special care has to be taken in terms of factor of safety adjacent to slope failures. Using Geotechnical Manual of slopes, (GCO 1991) Hong Kong for standards of safety factors. Chances of failure or risk of failure of slopes can only be worked out through quantitative or qualitative assessment. Trees methods like Fault and event tree analysis are the best examples as it tackles both types of assessments. A historical record is also one option but most often data records are not maintained properly. Risk assessment tools for example risk matrix method; risk graph method and numerical scoring method are used to calculate only risk levels.

RISK MANAGEMENT PLANNING

Soil cut slopes are subject to deterioration and prone to failures particularly during monsoons or as a consequence of seismic activities. In this regard risk based stabilization planning is developed to counter the deteriorating slopes. Risk based stabilization planning (Fig. 1) is used as a tool in decision taking to minimize the chances of slope failures and its consequences. The proper follow up of stabilization programme not only covers slope deterioration but also reduces the maintenance expenditure.

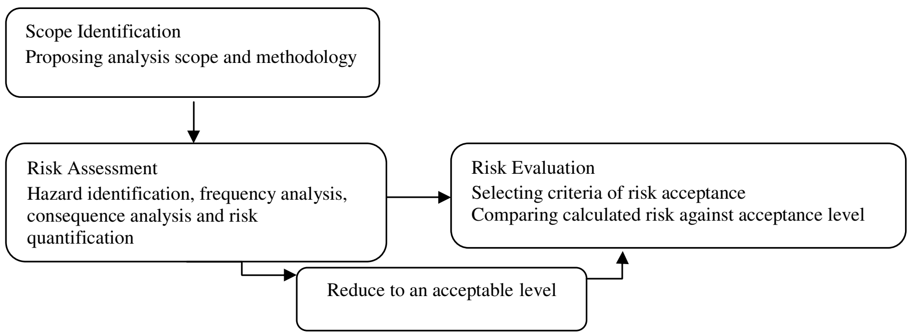

Figure 1: Risk based stabilization planning (Li, Zhang et al. 2009)

METHODOLOGY

Among 47 subtask items of design, construction and maintenance) this study has considered the most affected subtask items. Those subtask items are highly under the influence of human errors as its clear from Table 3. Case studies have been taken in this regard to more clarify the process.

Fault tree analysis has been proposed to work out the probability of failure due to these subtask items. Here author only produce those fault trees which are related to the selected case studies. Using the Boolean algebra basics AND gates are replaced with the product of the assigned values and OR gates by the sum of their inputs. The mentioned assigned values of basic events are used to work out the probability of failure due to considered subtask item. (Fig 2.) These assigned probabilities are selected on the basis of similarity in the sub events/judgements and by expert's decision. As probability of failure is one of the main components in evaluating risk levels. Consequences of failure the second main component used to evaluate risk. Unlike identification of hazard it performs in a quantitative manner, providing information about the significance level of the probable effects. When consequence estimation is related with some particular accident it is viable to decide from which aspect safety and health of surrounding community, integrity of environment can receive impact.

In this study author mentioned the causal factors of only those landslides which will act as case studies. Like the collapse of highland towers 1993 (MPAJ 1994) reported the following concluded factors responsible for this landslide.

a. buckling and shearing of rail piles foundation persuade by soil movement
b. Surface runoff due to improper drainage facility
c. Cut and fill slopes, rubble walls around Block I showed inadequate design (carrying safety factor less than 1) and poorly supervised construction
d. Slope gradient is suspected to be very steep
e. No maintained drainage system along with leakage from pipe culvert carrying diverted flow of East stream

From the computational analysis its clear that the designed wall would fail at 5m very easily even without water pressure. The calculated safety factor is 1.52 even without considering water forces at the back of the wall. Its also observed under the same study that wall composed of different size of stones with haphazard plaster carrying no drainage blanket over it. An alarming point was that it had no base directly rests on ground.

Another landslide, Bukit Antarabangsa 1999 in cut and fill slope is basically the outcome of several smaller landslides. Kumpulan Ikram Sdn Bhd (1999) pinpointed the most apparent causes can be recognized to the following factors

a. the slope has minimum safety factor of 1 to 1.35, not fulfilling the requirement as required safety factor is 1.4
b. presence of weak material in the slope body
c. no clue of berms drains construction within the collapsed slope section
d. blocked drains and previous unrepaired crack signs in drains
e. internal erosion

Again on the same area another massive landslide of (Bukit Antarabangsa 2008) has been taken place. The contributing factors investigated by (JKR) are:

a. loose soil from earth dumping on the slope during development
b. poorly maintained/damaged drainage on the failed slope and its around vicinity
c. soil creeping which initiates or widens existing cracks and forming new tension cracks
d. Great leaking from running water pipe along an abandoned housing scheme due to soil creep
e. Prolonged rainfall during the month of October and November.

The causes of the concerned landslides are evidence of those human errors which are committing from design phase till maintenance. Misleading safety factors, dumping of loose material, clogging or leaking of the drainage system, presence of unrepaired cracks all these causal factors indicating both technological and behavioural flaws of the whole system. Specifically talking about highland tower collapse inadequate drainage is the major contributor. Design flaws are also prevailing but the collapse of the tower has been taken place after 15 years of construction. In case of the next two case histories selected by the author Bukit Antarabangsa (1999) and (2008) one common feature among all three is the poor or inadequate drainage. Clogged drains or even no sign of berms drain construction like in Bukit Antarabangsa 1999. As its already concluded by the author human errors are highly dominating in drainage planning, design of drainage facility and in maintenance of surface and subsurface drainage after heavy rains. In connection with these landslides already drawn results work quite well to estimate the probability of failure of these selected case studies. Fault tree logics are used to work out the probability of failure (Fig. 2 and 3) due to non maintenance or poor maintenance of drainage system. As this feature is common in every case study that's why in that particular study only drainage facility is taken into account. The events and sub events or basic events are listed in Table 2.

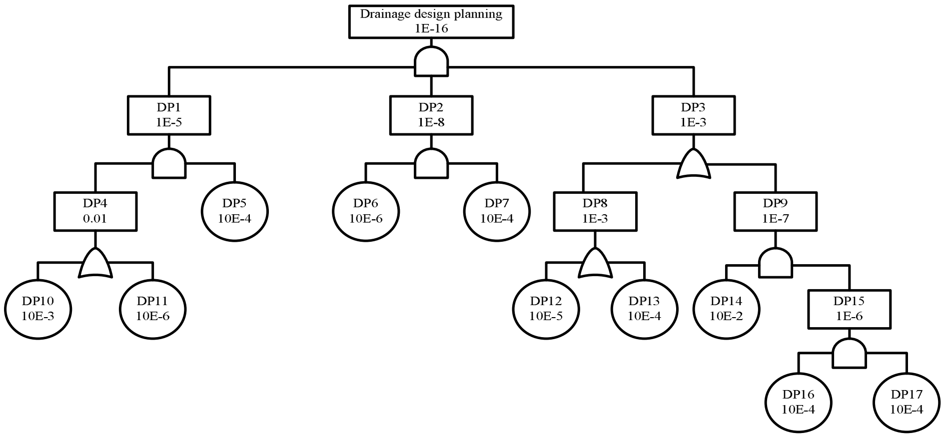

Figure 2: Fault tree logic of drainage design planning

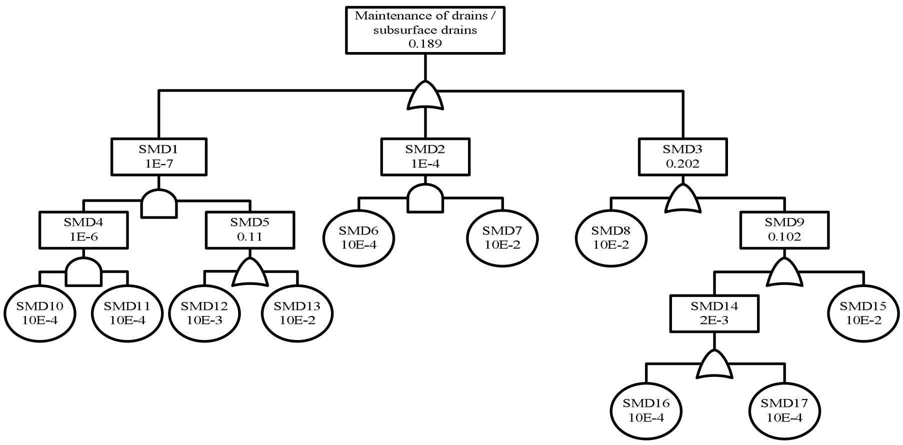

Figure 3: Fault tree logic of maintenance of special measures like surface/subsurface drainage

Table 2: Drainage system planning and special maintenance of drainage (SMD) system

DP1	Inaccurate site information	SMD1	Improper flowing through surface drains/channel
DP2	Unparsed economic feasibility	SMD2	Clogging/blockage of sub surface drainage facility
DP3	Furnished inadequate drainage capacity	SMD3	Infiltration of water into soil
DP4	Misconception about soil strata/	SMD4	Cracking/spalling
DP5	No practice of revisiting for topography	SMD5	No regular patrol
DP6	Lack of capital	SMD6	uncleared debris
DP7	Lack of resources	SMD7	No provision for any accidental flow
DP8	Unavailability of rainfall statistics	SMD8	Rainfall exceeds
DP9	Predicted ground water table	SMD9	Ground water table rise
DP10	Unsuitable outlets proposed	SMD10	Sustained loading/additional hydrostatic pressure
DP11	Improper layout of drains	SMD11	Deleterious effect of weather
DP12	Consider less preferable	SMD12	Consider it maintenance free
DP13	Organizational trend	SMD13	Less preference
DP14	Flaws in geological report	SMD14	Settling of ground
DP15	No counter check	SMD15	Piping occurs
DP16	Time stress	SMD16	Unflawed soil behaviour
DP17	Work stress	SMD17	Inaccurate measurements of piezometrics

Table 3: HEPs for drainage facility subtask items

Categories with cases	Planning (F3) 0.411	Designing (AC4) 0.226	Installation (PW3) 0.030	Maintenance (SM1) 0.69
Highland Tower (1993)				P_f (0.189)
Bukit Antarabangsa (1999)	x			
Bukit Antarabangsa (2008)				P_f (0.189)

RESULTS AND CONCLUSIONS

As fault tree analysis logics confirms that probability of failures of the proposed subtask items are more or less in same range. According to qualitative assessment scale it lies under the category of high risk. Highland tower (1993) and Bukit Antarabangsa (2008) both are the cases of poor or non maintenance of drainage system. Probability of failure of 0.189 is calculated shown in Table 3. Focussing case study of Bukit Antarabangsa 1999 level of risks has been estimated more as it shows that probability of failure is not only related to the maintenance aspect but flaws in planning is also contributing but due to no severe consequences this case study seems to be avoidable. It is now becoming strongly supported after having so much contribution of human errors that reliability of the structure is not only technology dependent but the quality of design, construction and maintenance must meet the specific. Until now Malaysia faced severe consequences due to these prevailing errors.

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