# HUMAN RELIABILITY ANALYSIS IN GEOTECHNICAL RISK ASSESSMENT FOR HILLSIDE DEVELOPMENT

W. P. Nanak & I. S. H. Harahap
Department of Civil Engineering
Universiti Teknologi PETRONAS
31750 Tronoh, Perak, Malaysia
Email: will1909@gmail.com

## ABSTRACT

Landslides represent one of the most destructive natural hazards and a major threat in most hillside development. Over the years, there are little or no concerns on the importance of human factors to be considered as one of the major causes of landslide. Human Reliability Analysis (HRA) which in turn has been applied for quite sometimes in other industry sector to assess the human factors contributing to a risk and identifying proper mitigation measures to reduce the risk can be proposed to adopt into the geotechnical risk assessment. The needs to focus on the aspect of human factors in geotechnical engineering is inevitably due to the facts that human interaction interrelated at all stages from planning to design, and construction to maintenance stages. This paper will review the current state of landslide, human factors and its influence in Malaysia, introduction of HRA and discusses on the second generation HRA method known as CREAM.

**Keywords:** Landslides, Human factors, HRA, CREAM

## INTRODUCTION

The development in hillside areas today proved to be one of the important factors which lead to the increasing landslide cases. In the future to come, hillside development may become unavoidable issue due to the ever present trends such as increasing population, limited flat land in the urban area and rapid economic development. Activities induce by the hillside development e.g. construction operation, could disrupt the nature equilibrium of the hill slope and increases the risk of landslides to occur. Most landslides were triggered by either or combination of physical and geological elements. But nowadays, it is reported that landslide cases to some extent were caused as results of human intervention. Landslides and engineered slopes have always involved some form of risk assessment and management and often done by the use of "engineering judgment" by experts in this field (Fell et al., 2005). Over the past few decades, the developments of risk assessment and management have been improved time by time perhaps with the help of today's technological advances. Although these advances may seem beginning to provide systematic and rigorous processes to formalize slope engineering practice and enhance slope management (Dai et al., 2002). One subject which yet to be accounted in the current reliability risk-based approach but often time been a talking point whenever engineering failures occurs is human factor. Finding in the past such as provided by Sowers (1993) based on 500 well documented foundation failures concludes that the majority (88%) of failures were due to "human shortcomings" whereas only 12% of the failures were due to lack of technology. Based on Sowers' findings, Bea (2006) further concludes that the current approach in reliability and risk analyses methods have addressed a very limited part of the challenges posed by uncertainties in geotechnical engineering.

In large complex system like hillside development where dynamic and multi-human interactions existed in every stage from planning to design, and construction to maintenance, uncertainty may arise since the whole process involves human to plan, organize, perform and completing the tasks, and at sometimes avoiding human error is somehow inevitable. Efforts to mitigate landslides e.g. restriction of development, using proper construction techniques, use of physical measures, etc. have been introduced for years but despite of their effectiveness as a controlling measures in most circumstances, landslide still a reoccurring issue and in most cases found to be involving human factors. This paper reviews the current state of landslides and the influence of human errors that arises at Klang Valley areas in Malaysia and discusses the possibility of adopting the application of human reliability analysis (HRA) in geotechnical risk assessment for hillside development. This paper will focus on the use of second generation HRA method known as cognitive reliability and error analysis method (CREAM).

## LANDSLIDE AND HUMAN FACTORS IN MALAYSIA

Since the collapsed of Tower 1 of Highland Towers which received vast coverage by the media both local and international, Klang Valley area have succumbed as one of most affected areas by landslides in Malaysia. Total of six (6) major cases of landslides were recorded from 1993 to 2008 and the recent landslide at Bukit Antarabangsa on 6th December, 2008 which resultant five (5) casualties, buried fourteen (14) bungalows, and forced about 2000 residents to evacuate their homes shows yet another milestone of numerous tragedies bordering the Klang Valley area. Leaking pipe along a row of abandoned house was found to be the main cause of landslide at Bukit Antarabangsa. Aside heavy rainfall, abuses of construction methods during development, lack of maintenance, and clogged drains were said to be other factors involved. According to the landslide forensic statistic data from year 2004 to 2007 of Slope Engineering Branch under the Public Works Department of Malaysia, 57% of landslides were due to human factors, whereas only 29% and 14% due to physical and geological factors, and most of the landslides occurred at man-made slopes (JKR, 2010). In another study conducted on the 49 cases of mostly large landslides on residual soil slopes, it was found out that 60% of failed man-made slopes were due to inadequacy in design, 8% because of failure due to construction errors, about 20% are caused by a combination of design and construction errors while only 6% account for geological features and lack of maintenance (Gue et al., 2010). Jamaluddin (2006) points out based that human factors such as negligence, incompetence, lack or poor maintenance system, ignorance of geological inputs, unethical practice and various negative human attitudes were amongst the factors that influence many cases of slope failure in Malaysia. Table 1 shows the summary of the results conducted on the 49 cases by Gue & Tan (2006).

Table 1: Causes of landslides (Gue & Tan, 2006)

| Causes of Landslides | No. of Cases | Percentage % |
|---|---|---|
| Design Errors | 29 | 60 |
| Construction Errors | 4 | 8 |
| Design & Construction Errors | 10 | 20 |
| Geological Features | 3 | 6 |
| Maintenance | 3 | 6 |
| Total | 49 | 100 |

## THE INFLUENCE OF HUMAN ERROR

According to the studies of the accidents, the factors involved in causation of the major failures most often involved human, organizational, and knowledge uncertainties. These were identified as extrinsic factors. The remaining 20% of the causation factors involved natural and model related uncertainties. These were identified as Intrinsic factors (Bea, 2006). This statement well defines the situation in Malaysia as most findings discussed previously suggested that human factors are indeed at large contributing to most landslides. Gertman and Blackman (1994) and Hollnagel (1998) reported that, regardless of the domain, there seemed to be general agreement that 60-90% of all system failures could be attributed to erroneous human actions (Forester et al., 2009). The causes of landslides i.e. in design, construction or maintenance, can be either because of the action or the consequence of the erroneous action but usually it is involves more than one or multiple human errors contribution to trigger the failure. Reason (1990) described that many cases of serious events occur because of a combination of unusual conditions and latent human errors that trigger active human errors. Active errors are those that have an immediate effect whereas latent errors are those that do not have an immediate effect but whose consequences can become important at a later time. Example of active errors can be well described during the construction stage, where inexperience operator excavating a slope surrounded with buildings or other infrastructures without proper guidance or following proper method can possibly trigger a slope failure. While pipe burst that leads to landslide at Bukit Antarabangsa is an example of latent errors.

## HUMAN RELIABILITY ANALYSIS (HRA)

The term "human reliability" defined as the probability that a person will correctly performs some system-required activity during given time period without performing extraneous activity that can degrade the system (Hollnagel, 2005). HRA is generally part of probabilistic risk assessment (PSA) and widely applied in nuclear power industry purposely to examine and estimate the likelihood of the potential unsafe acts or human errors. The method has been practice since the early 1960s but only in the middle of 1980s that most of HRA methods were developed (Hollnagel, 1998). The primary purpose of HRA is to estimate the likelihood of particular human actions (that may prevent hazardous events) not being taken when needed, or other human actions that may cause hazardous events (by themselves or in combination with other conditions) occurring. Failures to take action to prevent hazardous events, and actions that causes hazardous events are commonly called "human errors" in HRA (Wreathall et al., 2003).

The method is a critical part of PRA which involves the use of qualitative and quantitative methods to assess the human contribution to risk by embody the use of task analysis, models, data and judgment to assess human performance and its impact on the overall risk from potential accidents. The basic structure of HRA comprises of three main aspects: (1) identify accident scenario contexts and associated human actions, (2) quantify the probabilities of failure of each human action, and (3) identify ways to improve human performance and avoid important unsafe actions (Forester et al., 2009). There are two classes of methods in HRA namely the PRA-based and cognitive theory of control based. These methods can be further classified into (Bell & Holroyd, 2009): (a) First generation methods, primarily focus on the skill and rule base level of human action, (b) Second generation methods, focus on considering context and errors of commission in human error prediction, and (c) Expert judgment based methods provide a structured means for experts to consider how likely an error is in a particular scenario. Figure 1 illustrates the overall approach of a contemporary HRA.

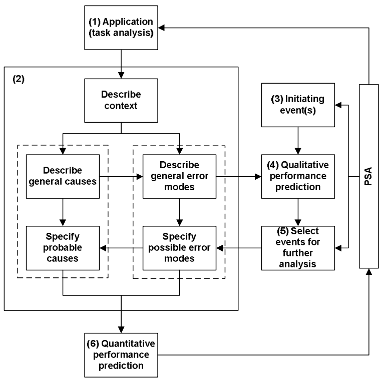


Figure 1: Contemporary HRA approach (Hollnagel, 1998)

## COGNITIVE RELIABILITY AND ERROR ANALYSIS METHOD (CREAM)

CREAM is the most widely applied second generation HRA method developed by Erik Hollnagel in 1998 for the purposes of evaluating the probability of a human error occurring throughout the completion of a specific task. CREAM is a bi-directional analysis method i.e. performance prediction and accident analysis, and it enables an analyst to achieve the following (Hollnagel, 2006):

1. Identify those parts of the work, as tasks or actions, that require or depend on human cognition, and which therefore may be affected by variations in cognitive reliability.
2. Determine the conditions under which the reliability of cognition may be reduced, and where therefore these tasks or actions may constitute a source of risk.
3. Provide an appraisal of the consequence of human performance on system safety which can be used in a PRA/PSA
4. Develop and specify modifications that improve these conditions, hence serve to increase the reliability of cognition and reduce the risk.

CREAM provides a basic and extended method in quantification approaches. The basic method corresponds to an initial screening of the human interactions. The screening addresses either the task as a whole or major segment of the task. The extended method uses the outcome of the basic method to look at actions or parts of the task where there is a need for further precision and detail (Hollnagel, 1998). Figure 2 shows the relationship between the basic and extended method.

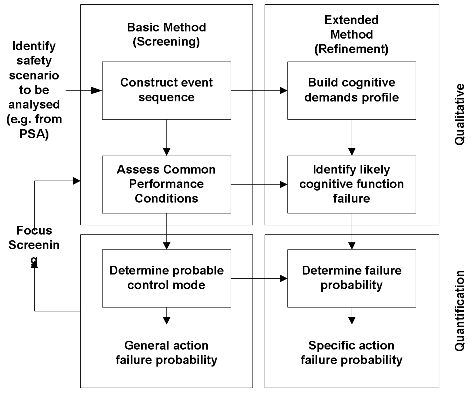


Figure 2: CREAM – basic and extended methods (Hollnagel, 1998)

This paper will only discuss the basic method in CREAM. The first step in the basic method is to perform task analysis through hierarchical task analysis (HTA). A list of activities will be produced based on the outcome of the HTA. The following step involves an examination and assessment of the work conditions under which the task is performed. The common performance conditions (CPCs) are used to characterize the overall nature of the task, and the characterization is expressed by means of a combined CPC score. The combined CPC score can be derived simply by counting the number of times where a CPC is expected: (1) to reduce performance reliability, (2) to have no significant effect, and (3) to improve performance reliability. This can be expressed as the triplet [$\Sigma_{\text{reduced}}$, $\Sigma_{\text{not significant}}$, $\Sigma_{\text{improved}}$]. The steps in assessing the CPCs can be described as follows:

1. Determine the expected level of each CPC by using the descriptor given in Table 4.
2. Determine the expected effects on performance reliability using the outcomes listed in Table 4.
3. Determine whether "working conditions", "number of goals", "available time" and "crew collaboration quality" should be adjusted for indirect influences, using the principles described in the rule above as shown in Table 3.
4. Make a total or combined score of the expected effects and express it as the triplet [$\Sigma_{\text{reduced}}$, $\Sigma_{\text{not significant}}$, $\Sigma_{\text{improved}}$].

The final step in the basic CREAM method is to determine the probable control mode and the general action failure probability. Figure 3 is referred to determine the probable control mode. The black dots represent the 52 different values of the combined CPC score whereas the color lines represent the four regions that correspond to the four control modes. The scrambled control mode is represented by the four cases where $\Sigma_{\text{improved}} = 0$ and $\Sigma_{\text{reduced}} > 5$. The strategic control mode is represented by nine cases; in four $\Sigma_{\text{reduced}} = 0$ and $\Sigma_{\text{improved}} > 3$, in three $\Sigma_{\text{reduced}} = 1$ and $\Sigma_{\text{improved}} > 4$, and the last two $\Sigma_{\text{reduced}} = 2$ and $\Sigma_{\text{improved}} > 5$. These represent the end regions of the distribution of the combined CPC score. The two remaining control mode are less regular. The opportunistic control mode covers the region where $\Sigma_{reduced}$ is moderately high to high while $\Sigma_{improved}$ is low. The tactical control mode cover the region where $\Sigma_{reduced}$ is low but $\Sigma_{improved}$ can be either low or high. The opportunistic control mode accounts for 15 values while the tactical control mode accounts for 24 values of the combined CPC score. This distribution corresponds to the assumption that the most frequent control modes are the tactical and the opportunistic and also that the strategic control mode is more frequent than the scrambled one (Hollnagel, 1998). Table 2 will be used to determine the reliability interval for the expected control mode.

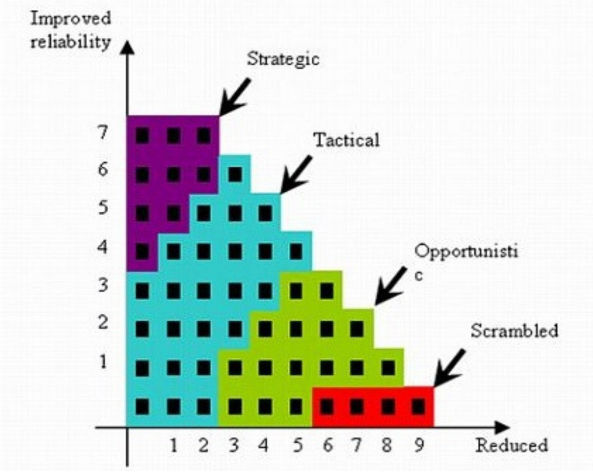


Figure 3: Relations between CPC score and control modes (Hollnagel, 1998)

Table 2: Control modes and probability intervals (Hollnagel, 1998)

| Control Mode | Reliability interval (Probability of action failure) |
|---|---|
| Strategic | 0.5 E-5 < p < 1.0 E-2 |
| Tactical | 1.0 E-3 < p < 1.0 E-1 |
| Opportunistic | 1.0 E-2 < p < 0.5 E-0 |
| Scrambled | 1.0 E-1 < p < 1.0 E-0 |

CONCLUDING REMAKS

The current state of landslides and the impact of human errors in most of the events happened in Klang Valley, Malaysia have been reviewed. The methodology of the basic CREAM method as described in this paper can be adopted into geotechnical risk assessment to evaluate the probability of human error in hillside development. The method provides a comprehensive analysis and recommendation to reduce error contributed by the human factors. Example on the application of basic CREAM method will be presented during conference.

Table 3: Rules for adjusting the CPCs (Hollnagel, 1998)

| **CPC** | **Depends on the following CPCs** | | | | |
|---|---|---|---|---|---|
| Working conditions | Adequacy of organization | Adequacy of MMI and operational support | Available time | Time of day | Adequacy of training and experience |
| Number of simultaneous goals | Working conditions | Adequacy of MMI and operational support | Availability of procedures / plans | | |
| Available time | Working conditions | Adequacy of MMI and operational support | Availability of procedures / plans | Number of simultaneous goals | Time of day |
| Crew collaboration quality | Adequacy of organization | Adequacy of training and experience | | | |

Table 4: CPCs and performance reliability (Hollnagel, 1998)

| CPC name | Evaluation | Level / descriptors | Expected effect on performance reliability |
|---|---|---|---|
| Adequacy of organization | The quality of the support and resources provided by the organization for the task or work being performed. This includes communication systems, safety management system, support for external activities, etc. | Very efficient | Improved |
| | | Efficient | Not significant |
| | | Inefficient | Reduced |
| | | Deficient | Reduced |
| Working conditions | The conditions under which the work takes place, such as ambient light, glare on screens, noise from alarms, interruptions from the task, etc. | Advantageous | Improved |
| | | Compatible | Not significant |
| | | Incompatible | Reduced |
| Adequacy of MMI and operational support | The quality of the MMI and/or specific operational support provided for operators. The MMI includes control panels, workstations, and operational support provided by specifically designed decision aids. | Supportive | Improved |
| | | Adequate | Not significant |
| | | Tolerable | Not significant |
| | | Inappropriate | Reduced |
| Availability of procedures / plans | The availability of prepared guidance for the work to be carried out, including operating / emergency procedures, routines, & familiar responses. | Appropriate | Improved |
| | | Acceptable | Not significant |
| | | Inappropriate | Reduced |
| Number of simultaneous goals | The number of task or goals operator must attend to. Since the number of goals is variable, this CPC applies to what is typical / characteristic for a situation. | Fewer than capacity | Not significant |
| | | Matching current reliability | Not significant |
| | | More than capacity | Reduced |
| Available time | The time available to complete the work; or the general level of time pressure for the task and the situation type. How well the task is synchronized to the process dynamics. | Adequate | Improved |
| | | Temporarily inadequate | Not significant |
| | | Continuously inadequate | Reduced |
| Time of day (circadian rhythm) | The time at which the task is carried out, in particular whether the person is adjusted to the current time. | Day-time (adjusted) | Not significant |
| | | Night-time (unadjusted) | Reduced |
| Adequacy of training and experience | The level of readiness for the work as provided (by the organization) through training and prior instruction. Includes familiarization to new technology, refreshing old skills, etc. as well as the level of operational experience. | Adequate, high experience | Improved |
| | | Adequate, limited experience | Not significant |
| | | Inadequate | Reduced |
| Crew collaboration quality | The quality of the collaboration between crew members, including the overlap between the official and unofficial structure, the level of trust, and the general social climate among crew members. | Very efficient | Improved |
| | | Efficient | Not significant |
| | | Inefficient | Not significant |
| | | Deficient | Reduced |

## REFERENCES


Andrews J.D. and Moss T.R. 2002. Reliability and Risk Assessment," *Professional Engineering Publishing Limited London and Bury St Edmunds*, UK.

Bea, R. 2006. Reliability and Human Factors in Geotechnical Engineering. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 132, No 5: 631-643.

Bell J. and Holroyd J. 2009. Review of Human Reliability Assessment Methods. *Health and Safety Laboratory Research Report*, RR679.

Dai F.C., Lee C.F., and Ngai Y.Y. 2002. Landslide risk assessment and management: an overview. *Engineering Geology*, 64 (2002) 65-87.

Fell R., Ho K.K.S., Lacasse S. and Leroi E. 2005. A Framework for Landslide Risk Assessment and Management. *Taylor & Francis Group, London*, ISBN 04 1538 043 X.

Forester, J.A., Cooper, S.E., Kolaczkowski, A.M., Bley, D.C., Wreathall, J. and Lois, E. 2009. An Overview of the Evolution of Human Reliability Analysis in the Context of Probabilistic Risk Assessment. *Sandia Report*, SAND 2008-5085, January 2009.

German, D.I. and Blackman, H.S. 1994. *Human Reliability and Safety Analysis Data Handbook*. John Wiley & Sons.

Gue, S. S., Wong, S. Y. and Cheah, S. W. 2010. Geotechnical Engineering for Hillsite Development. *G&P Geotechnics Sdn Bhd*.

Gue, S.S., and Tan, Y.C. 2006. Landslides: Abuses of the Prescriptive Method. *International Conference on Slope 2006*, Kuala Lumpur, 7-8 August 2006.

Hollnagel, E. 1998. *Cognitive Reliability and Error Analysis Method*. Elsevier Science Ltd.

Hollnagel, E. 2005. Human Reliability Analysis. www.ida.liu.se/~eriho/HRA_M.htm
Hollnagel, E. 2006. CREAM – Cognitive Reliability and Error Analysis Method. www.ida.liu.se/~eriho/CREAM_M.htm
Jabatan Kerja Raya. 2010. Guidelines for Slope Design. *Slope Engineering Branch*, January 2010.
Jamaluddin, T. A. 2006. Human Factors and Slope Failures in Malaysia. *Bulletin of the Geological Society of Malaysia*, 52, 75-84.
Reason, J. 1990. *Human Error*. Cambrigde University Press, London.
Sowers, G.F. 1993. Human Factors in Civil and Geotechnical Engineering Failures. *Journal of Geotechnical Engineering*, Vol. 119, No. 2: 238-256.
Wreathall, J., Roth, E., Bley, D., and Multer, J. 2003. Human Reliability Analysis in Support of Risk Assessment for Positive Train Control. *U.S. Department of Transportation Research and Special Programs Administration John A. Volpe National Transportation System Center Cambridge*, MA 02142-1093.