Application of Human Reliability Analysis in Risk Assessment for Hillside Development

Willon Paul Nanak
Department of Civil Engineering
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
Email: will1909@gmail.com

Indra S. H. Harahap
Department of Civil Engineering
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
Email: indrasati@petronas.com.my

Abstract— **In certain developing countries, limited flat lands have becoming an issue and thereby impeded their development progression. To resolve the situation, some development projects were extended to hillside areas. Today, landslide cases were reported globally and most cases can be closely associated with hillside development areas. While landslide is known as natural hazard, findings have revealed that human errors also play major role in contributing to landslide events nowadays. Over the years, there is little emphasis or even no concerns over the importance of human error to be considered with landslide related problems in hillside development areas. Human Reliability Analysis (HRA) which in turn has been applied in other industries to assess the human factors contributing to risks and facilitate in identifying proper mitigation measure to reduce the risks can be proposed to be adopted into the landslide risk management. As more and more technological advancements introduced to facilitate the complex human activities, the need to focus on the aspects of human errors related is inevitably as such human and technological interactions are interrelated in every stages of a project therefore poised more errors to be made by human. This paper will review the current state of landslides and human error related issues in Malaysia and discusses the approach in Human Reliability Analysis (HRA) and how it can be incorporated into the current landslide risk management. An example of a concept of HRA-based risk assessment also will be discussed in this paper.**

Keywords-landslide; human error; HRA; CREAM

I. Introduction

The increasing landslide cases nowadays can be closely related to the current urban development in hillside areas. This trait becoming clearer each day as issues such as limited flat land, increasing population and rapid economic growth primarily in developing countries which can no longer been sustained hence promotes urbanization developments to be extended to hillside areas. As such, more and more hillside areas were being exploited and this somehow results in overdevelopment in the some of the areas thus induces the risks of landslide occurrence on those hillside areas. Besides, human activities in hillside development projects e.g. earthworks carry out without proper construction practice, could disrupt the natural equilibrium of the hill slope and this in turn also increases the risks of landslide to occur. Landslides by definition can be described as the movement of rocks, debris or earth flowing down a slope [1]. It is commonly known that landslides were triggered by combination of several factors or not less than of the physical and geological elements such as rainfall, earthquake, changes in groundwater, disturbances and change of slope profile. But recent findings revealed that besides these factors, human error turns out also play major role in contributing to landslide.

Human errors which is one of the subject yet to be accounted in the current reliability risk based approach but often times been a talking point whenever engineering failure occurs are said to be the leading cause of landslides today. A landslide forensic statistic data from year 2004 to 2007 as provided by Slope Engineering Branch of Public Works Department of Malaysia pointed out the 57% of landslides was due to human errors, whereas only 29% and 14% due to physical and geological factors [9]. Other finding such as provided by Sowers (1993) concludes that the majority of foundation failures (88%) were due to "human shortcomings" whereas only 12% of the failures were due to lack of technology [6]. This also can be evidenced that the current issues are no longer new and unfamiliar problems at this stage. Based on Sowers' findings, Bea (2006) 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 [14].

Hillside development is a highly large complex system, the existence of dynamic and multi-human interactions in every stage can be observed entirely from the beginning of planning to design stages, and then construction to maintenance stages. Because of this whole progression involves human to plan, organize, perform and completing abundance of multiple tasks, uncertainties may arise due to the stochastic nature of human behavior. This vulnerability gives human somehow inevitable to make error at certain point. Efforts to mitigate landslides e.g. restriction of development, using proper

978-1-4577-1884-7/11/$26.00 ©2011 IEEE

construction techniques, use of physical measures such as retaining structures, etc. have been introduced and implemented 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 human errors related. This paper will attempt to address the current state of landslides and human errors related within Malaysia and introduce the Human Reliability Analysis (HRA) methods which possibly can be adopted into landslide risk management. The landslide event at Bukit Antarabangsa, Klang Valley, also will be highlighted and an example of a concept of HRA-based risk assessment also will be discussed in this paper.

II. LANDSLIDE AND HUMAN ERRORS

A. The current state of landslide in Malaysia

The collapsed of Tower 1 of Highland Towers in 1993 marks the beginning of public concerns over the landslide issues in Malaysia. The event received vast coverage by the media both local and international and since then, Klang Valley has succumbed as one of most landslide prone areas in Malaysia. By the year 2008, a total of six (6) major cases of landslide were recorded and the aftermaths of most cases not limited to property damage and economic losses but also amassed a number of casualties. The recent landslide at Bukit Antarabangsa on 6th December, 2008 which caused 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 vicinity of Klang Valley. Table 1 shows the summary of landslide tragedies in Klang Valley areas from 1993 to 2008.

TABLE I. LANDSLIDE TRAGEDIES IN KLANG VALLEY

Date	Site	Landslide Tragedy
11 December 1993	Taman Hillview, Hulu Klang, Selangor	48 people were killed when one block of Highland Towers Condominium collapsed
15 May 1999	Bukit Antarabangsa, Hulu Klang, Selangor	Landslide that caused most of the residents trapped.
20 November 2002	Taman Hillview, Hulu Klang, Selangor	The collapse of the President of Affin Bank's bungalow, General Tan Sri Ismail Omar due to the landslide.
December 2003	New Klang Valley Expressway near the Bukit Lanjan Interchange.	Rockfall caused the expressway to close for more than six months.
31 May 2006	Kampung Pasir, Ulu Klang, Selangor.	4 people were killed in the landslide.
6 December 2008	Bukit Antarabangsa, Hulu Klang, Selangor	5 people were killed in the landslide which buried 14 bungalows in Taman Bukit Mewah and Taman Bukit Jaya.

Other parts of Malaysia also affected by the landslides, the latest landslide is dated on 21th May, 2011 in Hulu Langat, Selangor where 16 people were killed. The landslide was triggered following heavy rain on that day and in the preliminary studies also reveals to be human errors related. The causes of many cases of landslides in Malaysia can be related to simplest of human mistakes such as negligence, incompetence, lack or poor maintenance system, ignorance of geological inputs, unethical practice and various negative human attitudes as pointed out by Jamaluddin [18]. His findings significantly explained the statistical data provided by Slope Engineering Branch as mentioned earlier where human errors were found to be dominating the current problems in most landslide cases. Their findings also indicate that most of the landslides occurred at man-made slopes [9].

According to a 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 i.e. the abuses of the prescriptive method on the slope for cut or fill slope without proper geotechnical analyses and assessment, inadequate subsurface investigation (S.I.) and laboratory tests, and lack of good understanding of fundamental soil mechanics, 8% because of failure due to construction errors i.e. tipping or dumping of loose fill down slopes to form filled platform or filled slope, errors in the construction method such as forming cut slopes by excavating slopes from the bottom (undermining) instead of the correct practice of cutting from the top downwards, and over-excavation of cut slopes, about 20% are caused by a combination of design and construction errors while only 6% account for geological features and lack of maintenance [17]. Table 2 shows the summary of the results conducted on the 49 cases [16].

TABLE II. CAUSES OF LANDSLIDES [16]

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

B. Anatomy of Bukit Antarabangsa landslide

The landslide that took place at Bukit Antarabangsa on 6th December, 2008 is classified as deep seated slide with an estimated of 101, 500 m^3 of earth had translated with the maximum run out distance of the failure debris was measured at approximately 210m from the toe of the slope. This type of landslides moves at a slow rate and cover a short distance. High pore water pressure is the common features associated with this type of failure. There are several factors attributed to the event based on the report of investigation. It is understood that in the event, leaking active pipe running across the slope to the adjacent abandoned house which leads to increase pore water pressure build-up to the slope was found to be the main cause of landslide. The buried leaked pipe is believed to be damaged by the prolong soil creep over the years thus caused continuous soil saturation at the non-engineered fill slope which at large consists of non-compacted earth fills. The factor leading to the landslide (pipe burst) can be considered as rare event. Other related factors that involved include abuses of construction methods during development e.g. improper cut and fill method, lack of maintenance, and clogged drains.

Generally speaking, if proper maintenance is regularly being performed e.g. clearing the clogged drains; this might prolong the slope from failing even with a slight action like taking necessary precaution to the leaking active water pipe. Nevertheless, the failure is somehow unavoidable in an extended time due to the facts that the entire slope is formed with non-compacted or loose soil following the non-engineered fill which took place during the construction stage. Stepping aside the rare event, the root causes of the slope failure can be traced back to the very beginning of the development i.e. during planning and design, at the construction stage or afterward of the entire operation such as lack of maintenance. Negligence, incompetence and other factors as pointed out by Jamaluddin (2006) are amongst the human related issues that possibly lead to the event. Assuming that human attributes are largely to blame in this case, the probability of human errors can be predicted through application of HRA methods. Fig. 1 illustrates a flowchart describing the mentioned possible links of the landslide event at Bukit Antarabangsa based on the contributing factors. It is observed that each factor can be interdependent with others factor which leading to the landslide event.

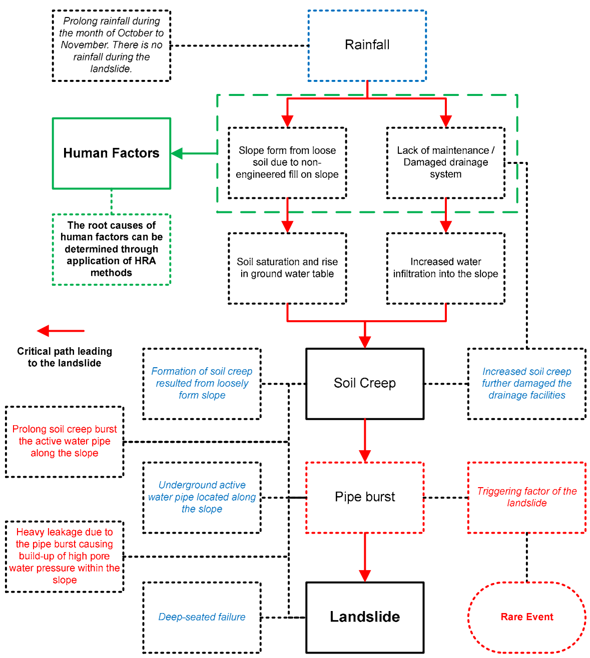

Figure 1. Flowchart of landslide at Bukit Antarabangsa based on the contributing factors that lead to the failure

C. *Human Error*

Studies of the accidents shows 80% of the extrinsic factors involved in causation of the major failures mainly involved human, organizational, and knowledge uncertainties. The remaining 20% of the causation factors involved natural and model related uncertainties. These were identified as Intrinsic factors [14]. This statement well defines the situation in Malaysia as most findings 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 [7].

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. This is understandably correct as what 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 [10]. 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 or new operator excavating a slope surrounded with buildings or other adjacent infrastructures without proper guidance or following proper method can possibly triggers a slope failure. While pipe burst that leads to landslide at Bukit Antarabangsa is an example of latent errors.

III. LANDSLIDE RISK ASSESSMENT AND RISK MANAGEMENT

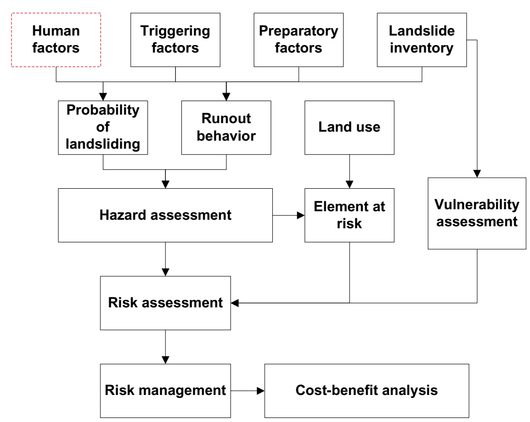

Figure 2. Framework for landslide risk assessment and management [5]

Landslide is often described in terms of risk as such of the expected number of lives lost, persons injured, property damaged, or economic activity disrupted because of the event [2]. Usually, the terms is defined as product of the probability or likelihood of an undesired event and the consequences of that event [13]. It can be assessed qualitatively and quantitatively and suitability of either assessment depends on both the desired accuracy of the outcome and the nature of the problem, and should be compatible with the quality and quantity of available data [5].

The typical framework of landslide risk assessment and risk management comprises the estimation of the level of risk, deciding the acceptability, and applying appropriate control measures to reduce risk when the risk level cannot be accepted as shown in Fig. 2 [12][5]. Some of the important issues to be addressed in the framework include (a) probability of landsliding, (b) runout behavior of landslide debris, (c) vulnerability of property and people to landslide and (d) management strategies and decision-making. This paper proposes that human factors can be included within the framework where it can be separately assessed through the use of HRA methods. It is suggests that through the application of HRA, the uncertainties of particular human erroneous action during any stages in hillside development projects can be identified by breaking down the tasks within each stages (e.g. planning, design, construction and maintenance). Through that, various available methods of HRA can be applied to quantify both qualitatively and quantitatively to the critical tasks that require human actions to execute. The following chapter will discuss further about HRA.

IV. Human Reliability Analysis

HRA can be defined as the use of systems engineering and behavioral science methods in order to render a complete description of the human contribution to risk and to identify ways to reduce that risk [15]. The method has been practice since the early 1960s but only in the middle of 1980s that most of HRA methods were developed mainly due to the accident in 1979 at the nuclear power plant at Three Mile Island [3]. Today, besides having been applied in nuclear power industry, HRA also has been diverged to other industrial fields such as aviation, medicine, space exploration, etc. The move to include HRA into the current landslide risk assessment and management practice could connote a positive turning point in attempt to broaden the current risk-based approaches. Today, as there are a lot of technology advancement were introduced and progressively assimilated to civil engineering fields to feed the ever present of fast track project development, there is a danger in injecting more errors. In any socio-technical systems such as hillside development project, humans play a crucial part in performing and executing the lists of tasks presented and with technological tools easing their ways to facilitate the complexity of the system, human errors could develop and spread throughout the system. Some may have immediate effect and some will be embedded, as time passes, will develop and cause failure later. Although specific rules of thumb may apply in any engineering project, but following the rules do not hinder human from committing erroneous actions. The contexts of human error are elusive therefore one can arrive with many possibilities and uncertainties.

The 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 [11]. 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 [7]. 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 [8]: (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. Fig. 3 illustrates the overall approach of a contemporary HRA while Table 3 shows some of the available methods in HRA. The following chapter will discuss an example of application of HRA using Cognitive Reliability and Error Analysis Method (CREAM).

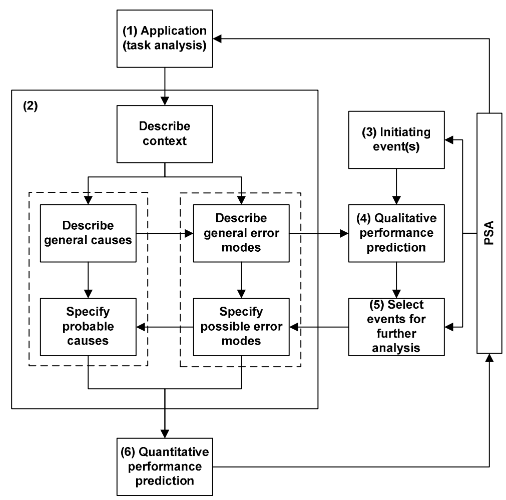

Figure 3. Contemporary HRA approach [3]

TABLE III. List of HRA methods

	Tool
1st Generation	THERP (Technique for Human Error Rate Prediction)
	HEART (Human Error Assessment and Reduction Technique)
	SPARH-H (Standardized Plant Analysis Risk - Human Reliability Analysis)
2nd Generation	ATHEANA (A Technique for Human Error Analysis)
	CREAM (Cognitive Reliability and Error Analysis Method)
Expert Judgment	SLIM-MAUD (Success Likelihood Index Methodology, Multi-attribute Utility Decomposition)
	APJ (Absolute Probability Judgment)

V. Example: Application of HRA using CREAM

This chapter will discuss the propose application of HRA in risk assessment for hillside development using CREAM. The landslide in Bukit Antarabangsa discussed previously was adopted in this example. CREAM is bi-directional analysis method i.e. performance prediction and accident analysis and it 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 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 [3]. Fig. 4 shows the relationship between the basic and extended method.

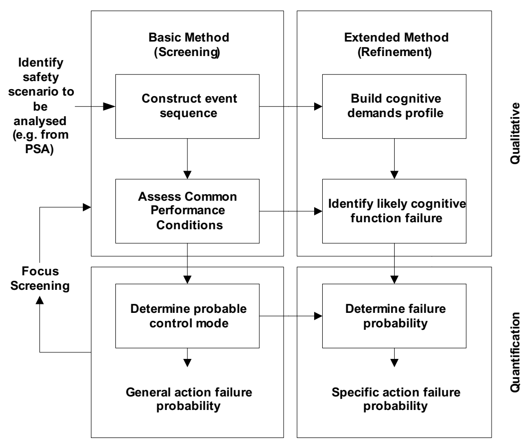

Figure 4. CREAM – basic and extended methods [3]

This example will only discuss the basic method in CREAM. In the Bukit Antarabangsa landslide, the available evidence perhaps put human to be the main perpetrator behind the event with the root causes can be stretched out as far as from the very beginning to later stage of the development. Assuming that human errors are largely to be blamed in this case, the probability of human errors can be predicted through application of CREAM. In general, hillside development project usually involves four (4) stages of development i.e. planning, design, construction and maintenance, CREAM can be applied in separately to each stages. Fig. 6 shows an example of application of CREAM in construction stage. The similar approach also can be applied to the other stages. In CREAM basic method, the first step is to perform task analysis through hierarchical task analysis (HTA). During construction stage, the contractor and consultant are the two organizations that usually get involves throughout the completion of this stage. Here, HTA can be performed on each important personnel e.g. project manager, the engineers, operators, etc. 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) shows in Table 4 are used to characterize the overall nature of the task, and the characterization is expressed by means of a combined CPC score.

TABLE IV. CPCs and performance reliability [3]

CPC name	Level / descriptors	Expected effect on performance reliability
Adequacy of organization	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	Not significant
	Incompatible	Reduced
Adequacy of MMI and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced
Availability of procedures / plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Not significant
	Matching current reliability	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporarily inadequate	Not significant
	Continuously inadequate	Reduced
Time of day (circadian rhythm)	Day-time (adjusted)	Not significant
	Night-time (unadjusted)	Reduced
Adequacy of training and experience	Adequate, high experience	Improved
	Adequate, limited experience	Not significant
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Not significant
	Deficient	Reduced

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 [$\Sigma_{reduced}$, $\Sigma_{not\ significant}$, $\Sigma_{improved}$]. The final step in the basic CREAM method is to determine the probable control mode and the general action failure probability. Fig. 5 is referred to determine the probable control mode and Table 5 will be used to determine the reliability interval for the expected control mode.

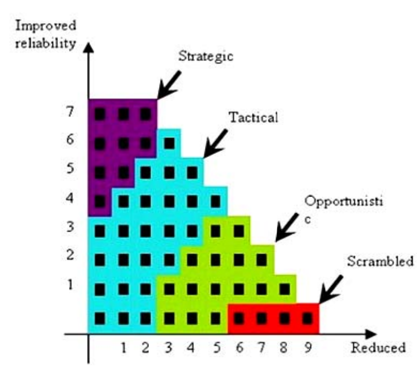

Figure 5. Relations between CPC score and control modes [3]

TABLE IV. Control modes and probability intervals [3]

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

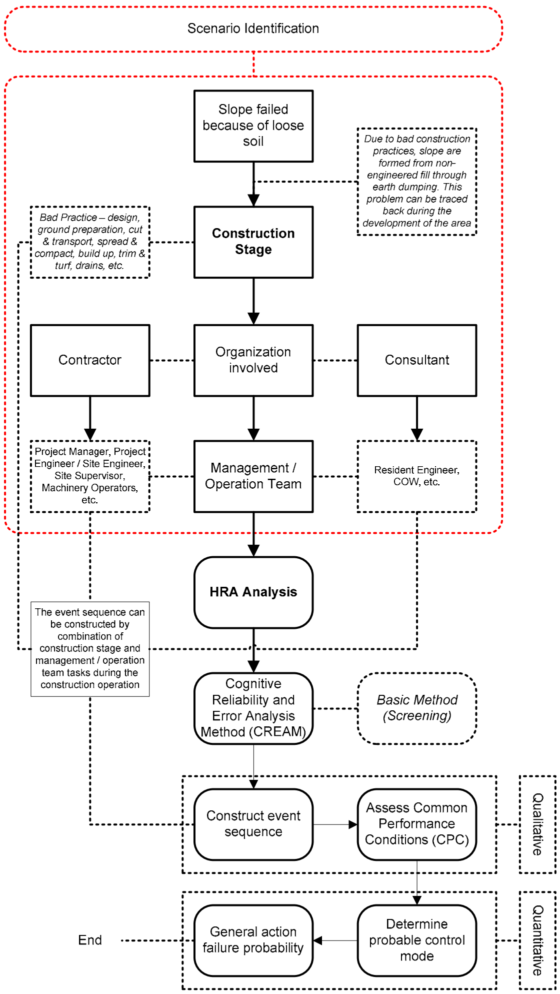

Figure 6. Flowchart of post-event analysis with application of CREAM

Through this method, it enables an analyst to achieve the following [4]:

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.
4. Develop and specify modifications that improve these conditions, hence serve to increase the reliability of cognition and reduce the risk.

VI. Conclusion

While the application of HRA is no longer new to other industries, the concept behind its application to risk assessment or risk management for hillside development is rather new. This paper discusses the current state of landslide in Malaysia where human errors were evidently dubbed as the main perpetrator in most of landslide cases. An example of the concept of HRA using CREAM in risk assessment for hillside development also been highlighted and to date, the research on this subject is still ongoing. The example in this paper shows that the application of HRA using CREAM can be used to identify parts of works, tasks or actions, which involve human cognition (qualitative evaluation) and determine the reliability of cognition that lead to the source of failure (quantitative evaluation). The analysis can be performed at any level in the hillside development project, as either performance prediction or event analysis where it provides consequence of human performance hence improve the reliability of cognition and reduce the overall risk.

References

[1] D. M. Cruden, "A Simple Definition of a Landslide," Bulletin of the International Association of Engineering Geology, 43, 27-29, 1991.

[2] D.J. Varnes, "Hazard Zonation: A Review of Principal and Practice," Commission of Landslide of IAEG, UNESCO, Natural Hazades, 1984.

[3] E. Hollnagel, "Cognitive Reliability and Error Analysis Method," Elsevier Science Ltd, 1998.

[4] E. Hollnagel, "CREAM – Cognitive Reliability and Error Analysis Method," www.ida.liu.se/~eriho/CREAM_M.htm, 2006.

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

[6] G.F. Sowers, "Human Factors in Civil and Geotechnical Engineering Failures," Journal of Geotechnical Engineering, Vol. 119, No. 2: 238-256. 1993.

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

[8] J. Bell and J. Holroyd, "Review of Human Reliability Assessment Methods," Health and Safety Laboratory Research Report, RR679, 2009

[9] J. K. Raya, "Guidelines for Slope Design," Slope Engineering Branch, January 2010.

[10] J. Reason, "Human Error," Cambrigde University Press, London. 1990.

[11] J. Wreathall, E. Roth, D. Bley, and J. Multer, "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. 2003.

[12] K. Ho, E. Leroi and B. Roberts, "Keynote Lecture: Quantitative Risk Assessment – Application, Myths and Future Direction," Proceedings of the Interntional Conference on Geotechnical and Geological Engineering, GEOENG 2000, Melbourne, Australia, vol. 1. Technomic, Lancaster, pp. 236-312.

[13] M. Th. Van Staveran, "Extending to Geotechnical Risk Management" First International Symposium on Geotechnical Safety & Risk, ISGSR 2007, Oct. 18-19, 2007 Shanghai Tongji University, China.

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

[15] R. Boring, "Human Reliability Analysis Methods for Space Safety," RMC, Session G: Human Error and Risk Assessment, Idaho National Laboratory, December 7, 2005.

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

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

[18] T. A. Jamaluddin, "Human Factors and Slope Failures in Malaysia," Bulletin of the Geological Society of Malaysia, 52, 75-84, 2006.