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Evaluation of the causes of Bukit Antarabangsa 2008 landslide by using fault tree analysis

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Abstract. Bukit Antarabangsa 2008 is considered as a deep-seated landslide which occurred in the landslide-prone area of Ulu Klang, Malaysia. The precipitation data obtained from previous studies show that there were comparatively less rainfalls immediately before the landslide which suggests that other potential triggers must be analyzed. This study analyses the causes of Bukit Antarabangsa 2008 landslide by performing fault tree analysis (FTA) which is a logical and diagrammatic method to evaluate the probability of an accident resulting from sequences and combinations of faults. The FTA is performed on four potential landslide contributors of improper shear strength parameters, flawed development plan, erroneous drainage planning & design and, ineffective slope strengthening works in order to determine the causes of the landslide. The analysis shows that the causes of Bukit Antarabangsa 2008 landslide potentially include ineffective slope strengthening works related to monitoring and maintenance which is followed by improper development plan having a probability of failure of 0.194 and 0.15 respectively. These causes actually correlate with the human errors which are often neglected during the slope construction and required to be addressed to increase the safety of the slopes.

1 Introduction

Bukit Antarabangsa is one of the most prominent landslides of Malaysia which occurred on 06 December 2008 in the area of Ulu Klang, Selangor, Malaysia. The history of the landslide area indicates that a number of slope failures have occurred previously and their causes must be thoroughly analyzed in order to take measures for the prevention of slope failures in future.

Bukit Antarabangsa, located in the north of Kuala Lumpur, forms a narrow ridge that extends in the northeast-southwest direction with a maximum elevation of 230 m. The hill is underlain by granite whose characteristics are grey color, coarse grained particles and slightly porphyritic texture. Extensive weathering has transformed the granite into the residual soil (grade VI) and weathered material (grade V). The average thickness of the

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weathered profile is approximately 30 m. The weathered material is sandy and rapidly loses its consistency with increasing amounts of water [1].

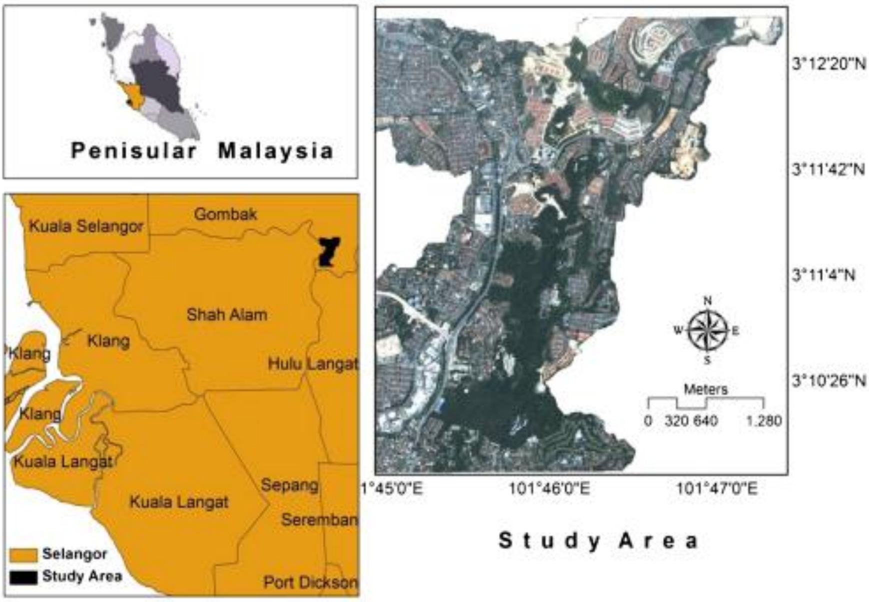

Figure 1. Location of Bukit Antarabangsa Landslide [2]

The Bukit Antarabangsa 2008 is referred to as a deep-seated landslide and several studies have showed that there were multiple causes that potentially triggered the failure. Ng [3] reported that the landslide area had faced a high level of precipitation in November 2008, a month before the landslide. However, no severe landslide happening was reported during this period. From the rainfall study, it is evident that there were no signs of heavy rainfall immediately before the landslide. Therefore, it is necessary to consider the role of other factors which were potentially responsible for the landslide. The potential triggers for the landslide can be related to drainage system, sub-soil conditions, geology, groundwater table, human errors and technical errors.

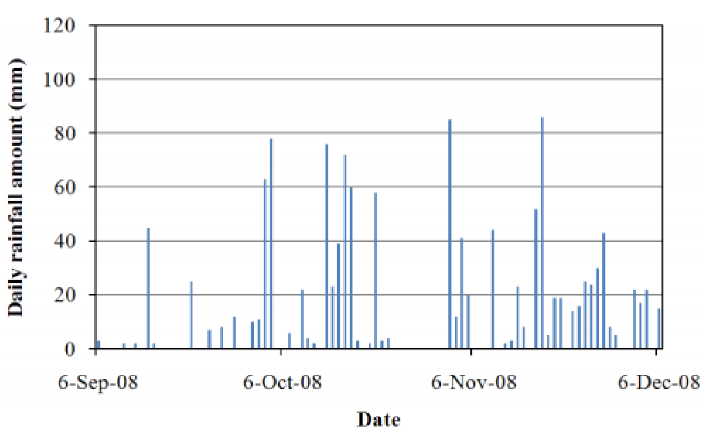

Figure 2. Daily Rainfalls for Bukit Antarabangsa 2008 Landslide [3]

The main causes of Bukit Antarabangsa 2008 landslide as reported by Huat et al., 2012 [4] are:

- Soil creep, due to non-engineered fill on the slope, developed tension cracks over the area.
- The soil creep over the years may have damaged the active water pipe along the abandoned houses and leaked the pipe. The leaks contributed to continuous soil saturation at the lower slope and this, in turn, accelerated creep.
- Prolonged rainfall during the month of October and November resulted in soil saturation, rise in ground water table and increased the rate of creep.
- An increased soil creep further damaged the drainage facilities and widened the existing cracks and opened up new tension cracks

2 Objective of the Study

The objectives of the study are:

- To investigate the causes of the Bukit Antarabangsa landslide in 2008 using fault tree analysis (FTA).
- To evaluate the role of human uncertainties in triggering the landslide.
- To discuss the benefits of using human reliability analysis (HRA) in slope construction.

3 Human reliability analysis

The major shortcoming of simple reliability analysis is that the results obtained from it are conditional as it does not encompass the effect of human uncertainties in the analysis. The utility of applying the human reliability analysis (HRA) is that it takes into account the phenomenon of human uncertainties which provides a more precise estimate of the stability of the slopes.

The core intention of HRA is to accurately weigh up the risks generated from human error and determine ways to mitigate them. A complete HRA process must have the following steps [5]:

a. Recognition and description of human error

b. Quantification of human error probability

c. Analysis of human error modes and effects

d. Design and authentication of protective measures for human error

4 Methodology of the study

This study is based on the application of fault tree analysis (FTA) technique to determine the causes of Bukit Antarabangsa 2008 landslide in terms of four potential landslide contributors of improper shear strength parameters, flawed development plan, erroneous drainage planning & design and, ineffective slope strengthening works.

Fault tree analysis (FTA) is a logical and diagrammatic method to evaluate the probability of an accident resulting from sequences and combinations of faults and failure events [6]. FTA is a powerful and computationally efficient technique to analyze and predict system reliability and safety. Many theoretical advances and practical applications have been achieved in this field to date. FTA is based on Boolean algebra and probability theory and it is consistent with the conventional reliability theory [7].

The subjective probabilities of basic events were determined from the experts of slope engineering division of Malaysian government department, Jabatan Kerja Raya (JKR). This research adopted consensus group method to conclude experts' opinion in relation to the Bukit Antarabangsa 2008 landslide.

5 Results

The fault tree analysis (FTA) is performed on four potential landslide contributors of improper shear strength parameters, flawed development plan, erroneous drainage planning & design and, ineffective slope strengthening works which are given below.

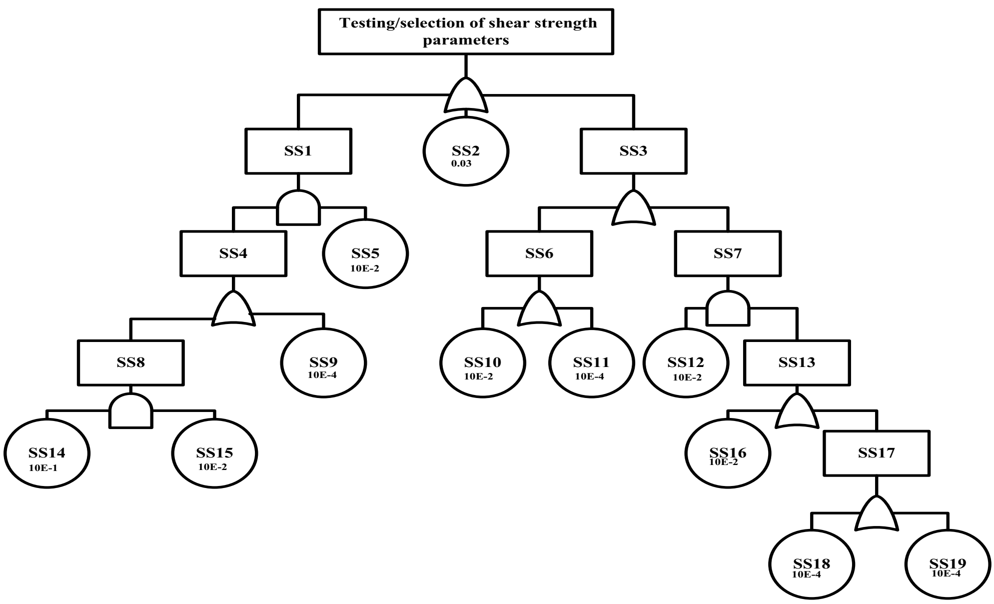

Figure 3. Fault Tree Analysis of Shear Strength Parameters

Table 1. Testing of Shear Strength Parameters and Subjective Probabilities

	Events	Subjective/ Calculated Probabilities		Events	Subjective/ Calculated Probabilities
SS1	Lack in following soil mechanics	0.000011	SS11	No counter check	10E-4
SS2	Improper experimental setup	0.03	SS12	Meet deadlines	10E-2
SS3	Providing results without testing	0.000103	SS13	Staff shortage	0.0102
SS4	Easy follow up of prevailing practices	0.0011	SS14	Poor perception	10E-1

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SS5	Overconfidence	0.0011	SS15	Bias records	0.01
SS6	Time period/Pressure	0.000102	SS16	Organizatio nal trend	0.01
SS7	Individuals attitude	0.000001	SS17	Unable to hire related personnel	0.0002
SS8	Misconception about consequences	10E-3	SS18	Out of worth	0.0001
SS9	Deliberately ignored innovations	10E-4	SS19	Lack of intellects	0.0001
SS10	Work load	10E-2			

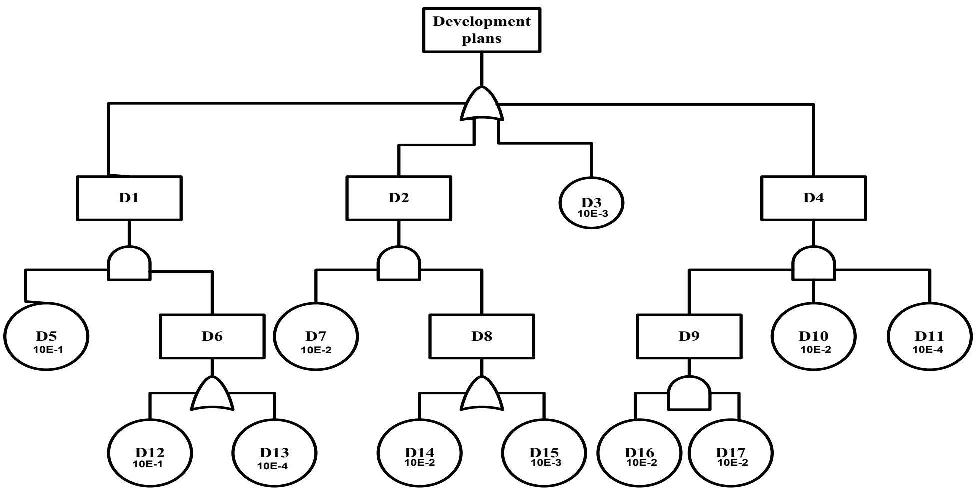

Figure 4. Fault Tree Analysis of Development Plans

Table 2. Development Plans and Subjective Probabilities

	Events	Subjective/ Calculated Probabilities		Events	Subjective/ Calculated Probabilities
D1	Flaws in proposing design strategies	0.01	D10	Nothing for Special Structures like soil nailing, ground anchors	0.01
D2	Consider construction activities less significant	0.00011	D11	No proper check in case of heavy rains	0.0001
D3	No experience of drainage system	0.001	D12	Trend of following thumb rules or patent methods	0.1
D4	Mismatch strategies for monitoring. inspection and maintenance	10E-9	D13	No practicing codes/standards	0.0001

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D5	Perception lacking	0.1	D14	No emphasis on sequencing of activities	0.01
D6	Information Shortage	0.1	D15	Lack of specific situation guidelines	0.001
D7	Timing expenditure not estimated	0.01	D16	Least concerned about its consequences	0.01
D8	Not Proposing extreme cases alternatives	0.011	D17	Treat like any other common structure	0.01
D9	Less Significant	0.01			

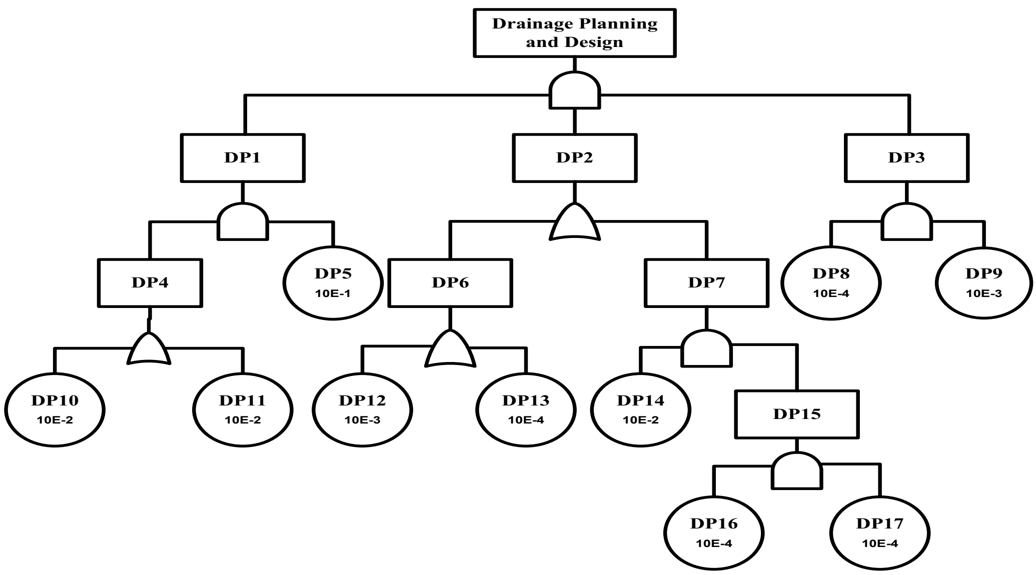

Figure 5. Fault Tree of Drainage Planning & Design

Table 3. Drainage Planning & Design and Subjective Probabilities

	Events	Subjective/ Calculated Probabilities		Events	Subjective/ Calculated Probabilities
DP1	Inaccurate site /topography and soil information	0.002	DP10	Unsuitable outlets proposed	0.01
DP2	Unparsed economic feasibility	10E-4	DP11	Improper layout of drains	0.01
DP3	Estimated inadequate drainage capacity	0.0011	DP12	Consider less preferable	0.001
DP4	Misconception about soil strata/properties	0.02	DP13	Organizational trend	0.0001

DP5	No practice to confirm the topography	0.1	DP14	Flaws in geological report	0.01
DP6	Lack of capital	0.0001	DP15	No concept of checking	10E-8
DP7	Lack of resources	0.001	DP16	Time pressure	0.0001
DP8	Unavailability of rainfall data	0.0011	DP17	Work stress	0.0001
DP9	Predicted ground water table	10E-10			

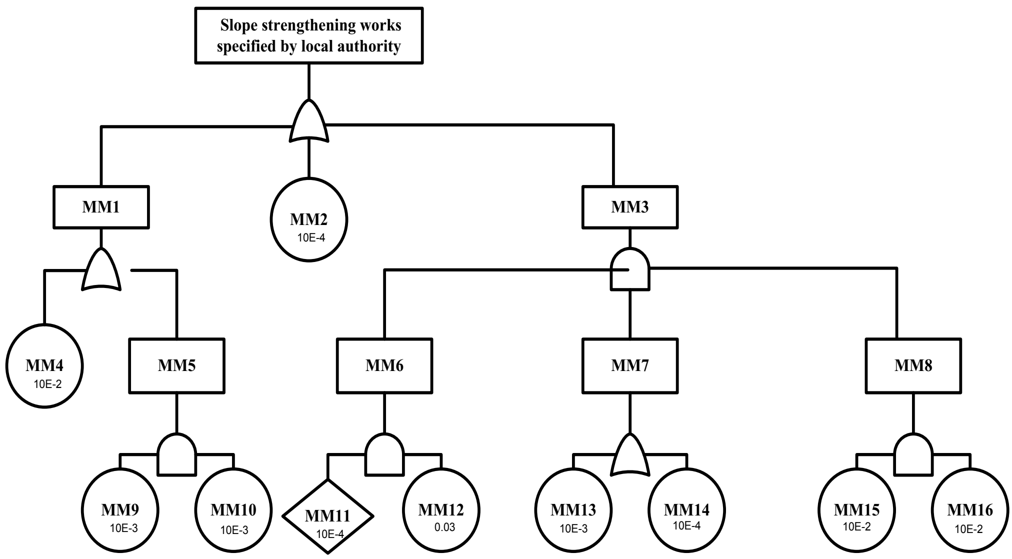

Figure 6. Fault Tree Analysis of Slope Strengthening Works

Table 4. Slope Strengthening Works and Subjective Probabilities

	Events	Subjective/ Calculated Probabilities		Events	Subjective/ Calculated Probabilities
MM1	Biased results through inclinometers	0.01	MM9	Uncelebrated equipment	10E-3
MM2	Maintenance free (assumed)	10E-4	MM10	No QAQC criteria	10E-3
MM3	Water damming effect	0.001	MM11	Unknown cause	10E-4
MM4	Fail to detect in inspection	10E-2	MM12	Improper fixing	0.03
MM5	Faulty deformation data	10E-6	MM13	Rainfall exceeds	10E-3
MM6	Obstruction in drainage	3E-6	MM14	Other outlet diversion	10E-4

MM7	Ground water table rise	0.001	MM15	Consider less preferable	10E-2
MM8	Piezometric pressures inadequacy	10E-4	MM16	Underestimat e its consequences	10E-2

Table 5. Probability of Failure of Potential Contributors

S.no	Symbols	Potential Contributors	Probability of failure using FTA
1	Shear Strength (SS)	Testing and selection of shear strength parameters	0.124
2	Development Plan (D)	Development plan	0.15
3	Drainage Planning and Design (DP)	Drainage planning and design	0.001
4	Monitoring & Maintenance (MM)	Slope strengthening works	0.194

6 Discussion

The analysis shows that the causes of Bukit Antarabangsa 2008 landslide were mainly the human errors committed from design till maintenance phase. It is observed through FTA that the major contributor of landslide was ineffective slope strengthening works related to monitoring and maintenance followed by flawed development plan having a probability of failure of 0.194 and 0.15 respectively. The probability of failure for improper shear strength parameters and erroneous drainage planning & design are found to be 0.124 and 0.001 respectively.

The technique of fault tree analysis (FTA) is fundamentally based on the subjective probabilities which are determined on the basis of respondents' judgment according to their experience and knowledge. The purpose of using FTA is to estimate the likelihood scenario of an accident [8]. According to Silva et al., 2008 [9], geotechnical engineers frequently encounter the challenge of determining the failure probabilities. Previous studies show that the subjective probabilities, such as quantified expert judgment, have been accepted for decades by practitioners and academics. According to Silva et al., 2008 [9], using subjective probability for risk assessment in geoengineering allows engineers to attain 80% of the advantage at 20% of the cost, as recommended by Pareto's principle.

The downside of safety factor approach is that it does not accommodate the influence of uncertainties in the construction which provides a less-accurate estimate about the stability of a slope. On the other side, the reliability analysis technique is comparatively a superior approach as it encompasses the effect of uncertainties particularly in terms of soil parameters. The benefit of utilising human reliability analysis (HRA) technique is that it also considers the effect of human errors during the construction process which is a neglected feature in the previous approaches. The application of HRA provides more accurate estimate about the safety and stability of the slope which also allows the stakeholders to take necessary initiatives if the requirements are not properly satisfied.

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7 Conclusion

This study shows that the causes of Bukit Antarabangsa 2008 landslide are mainly human errors which have been identified on the basis of the probability of failure using fault tree analysis. The major contributors of this landslide potentially include ineffective slope strengthening works related to monitoring and maintenance and improper development plan. The rainfall data before the landslide incident suggests that there were no heavy rainfalls immediately before the landslide hence, the rainfall cannot be termed as the sole triggering factor. The findings of the previous studies on Bukit Antarabangsa 2008 landslide also suggests that there were multiple causes that jointly contributed to the slope failure which mainly corresponds to the human errors. Therefore, this study suggests that human uncertainties should be properly addressed during the construction process using human reliability analysis (HRA) techniques to maximize the stability of the slopes.

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