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Geotechnical Uncertainties and Reliability Theory Applications

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Abstract Slope engineering is nowadays in great demand of proper risk management. Predictions regarding slope performances are subjugated by uncertainties. This includes uncertainties related to soil properties, model uncertainties and human uncertainties. In this study author discusses reliability analysis principles in relation with conventional practices and to prove its efficiency three case studies of Malaysian slope failures has been taken for further clarification. It is also mentioned that the concluded probability of failure still needs more refinement as no human uncertainties has been considered in this probabilistic analysis.
Probabilistic analysis afford greater insight into design reliability, hence, supporting the engineering judgment and recuperating the decision making process. So, the intelligibility, effortlessness and cost/time effectiveness are indispensable essentials in order to successfully express and commune a probabilistic methodology to practicing engineers

. 1. Introduction

In the field of geotechnical engineering (Phoon 2005) highlighted two major sources of uncertainties. First source refers evaluation of design soil properties and the second source is geotechnical calculation models. The first source of geotechnical uncertainty is complex because of spatial variability, quality of equipments, procedures used and models used to link field measurement with design properties. In this regard a significant role is played in furnishing realistic statistical estimate of design soil properties and to offer strategies for calibration of geotechnical reliability based design equations (Phoon, Kulhawy et al. 1995).

Model uncertainty arises due to mismatching of theory, adopted in prediction models and reality. Model uncertainties may be numerical or conceptual, Numerical uncertainty consists of simplified computational suppositions like 2-D model versus 3-D, empirical calibrations as in case of SPT blow counts and settlements and mathematical estimations. Conceptual uncertainty reflects in progressive failure, progressive development of internal erosion, undrained against effective strength characterization, time dependent softening processes. Regarding model uncertainty, use of different databases statistics also observed as one of the major source in producing biased results (Lacasse and Nadim 1996). Referring here for example current method of predicting offshore pile foundation capacities, they are on the basis of load tests having small diameter piles. The configuration of piles means pile length, diameter and capacity is not compatible in many cases. One most authentic way of quantifying model uncertainty is comparison of model predictions with observed performance. If discussing about the comparison of settlement of footings on sand with Pecks and Bazaaras model on SPT. The result shows high level uncertainty. As ratio of observed to predict settlement carries a mean of 1.46 and standard deviation of 1.32 (Baecher and Christian 2003).

Slope engineering is nowadays in great demand of proper risk management. Predictions regarding slope performances are subjugated by uncertainties. This includes uncertainties related to soil properties, model uncertainties. Slope failures and poor functioning of slopes are not rare; it is increasing worldwide. Conventional slope practices are unable to quantify the uncertainties as it only runs with judgement and experiences. These traditional practices have no provision of conquering the uncertainties. Reliability index is more significant measure of safety/stability rather than factor of safety. Slopes having high reliability index will expect to perform satisfactorily as compared to low reliability index slopes. If reliability index is alarmingly low, it may be categorize as hazard. Reliability index of slopes is defined by mean safety factor separating from unity, divided by number of standard deviations of safety factor. Once the shape of probability density function is estimated, the reliability index can be used to estimate the probability of failure. (Peterson 1999) reported in his work that through a fuzzy logic analysis of reply to a survey of geotechnical engineers, (Santamarina, Altschaeffl et al. 1992) ascertained Table 1. These criteria bracket together up to standard levels of probability of failure with various design conditions. Criteria for minimum values of reliability index for natural slopes has also been fixed by taking potential failure mode, location and type of slope and consequences into consideration (Chowdhury and Flentje 2003) .

(Husein Malkawi, Hassan et al. 2000) worked on the same lines to counter uncertainties by taking two \

reliability analysis tools. This study specifically provides a methodology (Figure 1) to analyze the uncertainties involved in slope stability. Two methods of First Order Reliability Method (FOSM) and Monte Carlo Simulation (MCS) have been taken into account to quantify the uncertainties present in calculated safety factor. Two slopes are taken as an example the homogeneous slope and the layered slope). The results were obtained by taking four prominent slope stability methods namely Jambu, Ordinary method of slices, Spencer and Bishops method. View of different static equilibrium conditions in different slope stability methods are shown in Table 2.

Table 1: Slope conditions and failure probabilities (Santamarina, Altschaeffl et al. 1992)

Conditions	Probability of Failures
Temporary structures with low repair cost	0.1
Existing large cut on interstate highway	0.01
\Acceptable in most cases EXCEPT lives may be lost	0.001
Acceptable for all slopes	0.0001

Table 2: Limitations of different slope stability methods (Husein Malkawi, Hassan et al. 2000)

Methods	Force Equilibrium		Moment Equilibrium
	1st Direction	2nd Direction	
Ordinary	Yes	No	Yes
Bishop	Yes	No	Yes
Jambu	Yes	Yes	No
Spencer	Yes	Yes	Yes

In deterministic analysis, computed safety factor must be greater than 1 as this is the confirmation for safe slopes but for probabilistic section statistical parameters like mean and coefficient of variance are workable. Factor of safety calculated through different methods is basically reflecting the lump of uncertainties which has to be dealt by statistical methods like FORM or Monte Carlo simulation methods and that is what author is trying to highlight in this study. The main objectives of this study are:

a. To discuss reliability analysis theory and its tools
b. To support reliability theory against conventional practices (in reference with slope engineering)
c. To make it evident by reassessing Malaysian slope failure cases through probabilistic means

2. Reliability theory

In Geotechnical engineering, uncertainties prevail from site characterization till last stage of the project. Uncertainties and risks are part and parcel in any of the project. Level of risks can be minimized if proper understanding of uncertainties fashioned from various routes is analyzed methodically. Among other approaches reliability analysis is recognized as best tool to surmount uncertainties generated from different sources. A reliability analysis aims to price the probability that capacity exceeds with respect to demand. As both capacity (bearing capacity) and demand (loading) are uncertain **(Whitman 2000).**

As reported by (Duncan 2000) that reliability theory is useful in measuring the combined effects of uncertainties. . Safety factor approach is logical as it is experienced based but the only problem it does not have the ability to counter uncertainties. The same value is used even for long term slope stability without caring the degree of uncertainties present in its calculations. (Peck 1969) put forwarded the Observational method to deal with uncertainties but feasibility of this method only goes in those situations where designs can be altered. Along with other researchers (Christian, Ladd et al. 1994) also put forward best examples in favour of reliability theory in geotechnical engineering. Like other disciplines geotechnical engineers have prepared some strategies to tackle the uncertainties (Christian 2004)

a. Ignoring it
b. Being conservative
c. Observational method
d. Quantifying uncertainties

A simple application of reliability theory is defined in Figure 1. It representing some of the main element of reliability based design. In reliability analysis probability of failure (P_f) is represented by reliability index (β). The relationship between reliability indices and failure probabilities is represented in Table 3. Reliability index is defined as the distance between mean safety margin and the failure limit. Initially for reliability assessment of geotechnical structures, target indices have to be taken. It is reported by U.S Army Corps of Engineers, that in any of the rehabilitation program better to work out the reliability indices, these calculated reliability indices must be more than the target ones. The main theme of reliability index is to give valued approximation of the coming performance.

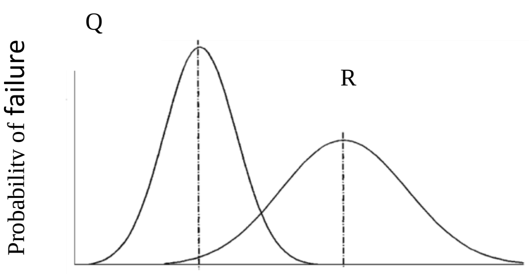

Figure 1: Joint Probability Distribution (Christian 2004)

Table 3: Relationship between Reliability Index and Probability of Failure
(U.S. Army Corps of Engineers)

Performance Level	Reliability Index	Probability of Failure
High	5	0.0000003
Good	4	0.00003
Above average	3	0.001
Below average	2.5	0.006
Poor	2	0.023
Unsatisfactory	1.5	0.07
Hazardous	1	0.16

2.1. Reliability analysis tools

There are basically three broad categories of reliability analysis. It includes direct reliability analysis, event / fault trees methodologies and other statistical techniques (Christian 2004). According to (Ayyub and Assakkaf) direct reliability analysis probabilistically belongs to level II and level III. Level II. Level II needs simple statistical parameters of random variables, sometimes taking linear approximation of non linear limit state Advanced first order second moment (AFOSM) is the example of level 11 also known as first order reliability method (FORM). Level III is complex as it requires full probabilistic information of each random variable. Level I includes mean value first order second moment (MVFOSM), it is less accurate as it does not take into consideration the distribution of the variables. Taking two variables and linear performance function the reliability index (β) can be stated as:

$$\beta = \frac{\lambda_R - \lambda_Q}{\sqrt{\delta_R^2 - \delta_Q^2}} \qquad (1)$$

where
λ_R = mean value of resistance
λ_Q = mean value of load
δ_R^2 = standard deviation of resistance
δ_Q^2= standard deviation of load

The reliability index mentioned above is known as Hasofer and Lind reliability index.

2.1.1. Mean value first order second moment

First order second moment method lies in Level II. First order second moment is used for the computation of reliability index. Uncertainty relates to the involved variables has been recognised only by mean and variance. Variance can be replaced by covariance in case of correlativity between the variables. Usually bias factor statistics are used to generate mean values of load and resistance. Reliability index needs information of various variables like dead load statistics (COVQD) live load statistics (COVQL) and dead load to live load ratio (QD/QL).

The limit state function, 'G" is linear at average values of random variables. Taylor's series expansion taking only first order term into calculations worked to determine the mean and standard deviation of G. The general limit state function can be described as (Baecher and Christian 2003)

$$G = R - Q \qquad (2)$$

$$\boldsymbol{\beta} = \frac{ln\left[\frac{\lambda_R\left(\frac{Q_D}{Q_L}+1\right)FS}{\lambda_{QD}\frac{QD}{QL}+\lambda_{QL}}\sqrt{\left(1+COV_R^2\right)/\left(1+COV_{QD}^2+COV_{QL}^2\right)}\right]}{\sqrt{\ln\left(1+COV_R^2\right)\left(1+COV_{QD}^2+COV_{QL}^2\right)}} \qquad (3)$$

2.1.2. First order reliability method

Advanced methods are not in favour to simplify the mathematical rules done in Mean Value First Order Second Moment (MVFOSM). Advance methods not only pursue mean and the standard deviation but also the normal and lognormal distribution. Process of FOSM is as follows:

a. Rosenblatt transformation is used to change variables from X space to U space
b. Locate the most probable point in U space
c. Determine reliability index
d. Find probability of failure/reliability

The approach of (Low and Tang 2007) is in actual the modified version of the approach, put forwarded in 2004. Considering correlation between variables not distributed normally. No use of calculating equivalent normal mean (μ^N) and equivalent normal standard deviation (σ^N) in 2007 approach. Getting '**β**' minimum by changing values of X_i is the main aim. Iteration needs Rackwitz and Fiessler equivalent normal transformation. In the following equations 'C' refers to covariance matrix and 'R' shows matrix of correlation.

$$\boldsymbol{\beta} = \sqrt{\left[\frac{X_i - \mu_i^N}{\sigma_i^N}\right]^T (\mathbf{R})^{-1} \left[\frac{X_i - \mu_i^N}{\sigma_i^N}\right]} \qquad (4)$$

Alternatively

$$\beta=\sqrt{(\boldsymbol{x}-\boldsymbol{m})^{T}\boldsymbol{C}^{-1}(\boldsymbol{x}-\boldsymbol{m})} \quad (5)$$

Where

$$\boldsymbol{\sigma}^{N} = \frac{\phi\{\Phi^{-1}[F(x)]\}}{f(x)} \quad (6)$$

$$\boldsymbol{\mu}^{N} = x-\boldsymbol{\sigma}_{i}^{N} * \boldsymbol{\Phi}^{-1}[F(x)] \quad (7)$$

In comparison with above mentioned 2004 approach, (Low and Tang 2007) approach is reported more efficient as it skips some tedious steps without showing any changes on conclusion.

$$\beta=\sqrt{(\boldsymbol{n})^{T}\boldsymbol{R}^{1}(\boldsymbol{n})} \quad (8)$$

For every trial, original basic random variable X_i is determined by design.

Where

$$X_i=\boldsymbol{F}^{-1}[\boldsymbol{\Phi}(\boldsymbol{n}_{i})] \quad (9)$$

and $[\Phi(n_i)]$ = standard normal cumulative distribution. Discussing about Second Order Reliability Method (SORM/, it is in actual the extension of First Order Reliability Method (FORM). In comparison with FORM, SORM found less efficient but more accurate as shown in Table 4. In case of number of performance functions to work out its efficiency, it requires more iteration but for geotechnical problems, results observed from SORM is almost same to FORM (Lacasse and Nadim 1999).

Table 4: Comparison of reliability index methods (Lacasse and Nadim 1999)

Methods	FORM	SORM
Probability of failure	$8.6908e^{-4}$	$8.7813e^{-4}$
No of evaluations	88	550

2.1.3. Monte Carlo simulation

This is a computerized mathematical technique. It randomly generates values for uncertain variables to simulate a model. Large numbers of iterations are involved to approximate the probability of certain outcomes by using random variables. Mathematically it can be expressed as:

$$\mathbf{P_f} = \frac{\textbf{number of failing trials}}{\textbf{Total number of trials}} \quad (10)$$

Random variables are generated according to already calculated basic statistical parameters of mean, coefficient of variance and type of distribution. These generated random variables are joined together to form a limit state function 'G' (on the basis of already determined limit state function). Taking the definition of failure G<0, number of failing runs will count.

2.1.4. Importance sampling technique

Importance sampling is a proficient approach which can trim down the number of simulations essential while attaining equivalent precision as in the basic Monte Carlo Simulation (Alf 1986). The valuation of reliability or feasibility is habitually a computationally exhaustive practice in reliability design. In one of the study an importance sampling based reliability analysis method is projected to accurately and efficiently approximate the reliability, prearranged the distributions of input variables (Fan and Wu 2007). In the proposed approach, the Most Probable Point MPP is sited and used to reduce the simulation territory. The random variables are influenced around the MPP, so the number of simulations can be condensed radically.

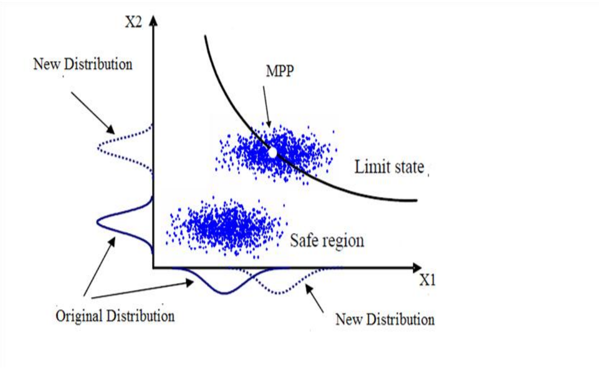

Figure 2: MPP based Importance Sampling

In short, the central idea of importance sampling is to draw the variables according to a substitute set of distributions such that more samples will be in the failure zone. Hence more samples will chip in the probability estimation. Mathematically it can be defined as:

$$\boldsymbol{P_f} = \int \boldsymbol{I}[\boldsymbol{g}(\boldsymbol{X})]\boldsymbol{f_x}(\boldsymbol{x})\boldsymbol{dx} \quad (11)$$

$$\boldsymbol{P_f} = \int \left\{\boldsymbol{I}[\boldsymbol{g}(\boldsymbol{X})]\frac{\boldsymbol{f_x}(\boldsymbol{x})}{\boldsymbol{h_x}(\boldsymbol{x})}\right\}\boldsymbol{h_x}(\boldsymbol{x})\boldsymbol{dx} \quad (12)$$

Where $h_x(x)$ is the importance-sampling density but same as original density f_x except that the means values of **X** are trade by the Most Probable Point (MPP).

The concept of importance sampling also can be applied in relation with system reliability (Song 1997). The work stands on the probability formula of the union of events and the conception of the importance sampling, a technique for computing structural system failure probability is build up. In Melcher's method, all importance sampling functions consequent to the structural worth failure modes should be pooled by some criteria, and they would affect the exactitude of results or computational efficiency (Melchers 1989). In this study of (Song 1997), the developed technique is on the numerous simulation using every importance sampling function in spin, the criterion for combination is not needed, so, the inadequacy of Melcher's method is overlooked.

3. Reliability theory applications in slope stability criteria

Propagation of probabilistic methods for slope stability analysis has also been pinpointed in a study of (Christian, Ladd et al. 1994). This study describes how probabilistic information of soil properties can be attained from field or laboratory data and incorporated into stability analysis. Mean value first order second moment approach is taken to elaborate with a design example of embankment dam having multi stage and single stage construction

The confirmation that reliability of slopes is better judged through whole system has been put forwarded in the study of (Oka and Wu 1990) .The substantiation of the stability of the slopes is done customarily by calculating one single factor of safety which is distinct characteristically as the ratio of the strength (capacity) to the demand and is changeable from case to case. In this coming research, author tries to reveal the fact of slope instabilities/failures of Malaysian region by using probabilistic theory. The probabilistic tools discussed before is going to utilized to make an objective comparison of the various types of conditions what was not acquired through old deterministic approach. The probabilistic approach is used to set standards/criteria for the codes and the standards dealing the calculation of the slopes by putting reliability indices and probability of failures instead of empirical total safety factor approach taking relation of the random dispersion of the soil parameters of cohesion, friction and soil unit/ weight.

One of the research also authenticated the use of Mean Value First Order Second Moment (MVFOSM) method to estimate the reliability of slopes (Hsu, Lin et al. 2007). In case of inhomogeneous soil slopes this method most often underestimates the failure probability. In other words it overestimates the reliability of the slopes. To counter this issue, projection method is used to authenticate the results of MVFOSM through geometrical means. Results of MVFOSM are extended to locate equivalent most probable failure point in material space. Critical safety factor calculated through this follow up must be equal to 1, as this is the only reason of supporting MVFOSM reliability index. If safety factor is less than 1, validity of this will become doubtful.

By taking an example of homogeneous and non homogeneous slopes, it is shown in two layered soil slope problem; Factor of safety obtained is 1.695, considering FOS a normal variant, MVFOSM gives a reliability index value of 3.82. Following back procedure gives a FOS value of 0.8. It is now confirmed that MVFOSM result corresponds to a failure point deep inside unsafe region in the material space and calculated reliability index automatically underestimates the probability of failure. Hasofer and Lind approach also proves by giving a reliability index of 2.26.

In relation with circular slip surfaces and ordinary method of slices a new technique of Importance sampling is presented. As it is known that ordinary method not bothers about iterations, importance sampling is used to search appropriate locations of IS PDF, followed by subsequent computation of probability of failure (Ching, Phoon et al. 2009). By taking case histories of different slopes, dealing with ordinary method of slices, FORM, Monte Carlo simulation and Importance sampling techniques has been utilized. Results of these three techniques are shown in Table 5

Table 5: Examples of Different Methods (Ching, Phoon et al. 2009)

Method	MCS	IS		FORM
Sample size N	10,000	100	1,000	-
Computational time		12	105	1
Estimated probability of failure	0.0044	0.0038	0.0041	0.0016
Estimator COV %	15.04%	20.9%	6.62%	-
Required N to achieve COV =20%	5,655	109	109	-

It is pretty sure now after having so much discussion that stability of slopes can easily be affected through different sources of uncertainties. Again by taking the case study of slope at El Berrinche, (Flores Peñalba, Luo et al. 2009), it is instituted that the variant in the stability of the slope is mostly depending on the uncertainty in shear strength factors and the inequality in the piezometric elevation. In radiance of these uncertainties, it is measured desirable to calculate the failure potential in terms of the probability of slope failure.

Quantification of uncertainties wishes reliability approaches and reliability analysis tools. It is totally a delusion that an abundant amount of data and thorough probabilistic knowledge requires in using reliability theory. Reliability theory can easily be applied on the same data and judgments used in conservative analyses. The two methodologies limit state design or load resistance factor design LRFD) tries to integrate reliability based design into practice. Till date their application in structural engineering is winning as compared to Geotechnical engineering

4. **Methodology application**

In this section author is going to deal with the very disastrous landslides of Malaysian region, to prove the above mentioned theory of reliability analysis. In connection landsides of Bukit Antarabangsa 2008 and the very previous Highland Towers 1993 are taken into consideration. The question of why selecting these particular landslides? The reply is very straight forward, these landslides have been taken place on almost the same location, reported soil properties are more or less same but the geometry of the slopes differs in heights and gradient. In one manner this will also help the author to determine that whether heights and gradients pose its influence on the reliability of the slopes or not.

In this regard Slope W software is utilized. SLOPE/W is a commanding slope stability analysis program. Using limit equilibrium, it has the skill to fix diverse soil types, composite stratigraphic and slip surface geometry, and uneven pore-water pressure conditions using a large assortment of soil models. Analyses can be carrying out by deterministic or probabilistic input parameters. It can execute probabilistic slope stability analyses, taking into account the variability and uncertainty allied with the analysis input parameters. A probabilistic analysis agrees to statistically reckon the probability of failure of a slope via Monte Carlo method. The results from all Monte Carlo attempts can then be used to figure out the probability of failure, factor of safety probability density and distribution functions. Changeability can be considered for material parameters such as unit weight, cohesion and friction angles, pore-water pressure conditions.

The search of the position and radius of critical slip surface is the trickiest part of the slope stability analysis. It is not only depending on the geometry of the slope being analyzed but also on the strength parameters. In deterministic analysis of slope, mean values of input parameter are always used and this will acquiesce on a particular failure surface. In SLOPE/W the use of a probabilistic analysis will not impinge on the deterministic solution. SLOPE/W calculates the factor of safety of all slip surfaces first and determines the critical slip surface as if no probabilistic analysis is elected. The probabilistic investigation is than performed, on the deterministic critical slip surface.

The factor of safety existing on the SOLVE main window during the probabilistic analysis is the deterministic minimum factor of safety of all considered slip surface; nevertheless when the analysis is ended, the factor of safety offered on the SOLVE main window is the mean factor of safety of all Monte Carlo tryouts.

Probabilistic /reliability analysis needs some more clarification and addition in unit weight, cohesion and friction. The mean, standard deviation, coefficient of variation are three required basic statistical parameters used to carry out probabilistic analysis (Refer Table 6).

Table 6: Statistical parameters of variables

Variables	Mean	Standard Deviation	Coefficient of Variance
Weight of Soil	19	1.2 (approx taken as 1)	0.06
Friction Angle	31	0.66 (Round off to 1)	0.02
Cohesion	9	1.6 (Round off to 2)	0.18

Though the safety factor methods differs in their nuts and bolts, like some of the methods satisfies only moment equilibrium, other follows both force and moment equilibrium, some of them neglect interslice horizontal forces and carry only the shear forces. The author has used four different methods but more or less safety factor from all the selected methods shows the same value. On the other hand derived safety factor value is also not satisfactory. When probabilistic analysis is performed, reliability index for three different cases of soil parameters has been taken (Refer Table 7). An inherent probabilistic tool of Monte Carlo simulation of Slope W software is utilized by having 1000, 2000 and 3000 trials. As the number of trials, make the vision more clear or present the results in more refined manner.

Table 7: Three Different Cases of Soil Parameters

Standard Deviation	Case I	Case II	Case III
Unit Weight	1	1	1
Cohesion	1	1	2
Friction	1	2	2

The output of the analysis is offered (in Table 8) shows that the probability of failure is a logical measure of the likelihood of the slope failure. Results of this study have demonstrated that the probability of failure gives better assess of slope stability in contrast to the factor of safety. As it provides an array of value, not a single value. As calculated through deterministic analysis safety factor value is around 1.18 (Refer Table 8). According to the safety factor classification of the slope it is not soundly safe, reliability indices and probability of failure shows slope is around average or above average for Case II and Case III. If referring Case I according to reliability index slopes have been maintaining good stability. This classification (proposed by U. S. Army Corps of Engineers) is already given by author in Table 9. Variation in the reliability indices for Case I, Case II and Case III is due to uncertainties in soil properties. By fluctuating standard deviation of cohesion and friction, posses clear difference on probability of failures or reliability indices values. It is evident now that safety factor approach is conservative or in other words misleading for design.

Table 8: Mean safety factor

Methods	Moment	Force
Ordinary	1.098	-
Bishop	1.190	-
Jambu	-	1.086
Morgenstern Price	1.183	1.181

Table 9: Probabilistic Results of Case I, II and III

Trial	Output Quantities	Case I	Case II	Case III
1000	Reliability Index	4.55	3.13	2.42
	Probability of Failure (%)	0.0002	0.084	0.76
2000	Reliability Index	4.59	3.02	2.43
	Probability of Failure (%)	0.0001	0.12	0.73
3000	Reliability Index	4.63	3.06	2.45
	Probability of Failure (%)	0.00015	0.10	0.70

Like Bukit Antarabangsa 2008 landslide reliability assessment of Highland Towers are also concluded. The same program of Slope W is followed. Safety level of the slope has been measured both deterministically and probabilistically. Concluded safety factor is maximum 1.502 even from the most rigorous method of Morgenstern-Price. Output quantities are mentioned below (Refer Table 10 and Table 11). In this specific landslide analysis author has followed the same strategy.

Table 10: Mean Safety factor

Methods	Moment	Force
Ordinary	1.425	-
Bishop	1.499	-
Jambu	-	1.403
Morgenstern Price	1.502	1.503

Table 11: Probabilistic Results of Case I, Case II and Case III

Trials	Output Quantities	Case I	Case II	Case III
1000	Reliability Index	1.03	1.13	1.10
	Probability of Failure (%)	12.12	12.88	13.45
2000	Reliability Index	1.01	1.04	1.09
	Probability of Failure (%)	11.98	11.99	12.14
3000	Reliability Index	1.05	1.07	1.01
	Probability of Failure (%)	10.98	11.12	11,18

5. Results and Conclusion

By taking the three landslides of approximately same location Bukit Antarabangsa 2008, Bukit Antarabangsa 1999 and Highland Towers 1993 slope stability analysis has been performed from both ways: deterministically and probabilistically. With the help of Slope W software three different scenarios has been observed. In case of Highland Towers 1993 reliability index is alarming low, but safety factor seems to be satisfactory, for Bukit Antarabangsa 1999 concluded reliability index is in negative and for Bukit Antarabangsa 2008 reliability index is very much on the safer side. From both types of analysis, it can visibly be noted that there is no relation between safety factor and probability of failure. Secondly make sure the concluded probability of failure is also have deficiency as it only accommodates soil/model uncertainties, not human uncertainties in relation with slope stability..

The appraisal of the stability of slopes, mostly natural slope, is one class of problems that is subjugated by uncertainties. Geological incongruities, material properties, environment conditions and analytical models are all factors participating to uncertainty. Conventional slope design practices do not report for these uncertainties, fully believed with the adequacy of predictions. On the other hand, reliability analysis for slope stability proffers a proficient framework for rational methodical inclusion of uncertainty, thus given that a more logical basis for design. It is tacit that there is uncertainty in any type of analysis. Conventional slope stability analysis has faith on a factor of safety approach to account for uncertainty. This approach does not essentially give up compact profitable designs. Nor does it clearly offer a set hint of the safety of the design. While Probabilistic slope analysis, (on the other hand) openly balance the uncertainty. The output of the probabilistic analysis, in terms of failure probability or reliability index, is a measure of the reliability of the design. Probabilistic analysis afford greater insight into design reliability, hence, supporting the engineering judgment and recuperating the decision making process. So, the intelligibility, effortlessness and cost/time effectiveness are indispensable essentials in order to successfully express and commune a probabilistic methodology to practicing engineers

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