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COMPUTER SIMULATION AND RISK ANALYSIS AROUND UNSTABLE CLIFFS. APPLICATION TO A FRENCH CASE.

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ABSTRACT

In France and since the beginning of the year 1995, some abandoned underground excavations or cliffs located in urban zones and by the administrative demands should undergo what is called a Plan for Risk Prevention (*Plan de Prévention des Risques Naturels Prévisibles, PPR*). This plan is supposed to include the analysis of environmental impact induced by the abandoned work as well as its geotechnical risk such as rock falls, slope slides, etc. The analysis is based on various parameters and leads to the evaluation of the induced risk into four classes according to French standards. It has been meagerly developed through the experience of geotechnical engineers that determine zones sensible to these different types of risks based on assuming discrete values for different judging parameters such as slope angle, joint inclination, etc. In the present paper, a simulation model has been proposed in order to replace a part of the experts' work by applying a Monte-Carlo simulation model accompanied by a statistical analysis of the various parameters affecting the stability. This simulation model is based on Normal and Uniform laws of statistics.

INTRODUCTION

The Analysis of risks induced by underground opening or unstable cliffs is one of the major and important tasks in earth science engineering. This analysis should take into account the effect of randomness, it should account also for the probability distributions of different parameters, and above all, the experience of the geotechnical engineer.

In 1992, and according to a new rule in the French law, some geotechnical works must undergo a special study aimed at determining the impact of the geotechnical work on the environment (visual impact, pollution, etc.) and also the geotechnical impact (rock falls, slope slides, etc.). A new extension of this law was published in 1995 including also all abandoned underground works.

According to that law, the area that is subjected to the PPR study, should be classified into four categories expressing the natural risk from High, Intermediate, Low, or Negligible. This classification is then used by local administrations, insurance companies, and political issues of urban planning. (this classification is then used for the prescription for future constructions in the area).

This paper shows part of the analysis made by the engineers of the INERIS (Institut National de l'Environnement Industriel et des Risques, in France) for the evaluation of geotechnical risks around a cliff zone situated in the Parisian basin (Région Parisienne). This work is based mainly upon the experience of the geotechnical engineers as well as observation and proposition of discrete values describing the state of the cliff overlying some times abandoned underground workings.

The authors have proposed -with the help and consultation of INERIS- some modifications to the current methodology in order to account for the randomness and probability in the estimation of each observed parameter. This methodology has been optimized and automated using Visual Basic Programming in order to aid and facilitate the judgment of the experts' work needed for the analysis. In order to perform such operations, the Monte-Carlo simulation method has been adopted and implemented with both Normal and Uniform statistical distribution for each observed parameter. The results at the end are presented in a form of histograms.

GENERAL METHODOLOGY FOR RISK ANALYSIS APPLIED TO A CLIFF AT PONTOISE

The methodology for the analysis of risk which is proposed by the engineers of INERIS is based upon the observation of some parameters at the sites under consideration. The method of analysis is inspired by the classical method of Rock Mass Classification proposed by Bieniawski (1989). The procedure of this analysis is divided into 4 stages. The first one is the observation stage in which the engineer has to observe and document some parameters from the field concerning the cliff, and the area around it. This stage is followed by a stage of calculations in order to find out the sensitivity of the site. The last two stages are stages of table crossing in order to find out the probability of occurrence of certain phenomena and the risk imposed on the site. Fig. 1 shows the different stages of this analysis.

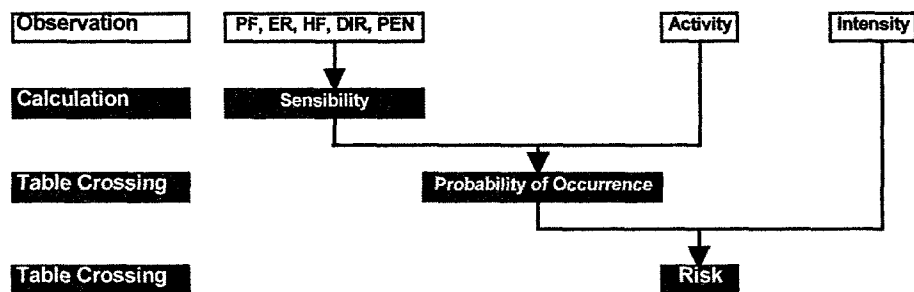


Figure 1. General Procedure of the Analysis applied to the cliff of Pontoise

All observed parameters (Intensity, Activity, Sensitivity Parameters) are classified into 4 classes. Table 1 shows the four classes of the intensity as well as their description in terms of elementary rock volume. This intensity could be considered as the severity in industrial engineering risk terms. Table 2 shows the classes of the activity of the site as well as their physical explanation. In addition, table 4 shows the different classes proposed for the different parameters judging sensitivity of the sites.

These parameters are the spacing between fractures (PF), the spacing and roughness of joints (ER), the humidity of fissures (HF), the structural direction with respect to the front (DIR) and finally the inclination of fissures with respect to the front (PEN).

TABLE 1
INTENSITY OF PHENOMENA

Intensity of Phenomena	Volumetric Index	
	Elementary (m ³)	Volumetric Mass (m ³)
Rock Fall	< 10 ⁻³	< 1
Block Fall	10 ⁻³ ~ 1	1 ~ 10
Collapse	> 1	10 ~ 10 ⁴
Major collapse	> 10	> 10 ⁴

TABLE 2
THE ACTIVITY OF THE ROCK MASS

Qualification	Principal Index of Activity
Sleeping	Shades of Morphological Traces No Massive Alteration No Mechanical Fractures No effect on the Infrastructure or the Environment
Inactive	New Morphological Traces Superficial Alteration Ancient Mechanical Fractures No clear Effect on the Infrastructure or the Environment
Fresh	Fresh Morphological Traces Deep Alteration Developed Mechanical Fractures Possible Effects on the Infrastructure or the Environment
Active	Morphological Traces Active Alteration Developed and Open Mechanical Fractures Effects on the Infrastructure and the Environment

The second stage of the analysis consist of the calculation of the sensitivity from the notes given to the fractures parameters mentioned earlier. This calculation of the sensitivity is inspired by the Rock Mass Classification (RMC) of Bieniawski (1989), and is adapted and adjusted to the present case according to the available data. The calculation of the sensitivity of the Pontoise cliff follows the next equation:

$$S=((4 \text{ PF})+(2 \text{ ER})+(\text{HF})+(\text{DIR})+(2 \text{ PEN}))\times(1/3)$$

The third and the fourth stages of the analysis consist of the crossing of tables in order to find the probability of occurrence (the activity vs. the sensitivity), and another crossing to find the risk (the probability of occurrence vs. the intensity). This crossing is in accordance with the methods of industrial risk quantification where the risk is the product of the probability vs. the severity.

TABLE 3
THE RISK

Probability of Occurrence	Negligible	Low	Intermediate	High
Intensity				
Rock Falls	Negligible	Low	Low	Intermediate
Block Falls	Low	Low	Intermediate	Intermediate
Collapse	Low	Intermediate	Intermediate	High
Major collapse	Intermediate	Intermediate	High	High

TABLE 4
SENSITIVITY PARAMETERS

Parameter	Note Assigned
<i>Spacing between Fractures (PF)</i>	
< 0.2 m	3
0.2 ~ 0.6 m	2
0.6 ~ 2 m	1
> 2 m	0
<i>Spacing and Roughness of Joints (ER)</i>	
Spacing > 5 mm, continuous filled with clays	3
Spacing < 5 mm, surface of potential sliding	2
Spacing < 1 mm, Altered surface	1
Closed, no alteration of roughness	0
<i>Humidity of Fissures (HF)</i>	
Water current	3
Water drops	2
Humidity	1
Dry	0
<i>Structural direction with respect to the front (DIR)</i>	
< 5°	3
5° ~ 15°	2
15° ~ 30°	1
> 30°	0
<i>Inclination of fissures with respect to the front (PEN)</i>	
-15° ~ -5°	3
-5 ~ 5°	2
5° ~ 15°	1
> 15°	0

TABLE 5
INDEX OF SENSITIVITY

Index of Sensitivity	Calculated value of Sensitivity
Very Favorable	$S < 25$
Favorable	$25 \leq S < 50$
Unfavorable	$50 \leq S < 75$
Very Unfavorable	$S > 75$

TABLE 6
THE PROBABILITY OF OCCURRENCE

Sensitivity	Very Favorable	Favorable	Unfavorable	Very Unfavorable
Activity				
Sleeping	Negligible	Low	Low	Intermediate
Inactive	Low	Low	Intermediate	Intermediate
Fresh	Intermediate	Intermediate	High	High
Active	High	High	High	High

THE NEED OF SIMULATION TO OVERCOME PROBLEMS OF RANDOMNESS

In a typical design of a geotechnical system, the engineer has to obtain an estimate of various rock and soil parameters to be used in the analysis, select the most suitable method of analysis, and interpret the results of

the analysis. Uncertainties are usually present in each of these three steps. Moreover, these steps are related to each other. In order to cope with these uncertainties, the engineer generally takes one of the following approaches Juang *et al* (1992) :

- a. Adopt the most conservative measure in each step -making a conservative estimate of the soil parameters, selecting a conservative method for the analysis, and conservatively interpreting the results (using a conservative factor of safety). In this approach, there is no need to quantify the randomness and uncertainties involved, and the procedure is deterministic.
- b. Employ a mean-value approach, which is also deterministic. This approach is the same as the conservative approach except that the mean values of soil and rock parameters are used.
- c. The use of a probabilistic approach. Randomness and uncertainties are considered in a random or frequency sense. The input for each soil or rock parameter is in the form of a probability density function or its statistical equivalent, and thus the uncertainty is explicitly taken into account. The analysis is straightforward through simulation by sampling these probability functions, and the result is in the form of histograms and probability density functions.

Among these common approaches, only the probabilistic approach gives a rigorous treatment of randomness and uncertainty. That is why this method is the preferred for complex systems where the calculations involve several parameters and is uncontrolled in terms of factors of safety, although it requires more facilities in terms of computer times.

COMPUTER PROGRAMMING

In order to perform the classical analysis as well as the simulation analysis, a computer program has been developed using Visual Basic edition Application (VBA) on EXCEL™. This computer program include three modules, one for the classical (Discrete analysis), the second is for the simulation analysis using different types of probability distribution, while the third module which is under construction, is devoted to the analysis using the fuzzy sets theory (which is out of the scope of this paper). This program could be adapted in later stages in order to take into account different parameters to analyze the risk in other sites encountering the same type of problems. Fig. 2 shows the opening dialog of this program.

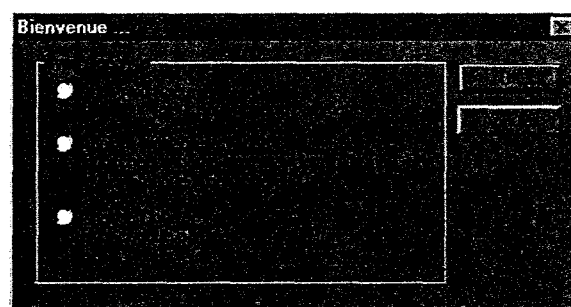


Figure 2. The opening dialog of the program

As it was mentioned earlier, the developed program has three modules, the second one, which is the main concern of this paper is devoted to the simulation process. This process requires the input of the minimum and maximum values for each parameter as well as the statistical distribution that this parameter is following

(For the moment, the program proposes only a Uniform or a Normal distribution, but we are developing the possibility of having other distributions), in this case the program will perform a Monte-Carlo simulation and repeat the calculations for the sensitivity, probability of occurrence and the risk for the required number of simulation and the result will be in the form of a histogram of the risk in order to account for the probability distribution of the input parameters.

SIMULATION

In order to take into account the randomness and the error of estimation of parameters in the phase of observation, and in order to aid the work of the expert charged for the observation and analysis, the method of Monte-Carlo simulation has been proposed in each phase of observation and calculation. The simulation is based on the proposition of statistical laws for each observed parameter. In the present study, only a uniform and a normal laws were proposed as a statistical distribution for each parameter. In order to make this simulation, the observer has to supply two values for the same parameter instead of one (the minimum and maximum). In the case of a uniform law, these two values are input directly in the program, while in the case of a normal law, these two values are considered to be the limits of the normal distribution at 90% confidence.

In the present study, three different analyses are made using the same minimum and maximum of parameters' estimation in order to show the effect of statistical distribution on the results. The first analysis is proposed using a uniform distribution for all observed parameters and simulated in order to produce a histogram of risk. The second type of analysis was made using the normal distribution for all observed parameters and simulated in order to produce a histogram of risk. The third and final type of analysis was made using a mixture of normal and uniform distribution for the observed parameters, and these observations are simulated in order to find out the histogram of the resulting risk.

SIMULATION RESULTS

Fig. 3 to 5 show the results of the analysis -after 1000 simulations- using the same minimum and maximum values for each parameter and using Uniform law, Normal law, and in the third case a mixture of the two laws. Table 7 details the chosen parameters and statistical laws.

TABLE 7
PARAMETERS DISTRIBUTIONS

Parameter	Minimum	Maximum	Statistical Law		
			First	Second	Third
Intensity	Block Falls	Collapse	Uniform	Normal	Uniform
Activity	Inactive	Fresh	Uniform	Normal	Normal
PF	0.2 m ~ 0.6 m	0.6 m ~ 2 m	Uniform	Normal	Uniform
ER	E < 5 mm	E < 1 mm	Uniform	Normal	Normal
HF	Water Drops	Humidity	Uniform	Normal	Uniform
DIR	5° ~ 15°	15° ~ 30°	Uniform	Normal	Normal
PEN	-5° ~ 5°	5° ~ 15°	Uniform	Normal	Normal

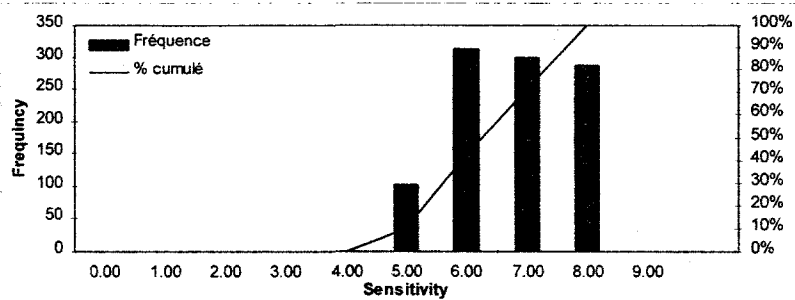


Figure 3-a. Histograms of Sensitivity proposing only a uniform law

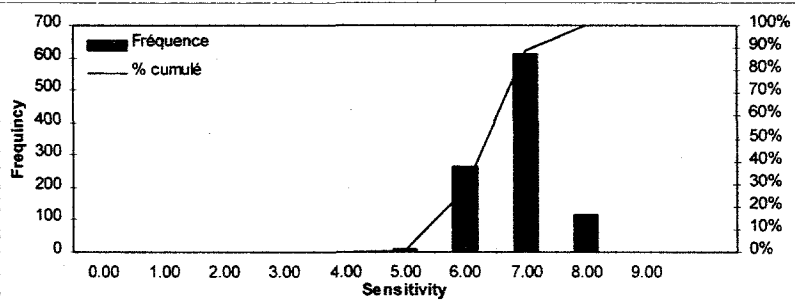


Figure 3-b. Histograms of Sensitivity proposing only a normal law

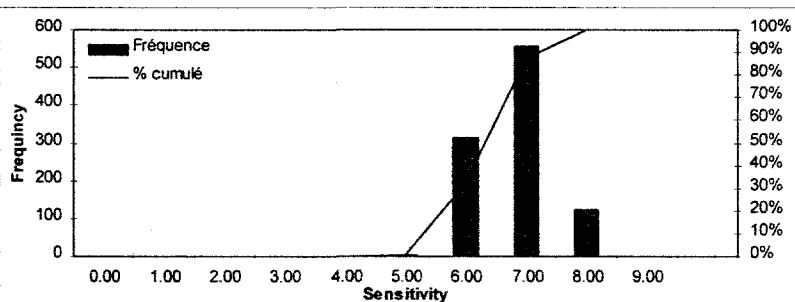


Figure 3-c. Histograms of Sensitivity proposing uniform and normal law

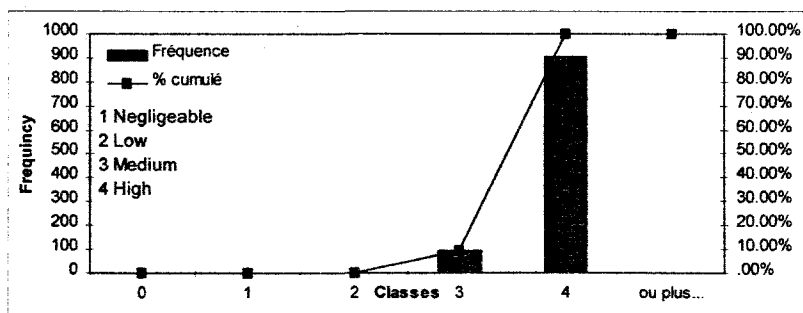


Figure 4-a. Histograms of Risk with only Uniform Distribution

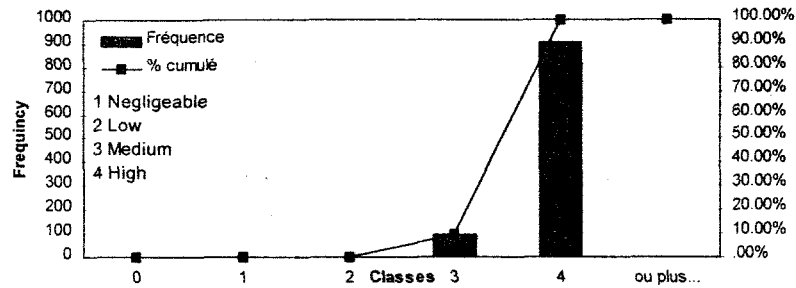


Figure 4. Histograms of Risk with only Normal Distribution

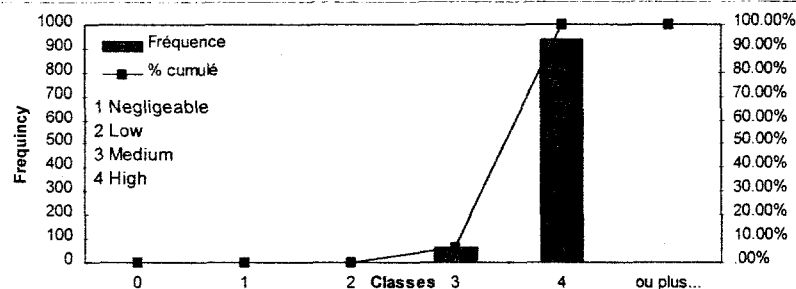


Figure 4-c. Histograms of Risk with Uniform and Normal Distribution.

In the first part of the figures (3-a, 3-b, 3-c), showing only the sensitivity of sites towards the risk, it is clear that the result is dependent on the type of statistical distribution chosen at the instance of observation. When the geotechnical engineer observes a uniform law of distribution, the histogram of the resulting sensitivity seems to follow a uniform law, while on the other side, if the observation reported normal law of distribution or a mixture of the two laws, the resulting histogram of the sensitivity, seems to follow a normal distribution. This dependency on the law of distribution proposed is due to the process of calculation of the sensitivity.

On the other hand, using the same parameters in order to calculate the final result of the risk, which is illustrated in the second part of the figures (4-a, 4-b, 4-c), the difference between the risk produced from parameters following normal distribution, uniform distribution, and a mixture of the two distributions, seems to be the same in all three cases. This result is explained by the fact that all observed parameters "the activity, the intensity", and the result of calculation for the sensitivity has to be normalized in order to make the dual process of table crossing (the first table cross is for the probability of occurrence, and the second table cross is for the risk itself). This process of normalization has eliminated the effect of the statistical distributions chosen to describe the parameters. In other words, the difference in the proposition of statistical laws at the moment of observation has no major effect on the final result of the risk.

The final result of risk shows the sense of probability and frequency in the result, which allows us to say that -in the current case- among 1000 simulations, the produced risk was high in 950 times (95%), and intermediate in 50 times only (5%). This result seems satisfactory since it implies the concept of probability and statistical distribution rather than providing a single and discrete value of the sensitivity and the risk.

CONCLUSION

Since the method of geotechnical risk analysis at the cliff under consideration is based upon the experience of the geotechnical engineer in charge, a computerized assistance is essential in order to aid the judgment of the engineer and in order to automate the process of analysis. Another need for this type of analysis is to overcome the problems and errors of randomness in parameters estimation. The method of Monte-Carlo simulation shows a good solution to the method although some points have to be considered such as the type of distribution chosen for the simulation -specially in the phase of sensitivity calculation- the level of confidence, and above all, the method of calculation and table crossing.

It was our concern in this paper to present the methodology of simulation in the estimation and quantification of risk. We have proposed the uniform and normal distributions as a way of input although it could be found that certain parameters are following certain distributions (Log normal, Poisson, etc.). In this case, these distributions could be introduced in the program in order to carry out the simulation.

In order to overcome the normalization of parameters to make a table cross, the fuzzy logic seems adequate and suitable for this type of problems. The authors are developing a similar system following this logic for the same problem.

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