Fuzzy Reasoning for the analysis of risks in geotechnical engineering Application to a French Case

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97-64

Fuzzy Reasoning for the analysis of risks in geotechnical engineering. Application to a French Case

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ABSTRACT : Since the beginning of the year 1995, in France, geotechnical works must undergo what is called a Plan of Natural Risks Prevention (Plan de Prévention des Risques Naturels, so called PPR). Such a plan is supposed to include the analysis of risks induced by the geotechnical works on the environment as well as its geotechnical impact (rock falls, rock slides, etc.). The analysis is based on various parameters and leads to the evaluation of the induced risk in order to classify it into four classes according to French standards. This type of study has been meagerly developed through the experience of geotechnical engineers using linguistic evaluation of parameters that determines zones sensible to these different types of risks based on classes of values for different judging parameters such as slope angle, joint inclination, etc. In the present study, a computer program has been developed for this analysis based on a fuzzy algorithm and fuzzy reasoning. The fuzzy algorithm has been developed in order to replace a part of the experts' work by using fuzzy numbers to overcome the problem of describing various parameters affecting the risk.

INTRODUCTION

The analysis of risks induced by unstable cliffs is one of the major and important tasks in geotechnical engineering. This analysis should take into account the fact that some engineering parameters that are necessary for any risk analysis around unstable cliffs are difficult to be quantified and/or they are vague and imprecise. That is why such risk analysis should depend meagerly on the experience of the geotechnical engineer in charge for measurements.
According to the French law, an area that is subjected to a PPR study, should be classified into four categories expressing the natural risk into High, Intermediate, Low, or Negligible. This classification is then used by local administrations, insurance companies, and political issues of urban planning.
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 an unstable cliff zone situated in the Parisian basin. 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 sometimes 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 vagueness, uncertainties and the imprecision 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, fuzzy numbers have been proposed in place of the discrete numbers used in the analysis and the fuzzy reasoning is used to evaluate the risk.

GENERAL METHODOLOGY FOR NATURAL RISK ANALYSIS

The methodology for risk analysis proposed by 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 at 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 towards a certain phenomena. The other two stages consist of table crossing in order to find out the possibility of occurrence of the phenomena and the risk imposed on the site. Figure 1 shows the different stages of this analysis.

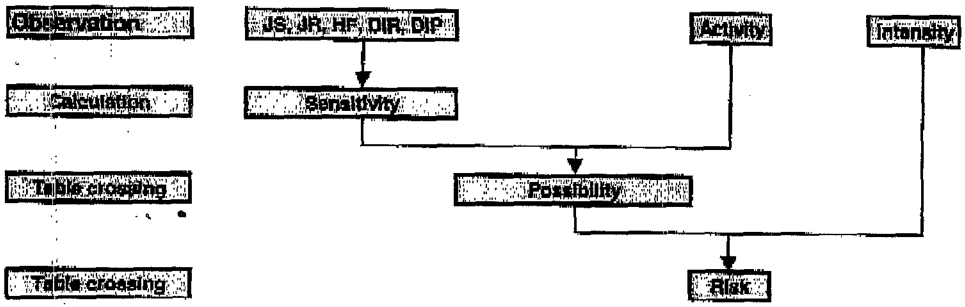

Figure 1. General Procedure of the Analysis applied to the cliff of under consideration

All observed parameters (Intensity, Activity, Sensitivity Parameters) are classified into 4 classes. In order to calculate the sensitivity of the site towards a certain phenomena, five parameters are measured. These parameters are: joint spacing (JS), joint roughness (JR), humidity of fissures (HF), direction of joints with respect to the front (DIR) and the dip angle of joints with respect to the front (DIP).

The activity of the site could be considered as the history of the site and classified into four classes as sleeping, inactive, fresh, and active. The intensity of the phenomenon is also classified into four classes determining the volume of the possible blocks fall. Table 1 shows the different classes of the sensitivity parameters and their classification.

The second stage of the analysis consists of the calculation of the sensitivity from the notes given to the sensitivity parameters mentioned earlier. This calculation of the sensitivity is adapted and adjusted to the present case according to the available data and is done in a way similar to the methods used for the RMC of Bieniawski (1989). The calculation of the sensitivity of the studied cliff follows the next equation:

$$S=((4\ JS)+(2\ JR)+(HF)+(DIR)+(2\ DIP))x(1/3)$$

The third and the fourth stages of the analysis consist of crossing rules tables in order to find the possibility (the activity vs the sensitivity), and another crossing to find the risk (the possibility vs the intensity). These table crossings define the rules for the fuzzy logic reasoning used in the analysis.

Table 1. Sensitivity Parameters

Parameter	Note Assigned
Spacing between Fractures (PF)	
< 0.2 m	3
0.2 ~ 0.6 m	2
0.6 ~ 2 m	1
> 2 m	0
Spacing and Roughness of Joints (ER)	
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
Humidity of Fissures (HF)	
Water current	3
Water drops	2
Humidity	1
Dry	0
Structural direction with respect to the front (DIR)	
< 5°	3
5° ~ 15°	2
15° ~ 30°	1
> 30°	0
Inclination of fissures with respect to the front (PEN)	
-15° ~ -5°	3
-5 ~ 5°	2
5° ~ 15°	1
> 15°	0

Index of Sensitivity	Calculated value of Sensitivity
Very Favorable	S < 25
Favorable	25 <= S < 50
Unfavorable	50 <= S < 75
Very Unfavorable	S > 75

Table 2. The Possibility rules

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

Table 3. The Risk rules

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

COMPUTER PROGRAMMING

In order to perform the classical analysis as well as the fuzzy analysis, a computer program has been developed using Visual Basic edition Application (VBA) on EXCEL™. This computer program includes three modules, the first one is for classical (Discrete) analysis, the second is for statistical simulation analysis using different types of probability distribution for each parameter, and the third module is devoted to the analysis using fuzzy sets theory.
This program could be adapted in later stages in order to take into account different parameters and to analyze the risk in other sites encountering the same types of problems. In the third module of the program, we have proposed two types of fuzzy numbers in order to describe each observed parameter. The first type is a continuous –Beta shape- number which could serve to describe an "around X" number. In this case, the user has to supply only the minimum and the maximum values of the number. The second type of fuzzy number is a trapezoidal shape number, which could serve in describing a parameter that has multiple values with multiple possibilities. Figure 2

FUZZY REASONING

In order to find out the results of the analysis using fuzzy numbers, we have applied the method of α-cut in order to convert –after normalization- the fuzzy numbers supplied by the user into 50 α-cuts. Then a fuzzy reasoning is applied to these numbers in accordance with the rules supplied in the tables in order to find out a fuzzy result for the sensitivity, the possibility, and the risk. This fuzzy reasoning is based on the Min-Max reasoning method as shown in figure 3.
The geotechnical engineers along with the experts have to define the classes of each parameter interfering in the analysis as well as the classes of the results for the sensitivity, possibility, and the risk.

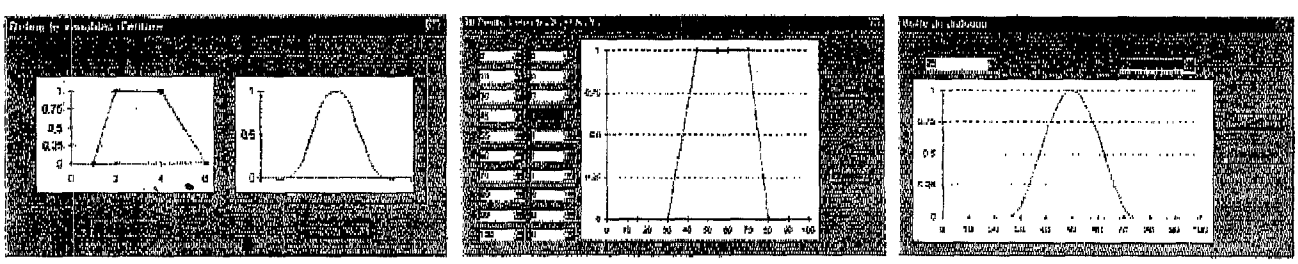

Figure 2. The choice between continuous and trapezoidal fuzzy number

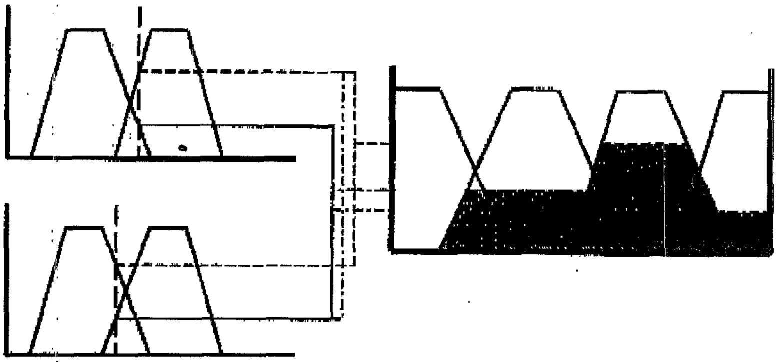

Figure 3. The Min-Max algorithm of reasoning

RESULTS

Figure 4 shows a result of the analysis carried on in a part of the cliff. It can be seen that the sensitivity plot which is situated to the left hand side of figure 4 is located in the second and the third class with a possibility of 82% in the second (Favorable) and an 18% in the third (Unfavorable), and the same possibilities for the risk plot which is on the right hand side of figure 4. In our analysis, we have used the method of center of gravity in order to defuzzify the fuzzy results. We can notice that the center of gravity for the sensitivity is at 51.6 as for the risk it is at 47.55. These values are measured on a pre-defined scale from 0 to 100.

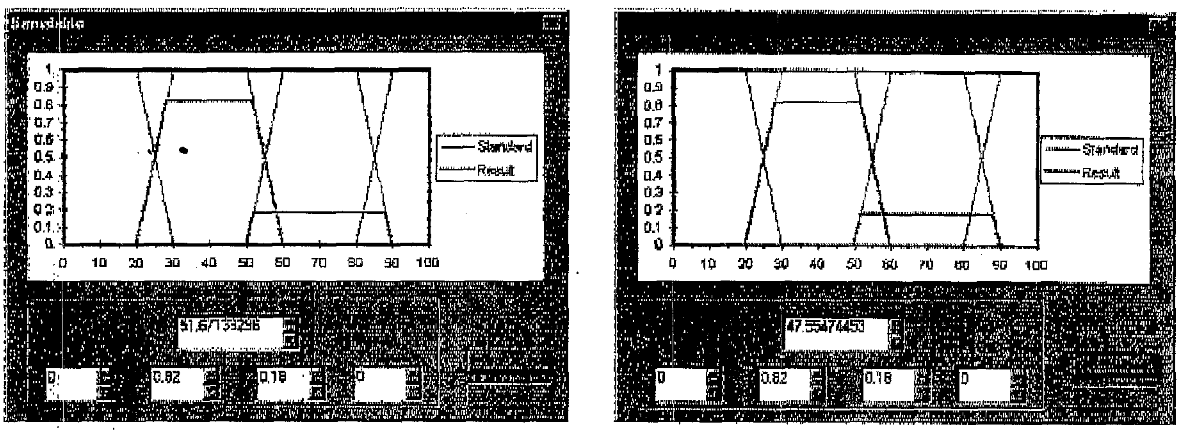

Figure 4. The result of the analysis showing the sensitivity and the final risk.

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, to normalize the decision, and to automate the procedure of the analysis. Another need for this type of analysis is to overcome the problems of uncertainties, imprecision, and vagueness in parameters estimation. The fuzzy algorithms are used here in order to find a feasible solution although some points have to be re-considered such as the definition of the classes for the input and the results and also in order to re-define the reasoning rules. This work is critical and requires the gathering of various experts and specialized engineers in the field of geotechnical engineering.

It was our main concern in this paper to present the methodology of fuzzy reasoning for the quantification of risk. We have found out that this method is applicable to our case and could be adapted to other cases and sites

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