Predicting geomechanical hazard: utopia or reality?

Adeline Delonca
Center for Research and Innovation in Mining (CIIM), Geomechanics Research Group, Department of Metallurgical Engineering and Materials, Universidad Técnica Federico Santa María, Santiago, Chile

ABSTRACT: Geomechanical hazard can be defined as a combination of the probability occurrence of an event and its intensity. Therefore, predicting a hazard level should give information about how (phenomenology of the failure), when (exact time of failure), and how much (with which intensity in terms of volume and energy) the event will occur. Several methods have been developed over the years to assess some or all these components. However, they do not allow a prediction to be made in terms of the time, location, and magnitude of the event. Indeed, in this assessment process, uncertainties are met at each step. Therefore, the prediction could be reached by answering two questions: can we remove all uncertainty? And if we do not have any uncertainty: are we able to predict the hazard? This paper proposed to discuss the two presented questions by going through various works realized during the author's academic career.

Keywords: Geomechanical hazard, uncertainties, risk assessment, prediction.

1 INTRODUCTION

As civilization grows, the need to expand our boundaries is met. This can be translated in the field of rock mechanics by the impressive geotechnical projects that are taking place all over the world. From open pit mines deep of thousands of meters in South Africa (Chilton, 2015; Milev, 2005), to the biggest open pit mine going underground in Chile (Olavarría et al., 2006), to the biggest and largest tunnels all around the world (Rehman et al., 2021; Tello-Toapanta, 2022) among other projects, engineers are pushing the actual knowledge to ensure working efficiently and safely. To do so, considering the geomechanical risk is critical. Risk can be defined as the effect of uncertainty on objectives (Hudson & Feng, 2015; ISO/GUIDE, 2009). It takes into account two notions: the hazard itself and the result of its occurrence. While the impact of an event is mainly practicable to assess, the hazard level can be more challenging to evaluate.

A hazard can be defined as a combination of the probability occurrence of an event and its intensity. Therefore, assessing a hazard level should give information about how (phenomenology of the failure), when (the exact time of failure), and how much (with which intensity in terms of volume and energy) the event will occur. Several methods have been developed over the years to assess some or all of these components and can be separated into three categories (Badri et al., 2012). The qualitative methods are mainly based on expert judgment. They consider the observation and ponderation of geomechanical parameters to describe the hazard by class. These methods are quick and easy to use but can be imprecise and complicated to replicate. Usually, they are used as a first approach to prioritize the zone presenting some hazard. A review of qualitative assessment methods can be found non-exhaustively in Ferrari et al. (2016) for rockfall or Aleotti & Chowdhury (1999) for landslides. The semi-quantitative methods are mainly based on statistical analysis combined with expert judgment. They allow a more detailed assessment to be realized than when using a qualitative assessment only and are mainly based on the ponderation of parameters (Ji et al., 2015) through statistical tools They are quick and relatively easy to use. Some examples of semi-qualitative methods are the analytic hierarchy process (Cai et al., 2022; Ding et al., 2019; He et al., 2019), the fault tree analysis (Kazmi et al., 2017; Krechowicz, 2021), the event tree analysis (Lacasse et al., 2008; Momeni et al., 2021). Finally, quantitative methods are mainly based on statistical analysis and/or numerical modeling. They aim to assess the occurrence probability value of the different identified risks. These methods are more complex and take more time, moreover, they require sufficient data quantity and quality. However, they allow the phenomenology of the hazard to be strongly understood and are the strongest tools to be closer to reality. Usually, it can be seen that there is an increase in complexity when going from qualitative, to semi-quantitative to quantitative methods (Badri et al., 2012).

While these methods allow the hazard to be assessed, they do not allow making a prediction in terms of the time, location, and magnitude of the event. Indeed, in the process of geomechanical hazard assessment, uncertainties are met at each step. These uncertainties can be separated into three groups (Baecher & Christian, 2005). Natural variability (also defined as aleatory uncertainty) depends on temporal and spatial variability. It is conditional on chance, due to intrinsic randomness and is considered irreducible (Hudson & Feng, 2015). It is associated with the random nature inherent in a natural process and is manifested by variability in the time of a phenomenon for a given place (temporal variability), by variability in space for a given instant (spatial variability), or by variability in time and space. This uncertainty can be approximated by mathematical simplifications and models, but even at best, they are only approximations. The knowledge uncertainty (also defined as epistemic uncertainty) depends on the lack of knowledge that exists in terms of site characterization, parameter variability, and phenomenology of the failure. It can be divided into three categories: (1) the uncertainty concerning the study site, which represents the difficulties encountered in interpreting the geology of a site with only surface data, (2) the model uncertainty, which identifies the differences between the chosen mathematical model and reality. It reflects the limits of the model to accurately represent the real physical behavior of the object under study, our inability to define the best model, and (3) the parameter uncertainty, which describes the precision with which the parameters of the model can be estimated. This uncertainty results from our inability to evaluate the value of the parameters by observations, and by inaccuracies. Knowledge uncertainty is supposedly reducible through further investigation. Finally, the decision uncertainty is due to the subjectivity of experts' assessment. It relates to our inability to decide, to define the objectives of a decision, to identify alternatives or to evaluate them, or to define our values or our preferences (Baecher & Christian, 2005).

Once this context is defined, predicting geomechanical hazard could theoretically be reached answering the two questions: can we remove all uncertainty? And if we do not have any uncertainty: are we able to predict the hazard? This approach is the one proposed in this paper. In the first part of the paper, the geomechanical hazard assessment process is presented to set the framework of the discussion. Moreover, the concept of prediction is introduced. Then, the challenges of reducing all type of uncertainty are discussed. Finally, some concluding remarks of the author are shared. It is to be noted that the author does not intend to answer the initial question: "predicting geomechanical hazard: utopia or reality?" as a definitive opinion but wishes to open a discussion based on personal though and community work.

2 GEOMECHANICAL HAZARD ASSESSMENT AND PREDICTION

As well presented in the Rock Engineering Risk book (Hudson & Feng, 2015), various risk assessment procedures exist and can be used to evaluate the impact of a hazard on a project. An example of these procedure is the risk flowchart proposed by the ISO/IEC Guide 51 (ISO/GUIDE, 2009), presented Figure 1. During the risk analysis process, both the consequence analysis and the probability analysis are defined and assessed for each hazard studied. The combination of both allows the level of risk to be evaluated. When assessing the probability analysis, the different methods presented in the introduction (qualitative, semi-quantitative, and quantitative methods) can be used.

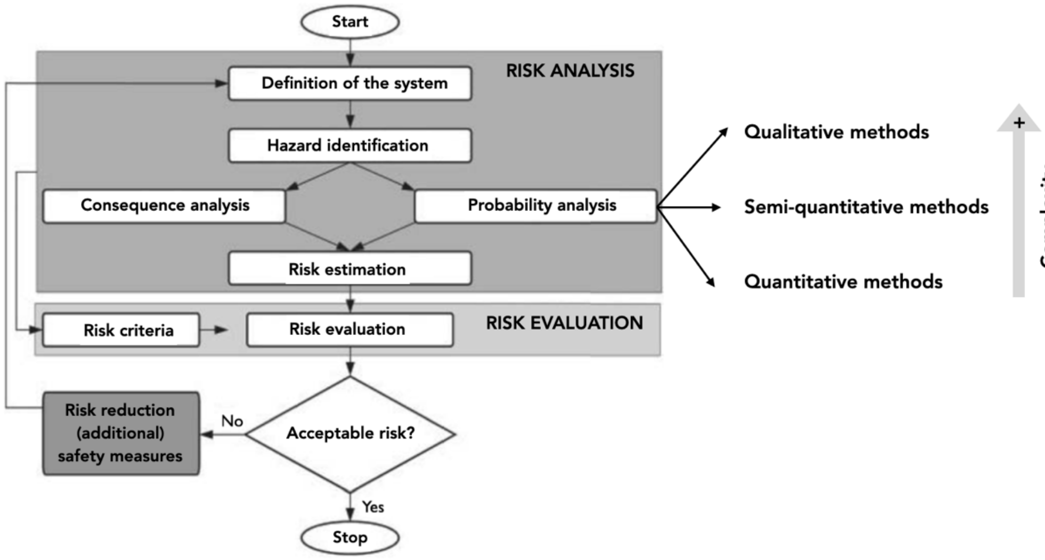

Figure 1. Risk flowchart from ISO/IEC Guide 51 (2014) modified based on the work of Badri et al. (2012).

A definition of prediction can be found in the seismic field, where it is proposed that a prediction must define three elements (Ismail-Zadeh, 2013): 1) the date and time, 2) the location, and 3) the magnitude. Therefore, a parallel can be done in the geomechanics field where, to predict an event, the three elements presented above should equally be assessed. The question related to this "when" is defining if a period (in 5 years) is enough to predict the event, or if we should be able to determine that the event will occur on the 5th of July of 2023, at 4pm. In terms of location, it is doable to precisely pinpoint the potential events in surface. However, it becomes harder when working underground where spatial 3D variability can be hard to define. Finally, assessing a magnitude means that the phenomenology of the events is perfectly clear, and it is well-known which parameter is a good indicator (the volume? The energy? Both? And how to assess them?). Therefore, the main limit to the prediction are the uncertainties that exist during the probability analysis, and one could assume that this prediction could be achieved by removing the three types of uncertainties.

3 IN THE WAY OF REDUCING UNCERTAINTIES

In this section, the author proposes to discuss each type of uncertainty with work that has been done by herself during her academic career complemented with the work of other authors.

3.1 Knowledge uncertainty

As commented previously, knowledge uncertainty should be reduced when adding information. More of the work done usually on improving the hazard assessment is related to decreasing this uncertainty as it is the one that seems more accessible. Knowledge uncertainty has been studied from the nineties (Dunnicliff, 1993; Jaksa, 1995) and is well documented (Bedi & Harrison, 2012; Hanss & Turrin, 2010; Morales-Torres et al., 2019; Stewart & Afshari, 2021, among others). Increasing the quality and quantity of data helps having a better understanding of a problem. Moreover, studying the phenomenology of the hazard can also help narrowing key parameters. However, it is not enough to predict the hazard in accordance with the definition proposed previously.

An example of this can be seen in a work realized on the phenomenology of the rock bridge's failure in a planar rock slide (Delonca et al., 2021). It has been shown that the rock bridge failure phenomenology can be associated with a cascade-effect failure (two phases in the failure propagation), which is consistent with previous research. This phenomenon can be explained by the increase in the shear stress in the vicinity of the open-crack areas, which can lead to the failure of the neighboring rock bridges. This highlights the unpredictability of the phenomenon as only a small decrease in the rock bridge proportion can lead to failure.

3.2 *Natural variability*

Natural variability depends on temporal and spatial variability and is associated with the random nature inherent in a natural process. An example of this can be seen in a study realized to correlate meteorological parameters and rockfall (Delonca et al., 2014, 2015). The objective of this study was to identify any possible correlation between meteorological factors and rockfalls, even in the case of databases containing very few events. Preliminary statistical analyses helped to identify several correlations in the case of a "rich" database. However, no correlation was detected in the more typical "poor" databases due to the sparse representation of days with several rockfalls. The proposed method uses the probability of occurrence of the chosen triggering factor to assess the influence of this factor on the rockfalls. This approach allows the correlation between a small number of events and a meteorological factor to be highlighted. Moreover, it allowed the probability of events to be estimated given the value of the meteorological factor studied. While this correlation can be used to determine when an event could occur, it has been shown that there is still around 10% of the events seemingly unrelated to any of the studied meteorological factors, that correspond to the natural variability of the rockfall nature.

3.3 *Decision uncertainty*

Decision uncertainty is due to the subjectivity of experts' assessment. To test the influence of the level of expertise on the rockfall hazard assessment, an experiment has been realized and presented by Delonca et al. (2013, 2016). It evaluated the influence of the level of expertise as well as the influence of the method used (qualitative and quantitative) on the rockfall hazard in three sectors of a proposed site. It shows that there is a significant influence of the method used on the rockfall hazard assessment, whatever the sector. However, there is a non-significant influence of the level of expertise of the population in two of the three sectors. On the other sector, there is a significant influence of the level of expertise, explained by the importance of the temporal probability assessment in the rockfall hazard assessment process. This work shows that it seems that the decision uncertainty can be reduced when using appropriate methods and ensuring the transfer of knowledge from the more experimented engineers to the youngest.

4 CONCLUDIND REMARKS

As our understanding of the hazard phenomenology increases in parallel with tool capability (numerical and statistical for example), the uncertainty that is inherent to the hazard prediction decreases. However, we must ask ourselves "is it possible to remove all uncertainty?" and if so, "could we predict an event?". Considering these two questions is fundamental when working in geomechanical environment. Indeed, it shapes our way of approaching the design of a project and forces us to humbleness. The author thinks it is critical to always integrate the influence of the data variability in any project and identify clearly which parameter is a key parameter in a risk assessment.

Reducing uncertainty helps narrow the three prediction elements. Nevertheless, there are still some unpredictable events that will always exist even by increasing the quantity and/or quality of data. While prediction may be an impossible goal to achieve, thanks to the quality and broadness of the ongoing and future research in the field, uncertainty can be decreased. Integrating probability into hazard assessment seems to be essential to better integrate the environment in which we evolve.

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