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MANAGEMENT OF UNDERGROUND ISSUES IN FRANCE USING PROBABILISTIC METHODS

As many other European countries, France has now to manage the "post-mining" phase, rather than mining activity as such. This paper focuses on presenting some post-mining issues and on discussing several improvements and benefits that probabilistic methods may bring to the management of problems related to a post-mining activity.

Как и другие европейские страны, Франция в настоящий момент должна скорее преодолеть стадию завершения разработки месторождений полезных ископаемых, чем развивать горное дело как таковое. Рассмотрен ряд вопросов, связанных с этапом завершения добычи полезных ископаемых, и обсуждаются некоторые нововведения и преимущества, которые могут являться следствием использования вероятностных методов в решении проблем, связанных с мероприятиями по завершению добычи полезных ископаемых.

Post-mining context in France. After largely exploiting its underground mineral resources for several centuries, France has gradually had to close its extraction sites (except for salt mining). However, closing down mining operations has not eliminated the risks likely to affect surface land within the geographical limits of the old workings. Damages (surface instabilities, surface flooding, gas emission, severe environmental impacts, etc.) may indeed develop, sometimes as soon as work has ceased but also much later. In order to manage properly those hazards and risks, French Authorities have developed a technical and administrative powerful tool: the Mining Risk Prevention Plans, aimed at identifying the most sensitive areas and to define technical and regulation rules able to manage the principles of the future urbanism development on surface [1]. INERIS institute and Ecole des Mines de Nancy are in France two of the main actors involved in the management of the "post-mining" risks and hazards. They efficiently perform in situ measurements, monitoring, laboratory tests, numerical modelling, etc.

Traditionally, risk analyses related to underground issues are performed in France in a qualitative way. Probabilistic approaches may therefore appear interesting in such a context as they would allow to deal with uncertainties that are inherent to the study of every natural object. They would also help answering questions from the public and the Authorities concerning the quantification of risks and homogenisation of natural risk analyses.

Through a practical example, this paper aims at presenting an efficient way to integrate uncertainties in analyses of risk related to old underground mines. Implications of a quantified forecasting of the spatial and temporal occurrence of surface collapses will also be discussed.

Presentation of the investigated underground gypsum mine. For that study an underground gypsum mine from Eastern France has been investigated. The exploitation was led from the 1890es at relatively shallow depths (20 to 60 meters) using the room-and-pillar extraction method. Numerous instability features that have been encountered in the mine (pillar failures, roof falls, floor heaves) have led to the development of surface collapses. In 1996, in order to post and manage the hazards, a first analysis was performed by the INERIS using the «representative configurations» methodology [2].

In 2006, an extensive surface investigation using a Global Positioning System device and several sets of aerial pictures has been undertaken in areas where sinkholes are relatively

prone to reach the surface. 35 events have thus been mapped. A spatial model of the area had then been built consisting in 246 meshes of $25 \times 25 m^2$. Each mesh has been characterized by information related to the workings (mining date, dimensions, number of undermined seams, etc.), the overburden (mining depth, geology, etc.) and the surface (number of sinkholes).

Analysis of the spatial and temporal occurrence of sinkholes above the underground mine. Because of the large spans of the rooms and the shallow mining depth, the mechanism of "caving" may explain the important number of sinkholes having reached the surface. A two-step approach has been chosen in order to investigate that mechanism. The first step consists in assessing the likelihood of an underground roof fall that may initiate the uprising movement of caving using a model of the bending induced failure of a plate. The second step consists in evaluating the potentiality of the sinkhole to reach the surface without being filled in by the bulking of the overburden materials using a volumetric model developed by the INERIS. As a result of that approach, a *hazard map* has been carried out, indicating for each cell the number of sinkholes likely to reach the surface. However, due to the uncertainties on the input parameters (resulting from a lack of knowledge or from natural variability), the hazard map is also uncertain. To deal with that problem, each of the input parameters has been expressed by a probabilistic distribution function, and using Monte Carlo simulations, *correction factors* (expressed by probabilities) have been used to weight the deterministic results and to draw a *probabilistic hazard map* that can also be referred as *susceptibility map*.

As numerous sinkholes occur since the end of the workings, a back-analysis of previous collapses has been undertaken. Comparing the number of expected sinkholes to the real sinkholes and using the results from the literature [3; 4] a model has been built to express the probability of occurrence of a sinkhole over time. It appears that this probability increases to be maximal around 65 years after the end of the workings. Then, it decreases to be relatively low 120 years after the end of the workings. It should be noted that those values are in great concordance with the literature.

Main results and conclusions. The taking into account of uncertainties according to the presented methodology has allowed the expert to have a spatial representation of the «post mining» hazard. Probabilistic results are from that point of view far more useful than deterministic ones as they make it possible to *rank* the level of hazard. Areas where the phenomenon is more likely may therefore be identified and technical or regulation rules (monitoring, fencing, etc.) may then be defined. It should be noted that probabilities have only been used in that case to quantify the uncertainty concerning input parameters. Therefore, they may only be seen as a complement of the *mean* analysis and the probabilistic figure does not have any real practical interpretation.

However, in a context of risk analysis, stakeholders need to have information about the temporal occurrence of the events. Probabilities are then expected in their *frequentist* meaning. In our study, as many events occur since the end of the exploitation, a back-analysis of previous collapses was possible and a model could have been built. This model is only valid for the mechanisms that are taking into account. Any modification of the water regime or of the stress environment for example will induce changes in the results. However, from a practical point of view, the integration of the temporal component of risk in the analysis may have important implications. As the *critical time* may be known, i.e. the time when the phenomenon is the more likely to occur, the implementation of a monitoring system may for example have more sense in certain periods of time. As the potentiality for a surface collapse to occur becomes low after a certain amount of time, stakeholders and Authorities may also be helped at defining a more efficient and sustainable surface development.

REFERENCES

1. *Didier C., Leloup J.* The MRPP: A powerful operational regulatory tool to prevent and manage post-mining risks. Proc. Post-Mining 2005, November 16-17, Nancy, France.

2. *Didier C., Tritsch J.-J., Watelet J.-M., Armangué A.* Evaluation du risque d'instabilité en surface à l'aplomb d'une ancienne carrière souterraine – principes d'une analyse par configurations types / Int. Cong. Rock Mechanics. 1999.

3. *Dyne L.A.* The prediction and occurrence of chimney subsidence in southwestern Pennsylvania. MSc thesis, Virginia Polytechnic Institute and State University, 1998.

4. *Peng S.S.* Surface subsidence engineering, SMME, Colorado, 1992.