Rockfall Hazard Zoning for Land Use Planning - Zonage de l'aléa rocheux pour l'aménagement du territoire

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RÉSUMÉ. Bien que les instabilités rocheuses représentent une menace pour les personnes et les infrastructures dans de nombreux pays, les procédures d'évaluation et de zonage de l'aléa rocheux sont loin d'être uniformisées. Après rappel du contexte général et classification de diverses approches existantes, les incertitudes et difficultés associées à l'établissement de cartes d'aléa sont discutées. Il est ensuite souligné combien les directives nationales conditionnent le zonage de l'aléa et les implications en termes d'aménagement du territoire. Finalement, une nouvelle procédure de zonage de l'aléa rocheux à l'échelle locale est présentée. Sur la base des résultats de calculs trajectographiques 2D ou 3D, cette méthode considère un couplage rigoureux de l'énergie et de la fréquence d'occurrence des événements potentiels (selon la définition stricte d'aléa admise au niveau international).

ABSTRACT. Although rock instabilities constitute a threat to human lives and settlements all over the world, methodologies for assessing and zoning rockfall hazards for urban development planning are far from being standardised. After presentation of the general background and classification of existing approaches, the report discusses uncertainties and difficulties which emerge when elaborating hazard maps. It is then underlined how national guidelines condition the hazard zoning and the implications on land use planning. Finally, a new procedure for rockfall hazard zoning is introduced. Starting from 2D or 3D trajectory modelling results, it estimates the hazard level based on a rigorous combination of rockfall energy and return period (according to the strict definition of hazard at the international level).

MOTS-CLÉS : Chutes de blocs ; Aléa ; Zonage ; Aménagement du territoire ; Calculs trajectographiques ; Méthodologie Cadanav.

KEY WORDS: Rockfall ; Hazard assessment ; Hazard zoning ; Land use planning ; Trajectory modelling ; Cadanav Methodology.

1. Introduction

Rockfall constitutes a severe threat to human lives and settlements in mountainous areas all over the world. Indeed, as rockfall is an extremely rapid process with long travel distances compared to other landslide mechanisms [CRU 96], the ability of persons to take evasive actions is very limited and the risk of loss of life or injury is high. Damages to buildings and infrastructures are likely as well. Although in many cases the hazard is managed with structural protection measures, an appropriate land use planning (e.g. prohibition and restriction to development) should be first considered to reduce the exposure of persons, buildings, infrastructures and facilities [OF 97].

The content of this keynote lecture is a summary of works and researches performed at the Rock Mechanics Laboratory (LMR) of the École Polytechnique Fédérale de Lausanne (EPFL) since several years in the field of rockfall hazard assessment and zoning. Section 2 hereafter merely lists issues about rockfall hazard guidelines and zoning methodologies developed in a book chapter [LAB 11], while Section 3 gives some insight on a hazard zoning methodology called Cadanav worked out at LMR-EPFL [ABB 13 and 14]. Anyone with an interest in the content and/or results is invited to look at the listed references.

2. Review of rockfall hazard guidelines and zoning methodologies

2.1. Terminology and types of landslide zoning

According to [FEL 08], various types of landslide zoning maps exist, namely: susceptibility, hazard and risk zoning. Although these terms are often used interchangeably in literature, these zoning types differ in the purpose of the study, the intended level of detail, the input data (availability and quality), the available resources and the mapping scale. It is usually suitable to carry out susceptibility zoning at the regional or valley scale before performing hazard or risk zoning for planning purposes at the local and/or site specific scales. Similarly, the adopted zoning methodology should be chosen to match the above-listed factors, in particular the desired objectives.

2.2. Guidelines

The diversity in rockfall zoning methodologies can be partly explained by differences in guidelines. [LAB 11] presents an overview of European guidelines for rockfall hazard and risk management. Only few of them include a comprehensive approach to: (i) the detection/characterisation of the potentially unstable areas, (ii) the definition/determination of landslide hazard (iii) regulations for land use planning associated to each foreseen degree of hazard. Moreover, even when this is the case, major differences are noticed from one country to the other, mostly related to the risk management strategy and accordingly to the regulations for the areas in danger (see section 2.6).

2.3. Zoning methodologies at the regional/valley scale

Zoning methodologies providing rockfall susceptibility maps at the regional or valley scale are usually desired by authorities to get a rough delineation at low cost of areas potentially endangered by rockfall [FEL 08, OF 97]. The goal is the early detection of potential conflicts with land use and accordingly the identification of zones of the territory where more detailed and expensive investigations will be required. Nowadays, such kind of preliminary zoning is frequently achieved by means of geographic information system (GIS) data [JAB 03]. After a preliminary identification of potential rockfall source areas from e.g. topographic vector maps and/or digital elevation models (slope steeper than a threshold value), a rough estimation of potential rockfall propagation can be computed by means of the so-called cone method [JAB 11].

2.4. Zoning methodologies at the local scale

At the local scale, in zones where potential conflicts are detected between human settlements and rockfall, a more detailed zoning is necessary for the purpose of planning land use. Several zoning methodologies are available. Though they all need detailed field investigations, they rely on different data, assumptions and approaches, and they provide diverse types of information and maps. [LAB 11] presents and discusses rating-based methods and quantitative methodologies based on trajectory modelling. Among the latter, the only methods that consider the expected intensity and return period of the rockfall events and thus that provide hazard maps are the Matterock and Cadonav methodologies developed in Switzerland and the Eurobloc methodology used in the Principality of Andorra. However, these methods still differ in the way the raw trajectory simulation results are processed and in the way the kinetic energy and the rockfall frequency are merged to obtain the hazard zoning map [LAB 11].

2.5. Sources of uncertainties emerging when elaborating hazard maps

Although trajectory-based methodologies coupling intensity and frequency should theoretically provide a more reliable and objective hazard analysis than other zoning methods, many uncertainties and assumptions affect the results [LAB 11]. A first set of major uncertainties is related to the departure zone: e.g. time recurrence of the events and associated magnitude [COR 08 and 11], size and shape of the blocks. A second important source of uncertainties lies in the input parameters used for the trajectory modelling (e.g. restitution coefficients), which should be carefully calibrated on the basis of field observations and data from documented events [DOR 11]. A third source of diversity in hazard zoning results is the post-processing of the raw trajectory simulation results. Questions arise with regard to the choice of probability of reach thresholds, to the percentile of the energy distribution that should be considered, to the possible removal of extreme blocks, and to the way kinetic energy and return period should be coupled. Finally, differences in hazard assessment are also related to the intensity/frequency diagram established for the zoning in the national guidelines.

In [LAB 11], some of these issues are examined and discussed on a case study. In particular, it is highlighted that zoning methodologies developed according to the same guidelines may provide fairly different zoning results and consequently that it is not straightforward to pass from trajectory simulation results to hazard zoning. Such differences are of course extremely questionable for stakeholders and potential users, since hazard maps are meant to be basic documents for land use planning.

2.6. Implications of zoning results in land use planning

As mentioned in previous section, another very important source of differences in hazard zoning is related to the national guidelines, which have conditioned the development of zoning methods. For example, though both the Swiss and Andorran guidelines use an intensity-frequency diagram for estimating the rockfall hazard and delineating the hazard zones, it is worth noticing how much different the adopted threshold values are for both parameters [LAB 11]. More, major differences in land use planning are noticed from one country to the other, mostly related to different risk management strategies and regulations for the areas in danger. For instance, constraints on urban development established by the Andorran Government are based on which degree of protection can be achieved by means of structural protection measures [COR 05], while in Switzerland natural hazards must at first be managed by means of land use planning measures (i.e. restrictions to urban development) and only second priority is given to structural measures [OF 97]. These considerations emphasise how social and political criteria (risk acceptance and risk management, respectively) must be carefully taken into account when comparing methodologies used in different countries [LAB 11].

3. Cadanav methodology for hazard mapping at the local scale

A first version of the Cadanav methodology was developed about 10 years ago at the Rock Mechanics Laboratory (LMR) of the École Polytechnique Fédérale de Lausanne (EPFL) with the objective of improving hazard assessment and zoning at the local scale [JAB 05, ABB 09, LAB 11]. Because two strong assumptions were somewhat affecting the hazard zoning results and limiting this original procedure, a new version of the methodology was recently worked out in a PhD thesis [ABB 11].

The new version of the Cadanav methodology is detailed and compared to its original version in [ABB 13] and hazard zoning results are illustrated along two different 2D slope profiles. The methodology takes into consideration all the main factors defining the hazard associated to rockfall processes, i.e. the temporal frequency of rockfall events, the number of blocks released, their size, their intensity, and their probability of reaching a given point of the slope with a specific energy. Based on trajectory simulation results, the Cadanav methodology merges in a strict way the expected magnitude (energy) and the return period of the rockfall events. “Hazard curves” are first drawn at each point of the slope by a set of energy-return period couples representing the hazardous conditions affecting that location. The hazard degree (e.g. high, moderate or low) prevailing at that point of the slope

is then determined by superimposing the hazard curve to the intensity-frequency diagram prescribed in the national guidelines.

The new Cadanav methodology constitutes a more rigorous and robust approach to hazard assessment and zoning compared to other existing procedures. Among others, it has a very low sensitivity with regard to the number of runs performed in a trajectory simulation and to the presence of possible outliers in the results (longer propagation path of one or a few blocks). It performs well on both regular and complex topographies and provides a more objective zoning. Indeed, once the failure frequency has been defined and the raw rockfall simulation results are available, the zoning proves to be completely independent of the user [ABB 13].

The implementation of the new Cadanav methodology is general and flexible. It can be used for evaluating rockfall hazard for complex scenarios involving several sources and event return periods as well as for performing hazard zoning for 3D topographies, starting from 3D trajectory modelling results [ABB 14]. Finally, as the drawing of the hazard curves does not depend on the intensity-frequency diagram, the procedure is actually applicable for any diagram prescribed in national guidelines.

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