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Development of a damage simulator for the probabilistic assessment of building vulnerability in subsidence areas

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ABSTRACT

The extraction of ore and minerals by underground mining often causes ground subsidence phenomena and may result in severe damage to buildings. Risk analysis in subsidence regions requires the assessment of both the hazards to and vulnerability of nearby buildings. However, many uncertainties exist and this assessment and its representation as well are still a complex objective. For this purpose a damage simulation tool is developed to investigate hazard and vulnerability under several possible scenarios of mining subsidence in which a large number of buildings may be affected. Ground movements assessment is based on the influence function method, and building damage is estimated using vulnerability functions. A case study is presented to illustrate the different results given by the damage simulator. Uncertainties about the collapsed zone of the mine and influence angles lead to the definition of different possible scenarios. A relative occurrence probability is then defined to implement a probabilistic approach to the hazard and vulnerability assessments. Different results, more or less synthetics, can then be obtained to assess both hazard and vulnerability over the exposed city. These results are compared and the maximal horizontal ground strains and the mean damage appear to be the most effective and relevant way to address the question. A final ranking based on scoring is then provided.

1. Introduction

Risk assessment and mitigation is a key concern for cities affected by natural hazards. These tasks require both an accurate prediction of the hazard and a careful evaluation of building vulnerability in spite of the existence of several uncertainties. In technical settings, the hazard can be quantitatively described as "the likely frequency of occurrence of different intensities for different areas" [1] and vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" [2]. However, the term "vulnerability" is frequently used in the strict sense of building strength.

In recent years, different risk assessment methodologies have been developed and incorporated in a considerable number of different software [3–6]. Such softwares and methodologies may significantly improve the assessment and the visualization of both hazard and vulnerability at a city scale. A first conclusion is that such approaches are actually seldom developed in the context of mining subsidence hazard. Recently, Malinowska and Hejmanowski [7] proposed a risk assessment method for mining subsidence zones with GIS data. This method represents an advance in risk assessment techniques for mining subsidence but is not comparable with existing methods for risk assessment associated with other natural hazards. Firstly it uses an empirical building damage assessment instead of vulnerability functions mainly used otherwise. Second this method does not consider the uncertainties in the two main parameters of the risk assessment, namely, building damage and hazard assessment, while this objective is crucial in this paper.

The objective of this paper consists into the development of a probabilistic approach of the building damage assessment and the analysis of the possible issues that may help for the risk assessment. This first leads to develop software named mining subsidence damage simulator (MSDS) in the following. This paper focuses on the influence of uncertainties, which is a key point for risk management and may affect both the building vulnerability and the hazard assessment. Uncertainties about vulnerability are first taken into account through vulnerability curves, which are based on the definition of a building typology, the use of a hazard intensity criterion and the definition of a damage scale.

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Vulnerability curves are relationships between the damage mean value μ_D for a given type of building and the value of the hazard intensity. They are developed for each building type, and they allow a quick and realistic damage assessment of all the buildings that are grouped into the same type. Vulnerability functions can be calculated with the fragility curves and the following equation [8]:

$$\mu_D = \sum P_k \times D_k \tag{1}$$

where μ_D is the mean damage for a particular value of hazard intensity, D_k the damage level between 0 to 5 for a five levels damage scale ($D_0=0$ for no damage and $D_5=5$ for very severe damage) and P_k is the probability of a damage level D_k.

The use of vulnerability function is now a common way to assess building damage for many natural hazards [3,8,9]. However, they require knowing the value of the hazard intensity, whereas this is also an uncertain parameter.

From a theoretical point of view, if uncertainties on hazard may be assessed by defining different possible scenarios with different intensities and probabilities, then risk management requires to address the building damage assessment by considering the whole possible scenarios. Methods used to define these scenarios may be specific for each kind of hazard. In the following, a methodology based on both expertise and computations is developed in the field of mining subsidence hazard to assess a set of scenarios. The MSDS is applied to this set of scenarios in order to develop a probabilistic assessment of the vulnerability. Different strategies are investigated to synthetize the results.

2. Development of the mining subsidence damage simulator (MSDS)

2.1. Underground mines and subsidence

Underground mining operations cause ground subsidence. This phenomenon leads to horizontal and vertical ground movements, which lead to deformation of and damage to buildings in undermined urban areas (Fig. 1). The maximum vertical displacement may reach several meters [10]. This vertical displacement is accompanied by horizontal ground strains, ground curvature and slope, the three types of ground movements that may cause structural damage. Depending on the mining extraction method used, whether it is longwall or rooms and pillars with or without caving of pillars, subsidence can be planned. In some cases it can also be unexpected a long time after the extraction. In all cases, the prediction of building damage is necessary when subsidence is expected in an urbanized area [11]. This paper mainly focuses on mining area with abandoned rooms and pillars mines that may induce unexpected subsidence.

Many countries are concerned with mining-subsidence-induced damage (for example, England, the United States, Poland, Germany, France, South Africa, India, China, etc.). Therefore, different methods have been developed to assess ground movement: empirical [12,13] or analytical [14,15]. The most important parameter used to quantify the subsidence intensity and assess the building damage is the horizontal ground strain. These two kinds of methods may be used to develop vulnerability curves for different buildings types [16,17]. These curves will be used in the following.

2.2. Principles of the MSDS

The MSDS aims to use a geographical information system (GIS) for the representation and the spatial localization of both the buildings and underground mines. Its objective is to assess and represent building damage for any specific mining subsidence. The MSDS is based on a very simple scheme illustrated in Fig. 2 with the following input and methods:

(a) A method to predict the subsidence parameters over a geographical area due to the collapse of a mine or part of it (vertical subsidence, curvature and horizontal ground strain). As in Malinowska and Hejmanowski [7], the influence function method is chosen because it allows realistic assessments for any shape of the underground mine [16]. This method is based on the superimposition principle [10] and uses a set of parameters that must be adjusted in relation to any specific case study. In the perspective of the development of a probabilistic approach, these parameters can be assumed uncertain;

(b) Vulnerability functions to assess building damage due to mining subsidence, based on Refs. [13,17]. For each case study, this requires to classify each building into a given typology and to develop specific vulnerability curves. In the perspective of the development of a probabilistic approach, the vulnerability functions may also be assumed uncertain;

(c) A set of realistic subsidence scenarios in relation to the characteristics of the underground mines. Each scenario

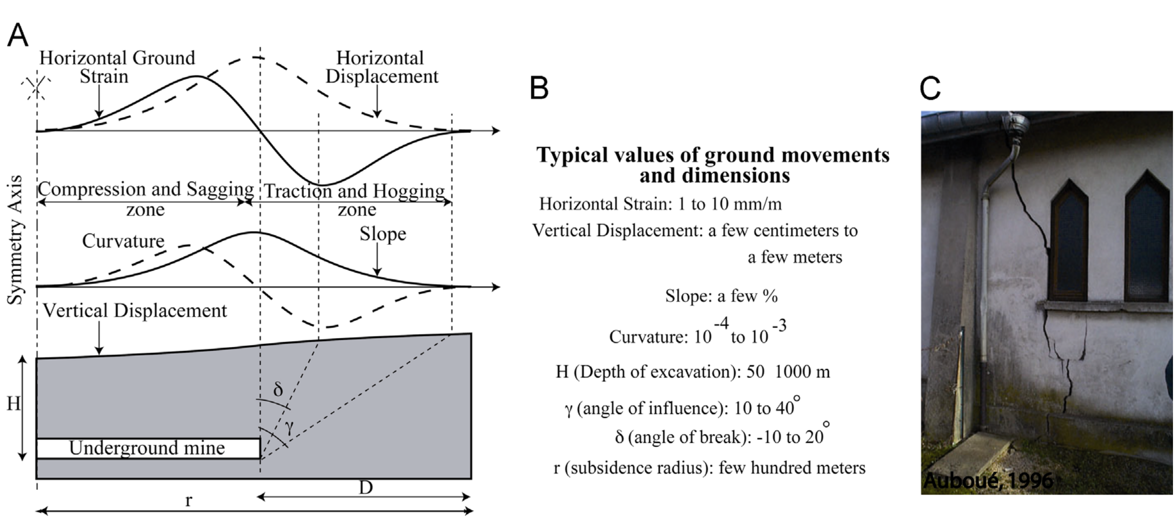

Fig. 1. Description of the main characteristics involved in mining subsidence and their associated consequences. (A) Typical profiles of the ground displacements. (B) Typical values of the subsidence dimension and ground movements. (C) Typical damage due to mining subsidence in the city of Auboué, France.