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Behavior of a masonry wall subjected to mining subsidence, as analyzed by experimental designs and response surfaces

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ABSTRACT

In this paper we present the principles of a methodology for studying the impact of mining subsidence on masonry buildings, using numerical experimental designs, statistical analysis and surface responses, where the subsidence is the input variable, joint tensile strength and cohesion are the control variables and the total length of cracks is the output variable. Numerical experiments are carried out using a distinct element model of a masonry wall where masonry blocks are explicitly taken into account. Calculations are also carried out for two types of subsidence according to the position of the building in the convex curvature or the concave curvature zone of the ground surface subsidence. Statistical analysis of the results shows the dominant influence of the joint tensile strength over the joint cohesion and the absence of interaction between these two parameters.

1. Introduction

This paper primarily focuses on a risk to the natural environment from mine subsidence which many authors have studied. As encountered in many papers, the definition of that risk involves two key aspects: hazard in one hand and vulnerability on the other.[1–3]

In the case of mining subsidence, hazard characterizes an undesirable event that may arise at the ground surface in the form of a topographic depression referred to as a subsidence depression. The hazard assessment is intended to determine both the probability that such an event occurs and its magnitude. In the case of the Lorraine Region's iron ore basin under study herein (North-East of France), mining excavations have been operated according to the room-and-pillar method and it is supposed that subsidence events mainly result from the failure of mine pillars that had become too weak to support the overburden load or from the breaking of interlayers in the case of mining multilayer deposits (Fig. 1).

Vulnerability which constitutes the other side of the risk is characterized by the expected level of damage which exposed assets may suffer from, where exposed assets typically consists of the people, goods and activities potentially adversely affected by the subsidence event.[3,4]

Mining subsidence phenomena are composed of slow and gradual movements and therefore do not present any direct risk to human life (Fig. 2A). On the other hand, they may cause considerable damage to residential structures built on the ground surface (Fig. 2B) as well as to infrastructure (utility networks, roads, etc). Several authors[5–7] have studied the effects of ground subsidence on surface buildings while others like[6–12] among others, have particularly focused on the effects of mining subsidence on structures.

The Lorraine Region has experienced several events of this nature during the past decades that have led to damage, primarily to dwellings, such as at Auboué in 1996, Moutier in 1997, Moyeuvre in 1998 or Roncourt in 1999. In the Auboué subsidence for example, around one hundred dwellings were completely destroyed.[1]

When exposed to the effect of a subsidence event, masonry structures (which represent the majority of typical dwellings throughout the Lorraine Region) exhibit a mechanical behavior governed for the most part by the discontinuities found in such structures, composed of masonry blocks and discontinuities (i.e. mortar joints, expansion joints, openings, etc.). The mortar joints are frequently accounted for by the use of cohesive surface elements as in Lourenço.[13] The mortar material is represented as discontinuum elements (Head (or vertical) and Bed (or horizontal) joints). An expansion joint provides space for the blocks to move when its volume increases. Clay masonry is constructed with expansion joints which should be installed in the specific locations (at concrete masonry control joints in composite walls, as well as at offsets, junctions and corners). In order to prevent distress in the masonry structures, vertical and horizontal expansion joints are used to accommodate movements. When the spacing between expansion joints is too large, cracks may develop at window and door openings. The openings in the masonry structures are weak points with concentration of tension in the corners. The first cracks in case of a movements in the masonry

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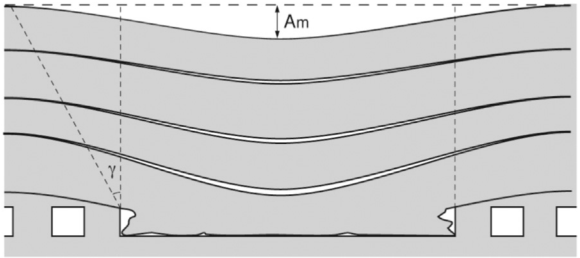

Fig. 1. Schematic view of the process of pillar rupture leading to an upper ground subsidence (γ is the angle of influence, A_m is the maximum vertical subsidence).

walls will occur from the corners of the opening.

The number of parameters entering into a mechanical behavior model for this category of structure is therefore quite high, consisting, in particular, of both the elastic or elastoplastic properties of the masonry blocks and the discontinuities (joints). Determining some of these parameters with great precision has been proved to be a difficult task (especially for parameters relative to the discontinuities), and common practice calls for using estimates based on data extracted from the literature. Moreover, the variability found in parameters from one structure to the next or within the same structure also generally necessitates introducing uniform characteristic values in models assumed to be representative.

In the present paper, it will be shown that experimental designs and response surface methodology are well adapted to study the influence of such parameters on the mechanical behavior of masonry walls subjected to mining subsidence events. But, as we are concerned with a methodological perspective, only two controlling parameters will be investigated: the masonry joint tensile strength (denoted Jtens) and the joint cohesion (Jcoh).

The study presented herein has been conducted by means of numerical modeling using the distinct element method (UDEC computation code) for two types of loading; it is intended to examine the influence of the above mentioned parameters on the behavior of a masonry wall (simplified representation of a house). The state variable targeted by this analysis is the cumulative crack length appearing in the modeled wall after loading. We shall adopt the hypothesis that this variable characterizes the global wall damage.

2. The subsidence model used

Fig. 3A displays the King and Whetton subsidence model mentioned in the work by Whittaker and Reddish.[8] This model yields the vertical displacement of the ground surface movement, as specified in the following expression Eq. (1)[14]:

$$V(x) = \frac{A_m}{2}\left[1 - \tanh\left(\frac{2x}{h \tan\gamma}\right)\right] \tag{1}$$

where A_m is the maximum vertical subsidence, x the distance to the inflection point (Fig. 3A), h the mining depth, and γ the angle of influence. This model was selected among several existing models, similar to each other and all able to roughly reproduce observed data, this one being relatively simpler to manipulate.

In our models, we are assuming that the mining subsidence results from a collapsed mine, located at a depth of 120 m and producing a maximum surface subsidence of 1 m (average value observed in the Lorraine region,[14] p 23), with a 30° angle of influence and with the radius of the collapsed zone set at 300 m. This specific model approximately corresponds to the conditions found in the Lorraine city of Joeuf, which is indeed exposed to a mining hazard.[15]

Fig. 3A also reveals the two studied wall positions numbered 1 and 2 at the top-right of the figure (position 1 in convex zone and position 2 in concave zone). Each of these positions has been the focus of an experimental design including 48 numerical experiments of the studied wall for different values of the controlling parameters. Each experiment provides a result in terms of cumulative crack length within the wall. After all, a multiple regression analysis tries to correlate the observed cumulative crack length with the used controlling parameters

The wall is placed at two distinct positions where deformation is presumed to be maximal: the first position 1 (Fig. 3C) corresponds to a spot where the wall base is subject to extension (i.e. convex zone or horizontal tension), while position 2 (Fig. 3B) corresponds to a zone where the wall is subjected to horizontal compression (i.e. concave zone). These two situations are thus exerting effects on the structure that seem to differ substantially, which is why we have decided to distinguish them.

While mining subsidence has both a vertical and a horizontal component, we decided to focus on the single effect of the vertical component coming from terrain curvature (convex zone and concave zone).

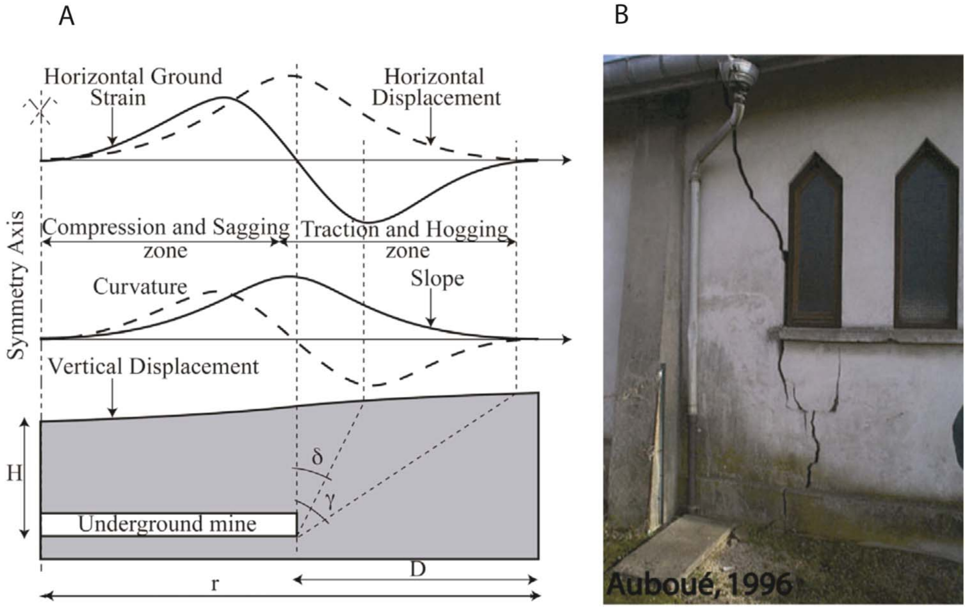

Fig. 2. Description of the main characteristics involved in mining subsidence and their associated consequences. (A) Typical profiles of the ground displacements. (B) Example damage due to mining in the city of Auboué in 1996, France.