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Original Study

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Analysis of the behavior of structures under the effect of progressive rupture of a cavity

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Abstract: The ground movements related to the presence of old underground cavities are often damaging to structures and infrastructures. Considering these ground movements in calculations will prevent considerable human loss and material damage. Many areas, both in Algeria and in abroad, are prone to instability caused by ground rupture and the phenomenon of sinkhole progression. The objectives of this work are first to numerically simulate the process of cavity collapse and second to analyze the impact of cavity properties on structure stability. A finite element model was established to analyze the influence of several cavity parameters (dimensions, volume, and spacing). Validation of the model relied on comparing numerical results with experimental data from scientific research, as well as those from analytical approaches. Adequate correlation was achieved. The study allowed deriving mathematical equations relating to several parameters, including cavity dimensions and position in the soil, soil characteristics, and footing width. These results will be considered to reduce the risk of surface structure instability.

Keywords: Soil-structure interaction; cavity; structure; modeling; rupture; footing; displacement.

1 Introduction

The frequent presence of underground cavities in certain developable areas poses a potential collapse risk that can be detrimental to the proper functioning of infrastructures and the safety of their users. Various studies have been conducted to investigate the issues caused by the collapse of underground cavities and the impact of these collapses on surface structures.

Table 1 summarizes the main research studies analyzing cavity collapse using experimental and numerical methods, classified chronologically.

Our work focuses on analyzing the interaction between the soil and the structure, first examining the progressive collapse of an underground cavity beneath a structure and then evaluating its impact on the stability of the structure. Finally, we conduct a parametric study to understand how cavity volume, depth, and spacing influence the stability of the structure.

To predict ground movements caused by cavity degradation, geotechnical engineers have various methods at their disposal. These methods include empirical approaches using detailed field data, analytical methods based on mechanical equations, and numerical methods. These approaches are documented in the scientific literature notably by Deck et al. (2006) and Dolzhenko (2002).

The main objectives of this study are to minimize the consequences of cavity collapse, maintain the stability of the structure, and reduce deformations observed at the structural elements level. Our methodological approach involved initially validating a numerical model, followed by calculating the collapse values using an analytical method. Test results were presented using a scaled-down model. In practice, empirical methods are often guided by analytical approaches or finite element calculations. These methods are then adjusted based on experimental curves, as highlighted by Aftes (1982).

The empirical approaches described by Peck (1969) for vertical displacements and by Lake et al. (1992) for horizontal displacements are used to predict ground surface movements after the excavation of a circular tunnel (see Figure 1). Equations 1 and 2 express vertical and horizontal displacements, respectively:

$$\text{Vertical displacement: } S(x) = S_{max} \times e^{-x^2/2i^2} \quad (1)$$

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