COMPUTATIONAL POTHOLE MINING SUBSIDENCE ANALYSIS

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ABSTRACT: The use of sites over old or active mining regions or with natural openings in the ground includes an elevated technical risk, as constructions can be constrained due to unplanned deformations of the subsoil. Typical failure modes include pothole subsidence or earthfalls, when failing soil masses are displaced and loosened stepwise toward a collapsing opening in the ground. The displacement process continues until a stable static equilibrium is reached and a further propagation of displacements is prevented. To determine the failure probability on a given site due to pothole subsidence, an efficient computational prognosis method for the practical estimation of the expected subsidence volume is required and proposed that is based on simple geotechnical assumptions.

Keywords: mine, subsidence, pot-hole, deformation, prognosis, numerical method

ИЗЧИСЛИТЕЛЕН АНАЛИЗ ПРИ СЛЯГАНЕТО НА МУЛДА

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РЕЗЮМЕ: Използването на терени, разположени над стари или действащи рудници или такива с естествени отвори на повърхността предполага повишен технически риск. Строителството може да бъде възпрепятствано поради непланирани деформации на грунтовия слой. Обичайните начини на пропадане включват пропадане на отвора в горнището на мулдата или поява на срутища, при които пластове земна маса се деформират и постепенно се изместват, придвижвайки се към обрушващ се отвор. Процесът на пропадане продължава, докато се достигне стабилно статично равновесие и се предотврати по-нататъшното разпространение на деформациите. За да се определи вероятността за поддаване на даден участък в резултат от пропадане на отвора на мулдата, е необходимо да се предложи ефективен изчислителен прогностичен метод за практическото изчисление на очаквания обем, на слягане.

Ключови думи: мулда, слягане, отвор в горнището, деформация, прогноза, цифров метод

Introduction

The use of sites over old or active mining regions or of sites with natural openings in the ground includes an elevated technical risk, as constructions can be constrained due to unplanned deformations of the subsoil. Typical failure modes include pothole subsidence or earthfalls, when failing soil masses are displaced and loosened stepwise toward a collapsing opening in the ground. The displacement process continues until a stable static equilibrium is reached and a further propagation of displacements is prevented.

To determine the failure probability on a given site due to pothole subsidence, an efficient computational prognosis method for the practical estimation of the expected subsidence volume is required and proposed that is based on simple geotechnical assumptions. In computational methods for potential pothole subsidence analysis, the emphasis is not on the time required until a failure happens but on the development of a static equilibrium stopping a further extension of the failure zone.

Computational pothole subsidence analysis

The different theoretical approaches proposed for the computational pothole subsidence analysis have been categorized by Fenk et al. (2004) into failure volume balance methods, force equilibrium methods, arch failure methods, and complex methods. The practical application of computational methods for pothole subsidence analysis proves to be difficult, as information on the structure of the ground and on the spatial distribution of material specific parameters is limited and an additional geotechnical ground prospection is often not feasible.

In the mechanical process of a pothole subsidence, the tensile strength of the material in the subsoil has very high importance. The driving force behind the failure mechanism is given by the gravity forces directed vertically downwards. During the extension of a pothole failure zone, sequential partial failures take place. After a partial failure, the occurring changes in the stress state are temporarily supported by the neighbouring subsoil regions for a certain time period, but the extension of the pothole failure zone probably slowly continues until a stable static and volumetric equilibrium is reached. These assumptions are backed by the common field experience that pothole failures typically take several decades to centuries to develop and reach the ground surface.

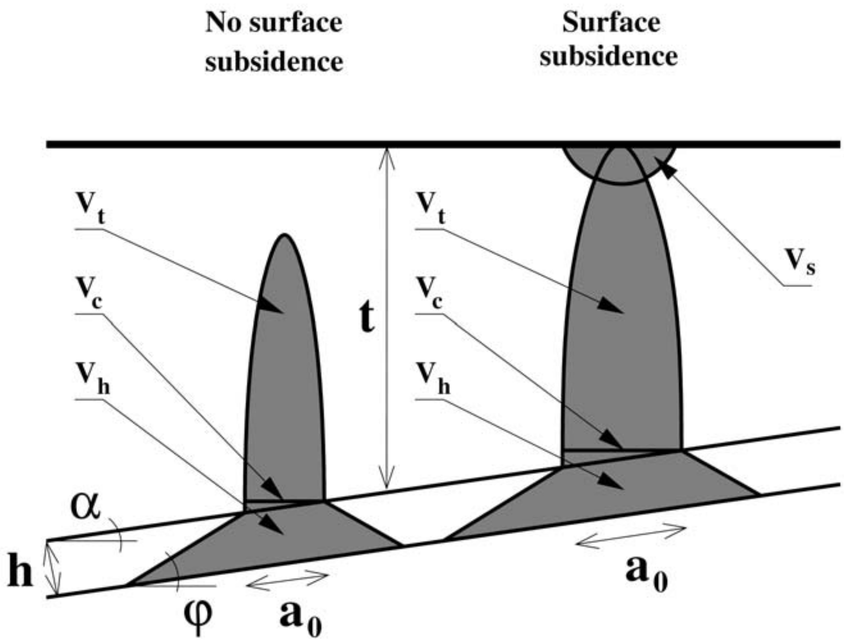

Fig. 1. Pothole surface subsidence concept

The very simple and robust theoretical concept of the failure volume balance method (FVBM) can be seen in Figure 1. In an artificial or natural void space with the height of h and inclination α, a local failure takes place on the roof over a length of a_0. The void space is filled by failing masses in the subsoil over the failure zone in the roof, where the initial volume V_h develops with a typical bulk friction angle φ. In the subsoil, a failure zone with the volume of V_c and V_t develops towards the ground surface. If the ground surface has been reached by the failure mechanism and a static equilibrium has not been reached, an additional surface failure volume V_s must be included into the volumetric balance. During the failure process, the moving and failing masses with the volume V_c, V_t and eventually V_s, the volume is increased with a material specific loosening factor s. The theoretical concept of the failure volume balance method (FSVM) is based on the governing volume conservation equation

$$V_t + V_c + V_h = s \cdot (V_t + V_c + V_s) \ , \ [m^3] \ .$$

Re-formulating the governing equation of volume conservation for the volume V_s of the pothole subsidence failure on the ground surface, the equation takes the form

$$V_s = \frac{1}{s} \cdot (V_t + V_c + V_h) - (V_t + V_c) \ , \ [m^3] \ \succeq \ 0 \ .$$

Re-arranging the terms for the condition that the volume of surface failure vanishes $V_s=0$, an equation for the minimum height of the subsoil overburden t_{min} can be derived, when no subsidence volume is expected to appear on the ground surface

$$V_t(t_{min}) = \frac{V_h}{s-1} - V_c \ , \ [m^3[\ .$$

The simple theoretical framework of the failure volume balance method (FVBM) uses only the failure length of a_0 in the void space roof, the inclination α and height h of the void space, the typical bulk friction angle φ in the subsoil, the loosening factor s, and the geometrical configuration of the failure as its input parameters.

Depending on the regarded plane or spatial geometrical configuration, different analytical concepts for the mathematical formulation of the initial failure zone in the failing void space V_h and for the volume in the failing subsoil V_c and V_t have been proposed by Meier et al. (2005) and Tamáskovics et al. (2017).

From information on the void space configuration, subsoil height over the failing void space, and observed failure volumes on the ground surface, the specific parameters of the missing material can be estimated with back calculation. With the small number of process parameters, the robustness of the method increases, since the input values can be determined with higher accuracy.

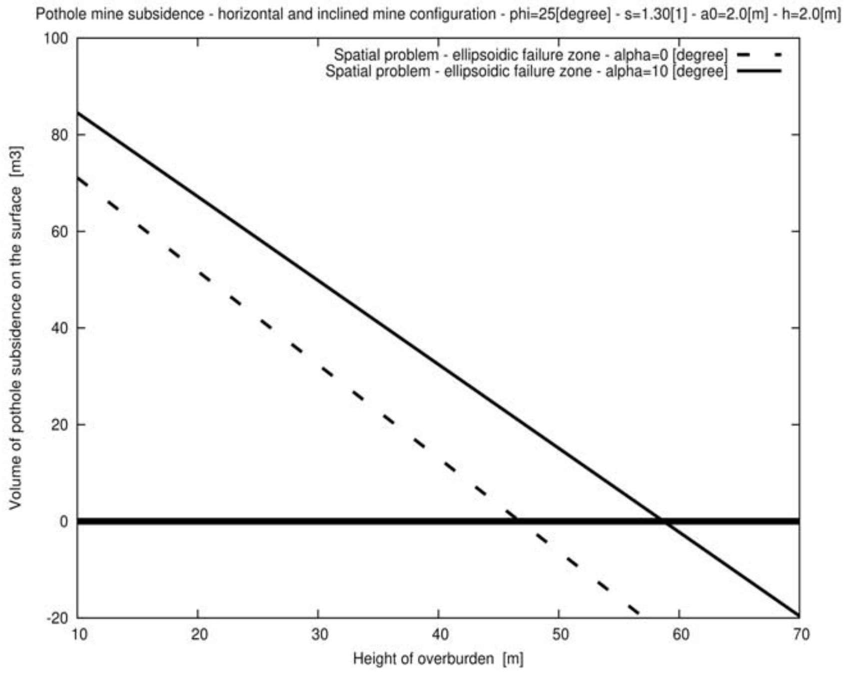

Fig. 2. Computational pothole surface subsidence prognosis

Practical application

For a practical three-dimensional case, a computational pothole mine subsidence analysis has been carried out. The friction angle for the bulk mass in the primary volume with a failing roof extension of a_0=2.0 m and a height of h=2.0 m has been assumed with φ=25°. The loosening factor for the failing volume in the subsoil with a half ellipsoid form over the primary volume with a cone frustum form has been introduced with s=1.3 [1]. The inclination of the failing void space was assumed with α=0° and α=10°.

The computational results can be seen in Figure 2. With low values for the height of the overburden t over the failing void space, a positive volume for the pothole subsidence on the ground surface V_s is calculated. Negative values mean no volume subsidence on the ground surface. The short computational analysis example clearly shows the great advantage and potential of the failure volume balance method (FSVM) for practical applications.

Summary and conclusions

Technical risk is involved in the use of sites that are either over old or active mining regions or are with natural openings in the ground, since unplanned deformations of the subsoil can lead to constraints in the constructions. The failure modes include pothole subsidence or earthfalls, when failing soil masses are displaced and loosened stepwise toward a collapsing opening in the ground. The process continues until a stable static equilibrium is reached and a further propagation of displacements is prevented.

To determine the failure probability on a given site due to pothole subsidence, it is necessary to estimate the expected subsidence volume; for this purpose, an efficient computational prognosis method is proposed that is based on simple geotechnical assumptions. In computational methods for potential pothole subsidence analysis, the emphasis is not on the time required until a failure happens but on the development of a static equilibrium that stops the further extension of the failure zone.

The simple theoretical framework of the failure volume balance method (FVBM) uses only the failure length of a_0 in the void space roof, the inclination α and height h of the void space, the typical bulk friction angle φ in the subsoil, the loosening factor s, and the geometrical configuration of the failure as its input parameters. With the small number of process parameters, the robustness of the method increases, since the input values can be determined with higher accuracy.

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