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 the determination of 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 based on simple geotechnical assumptions.

1. 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 the determination of 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 based on simple geotechnical assumptions. In computational methods for potential pothole subsidence analysis, the emphasis lays 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.

2. Computational pothole subsidence analysis

The different theoretical approaches proposed for the computational pothole subsidence analysis have been categorized by FENK,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. This assumptions are backed by the common field experience, that pothole failures typically take several decades to centuries to develop and reach the ground surface.
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 $\alpha$, 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 $\varphi$. 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 is based on the governing volume conservation equation

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

Reformulating the governing equation of volume conservation for the volume $V_s$ of the pothole subsidence failure on the ground surface takes the form

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

Rearranging 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 $t_{\text{min}}$ can be derived, when no subsidence volume is expected to appear on the ground surface

$$V_t(t_{\text{min}}) = \frac{V_h}{s - 1} - V_c, \quad [m^3].$$
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 \( \alpha \) and height \( h \) of the void space, the typical bulk friction angle \( \varphi \) 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,2005 and TAMASKOVICS,2017.

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

![Figure 2.: Computational pothole surface subsidence prognosis](image)

### 3. 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 \( \varphi=25 \) [degrees]. 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 \( \alpha=0 \) [degrees] and \( \alpha=10 \) [degrees].

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 (FVBM) for practical applications.
4. Summary and conclusions

The use of sites over old or of sites 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 the determination of 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 based on simple geotechnical assumptions. In computational methods for potential pothole subsidence analysis, the emphasis lays 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.

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 $\alpha$ and height $h$ of the void space, the typical bulk friction angle $\varphi$ 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, as the input values can be determined with higher accuracy.

References


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