NUMERICAL ANALYSIS OF TUNNEL FACE STABILITY IN NON-COHESIVE MATERIALS WITH AN INNOVATIVE CONSTITUTIVE MODEL

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1. Introduction

Tunnel face stability is generally of great concern in tunnel excavation with both traditional methods and with modern tunnel boring machines (TBMs). Several methods have been proposed in the literature for the analysis of face stability [1, 2], which are generally based on the limit equilibrium method and on different assumptions of the failure mechanisms. The major uncertainties typically concern the purely frictional materials. The aim of this work is to analyse the tunnel face stability in non-cohesive soil by employing the finite element method (FEM) with the constitutive model recently proposed by Argani & Gajo [3], and to compare the computed failure mechanisms and support forces with the results proposed in literature [1, 2].

2. Methods

FEM is employed to model the tunnel for a prescribed value of tunnel diameter $D = 6.5\,\mathrm{m}$ (circular cross-section) and overburden levels ($0.5D$, $1.2D$, and $2D$). For the sake of simplicity, the soil is assumed homogeneous and non-cohesive, for which a perfectly plastic Mohr-Coulomb yield surface with rounded corners and edges [4] is assumed as the failure criterion. In particular, to enhance the numerical convergence of such constitutive model for low mean stress states, the recent hyper-elastic formulation proposed by [3] is employed together with special line-search solution procedures. This constitutive model is implemented in a user defined subroutine for Abaqus Unified FEA [3].

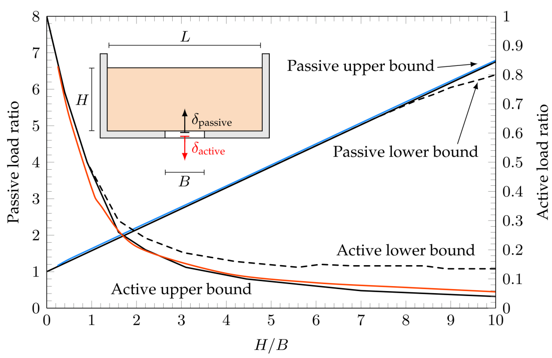

Figure 1. Reference scheme for the trapdoor problem and comparison of the limit load obtained with the Argani & Gajo [3] constitutive model with upper and lower bound solutions [5].

The performance of this numerical tool has been preliminarily validated by analysing the problem of an active and a passive trapdoor (figure 1), which involve low stress states at soil failure conditions, in an analogous manner with respect to the tunnel face stability problem. Figure 1 shows that, assuming an associative framework, the agreement of model simulations with lower and upper bound solutions of the limit analysis method is excellent.

For the tunnel face stability problem, both plane strain and full 3D frameworks are considered; a friction angle of 35° was employed for the 3D simulations, whereas different values of the friction angle (ranging from 5° to 50°) have been investigated for the plane strain framework. The length of the tunnel excavation is assumed equal to 8 m and is supported by lining elements. The domain size is taken sufficiently large to avoid any boundary effect on the development of the failure mechanism. The analysis is performed in a static regime in two ways: i) controlling the displacement of the rigid wall (representative of the cutters) supporting the tunnel face, ii) controlling the pressure distribution of the conditioned soil mixture (e.g. bentonite slurry) supporting the tunnel face.

3. Results

The failure mechanisms obtained for the tunnel face are reported in figure 2. It can be noted (figure 2 left) that a well defined plateau in the displacement vs. support pressure/support force diagram is obtained thus ensuring the formation of a well defined failure mechanism. The continuous lines in figure 2 separate the zones affected by large displacements with respect to the surroundings and thus identify the collapse mechanism. It can be noted that the computed failure mechanism compares well with the failure lines postulated in some limit equilibrium methods proposed in the literature.

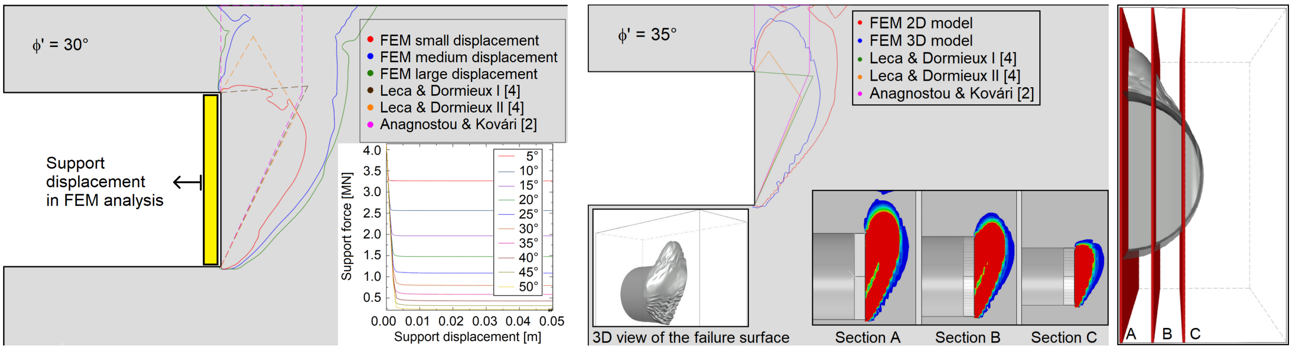

Figure 2. Results for the 2D (left) and 3D (right) modelling of the tunnel face in terms of failure mechanism and displacement-support force curves and comparison with literature results [1, 2].

Chimney formations are observed in the numerical simulations depending on the overburden level, as obtained with the limit equilibrium methods, thus leading to large subsidence at ground surface. It can be concluded that the FEM based modelling technique proposed in this study presents interesting preliminary results for the evaluation of the tunnel face stability and paves the way for more detailed analyses and a better understanding of this kind of failures.

References

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