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Theoretical and Numerical Investigations on Shallow Tunnelling in Unsaturated Soils

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Excavation of shallow tunnels with the New Austrian Tunnelling Method (NATM) requires proper assessing of the tunnel face stability, to enable an open-face excavation, and the estimation of the correspondent surface settlements. Soils in a partially saturated condition exhibit a higher cohesion than in a fully saturated state, which can be taken into account when assessing the stability of the tunnel face.
For the assessment of the face support pressure, different methods are used in engineering practice, varying from simple empirical and analytical formulations to advanced finite element analysis. Such procedures can be modified to account for the unsaturated state of soils.
In this study a method is presented to incorporate the effect of partial saturation in the numerical analysis. The results are then compared with a simple analytical formulation derived from parametric studies.
As to the numerical analysis, the variation of cohesion and of Young's modulus with saturation can be considered when the water table lies below the tunnel in a soil exhibiting a certain capillary rise, so that the tunnel is driven in a partially saturated layer. The linear elastic model with Mohr-Coulomb failure criterion can be extended to partially saturated states and calibrated with triaxial tests on unsaturated.
In order to model both positive and negative pore water pressure (suction), Bishop's effective stress is incorporated into Mohr-Coulomb's failure criterion.
The effective stress parameter in Bishop's formulation is related to the degree of saturation as suggested by Fredlund. If a linear suction distribution is assumed, the degree of saturation can be calculated from the Soil Water Characteristic Curve (SWCC). Expressions exist that relate the Young's modulus of unsaturated soils to the net mean stress and the matric suction.
The results of the numerical computation can be compared to Vermeer & Ruse's closed-form formula that expresses the limit support pressure of the tunnel face.
The expression is derived from parametric studies and predicts stability of the tunnel face when negative values are returned, suggesting that open-face tunnelling can be performed. The formula can be modified to account for the variation of cohesion along the tunnel face.
The results obtained from both the numerical analysis and the analytical formulation are well in agreement and show that the stability of the tunnel face can greatly benefit from the enhanced cohesion of partially saturated soils.