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Simplified Assessment of Swelling Loads on Underground Structures in Southern Ontario Shales

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1 INTRODUCTION

Shale formations in southern Ontario exhibit time dependent swelling after excavation that can damage underground structures [1]. Various visco-elastic/plastic constitutive models have been proposed to describe this behavior [2]. These constitutive models are, however, not included in commercially available finite element (FE) programs. This contribution presents a simple approach based on common elasto-plastic constitutive models that may be used in lieu of more complex time-dependent models for the estimation of swelling loads for design.

2 SWELLING MECHANISM

Swelling in Ontario shales is caused by a change in their pore fluid composition [2]. Cations are leached from the fluid when clay minerals are exposed to fresh water. This reduction in cation concentration increases the double layer repulsion between clay minerals & leads to a volume increase. The associated swelling strains are time & stress dependent. Free swelling strains, ε_f, occur in unconfined rock samples up to a threshold stress, σ_t, & are completely suppressed at a suppression stress, σ_c. The observed swell strain, $\varepsilon_s(\sigma,t)$, therefore decreases linearly with the logarithm of the applied stress, from free swelling at the threshold stress to no swelling at the suppression stress. Swell strain additionally increases logarithmically with time. This behavior, described in [1], is used as the basis for the proposed prediction of design swelling loads below.

3 EXISTING METHODS FOR ASSESSMENT OF SWELLING LOADS

Lo & Yuen [1] developed the first approach to estimate the effects of Ontario shale swelling on tunnels. This analytical approach is still used for initial design but is known to be conservative. Consequently, new numerical algorithms for improved prediction of swelling behavior have been proposed [2]. PLAXIS & RS2 also feature swelling constitutive models based on [3, 4], but these are not consistent with [1]. As such, practicing engineers do not have access to commercially available numerical tools for the prediction of swelling loads in Ontario shales.

4 PROPOSED METHODOLOGY

The proposed approach forgoes the use of visco-elastic/plastic constitutive models in favor of a staggered approach based on a static FE analysis. First, the stress state after excavation is determined through FE analysis in which the rockmass is modelled using a suitable elastic/plastic constiutive law (e.g. Hoek-Brown). Second, the swelling potential (swell strain/log cycle of time) is determined at every point at which the stress is under the suppression stress. The horizontal & vertical stresses should be used as swelling occurs along bedding planes & Ontario shales are horizontally bedded. The swelling potential is then integrated in time over the design life to obtain swell strains per unit length. Afterwards, the swelling potential is integrated along a distance normal to the structure's surface to obtain swell displacements. Finally, a separate "ersatz" structural model is used to determine the load distribution required to generate these swell displacements. This load may be considered as the characteristic swelling load. This process is shown in Figure 1 for a recent NATM tunnel design in Toronto.

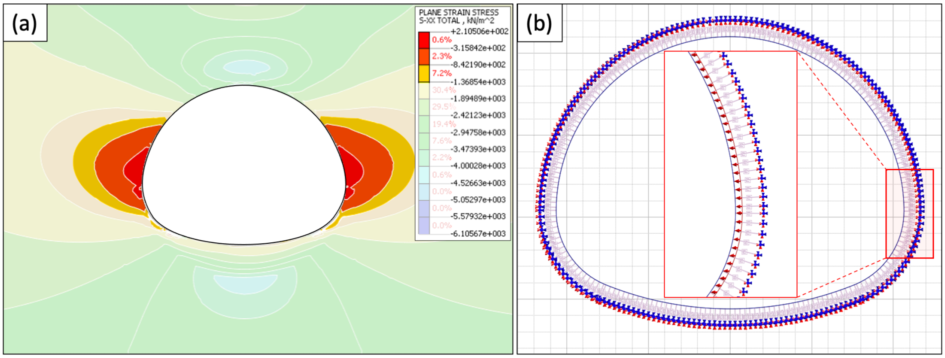

Figure 1: a) Horizontal (σ_{xx}) stresses in rockmass below suppression stress (σ_c) after tunnel excavation; b) beam-spring model of tunnel lining for calibration of equivalent swell loadings.

5 CONCLUSIONS

The proposed approach requires no specialized software to determine swelling loads & may therefore be easily applied by engineers with limited resources in early design stages. The approach is compatible with commonly used Ultimate Limit State design methodologies & it retains a degree of conservatism, as it does not account for the increased confinement of the ground due to the reaction force of the structure resisting the ground during swelling.

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