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MODELLING THE TIME BEHAVIOUR OF A TUNNEL USING A VISCOPLASTIC BOUNDING SURFACE MODEL

J. R. Maranha* and A. Vieira†

* Laboratório Nacional de Engenharia Civil (LNEC)
Av. do Brasil, 101 1700-066 Lisboa, Portugal
e-mail: jmaranha@lnec.pt

† Laboratório Nacional de Engenharia Civil (LNEC)
Av. do Brasil, 101 1700-066 Lisboa, Portugal
Email: avieira@lnec.pt

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Summary. *In order to realistically evaluate the behaviour of a tunnel in soils with creep, including problems such as long-term load transfer to the final support, a rate-dependent material model is inescapable. In this work, an elastoplastic-viscoplastic bounding surface material model, following the formulation of Kaliakin and Dafalias, is applied to the modelling of time effects in the construction and operating phases of a tunnel is saturated cohesive soils.*

1 INTRODUCTION

The motivation for this work is the question of time evolution of load in the final support of a tunnel in a saturated cohesive soil due to creep. In order to achieve this, a soil model capable of describing rate-dependent behaviour of cohesive soils is required. The elastoplastic-viscoplastic bounding surface model proposed by Kaliakin and Dafalias[1,2]. This model enhances the simplified version[3] of the model of Dafalias and Herrmann[4] by adding a viscoplastic mechanism.

2 MODEL DESCRIPTION

The bounding surface has an elliptic shape in the invariant (I,J) space. It is defined by the following expression[3]

$$F(\bar{\boldsymbol{\sigma}}, I_0) = F(\bar{I}, \bar{J}) = (\bar{I} - I_0)\left(\bar{I} + \frac{R-2}{R} I_0\right) + (R-1)^2 \left(\frac{\bar{J}}{N}\right)^2 = 0\,, \tag{1.1}$$

and represented in Fig. 1. The stress point $\boldsymbol{\sigma}$ must be inside or on the bounding surface and always has an image on it, $\bar{\boldsymbol{\sigma}}$ defined by a radial projection from a center on the isotropic axis. I_0 defines the size of the bounding surface and is the only internal variable in this model being responsible for isotropic hardening. The material constant R allows the flattening of the ellipse without moving the Critical State Line. N defines the inclination of the Critical State

Line and may vary with invariant α (Lode angle) in which case 2 constants are needed for its specification (N_c for triaxial compression and N_e for triaxial extension).

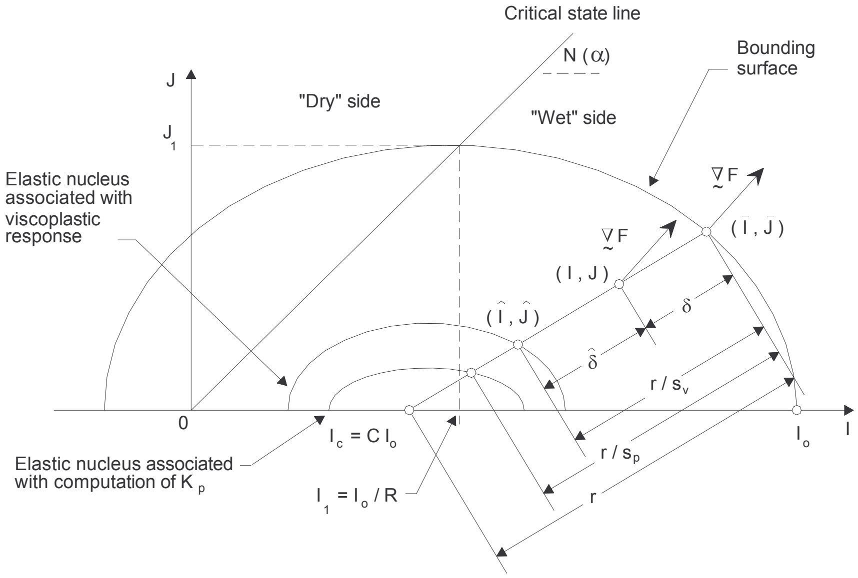

Figure 1 : Bounding surface model.

The stress invariants used are

$$I = \mathrm{tr}\,\boldsymbol{\sigma}, \qquad J = \sqrt{\mathbf{s}:\mathbf{s}/2} \quad \text{and} \quad \alpha = \sin^{-1}\left[3\sqrt{3}\det\mathbf{s}/(2J^3)\right]/3 \quad , \tag{1.2}$$

with $\mathbf{s} = \boldsymbol{\sigma} - I/3\mathbf{I}$ being the deviatoric stress. The projection operator is defined by

$$\overline{I} = b\,I + (1-b)\,C\,I_0\,, \qquad \overline{J} = b\,J \quad \text{and} \quad \overline{\alpha} = \alpha\ , \tag{1.3}$$

where C defines the projection center and b is a parameter to be determined. It varies between $b = \infty$ when the stress point coincides with the center of projection and $b = 1$ when on the bounding surface.

A basic assumption of this model is the addictive decomposition of the inelastic strain rate into an elastoplastic strain rate and a viscoplastic one,

$$\dot{\boldsymbol{\varepsilon}}^{i} = \dot{\boldsymbol{\varepsilon}}^{p} + \dot{\boldsymbol{\varepsilon}}^{v}, \quad \text{with} \quad \dot{\boldsymbol{\varepsilon}}^{p} = \langle L \rangle \frac{\partial F}{\partial \overline{\boldsymbol{\sigma}}} \quad \text{and} \quad \dot{\boldsymbol{\varepsilon}}^{v} = \langle \phi \rangle \frac{\partial F}{\partial \overline{\boldsymbol{\sigma}}}, \tag{1.4}$$

where L is the plastic multiplier, ϕ is the overstress function and the operator $\langle x \rangle = (x + |x|)/2$. The bounding function´s F stress gradient is evaluated at the image point. There are two implicitly defined surfaces associated with each of the two inelastic mechanisms. The first one defines the boundary outside which the plastic mechanism may be active (in the loading case when L>0) and is specified by the constant s_p such that on this surface $b = s_p/(s_p - 1)$. The second one defines the boundary outside which viscoplastic strain occurs, is defined by constant s_v and on this surface $b = s_v/(s_v - 1)$. The overstress function that controls the magnitude of the viscoplastic strain rates is measured relative to this surface (see Fig. 1) and is given by

$$\phi = \frac{1}{V}\exp\left(\frac{J}{NI}\right)\left(\frac{\hat{\delta}}{r - r/s_v}\right)^n . \quad (1.5)$$

The plastic modulus K_p used in the evaluation of the plastic multiplier L is interpolated from the one evaluated at the bounding surface $\bar{K}_p$ that is determined by invoking the plastic consistency condition of the image point so that it makes a monotonous decreasing transition from $K_p = \infty$ at the s_p surface to $K_p = \bar{K}_p$ at the bounding surface. The interpolation function[3] was modified to

$$\hat{H} = \frac{1+e_0}{\lambda - \kappa}\left(10\,p_a\right)^3\left[h(\alpha)\,z^{0.02} + h_0(1 - z^{0.02})\right]f , \quad (1.6)$$

in order to have dimensional consistency and so that the constants h_c and h_e are dimensionless.

An explicit numerical integration algorithm of the model was implemented in the FLAC explicit finite difference code. The explicit approach was chosen because of the explicit nature of the code that requires very small time steps to maintain stability.

3 OEDOMETRIC TEST

Before applying the model in a boundary value problem it is important to assess its behaviour under homogeneous stress/strain tests. The algorithm implemented in the FLAC program was used to model an oedometric test, with unloading/reloading cycles, of a material with the material constants calibrated for samples of San Francisco Bay Mud[2].

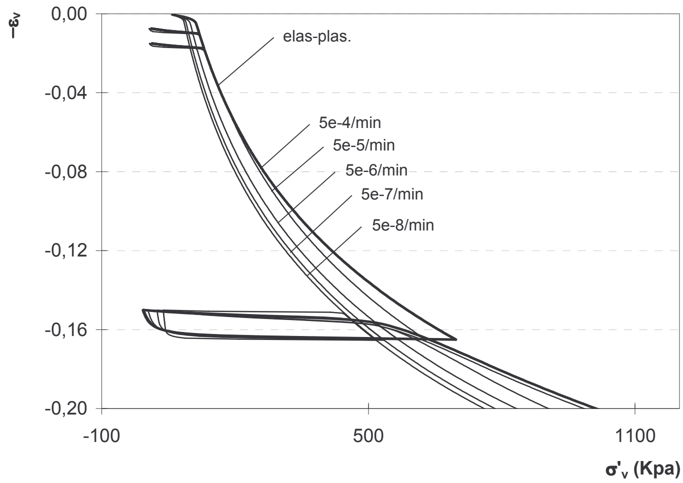

Figure 2 : One dimensional compression response computed with different strain rates.

The computed response using different strain rates can be observed in Fig. 2. For large strain rates the response approaches that of the elastoplastic only material. The response stress-strain curve tends to an inferior limit (in terms of stress) with the reduction of the strain rate.

4 TUNEL CREEP

The construction and 1 year of operation of a tunnel were simulated using FLAC. The tunnel has a circular cross-section with 10m diameter and has 20m cover. It is built in a soil having similar characteristics to those of SF Bay Mud[2]. The water level coincides with the ground level and the soil is saturated. The value assumed for K_0 is 0.43. It is also assumed that the ground before the construction of the tunnel is in a state of equilibrium and no creep is taking place. As such the field of I_0 values is computed so that the initial effective stress is on the creep boundary defined by the constant s_v. This is equivalent to apparent overconsolidation due to creep. It is considered that the tunnel is built using a TBM. The analysis is plane strain and the stress relief is gradually applied in 10 days. The lining is activated after 30% stress relief. Undrained conditions are assumed so that only the effect of creep takes place. Some results are presented in Fig. 3.

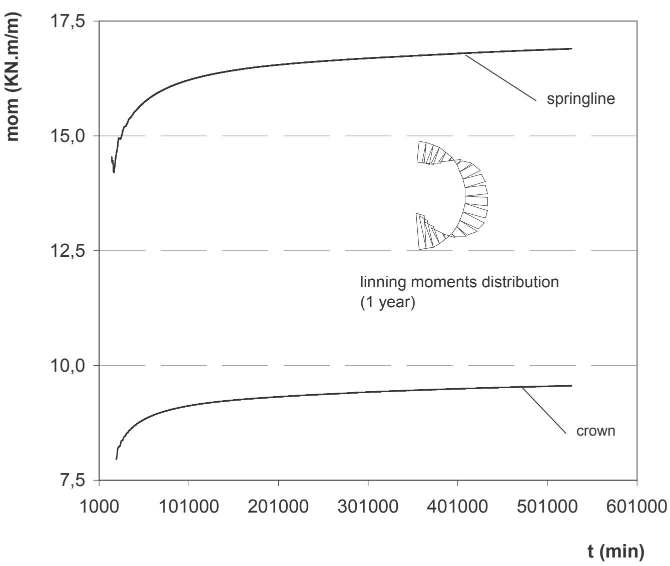

Figure 3 : Lining moments evolution after construction.

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