ON MODELING OF TIME-DEPENDENT BEHAVIOUR OF SOILS

T. Nakai[1], H.M. Shahin[2] and H. Takahashi[3]
[1] Geo-Research Institute, Nagoya, Japan
[2] Islamic University of Technology, Dhaka, Bangladesh
[3] JIP Techno Science, Osaka, Japan

A simple method to describe time-dependent behavior of various soils in 3D stress conditions is presented. In the previous model, the soil behavior was reliably captured using the t_{ij} concept [1], and the influence of density, confining pressure and structured behavior of naturally deposited soils was described using the subloading surface concept [2] and incorporating the effects of bonding [3, 4]. In the present model, the time-dependent properties are accounted for within the framework of subloading surface by considering the experimental fact that the normal consolidation line (NCL) shifts with strain rate. The approach does not use viscoplasticity, and only the coefficient of secondary consolidation is added as a parameter. In this work, the implicit formulation of the model is presented and the numerical examples involving undrained tests are provided.

1. Formulation of the model and numerical simulations of undrained shear tests

Figure 1 shows the yield function (f=0) and two kinds of plastic strain increments (*i.e.*, a component shown in red which satisfies the associated flow rule in t_{ij} space, and the one shown in blue arrow which is an isotropic component). To consider 3D effect appropriately, the yield function is formulated using stress invariants (t_N and t_S) based on the t_{ij} concept instead of usual (p and q), and the flow rule is assumed not in σ_{ij} space but in t_{ij} space. To account for the stress path dependency of strain increments, the plastic strain increments are expressed by the summation of the component satisfying the associated flow rule and the isotropic component.

Figure 2 shows the NCL line and the actual void ratio in the e – ln t_{N1} relation (t_{N1}: the value on t_N axis of the yield surface) at the initial state (denoted by subscript 0) and the current state. Here, NCL shifts with strain rate, and the amount of shift (ψ - ψ_0) is determined from the well-known secondary consolidation coefficient (λ_α) as shown in the interpolation diagram. The variable ρ implies difference between the actual void ratio and the void ratio on NCL for the same stress level. The variable ω is an imaginary increase in void ratio for describing the bonding effect of structured soil. Evolution rules of ρ and ω are defined by monotonically decreasing functions of plastic strain.

The return mapping equations of the model are expressed as

$$\begin{cases} \bullet\ \mathbf{b}_1 = \boldsymbol{\varepsilon}^e - \boldsymbol{\varepsilon}^{e(trial)} + \Delta\gamma\mathbf{N} - L^{(IC)} \ln\dfrac{t_N}{t_{N,n}}\left(\dfrac{\mathbf{N}}{\mathrm{tr}\mathbf{N}} - \mathbf{N}^{(IC)}\right) = 0 & (1) \\ \bullet\ b_2 = \rho - \rho_n - \Delta\gamma\left\{-(1+e_0)\sqrt{3}\,\dfrac{a\rho/(1+k_a X) + b\omega/(1+k_b X)}{t_N}\right\} + \boxed{\psi - \psi_n - \Delta\psi} = 0 & (2) \\ \bullet\ b_3 = \ln\dfrac{t_N}{t_{N0}} + \varsigma(X) - \dfrac{1+e_0}{\lambda-\kappa}\left\{\varepsilon^p_{v,n} + \Delta\gamma\mathrm{tr}\mathbf{N}\right\} - \dfrac{1}{\lambda-\kappa}\left\{(\rho_0-\rho) + \boxed{(\psi_0-\psi)}\right\} = 0 & (3) \end{cases}$$

where $\mathbf{N}=\partial f/\partial \boldsymbol{t}$, $X=t_S/t_N$. Superscripts (IC), e and p represent the isotropic component, and elastic and plastic components, respectively, while $\Delta\gamma$ is the plastic multiplier. The terms added to account for time-effect characteristics are enclosed in blue dashed lines in the above equations. The shift (ψ - ψ_0) is expressed as a function of the rate of equivalent plastic void ratio $(-\dot{e})^p_{(equ)}$

$$\psi - \psi_0 = -\lambda_\alpha \ln\left((-\dot{e})^p_{(equ)} \big/ (-\dot{e})^p_{(equ)0}\right) \qquad (4)$$

Figures 3 and 4 show (a) stress-strain curves, and (b) effective stress paths in undrained shear tests with varying strain rates on normally consolidated clay and structured clay. In these figures, black solid lines show the result without time effect, and blue curves show the results with time effect.

The model can describe the strain rate effects including isotach and the change in shape of effective stress path for structured clay.

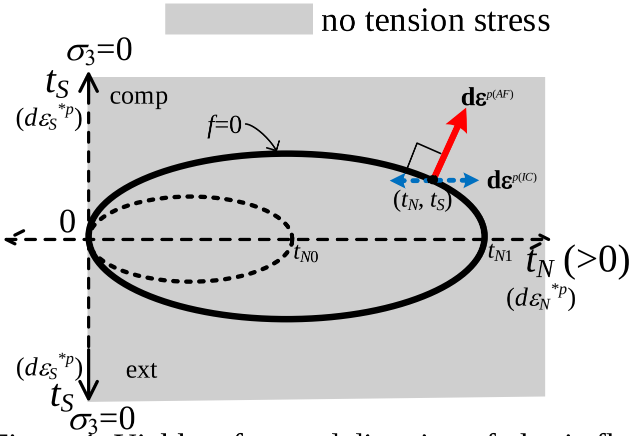

Figure 1. Yield surface and direction of plastic flow

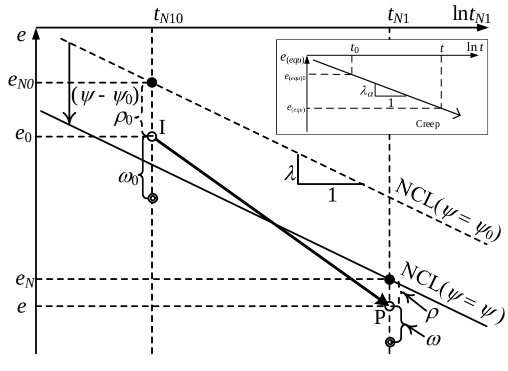

Figure 2. $e - \ln t_{N1}$ relation

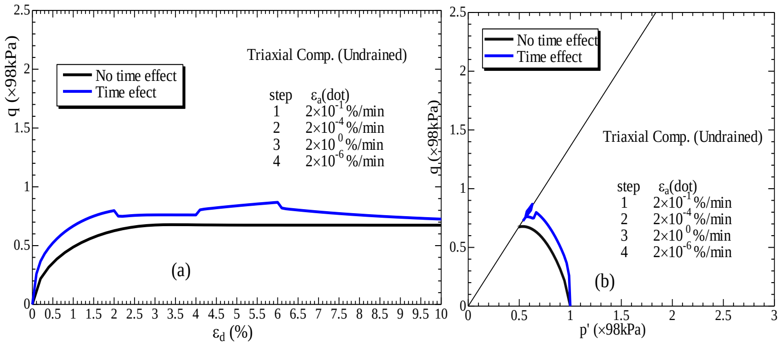

Figure 3. Simulation of normally consolidated clay

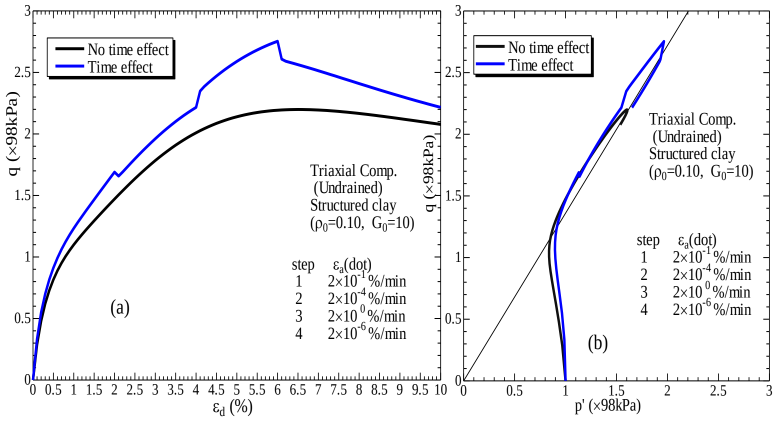

Figure 4. Simulation of structured clay

2. References

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