Ⅲ－8 **A Finite-element Analysis for a Cut Slope Unifying Swelling and Softening Effects**

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1. Introduction

Failure of a cut slope in stiff over-consolidated clays may be delayed primarily due to the equilibration of pore water pressure [1](swelling effect) and the strength deterioration [2] (softening effect). The swelling effect may last several years or decades after excavation, which depends on the permeability of the soils, and softening effect may last longer. To some extent, the two effects can not be separately considered in analyzing the stability of a cut slope.

An attempt is made in this paper to take into account both swelling and softening effects by proposing a coupled finite element analysis approach. In the simulation of dissipation of pore water pressure, a three-phase unsaturated model is employed. The softening process may be formulated in terms of a time-dependent yield surface.

Finally a cut slope is analyzed as an example. The results indicate that the proposed method has the potential to deal with both swelling and softening behavior.

2. Softening effect

Fissured, over-consolidated clays tend to soften with time due to water absorption upon unloading. It is understandable from Fig.1 that the clay, when experiencing softening, shows smaller shear strength and less tendency to dilate [4]. With the decrease of the shear strength, the yield surface shrinks from initial one to fully softened one (see Fig.2).

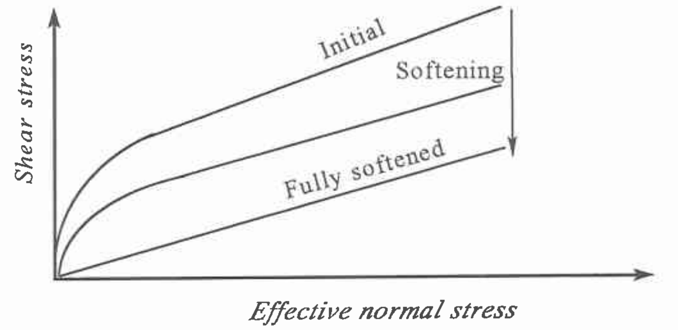

Fig.1 Shear strength reduction due to softening (after Yoshida *et al* 1991)

3. Finite element formulations

The finite-element method follows the conventional coupled elasto-plastic formulations. The governing equations [3] were derived by Schrefler *et al* (1990) and modified by the authors, which can be applied to unsaturated problems. The semi-discritized equations are given here:

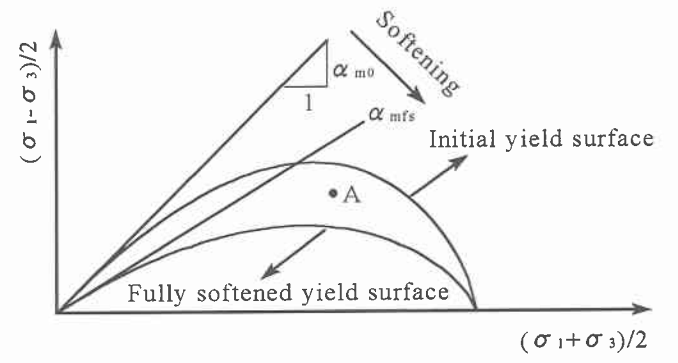

Fig.2 Yield surface and its variation during softening

$$\underline{K}\dot{\underline{u}} + \underline{C}_{sw}\dot{\underline{p}}_w = \dot{\underline{F}}_s + \dot{\underline{F}}_y \quad (1)$$

$$\underline{C}_{ws}\dot{\underline{u}} + \underline{P}_{ww}\dot{\underline{p}}_w + \underline{H}_{pp}\underline{p}_w = \dot{\underline{F}}_w \quad (2)$$

where

$$\dot{\underline{F}}_y = \int_\Omega \frac{[B]^T\left[D^e\right]\left\{\frac{\partial F}{\partial \sigma}\right\}\frac{\partial F}{\partial t}}{H + \left\{\frac{\partial F}{\partial \sigma}\right\}\left[D^e\right]\left\{\frac{\partial F}{\partial \sigma}\right\}} d\Omega$$

Owing to the limited space, we refer to literature [3].

The computational procedure of solving equations (1) and (2) may be briefly expressed as follows: An element where

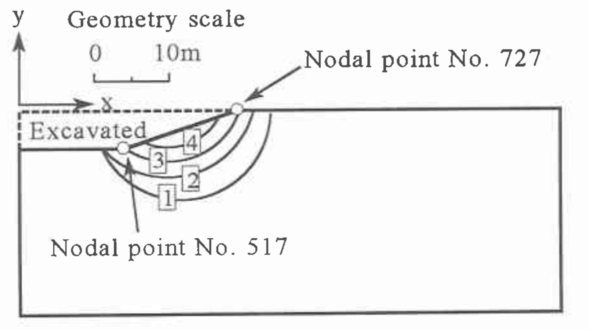

Fig.3 Analysis region and the assumed slip surfaces

negative pore-water pressure is evaluated at the end of excavation is registered as a "softening potential" element which will undergo softening later. Then swelling process develops, during this process, the pore-water pressure in a "softening potential" element may reach zero. For this element, softening starts: the shear strength reduction is computed. If existing stress points violate the new yield condition (e.g. in Fig.2 point A violates fully softened yield surface), load vectors due to this overshooting are also computed (the second term in the right hand of eq. (1)).

4. *Example problem*

The finite-element analysis here deals with a cut slope excavated step by step as shown in Fig.3.

The boundary condition for displacement is that there are only horizontal restriction at two sides, and both horizontal and vertical restrictions on bottom side. Impervious boundary condition for pore water pressure is assumed on the whole boundary surfaces. Air pressures are assumed to remain atmospheric pressure in all unsaturated zones.

The material parameters are summarized in Table 1.

Table 1 Material parameters

c_s	c_c	$\alpha_{m0}(\alpha_{mfs})$	α_0
0.0042	0.0404	1.02(0.7)	0.65
c_a	k_x=k_y (m/s)	K_0	γ (KN/m^3)
0.01	3.5×10^{-9}	0.68	19.2

5. *Results and conclusions*

Fig.4 and Fig.5 show the variations with time in horizontal and vertical displacements, respectively. It can be seen that the displacements develop gradually with time due to swelling and softening. The displacements of point 517 develop faster than those of point 727 do. This indicates that there is more influence of softening at toe than at crest of the slope.

The influence of softening can also be demonstrated through the results of time dependent factors of safety. The factors of safety are evaluated here based on ϕ u=0 analysis[5]. It can been seen from Fig.6 that the softening effect is limited to the shallow slips (slips 3 and 4).

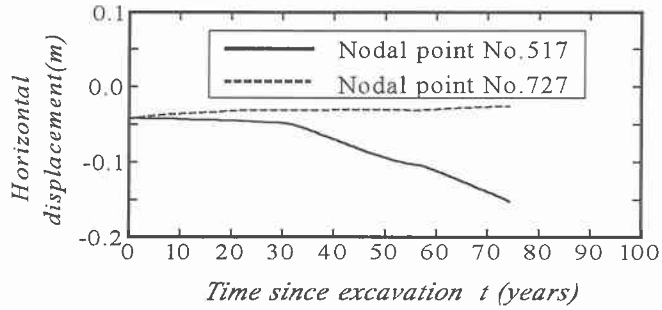

Fig.4 Variation with time in horizontal displacement

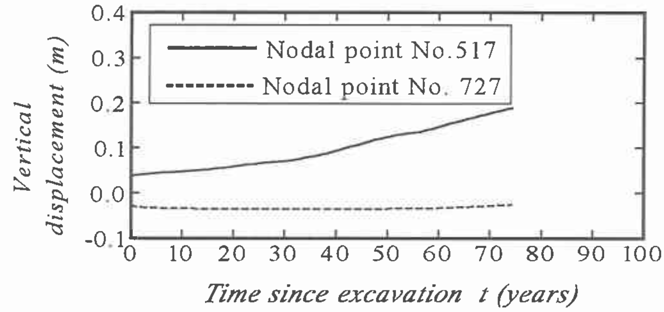

Fig.5 Variation with time in vertical displacement

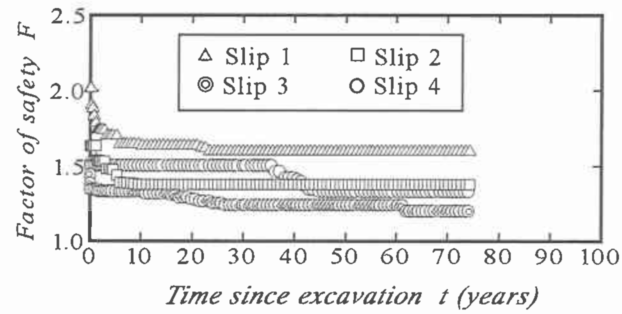

Fig.6 Variation with time in factor of safety

References:

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