Ⅲ－A229 A FE Viscoplastic Consolidation Analysis with Finite Deformation Theory

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1. INTRODUCTION

It is known that most of soils are rate sensitive materials and small strain theory commonly used in FE analysis is of some limits to describe the progressive failure of soils. It is also known that most of practical engineering should be considered as 3-dimensional problem. Here in this presentation is presented a consolidation analysis using 3-D FE program with viscoplastic models and finite deformation theory developed recently by the authors.

2. VISCOPLASTIC MODELS AND FINITE DEFORMATION THEORY

Since the material time derivative of Cauchy stress is not objective, Jaumann rate of Cauchy stress is used in the constitutive laws for elastic deformation rate.

2.1 Original Adachi-Oka model (1982)

A generalized viscoplastic model for normally consolidated clay was firstly proposed by Adachi and Oka (1982). Based on the model, viscoplastic deformation ratio in the field of finite strain field is expressed as the following.

$$D_{ij}^{vp} = \gamma\langle\phi(F)\rangle\frac{\partial f}{\partial T_{ij}^{'}}, \quad \langle\phi(F)\rangle = \begin{cases} 0 & (F \le 0) \\ \phi(F) & (F > 0) \end{cases}, \quad F = \frac{f - k_s}{k_s} \tag{1}$$

$$\gamma\phi(F) = M^* T_m^{'} C_N \exp\left\{ m_N^{'}\left(\frac{\eta^*}{M^*} + \ln\left(\frac{T_m^{'}}{T_{my}^{'}}\right) - \frac{1+e}{\lambda-\kappa}v^p \right)\right\}, \quad v^p = \int D_{ii}^{vp} dt \tag{2}$$

Where. D_{ij}^{vp}, $T_m^{'}$ is the viscoplastic deformation rate tensor and mean effective Cauchy stress. λ, κ, M^*, e C_N, $T_{my}^{'}$, $m_N^{'}$ are the compression index, the swelling index, the deviatoric stress ratio at failure, the void ratio, and the three rate-sensitive parameters. $\eta^* = (\eta_{ij}^*, \eta_{ij}^*)$. $\eta_{ij}^* = S_{ij} / T_m^{'}$. S_{ij} is the deviatoric stress. t is the time. v^p is the volumetric viscoplastic strain. f, k_s are dynamic yield function and hardening parameter respectively.

2.2 Adachi-Oka model with strain-softening factor (1987)

To describe the acceleration creep behavior of clay, Adachi et al (1987) and Oka et al (1994) introduced a second material function into the model. The $\gamma\langle\phi(F)\rangle$ in the Eq. (2) is replaced with $\gamma\langle\phi_1(F)\rangle\phi_2(\xi)$, where,

$$\phi_2 = 1 + \xi \quad , \quad \dot{\xi} = \frac{M^{*2}}{G_2^*\left(M^* - \eta^*\right)^2}\dot{\eta}^* \tag{3}$$

where, G_2^* is the parameter to describe strain softening.

2.3 Viscoplastic model with second order gradient of viscoplastic strain (1991)

In order to consider non-local effect of formation of shear band, Oka et al (1991) introduced the second order gradient of volumetric viscoplastic strain into the constitutive model. The yield function including the term is expressed as follows

$$f - k_s = \frac{\eta^*}{M^* T_m^{'}} + \ln\frac{T_m^{'}}{T_{my}^{'}} - \alpha_3 \Delta v^p = 0 \tag{4}$$

where, α_3 is the parameter related to second order gradient of viscoplastic strain.

3. NUMERICAL ANALYSIS

Based on the viscoplastic models and Biot's two-phase theory, a 3-D FE program has been developed with the updated Lagrangian method. Displacement is defined at 20 nodes and pore pressure is defined at 8 corner nodes. In this paper we have carried out the consolidation analysis of a simple, 20m thick clay ground. Only the upper surface is permeable and ten elements with the same size are used for the analysis. The load is applied in 6 steps with each step of load as 0.1 kgf $/cm^2$. In Table 1 is listed the model parameters used in the analysis. Focus is put on the effect of parameter $G_2^{'}$ and α_3.

Table 1 Model parameters used in numerical analysis

C_N	$m_N^{'}$	M^*	k_x	k_y	k_z	$T_{my}^{'}$	K_0	λ	κ	G	e_0	α_3			G_2^*		
1/d	10^{-8}		m/d 10^{-2}	m/d 10^{-2}	m/d 10^{-2}	kgf/ cm^2				kgf/ cm^2		m^2			kgf/ cm^2		
21.5	4.5	1.05	1.16	1.16	1.16	1.0	1.0	0.372	0.054	132	1.28	-1.0	0.0	1.0	10	100	1000

Fig.1 shows the relationship between settlement and time with finite deformation theory computed by the 3-D FE

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program, where the result computed by 2-D FE program (Oka et al 1991) is also shown. In Fig.2 is shown the stress path of element 5 at the depth of 9 m for the all cases. In Fig.3 and Fig.4 are shown the relationships of settlement vs. time with different G_2^* and different α_3 respectively. In the case of $\alpha_3=0$, viscoplastic strain is evaluated at 8 Gaussian points of element, while in other cases the strain is evaluated at 20 nodes of element In Fig.5 and Fig.6 are shown the relationships of pore water pressure vs. time at element 5 with different G_2^* and different α_3 respectively.

4. CONCLUSIONS AND DISCUSSIONS

Based on finite deformation theory, Adachi-Oka models, and Biot's two-phase theory, a 3-D FE program has been developed with updated Lagrangian method. The consolidation analysis of a simple clay ground shows that:

(1) A little difference may occur between 3-D & 2-D analyses in some case due to higher order gradient of viscoplastic strain defined with different nodes, i.e. 8 nodes for 2-D and 20 nodes for 3-D cases.

(2) Parameter G_2^* has little influence on the relationships of settlement vs. time, and pore water pressure vs. time. This is because the stress states are far from failure states.

(3) In the case of $\alpha_3=0$, settlement is 10% larger at the time of 30000 day than those in other cases. When $\alpha_3=-1.0$, a phenomenon of increasing of pore pressure is found at the time of 100 day and then go down to the other curves with the time, which is in a agreement with the instability structure pointed by Oka et al (1991).

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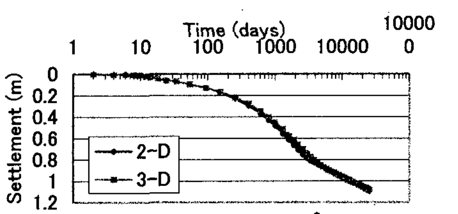

Fig.1 Settlement vs. Time (G_2^*=10.0, α_3=1.0)

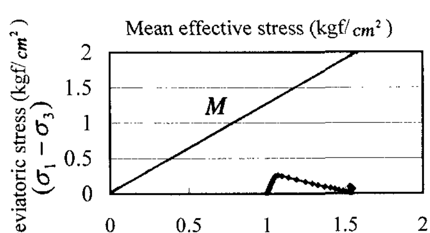

Fig.2 Stress Path of Element 5

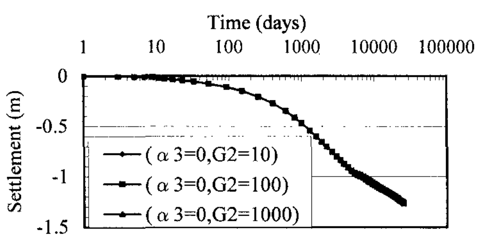

Fig.3 Settlement vs Time with Different G_2^*

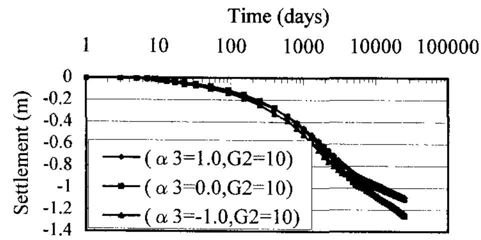

Fig.4 Settlement vs. Time with Different α_3

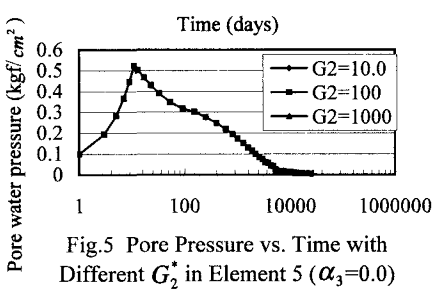

Fig.5 Pore Pressure vs. Time with Different G_2^* in Element 5 (α_3=0.0)

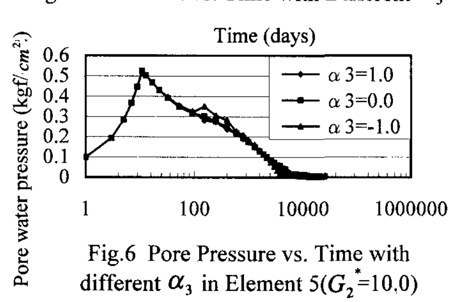

Fig.6 Pore Pressure vs. Time with different α_3 in Element 5(G_2^*=10.0)