Juan
Department of Geotechnical Engineering, Tongji University
Laboratory of Geotechnical and Underground Engineering of Ministry of Education
Shanghai, China
e-mail: ...1406@163.com

Department of Geotechnical Engineering, Tongji University
Laboratory of Geotechnical and Underground Engineering of Ministry of Education
Shanghai, China
e-mail: yuanjuyun@tongji.edu.c

***Abstract*—There** ...

***Keywords*—different constitutive model; Laplace transform;**

INTRODUCTION

ABAQUS ... a ... advanced large-... finite element software in the world, possesses the computing and extensive element ... and it has a large number of different element models, material models and analysis procedures ... It is good on nonlinear analysis ... world ... The elastic effect ... premises ... models ... series-parallel ... between elastic (hooke body) and viscous element (Newton body). For example, the Maxwell model is an elastic element in series with viscous element (N); the Kelvin model is an elastic element in parallel with viscous element ... the model ..., the H-K model ... three parameters model), Thomson model ... four parameters ... model (Burgers model) ... to prony series form of relaxation modulus ... called by ABAQUS directly. ...

EQUATION PRONY

element(H)

H-K(Merchant H-M(Poyningbe expressed as (3): Then use Laplace transform (the initial values are 0).

$$\bar{P}_{(s)}\,\bar{\sigma} = \bar{Q}_{(s)}\,\bar{\varepsilon} \qquad (2)$$

In order to obtain the relaxation modulus, put the constant strain ε_0 in Laplace transform, then $\bar{\varepsilon} = \varepsilon_0 / s$, the relaxation modulus $Y_{(t)}$ is:

$$Y_{(s)} = \frac{\bar{Q}_{(s)}}{s\,\bar{P}_{(s)}} \qquad (3)$$

B. Convert Burger model into Prony series form of relaxation modulus

Burger model is a body in series with Kelvin body which is shown in Fig.1.

Fig.1 Burger model

The constitutive relation of Burger model:

$$\sigma + p_1\dot{\sigma} + p_2\ddot{\sigma} = q_1\dot{\varepsilon} + q_2\ddot{\varepsilon} \qquad (4)$$

As p_1, p_2, q_1, q_2 is expressed by elastic modulus, then

$$p_1 = \frac{\eta_M E_M + \eta_M E_K + \eta_K E_M}{E_M E_K},\quad p_2 = \frac{\eta_M \eta_K}{E_M E_K} \qquad (5)$$

$$q_1 = \eta_M,\quad q_2 = \frac{\eta_M \eta_K}{E_K}$$

Take shear modulus expressed as the three dimensional forms, $E_M = 2G_M$, $E_K = 2G_K$, $\eta_M = 2\eta'_M$, $\eta_K = 2\eta'_K$, so

$$p_1 = \frac{\eta'_M G_M + \eta'_M G_K + \eta'_K G_M}{G_M G_K},\quad p_2 = \frac{\eta'_M \eta'_K}{G_M G_K}, \qquad (6)$$

$$q_1 = 2\eta'_M,\quad q_2 = 2\frac{\eta'_M \eta'_K}{G_K}$$

Where:

$$G_M = \frac{E_M}{2(1+\mu_M)},\quad G_K = \frac{E_K}{2(1+\mu_K)}, \qquad (7)$$

$$\eta'_M = \frac{\eta_M}{2(1+\mu_M)},\quad \eta'_K = \frac{\eta_K}{2(1+\mu_K)}$$

We take no account of the deformation of viscoelastic bulk, where $\mu_K = \mu_M = 0.5$.

Convert Burger model in Laplace transform,

$$\bar{E}_{(s)} = \frac{q_1 s + q_2 s^2}{s(1 + p_1 s + p_2 s^2)} = \frac{1}{p_2}\Big\{\Big[\frac{q_1}{(s+\alpha)(\beta-\alpha)} + \frac{q_1}{(s+\beta)(\alpha-\beta)}\Big]$$

$$+\Big[\frac{q_2\alpha}{(s+\alpha)(\beta-\alpha)} + \frac{q_2\beta}{(s+\beta)(\alpha-\beta)}\Big]\Big\} \qquad (8)$$

where

$$\alpha, \beta = \frac{p_1 \mp \sqrt{p_1^2 - 4p_2}}{2p_2}$$

The Laplace inverse transform is applied to the last expression,

$$Y_{(t)} = \frac{1}{p_2(\beta-\alpha)}\Big[\Big(\alpha - \frac{q_1}{q_2}\Big)\cdot e^{-\alpha t} + \Big(\frac{q_1}{q_2} + \beta\Big)\cdot e^{-\beta t}\Big] \qquad (9)$$

Shear relaxation modulus is required in ABAQUS, and engineering shear strain is used, substituting equation (7) into (9), so

$$G_{(t)} = \dots \qquad (10)$$

Shear relaxation modulus can be expressed by prony series form.

$$G_{(t)} = G_\infty + \sum_{i=1}^{n} G_i \cdot e^{-t/\tau_i} \qquad (11)$$

By (10), the series are expanded into two items:

$$G_{(t)} = G_\infty + G_1 e^{-t/\tau_1} + G_2 e^{-t/\tau_2} \qquad (12)$$

Compare (10) and (12), so

$$\dots \qquad (13)$$

and g_i is the normalized modulus in ABAQUS, that is, $g_i = G_i / G_0$, so

$$\dots \qquad (14)$$

$E_M, \mu_M, g_1, g_2, \tau_1, \tau_2$ are parameters of Burger's model which can be used in ABAQUS.

C. Merchant model

One-dimensional Merchant model is constituted as shown in Fig.2.

Fig.2 Merchant model

stress relaxation and analytic calculation of the three models shown in Fig.6. Burgers model has stress relaxation but stress decreases with increase of time. Merchant model and Poynting-Thomson model have relaxation property but stress approach stable level with the increase of time. As can be seen from Fig.5, analytic calculation for stress relaxation of the three models are consistent with numerical solutions.

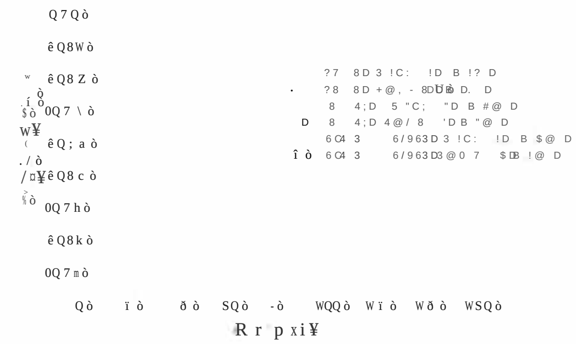

Fig.5 Comparison of axial strain between analytical and numerical result

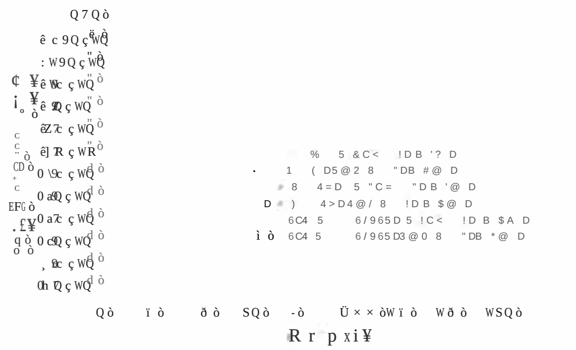

Fig.6 Comparison of axial stress between analytical and numerical result

IV. !1#&1 6(1#n362+ <n

The pile cap's height of bridge foundation is 8.5m, the depth of pile caisson is 46.5m, the wall thickness of caisson foundation is 4m, external diameter D=6m, internal diameter d=4.4m, and the wall thickness is 0.8m. The calculated loads are shown in Fig.7. The downward vertical force is considered, moment along the longitudinal direction of bridge, and horizontal force in positive direction of bridge. The finite element computation models of soils, open caisson and pile cap are shown in Fig.8(a) and Fig.8(b), the x coordinate is longitudinal direction, y coordinate is the width direction, the z coordinate is the vertical direction. Half of the structure is calculated for symmetry. Eight-node linear hexahedral element is used in soils, open caisson and pile cap, and the element number of the half finite element model is 13000. The linear viscoelastic model is used for the soils and the elastic model is used for caisson and pile. The calculation parameters are listed in Table

	Fine sand	Gravel	Caisson	Pile
(MPa)	30	150.0	20000	32500
	0.3	0.25	0.20	0.20
(10^8 MPa.s)	1.38	-	-	-
γ (kN/m^3)	9.20	11.0	16.0	15.0

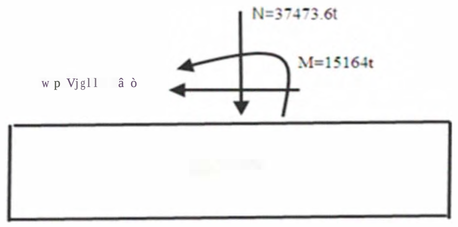

Fig.7 Graph of calculated loads

9

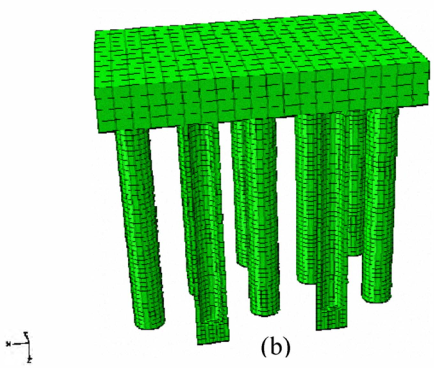

Fig.8 Mesh of finite element (soils, pile cap and caisson)

Figure 9(a), 9(b) are the caisson and pile cap horizontal and vertical displacement without considering creep, the maximum horizontal displacement is 6.79cm. Fig.10(a), 10(b) are the horizontal and vertical displacement considering creep, the maximum viscoelastic horizontal displacement is 20.1cm. As the overall rigidity of pile cap is greater, the horizontal displacement of pile cap is essentially symmetry. Taking account of creep, the horizontal and vertical displacement of pile cap and caisson shown increase greatly.