Application of Adaptive Time Steps in the Settlement Analysis of Local Material - Applying to DakYen dam in Vietnam

Quang Hung Nguyen, Hoang Hung Vu

Abstract: Accuracy improvement the and convergence of the solution of finite element problems are of interest to many scientists. The Biot consolidation theory is used to investigate the adaptive time steps in the construction process, water accumulation and operation of local material dams which is designed according to Cam-Clay material model. From the principles of Biot consolidation theory, basing on energy errors control to provide time steps to control effective stress field as well as pore water pressure in the body and foundation dam. The investigation is very significant for the construction of local material dams, especially for dams using embankment material with high clay content such as DakYen dam in Vietnam.

Keywords: Adaptive time steps, Error control, Local material dams, DakYen dam.

I. INTRODUCTION

During the construction process as well as during the reservoir process, the dam is always subject to variable load. Under the effect of external load, stresses in soil particles as well as stresses in water in the soil are constantly changing. This change completely depends on the dispersion of water pressure in the pore. Finally, overcoming the stable permeability pressure, the water pressure in the pore gradually diminishes. The external load is also gradually transferred to the soil particles resulting in soil being compressed to a stable level. This whole process is called consolidation. The purpose of the coherent analysis process is to understand the variability of the permeability process as well as the pore pressure in the dam and the sticky substrate. At the same time, it is also possible to understand the time settlement process of the dam and ground. This issue is very significant in assessing the stability of dams and ground [1]

II. THEORY

A. Biot consolidation equation

The basic assumption of the Biot theory [2-4], [9]:
Apart permeability, the soil properties is homogeneous isotropic, permeable soil properties do not change over space and time, regardless of inertial forces.

(1) Balance equation

For homogeneous soil isotropic, combines the equilibrium equation and the effective stress principle obtained:

$$\begin{cases} d_1\dfrac{\partial^2 u}{\partial x^2}+d_3(\dfrac{\partial^2 u}{\partial y^2}+\dfrac{\partial^2 u}{\partial z^2})+(d_2+d_3)(\dfrac{\partial^2 v}{\partial x\partial y}+\dfrac{\partial^2 w}{\partial x\partial z})-\dfrac{\partial p}{\partial x}=0 \\ d_1\dfrac{\partial^2 v}{\partial y^2}+d_3(\dfrac{\partial^2 v}{\partial x^2}+\dfrac{\partial^2 v}{\partial z^2})+(d_2+d_3)(\dfrac{\partial^2 u}{\partial y\partial x}+\dfrac{\partial^2 w}{\partial y\partial z})-\dfrac{\partial p}{\partial y}=0 \\ d_1\dfrac{\partial^2 w}{\partial z^2}+d_3(\dfrac{\partial^2 w}{\partial y^2}+\dfrac{\partial^2 w}{\partial x^2})+(d_2+d_3)(\dfrac{\partial^2 u}{\partial z\partial x}+\dfrac{\partial^2 v}{\partial z\partial y})-\dfrac{\partial p}{z}=0 \end{cases} \quad (1)$$

Where:

$$d_1=E_s$$
$$d_2=\frac{\mu}{1-\mu}E_s$$
$$d_3=\frac{E}{2(1+2\mu)} \quad (2)$$
$$E_s=\frac{E(1-\mu)}{(1+\mu)(1-2\mu)}$$

u, v, w are displacements on the x, y and z axes respectively.

p: pore pressure.

(2) Continuous equation

Continuous equation

$$\frac{1}{\gamma_w}[k_h(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}+\frac{\partial^2 p}{\partial z^2})]=\frac{\partial}{\partial t}(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}) \quad (3)$$

Where:
$\gamma_w=\rho_w g$: Weight of water in pore
k_h : coefficient of permeability

B. Basic equations of space

Considering the calculation domain at two times t_n và t_{n+1} , and variables, respectively $\{\delta\}_n$, $\{\delta\}_{n+1}$, $\{p\}_n$, $\{p\}_{n+1}$ .In the period $\Delta t=t_{n+1}-t_n$ with $\{\dot{\delta}\}=\{\Delta\delta\}/\Delta t$ and , selecting linear function: [3], [5], [6] [9]

$$\begin{cases} [K]\{\Delta\delta\}+[C]\{\Delta p\}=\{\Delta R_F\} \\ [C]^T\{\Delta\delta\}-\theta\Delta t[H]\{\Delta p\}=\{\Delta R_q\} \end{cases} \quad (4)$$

Where:

Vector increased the load during the period Δt .

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$$\{\Delta F\} = \begin{Bmatrix} \Delta F_x \\ \Delta F_y \\ \Delta F_z \end{Bmatrix}$$ Vector marginal increase in load periods Δt

$\{\Delta R_q\} = \Delta t(\{R_q\} + [H]\{p\}_n)$: Vector increases traffic in the period Δt

θ : Integral parameter, can be selected within 0.5~1.0.

C. Error control

Local error is calculated according to the formula: [3], [7-9]

$$\begin{cases} e^u = \Delta t \dfrac{1}{2}(\dot{u}^{Int}_{n+1} - \dot{u}_n) \\ e^p = \Delta t \dfrac{1}{2}(\dot{p}^{Int}_{n+1} - \dot{p}_n) \end{cases} \tag{5}$$

D. Time step control

Considering the effect of stress and pore pressure, the Euclid error is used to control the time step in the calculation process.
Pore pressure error: [9]

$$\eta^p = \|e^p\| = \Delta t \frac{1}{2}\|(\dot{p}^{Int}_{n+1} - \dot{p}_n)\|$$

or $$\eta = \frac{\|e^p\|}{\|p\|_{\max}} \tag{6}$$

Stress error:

$$\eta^u = \|e^u\| = \Delta t \frac{1}{2}\|(\dot{u}^{Int}_{n+1} - \dot{u}_n)\|$$

or $$\eta = \frac{\|e^u\|}{\|u\|_{\max}} \tag{7}$$

Calculation time step in the next period is calculated according to the formula:

$$\Delta t^u_{new} = \sqrt{\eta^u_t / \eta}\,\Delta t^u_{old} \qquad \Delta t^p_{new} = \sqrt{\eta^p_t / \eta}\,\Delta t^p_{old} \tag{8}$$

η_t Predetermined control errors:

$$\gamma_1\eta_t \le \eta^p \le \gamma_2\eta_t \qquad \gamma_1\eta_t \le \eta^u \le \gamma_2\eta_t$$
$$\gamma_1 \in (0,1.0) \qquad \gamma_2 \ge 1.0 \tag{9}$$

The control step must simultaneously satisfy two conditions of pore pressure error and stress error

E. Verification of computer program

Using the Fortran programming language, based on the above-mentioned theories set up SCRIP 04 calculation program.
SCRIP 04 program has several main features as follows:
Scope of calculation: Drainage, non-drainage, bi-directional consolidation problem, homogeneous or non-homogeneous elastic problem, limit state of soil (Cam-clay, modified Cam-clay) [10]
Element type: triangular element, quadrilateral, order 1 or 2, for the consolidation problem, increase the freedom of pore pressure
The calculation in the scope of this problem selects the element of triangle type with 6 nodal points with 7 integral points. For a two-dimensional problem, the above element has 15 degrees of freedom with 12 displacement degrees and 3 degrees of freedom due to pore pressure.Fig. 1. [9]

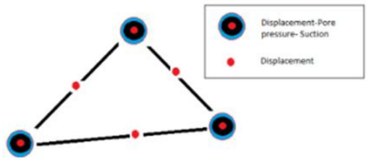

Fig. 1. Consolidation finite element

Fig. 1 shows the element and image of the integrator point used in the program. In which O represents the degree of freedom of displacement, ● represents the degree of freedom of pore pressure.
Using SCRIP04 program to calculate the example of one-way consolidation problem to check the accuracy of the program.

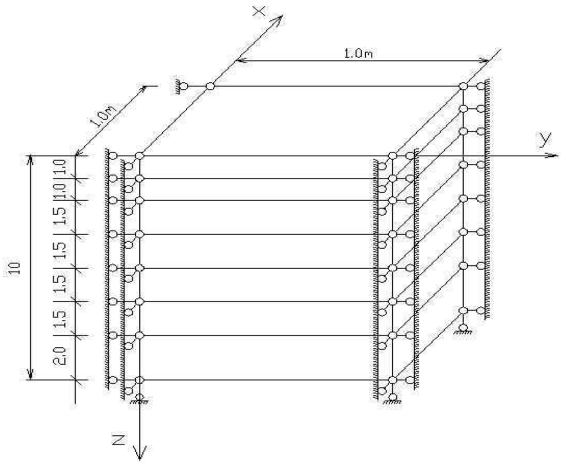

Fig. 2. Typical 1-D consolidation problem

The example used here is shown in **Fig.** 2 with the following main parameters: μ=0.301, E=3 Mpa, kv=10^{-6} cm/s , H= 10m ,q_o=100kPa, t_0=70d, upper surface drainage and undrained underside.
Results of calculating pore pressure, settlement , consolidation change over time with time step Δt = 3.5d are shown in Fig. 3 and Fig. 4.

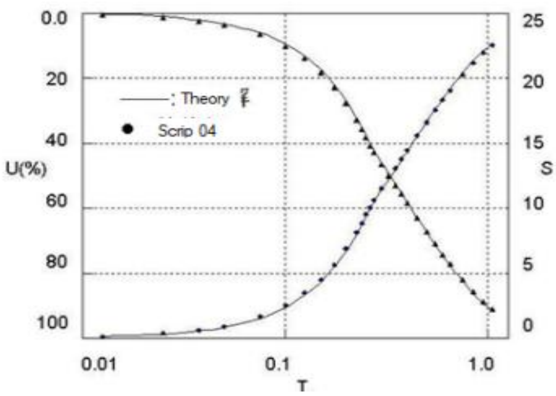

Fig. 3. Comparison of pore pressures

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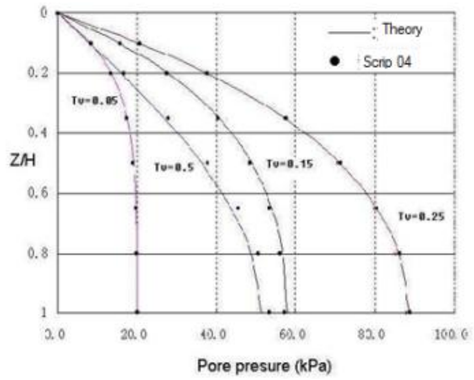

Fig. 4. Settlement and degree of consolidation results comparison

Calculation results comparing pore pressure based on theoretical and numerical methods are implemented by SCRIP 04 program shown in table 1 at times t = 14d, 42d, 70d, 140d（similar application Tv = 0.05, 0.15, 0.25, 0.5.

Table 1. Pore pressure results comparison

point	z/H	Pore pressure t=14d Theory	t=14d Scrip04	t=42d Theory	t=42d Scrip04	t=70d Theory	t=70d Scrip04	t=140d Theory	t=140d Scrip04
8	0.00	(0.0)	0	(0.00)	0	(0.00)	0	(0.00)	0
7	0.10	8.1	8.3	15.5	15.6	20.5	20.6	8.4	8
6	0.20	13.2	13.5	27.5	27.7	37.4	37.6	16.6	15.9
5	0.35	17.3	17.6	40.3	40.7	56.9	57.3	27.9	26.8
4	0.50	19.0	19.3	48.4	49	70.7	71.2	37.7	36.3
3	0.65	19.7	19.8	53.2	53.9	79.8	80.5	45.4	43.7
2	0.80	19.9	20	55.8	56.6	85.2	86.1	50.5	48.8
1	1.00	20.0	20	57.0	57.7	87.8	88.6	53.2	51.3

Table 2. Settlement and degree of consolidation results comparison

Time t(d)	Settlement (cm) Theory	Settlement (cm) Scrip04	Tv	Consolidation U (%) Theory	Consolidation U (%) Scrip04	Time t(d)	Settlement (cm) Theory	Settlement (cm) Scrip04	Tv	Consolidation U (%) Theory	Consolidation U (%) Scrip04
3.5	0.141	0.104	0.0125	0.57	0.42	84	11.498	11.352	0.3000	46.57	45.98
7	0.349	0.294	0.0252	1.41	1.19	91	12.318	12.203	0.3250	49.89	49.42
10.5	0.607	0.540	0.0375	2.46	2.19	98	13.074	12.978	0.3500	52.95	52.56
14	0.908	0.831	0.0500	3.68	3.37	105	13.777	13.694	0.3750	55.80	55.46
21	1.647	1.526	0.0750	6.67	6.18	112	14.432	14.361	0.4000	58.45	58.17
28	2.503	2.350	0.1000	10.14	9.52	126	15.587	15.568	0.4500	63.13	63.05
35	3.462	3.284	0.1250	14.02	13.30	140	16.612	16.630	0.5000	67.28	67.36
42	4.514	4.316	0.1500	18.28	17.48	154	17.525	17.566	0.5500	70.98	71.15
49	5.652	5.439	0.1750	22.89	22.03	168	18.340	18.394	0.6000	74.28	74.50
56	6.868	6.644	0.2000	27.82	26.91	182	19.069	19.125	0.6500	77.23	77.46
63	8.159	7.926	0.2250	33.04	32.10	210	20.230	20.342	0.7500	81.94	82.39
66.5	8.821	8.595	0.2375	35.73	34.81	238	21.163	21.293	0.8500	85.71	86.24
70	9.501	9.280	0.2500	38.48	37.59	266	21.913	22.036	0.9500	88.75	89.25
73.5	10.071	9.876	0.2625	40.79	40.00	294	22.517	22.617	1.0500	91.20	91.60
77	10.593	10.405	0.2750	42.90	42.14						

The analytical results in Fig. 3 and Fig. 4 as well as the values of settlement and consolidation in Table 1, Table 2 clearly show the similarity between the calculation by SCRIP 04 program and the complete numerical method. in accordance with the theory. Calculated results by SCRIP 04 program are extracted from point 8 with coordinates (0,0). These comparative evaluations have proved the accuracy of SCRIP 04 program.

III. APPLYING FOR DAK YEN VIETNAM DAM

At the time of designing DakYen local dams, Vietnam is using the TCVN 11-77 dam design criteria as follows:

Table 3. Physical and mechanical criteria used in calculation

Layer	γ_{KTK} T/ m^3	W %	φ degree	C kg/ cm^2	K cm/s
Layer 1	1.65	16±2	15	0.20	5.10^{-5}
Layer 2	1.44	25±2	15	0.20	1.10^{-5}
Layer 3	1.5	17±2	12	0.17	1.10^{-4}

Recognizing the complexity of the embankment soil for the Dak Yen local dam, it was proposed to use additional compacting standards for both options $I = \frac{\gamma_K}{\gamma_{max}} \geq 0{,}97$ to assess the quality of Dak Yen dam.

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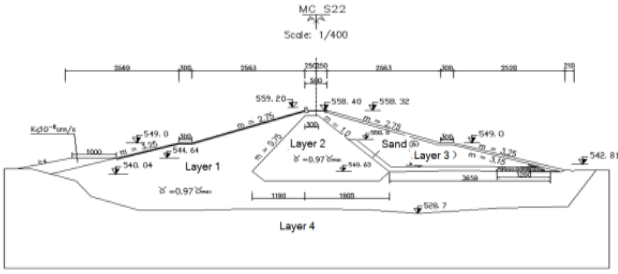

Fig. 5. Distribution of embankment materials for Dak Yen dam

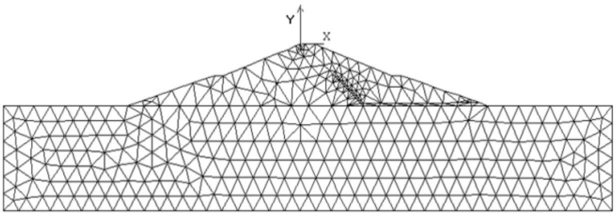

Fig. 6. Element grid calculates the operation process

In calculating the dam divided into 26 classes, each layer is 0.746m thick, the self-adaptive time step for each different class, the smallest is 1.473 days in the 3rd class, the average time is 15.938 – 16.712 days in the 8th grade and class 22 (cf Fig. 5 and Fig. 6), the longest time is 29.396 – 33.782 occurs in grades 12 and 13. The damming time used in the calculation is 180 days, the water retention time is 90 days. The results of pore water pressure variation at the point between the base of the dam and subsidence of the dam crest is shown in Fig. 7 and Fig. 8.

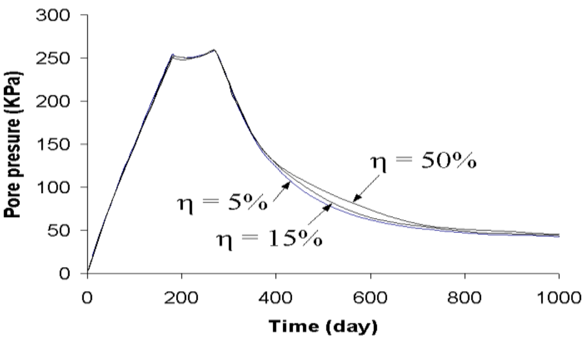

Fig. 7. The process of changing pore water pressure in the middle of the dam in time

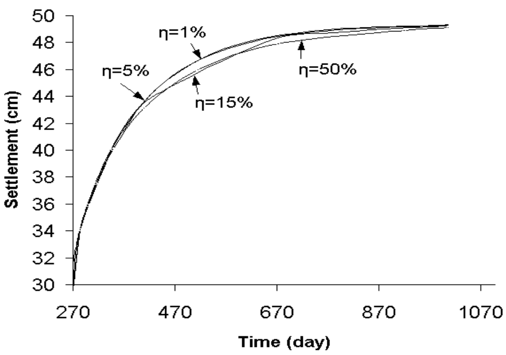

Fig. 8. The settlement of the dam crest over time during operation

Basing on the analysis results of dispersion of pore water pressure as well as the effective stress field in the dam body and the base, the speed of dam construction can be proposed as follows:

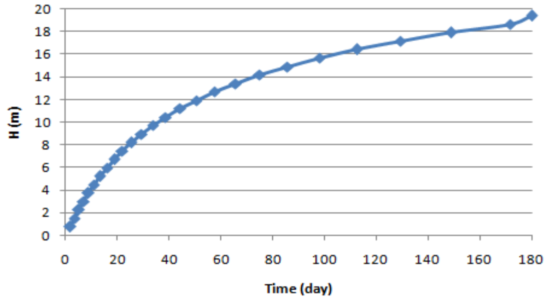

Fig. 7. Speed control of dam construction

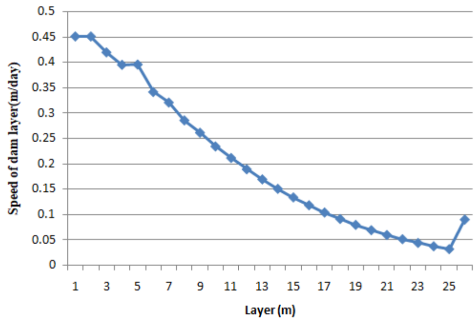

Fig. 8. Speed to control dam layers

IV. CONCLUSION

This paper is based on the Biot consolidation theory in order to improve the accuracy of the calculation, the paper has studied the self-adaptive time step in the consolidation process using the theory of biotransformation with Cam-clay material model. Using the principles have a copy to give the formula to control errors, which can control the error of stress field and pore pressure field. The results of this study aim to correct the process of deformation stress development. The research results applied to the local material dam Dak Yen - Vietnam is one of the relatively complex embankment dams. The research results are conducted for the construction phase of dams, water accumulation as well as operation of the dam. The results are very significant in the process of designing and construction of local materials.

The problem of choosing the permissible error value [η] still has many problems. Currently based solely on the experience of the calculator to determine this value.

This paper uses 2 distinct errors η = η (u) and η = η (p) to control the error of stress field and pore pressure field is incomplete. In fact, these two schools have mutual interactions and effects. Therefore, the next study will combine only these 2 errors and give 1 error function η = η (u, p).

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Quang Hung Nguyen was born in 1975 in Hanoi, Viet Nam. He received the Engineering's degree and M.S. degrees in hydraulic construction from the Thuyloi University of Vietnam, in 1997 and 2000 and the PhD. degree in hydraulic structure from Wuhan University, China. Since 1998, he is a lecture in Faculty of Civil Engineering, Thuyloi University and becomes Associate Professor since 2009.

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