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基于时域自适应算法的单向粘弹性节理岩体的等效分析

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摘 要:在粘弹性节理岩体的数值仿真中,必需合理地计及节理的影响。若将节理与岩体作为独立的材料组分考虑,在节理密集的情况下,时空两方面的计算开销可能是很难承受的。本文通过时域展开技术与一个简单的等效假定,得到了递推格式的粘弹性单向节理岩体的等效本构关系,及等效场的递推求解格式,并由此数值模拟了一个粘弹性节理岩体中的洞室,计算结果与考虑独立组分的 ANSYS 粘弹性分析进行了比较,二者的计算平均误差约为 11.03%,但前者的计算效率为后者 16.81 倍。本文工作有可能为粘弹性节理岩体的数值模拟提供一条新的途径。

关键词:节理岩体;粘弹性;时域精细算法;递推

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1 引 言

如何合理地计及节理的影响,是粘弹性节理岩体的数值仿真中必须考虑的重要因素,具有重要的理论探讨价值和工程实际意义。

一种处理方法是将节理与岩体作为独立的材料组分,分别建立各自的力学模型,如 Goodman[1] 节理单元技术、离散元技术[2]等。当节理密集存在时,加之时域分析,计算复杂的程度和开销通常是很难承受的。一种变通的办法,是将节理岩体作为一种广义复合材料,在宏观层次上建立复合等效本构关系,并进行整体等效分析。

节理岩体的复合等效本构关系研究已有不少相关文献报道[3-7],Singh[3] 预测了等效各向异性节理岩体的弹性模量;牛斌等[4] 基于均匀化方法给出了给出斜交节理岩体的等效本构关系并计算了场问题;Zienkiewicz 和 Kelly[5] 用等效连续体方法,建立了节理岩体的多层材料模型;Gerrard[6] 用能量等效法得到了层状和含三组节理的岩体的等效本构关系;张武和张宏宪[7] 基于叠加方法,用应力、位移协调关系推导了单向、双向和多向节理的弹性模型。

有关粘弹性节理岩体等效本构关系研究相对较少:刘书田等基于均匀化方法给出了单向节理岩体粘弹性性能的预测方法[8],但没有进行场问题计算。

本文考虑单向粘弹性节理岩体为对象,通过时域自适应算法[11] 和一种简单的应力-应变等效假定[12],建立了递推形式的粘弹性等效本构关系,并由此数值模拟了一个粘弹性节理岩体中的洞室,计算结果与考虑独立组分的 ANSYS 粘弹性分析进行了比较,二者的计算平均误差约为 11.03%,但前者的计算效率为后者 16.81 倍。

2 粘弹性静力问题的控制方程

粘弹性静力问题的基本方程为[13]:

平衡方程: $\Omega\{\sigma(t)^L\}+\{f(t)^L\}=0$ (1)

几何方程: $\{\varepsilon(t)^L\}=\Omega^{\mathrm{T}}\{u(t)^L\}$ (2)

边界条件:

$$\{p(t)^L\}=\{\widetilde{p(t)^L}\},\quad x,y\in\Gamma_p \tag{3}$$

$$\{u(t)^L\}=\{\widetilde{u(t)^L}\},\quad x,y\in\Gamma_u \tag{4}$$

式中

$$\Omega=\begin{bmatrix}\frac{\partial}{\partial x} & & & & \frac{\partial}{\partial z} & \frac{\partial}{\partial y}\\ & \frac{\partial}{\partial y} & & \frac{\partial}{\partial z} & & \frac{\partial}{\partial x}\\ & & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} & \end{bmatrix}$$

上标 $L=r,j$,表示材料为岩石或节理,$\{\sigma(t)^L\}$ 和

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$\{\varepsilon(t)^L\}$ 分别为应力和应变，$\{f(t)^L\}$ 为体力，$\{u(t)^L\}$ 为位移，$\{p(t)^L\}$ 为面力，$\{\widetilde{u(t)^L}\}$ 和 $\{\widetilde{p(t)^L}\}$ 为 $\{u(t)^L\}$ 和 $\{p(t)^L\}$ 在边界 Γ_u 和 Γ_p 的指定值，$\Gamma=\Gamma_u+\Gamma_\sigma$ 代表整个问题的边界。

二维粘弹性问题的积分型本构方程可写为[14]：

$$\{\varepsilon^L(t)\}=[K^L]\left\{J^L(0)\sigma^L(t)+\int_{0+}^{t}\sigma^L(\tau)\frac{\mathrm{d}J^L(t-\tau)}{\mathrm{d}(t-\tau)}\mathrm{d}\tau\right\}\quad t\geqslant 0 \tag{5}$$

选用三参数固体模型[15]：

$$J^L(t)=\frac{1}{E_2^L}+\frac{1}{E_1^L}(1-e^{-\frac{t}{\tau_1^L}}),\quad \tau_1^L=\frac{\eta_1^L}{E_1^L} \tag{6}$$

与式(5)等价的微分型本构方程为

$$\begin{cases}\{\varepsilon^L(t)\}=\dfrac{1}{E_2^L}[K^L]\{\sigma^L(t)\}, \quad t=0 & (7.1)\\ q_0^L\{\varepsilon^L(t)\}+q_1^L\dfrac{d\{\varepsilon^L(t)\}}{\mathrm{d}t}= \\ \qquad [K^L]\left(\{\sigma^L(t)\}+p_1^L\dfrac{\mathrm{d}\{\sigma^L(t)\}}{\mathrm{d}t}\right), \quad t>0 & (7.2)\end{cases}$$

式中

$$p_1^L=\frac{\eta_1^L}{E_1^L+E_2^L},q_0^L=\frac{E_1^LE_2^L}{E_1^L+E_2^L},q_1^L=\frac{E_2^L\eta_1^L}{E_1^L+E_2^L} \tag{8}$$

$$\{\varepsilon^L(t)\}=\begin{pmatrix}\varepsilon_x^L(t)\\ \varepsilon_y^L(t)\\ \gamma^L(t)\end{pmatrix},\ \{\sigma^L(t)\}=\begin{pmatrix}\sigma_x^L(t)\\ \sigma_y^L(t)\\ \tau^L(t)\end{pmatrix} \tag{9.1-2}$$

$$[K^L]=\begin{pmatrix}K_{11}^L & K_{12}^L & 0\\ & K_{22}^L & 0\\ symm & & K_{33}^L\end{pmatrix} \tag{10}$$

对于平面应力：

$$K_{11}^L=K_{22}^L=1,\quad K_{33}^L=2(1+\nu),\quad K_{12}^L=-\nu \tag{10.1}$$

对于平面应变：

$$K_{11}^L=K_{22}^L=1-\nu^2,\quad K_{33}^L=2(1+\nu)$$
$$K_{12}^L=-\nu(1+\nu) \tag{10.2}$$

式中 t 和 τ 分别指当前时间和过去的时间；ν,E_1^L,E_2^L η_1^L 是材料参数。

3 递推格式的控制方程

将整个时域离散为一系列小时段，各时段的起点和大小分别为 $t_0,t_1,t_2\cdots t_k\cdots$ 和 $T_1,T_2\cdots T_k\cdots$ 按时域精细算法[11]，将各变量展开为

$$\{\sigma(t)^L\}=\sum_{m=0}\{\sigma_m^L\}s^m \tag{11}$$

$$\{\varepsilon(t)^L\}=\sum_{m=0}\{\varepsilon_m^L\}s^m \tag{12}$$

$$\{f(t)^L\}=\sum_{m=0}\{f_m^L\}s^m \tag{13}$$

$$\{u(t)^L\}=\sum_{m=0}\{u_m^L\}s^m \tag{14}$$

$$\{\widetilde{u(t)^L}\}=\sum_{m=0}\{\widetilde{u_m^L}\}s^m \tag{15}$$

$$\{p(t)^L\}=\sum_{m=0}\{p_m^L\}s^m \tag{16}$$

$$\{\widetilde{p(t)^L}\}=\sum_{m=0}\{\widetilde{p_m^L}\}s^m \tag{17}$$

$$s=\frac{t-t_{k-1}}{T_k} \tag{18}$$

式中 $\{\sigma_m^L\}$ 和 $\{\varepsilon_m^L\}$ 分别表示 $\{\sigma(t)^L\}$ 和 $\{\varepsilon(t)^L\}$ 的展开系数 $\{u_m^L\}$，$\{p_m^L\}$，$\{\widetilde{u_m^L}\}$ 和 $\{\widetilde{p_m^L}\}$ 分别表示 $\{u(t)^L\}$，$\{p(t)^L\}$，$\{\widetilde{u(t)^L}\}$ 和 $\{\widetilde{p(t)^L}\}$ 的展开系数。T 与 s 之间求导的转换关系为

$$\frac{\mathrm{d}}{\mathrm{d}t}=\frac{1}{T_k}\frac{\mathrm{d}}{\mathrm{d}s},\quad \frac{\mathrm{d}^2}{\mathrm{d}t^2}=\frac{1}{T_k^2}\frac{\mathrm{d}^2}{\mathrm{d}s^2}$$

将式(11)～(17)代入(1)～(4)可得

$$\begin{cases}\Omega\cdot\{\sigma_0^L\}+\{f_0^L\}=0\\ \{\varepsilon_0^L\}=\Omega^{\mathrm{T}}\{u_0^L\}\\ \{u_0^L\}=\{\widetilde{u_0^L}\}\\ \{p_0^L\}=\{\widetilde{p_0^L}\}\end{cases}\quad (m=0) \tag{19}$$

$$\begin{cases}\Omega\cdot\{\sigma_m^L\}=0\\ \{\varepsilon_m^L\}=\Omega^{\mathrm{T}}\{u_m^L\}\\ \{u_m^L\}=\{\widetilde{u_m^L}\}\\ \{p_m^L\}=\{\widetilde{p_m^L}\}\end{cases}\quad m>0 \tag{20}$$

在第一时段：

$$\{\sigma_0^L\}=[D^L]\{\varepsilon_0^L\} \tag{21.1}$$

在 $k+1$ 时段：

$$\begin{cases}\{\varepsilon_0^L\}_{(k+1)}=\sum\limits_{i=1}\{\varepsilon_0^L\}_k\\ \{\sigma_0^L\}_{(k+1)}=\sum\limits_{i=1}\{\sigma_0^L\}_k\end{cases} \tag{21.2}$$

将式(11)和式(12)带入式(7.2)，并比较等式两边的同次幂可得

$$\{\sigma_m^L\}=[D^L]\{\varepsilon_m^L\}+[C_m^L]\quad(m>0) \tag{21.3}$$

式中

$$\{\sigma_m^L\}=\{\sigma_{xm}^L\quad\sigma_{ym}^L\quad\tau^L\}^{\mathrm{T}}\quad(m\geqslant 0)$$

$$\{\varepsilon_m^L\} = \{\varepsilon_{xm}^L \quad \varepsilon_{ym}^L \quad \gamma^L\}^{\mathrm{T}} \quad (m \geqslant 0)$$

$$[D^L] = \begin{pmatrix} D_{11}^L & D_{12}^L & 0 \\ & D_{22}^L & 0 \\ symm & & D_{33}^L \end{pmatrix}$$

对于平面应力：

$$D_{11}^L = s_1^L + \frac{\nu^2}{s_2^L}, D_{22}^L = \frac{1}{s_2^L}, D_{33}^L = \frac{1}{s_3^L}, D_{12}^L = \frac{\nu}{s_2^L}$$

$$[C_m^L] = \left\{\frac{\nu w_2^L}{s_2^L} + w_1^L \quad -\frac{w_2^L}{s_2^L} \quad -\frac{w_3^L}{s_3^L}\right\}^{\mathrm{T}}$$

$$s_1^L = \frac{q_1^L}{p_1^L}$$

$$w_1^L = \frac{\nu T}{m}\frac{1}{p_1^L}\sigma_{y(m-1)}^L + \frac{T}{m}\frac{q_0^L}{p_1^L}\varepsilon_{x(m-1)}^L - \frac{T}{p_1^L m}\sigma_{x(m-1)}^L$$

$$s_2^L = (1-\nu^2)\frac{p_1^L}{q_1^L}$$

$$w_2^L = \frac{(1-\nu^2)T}{m}\frac{1}{q_1^L}\sigma_{y(m-1)}^L - \frac{\nu T}{m}\frac{q_0^L}{q_1^L}\varepsilon_{x(m-1)}^L - \frac{Tq_0^L}{q_1^L m}\varepsilon_{y(m-1)}^L$$

$$s_3^L = 2(1+\nu)\frac{p_1^L}{q_1^L}$$

$$w_3^L = \frac{2(1+\nu)T}{m}\frac{1}{q_1^L}\tau_{m-1}^L - \frac{T}{m}\frac{q_0^L}{q_1^L}\gamma_{m-1}^L$$

$$p_1^L = \frac{\eta_1^L}{E_1^L + E_2^L}, q_0^L = \frac{E_1^L E_2^L}{E_1^L + E_2^L}, q_1^L = \frac{E_2^L \eta_1^L}{E_1^L + E_2^L}$$

对于平面应变问题，须将(21.1)和(21.3)中 E_1^L，E_2^L，ν 分别换作 $\frac{E_1^L}{1-\nu^2}$，$\frac{E_2^L}{1-\nu^2}$，$\frac{\nu}{1-\nu}$。

4　等效假定与递推等效本构方程

4.1　等效假定

图 1 为相对宽度为 β 的单向粘弹性节理岩体及相应的单胞，总体坐标系 x-y 与局部坐标系 x'-y' 之间的夹角为 α。

设等效宏观应和应变为

$$\{\sigma(t)\} = \{\sigma_x(t) \quad \sigma_y(t) \quad \tau(t)\}^{\mathrm{T}}$$

$$\{\varepsilon(t)\} = \{\varepsilon_x(t) \quad \varepsilon_y(t) \quad \gamma(t)\}^{\mathrm{T}}$$

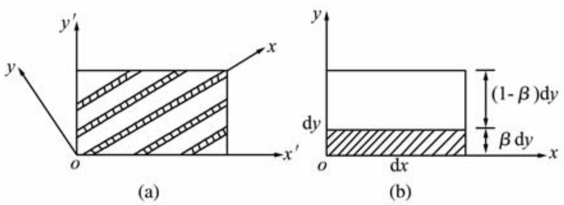

图 1　单向粘弹性节理岩体

Fig. 1　The uni-directional viscoelastic jointed rock

假定等效应力与应变场满足：

$$\begin{cases} \sigma(t)_x = \beta\sigma(t)_x^j + (1-\beta)\sigma(t)_x^j \\ \sigma(t)_y = \sigma(t)_y^j = \sigma(t)_y^r \\ \tau(t) = \tau(t)^r = \tau(t)^j \end{cases} \tag{22}$$

$$\begin{cases} \varepsilon(t)_x = \varepsilon(t)_x^j = \varepsilon(t)_x^r \\ \varepsilon(t)_y = \beta\sigma(t)_y^j + (1-\beta)\sigma(t)_y^r \\ \gamma(t) = \beta\gamma(t)^r + (1-\beta)\gamma(t)^j \end{cases} \tag{23}$$

将等效宏观应力、应变展开为

$$\{\sigma(t)\} = \sum_{m=0}\{\sigma_m\}s^m \tag{24}$$

$$\{\varepsilon(t)\} = \sum_{m=0}\{\varepsilon_m\}s^m \tag{25}$$

式中 $\{\sigma_m\}$ 和 $\{\varepsilon_m\}$ 分别表示 $\{\sigma(t)\}$ 和 $\{\varepsilon(t)\}$ 的展开系数($m = 0,1,2,\cdots$)。将式(24-25)与(21.1)(21.3)带入到式(22)及式(23)中可得：

当 $t = 0$，

$$\{\sigma_0\} = [D^H]\{\varepsilon_0\} \quad (t=0) \tag{26}$$

当 $t > 0$，

$$\{\sigma_m\} = [D^H]\{\varepsilon_m\} + [C_m] \quad (m > 0) \tag{27}$$

式中

$$\{\sigma_m\} = \{\sigma_{xm} \quad \sigma_{ym} \quad \tau_m\}^{\mathrm{T}}, \quad m \geqslant 0$$

$$\{\varepsilon_m\} = \{\varepsilon_{xm} \quad \varepsilon_{ym} \quad \gamma_m\}^{\mathrm{T}}, \quad m \geqslant 0$$

$$[D^H] = \begin{pmatrix} D_{11}^H & D_{12}^H & 0 \\ & D_{22}^H & 0 \\ symm & & D_{33}^H \end{pmatrix}$$

对于平面应力问题：

$$D_{11}^H = s_1 + \frac{\nu^2}{s_2}, D_{22}^H = \frac{1}{s_2}, D_{33}^H = \frac{1}{s_3}, D_{12}^H = \frac{\nu}{s_2}$$

$$[C_m] = \left\{\frac{\nu w_2}{s_2} + w_1 \quad -\frac{w_2}{s_2} \quad -\frac{w_3}{s_3}\right\}^{\mathrm{T}}$$

$$s_1 = \frac{\beta q_1^j}{p_1^j} + \frac{(1-\beta)q_1^j}{p_1^j}$$

$$w_1 = \frac{\nu T}{m}\left(\frac{\beta}{p_1^j} + \frac{1-\beta}{p_1^j}\right)\sigma_{y(m-1)} + \frac{T}{m}\left[\frac{\beta q_0^j}{p_1^j} + \frac{(1-\beta)q_0^r}{p_1^r}\right]\varepsilon_{x(m-1)} - \frac{\beta T}{p_{1j}m}\sigma_{x(m-1)}^j - \frac{(1-\beta)T}{p_{1r}m}\sigma_{x(m-1)}^r$$

$$s_2 = (1-\nu^2)\left(\frac{\beta p_1^j}{q_1^j} + \frac{(1-\beta)p_1^r}{q_1^r}\right)$$

$$w_2 = \frac{(1-\nu^2)T}{m}\left(\frac{\beta}{q_1^j} + \frac{1-\beta}{q_1^r}\right)\sigma_{y(m-1)} -$$

$$\frac{\nu T}{m}\left[\frac{\beta q_0^j}{q_1^j}+\frac{(1-\beta)q_0^r}{q_1^r}\right]\varepsilon_{x(m-1)}-$$

$$\frac{\beta T q_0^j}{q_1^j m}\varepsilon^j_{y(m-1)}-\frac{(1-\beta)Tq_0^r}{q_1^r m}\varepsilon^r_{y(m-1)}$$

$$s_3=2(1+\nu)\left(\frac{\beta p_1^j}{q_1^j}+\frac{(1-\beta)p_1^r}{q_1^r}\right)$$

$$w_3=\frac{2(1+\nu)T}{m}\left(\frac{\beta}{q_1^j}+\frac{1-\beta}{q_1^r}\right)\tau^{m-1}-$$

$$\frac{T}{m}\left[\frac{\beta q_0^j}{q_1^j}\gamma^j_{m-1}+\frac{(1-\beta)q_0^r}{q_1^r}\gamma^r_{m-1}\right]$$

当 $t>0, m=0$，见式(21.2)。

对于平面应变问题，须将式(26)和式(27)中 E_1^L, E_2^L 和 ν 分别换作 $\frac{E_1^L}{1-\nu^2}, \frac{E_2^L}{1-\nu^2}$ 和 $\frac{\nu}{1-\nu}$。

根据虚功原理[13]，对等效场有

$$\int_V \delta\{\varepsilon\}^{\mathrm T}\{\sigma(t)\}\mathrm{d}v=\int_V \delta\{u\}^{\mathrm T}\{f(t)\}\mathrm{d}v+\int_\Gamma \delta\{u\}^{\mathrm T}\{p(t)\}\mathrm{d}\Gamma \tag{28}$$

式中 $\delta\{\varepsilon\}$ 和 $\delta\{u\}$ 为虚应变和虚位移。

经有限元离散后：

$$\delta\{\bar u\}^{\mathrm T}\int_{V_e}[B]\{\sigma\}\mathrm{d}v=\delta\{\bar u\}^{\mathrm T}\int_{V_e}[N]^{\mathrm T}\{f(t)\}\mathrm{d}v+\delta\{\bar u\}^{\mathrm T}\int_{\Gamma_e}[N]^{\mathrm T}\{p(t)\}\mathrm{d}\Gamma$$

$$\int_{V_e}[B]\{\sigma(t)\}\mathrm{d}v=\int_{V_e}[N]^{\mathrm T}\{f(t)\}\mathrm{d}v+\int_{\Gamma_e}[N]^{\mathrm T}\{p(t)\}\mathrm{d}\Gamma$$

将式(11)和式(16,17)代入得

$$\int_{V_e}[B]\{\sigma_m\}\mathrm{d}v=\int_{V_e}[N]^{\mathrm T}\{f_m\}\mathrm{d}v+\int_{\Gamma_e}[N]^{\mathrm T}\{p_m\}\mathrm{d}\Gamma \tag{29}$$

将式(26,27)带入式(29)得

$$[K]\{\overline{u_m}\}=[F_m],\ m=0,1,2\cdots \tag{30}$$

式中

$$[K]=\int_{V_e}[B]^{\mathrm T}[D_H][B]\mathrm{d}v$$

$$[F_m]=\begin{cases}\int_{V_e}[N]^{\mathrm T}\{f_0\}\mathrm{d}v+\int_{\Gamma_e}[N]^{\mathrm T}\{p_0\}\mathrm{d}\Gamma \\ \qquad m=0 \\ -\int_{V_e}[B][C_m]\mathrm{d}v \quad m>0\end{cases}$$

$\{\overline{u_m}\}=(\overline{u_{mx}}\quad \overline{u_{my}})^{\mathrm T}$，是节点位移第 m 阶展开系数，计算中所有节点需满足收敛判据：

$$\mathrm{abs}\left(\bar u_{mi}/\sum_{k=0}^{m-1}\bar u_{ki}\right)_{s=1}\leqslant\beta_e, i=x,y。\beta_e \text{ 为误差限。}$$

5　数值算例

数值模拟一个受一组单向粘弹性节理切割的岩石中的圆形洞室，如图 2 所示。岩石为弹性，$E_{2r}=3.5\times10^{10}$ Pa，$\nu_r=0.3$，节理为粘弹性 $E_{1j}=2\times10^8$ Pa，$E_{2j}=1\times10^9$ Pa，$F_{1j}=1\times10^{10}$ Pa，$\nu_j=0.3$，$\beta=0.2$，$\alpha=45°$。

将计算结果与考虑独立组分的 ANSYS 粘弹性分析进行了比较。图 3 给出洞室周围 12 个点的位移随时间变化对比，图中 fortran_x，fortran_y 分别表示等效分析的 x 和 y 方向位，ansys_x，ansys_y 分别表示 ANSYS 计算的 x 和 y 方向位移。若定义平均误差为所选 12 个点的误差平均，则图 4 为平均误差随的时间变化，有关计算信息对比列入表 1，图 5 给出两者的计算时间对比。

表 1　计算信息对比

Tab.1　Comparation of calculated information

	等效分析	Ansys
计算时间(s)	6992.03	117537.00
单元数	174	5025
节点数	570	15230
时段个数	10000	20000
最终平均(%)	11.03	

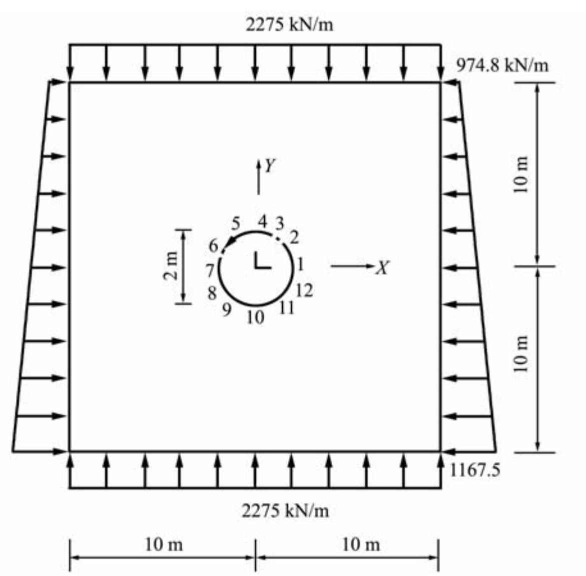

图 2　节理岩体中的圆形洞室

Fig.2　A cave in the joined rock

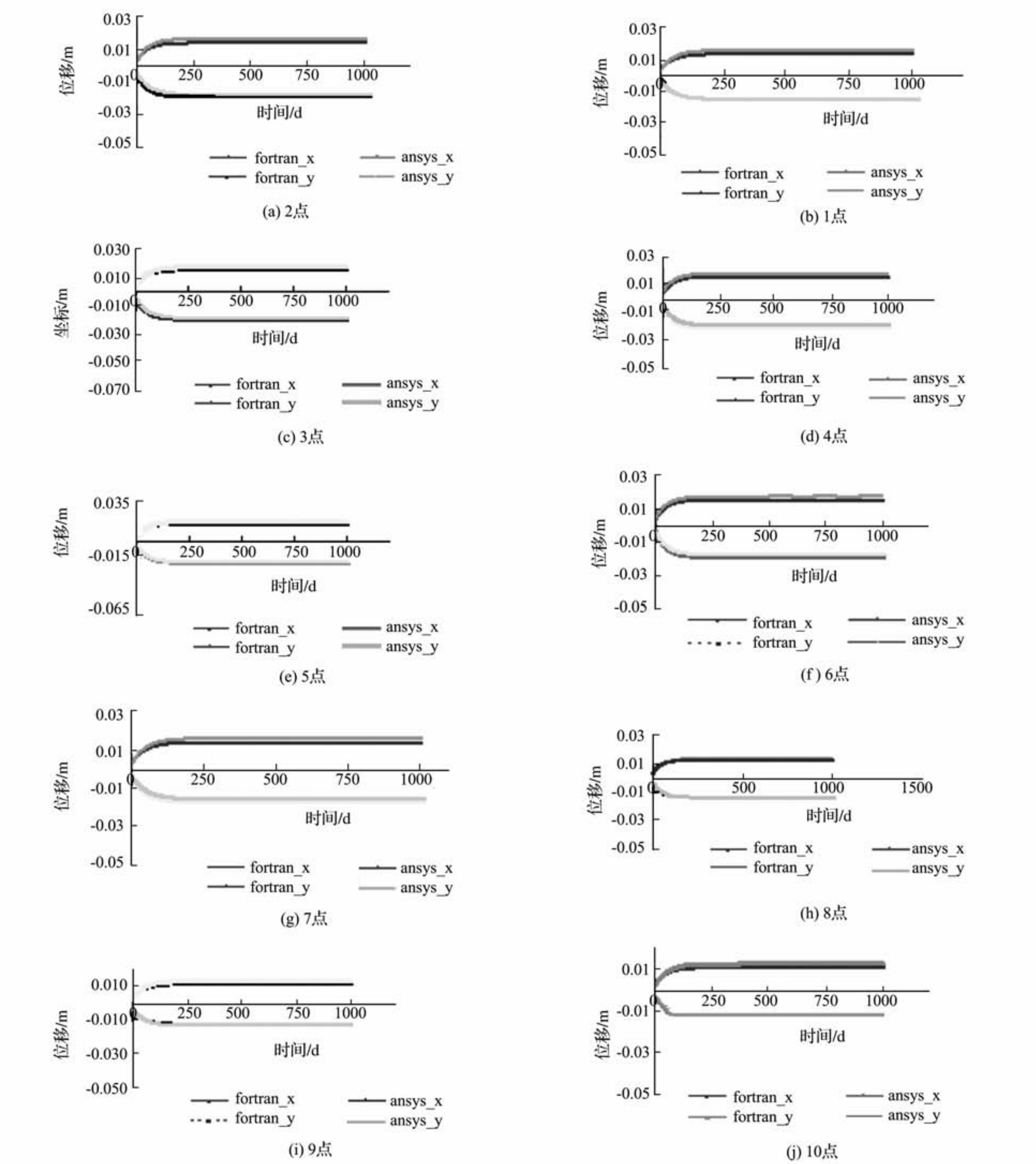

图 3　位移随时间变化

Fig. 3　The variation of displacement with time

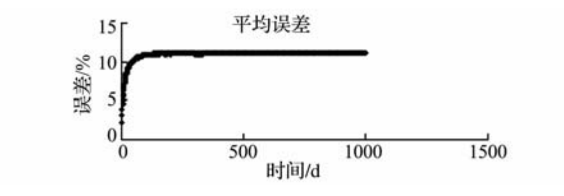

图 4　平均误差

Fig. 4　The average error

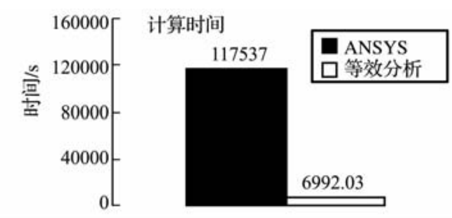

图 5　计算时间

Fig. 5　Computation time

6 结 论

通过时域展开技术和一个简单的等效假定，得到了递推格式的粘弹性单向节理岩体的等效本构关系及等效场的递推求解格式，并模拟了一个粘弹性节理岩体中的洞室，与考虑独立组分的 ANSYS 粘弹性分析相比，计算精度与计算效率的综合效果令人满意。应该指出，本文采用的等效假定在数学及物理上都不够严密，须经进一步完善和改进，一个可能出现的问题是，当等效假定足够严密时，粘弹性等效的计算量将大大增加，本文工作有可能为粘弹性节理岩体的数值模拟提供一条新途径，也可能为构型相同的粘弹性复合材料的等效分析提供一个有益的参考。

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Study on the energy storage ability criterion in a kind of rockburst and application

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Abstract: Study on a kind of rockburst-strain bursting from the point of energy. The researches give a complete discussion on the sources of energy, the way energy dissipation, the magnitude of the released energy and its reason. The energy storage ability criterion is put forward: the capacity of energy storage of rockmass is not a constant, it changes with the stress. When the stress changes suddenly, resulting the energy stored larger than the capacity of energy storage under present stress, the residual energy will release in kinds of way, including the kinetic energy. The simplified one-dimensional and three-dimensional models are analyzed based on the energy storage ability criterion, and the process of rockburst in the condition of unloading is reappeared using the discrete element software 3DEC.

Key words: rockburst; energy; energy storage ability; stress

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An equivalent analysis of unidirectional viscoelastic jointed rock based on the adaptive algorithm in time-domain

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Abstract: A reasonable joint model is necessary for the numerical simulation of viscoelastic jointed rock, If considering joints and rock mass individually with their own constitutive model, the computational expense will be challenged when the number of joints is fairly large. This paper presents a numerical model to predict equivalent constitutive relationship and deformation of unidirectional viscoelastic joint rock. An adaptive precise algorithm in the time-domain and a simple equivalence assumption are combined to convert a time dependent inhomogeneous problem into a series of recursive time independent homogeneous problems which can be solved either by FEM or other well developed numerical schemes. An equivalent numerical simulation for an underground cave in unidirectional viscoelastic joint rock is given and compared with the solution provided by ANSYS In the viewpoint of balance between computing accuracy and efficiency, the results are fairly good.

Key words: Jointd Rock; viscoelasticity; equivalent analysis; adaptive algorithm; finite element