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ENERGY DISSIPATION AND SENSITIVITY ANALYSIS OF BLOCK-HIERARCHICAL ROCK MASS ON PENDULUM-TYPE WAVES PROPAGATION

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The study focuses on the energy dissipation of block-hierarchical rock mass and parameters of block-hierarchical structure sensitivity to energy dissipation on the pendulum-type waves propagation in an assembly of block structure which parted alternatively by elastic springs and viscous damping elements. Base on the mechanical model kinetic energy of blocks, elastics potential energy between blocks and mechanical energy of the block mass system are obtained. The effect of block rock structure parameters including block mass, property of visco-elasticity medium between block rocks to the energy dissipation are compared.

Keywords: Block hierarchical rock medium, pendulum-type waves, kinetic energy, elastics potential energy.

Introduction. The contemporary geomechanical and geophysical sciences describe deformation of a rock mass as of a complex hierarchy of block structure. As per this concept, a rock mass is a system of various scale blocks embodied into one another [1]. Inter-block layers are usually composed of weaker and fissured rocks, based on that, there is a new phenomenon of dynamic response of rock mass called pendulum-type waves. Pendulum-type waves occur due to the deformation of these partings and closely contacts with geomechanical structure. Theoretical and experimental research on pendulum-type waves with great development [2–9]. Aleksandrova [5] study the effect of viscosity of partings in block-hierarchical media on propagation of low-frequency pendulum waves. It is point out that energy dissipation in the partings influences largely the wave propagation in a block system, which calls for theoretical modeling of this process. Visco-elastic behavior of partings is one of the causes of energy dissipation. Partings have successfully been taken into account in modeling wave propagation in one-dimensional chain of masses with two couples of elastic and damping elements inserted in line or in parallel [2, 3].

This article is a study of energy dissipation in one-dimensional model. Aleksandrova [5] put forward a model with partings and parallel arranged elastic and damping elements as Fig. 1. in the form of chains of elastic blocks with friable layers between them showed that wave propagation in such media is sufficiently described by an approximation that the blocks are non-deformable bodies. First energy dissipation of this dynamic process are analyzed theoretically. Then, kinetic energy, elastics potential energy and mechanical energy of block-hierarchical rock structure are compared respectively when change the mass of block and visco-elastic coefficient of partings.

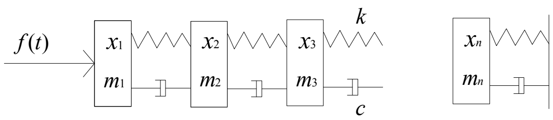

Fig. 1 Model of block-hierarchic rocks structure with visco-elastically linked

Problem Statement. Dynamic equations of the block rocks structure expressed as matrix form (1)

$$M \times \ddot{x}(t) + C \times \dot{x}(t) + K \times x(t) = F(t). \quad (1)$$

Where

$$\boldsymbol{M} = \begin{bmatrix} m_1 & & & \\ & m_2 & & \\ & & \ddots & \\ & & & m_n \end{bmatrix}, \quad \boldsymbol{C} = \begin{bmatrix} c_1 & -c_1 & & & & \\ -c_1 & (c_1+c_2) & -c_2 & & & \\ & \ddots & \ddots & \ddots & & \\ & & -c_{i-1} & (c_{i-1}+c_i) & -c_i & \\ & & & \ddots & \ddots & \ddots \quad -c_{n-1} \\ & & & & -c_{n-1} & (c_{n-1}+c_n) \end{bmatrix},$$

$$\boldsymbol{K} = \begin{bmatrix} k_1 & -k_1 & & & & \\ -k_1 & (k_1+k_2) & -k_2 & & & \\ & \ddots & \ddots & \ddots & & \\ & & -k_{i-1} & (k_{i-1}+k_i) & -k_i & \\ & & & \ddots & \ddots & \ddots \quad -k_{n-1} \\ & & & & -k_{n-1} & (k_{n-1}+k_n) \end{bmatrix},$$

$x = [x_1, \cdots, x_n]$ is the displacement of each block rock, $F(t) = [f(t), 0, \cdots, 0]$ and $f(t)$ is the initial impact loading. Formula (1) can be expressed as (2)

$$A\dot{y}(t) + By(t) = \tilde{f}(t) \quad (2)$$

Where

$$A = \begin{bmatrix} C & M \\ M & 0 \end{bmatrix}, \quad B = \begin{bmatrix} K & 0 \\ 0 & -M \end{bmatrix}, \quad \tilde{f}(t) = \begin{bmatrix} F(t) \\ 0 \end{bmatrix}, \quad y(t) = \begin{bmatrix} x(t) \\ \dot{x}(t) \end{bmatrix}.$$

The solution of equations (2) on transient impulse loading $f(t)$ is as (3)

$$y(t) = [x_1(t), \cdots, x_n(t), \dot{x}_1(t), \cdots, \dot{x}_n(t)]^T = \Phi d q_0 \quad (3)$$

where $\Phi = [\varphi_1 \cdots \varphi_{2n}]$ and φ_i is generalized eigenvector of $B^{-1}A\varphi = \lambda^{-1}\varphi$; $d = \mathrm{diag}(e^{\lambda_1 t}, e^{\lambda_2 t} \cdots, e^{\lambda_{2n} t})$, λ_i is eigenvalue corresponding with generalized eigenvector φ_i, $q_0 = a^{-1}\Phi^T Ay(0)$, $y(0)$ is initial condition and $x_i(0) = 0$, $i = 1 \cdots n$, $\dot{x}_1(0) = v$, $\dot{x}_i(0) = 0$, $a = \Phi^T A \Phi = \mathrm{diag}(a_1, a_2, \cdots, a_{2n})$.

Energy of Block Rock in Block-Hierarchical Structure on pendulum type waves propagation. Because of block rocks are non-deformable bodies only with kinetic energy on impact loading, kinetic energy of block rock i and the system as formula (4).

$$E_{k(i)}(t) = \frac{1}{2} m_i \dot{x}_i^2(t) \quad i = 1, \cdots, n \text{ and } E_k(t) = \frac{1}{2}\sum_{i=1}^{n} m_i \dot{x}_i^2(t). \quad (4)$$

Let be the r pairs conjugate eigenvalues of $B^{-1}A\varphi = \lambda^{-1}\varphi$ are $\lambda_r = -\beta_r + j\omega_r$ and $\bar{\lambda}_r = -\beta_r - j\omega_r$, $\beta_r, \omega_r > 0$. Corresponding the conjugate eigenvectors are φ_r and $\bar{\varphi}_r$. As a result

$$x_r(t) = \varphi_r e^{\lambda_r t} + \bar{\varphi}_r e^{\bar{\lambda}_r t} = 2e^{-\beta_r t}[\mathrm{Re}(\varphi_r)\cos\omega_r t - \mathrm{Im}(\bar{\varphi}_r)\sin\omega_r t] \quad (5\text{-a})$$

the displacement motion of formula (5-a) has the matrix form

$$x_r(t) = e^{-\beta_r t}\begin{bmatrix} a_{1r}\cos(\omega_r t + \theta_{1r}) \\ \vdots \\ a_{nr}\cos(\omega_r t + \theta_{nr}) \end{bmatrix} \quad (5\text{-b})$$

where $a_{ir} = 2\sqrt{\mathrm{Re}^2(\varphi_{ir}) + \mathrm{Im}^2(\varphi_{ir})}$, $\theta_{ir} = \arctan(\frac{\mathrm{Im}(\varphi_{ir})}{\mathrm{Re}(\varphi_{ir})})$, $i = 1, \cdots, n$. There are $2n$ pairs conjugate eigenvalues and conjugate eigenvectors in n-degree of freedom block structure system, as a result the displacement of each block in block rock structure has vector form of (6)

$$x = \sum_{r=1}^{n} x_r. \quad (6)$$

Then the displacement and velocity of x_i as (7)

$$x_i = \sum_{r=1}^{n} x_{ir} = \sum_{r=1}^{n} e^{-\beta_r t} a_{ir}\cos(\omega_r t + \theta_{ir}) \text{ and } \dot{x}_i = \sum_{r=1}^{n} -e^{-\beta_r t} b_{ir}\cos(\omega_r t + \theta_{ir} - \theta'_{ir}), \quad (7)$$

where $b_{ir} = \sqrt{(\beta_r a_{ir})^2 + (\omega_r a_{ir})^2}$, $\theta'_{ir} = \arctan(\frac{\omega_r}{\beta_{ir}})$, $i = 1, \cdots, n$. As a result, kinetic energy of rock block structure system as (8)

$$E_k = \frac{1}{2}\sum_{i=1}^{n} m_i [\sum_{r=1}^{n}(\lambda_r \varphi_{ir} e^{\lambda_r t} + \bar{\lambda}_r \bar{\varphi}_{ir} e^{\bar{\lambda}_r t})]^2 = \frac{1}{2}\sum_{i=1}^{n} m_i [\sum_{r=1}^{n} e^{-\beta_r t} b_{ir}\cos(\omega_r t + \theta_{ir} - \theta'_{ir})]^2. \quad (8)$$

Energy of Block Rock Partings in Block-Hierarchical Structure on pendulum type waves propagation. Hypothesis the partings weaker medium between the block rocks is uniform deformation elastomer, and only have shape changed on impact loading, the energy between the block rocks is elastic strain energy caused by oneself distortion as Fig 2.

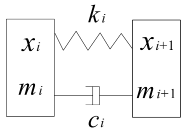

Fig.2 Model of adjacent blocks linked with visco-elastically medium

Let be $f_i(t)$ the external dynamic loading of visco-elastically medium between block rock x_i and x_{i+1}, then

$$f_i(t) = k_i \cdot \Delta x_i \text{ and } \Delta x_i = x_i - x_{i+1} \quad (9)$$

Elastic strain energy of visco-elastically medium between block rock x_i and x_{i+1}, and the block rock system as (10).

$$E_{p(i)}(t)=\int_0^{\Delta x_i} f_i(t)d(\Delta x_i)=\frac{1}{2}k_i\cdot\Delta x_i^2,\ i=1,\cdots,n \text{ and } E_p(t)=\frac{1}{2}\sum_{i=1}^{n}k_i\cdot\Delta x_i^2 . \qquad (10)$$

Because of $\Delta x_i=\sum_{r=1}^{n}e^{-\beta_r t}a_{ir}\cos(\omega_r t+\theta_{ir})-\sum_{r=1}^{n}e^{-\beta_r t}a_{i+1,r}\cos(\omega_r t+\theta_{i+1,r})$ and the elastics potential energy of the block rock structure system as (11)

$$\begin{aligned}E_p&=\frac{1}{2}\sum_{i=1}^{n}k_i[\sum_{r=1}^{n}(\varphi_{ir}e^{\lambda_r t}+\bar\varphi_{ir}e^{\bar\lambda_r t})-\sum_{r=1}^{n}(\varphi_{i+1,r}e^{\lambda_r t}+\bar\varphi_{i+1,r}e^{\bar\lambda_r t})]^2=\\&=\frac{1}{2}\sum_{i=1}^{n}k_i[\sum_{r=1}^{n}e^{-\beta_r t}a_{ir}\cos(\omega_r t+\theta_{ir})-\sum_{r=1}^{n}e^{-\beta_r t}a_{i+1,r}\cos(\omega_r t+\theta_{i+1,r})]^2.\end{aligned} \qquad (11)$$

As a result, the mechanical energy of the block rock structure and the energy dissipation as (12)

$$W(t)=E_k(t)+E_p(t) \text{ and } W_D=W_I-(E_k+E_p), \qquad (12)$$

where W_I is the initial energy of the block structure system.

Sensitivity Analysis of The Block Rock Structure Parameters to Energy Dissipation. From the analysis of energy express we know block rock structure parameters have great influence to energy dissipation. Following we will analysis of the system parameters including mass and visco-elasticity parameters sensitivity to energy dissipation.

$$\begin{aligned}\frac{\partial(E_p+E_k)}{\partial m_i}&=\frac{\partial E_k}{\partial m_i}+\frac{\partial(E_p+E_k)}{\partial\lambda_r}\cdot\frac{\partial\lambda_r}{\partial m_i}+\frac{\partial(E_p+E_k)}{\partial\bar\lambda_r}\cdot\frac{\partial\bar\lambda_r}{\partial m_i}+\frac{\partial(E_p+E_k)}{\partial\varphi_{ir}}\cdot\frac{\partial\varphi_{ir}}{\partial m_i}+\\&+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{ir}}\cdot\frac{\partial\bar\varphi_{ir}}{\partial m_i}+\frac{\partial(E_p+E_k)}{\partial\varphi_{i+1,r}}\cdot\frac{\partial\varphi_{i+1,r}}{\partial m_i}+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{i+1,r}}\cdot\frac{\partial\bar\varphi_{i+1,r}}{\partial m_i}\end{aligned} \qquad (13)$$

$$\begin{aligned}\frac{\partial(E_p+E_k)}{\partial c_{kl}}&=\frac{\partial(E_p+E_k)}{\partial\lambda_r}\cdot\frac{\partial\lambda_r}{\partial c_{kl}}+\frac{\partial(E_p+E_k)}{\partial\bar\lambda_r}\cdot\frac{\partial\bar\lambda_r}{\partial c_{kl}}+\frac{\partial(E_p+E_k)}{\partial\varphi_{ir}}\cdot\frac{\partial\varphi_{ir}}{\partial c_{kl}}+\\&+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{ir}}\cdot\frac{\partial\bar\varphi_{ir}}{\partial c_{kl}}+\frac{\partial(E_p+E_k)}{\partial\varphi_{i+1,r}}\cdot\frac{\partial\varphi_{i+1,r}}{\partial c_{kl}}+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{i+1,r}}\cdot\frac{\partial\bar\varphi_{i+1,r}}{\partial c_{kl}}\end{aligned} \qquad (14)$$

$$\begin{aligned}\frac{\partial(E_p+E_k)}{\partial k_{kl}}&=\frac{\partial E_p}{\partial k_{kl}}+\frac{\partial(E_p+E_k)}{\partial\lambda_r}\cdot\frac{\partial\lambda_r}{\partial k_{kl}}+\frac{\partial(E_p+E_k)}{\partial\bar\lambda_r}\cdot\frac{\partial\bar\lambda_r}{\partial k_{kl}}+\frac{\partial(E_p+E_k)}{\partial\varphi_{ir}}\cdot\frac{\partial\varphi_{ir}}{\partial k_{kl}}+\\&+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{i+r}}\cdot\frac{\partial\bar\varphi_{i+r}}{\partial k_{kl}}+\frac{\partial(E_p+E_k)}{\partial\varphi_{i+1,r}}\cdot\frac{\partial\varphi_{i+1,r}}{\partial k_{kl}}+\frac{\partial(E_p+E_k)}{\partial\bar\varphi_{i+1,r}}\cdot\frac{\partial\bar\varphi_{i+1,r}}{\partial k_{kl}}\end{aligned} \qquad (15)$$

where c_{kl} and k_{kl} are viscosity and elastic coefficient between block k and l, m_i the mass of block *i* and

$$\frac{\partial E_k}{\partial\varphi_{ir}}=\sum_{i=1}^{n}m_i\dot x_i\sum_{r=1}^{n}(\lambda_r e^{\lambda_r t}+\bar\lambda_r e^{\bar\lambda_r t}),\quad \frac{\partial E_k}{\partial\lambda_r}=\sum_{i=1}^{n}m_i\dot x_i\sum_{r=1}^{n}(\varphi_{ir}e^{\lambda_r t}+t\lambda_r\varphi_{ir}e^{\lambda_r t}+\bar\varphi_{ir}e^{\bar\lambda_r t}+t\bar\lambda_r\bar\varphi_{ir}e^{\bar\lambda_r t}),$$

$$\frac{\partial E_p}{\partial\varphi_{ir}}=\sum_{i=1}^{n-1}k_i\Delta x_i\sum_{r=1}^{n}(e^{\lambda_r t}+e^{\bar\lambda_r t})=-\frac{\partial E_p}{\partial\varphi_{i+1,r}},\quad \frac{\partial E_p}{\partial\lambda_r}=\sum_{i=1}^{n-1}k_i\Delta x_i\sum_{r=1}^{n}[p_{ir}(\lambda_r)-p_{i+1,r}(\lambda_r)],$$

$$p_{ir}(\lambda_r)=t\varphi_{ir}e^{\lambda_r t}+t\bar\varphi_{ir}e^{\bar\lambda_r t},\quad \frac{\partial E_k}{\partial m_i}=\frac{1}{2}[\sum_{r=1}^{n}(\lambda_r\varphi_{ir}e^{\lambda_r t}+\bar\lambda_r\bar\varphi_{ir}e^{\bar\lambda_r t})]^2,$$

$$\frac{\partial E_p}{\partial k_i}=\frac{1}{2}[\sum_{r=1}^{n}(\varphi_{ir}e^{\lambda_r t}+\bar\varphi_{ir}e^{\bar\lambda_r t})-\sum_{r=1}^{n}(\varphi_{i+1,r}e^{\lambda_{rt}}+\bar\varphi_{i+1,r}e^{\bar\lambda_r t})]^2 .$$

Paper [10] given sensitivity analysis of λ_r, φ_{ir} to local mass and visco-elasticity as following

$$\frac{\partial\lambda_r}{\partial m_i}=-\lambda_r^2\frac{\varphi_{ir}^2}{a_r},\quad \frac{\partial\varphi_{ir}}{\partial m_k}=-\lambda_r\frac{\varphi_{kr}^2}{a_r}\varphi_{ir}+\varphi_{kr}\sum_{j=1,j\neq r}^{2n}\frac{\lambda_r^2}{\lambda_j-\lambda_r}\frac{\varphi_{kj}\varphi_{ij}}{a_j},$$

$$\frac{\partial\lambda_r}{\partial c_{kl}} = -\lambda_r \frac{(\varphi_{kr}-\varphi_{lr})^2}{a_r}, \quad \frac{\partial\varphi_{ir}}{\partial c_{kl}} = -\frac{1}{2}\frac{(\varphi_{kr}-\varphi_{lr})^2}{a_r}\varphi_{ir} + (\varphi_{kr}-\varphi_{lr})\sum_{j=1,j\neq r}^{2n}\frac{\lambda_r}{\lambda_j-\lambda_r}\frac{(\varphi_{kj}-\varphi_{lj})\varphi_{ij}}{a_j},$$

$$\frac{\partial\lambda_r}{\partial k_{kl}} = -\frac{(\varphi_{kr}-\varphi_{lr})^2}{a_r}, \quad \frac{\partial\varphi_{ir}}{\partial k_{kl}} = (\varphi_{kr}-\varphi_{lr})\sum_{j=1,j\neq r}^{2n}\frac{1}{\lambda_j-\lambda_r}\frac{(\varphi_{kj}-\varphi_{lj})\varphi_{ij}}{a_j}.$$

So we can get sensitivity analysis of local mass and visco-elasticity to mechanical energy dissipation.

Numerical analysis. Energy dissipation of block-hierarchical rock structure with 20 blocks are compared when changing structure parameters. The original computation parameters: $c_i = 35kg/s$, $k_i = 6\times10^5 kg/s^2$, m_i=10kg, $i = 1,\cdots,20$. Initial impact energy 500J and $\dot{x}_1(0) = 10m/s$. Define unite i as block i and the weaker medium between block i and $i+1$. Energy transformation in unite i is kinetic energy of block rock and elastics potential energy of sandwich medium.

Fig.3 shown kinetic energy of block rock and elastics potential energy between block rocks medium presented periodically attenuation. At the beginning of impact loading kinetic energy more than elastics potential energy, but passing by 3 cycles the result is opposite, At this time deformation energy more than rock swinging energy and the main forms of energy is extrusion and tensile of the weaker medium. At the same time kinetic energy attenuation rapidly than elastics potential energy during the whole time. Fig.4 shown at the beginning of impact loading elastics potential energy more than kinetic energy, but passing by 5 cycles the result is opposite, At this time deformation energy of weaker medium less than block rock swinging energy, the main forms of energy dissipation is elastics potential energy. Kinetic energy attenuation is lower than elastics potential energy during the whole time.

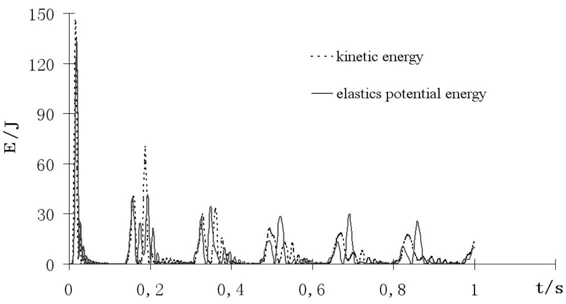

Fig. 3. Kinetic and elastics potential energy in unite 4 dynamic model of Pendulum-type wave

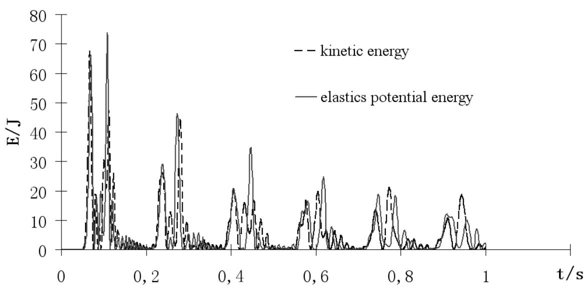

Fig. 4. Kinetic and elastics potential energy in unite 16

Fig. 5 shown kinetic energy and elastics potential energy of the system transformed each other during the whole time and the two kind's energy with the similar index attenuation. $\Delta E/\Delta t$ expressed the average rate of energy dissipation. By the end of 2s peak value of kinetic energy and elastics potential energy are 71J and 61J then $\Delta E_k/\Delta t = 214.5$. The initial peak value of elastics potential energy is 269J then $\Delta E_p/\Delta t = 104$. As a result, kinetic energy dissipation is about two times compared with elastics potential energy before 2s. Fig.6 shown the system energy with a fast attenuation before 1s and close to linear decay but slower during 2-10s. By the end of 1s and 10s system energy is 148J and 48J then $\Delta E_1/\Delta t = 352$ and $\Delta E_{10}/\Delta t = 45.2$.

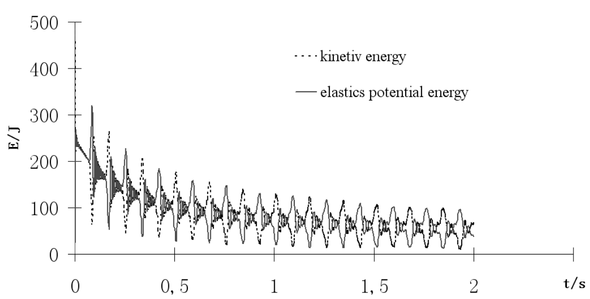

Fig. 5. The system kinetic and elastics potential energy

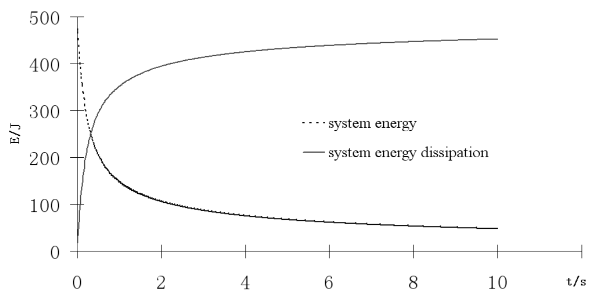

Fig. 6. The system energy and energy dissipation

Energy dissipation are compared when half of the original computation parameters respectively m_i=5 kg by the principle of energy conservation $\dot{x}_1(0) = 10\sqrt{2}m/s$; $k_i = 3\times10^5 kg/s^2$; $c_i = 17.5kg/s$.

Fig. 7 and Fig. 8 shown that at the beginning of the block rock structure in unit 4 kinetic energy and elastics potential energy attenuation cycle have the relationship $T_{(3)} > T_{(2)} > T_{(1)}$. Attenuation of peak value of kinetic energy and elastics potential energy most fast when changing (1) and most slow when changing (2).

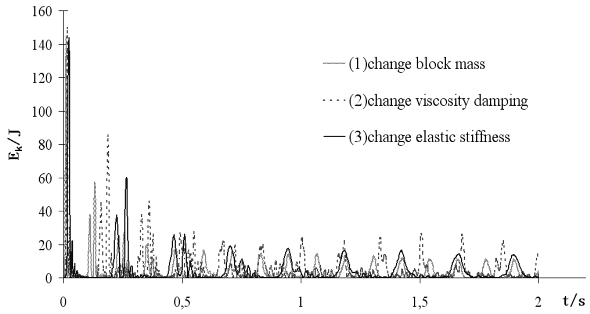

Fig. 7. Kinetic energy in unit 4 when changing block structured medium parameters

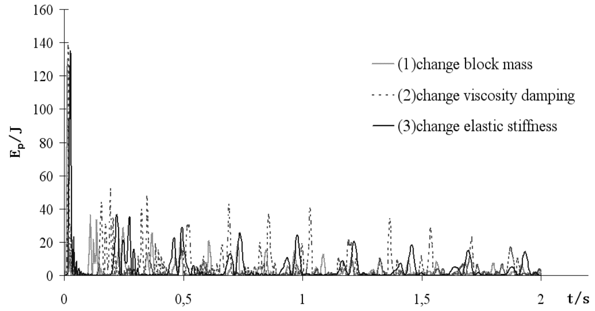

Fig. 8. Elastics potential energy in unit 4 when changing block structured medium parameters

Fig. 9 and Fig. 10 shown at the end of the block rock structure in unit 16, kinetic energy and elastics potential energy attenuation cycle have the relationship $T_{(3)} > T_{(2)} > T_{(1)}$. Attenuation of peak value of kinetic energy and elastics potential energy most fast when changing (1) and most slow when changing (2).

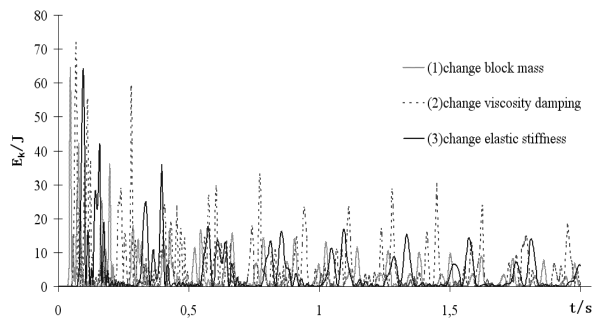

Fig. 9. Kinetic energy in unit 16 when changing block structured medium parameters

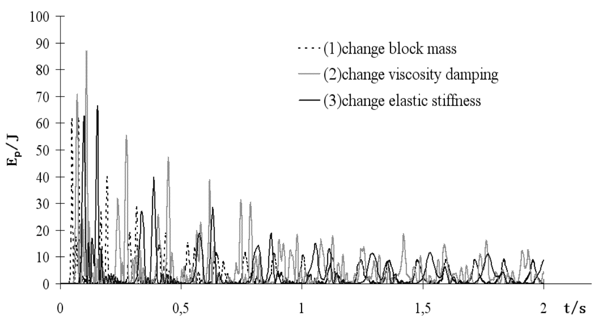

Fig. 10. Elastics potential energy in unit 16 when changing block structured medium parameters

Fig.11 and Fig.12 shown kinetic energy and elastics potential energy of the block rock system are all with the similar exponential attenuation but energy amplitude center have the relationship (2) > (3) > (1).

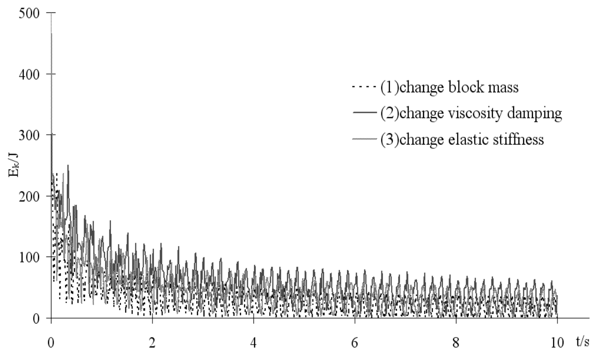

Fig. 11. System kinetic energy when changing parameters

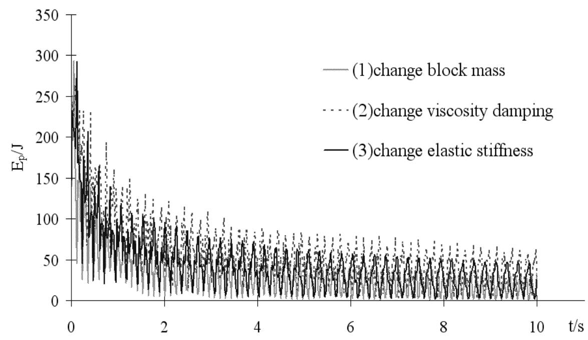

Fig. 12. System elastics potential energy changing parameter

Fig. 13 and Fig. 14 shown dissipation regularity of system mechanical energy is similar when changing block rocks system parameters. At the end of 1s system mechanical energy: $E_{(1)}$=106J, $E_{(2)}$=205J, $E_{(3)}$=148J and $\Delta E/\Delta t$ respectively 394, 295, 352.By the end of 10s system mechanical energy: $E_{(1)}$=34J, $E_{(2)}$=67J, $E_{(3)}$=48J and $\Delta E/\Delta t$ respectively 46.6,43.3,45.2. Therefore, energy dissipation the most fast when change block mass, slowly when change viscosity.

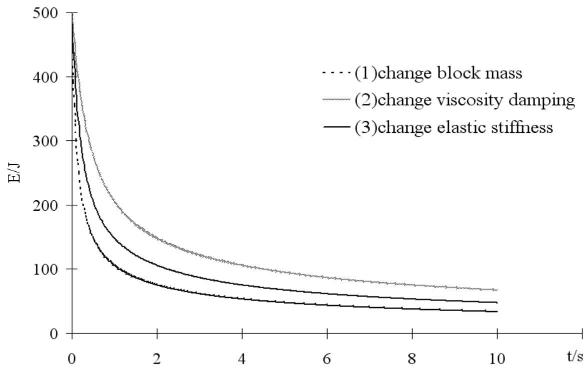

Fig. 13. System mechanical energy

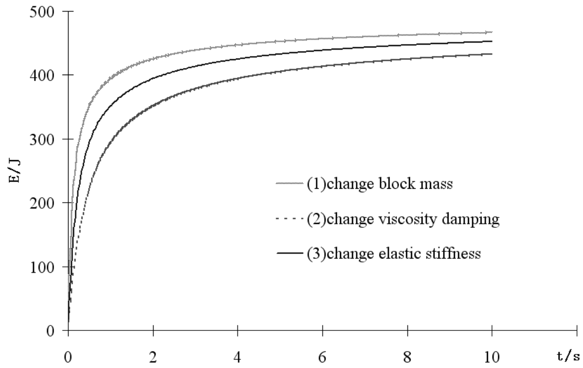

Fig. 14. System mechanical energy dissipation

Conclusion. Energy dissipation of block rock structure during pendulum-type wave's propagation is analyzed. The system parameters sensitivity to energy dissipation is analyzed. Both kinetic energy and elastics potential energy are periodically attenuation. Energy dissipation rapidly in the unite of the initial area and kinetic energy recharge elastics potential energy, kinetic energy is the main forms of energy dissipation; energy dissipation slowly in the unite of the end area and elastics potential energy recharge kinetic energy, elastics potential energy is the main forms of energy dissipation.

Attenuation cycle of kinetic energy and elastics potential energy are shortened and energy attenuation more large when reduce mass of block. Attenuation cycle of kinetic energy and elastics potential energy are longer and amplitude of energy is lower when reduce elastic of weaker medium. Attenuation cycle have no changed and amplitude of energy have less change when reduce viscosity of weaker medium.

РЕЗЮМЕ

Исследование сконцентрировано на вопросе рассеяния энергии волны, типа маятника, при распространении её в случае монтажа блочной конструкции, разделенной альтернативно упругими пружинами и вязкими элементами демпфирования при воздействии импульсной нагрузки. На основе исследования механической модели кинетической энергии блоков получена упругая потенциальная энергия между блоками и механическая энергия цепочки блочных систем масс. Изучено влияние параметров системы, включая вязкость блоков масс и упругость между блоками, на ее энергию.

Ключевые слова: блочно-иерархическая структура горной породы, мятниковые волны, упругий потенциал.

РЕЗЮМЕ

Дослідження сконцентровано на питанні розсіяні енергії хвилі, типу маятника, при поширенні її у випадку монтажу блокової конструкції, розділеної альтернативно пружними пружинами і грузлими елементами демпфірування при впливі імпульсного навантаження. На основі дослідження механічної моделі кінетичної енергії блоків, отримана потенційна енергія пружності між блоками і механічною енергією ланцюжка блокових систем мас. Вивчено вплив параметрів системи, включаючи в'язкість блоків мас і пружність між блоками, на її енергію.

Ключові слова: блочно-ієрархічна структура гірської породи, мятникові хвилі, пружний потенціал.

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